NASA NOISE REDUCTION PROGRAMS FOR ADVANCED TRANSPORT AIRCRAFT

David G. Stephens, Clemans A. Powell, and F. W. Cazier, Jr.
NASA Langley Research Center
Fluid Mechanics and Acoustics Division
Hampton, Virginia 23681, USA

Abstract

Noise reduction technology is becoming increasingly important to the development and operation of the world's air transportation system. The future growth of air transportation will, to a large extent depend on the ability of the industry to meet the demands of the public, the marketplace, and the regulatory agencies for quieter products. As a consequence, noise reduction is gaining in prominence in most of the aeronautical technology programs being conducted for future systems. Several aeronautical programs are discussed to illustrate the areas of emphasis in noise reduction and the technologies being exploited to achieve the required levels of reduction. The programs and technologies represent the joint efforts of NASA, the FAA, and the U.S. industry which includes the manufacturer, operators, and airport/community planners.

Introduction

Aircraft noise is an important byproduct of the world's air transportation system. Because of growing public interest and sensitivity to noise, noise reduction technology is becoming increasingly important to the unconstrained growth and utilization of the air transportation system. Unless noise technology keeps pace with public demands, noise restrictions at the international, national and/or local levels may unduly constrain the growth and capacity of the system to serve the public. In recognition of the importance of noise technology to the future of air transportation as well as the viability and competitiveness of the aircraft that operate within the system, NASA, the FAA and the industry have developed noise reduction technology programs having application to virtually all classes of subsonic and supersonic aircraft envisioned to operate far into the 21st century. The purpose of this paper is to describe the scope and focus of the NASA Noise Reduction Program with emphasis on the advanced technologies[1,2] that form the foundation of the program.

Historical Perspective

NASA's responsibility in noise research is to generate advanced noise prediction and noise reduction technologies for use by the Federal Aviation Administration (FAA) as a technical basis for establishing noise standards, and for use by the aeronautical industry to assure the development of products that will meet the standards without undue economic penalties. The information also supports the development of flight operational procedures as well as airport and community planning measures which can be used to further reduce undesirable effects of noise.

NASA's noise research, which dates back to the 1940's, became a major program shortly after the introduction of jet transports, when it was recognized that unless large noise reductions were achieved, noise could become a serious public nuisance and an obstacle to the development of an adequate national air transportation system. The effort has been a closely coordinated activity involving the NASA research centers, the FAA, the engine and airframe manufacturers, and a number of university and private research groups. The noise reduction research has been focused on understanding, predicting, and suppressing all of the various noise sources. It has also of necessity included intensive analytical and experimental studies of the noise propagation from the aircraft to the ground, as well as the perceived effects of the noise—and of various noise alleviation measures—on human beings.

Figure 1 gives a history of jet commercial airplane noise levels. Plotted in this figure courtesy of the Boeing Company is the sideline certification point noise level normalized to 100,000 lb thrust for each airplane/engine configuration at the time of initial service. In early turbojet engines, the high-velocity jet exhaust, mixing with the surrounding air, was the major noise source. In the 1960's, low-bypass-ratio turbofan engines were introduced. The turbofans offered greater propulsive efficiency than the turbojets, and they provided some noise relief as well. With the help of internal mixers, the engine core and fan exhausts were combined, resulting in a lower jet exhaust velocity and therefore a significant reduction in jet exhaust noise.

An even greater reduction in jet exhaust noise was achieved when the higher-bypass-ratio second generation turbofans arrived with the wide-bodied transports. However, with the reduced jet exhaust noise no longer the primary noise source, further improvements required reduction of the fan generated noise as well as the jet noise. In 1967, NASA initiated an acoustically treated nacelle program, in which engine ducts and inlets were lined with acoustic treatments and flight tested on a Boeing 707 and a Douglas DC-8. Successfully achieving the design goal of reducing noise under the approach path by as much as 15 PNdB, the Quiet Nacelle[3] program proved that acoustic treatment was feasible and effective. The program also enabled one to determine the weight and cost penalties associated with varying degrees of noise reduction by acoustic treatment.

