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NASA Aeropropulsion Research in Support of Propulsion Systems of the 21st Century

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NASA AEROPROPULSION RESEARCH IN SUPPORT OF PROPULSION SYSTEMS OF THE 21ST CENTURY

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INTRODUCTION

On this occasion and as the new century approaches, it is very appropriate to consider what the future may hold for aeronautical propulsion. We certainly expect that the aeronautical industry, in all of its many civilian and military facets, will continue to be a major source of economic activity and earnings for this country into the foreseeable future.

Perhaps it is unnecessary to remind the reader that propulsion advances have historically been linked to the most important developments in aviation. From the earliest engines to the most modern (Figure 1), the message is clear: better engines mean better airplanes. And of course, better engines come about only as a result of substantial, long-term and appropriately directed Research and Technology efforts.

At NASA, we are understandably proud of our role in aeropropulsion R&T. We feel very comfortable in acknowledging that other agencies and organizations are also performing important aeropropulsion research. But we feel that our own program is somewhat unique in its scope and long-term emphasis, and is therefore likely to have a major impact on 21st century propulsion systems. We do not just have plans, we have a <u>vision of the future</u>; and we will now share with you some aspects of that vision as they relate to aeronautical propulsion.

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Of course, the ultimate purpose for NASA's aeropropulsion research program is to maintain and improve the U.S. aviation industry's technical and competitive edge in the face of competent, growing and relentless foreign competition. This includes, with appropriate emphasis, all parts of civil aviation and selected military aviation areas as well. Since the Lewis Research Center is NASA's designated propulsion research facility, our remarks today will refer primarily to the work of that Center.

An aerial view of Lewis and some of its' facilities is shown in Figure 2. It was established 50 years ago and soon became an international center of excellence in the development of advanced gas turbine technology. World-class experimental and computational facilities have been developed, many of which are unique. The current aeropropulsion R&D budget of $150 million to $200 million is administered by a stable research staff of about 1000, about two-thirds of whom are Civil Service professionals.

Notable Lewis accomplishments over the years range from solving B-29 engine problems during WW-II to the Energy Efficient Propulsion Technology program of the past decade. The final phase of that program, known as the Advanced Turboprop Project or ATP and illustrated in Figure 3, applied advanced technology in such areas as propellers, installation effects, drive trains, and noise/vibration control to define a new, modern and highly effective version of an early but long neglected gas turbine propulsion concept. In recognition of this effort, the NASA Lewis Research Center and its' associated industry team were awarded the 1987 Collier Trophy. The studies, model tests, and flight tests all showed that turboprops with thin, swept, highly loaded blades can operate at high speeds (Mach 0.65 to 0.85) and reduce fuel consumption 25 to 30 percent relative to advanced turbofans and 40 to 50 percent relative to today's aircraft.

What comes next? The Lewis Research Center Strategic and Tactical plans are established and annually updated with valuable inputs from the aeropropulsion industry. The chart in Figure 4 illustrates our current Strategic Thrusts. These provide the focus for specific elements of the aeropropulsion program. We are implementing our efforts through five vehicle-focused elements (subsonic transports, supersonic cruise, hypersonic/transatmospheric vehicles, high-performance military aircraft, and small-engine technologies for rotorcraft/general aviation aircraft) plus generic technology elements involving both basic-disciplinary and multi-disciplinary research.

The current plan encompasses a wide variety of vehicle types and related disciplines. Before proceeding with this discussion, we should point out that the aeropropulsion program was reviewed in it's entirety at the "Aeropropulsion '91" conference, which was held in March 1991 at the Lewis Research Center. Extensive information on the areas to be discussed herein, as well as many that must be omitted, may be found in the Proceedings of that conference (Reference 1). In this presentation, we are going to address mainly the two highlighted, primarily civilian areas of subsonic transports and supersonic cruise aircraft. Without detracting from the importance of other activities, it is fair to say that these two account for the vast majority of the present and likely future revenues earned and passenger miles flown in the U.S. By any standard, they represent the civil core of this industry.

SUBSONIC TRANSPORT PROPULSION TECHNOLOGY

The major goal of this program is to achieve revolutionary advances in efficiency and environmental acceptability of large subsonic transport aircraft. Illustrated in Figure 5, this is the engine and vehicle class that accounts for the lion's share of the aviation industry's revenues and profits today. Thus, the accomplishment of our program is clearly a matter of national priority.

Previous work has already demonstrated the technology for fuel-efficient, unducted, advanced turboprops. That effort is concluding with some final work aimed at maturing the technology and transferring it to U.S. industry. Unducted ultra-high-bypass ratio engines, however, are subject to total thrust limits due to diameter constraints. Therefore the current work emphasizes ducted prop/fan configurations suitable for large wide-body aircraft with two underwing, high-thrust engines. Major elements of the program include ducted prop/fan technology for high propulsive efficiency, and high thermal efficiency cores.

The effects of low spool propulsive efficiency and core thermal efficiency on overall propulsion efficiency are shown in Figure 6. The historical progression from the first generation turbojets to low-bypass turbofans to current high-bypass turbofans is illustrated. Advanced turboprop technology provided a major increase in propulsive efficiency. The present goal is to develop the core and low-spool technology to reach the overall efficiency targets shown. In the unducted case, the goal is obtainable through core thermal efficiency gains combined with demonstrated advanced turboprop propulsive efficiencies. However, in the ducted case, new low-pressure spool technology is required in addition to the core improvements.

As indicated in Figure 7, the two environmental constraints which must be satisfied while the efficiency gains are pursued are noise and emissions. Currently, new aircraft must meet the FAR 36, Stage 3 noise rules. The example shown for two-engine aircraft at approach shows that certified effective perceived noise levels (EPNL) for the newest aircraft are already lower than those required for the maximum takeoff gross weights between 100 000 and 400 000 pounds. Part of the reason they are quieter is because they need to meet the current operating environment, which is constrained by local airport noise rules. These are considerably more stringent than FAR 36, Stage 3. Aircraft noise also poses a significant constraint on the capacity of the air transport system by limiting the hours of operation and airport expansion. Thus, a noise goal for new ultra-high-bypass technology of FAR 36, Stage 3 minus 10 EPNdB has been chosen by NASA for technology development. A band is shown to reflect the fact that a 2 to 3 EPNdB margin must be built in to reduce certification risk.

Emission constraints are not as well defined. Emission index (EI) in grams of NOx per kilogram of fuel burned is plotted against a NOx severity parameter which is a function of combustor temperature and pressure. The trends for conventional combustors and the more advanced technology developed under the

NASA/GE Experimental Clean Combustor Program (ECCP) are shown. High-efficiency core technology utilizing higher pressures and temperatures will increase the NOx severity parameter significantly, as indicated by the range labeled on the abscissa for the cycle parameters being studied. Therefore, while specific numerical goals have not been set at present, there is clearly the technical challenge to develop low-NOx combustors as part of high-efficiency core technology.

Ultra-High Bypass

The two main subdivisions of ultra-high-bypass technology, unducted and ducted props/fans, are shown pictorially in Figure 8. Illustrated is an unducted counterrotation configuration with combined forward and aft swept rotors and a single wide-chord swept rotor in a very short duct. Although the first generation of aft-swept advanced turboprop technology is well in hand, forward sweep is being investigated as part of the conclusion of unducted research. Aerodynamic and acoustic aspects of this work are expected to carry over to a comprehensive investigation of ducted rotors with either forward or aft sweep. The ducted picture comes from computational work to analyze both the internal and external flow fields in one integrated computational fluid dynamics (CFD) calculation. Because the duct is short and thin to minimize weight and cruise drag, not only integrated aerodynamic but also an integrated aeroacoustic analysis will probably be required to capture the performance and noise characteristics of these propulsors.

Some features and technology issues associated with ducted ultra-high-bypass propulsors are shown in Figure 9. The rotor is expected to have fewer blades with wider chords than current turbofans. Bypass ratios greater than 10 and as high as 20 or more are under consideration. Geared versus ungeared rotor drives and variable-versus fixed-pitch rotors are also under consideration. Such choices will be based on the outcome of noise-constrained cycle studies and mission analyses now underway. The short, low-drag nacelle (having a total length of up to one rotor diameter) is a particular acoustic concern since space for acoustic treatment is severely limited.

Advanced tip and casing treatments can provide improved surge and stall margins with little or no performance penalty. In addtion the acoustic shielding effect of the cowl itself has a beneficial impact on the total noise problem, particularly cabin noise. Using a simple barrier-shielding model to estimate the noise on the fuselage, as shown in Figure 10, indicates that the fuselage noise-reduction potential of a ducted, as compared with an unducted, propeller is significant even for very short ducts.

