Recent aeroacoustics research in the United States

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It is expected that with the projected increase in air travel aeroacoustics research will be very critical in meeting increasingly stringent aircraft noise certification standards. In the United States aeroacoustics research has steadily progressed toward enhanced safety, noise benefits and lower costs. This report provides a brief summary of selected recent aeroacoustics activity in the US. Four topics of great interest to the aerospace industry are: (1) Advanced Subsonic Technology (AST) for future subsonic aircraft, (2) High Speed Research (HSR) for future supersonic commercial aircraft, (3) Rotorcraft noise control efforts, and (4) Weapons bay and other noise control applications for the military. Examples of good progress in the areas of jet, fan, airframe and helicopter noise as well as liner design and weapons bay noise suppression are provided herein. In the next few years we look forward to seeing major strides in noise reduction technology and our ability to predict situations of aeroacoustics interest.

1. Introduction

It is anticipated that with the projected increase in air travel aeroacoustics research will be more critical for the certification of future aircraft. Many organizations in government and industry have taken major strides in preparing plans for reducing aircraft noise. This includes noise emanating from the airframe and engine components such as the fan, compressor, combustor, turbine and last but not least, jet exhaust noise (both subsonic and supersonic). In addition, noise issues are increasingly important on account of both environmental and structural concerns. The latter concern cannot be ignored for the world's aging aircraft fleet and for strategic military applications such as weapons bay noise suppression and the Short Take-Off and Landing (STOVL) ground environment of future aircraft with very powerful engines. Higher acoustic loads on aircraft translates to more expense and more weight for reinforced aircraft structures. In the US primary activity falls into four main groups: Advanced Subsonic Transport (AST), High Speed Research (HSR), rotorcraft noise control, and weapons bay and STOVL aeroacoustics control.

In the past few years under the leadership of NASA Langley, the AST program delivered design tools and noise-reducing concepts for advanced passive liners, directional inlets, active fan noise control, jet mixing devices, and fan exit guide vane lean and sweep. Supporting General Electric Aircraft Engines conducted major experimental programs under NASA's HSR effort for detailed measurements of the velocity, vorticity, and radiated noise field produced by the new mixer/ejector exhaust nozzle. NASA Langley developed and tested new rotorcraft aeroacoustics methodology for helicopter rotor noise prediction. A multi-nation NATO group conducted a helicopter noise test in Canada to develop an international standard for measuring and analyzing helicopter noise directivity. In the tilt-rotor area, the second XV-15 terminal area acoustics flight test was conducted to determine quiet, safe, and easy flight procedures. Air Force Research Labs, the Air Force Office of Scientific Research, the Naval Air Weapons Center, Boeing and DERA have all initiated new coordinated weapons bay aeroacoustic control programs to enhance our ability to dispense weapons over a larger flight envelope. New experiments were conducted at DERA (UK) where cavity noise was suppressed using high frequency powered resonance tube actuators. Each of the above topics are covered briefly in what follows.

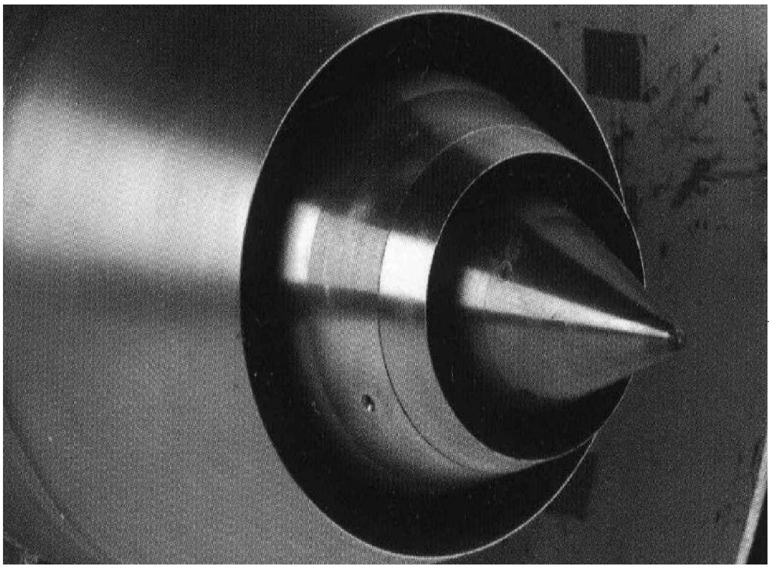


Figure 1. Separate flow nozzle technology at the NASA Glenn Aero-Acoustic Propulsion Laboratory. Photo courtesy of NASA