During the 70's, research continued on a variety of techniques for reducing fan noise in the engine itself. These measures included eliminating inlet guide vanes, reducing the number of fan blade rows, reducing the rotational speed, increasing rotor/stator separation, and improving fan blade aerodynamic design. In the early 1970's, these concepts were integrated and evaluated in ground tests of an experimental engine. The results of this Quiet Engine Program[4] verified the predictions of considerable noise reduction in both approach and takeoff, and provided an improved data base for future designs.

In more recent NASA research programs, such as the Quiet, Clean, Short-Haul Experimental Engine (QCSEE)[5] program; the Quiet, Clean General Aviation Turbofan (QCGAT)[6] program; and the Advanced Turboprop Program (ATP)[7]; noise reduction principles were extended to produce even quieter engines.

Advanced Subsonic Technology Program

In an effort to augment and accelerate ongoing subsonic technology in several key areas, NASA initiated the Advanced Subsonic Technology (AST) Program in late 1993. The goal of the AST program is to develop high payoff technologies to enable a safe, highly productive global air transportation system that includes a new generation of environmentally compatible, economical U.S. subsonic aircraft. The elements of the program are noise reduction, propulsion, integrated wing design, terminal area productivity, general aviation/ commuter, civil tiltrotor, composites, aging aircraft, fly-by-light/power-by-wire, technology integration, and environmental assessment. The goal of the noise reduction program is to provide noise reduction technology readiness to achieve unrestrained market growth and compliance with international environmental requirements. To achieve this goal, NASA has established an objective of 10 dB noise reduction relative to 1992 technology. The objective will be achieved by combined noise reduction improvements in the engine, the aircraft system, and in aircraft operations.

The AST noise reduction program and several other AST program elements are strongly related. Noise reduction is an enabling technology for the rotor and the design for the Civil Tiltrotor and will be a primary consideration in the development of its terminal area operating procedures. Noise reduction is also of prime importance to the general aviation/commuter element, the propulsion element,