To summarize the UHB area, unducted rotor research is concluding with an investigation of forward sweep. Forward sweep can reduce the tip vortex strength and, hence, has a potential for reducing the noise for counter-rotating unducted rotors. The aerodynamic performance can also be improved slightly over an aft-swept blade.

Short cowls have most of the aerodynamic advantages of conventional cowls with very few disadvantages. Experiments show that they do a good job of flow straightening and have delayed lip separation as compared with conventional length cowls. The reduced length also means less boundary layer buildup, less weight, and less drag.

NASA's acoustic research effort is currently directed towards developing an understanding of propeller/fan acoustics in short ducts. The reduced duct length means that there might be insufficient duct length for acoustic cutoff. With less length and less cowl thickness, the space for acoustic treatment is limited, requiring integrated aeroacoustic designs.

Continuing CFD analysis tool development will provide Euler and Navier-Stokes codes for advanced high-bypass ratio engine concepts. These tools, which do an integrated calculation of the rotor and cowl flow fields, will handle steady inflow as well as angle-of-attach calculations.

High Efficiency Core

The second ingredient for improved overall efficiency is raising the thermal efficiency of the core itself. Some features and technology issues associated with high-thermal-efficiency cores are reflected on Figure 11. Overall pressure ratios being investigated range from 50 to 100, and combustor inlet temperatures are greater than 1000°F. High-temperature, lightweight materials with minimal cooling requirements are needed along with combustor designs to limit NOx, in spite of the high temperatures and pressures. In such a compression system at high pressure ratios, conventional compressor design approaches lead to very small flow path and blade heights. Consequently, the usual problems in attaining high component efficiencies in small turbomachinery are multiplied, and unconventional approaches such as off-axis core modules are being studied. For example, each module might contain a centrifugal compressor, combustor, and radial turbine; and several of these modules may be spaced circumferentially around the engine axis.

Because an off-axis core does not have a fan or low-spool shaft running through it, the hub diameter can be reduced. This adds design flexibility to the high pressure spool; many of the aerodynamic and structural penalties from small sizes in an in-line configuration can be avoided. Also, since centrifugal compressor and radial in-flow turbine stages are feasible in an off-axis configuration, the parts count can be reduced compared to a conventional all axial configuration. If multiple off-axis cores are used, there is redundancy in the hot section which could potentially increase reliability. Hot section maintenance could also be simplified because the low pressure spools would not have to be removed for access to the high pressure spool.

The typical 100:1 overall pressure ratio engine consists of a two-spool geared configuration with a bypass ratio of 20 to 25. The resulting fan pressure ratios are 1.3 to 1.4. Low drag nacelles are required to minimize the losses associated with the high bypass ratios. Efficiency improvements are needed in both the compressor and the turbine to enable thermal efficiency improvements at the higher pressure ratio. Advanced materials such as ceramic matrix composites (CMC) are used extensively throughout the hot section of the engine to reduce or eliminate cooling flow requirements. Since the fan must be geared to achieve the very high bypass ratios with a reasonable number of turbine stages, advanced gearbox technology will be needed to achieve the required transmission power of about 50 000 hp.

As a result of the high overall pressure ratio, the combustor entrance pressure and temperature are very high. This would result in NOx formations exceeding current levels with current technology combustors. Therefore, NOx combustor technology must be developed for very small combustors in this type of engine.

Figure 12 illustrates the severity of the challenge. As the pressure ratio is increased, the combustor entrance pressure and temperature increase. The severe combustor entrance conditions produce very high NOx emissions compared to the baseline configuration, even when fuel savings are included. These high emissions can potentially be reduced to levels at or below those found in the baseline by using rich-burn/quick-quench/lean-burn (RQL) or lean-premixed-prevaporized (LPP) combustor technology, which is being developed under the High-Speed Research (HSR) program. However, the combustor required for the high-pressure-ratio subsonic engine is an order of magnitude smaller in airflow size compared to the HSR combustor. Therefore, additional work may be required to develop the RQL and LPP technology for such small combustors.

In summary, the advanced high-efficiency core study engines with an IOC date of 2015 have the potential for large fuel savings and DOC improvements for both large turbofan and small turboshaft engines. The fuel savings resulting from the large subsonic transport engines were 19 to 28 percent when compared to a proposed next-generation turbofan engine with an entry into service date of 1993. The corresponding DOC improvements are 6 to 14 percent for a fuel cost of $1.00/gal. These improvements result from high cycle pressure ratios, high bypass ratios, enhanced component efficiencies, and advanced materials. The advanced materials allow high temperatures without severe cooling penalties and thus enable the high specific power needed for bypass ratios of 10 to 25.

Figure 13 illustrates how we expect to get from "here" to "there', at least for the balance of this decade. The elements of the overall NASA program in aeropropulsion research for subsonic transports are shown in their planned sequence. Unducted ultra-high-bypass work is winding down and effort should be essentially complete by the end of FY92. On the other hand, the base research and technology program in ducted props/fan is well established and growing with a multiyear effort planned. In addition, a noise reduction initiative has been planned for a possible FY93 start. That effort would draw on the base aerodynamic and source noise reduction technology to arrive at a total design-for-noise capability. An experimental validation using a large powered transport model incorporating high lift and installation aerodynamics technologies with the source noise reduction element would be the program endpoint. Parallel to the ultra-high-bypass propulsor technology is the high-efficiency core research effort. A base program is underway with cycle and technology definition studies nearing completion in preparation for a sustained base technology effort. The intent is to support the advocacy of a high-efficiency core initiative in the FY95 time period.

Finally, it should be recalled that noise reduction is emerging as a dominant theme as a means to alleviate noise constraints on the capacity of the air transport system. The impact is greatest on the design of the low-pressure (prop/fan) portion of the engine because the dominant noise source is the rotor. Since a large body of technology was developed for unducted rotors over the last decade and application of that technology to commercial products has been delayed by market forces, current research emphasis is on technology for ducted configurations suitable for new twin-engined, long-range aircraft. A parallel effort to develop high thermal efficiency cores is about to move into base technology work now that cycle studies have identified the technology issues and concepts to address them.

SUPERSONIC CRUISE

Based on worldwide population and economic trends, it is widely predicted that long-range, high-speed, trans-Pacific flight will be a key ingredient of the global air transport system of the 21st Century. NASA and many other groups believe that the time is at hand for a commercially viable supersonic transport airplane.

As Figure 14 implies, significant advances in propulsion performance are required if supersonic transport vehicles are to become an important part of the 21st Century international air transportation system. The NASA Phase I High-Speed Research Program (HSRP) emphasizes solutions to the critical environmental barrier issues associated with any future HSCT aircraft. As illustrated in Figure 15, the barrier issues may be separated into those of an environmental nature and those related to economics. Two of these barrier issues - atmospheric ozone depletion and community noise - are primarily propulsion issues and are addressed in the Lewis portion of HSRP. Specifically, environmental programs are aimed at low emissions combustor technology that will result in no measurable impact on the ozone layer and low noise nozzle technology that will contribute to complying with FAR 36 Stage 3 noise rules. The critical economical viability issues will be the emphasis of a proposed Phase II HSRP, which could be initiated as early as FY93. To address these issues, programs will be established to develop and demonstrate the enabling materials and critical component technologies.

Far-term efforts will be directed at the development of advanced technologies for enhancing the performance of supersonic cruise propulsion systems. One example of such an effort is the development of supersonic throughflow fan technology to provide a basis for alternate propulsion system designs.

Emission Reduction

The HSR NOx emissions challenge is shown in Figure 16. Initial two-dimensional atmospheric impact studies suggest that ultra low NOx combustor technology will be required if no adverse impact on the ozone layer is to occur. The standard term for expressing NOx emissions levels is the emissions index (EI), defined as

$$EI = \frac{\text{g of equivalent } NO^2 \text{ produced}}{\text{kg of fuel burned}}$$

These ultra-low NOx levels would have EI's in the range of 3 to 8. The figure shows the emissions parameter as a function of a severity parameter, which is itself a function of combustor pressure and temperature levels. The HSRP goal is compared to the performance of current in-the-fleet combustors and to performance levels demonstrated in the NASA/Industry Experimental Clean Combustor Program.

The major elements of the low emissions combustor technology portion of HSRP are shown in Figure 17. Initially, emphasis will be on the development and validation of the computer analyses to predict the details of the combustion process within candidate combustor configurations. Also, laboratory experiments will be conducted to evaluate candidate low-NOx combustion approaches. These laboratory tests will be used in conjunction with advanced diagnostics to develop a comprehensive combustion code validation data base.

