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Engine Technology Challenges for a 21st Century High Speed Civil Transport

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PROPULSION CHALLENGES FOR A 21ST CENTURY ECONOMICALLY VIABLE, ENVIRONMENTALLY COMPATIBLE HIGH-SPEED CIVIL TRANSPORT

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Abstract

Recent NASA funded studies by Boeing and Douglas suggest an opportunity exists for a 21st Century High Speed Civil Transport (HSCT) to become part of the international air transportation system. However, before this opportunity for high speed travel can be realized, certain environmental and economic barrier issues must be overcome. This paper will outline these challenges and indicate the propulsion research activities which NASA has underway and has planned to address these barrier issues and provide a technology base to allow the U.S. manufacturers to make an informed go/no go decision on developing an HSCT.

Introduction

Recent NASA funded studies[1-2] have indicated that an opportunity exists for a supersonic commercial transport to become a key part of the 21st century international air transportation system. Indeed, a High-Speed Civil Transport (HSCT) could have a similar impact on the commercial air transportation system as did the jet transports of some 30 years ago. However, these studies as well as one conducted by an ad hoc group of the NASA Aeronautics Advisory Committee[3] indicate that significant technical challenges must be overcome before industry would consider committing to the production of an HSCT. The development and certification of an HSCT is estimated to be as high as 10 to 15 billion dollars.[4]

The technology challenges primarily fall into two categories - environmental and economic. The three environmental barrier issues are atmospheric ozone depletion, community noise, and sonic boom. The first two of these barrier issues - ozone depletion and community noise - must be solved before industry would consider launching an HSCT.

Specifically, low emissions combustor technologies must be available that would result in the design of a combustor which would produce ultra low levels of nitrogen oxides and thus allow HSCT's to cruise in or near the stratosphere without damaging the ozone layer. HSCT's must be no noisier in take-off, approach, and landing conditions than current subsonic transports. This requires jet noise reduction technologies to be available which are far greater than those the industry currently possesses. These jet noise reduction technologies must be incorporated in a high performance exhaust nozzle design compatible with the HSCT propulsion cycle.

The economic challenges center about those enabling propulsion, airframe, and flight control technologies required to allow the design of an HSCT that will compete economically with the current as well as next generation long range subsonic wide body transports.

Specifically, the enabling propulsion technologies are viewed to be:

- Advanced engine materials which would permit the extended operation times of the propulsion system at the high temperatures and pressures required and propulsion system designs with significantly reduced weights relative to the levels possible using currently available materials.
- Propulsion component designs which perform at high efficiency levels throughout the mission profile.
- Component integration and control technologies which enable the design of a propulsion system which has high performance and stability throughout the mission profile.

NASA initiated in Fiscal Year (FY) 1990 a 6 year program aimed at addressing the key environmental barrier issues. This program, called the High-Speed Research Program (HSRP) is described in Ref. 5. This paper will examine the propulsion technology challenges associated with the environmental barrier issues and in particular the NASA/industry/university approaches to achieving the propulsion oriented objectives of HSRP. The three main propulsion objectives are:

(1) Demonstrate low emissions combustor concepts.

(2) Demonstrate low noise exhaust nozzle concepts.

(3) Evaluate candidate engine cycle concepts and determine those concepts which are compatible with the environmental and economic requirements for an HSCT.

Currently, it is felt that viable approaches to designing low emissions combustors and low noise nozzles must be in hand prior to any follow-on efforts related to the economic barrier issues being initiated. Thus the attainment of these objectives is of prime importance in HSRP. Accomplishment of these objectives will come from the combined efforts of NASA Ames, Langley, and Lewis Research Centers working with the U.S. aerospace community and selected universities.

Figure 1 overviews the efforts related to the three objectives. The succeeding sections of this paper will describe these activities in more detail.

HSCT Propulsion System Cycle Evaluation

Arguably, the most critical element of a viable, compatible HSCT is the propulsion system.

The engine cycle selected must provide for efficient performance across the subsonic-supersonic range while at the same time not contribute to unacceptable emissions at supersonic cruise or noise at low speed conditions. Efficient performance at subsonic cruise will be mandatory if an HSCT must fly subsonically over land, i.e., no acceptable solutions to the sonic boom problem are found. The studies of results of Refs. 1 and 2 suggest that as much as 25 percent of an HSCT mission might be over land.

The requirement of efficient performance both subsonically and supersonically strongly suggests that an HSCT propulsion system must have an engine cycle, which can be varied across the speed range. Good supersonic cruise performance requires a high specific thrust, turbojet-like cycle while low take-off noise suggests a low specific thrust, high bypass turbofan-like cycle is required. Engine cycles which have these characteristics while maintaining high component efficiency across the speed range are being evaluated in HSRP. As Fig. 2 suggests, the engine cycle selection process in HSRP is one of evaluation, optimization, and finally selection. The figure also suggests that this process must be done in close concert with the development of the propulsion component technologies. The evolution of these component technologies will have a strong impact on the fidelity of the cycle evaluations, and in turn the cycle evaluations will impact the component technology efforts.

As the figure also indicates, the propulsion system cycle evaluation process is strongly influenced by the evolving design criteria for environmental compatibility. Specifically, the continuing assessments by members of the international atmospheric research community of the impact on the ozone layer of fleets of HSCT's flying various fleet scenarios will impact many elements of HSRP including the engine cycle evaluations. Reference 6 gives an overview of the atmospheric assessment activities which are also a part of HSRP. Additionally, the Federal Aviation Administration's (FAA) process to develop noise certification rules for future HSCT's will directly impact the cycle evaluations.

The propulsion system cycle evaluation process began in FY 1986 prior to the initiation of HSRP. These initial evaluations essentially picked up where the NASA Supersonic Cruise Program (SCR) left off in the early 1980's[7] and were used to provide propulsion inputs to the studies of Refs. 1 and 2. The cycle evaluation process is being conducted by the two U.S. large engine manufacturers - General Electric and Pratt & Whitney - with complimentary efforts being conducted by NASA Lewis.

