AIRCRAFT NOISE PREDICTION AND REDUCTION TECHNOLOGY

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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 prominance in most of the aeronautical technology programs being conducted for future systems. Several aeronautical programs will be used 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 manufacturers, 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 technology programs having application to virtually all classes of aircraft envisioned to operate far into the 21st century. The purpose of this paper is to describe the scope and focus of these technology programs with emphasis on the advanced technologies [1] that form the foundation of these programs.

Background

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 effort 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

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perceived effects of the noise—and of various noise alleviation measures—on human beings.

In the 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 velocity jet exhaust 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 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 this period, research was also continuing 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 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) program; the Quiet, Clean General Aviation Turbofan (QCGAT) program; and the Advanced Turboprop Program (ATP); noise reduction principles were extended to produce even quieter engines.

Research has also been directed at the effects of atmospheric, terrain, and meteorological variations on propagation and attenuation. Considerable effort has been devoted to developing accurate prediction techniques and to quantifying the benefits of various noise reduction alternatives in terms of human response. NASA's Aircraft Noise Prediction Program (ANOPP), for example, has become a valuable tool for guiding the design and assessment of aircraft and flight operations with respect to noise impact.

With respect to supersonic transports (SST's), technology has been under development since the 1960's with varying levels of intensity. Environmental and economic issues were recognized as being essential to the success of a commercial supersonic venture. Concern for these issues was a factor in the cancellation, in 1971, of a major U.S. effort to build an SST. Subsequent to the abandonment of the U.S. effort, the Concorde entered commercial service with noise levels about 16 decibels (dB) higher than international (ICAO) noise standards. For an airplane of the size being considered today, this would translate to about 20 dB above required levels.

Advanced Subsonic Technology Program

In an effort to augment and accelerate ongoing subsonic technology in several key areas, NASA has initiated (FY 94) the Advanced Subsonic Technology (AST) Program. The focus of each element of the program is on the economic value added by the various technologies which include: noise reduction; propulsion; integrated wing design; terminal area productivity; general aviation/commuter; civil tiltrotor (Fig. 1);

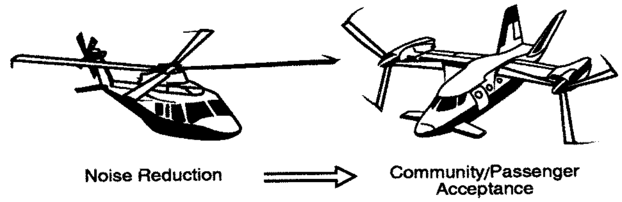

Fig. 1 Advanced Subsonic Technology-Civil Tiltrotor Program

composites; aging aircraft; fly-by-light/power-by-wire; technology integration; and environmental assessment. The objectives of the noise program are to provide noise reduction technology readiness to achieve: unrestrained market growth; increased U.S. market share; and compliance with international environmental requirements. In an effort to achieve these objectives, NASA has established a noise goal of 10 dB noise reduction relative to 1992 technology. The noise reduction goal will be achieved by combined noise reduction improvements in the engine, the aircraft system, and in aircraft operations (Fig. 2).

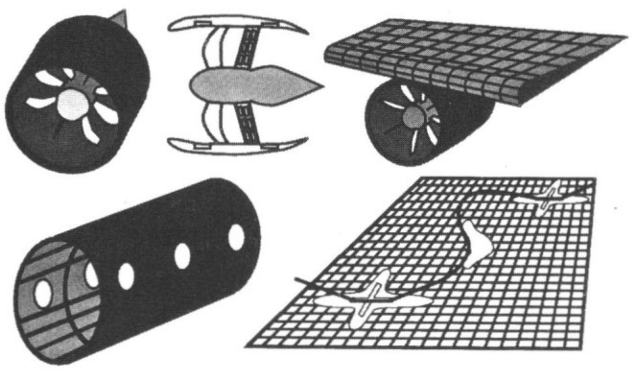

Fig. 2 Advanced Subsonic Transport-Noise Reduction Program Subelements

In addition to the noise reduction element of the AST program, noise technology will be fundamental to nearly all aspects of a civil tiltrotor air transport system. It will be a primary driver in rotor technology and design and will be a primary constraint and driver for development of terminal area operating procedures. Noise reduction is also important to the general aviation/commuter program, the propulsion element, terminal area productivity and integrated wing elements of the program.