These experimental data bases and the analytical prediction codes will form the basis for the conceptual design of candidate low-NOx combustors. The deliverable of this element of HSRP will be the demonstration of ultra-low-NOx combustor configurations in rig demonstrations.

Currently, two combustor concepts appear to hold promise for meeting the HSRP emissions goal of EI = 3 to 8: the lean-premized-prevaporized (LPP) and the rich-burn/quick-quench/lean-burn (RQL). The key to achieving ultra-low-NOx production levels is to accomplish all burning away from stoichiometric conditions. The LPP concept features burning at lean fuel-air conditions. The RQL concept requires two stages of burning. The first stage burning is conducted in a fuel rich environment. The transition from rich to lean burning is accomplished through an introduction of quench air between the two stages. The quench air must be introduced into the combustion stream so that mixing occurs rapidly and uniformly such that no localized burning zones occur at close to stoichiometric conditions, which would significantly increase the NOx produced. Figure 18 indicates some of the critical technology challenges that must be overcome before an ultra-low-NOx RQL combustor could be designed. (The LPP combustor has a comparable set of challenges). HSRP with combined experimental and analytical efforts will develop the required combustor subcomponent technologies for LLP and RQL combustors and incorporate them as required in the combustor rig demonstrations at the conclusion of the program.

Noise Reduction

The HSCT source noise challenge is illustrated in Figure 19. The jet exhaust noise levels at takeoff and landing conditions must be reduced by 15 to 20 db relative to reference conic nozzle levels before any future HSCT can hope to have noise levels below FAA noise regulation limits. At the same time, the nozzle aerodynamic performance levels must be kept high if vehicle overall mission performance goals are to be met. This combined acoustic-aerodynamic challenge is often expressed as a ratio of decibel noise reduction to resultant percent thrust loss. For a viable HSCT design this ratio should be in the neighborhood of 4:1. As this figure shows, current technology would yield a nozzle design with a ratio of no better than 2:1.

The major elements of the source noise portion of HSRP are shown in Figure 20. Much like the low NOx combustor area, heavy emphasis is being placed in the first years of HSRP on computer code development and validation and on subscale experiments to evaluate potentially attractive nozzle concepts. The emphases regarding the codes is again on applying available solvers for both nozzle aerodynamic flows and for the acoustic signatures of the various configurations. The laboratory experiments and computer code developments and the insights they provide as to the governing fluid physics will be key inputs to the development of advanced nozzle configurations that will meet the HSRP goals, both for aerodynamic performance and acoustic suppression.

Future Plans

The road map for the propulsion elements of NASA's overall High-Speed Research Program is shown in Figure 21. HSRP Phase I efforts will result in demonstrations of low-NOx combustor and low-noise nozzle concepts as well as determination of preferred HSCT propulsion cycles. NASA's HITEMP engine materials program will provide the basis for the development of the advanced composite materials required for the combustor and nozzle components of any future HSCT engine.

The HSRP Phase I and HITEMP research results will be the inputs to the proposed HSRP Phase II Program currently advocated by NASA. The propulsion elements of HSRP II would demonstrate HSCT propulsion technology readiness initially through large-scale testing of the critical components (inlet, fan, combustor, and nozzle); then these components would be combined with an available core engine in propulsion systems technology demonstrations at both low-speed (takeoff) and high-speed (supersonic cruise) conditions.

The Enabling Propulsion Materials of HSRP II would demonstrate the materials technology readiness through tests of an uncooled ceramic matrix composite (CMC) combustor liner and a nozzle substructure element fabricated from an advanced intermetallic matrix composite (IMC) developed in HSRP II.

Supersonic Through-Flow Technology

The long-term emphasis in the supersonic cruise propulsion research is on examining alternate high performance propulsion system concepts and pursuing the appropriate critical component and system technologies. Currently, as indicated in Figure 22, the main effort is on developing the supersonic through-flow technology and, in particular, on demonstrating the viability of the critical components (fan stage, inlets, and nozzle) and eventually system performance and control across the speed range.

A baseline fan stage, illustrated in Figure 23, is currently being tested at NASA Lewis to demonstrate the viability of establishing and maintaining supersonic flow-through a turbomachinery stage. Detailed flowfield mapping experiments will also be conducted, the results of which will be used to validate the various computer codes used in the design and analysis process.

Figure 24 shows the fan installed in a test section. The photograph of the supersonic fan test section shows the rotor and stator blades installed and also the hub and tip bleed regions, which can be used to vary the incoming boundary layer profiles to the fan stage. Although much testing remains to be done, we can say that the results to date are highly encouraging -- perhaps better than expected -- and in line with CFD predictions, no starting or unstart problems at all have been experienced. This alone is a research "first" of major importance.

Additional components however would be required to make up a complete supersonic propulsion package. These include the supersonic fan inlet (Figure 25), the core inlet and the fan nozzle. Currently underway are experimental and analytical studies of inlet concepts that would be appropriate for a supersonic fan. To the small-scale inlet tests being conducted at low- and high-speed conditions, the advanced Navier-Stokes flow solvers were applied to predict the inlet steady-stage and dynamic performance characteristics. Similar combined analytical and experimental efforts will be started in FY91 to investigate aft inlet and fan nozzle concepts.

In summary, supersonic cruise propulsion research is a growing part of NASA's aeropropulsion program and is poised to provide the propulsion technologies required to maintain U.S. leadership in the international aerospace market in the 21st century. The research efforts include a "near term" thrust to support supersonic cruise technology in the early 2000's, and a longer term emphasis to demonstrate the supersonic fan and perhaps other, as-yet unforeseen advances of the future.

CONCLUDING REMARKS

The past half century at NACA/NASA Lewis has seen great accomplishments in aeropropulsion technology. From fixing the B-29 engine problems to validating the advanced turboprop, we have contributed to expanding the aeropropulsion operating envelope while improving fuel efficiency, environmental acceptability, and flight safety. The recent award of the Collier Trophy leads us to believe that our current strategy is working. Where will it lead us?

With that question in mind, the chart in Figure 26 illustrates some selected milestones that we expect to accomplish by the year 2000. In the subsonic area, the ATP work is winding down towards its conclusion next year. Major emphasis is being placed on ducted Ultra-High Bypass (aka ducted-fan) engine R&T. Very low noise technology together with still higher efficiency and low emissions should be demonstrated before the end of the decade and should then enter the pipeline to commercial introduction. In the high speed arena, work for the next several years will address the propulsion technology for a commercially viable supersonic transport. Initial emphasis will be on the NOx and noise barriers and assessing the feasibility of the novel Supersonic Fan concept. Later in the decade, economic feasibility will be demonstrated with a complete scale model of a supersonic propulsion system, including composite materials and structures.

Improvements in propulsion technology, dramatized in this final chart (Figure 27), have always provided a major share of aircraft performance improvements. We believe that propulsion advances will be even more critical in the future. We also believe that the efforts that have been described here will be major contributions to the technology advancements required for 21st century aeropropulsion.

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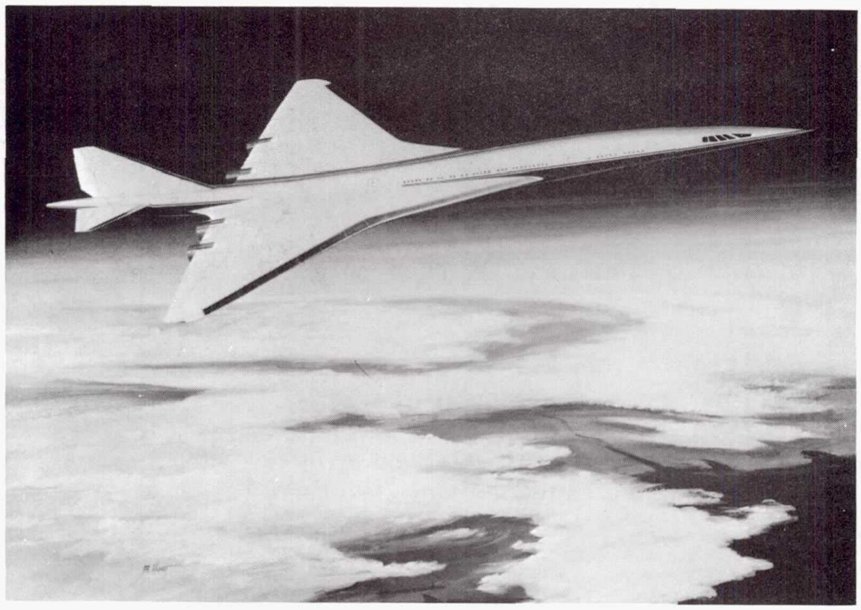


Figure 1.—NASA aeropropulsion research for the 21st century.