The process will continue into an optimization phase during fiscal years 1990 through 1992. During this phase, data acquired from the nozzle and combustor technology elements of HSRP will be critical inputs. Also, an input will come from the initial results of an inlet concept screening effort that will be a part of HSRP. Inlet geometry tradeoffs (axisymmetric versus two-dimensional) and inlet/nozzle airframe integration will be considered, both analytically and experimentally, in these efforts. For each cycle selected by NASA, General Electric and Pratt & Whitney, optimized characteristics will be determined and engine performance compared (uninstalled). Each optimized propulsion system will be installed on baseline aircraft configurations developed by Boeing and Douglas and the cycles further optimized to account for installation effects. The reference aircraft will be flown over typical HSCT mission profiles to allow for comparison of the installed performance of each candidate propulsion system. This process will result in the determination of those engine cycles which would be viable candidates for an HSCT which would be economically viable and environmentally compatible.

The selection of these preferred engine cycles will then allow flowpath layouts and preliminary mechanical designs to be initiated. The preliminary designs will allow for a more accurate estimate of the weight of the propulsion system and will suggest other component technology challenges which must be addressed. The final selection of an engine cycle for an actual HSCT vehicle will be accomplished by the airframe and engine manufacturers.

Low Emissions Combustor Technology

Perhaps no problem is of greater concern to the world today than the adverse impact on the Earth's atmosphere of various man-made chemicals. Of particular concern is the destruction of the protective ozone layer. Since a fleet of HSCT aircraft would fly either in the tropopause or stratosphere, concern exists that engine emissions (and in particular nitrogen oxide [NO_x] emissions) could seriously damage the ozone layer. Concern over NO_x emissions effects on the ozone layer contributed to the decision to terminate the first U.S. SST program.[8] It is mandatory that with regard to any proposed HSCT, two closely interrelated objectives be met:

(1) The level on NO_x emissions for which no adverse impact on the ozone layer must occur must be rigorously determined and accepted by the world wide public at large.

(2) Low emissions combustor technology must be developed and demonstrated which results in acceptably low levels of NO_x emissions at supersonic cruise conditions while maintaining acceptably high levels of combustor performance.

As already indicated, the first objective is being addressed in another element of HSRP and will be only briefly discussed in the following paragraphs. A detailed overview of these efforts is contained within Ref. 6.

The goal of the atmospheric assessment portion of HSRP is to determine what atmospheric effects may be expected for a fleet of HSCT's for given levels of technology and operational scenarios. This assessment is being accomplished by members of the international atmospheric community and coordinated by leaders of the NASA Upper Atmospheric Research Program.

The major elements of the atmospheric assessment include application of a hierarchy of theoretical models supported by laboratory and field (flight) measurements to improve/validate the models being employed.

Currently one- and two-dimensional atmospheric models are being used to perform the assessments. Figure 3 presents some of the early one-dimensional results and indicates the predicted impact on the ozone layer (expressed as column ozone depletion) significantly varies with the cruise altitude and combustor emissions levels which is expressed as an Emissions Index (EI). The EI factor is defined as the number of grams of equivalent NO_2 produced per kilogram of fuel burned.

These initial atmospheric model predictions strongly suggest that ultra low NO_x combustor technology will be required if no adverse impact on the ozone layer is to occur.

The HSRP goal is to demonstrate viable combustor concepts which would have ultra low NO_x levels with EI's in the range of 3 to 8 at supersonic cruise operating conditions. The HSRP emissions' challenge is shown in Fig. 4. As indicated, the EI of the Concorde's Olympus engine has been indicated to be about 20. The cycle characteristics (temperature and pressure levels) of the Olympus engine are lower than would be required for a viable HSCT propulsion system. If current combustor technology were employed to design a combustor which would operate at the elevated temperatures and pressures required, estimated levels of the emissions index (EI) range from 30 to 80. Clearly the development of combustor technology which will reduce the EI level by as much as 90 percent while maintaining acceptably high combustor performance is a supreme challenge. Previous U.S. Department of Energy sponsored research for stationary gas turbine power plans suggest that reduction of NO_x to these ultra low levels is possible. However, the technology improvement required clearly is of a revolutionary rather than evolutionary nature.

Two combustor concepts appear to hold promise for meeting the HSRP emissions goal of EI = 3 - 8. The two concepts shown in Fig. 5 are known as the Lean Premixed-Prevaporized (LPP) and the Rich Burn-Quick Quench-Lean Burn (RQL). The basic approach of each concept is also shown in the figure. The key to achieving low NO_x levels is to accomplish all burning away from stoichiometric conditions where flame temperatures become excessively high and result in large production rates of NO_x. The LPP approach features one stage of burning conducted in a fuel lean environment. The RQL approach would have two stages of burning - the initial stage being conducted in a fuel rich environment and the final stage in a fuel lean environment. The transition from the rich zone to lean zone in an RQL combustor would be accomplished by a rapid introduction of quench air into the combustor.

While both combustor concepts appear to be attractive for HSCT applications, the low NO_x production levels of each combustion concept must be demonstrated prior to the decision to proceed with the more costly design, fabrication and rig tests of combustor concepts. As Fig. 1 suggests, one of the two major efforts in the early years of this element of HSRP will be to experimentally evaluate the NO_x production characteristics of each of the two concepts in the laboratory.

Figure 6 is a photograph of the NASA Lewis flame tube currently being used to evaluate the LPP combustion concept. The figure points out some of the key characteristics of the flame tube. Production levels of NO_x are being measured over a range of inflow temperature and pressure conditions which are representatives of HSCT cycle conditions. Different approaches to fuel injection and fuel/air mixing are being evaluated to determine the impacts on NO_x production.