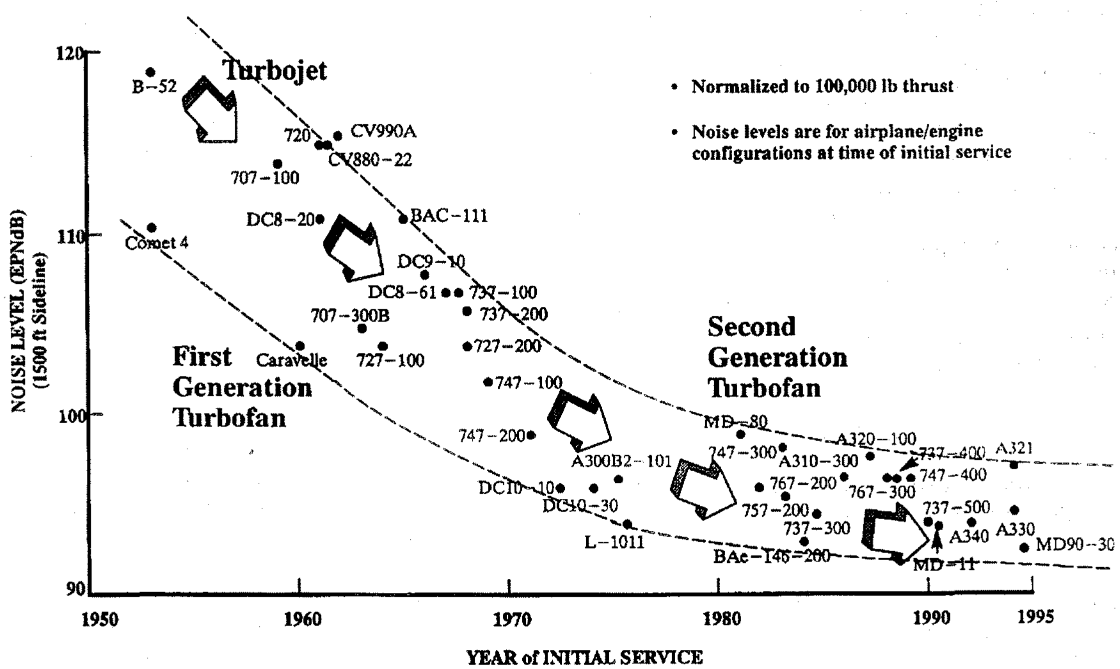


Figure 1. Progress in Noise Reduction

terminal area productivity and integrated wing elements of the program. The noise reduction element of the AST Program consists of five subelements depicted in Figure 2 namely, engine noise reduction, nacelle aeroacoustics, engine airframe integration, interior noise reduction, and airport community noise impact. Each of the subelements is discussed in the following subsections.

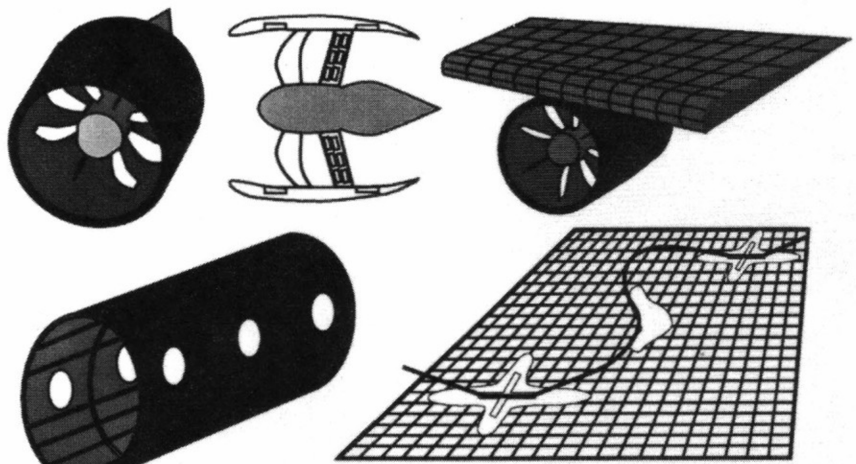


Figure 2. Advanced Subsonic Technology Noise Reduction Program Subelements.

Engine Noise Reduction

The objective of the engine noise reduction subelement is to provide technology to reduce engine noise levels 6 dB relative to 1992 technology by the end of the decade. A near term objective (1996) is to provide technology for reducing jet noise for lower bypass ratio (1.5-6.0) engines, and the technology for reducing fan noise 3 dB. Advanced noise prediction methods based on fundamental principles are being developed. These codes will be used to understand noise generation mechanisms, and to evaluate noise reduction concepts. These noise reduction concepts will be tested on high fidelity scale model engines. Several engine simulators will be used in the program including the 12 in., 17 in. and 22 in. models of the Pratt and Whitney Advanced Ducted Prop (ADP), a 22 in. model of the General Electric Universal Propulsion Simulator, and a 22" in. Allison engine model. Figure 3 shows the 17 in. model of the P&W ADP being tested in the NASA Lewis Research Center 9 ft. x 15 ft. wind tunnel. Figure 4 is a comparison of predicted and measured fan tone noise levels from this test. A key technology to the success of the noise reduction program is the ability to predict from fundamental principles the performance and acoustics of advanced fans. The predicted values shown are from an integrated prediction code which