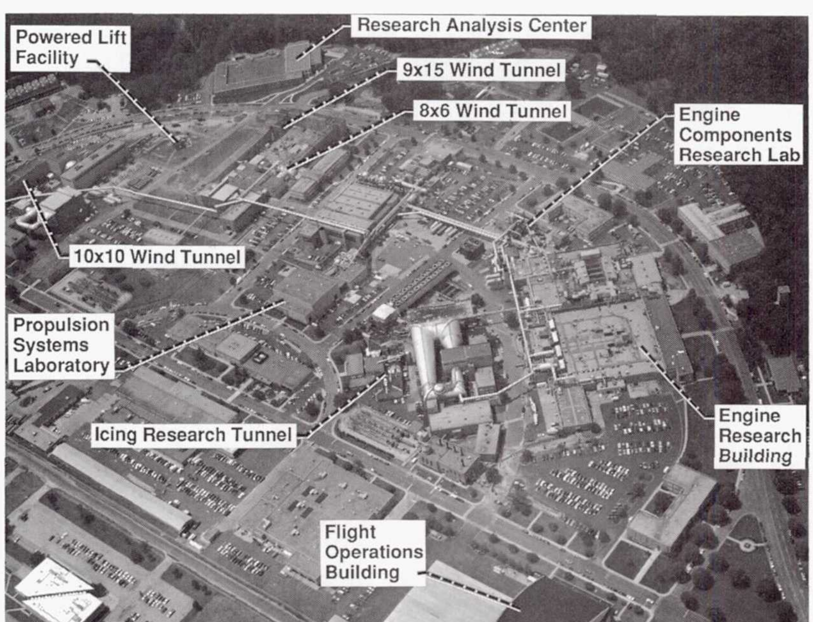


Figure 2.—Lewis Research Center and its aeropropulsion facilities.

Figure 3.—Advanced turboprop proof of concept.

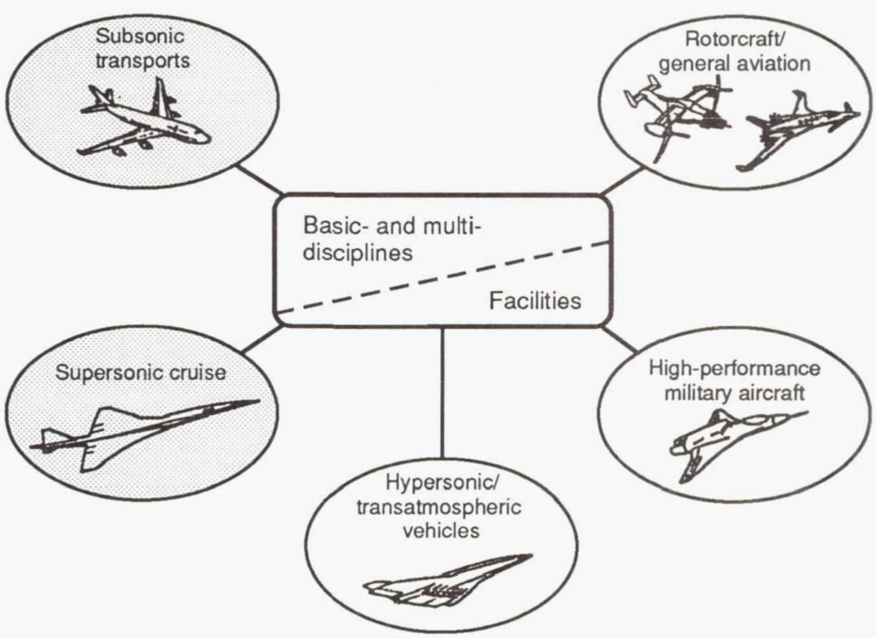


Figure 4.—Strategic thrusts.

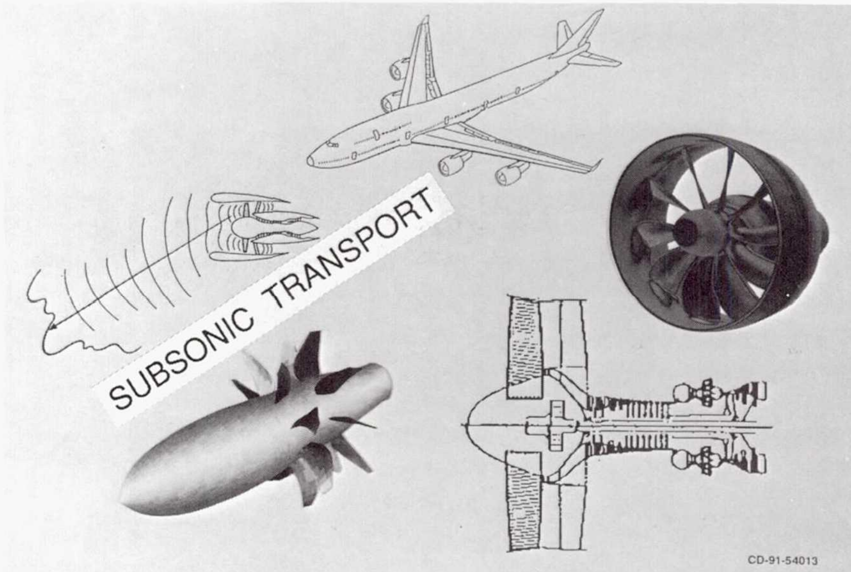


Figure 5.—Subsonic transport.

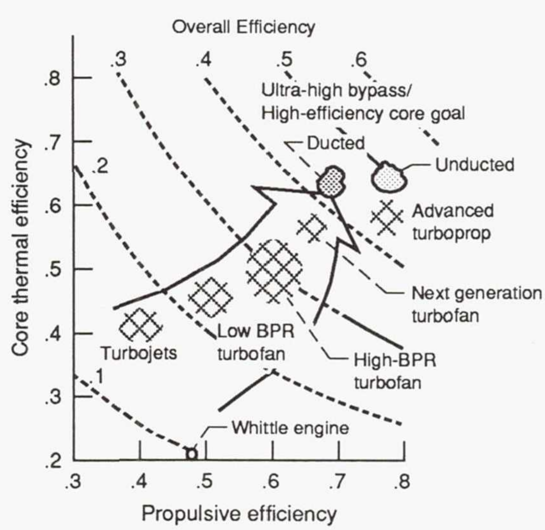


Figure 6.—Subsonic propulsion efficiencies.

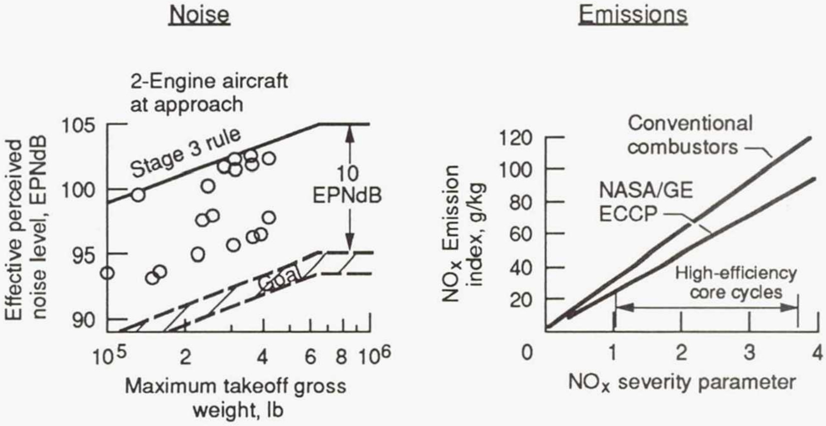


Figure 7.—Subsonic transport environmental constraints.

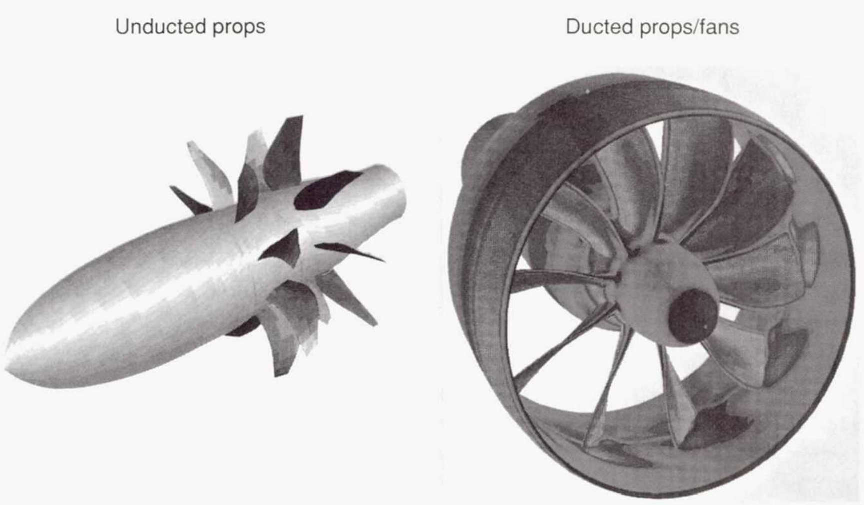


Figure 8.—Ultra-high bypass.

