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ADVANCED SUBSONIC AIRCRAFT ENGINE NOISE REDUCTION RESEARCH

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ABSTRACT

Engine noise reduction research currently underway in the NASA Advanced Subsonic Technology Noise Reduction Program is described. Emphasis is on noise reduction technology for high to ultra-high bypass ratio turbofan engines which will dominate the airline fleets early in the 21st century. In terms of noise components, primary emphasis is on the fan with secondary effort on the jet for engines at the lower end of the bypass ratio range. The approach to fan noise prediction consists of modeling the chain of physical processes beginning with flow disturbances on fan blades and ending with far field sound levels. For the jet, CFD solutions for the nozzle geometries are coupled to combined aeroacoustic source/radiation models. On the experimental side, realistic models of fans, nacelles, and nozzles are tested in aeroacoustic wind tunnels. Comparisons of predicted and measured noise levels are presented as indicators of progress toward developing improved low-noise design tools. The challenges of applying active control concepts to turbofan noise are discussed including both cancellation and source modification approaches.

INTRODUCTION

The Noise Reduction Program was initiated in 1993 as one element in the overall NASA Advanced Subsonic Technology Program which is continuing through the end of the decade. The overall noise goal is to develop technology to enable the next generation of commercial aircraft to meet more stringent noise rules. Specific goals are to reduce total aircraft noise 10 Effective Perceived Noise decibels (EPNdB), 6 EPNdB of which would be due to the engine, and both with respect to 1992 technology. The three NASA aeronautics centers; Ames, Langley, and Lewis; are working with industry and academia on the five program elements: engine, nacelle, integration (including airframe), interior, and community impact. Lewis has prime responsibility for the engine. This paper gives a brief overview of recent Lewis led research efforts including contract, grant, and in-house work.

The engine cycles addressed include current products in the range of bypass ratio (BPR) 1.5 to 10, and ultra-high BPR turbofans in the range 10 to 20 [1]. As BPR is increased to 10 and beyond, the fan noise component becomes increasingly dominant in the total engine noise signature; and jet noise contributes less since core engine exhaust velocity decreases as a progressively larger fraction of engine thrust is produced by the fan stream. In addition, fan diameter increases with BPR and thrust while, relative to diameter, shorter fan nacelles are required to limit engine weight and nacelle drag. As a result, the length available for nacelle acoustic treatment L per unit passage diameter D (or passage height between treated surfaces) becomes constrained to smaller values of L/D than current practice. Therefore, more of the total fan noise reduction must be achieved by lowering the noise at the source through such design features as swept rotor blades and stator vanes which are spaced two or more rotor chords apart.

FAN NOISE

For modern aircraft turbofans operating at subsonic rotor tip speeds (approach and takeoff with power cutback), the dominant fan noise generation mechanism is rotor-stator interaction, i.e., flow disturbances created by an upstream rotor interacting with stator vanes to produce both tone and broadband noise [2]. Work to develop a prediction/design system [3,4] emphasizes an approach which uses unsteady aerodynamic and aeroacoustic analyses to lessen dependence on semi-empirical data correlations. Contours of computed fan inlet and aft sound pressure levels at blade passage frequency are shown superimposed on a fan cross-section in Fig. 1. The calculations begin by using a semi-empirical description of the rotor wakes as input to an unsteady aerodynamic gust response model to compute stator blade surface unsteady pressures; the stator pressures are input to a mode coupling analysis to give the amplitudes and phases of the annular duct modes; and the computed modes are input to a finite element or finite difference propagation and radiation code which accounts for actual duct geometry and mean flow to ultimately arrive at far field sound pressure levels. At present, the first generation tone model is complete; blade row, inlet and nozzle coupling effects are being added [5]; and fan broadband models are also under development [6].

The relative importance of tone and broadband spectral components to total fan noise was studied in Ref. 7. Figure 2 shows a summary of the results for a range of engine cycles having BPR's from roughly 6 to 16 and corresponding fan pressure ratios from 1.75 to 1.3. For each cycle, the EPNdB levels are shown for takeoff, cutback, sideline, and approach conditions. By comparing the shaded bars which include the fan tones plus broadband with the unshaded bars which have the first three tones removed, it can be seen that the broadband component must be reduced along with the tones if community noise reductions of more than a couple of EPNdB are to be achieved. Broadband generation mechanisms are less well understood than tone mechanisms and are the subject of current research.