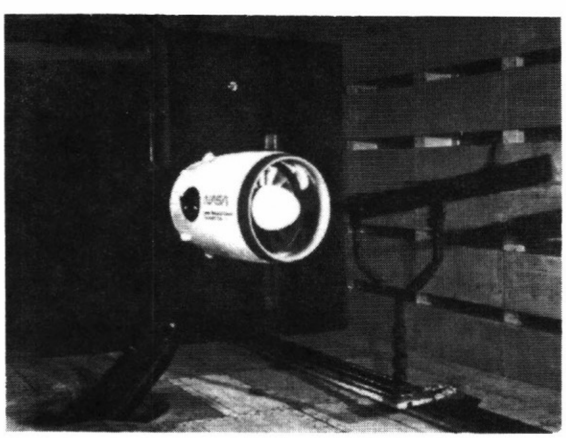


Figure 3. Engine Model in 9' x 15' Wind Tunnel

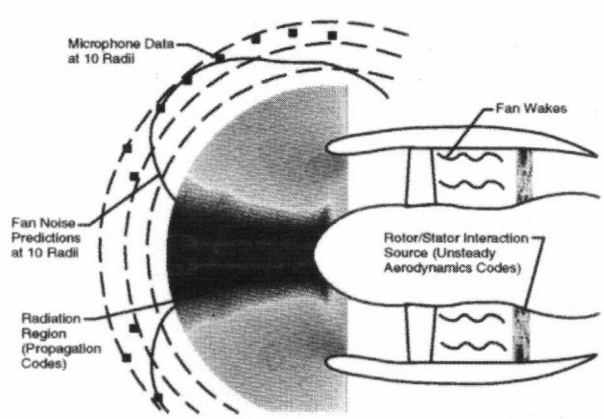


Figure 4. Measured and Predicted Fan Noise

brings together source noise, propagation within the nacelle, and radiation prediction codes. Predicted unsteady pressure distributions on the engine struts, a key noise source mechanism, and the noise field at the inlet of the engine are also shown. The microphone and predicted data are at 10 radii and displayed on noise contours with the inner contour being 80 dB, the middle contour 90 dB and the outer contour 100 dB.

Nacelle Aeroacoustics

The goal of this research is to provide technology to increase the effectiveness of the nacelle in absorbing, canceling or redirecting turbomachinery noise. Research will include analytical modeling to estimate nacelle geometry effects on noise propagation; laboratory experiments to improve duct noise control treatments including passive, adaptive and active control strategies, and scaling validation of noise control technologies through scale model and full scale tests. The ultimate goal is to achieve a 50 percent increase in suppression effectiveness by the year 2000. An intermediate goal is to increase treatment efficiency by 25 percent by 1997. Figure 5 shows how existing high bypass engines and long

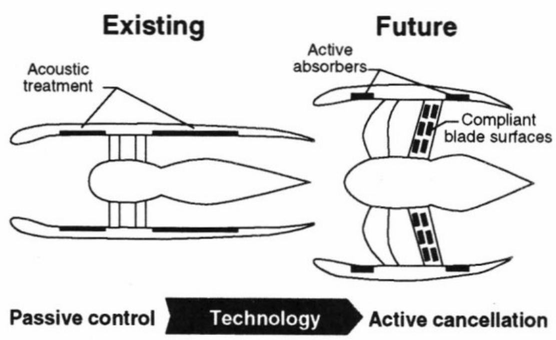


Figure 5. Noise Control Treatments

nacelle technology with passive acoustic treatment in the inlet and exhaust may, through technology development, be replaced by even higher bypass ratio engines, with short nacelles and active acoustic absorption and active noise cancellation at the source.

Acoustic/Aerodynamic Integration and System Evaluation

The objective of the integration and system evaluation subelement is to develop and validate system noise prediction and minimization methods to include engine/pylon/wing installation effects and airframe noise. The emphasis is on the acoustic and aerodynamic integration of turbofan engines with high-lift systems operating under both takeoff/climbout and approach/landing conditions. Figure 6 from chapter 3 of reference 8 illustrates some of the airframe noise sources. Specific goals of this subelement include the capability to reduce airframe noise 4 dB below current levels, eliminate the noise penalty due to the interaction of the engine and the wing high-lift system while at least maintaining the current level of high-lift performance, and identify or eliminate areas of risk when model scale experiments are used to predict the performance of flight hardware under flight conditions.