In addition to the NO_x production level measurements being made with conventional gas sampling probes, dedicated runs will be conducted to acquire detailed data for comparison with predictions being made using the combustion modeling codes also being involved in HSRP. This code validation data will be acquired using advanced diagnostic techniques such as laser induced fluorescence, laser doppler velocimetry, and high speed photography.

A flame tube rig with similar features is operational and being used to evaluate the RQL combustion approach. Similar sets of measurements are being made as those already discussed for the LPP concept.

Current HSRP plans call for the completion of initial flame tube data acquisition to occur at the end of FY91. These two data sets will allow a rigorous comparison to be made of the ultra low NO_x production potential of each of the two concepts. These data sets will form the basis for a subsequent decision as to which concept(s) to take into the follow-on phases of HSRP which will conclude with annular/rig demonstrations of combustor concept(s) which meet the ultra low NO_x goals of EI = 3 - 8 at supersonic cruise conditions.

As already indicated, the other major activity occurring in the early years of this element of HSRP is the assessment and upgrade (as required) of combustion modeling codes. It is felt that the development/modification/validation of computer modeling codes is a key output (or "deliverable") of almost every element of HSRP. Once validated, codes can be confidently used by industry as part of their design/analysis methodology to design the actual HSCT vehicle including the propulsion system.

In general, to be useful in the aerospace design/analysis process, a computer modeling code must be able to predict the governing physical processes to an acceptable level of detail for the particular application of interest. In particular for HSCT ultra low NO_x combustor applications, the code(s) employed must be able to model a wide range of key physical processes:

(1) Three-dimensional viscous flow (including large-scale vortical motion)
(2) Turbulence and turbulent mixing
(3) Finite-rate combustion chemistry (especially NO_x formation)
(4) Soot formation
(5) Convection and radiation heat transfer

The requirements to adequately capture these physical processes are dictated by the modeling requirements to design/analyze an HSCT combustor. Many of these requirements are indicated in Fig. 7.

While an RQL combustor is shown in this figure, the LPP combustor has largely the same requirements.

Currently, a number of codes are being evaluated for application to various aspects of the HSCT combustor design/analysis process. Particular emphasis is being placed on the KIVA family of codes developed at Los Alamos to model the combustion processes. Figure 8 gives one recent example of application of the two-dimensional version of the KIVA code to the RQL combustion approach. Other codes being evaluated include a version of the Adamczyk passage analysis[9] to model the three-dimensional flowfield associated with dome swirler configurations. Figure 9 taken from Ref. 10 shows the three-dimensional Mach number contours predicted by this the code. These three-dimensional velocity fields would serve as an input to the analysis code used to predict the fuel spray/air interaction including droplet breakup, coalesce, and vaporization.

As already indicated, detailed code validation data bases will be acquired in the flame tube test rigs using advanced flow diagnostic techniques. These data bases will be used to validate the codes as well as indicate the areas where code modifications/upgrades are required. The codes will also be applied to the combustor sector/annular configurations which will be tested in the later phases of HSRP. Again code modification/upgrades will be identified and initiated through these comparisons.

Figures 10 and 11 indicate some of the technology issues associated with the design of RQL and LPP combustors respectively. These technology issues will be confronted in HSRP through the development of the critical subcomponent technologies and then employing them in the designs of the combustor configuration(s) chosen for the final sector/annular rig tests in the later phase of the program. Some of the subcomponent technology developments being emphasized in the early phase of the program include fuel injectors, dome swirlers, and quick quench mixers.

Currently, it is envisioned that the information acquired during the early efforts of HSRP - engine cycle evaluations, atmospheric impact assessment, flame tube experiments, combustor modeling, and subcomponent technology development - will be the basis of a combustor concept selection. The combustor concept(s) selected will then be carried through a series of sector/annular rig tests to result in the final demonstration of at least one combustor concept which will produce acceptably low NO_x and acceptably high combustor efficiency at supersonic cruise conditions.

Source Noise

The requirement that an HSCT be as quiet as subsonic transports for take-off, approach and landing conditions also represents a significant challenge to the HSCT designer. Of the three separate noise measurements currently required to certify a commercial transport (sideline, fly-over, and landing/approach), the sideline appears to be the most difficult to reduce to acceptable levels. As a reference, the sideline noise levels of the Concorde are as much as 20 EPNdB over the FAA FAR36 Stage III noise regulations level of 102 EPNdB.

The predominant noise source for an HSCT will be the jet noise which will generate as much as 99 percent of the total vehicle noise levels. The keys to developing an HSCT with acceptable noise characteristics are two-fold: (1) selection of an engine cycle which will have a reduced specific thrust (lower jet velocity) at take-off and (2) development of an exhaust nozzle design which is compatible with the engine cycle and contributes to jet noise reduction. Of course, the jet noise problem must be solved consistent with the requirement of economic viability of the aircraft. This constraint places significant limitations on the "solution space" available.

The HSCT source noise reduction challenge is shown in Fig. 12. The propulsion system cycle evaluations indicate a source noise reduction of as much as 18 to 20 dB is required. However, the noise reduction achieved cannot be at the expense of nozzle aerodynamic performance. The nozzle must maintain high levels of thrust performance across the complete HSCT operating range (take-off, subsonic/transonic, supersonic). Nozzle noise suppression often comes at the expense of aerodynamic performance, and as Ref. 11 points out, an HSCT nozzle must have a ratio of noise suppression (dB) to aerodynamic performance loss (percent thrust) of at least 4 to 1. Nozzle technology developed during the SCR program would result in designs where this ratio would be no better than 2 to 1 so clearly some major advances in technology will be required.