High-Speed Research Program

The High-Speed Research program is being conducted in two phases. Phase I, a 7-year effort which began in FY 90, is defining critical HSCT environmental compatibility requirements in the areas of atmospheric effects, community noise and sonic boom, and is establishing a technology foundation to meet these requirements (Fig. 3). The High-Speed Research goal for airport community noise is to determine the feasibility of economical compliance with the appropriate international noise regulations and community

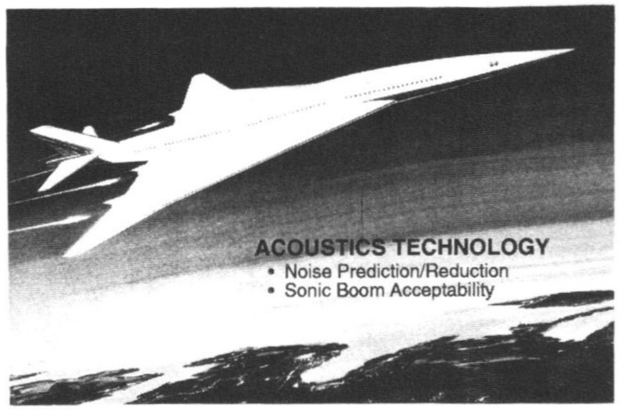

Fig. 3 High Speed Research Program-Acoustics Technology Drivers

acceptance levels now applied to newly designed subsonic transports. Progress to date in Phase I is providing growing confidence that the necessary technology can be developed to meet this noise goal with a combination of advanced engine cycles, advanced nozzle designs, aircraft high-lift devices, and specialized operating procedures resulting from automated flight control systems.

Phase II of the High-Speed Research program, an 8-year effort starting in FY 94, is focused on research and verification of the high-leverage technologies essential for economic viability in addition to assuring environmental compatibility. This technology research is being conducted in order to place the U.S. aeronautics industry in a position to make informed decisions near the turn of the century regarding future HSCT development and production.

The scope of the various engine concepts being studied under Phase I is illustrated in Fig. 4 (2). The concepts include the

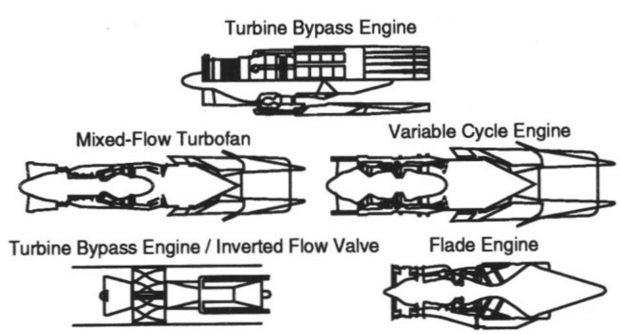

Fig. 4 High Speed Civil Transport Engine Noise-Suppression Concepts

Turbine Bypass Engine (TBE), the Mixed-Flow Turbofan Engine (MFTE), the Variable Cycle Engine (VCE), the Turbine Bypass Engine/Inverted Flow Valve (TBE/IFV), and the Flade Engine (FLADE). In Phase II, the best two concepts from Phase I will be carried through component sub-scale testing and large scale design before selecting the best concept in late FY 95. This best concept will then be carried through large scale testing to validate critical technologies.

Sonic boom technology involves the development of acceptability criteria for supersonic overland flight, the design of aircraft that can meet these criteria, and the development and validation of methods to model the propagation of sonic booms through the atmosphere (Fig. 5). In the first 2 years of the Phase II program, sonic boom efforts will focus on demonstrating that the low-sonic boom signatures which are being used in the designs can maintain their characteristics when propagating through the turbulence in the atmosphere. This objective will be accomplished using a remotely piloted vehicle with a modified nose section which produces the desired sonic boom signature. Following this effort, the research will depend on industry's decision of whether to include low-sonic boom in their HSCT design. If that is