Figure 6. Airframe Noise Sources

Interior Noise Reduction

The goal of the interior noise reduction subelement is to develop and validate weight-efficient technology to minimize cabin and cockpit noise in commercial and general aviation aircraft, including advanced civil tiltrotors. Design tools for low noise transmission will be developed, and practical broad-band control demonstrated through passive concepts and through active noise control. The objective is to produce technology capable of yielding a 6 dB overall interior noise reduction by the year 2000 with no increase in treatment weight. The application of active structural acoustic control technology is illustrated in figure 7 from a test at the NASA Langley Research Center. A filament wound graphite epoxy composite shell, approximately 5.5 feet in diameter and 11.5 feet long, represents the fuselage of a commuter airplane. An external speaker representing a propeller source is driven at a fixed frequency. The resulting exterior acoustic pressure fluctuations excite the shell and generate the interior pressures indicated in the pressure contours. Piezoelectric actuators, bonded to the skin at two locations shown in the figure by arrowheads are driven by a feedback control system using interiormicrophones as an input signal. Using just these two actuators, an average and peak SPL reductions of approximately 12 dB were attained throughout the interior space.

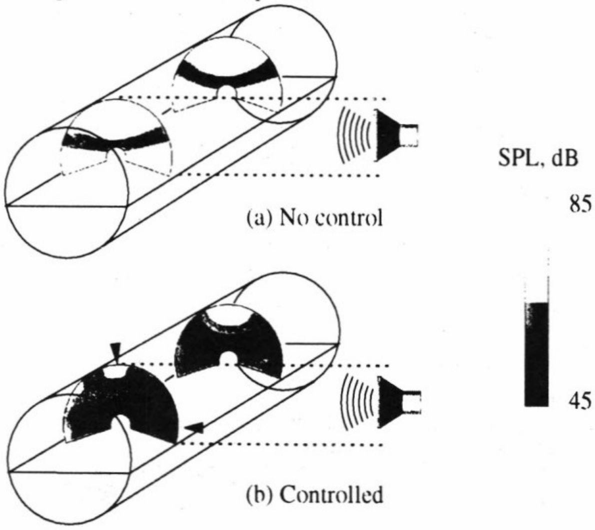


Figure 7. Active Interior Noise Control System

Community Noise Impact

The goal of the community noise impact subelement is to provide technology to reduce noise impact of aircraft and airport operations through application of new aircraft technologies and operational procedures, through improved noise impact modeling and prediction, and through improved understanding of relationships between human response and aircraft noise exposure variables. The specific goal is to produce a community noise impact minimization model by 1999 which can be used to determine optimal landing approach and takeoff procedures for arbitrary aircraft at any given airport.

Short Haul (Civil Tiltrotor)

The civil tiltrotor offers a unique opportunity to create a new aircraft market while off loading major airports of a large portion of the short haul traffic. Studies have shown the civil tiltrotor, figure 8, to be a viable candidate for air traffic congestion relief. Without significant new noise reduction technology, however, it will be impossible to achieve community acceptance that is essential to the establishment of conveniently located vertiports. The Short Haul (Civil Tiltrotor) element of the AST program is an effort to develop the most critical technologies for a civil tiltrotor: noise reduction; cockpit technology; and power for one engine inoperative operation. Two subelements of this program provide the noise reduction technology from which full scale development decisions can be made.

Figure 8. Forty Passenger Civil Transport-Artist Concept

These are the noise reduction, and the efficient, low-noise proprotor subelements which are described below.