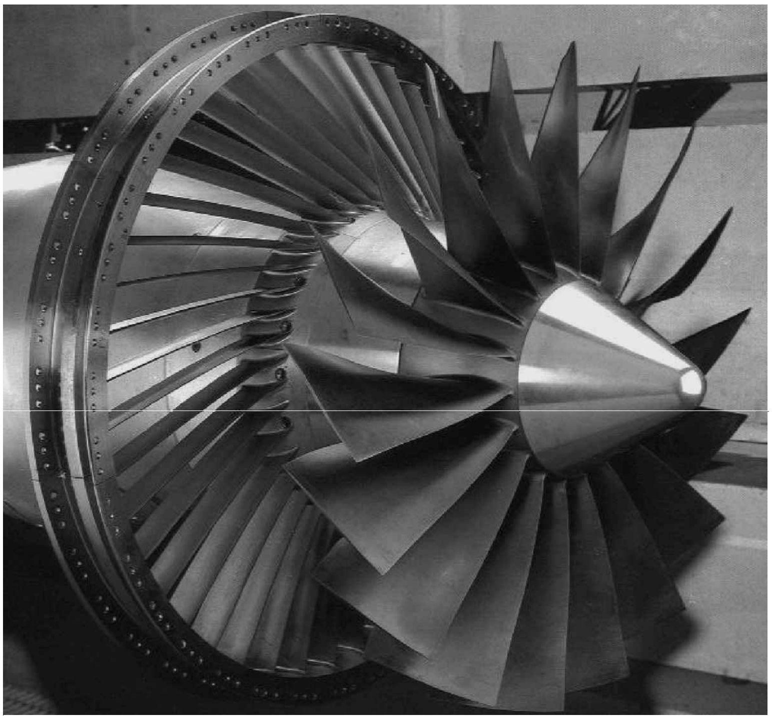


Figure 2. New technology for reducing fan blade noise using swept and lean stator vane technology. NASA/Allison scale model installed in the NASA Glenn 9x15 foot wind tunnel. Photo courtesy of NASA

2. Noise reduction technology for subsonic transport aircraft

As part of NASA's AST Noise Reduction Program, Pratt & Whitney teamed with Boeing, BFG Aerospace, and the NASA Glenn and Langley Research Centers to test the newly certified PW4098 engine with a revolutionary low-noise, scarfed inlet provided by Boeing. The PW4098 engine is currently one of the world's highest thrust certified engines, and will power new versions of the Boeing 777 aircraft. Advanced technology noise treatment is installed in this inlet and in the engine's modified forward fan case, both of which provide broadband noise attenuation characteristics. Several noise tests were undertaken during 1998 and 1999. Significant noise reductions are expected from this engine/inlet combination in flight.

In the subsonic propulsion aeroacoustics technology arena, significant progress was made by General Electric Aircraft Engines in demonstrating, through extensive model scale test simulations under both NASA and IR&D programs, the effectiveness of exhaust system mixing enhancement devices in substantially reducing jet noise while minimizing loss in exhaust system performance. The effort to attenuate the noise from the exhaust portion of the engine (the nozzle) had a very significant test in 1997, demonstrating a 3-dB jet noise reduction. This joint research and laboratory test project among NASA, GE Aircraft Engines, and Pratt & Whitney developed separate flow nozzle technology. Follow-on performance tests for the separate flow nozzles verified that 3 dB of jet noise suppression was achieved with minimal impact on thrust. Figure 1 shows the separate flow nozzle that was tested at the NASA Glenn Aero-Acoustic Propulsion Laboratory. The technology transfer from this test and other jet noise reduction tests emphasized both noise reduction technology and source diagnostic data to be used in future engine technology development.

NASA teamed with the Allison Engine Company to investigate new ways of reducing fan noise from turbofan engines. A 22-inch-scale model was built and tested (Woodward et al. [1]) in the Glenn Research Center's 9x15-foot Low-Speed Wind Tunnel (see Figure 2). This work was successful in helping the program meet a major milestone with a demonstrated 3 EPNdB (Effective Perceived Noise) fan noise reduction.

The noise reduction concept uses a highly swept and leaned geometry in the design of the outlet guide vanes. The tested sweep and lean configuration was designed at NASA Glenn Research Center (see Envia et al. [2]) and built by the Allison Engine Company. Noise reduction occurs because sweep and lean alter the kinematic relationship between the rotor wakes and stator vanes and thus change the number of wake intersections experienced by a given vane. The change in the number of intersections, in turn, alters the distribution of the phase of the unsteady pressure induced on the vanes as a result of rotor wake impingement. Since the rotor-stator tone levels are related to the surface integrals of the vane unsteady surface pressure, the more phase variation there is in the vane unsteady pressure, the more cancellations will occur in the integral resulting in weaker interaction tones. Clearly, when sweep and lean are chosen properly, significant variation in the phase of unsteady pressure occurs compared with the radial stator.