The approach being followed in the SOURCE NOISE element is indicated in Fig. 1. As this figure suggests, a series of subscale nozzle concepts are being tested in NASA and industry facilities to assess the current state of low noise nozzle technology and thus to provide a significant data base which will allow an early assessment of which approach(es) offer the most promise for continued development. The tests will emphasize measurement of aero and acoustic performance at simulated take-off conditions. Some of the configurations are derivatives of concepts developed in the SCR program; some have evolved from NASA support; and others have evolved through industrial research.

One example of this concept assessment process is shown in Figs. 13 and 14. NASA Lewis and Pratt & Whitney have initiated a multiphase effort to evaluate a selected mixer-ejector nozzle concept. Initially, a test program was conducted in the Lewis 9 by 15 Low-Speed Wind Tunnel (LSWT) (Fig. 13) to evaluate the approach using a simple two-dimensional model. Parametric tests were run to develop a data base which related variations in near field acoustic signatures to variations in model geometry. In addition, limited temperature and pressure surveys were measured at the nozzle exit plane.

These test results provided enough information to allow the design of a full axisymmetric nozzle configuration. This nozzle concept was tested in the Boeing Low Speed Acoustic Facility (LSAF) to measure nozzle far field acoustic signatures and thrust coefficient (Fig. 14). These test results are currently being analyzed to determine the most appropriate nozzle modifications to pursue to improve aero/acoustic performance.

It is envisioned that a number of nozzle concepts will be tested during HSRP. The subscale tests conducted at NASA Lewis will employ a jet exit test rig (Fig. 15). This test rig, initially conceived to support the National Aerospace Plane Program (NASP), will be able to provide simulated engine temperature flows into the nozzle using the hydrogen/air combustor indicated. Forces and moments will be measured with a six component balance. The jet exit rig will be capable of testing both axisymmetric and two-dimensional nozzles with a throat area of approximately 15 in.^{2}.

Nozzle concept tests will be conducted in the Lewis 9 by 15 LSWT to measure near field acoustic and gross aerodynamic characteristics to allow for concept assessment and comparison. In addition, more detailed aerodynamic and acoustic measurements are being made in the 9 by 15 LSWT to provide an aero/acoustic code validation data base. Far-field acoustic measurements will be made in a free jet test facility which will be operational at NASA Lewis early in FY92 (Fig. 16). The same jet exit test rig will be used in the free jet test facility.

Concurrent with this initial series of nozzle concept evaluations, NASA Langley researchers are testing a series of subscale generic nozzle configurations in the Langley Jet Noise Laboratory (JNL). These generic configurations will have many of the features of the subscale nozzles being tested in Lewis and industry facilities. The prime intent of these tests is to acquire a better understanding of the controlling physics of each configuration through the comprehensive set of diagnostic measurements being made. These results and the knowledge gained from these tests will contribute significantly to interpreting the Lewis/industry subscale nozzle concept tests as well as suggesting the most attractive approaches to take to modify the concepts to improve aero/acoustic performance.

Much like the LOW EMISSIONS COMBUSTOR TECHNOLOGY element just discussed, significant emphasis is being placed early in HSRP on computer code evaluation/upgrade - in this case codes to predict nozzle aerodynamic and acoustic performance. Nozzle aero/acoustic code assessment activities are underway at both NASA, industry, and selected universities.

In the case of nozzle aerodynamic performance prediction, the significant accomplishments from various vehicle focused programs such as NASP should directly benefit the HSCT program. The NASP program in particular has demonstrated the leadership role applied computational fluid dynamics (CFD) can assume.

One example of the code assessment process already is shown in Fig. 17. The PARC Reynolds averaged Navier-Stokes code was used to predict the flowfield characteristics of the three-dimensional mixer-ejector nozzle concept tested in the Boeing LSAF. The code predictions suggest that an incomplete mixing occurred within the nozzle configuration which resulted in local hot streaks in the flow. These hot streaks were found to exist in the experimental data when the infrared camera data acquired during the test were analyzed. While these comparisons do not suggest the PARC code has been validated for HSCT nozzle applications, the results do suggest that the PARC code in its current state can be used to determine qualitatively the effects of design changes on nozzle performance.

Comparable code assessment activities of a similar nature to those described above are being conducted at NASA Langley and within industry. Thus a number of codes will be assessed early in HSRP to determine which code(s) should be emphasized in the later phases of HSRP and what code upgrades are required. Fundamental experiments will be conducted to acquire the code upgrade data required. One area most likely to require code upgrade is that of turbulence modeling. Currently most codes being employed use simple engineering turbulence models (either Baldwin-Lomax or k-E). It is doubtful that these simple models will be sufficient to allow an adequate prediction to be made of the shear flow mixing process occurring within the nozzle which is a prime contributor to the noise generation.

In a similar fashion, existing acoustic prediction approaches will be assessed. Most existing acoustic prediction methodologies rely heavily on empiricisms and thus will certainly require modifications. In addition, efforts have begun at both NASA Langley and Lewis to develop more fundamentally based acoustic prediction methodologies. These approaches would rely on time-accurate Navier-Stokes solutions to predict the instantaneous nozzle flowfield characteristics which would be used to directly calculate the acoustic field characteristics. The Navier-Stokes solver would not employ conventional turbulence models but would rely on direct simulation techniques. Obviously these approaches will be extremely computer intensive and will require many years of effort to perfect. However, such first principles based acoustic analyses can be used to gain insight into the governing physics occurring within the nozzle as well as to suggest improvements in the simplified engineering oriented acoustic prediction tools which will continue to be heavily used.

The subscale nozzle data base along with the generic nozzle data base and evolving computer prediction methodologies will allow a selection of the most promising concept(s) on which to focus the continued development efforts in the later phase of HSRP. Of course the concept(s) selected must be compatible with the preferred engine cycles which will be selected. The final tests of this element of HSRP will involve the most promising of the second generation configurations in the NASA Ames Research Center's 40x80 facility. The Lewis jet exit rig will be used and far-field acoustic signatures will be measured to demonstrate that nozzle concept(s) exist which meet FAR36 Stage III noise requirements.