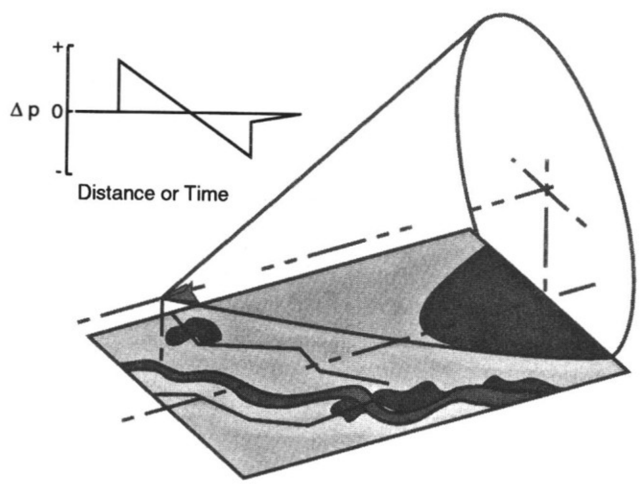

Fig. 5 Sonic Boom Generation, Propagation, and Effects Technology

the case, the NASA effort will be focused on producing an acceptable low-boom design that has no more than a 2 percent performance penalty and satisfies the many practical constraints of a commercial product. However, if industry cannot support a low-boom aircraft, the NASA effort will be geared towards 'softening' the boom of industry's design to minimize environmental impact even over water.

Hypersonic Acoustic Technology Program

The challenge of hypersonic flight is to understand the noise environment that vehicles will experience during flight and secondly to determine the effects of the noise on the structural integrity of the vehicle. The problem is complicated by the fact that the structure will be very hot during long portions of the flight, and the structural materials will be relatively lightweight. Furthermore, the acoustic loads associated with the propulsion system and the flow over the vehicle are estimated to be very high (Fig. 6) and in a frequency range where sonic fatigue will be a very important design consideration. The thrust of the current NASA acoustics program is to develop acoustics technologies for long life airframe and propulsion structures that can sustain high levels of combined thermal and acoustic loads.

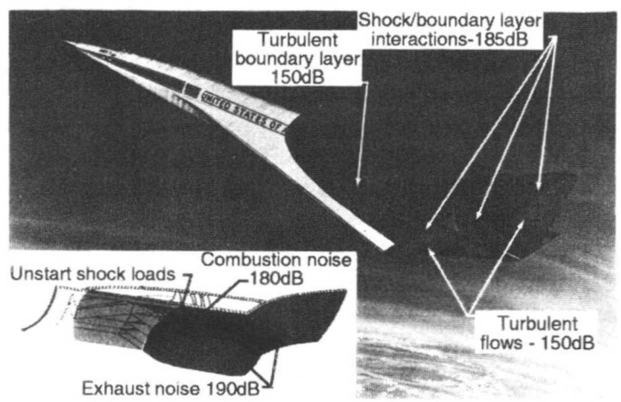

Fig. 6 The Acoustic Environment of Hypersonic Flight

Noise Reduction Technology

Advanced Subsonic Technology

- Rotorcraft/Tiltrotor—Two methods are available for the reduction of the noise levels that impact the ground near a vertiport: The reduction of the source noise in the rotor system; and, the use of complex flight procedures to avoid operating conditions of high rotor noise, primarily where blade slap occurs, and the control of flight paths to avoid sensitive areas on the ground. Efforts to date have concentrated on the measurement, analysis, and prediction of the noise of conventional helicopters (3). Using improved prediction systems, noise reduction concepts are being evaluated ranging from advanced planform and tip shapes to the use of actively controlled blades or blade devices to minimize the noise. These technologies will be exploited and extended in the NASA Civil Tiltrotor Program which has a goal of 11-12 dBA noise reduction on the ground relative to current technology. A reduction of 6 dBA is targeted for rotor source noise and another 6 dBA is targeted through optimized flight procedures.

• Noise Reduction—The noise reduction element of the AST Program consists of five subelements (Fig. 2) namely, source noise reduction, nacelle aeroacoustics, engine airframe integration, interior noise, and flight procedures to reduce airport community noise while maintaining high efficiency.

- 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. The technology will provide design techniques for lowering noise while maintaining high performance for advanced turbofan engines. A near term goal (1996) is to provide technology for reducing jet noise for lower bypass ratio (3-6) engines. In the same time frame, technology for reducing fan noise 3 dB will be demonstrated in model scale for advanced fan designs (Fig. 7). The