The noise reduction subelement will identify and analyze concepts and flight procedures that will minimize the noise levels of a tiltrotor aircraft in critical terminal area operations. While the tiltrotor is generally quieter than a helicopter in forward flight it has noise characteristics similar to a helicopter in the terminal area. Two methods are available for the reduction of the noise levels at ground level near the vertiport: (1) the reduction of the source noise from the rotor system, and (2) the use of advanced flight procedures to avoid operating condition of high rotor noise where blade vortex interaction (BVI) noise occurs and the control of flight paths to avoid sensitive areas on the ground. The objective of this subelement is to achieve a 65 DNL outside the vertiport control area to meet the FAA recommended community noise criterion. A reduction of 6 dBA is the goal for rotor source noise and another 6 dBA through optimized flight procedures. This subelement will investigate a range of rotor concepts that employ tip speed reduction, disk loading reductions, advanced planforms, optimal number of blades and mechanical devices to reduce the rotor noise. The noise reduction concepts of the noise reduction subelement will provide the foundation for the development, analysis and testing of viable proprotor configurations for advanced tiltrotors. However, noise reduction is only one of the constraints on a viable proprotor configuration. In achieving the noise reduction targets, the rotor must not suffer from degradation in performance, loads, aeroelastic stability and vibration. The deliverables of this element are one or more efficient, low noise proprotor concepts validated in model scale and rotor noise reduction validated in a large scale test.

Higher Harmonic Control Test

When helicopter main rotor blades or tiltrotor blades interact with the tip vortices shed by previous blades, blade-vortex interaction (BVI) noise is produced. The very intrusive noise produced by these interactions in low-speed descent and in maneuvers may be reduced by modifying the vortex trajectories and/or reducing the strength of the shed tip vortices. Understanding and controlling or avoiding BVI is essential to community acceptance of a Civil Tiltrotor. Figure 9 shows the test rig used in one of the most comprehensive tests of the aeroacoustics of BVI and its reduction. This test was conducted in the German-Dutch acoustic tunnel (DNW) and is a unique resource since dynamic surface pressures, acoustics and unsteady wake measurements (using laser velocimetry) were all acquired during the experiment. The BVI noise reduction concept of Higher Harmonic Control (HHC) of blade pitch was extensively studied in a cooperative test with DLR, ONERA, US Army, and NASA as indicated by the different logos shown in the figure. In the test, the pitch of a blade was varied in the vicinity of the vortex produced by a preceding blade. By varying the angle and location of the pitch change, it was possible to significantly reduce the BVI noise.

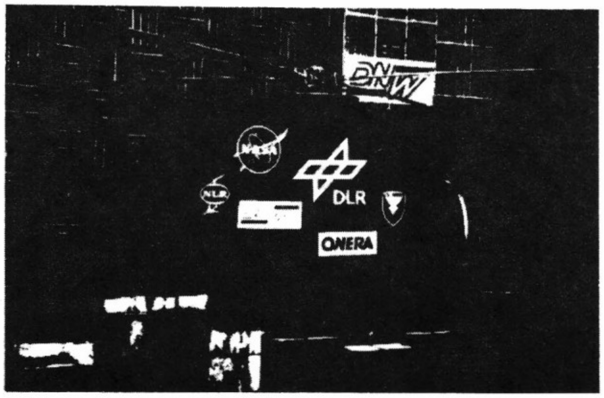


Figure 9. Aeroacoustics of BVI and BVI Reduction Test Rig

High Speed Civil Transport Noise Program

The emergence of the Pacific Rim Nations as major financial and industrial powers has greatly increased the need for faster air transportation between the Pacific Rim and Europe and the Americas. NASA along with their industry partners is developing technology needed to build an environmentally compatible and economically competitive High Speed Civil Transport early in the 21st century. As proposed, the HSCT would be capable of flying at Mach 2.4 with 300 passengers and a range of about 6000 nautical miles. High Speed Research (HSR) is NASA's name for the program for developing the enabling technologies for the HSCT. The first phase of the HSR program which started in 1990, addressed the major environmental concerns of sonic boom, community noise and emissions which might affect the ozone layer. Based on the encouraging results of phase one, the second phase of the program was begun in October 1993, and has continued work on community noise, primarily jet noise reduction, and sonic boom. The sonic boom emphasis has shifted from improving prediction methods and the effects on people to the effects on marine mammals since the proposed HSCT would fly supersonically only over water or uninhabited land masses. The second phase is also supporting work on interior noise prediction and control and on sonic fatigue of the structure. These areas are illustrated in figure 10.