Concluding Remarks

This paper has summarized the challenges the HSCT propulsion community faces to solve the two critical environmental barrier issues of ozone impact and community noise. The approaches being followed will result in the demonstration of combustor and nozzle concepts which would contribute to the design of an environmentally compatible, economically viable HSCT. Achievement of these objectives of HSRP will provide the incentive to continue focused NASA/Industry technology efforts to address the economic viability issues associated with future HSCT designs.

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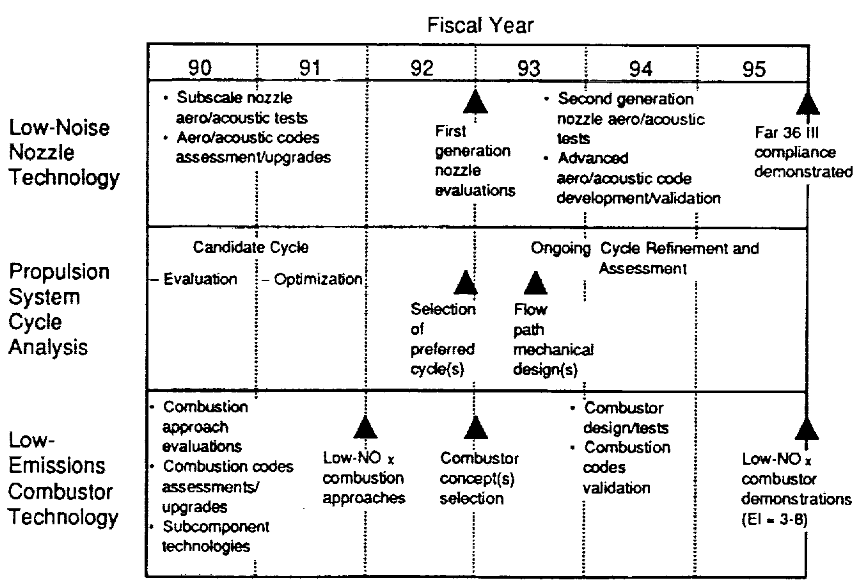

Figure 1.—Overview of the propulsion elements of NASA's high-speed Research Program (HSRP).

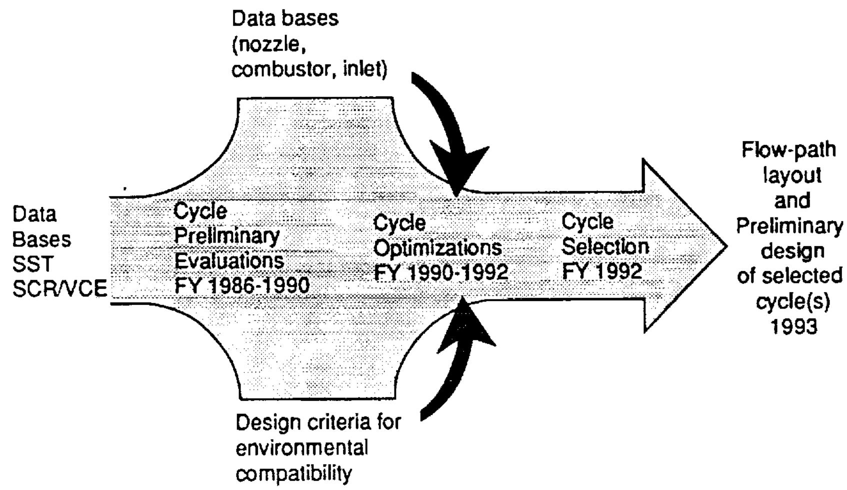

Figure 2.—HSCT propulsion cycle evaluation process.

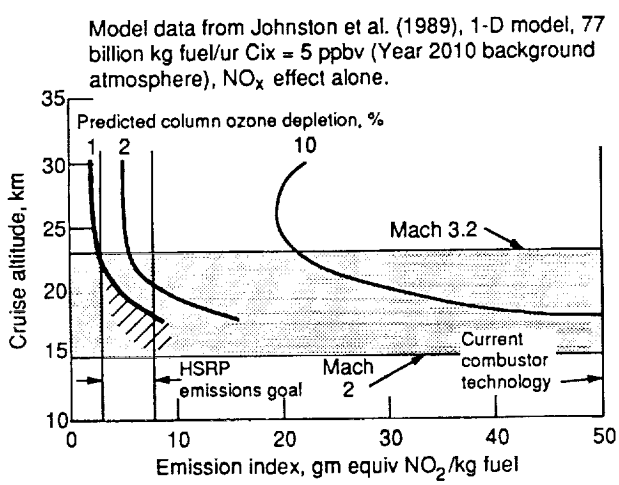

Figure 3.—Initial assessment of HSCT ozone depletion.

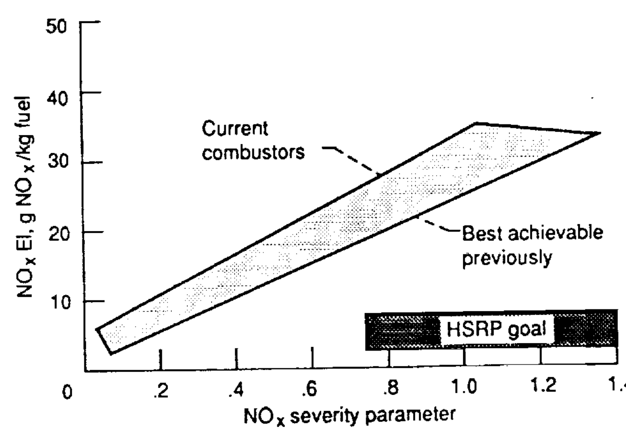

Figure 4.—The HSRP NO_x Emissions Challenge.