Two kinds of fan noise experiments are conducted at Lewis. A model turbofan simulator is used to measure fan noise in an anechoic wind tunnel which simulates flight conditions. Figure 3a shows a 22 in. diameter model of a high BPR Advanced Ducted Propulsor model installed in the NASA Lewis 9- by 15-foot Anechoic Wind

Tunnel, which has acoustically treated walls making the test section anechoic above about 250 Hz. A series of these 22 in.-diameter models are being used to investigate fan noise reduction concepts and scale the results to full size to predict flyover noise levels. The scale factors range from about 1/6 for the largest engines (~120-in.-diameter, 100,000 lb thrust) to nearly full scale for small turbofans (~5000 lb thrust).

Another fan rig which has been used to study generation/radiation fundamentals and active fan noise control concepts is shown in Fig. 3b. This is a 4-ft diameter, low-speed fan (400 ft/sec tip speed) which is installed in the Lewis Aeroacoustic Propulsion Laboratory (APL) (a 130-ft dia. hemispherical anechoic chamber). A cross-sectional view of the fan is shown in Fig. 4. A unique rotating microphone rake which is synchronized to about 1/200 of the fan rotational speed is used to obtain the magnitude and phase of the duct modes generated [8]. The mode measurements are also made on the 22-in. fans tested in the Wind Tunnel, and provide an intermediate check point between the generation and radiation processes when applying the noise prediction code.

When the generation theory described above is applied, results such as those shown in Fig. 5 are obtained. In this case,the predicted fan tone directivities are in good agreement with measurements made on the large, low-speed fan [9].

ACTIVE CONTROL

The large, low-speed fan is also used for active noise control experiments. Two approaches are being explored: cancellation in the fan ducts after generation [10], and modification at the source, e.g., the stator vane surface pressures [11]. While the former involves controlling multiple sound sources mounted on the duct walls, the latter uses controlled actuators mounted on the vane surfaces. A fundamental technical barrier to be overcome for aircraft engine fan tone control is the fact that usually more than one higher order duct mode must be dealt with at each tone, and their number increases with harmonic number. For broadband control, the multi-mode problem is multiplied many fold.

JET NOISE

Reducing jet noise from turbofan engines inherently involves promoting mixing between the higher velocity core and the lower velocity fan streams. For lower BPR engines with full length nacelles the mixing is promoted by a lobed internal mixer upstream of a common exhaust nozzle [12]. As described with regard to fan prediction, the jet is also approached with fluid dynamic computations coupled to aeroacoustic analyses as a departure from semi-empirical correlation. For the jet, the flow gradients and turbulence intensities in the jet plume are computed using a Navier-Stokes code [13]. This flow field information is used in an aeroacoustic calculation which includes convective effects called the MGB code [14] to compute the far field radiation. The approach which uses Computational Fluid Dynamics as the starting point is currently under development. Sample results [15] for a splitter exhaust and a 12- lobed internal mixer nozzle are shown in Fig. 6 where the calculated directivities are compared to measurements acquired on the model nozzles in the Lewis APL. Initial results are encouraging, but additional refinement of the code is required.

SUMMARY

The engine noise reduction technology being developed in the NASA Noise Reduction Program has been briefly reviewed. The program is directed toward realizing a 10 EPNdB reduction (6 EPNdb from the engine) in flyover noise relative to 1992 certified levels. Both fan and jet components of engine noise are addressed. Development of prediction/design codes emphasizes fluid dynamic and aeroacoustic descriptions which minimize dependence on semi-empirical correlations. Noise reduction approaches are tested with realistic model fans and nozzles in aeroacoustic wind tunnels which simulate flight. Active control of fan noise is one example of advanced noise reduction technology being studied.

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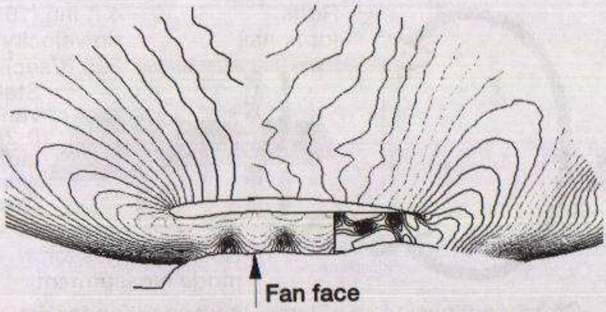

Figure 1.—Predicted sound pressure level contours for advanced ducted propulsor at blade passage frequency, 16 blades, 22 vanes, 12 000 rpm.