Significant progress was also made in identifying concepts for reducing fan tone and broadband noise, through extensive advanced acoustic liner and aerodynamic performance trade studies. Figure 3 shows Pratt and Whitney's low speed fan with advanced acoustic liners that was tested at NASA Glenn's 9 x 15 foot wind tunnel. In addition, experimental investigations of multiple mode Active Noise Control of fan stage interaction tones were carried out under NASA sponsorship, and significant reduction in these modes was demonstrated.

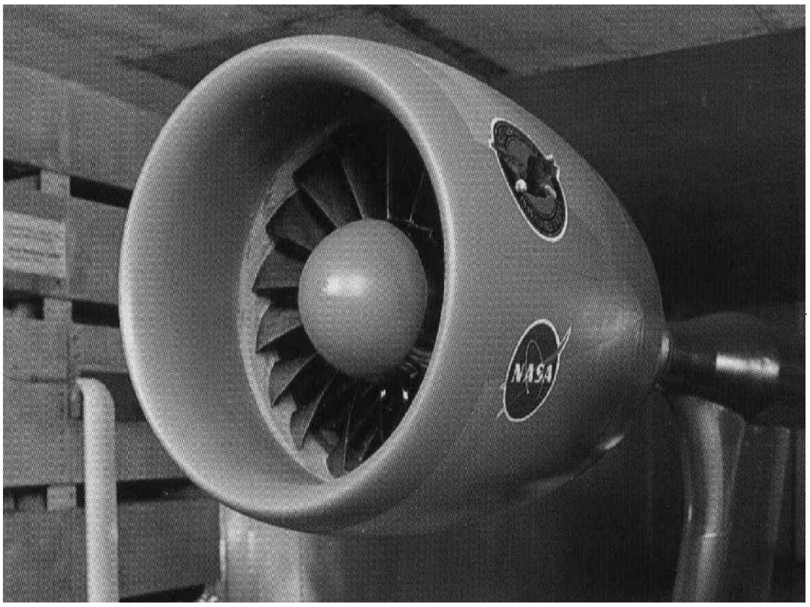


Figure 3. Pratt and Whitney's low speed fan with advanced acoustic liners was tested at NASA Glenn's 9x15 foot wind tunnel. Photo courtesy of NASA

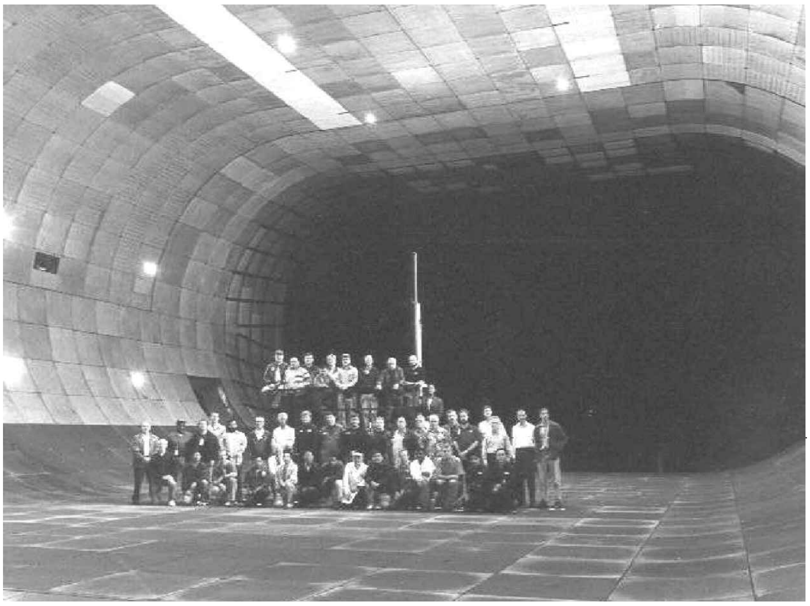


Figure 4. The NASA Ames 40x80 foot anechoic facility shown after installation of a new acoustic lining The entire crew responsible for the lining design and performance testing pictured in the tunnel emphasize the enormous cross-section of the facility. Photo courtesy of NASA.

Airframe noise studies are growing as noise produced from flaps, slats, and landing gear in today's transport aircraft matches engine noise levels during approach. A recent accomplishment demonstrated technology to reduce flap noise, one of the three main airframe noise sources, by 4 dB. NASA researchers in partnership with industry, academia, and the FAA accomplished this. Results of a series of wind tunnel experiments, guided by newly developed noise and flow prediction models, successfully demonstrated significant reductions from a new leading-edge slat design and three new flap designs. The airframe noise reduction program involved several NASA wind tunnels, each with unique performance capabilities. The Langley Research Center facilities used included the Quiet Flow Facility, the Basic Aerodynamics Research Tunnel (shown in Figure 4), and the Low Turbulence Pressure Tunnel. Facilities used at the Ames Research Center included the 40x80-foot section of the National Full-Scale Aerodynamics Complex, the 7x10-foot Wind Tunnel, and the 12-foot Pressure Tunnel.