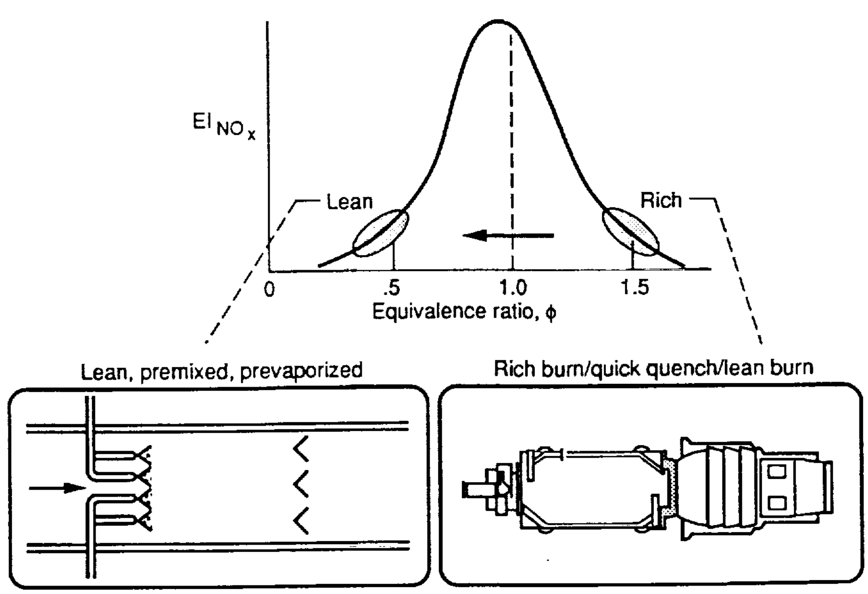

Figure 5.—Variation of NO_x with Equivalence Ratio.

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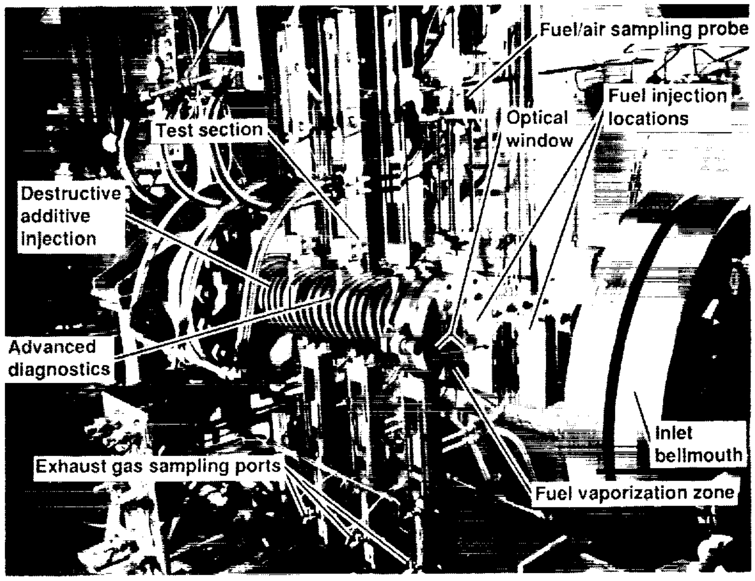


Figure 6.—HSR flame tube rig to evalute the lean premixed/prevaporized combustion concept.

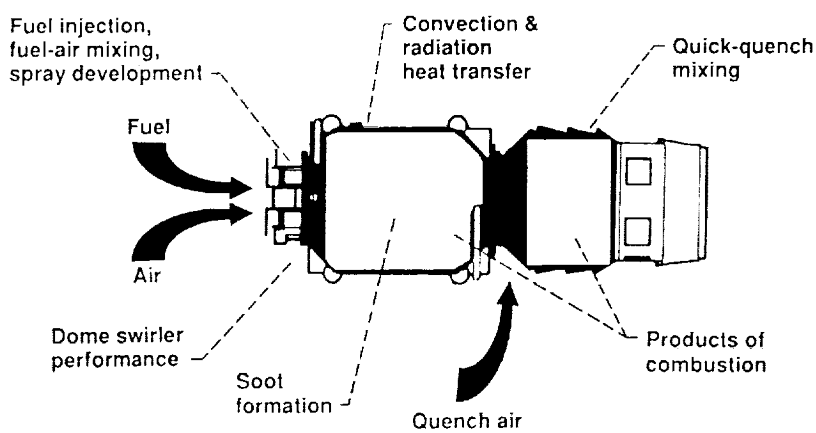
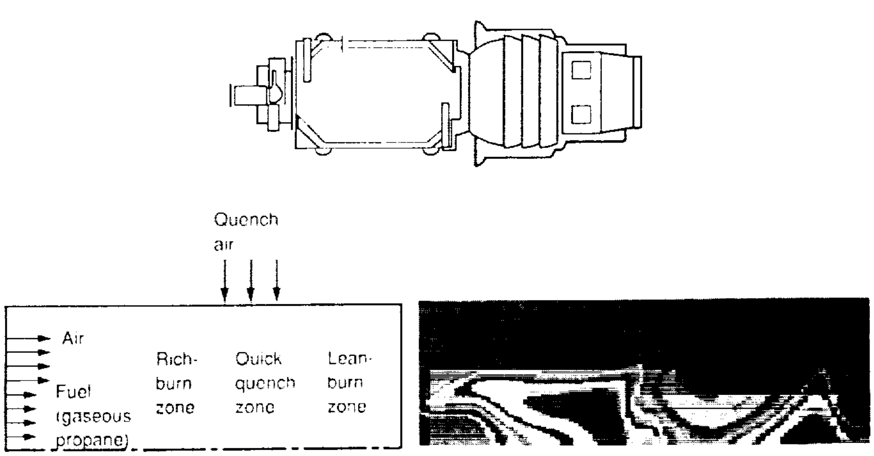


Figure 7.—Computer modeling requirements for HSCT combustors.