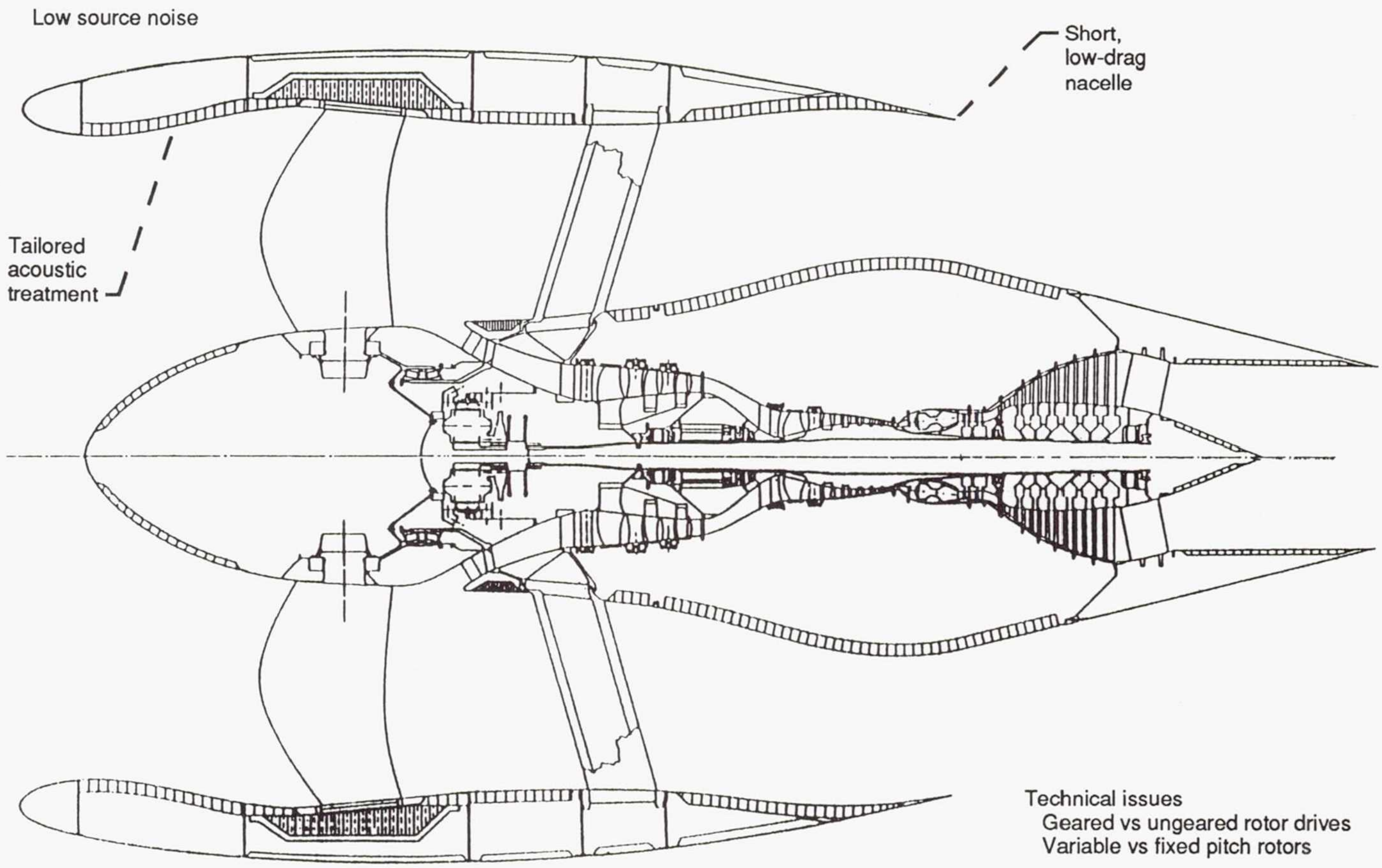


Figure 9.—Ducted ultra-high bypass; ratios, bypass 10 to 20+.

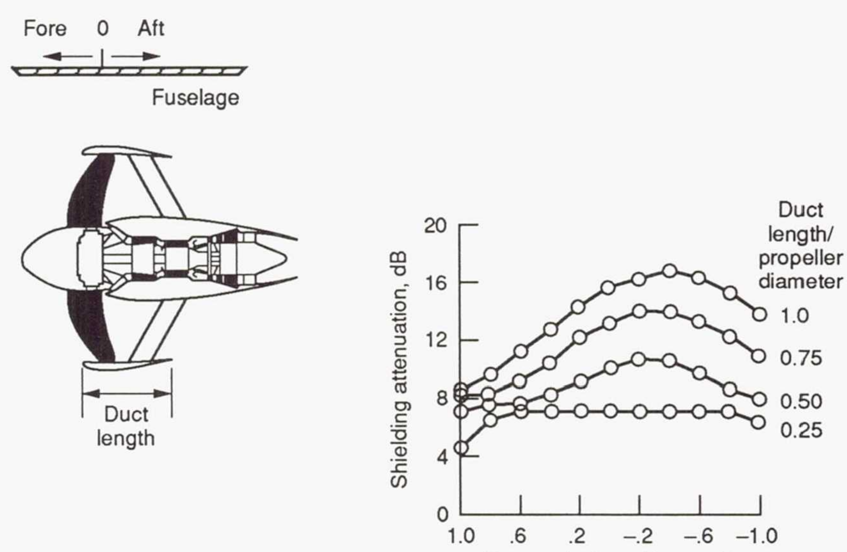


Figure 10.—Predicted short-duct noise shielding.