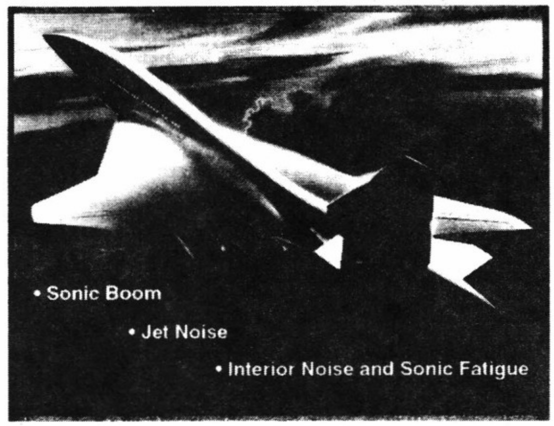


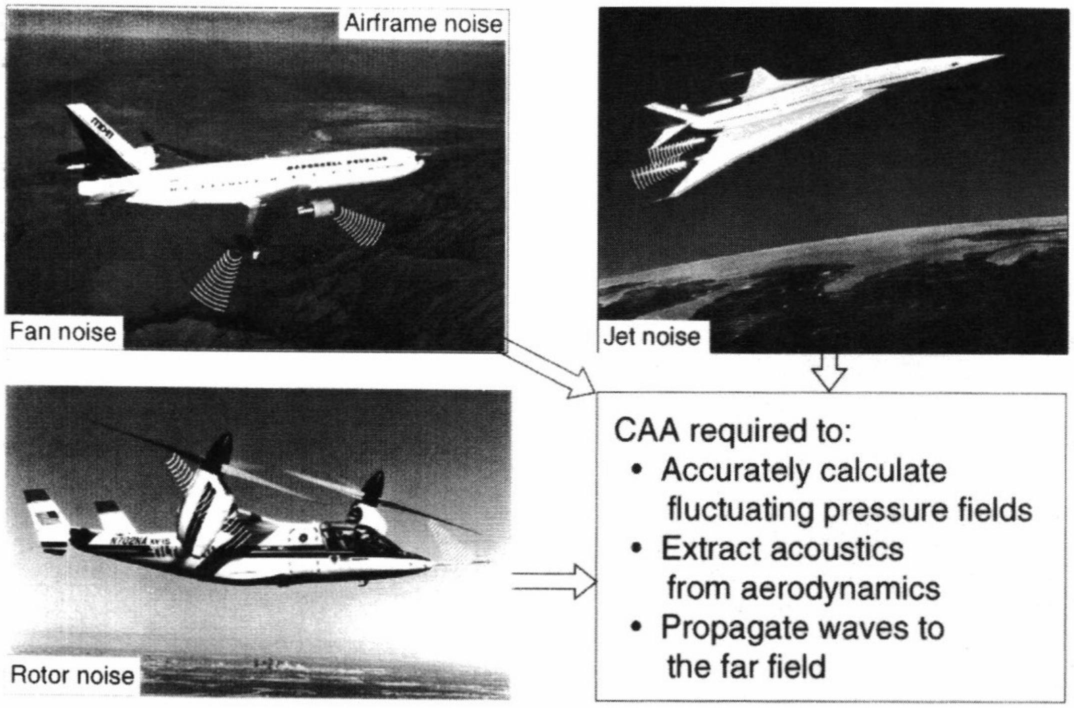
Figure 10. High Speed Civil Transport Noise Research

Advanced Technologies

Several exciting new technologies are being developed in both the subsonic and supersonic programs noise reduction programs. Two of the more promising technologies are discussed below.