Simplified Combustor Model

Predicted Temperature Contours

Figure 8.—Low NO_x Combustor Analysis using the KIVA II analysis code.

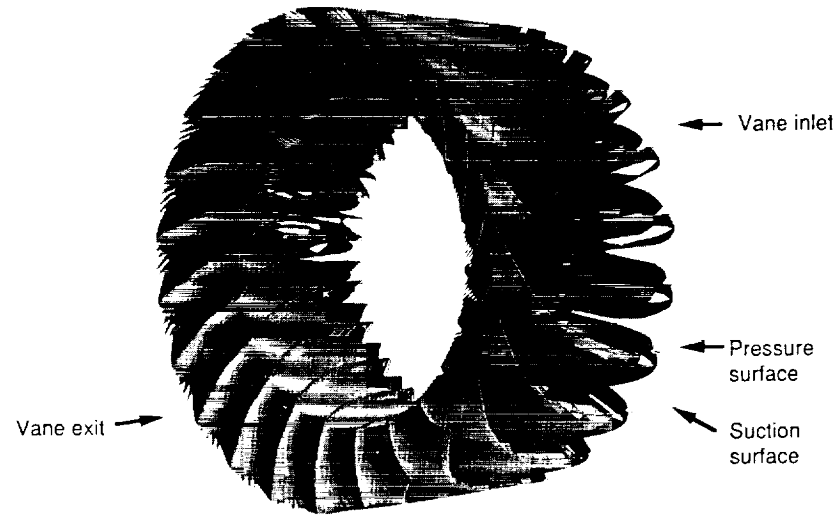


Figure 9.—Dome swirler predicted mach number contours.

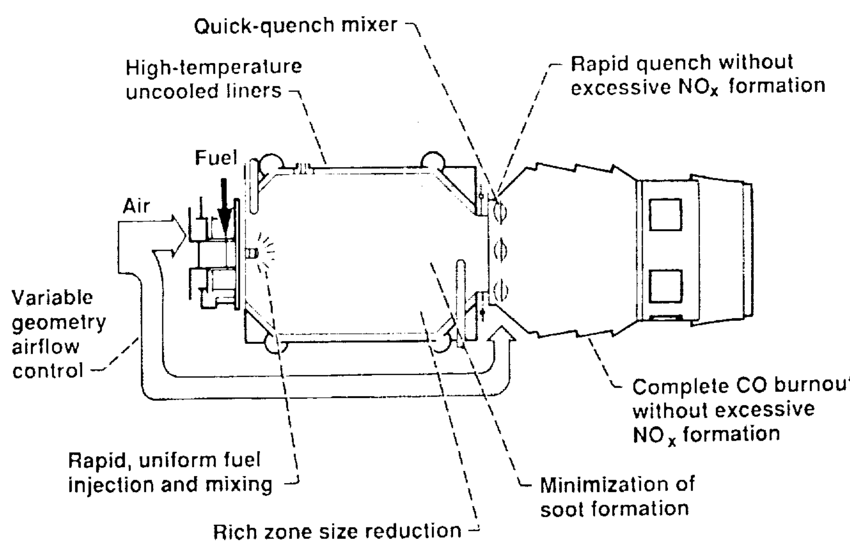


Figure 10.—Technology issues – RQL combustors.

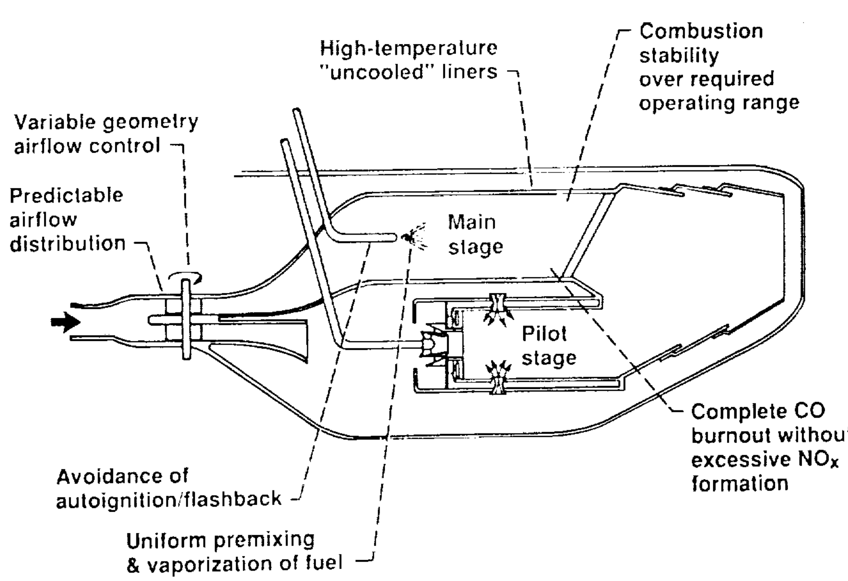


Figure 11.—Technology issues – LPP Combustors.

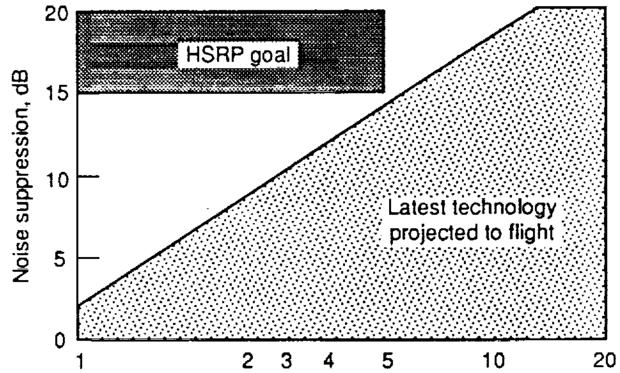


Figure 12.—HSRP Source Noise Challenge.