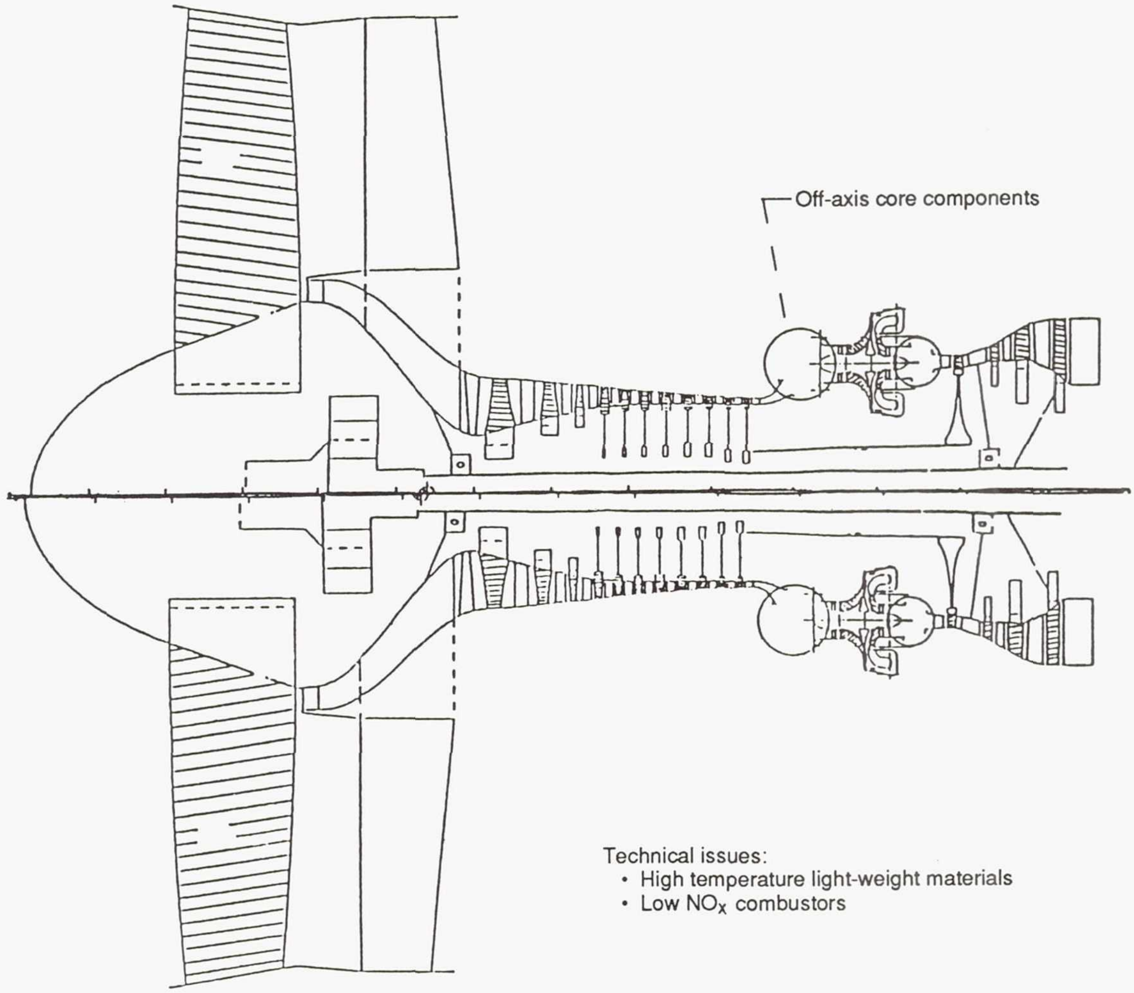


Figure 11.—High-efficiency core. Overall pressure ratio, 50 to 100; combustor inlet temperature, >1000 °F.

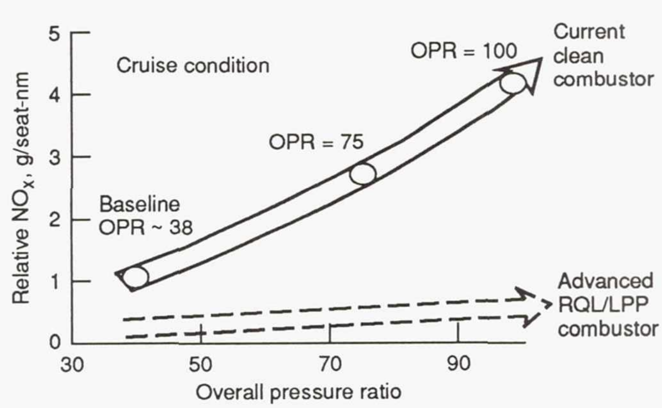


Figure 12.—Engine emissions challenge.

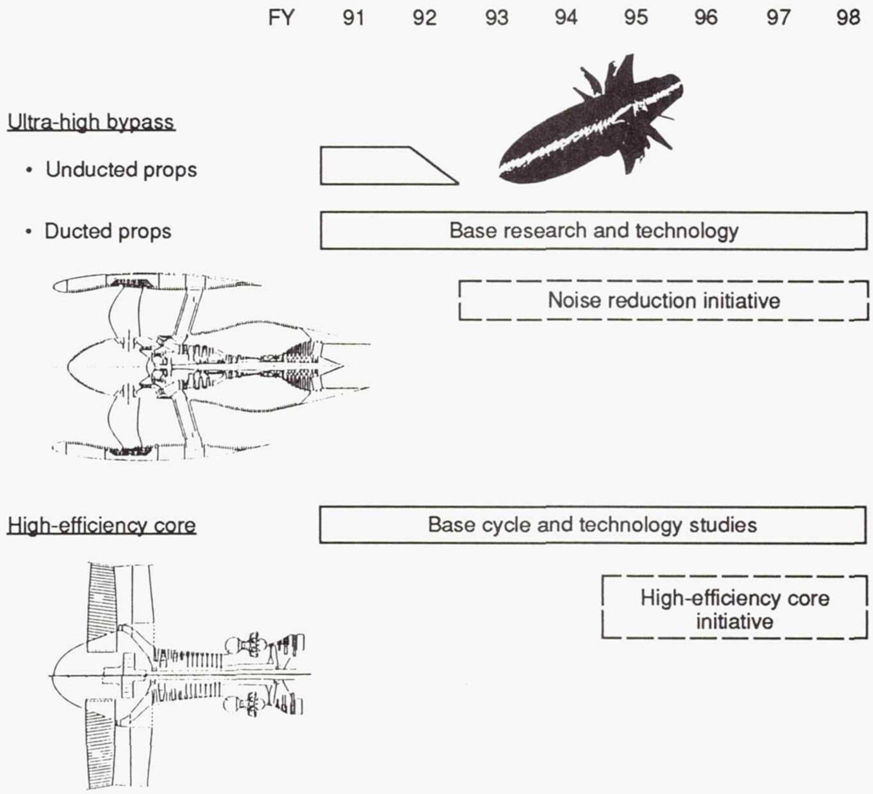


Figure 13.—Subsonic transport aeropropulsion program.

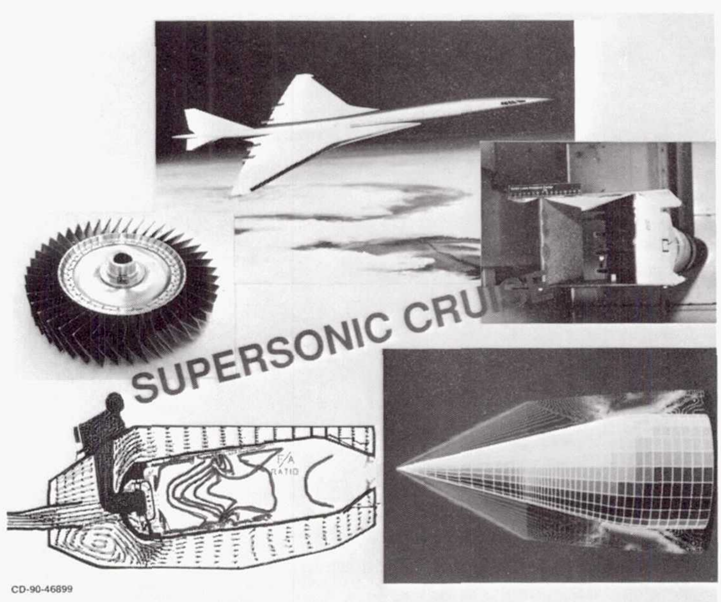


Figure 14.—Supersonic cruise.

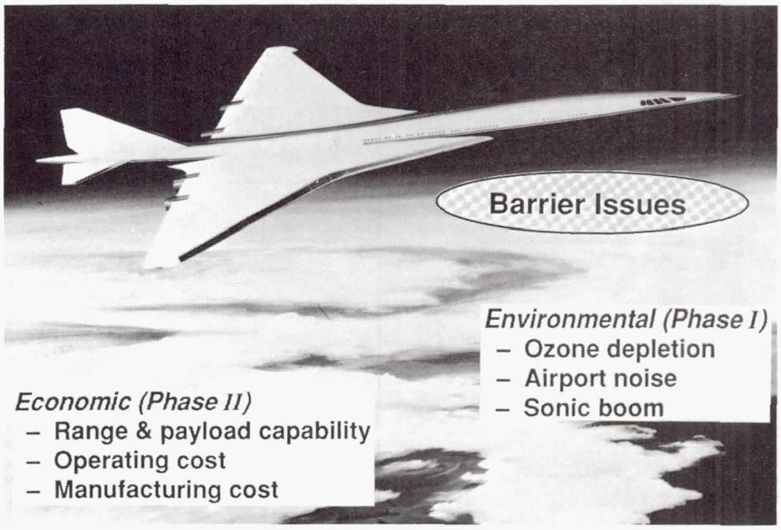


Figure 15.—High-speed research program.

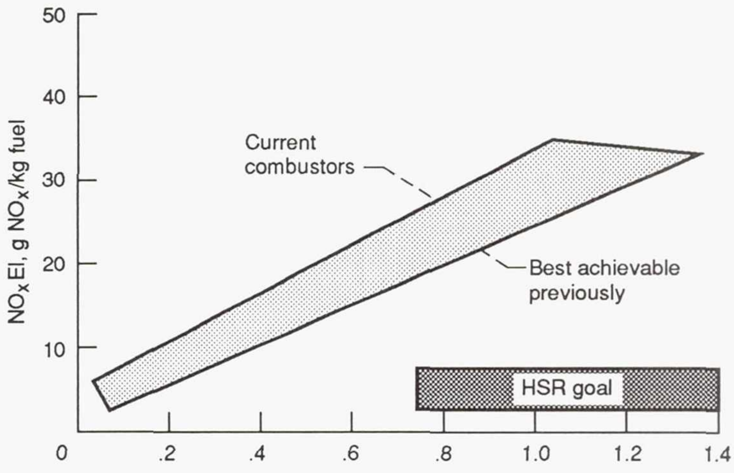


Figure 16.—HSR NO_x emissions challenge.