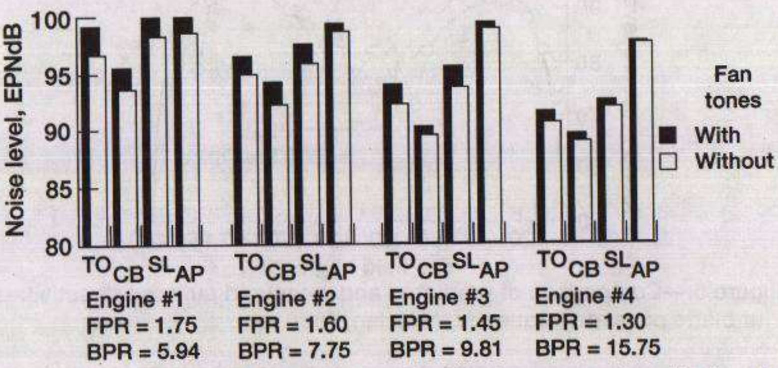

Figure 2.—Fan tone (1,2,3 BPF) contribution to community noise levels

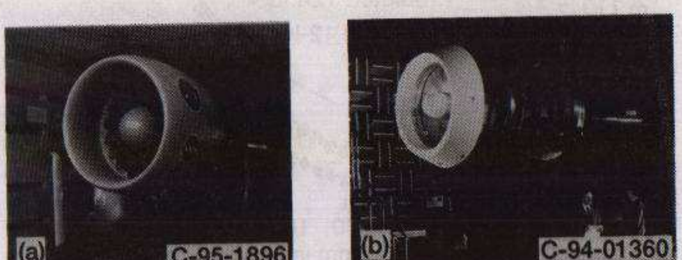

Figure 3.—Fan noise reduction experiments. (a) Model fan in Lewis 9X15 Anechoic Wind Tunnel. (b) Large, low speed fan in Lewis Aeroacoustic Propulsion Facility.

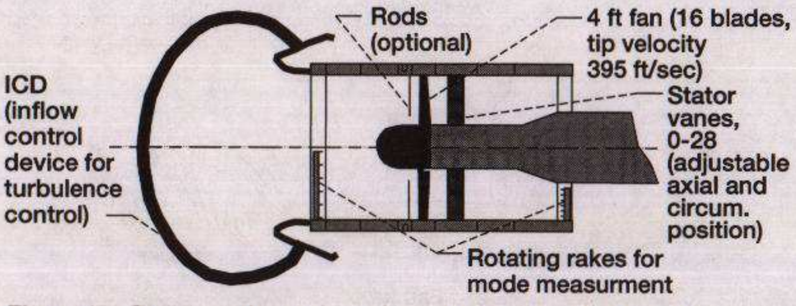

Figure 4.—Cross-sectional view of large, low speed fan for active noise control studies.

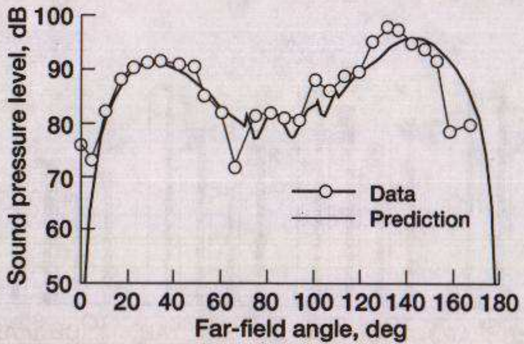

Figure 5.—Comparison of predicted and measured fan tone directivities at blade passage frequency, ANC fan, 1886 rpm.

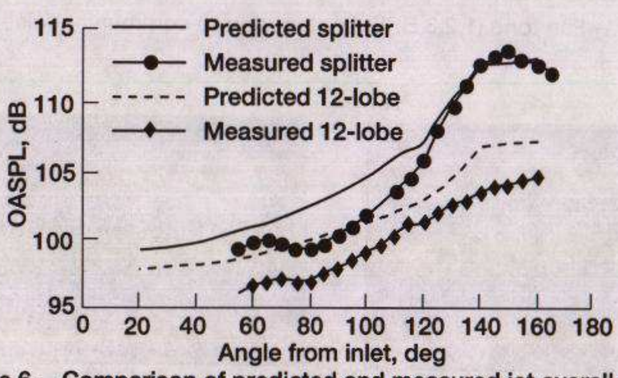

Figure 6.—Comparison of predicted and measured jet overall sound pressure level directivities for confluent nozzle (splitter) and an internal 12 lobe mixer.