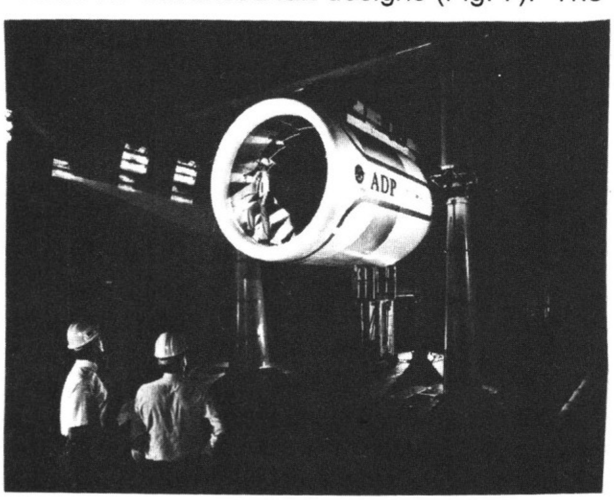

Fig. 7 Wind Tunnel Tests of Advanced Engine Concepts

technology will address acoustic, aerodynamic and structural disciplines and will provide experimental data and analyses, including computational aeroacoustic (4), and active noise control methods (5), (Fig. 8) that lead to improved low-noise turbofan design methodology.

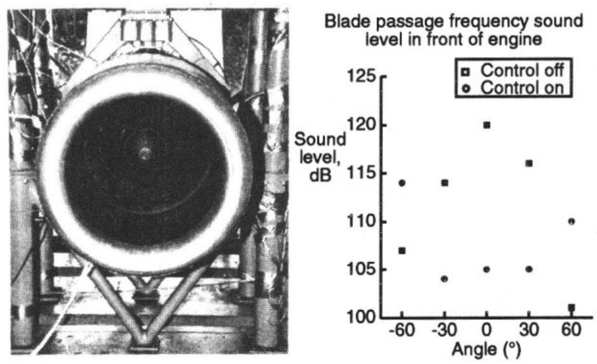

Fig. 8 Active Noise Control Performance

- Nacelle Aeroacoustics—The objective 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 (Fig.9);

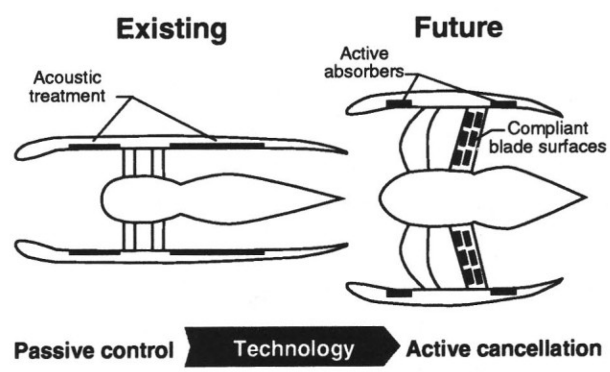

Fig. 9 Active Noise Control Treatments

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.

- Acoustic/Aerodynamic Integration and System Evaluation—The objective of integration and system evaluation is to develop and validate design methods and advanced concepts for low-noise, aerodynamically efficient aircraft. Emphasis is on the acoustic and aerodynamic integration of turbofan engines with high-lift systems operating under both takeoff/climbout and approach/landing conditions. Specific goals 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.

- Interior Noise Reduction—The objective 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 tiltrotors. The goal is to produce technology capable of yielding a 6 dB overall interior noise reduction by the year 2000. The application of active noise control technology has been shown to be very effective under laboratory conditions [6], (Fig. 10). and is one of the advanced technologies that will be exploited in this program (Fig. 11).