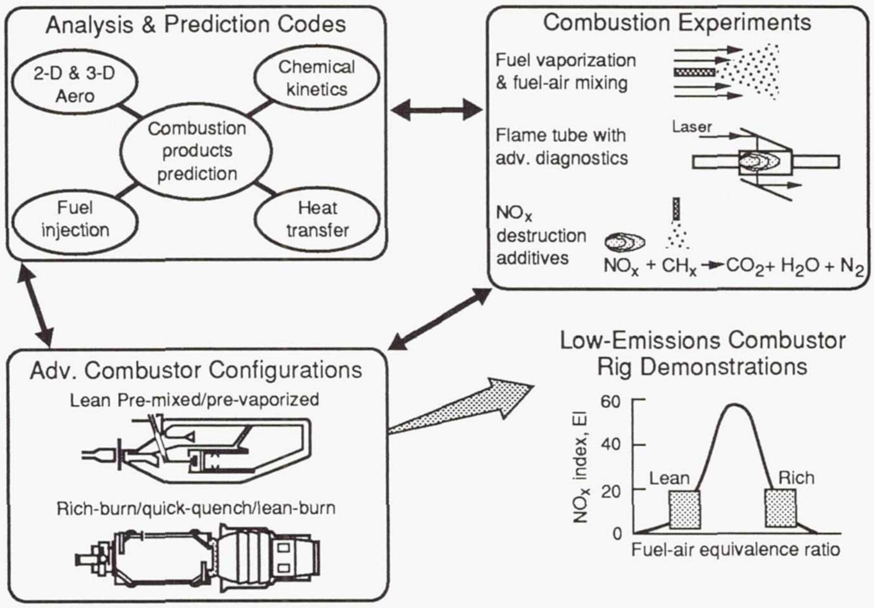


Figure 17.—Low-emissions combustor technology elements.

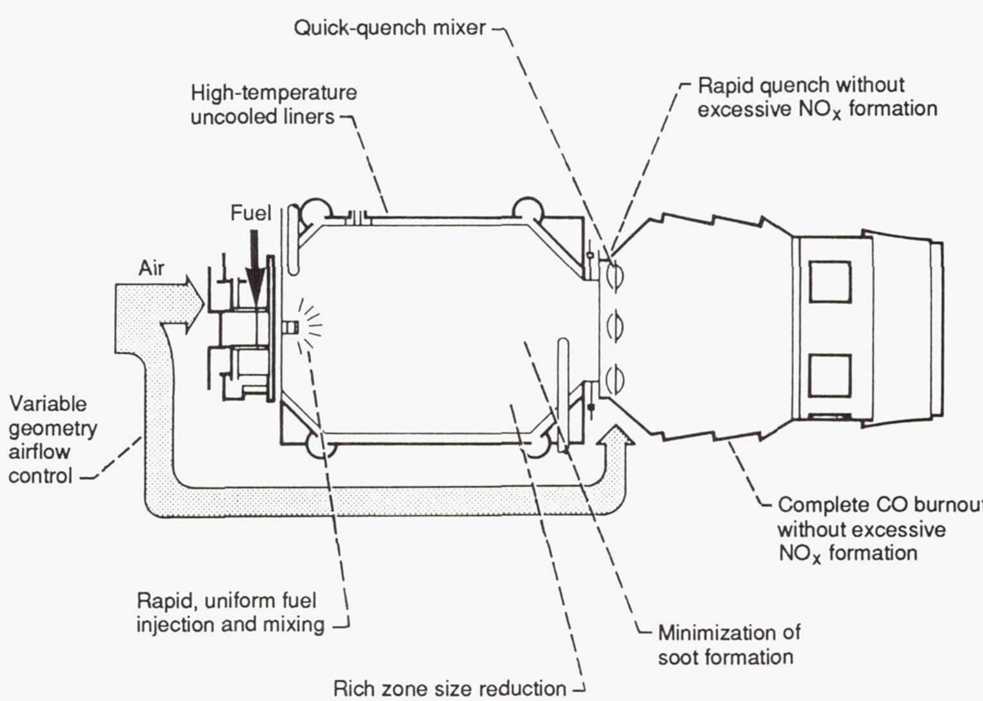


Figure 18.—Technology issues-RQL combustors.

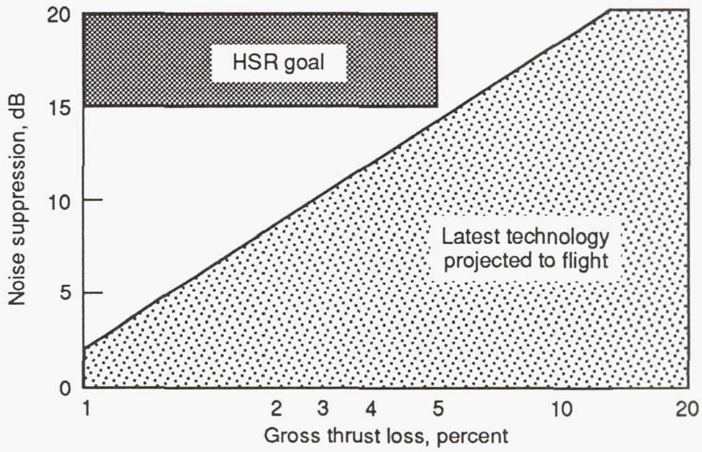


Figure 19.—HSCT source noise challenge.

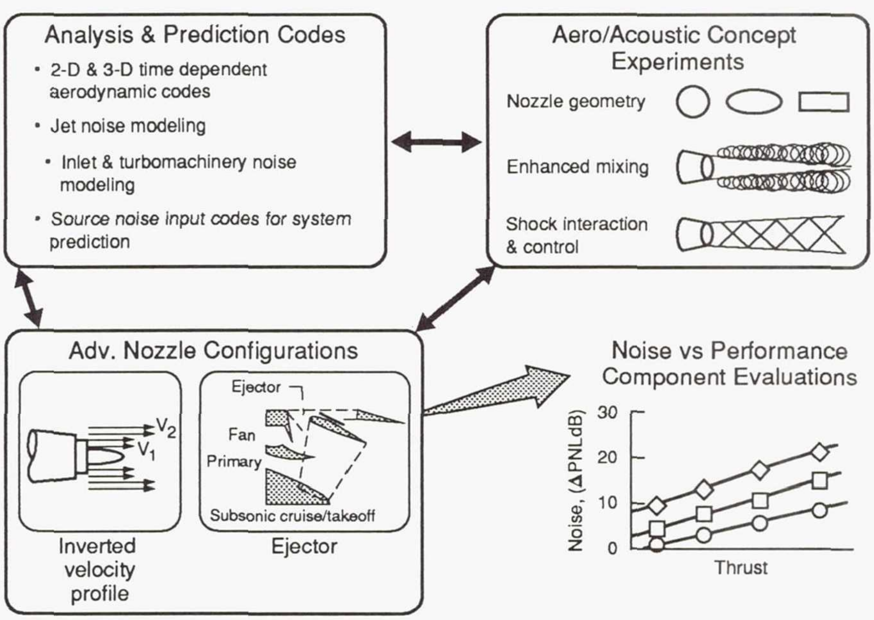


Figure 20.—Low-noise nozzle technology elements.

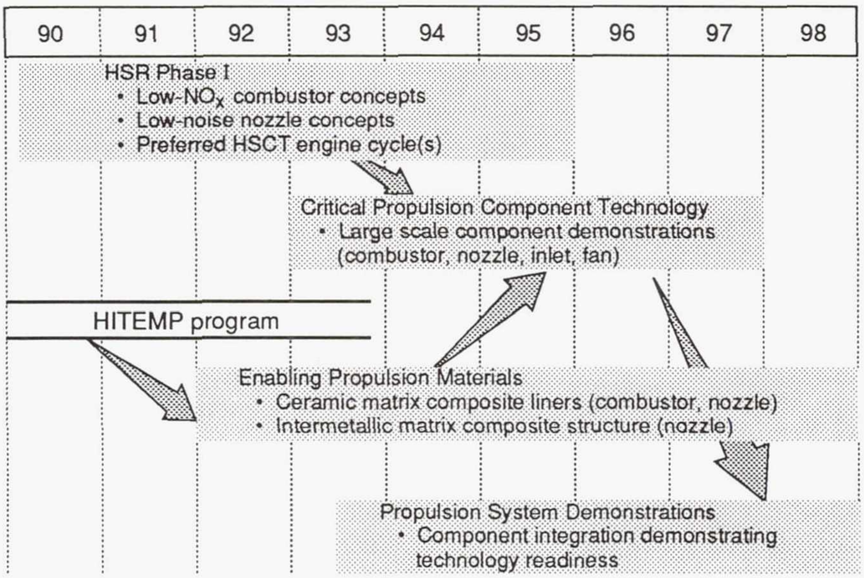
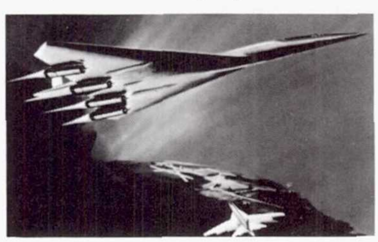
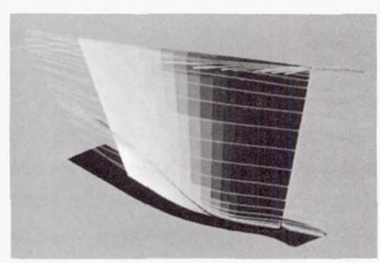


Figure 21.—NASA high-speed research plan propulsion elements.