Computational Aeroacoustics

As more progress is made in reducing aircraft noise it becomes increasingly more difficult to make additional significant reductions. It also becomes necessary to greatly improve the accuracy in predicting the many noise sources on the various aircraft types, indicated in Figure 11. The advances in today's high speed computing power in terms of both speed and storage has now made possible a new approach to noise prediction, namely computational aeroacoustics (CAA). CAA is the direct calculation of aerodynamic noise from the fluid mechanic governing equations (i.e., Euler or Navier Stokes). CAA, although in its embryonic stage of technology development, holds great promise for more accurate noise prediction of a variety of noise sources, such as fan, jet, airframe, and rotor noise. It therefore has



become a major new activity in NASA's basic and focused research programs.

Active Noise Control

The application of Active Noise Control (ANC) technology to aircraft has recently become a reality with several manufacturers of commuter propeller airplanes offering active interior noise control packages. Likewise there is a lot of interest in ANC applications in NASA's aircraft noise reduction programs. As indicated in Figure 12, and ANC is being investigated for reduction of fan noise for the new generation of ultra-high by-pass ratio engines. Research is continuing on reduction of interior noise resulting from engine and propeller

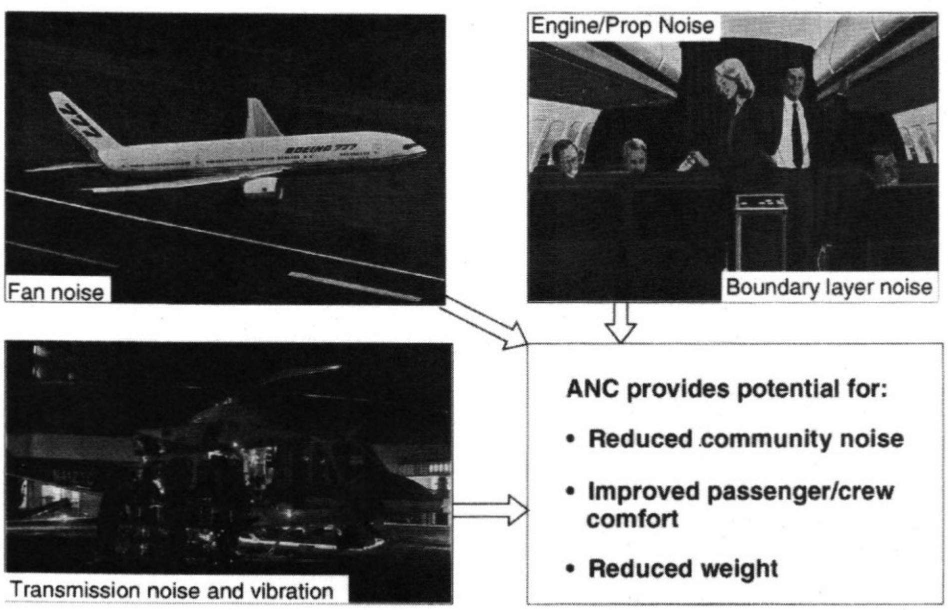


Figure 12. Active Noise Control- Aircraft Applications

tones. ANC research is also now being started for the much more challenging task for reduction of broadband noise resulting from the boundary layer and engines. For conventional rotorcraft, the dominant interior noise is structureborne noise from the gearbox. Active isolation mounts between the gearbox and fuselage are being investigated to reduce the very high interior noise levels in helicopters. The research and technology being developed in these areas are hoped to make major reductions in both community and passenger noise with less weight penalty than required for conventional noise control measures.

Summary

NASA noise reduction programs are developing noise reduction technology for both advanced subsonic and supersonic commercial transports. The Advanced Subsonics Technology program, consisting of 10 elements, was initiated in late 1993. The AST Noise Reduction program and the AST Short Haul-Civil Tiltrotor program are discussed in some detail. The High Speed Research program for developing enabling technology for a High Speed Civil Transport was initiated in 1990. The objective of these acoustics programs is to provide innovative acoustics technology required by the industry for developing environmentally compatible and economically viable transport aircraft These programs are exploiting advanced technologies such as computational aeroacoustics, active noise control, and advanced propagation and prediction methods.

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