Figure 13.—Two-Dimensional Mixer-Ejector Nozzle in NASA Lewis 9x15 LSWT.

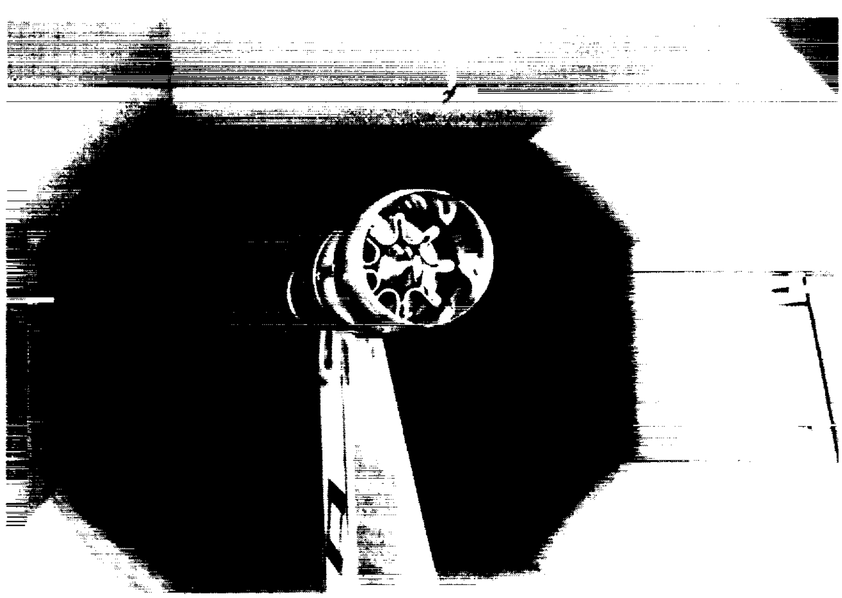


Figure 14.—Axisymmetric Mixer-Ejector Nozzle in Boeing Low-Speed Aeroacoustic Facility.

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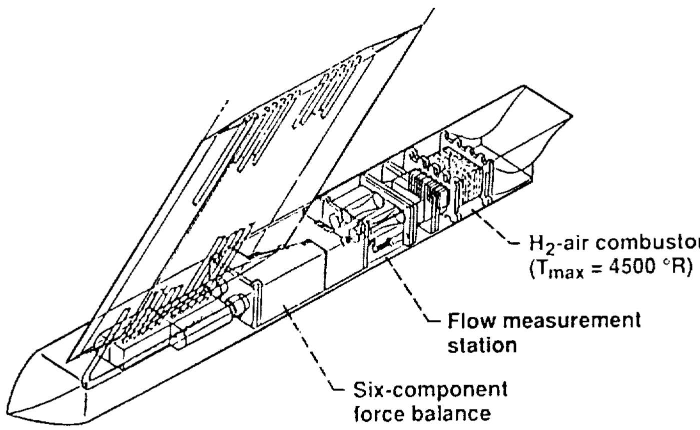

Figure 15.—Jet Exit Rig Details.

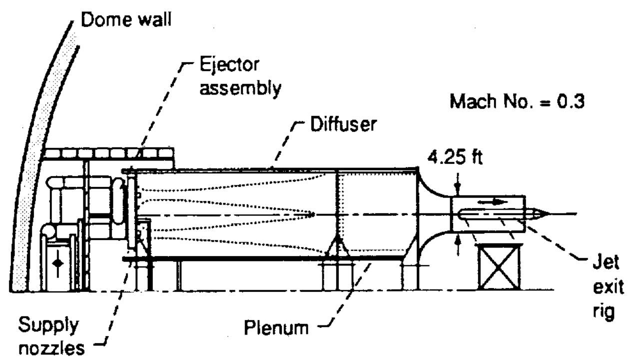

Figure 16.—Nozzle acoustic test rig (NATR) detail.

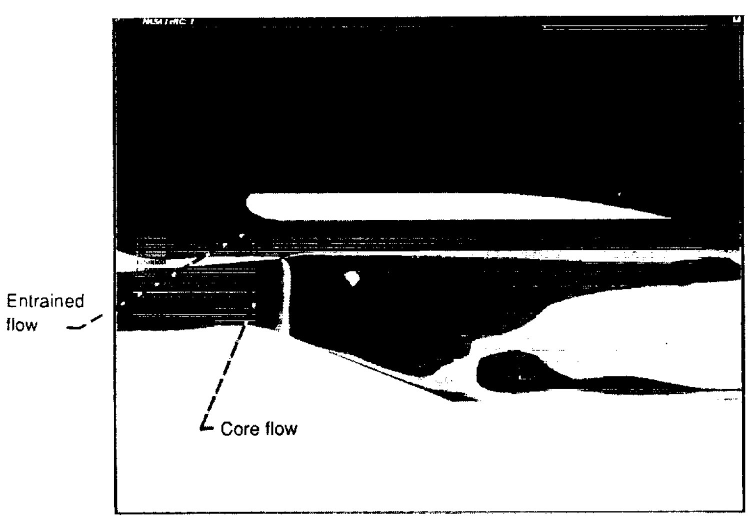

Figure 17.—Predicted mach number contours of mixer-ejecter nozzle concept.

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16. Abstract

Recent NASA funded studies by Boeing and Douglas suggest an opportunity exists for a 21st Century High Speed Civil Transport (HSCT) to become part of the international air transportation system. However, before this opportunity for high speed travel can be realized, certain environmental and economic barrier issues must be overcome. This paper will outline these challenges and indicate the propulsion research activities which NASA has underway and has planned to address these barrier issues and provide a technology base to allow the U.S. manufacturers to make an informed go/no go decision on developing an HSCT.

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