Objective:

Establish supersonic through-flow technology enabling revolutionary improvement in high-speed aircraft



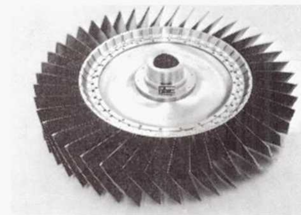


Focus:

Conduct analytical/experimental research to demonstrate the performance potential of supersonic through-flow compression

Figure 22.—Supersonic through-flow technology program.

Goals:
Prove concept of a supersonic through-flow fan stage demonstrating subsonic, transition, and supersonic performances; obtain detailed flowfield mapping for code validation



Pressure ratio	2.45
Inlet axial Mach number	2.00
Rotor tip speed	1500 ft/sec
Tip diameter	20 in.

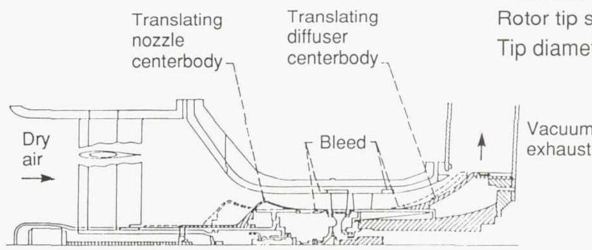


Figure 23.—Supersonic through-flow program; baseline fan.

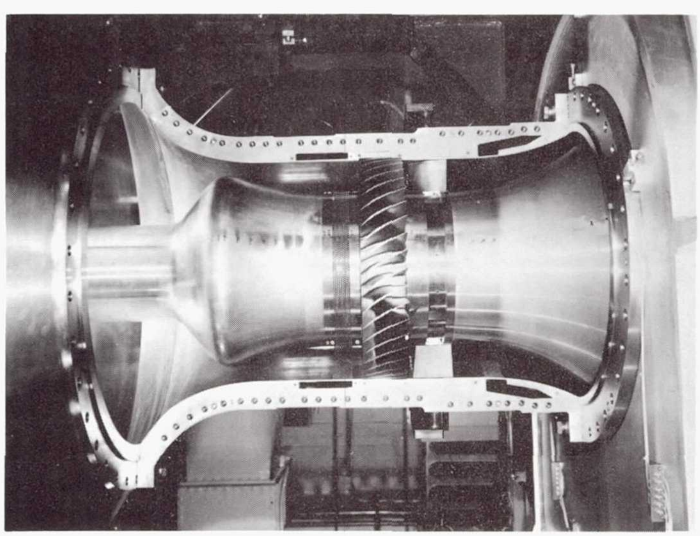


Figure 24.—Supersonic fan test section.

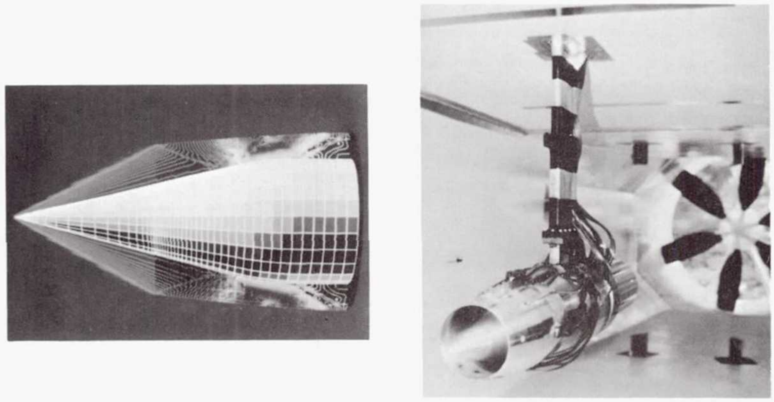


Figure 25.—Supersonic through-flow inlet technology.

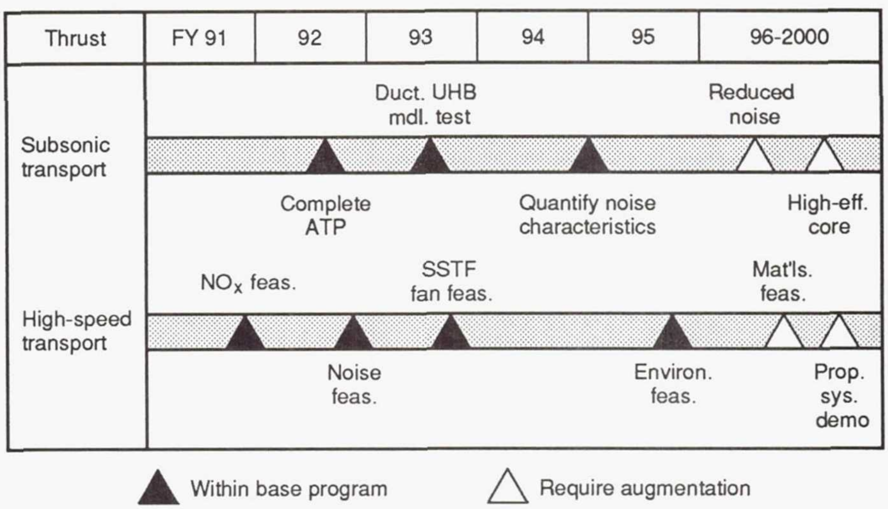


Figure 26.—Aeropropulsion program; selected propulsion milestones.

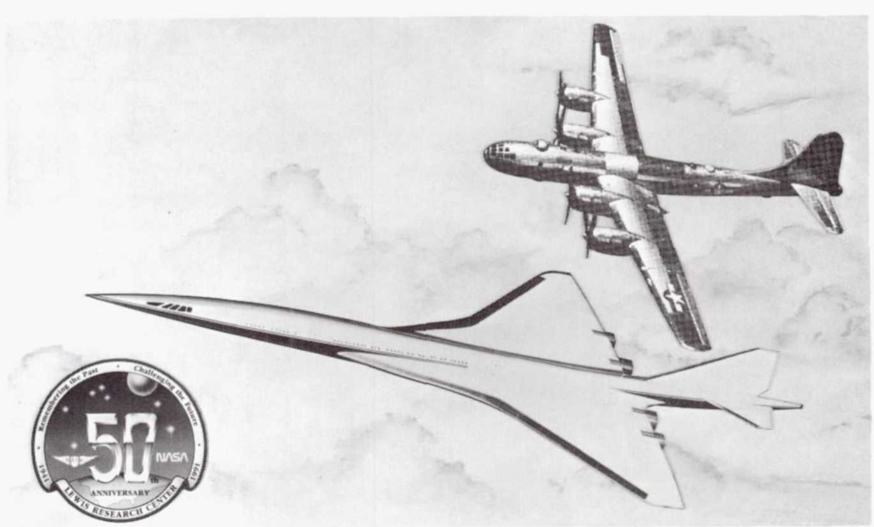


Figure 27.—Lewis aeropropulsion technology, past and future.

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16. Abstract

A review is given of NASA's ongoing and planned research and technology programs leading to advanced air-breathing propulsion systems of the next century. The primary focus is on efforts being performed or sponsored by NASA's Lewis Research Center, with emphasis on civil, subsonic and supersonic transportation systems which should begin to enter service within 10 to 20 years. Subsonic transport propulsion program elements, including ducted UHB engines and high efficiency cores are discussed in terms of goals, technical issues and problems, approaches and plans. Similarly, The Supersonic Cruise Propulsion Program is reviewed via discussion of near-term and far-term goals; barrier issues such as NOx and noise reduction and the consequent Phase I (near-term) research plans are described; and finally, emerging technologies such as the supersonic through-flow fan are considered for their potential long-term impact.

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