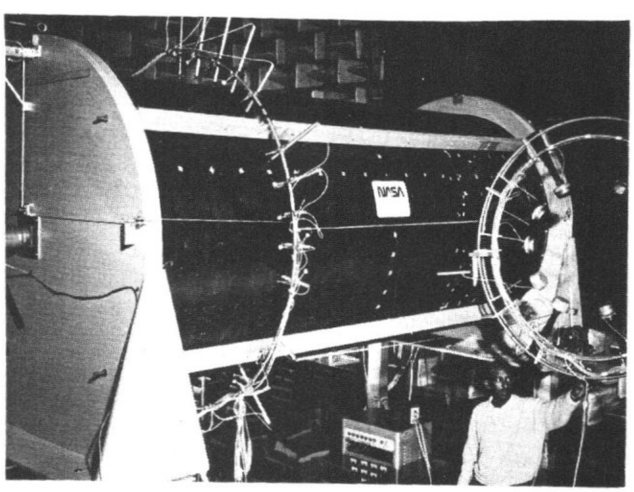

Fig. 10 Interior Noise Transmission and Reduction Study

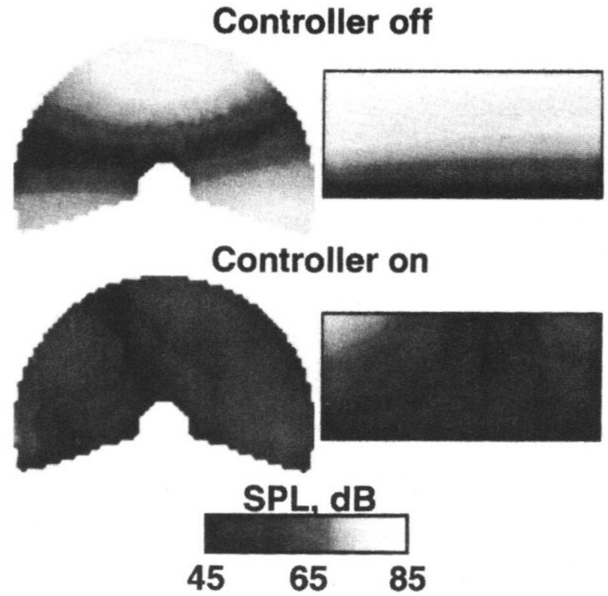

Fig. 11. Performance of Active Interior Noise Control System

- Community Noise Impact—The objective 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.

High Speed Civil Transport Technology

Enabling noise technology developments for noise reduction include:

- Noise and economic trade studies of various engine-cycles (Fig. 12)
- Mixer-ejector concepts for enhanced jet mixing and velocity reduction
- Sound absorbing engine liners for noise attenuation
- High-flow fan concepts for noise reduction
- High-lift concepts for improved takeoff and landing performance and noise abatement flight profiles

- Weight reduction resulting from advanced airframe aerodynamics (e.g. SLFC), advanced materials and structures, and other technologies
- Environmental impact prediction and reduction methods specific to an HSCT having advanced airframe and operational procedures

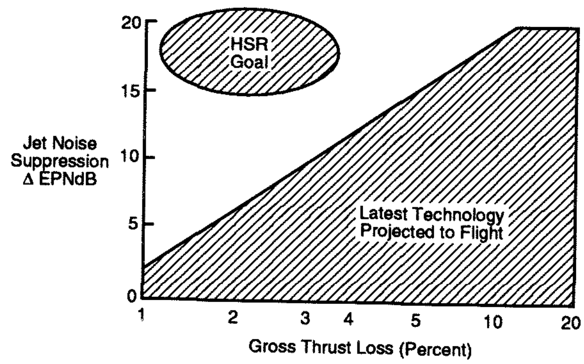

Fig. 12 High-Speed Research Source Noise Challenge

A major thrust of the sonic boom technology program has been the development of criteria for sonic boom acceptance. In particular, the benefits of sonic boom shaping have been quantified through a series of laboratory and in-home tests (7). Typical benefits are illustrated in Fig. 13 where the effective

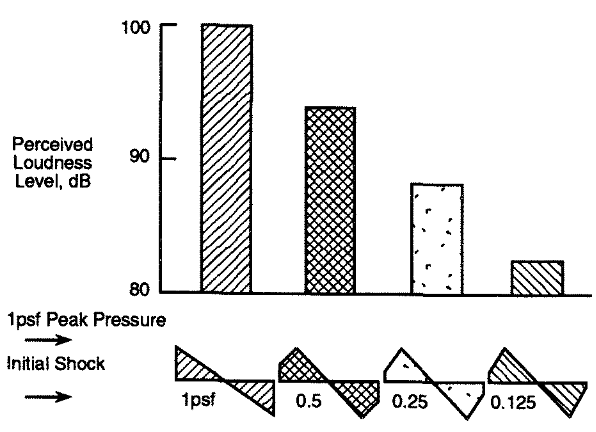

Fig. 13 Subjective Benefits of Sonic Boom Shaping

loudness levels are reduced by over 15 dB for the family of boom shapes illustrated.

Hypersonic Technology

Efforts are currently underway to define the acoustic loading on the vehicle resulting from engine, boundary layer, and shock/boundary layer excitation and to develop methods to predict the structural response and sonic fatigue associated with these loads. Extensive testing is being conducted in a grazing incidence sonic fatigue facility that can expose structural panels to combined thermal-acoustic loads.

Summary

Aeronautical technology programs are underway in the United States which include vehicles ranging in speed from subsonic to hypersonic conditions. Acoustics technology is an important element in virtually all of these programs. The objective of the acoustics programs is to provide innovative acoustics technology required by the industry for developing environmentally compatible and economically viable aircraft for all flight regimes. These programs are exploiting advanced technologies such as computational aeroacoustics, active control and advanced propagation and prediction methods.

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