Much of the airframe noise is generated by separated and vortical flow produced by the high-lift system. A joint NASA-industry team has been investigating these noise sources to develop predictive models based on the flow physics. These models would enable designers to estimate changes in airframe noise from design changes in high-lift system components. In addition, detailed knowledge of the noise-generation physics opens the door to developing strategies to reduce or eliminate such noise with minimal impact on aircraft performance. One success has been to verify the physics of the noise generated by the side-edge of a trailing-edge flap. It had been postulated that a major component of the noise produced by such a flowfield came from fluctuations in the shear layer feeding the trailing vortex. NASA Langley researchers have successfully predicted the shape of the noise spectrum produced by a simple part-span flap model. These first-of-a-kind computations are in good agreement with experimental results, and the postulate noted above.

3. High speed research

Significant progress has been made in the area of high speed aeroacoustics at GE Aircraft Engines under the High Speed Research program sponsored by NASA during 1998. One area is the detailed measurements of the velocity and vorticity field produced by the mixer in the mixer/ejector exhaust nozzle for the HSCT. These measurements, internal to the ejector, provide a better understanding of what various types of mixing enhancement devices on the mixer are doing to the flow field and ultimately to the radiated acoustic field. Another major stride was made in the analysis of scaling and flight effects. An approximately one half-scale mixer/ejector exhaust nozzle was statically tested behind an F100 engine at Pratt & Whitney. This is a major undertaking to determine how well small scale data acquired under the HSR program can be scaled and corrected for flight effects to a product size. All of these experiments are being performed with careful evaluations of the thrust penalties associated with each configuration. Boeing and Georgia Tech researchers are leading the effort to identify noise source locations including the ability to determine the portion of noise produced inside the ejector as distinguished from that produced by the mixing in the jet downstream of the ejector nozzle.

4. Rotorcraft

A NATO CCMS (Committee on the Current Challenges of Modern Society) Helicopter Noise Flight Test was conducted at the Canadian Forces Base, Moose Jaw, Saskatchewan, in June 1998. The overall purpose for the test was to develop an international standard for measuring and analyzing the noise directivity characteristics of helicopters. Acoustic data were acquired by organizations from the U.S. (NASA Langley and Wright Patterson AFB), the U.K. (Royal Air Force and Defense Evaluation and Research Agency), Germany (Federal Environment

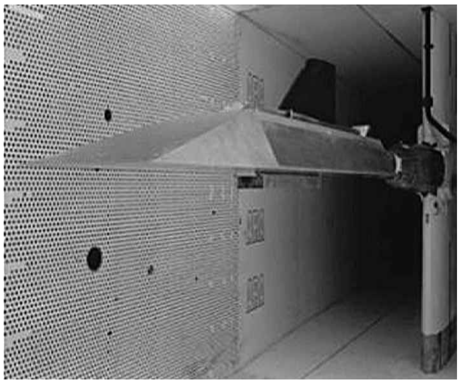
Figure 5. Terminal area acoustic flight tests on the XV-15 at Waxahachie, Texas. Photo courtesy of NASA

Agency), Norway (SINTEF DELAB), and Denmark (Delta Acoustics and Vibration). In addition, Wright Patterson AFB personnel acquired GPS tracking and aircraft attitude data while NASA LaRC personnel acquired weather data. In the future NATO countries will also define a common data base format that will be adopted as the international standard. In addition, NASA Langley will use the data to verify the propagation algorithms that are contained in its Rotor Noise Model (RNM). Data were acquired for 158 runs including 66 level flyovers, 53 approaches (3°, 6°, 9°, and 12° descent angles), 36 take-offs (500, 1000 & 1500 ft/min ascent rates), and three hovers (on ground flat blade pitch, IGE, and OGE).

The second in a series of three XV-15 Terminal Area Acoustics flight tests was conducted at Waxahachie, Texas, (see Figure 5). The overall program objective was to determine flight procedures for tilt-rotors that are quiet, safe, and easy to fly. The program approach was to measure the far-field noise of a tilt-rotor during terminal area operations. These measurements would help develop low noise operating procedures by optimizing the nacelle tilt schedule and the approach profile to reduce the radiated noise. The far-field acoustic database will also validate noise prediction methodologies and community noise impact models. The first test, conducted in the fall 1995, showed that the Sound Exposure Level (SEL) can be reduced by up to 10 dB by varying the nacelle angle, and the noise footprint can be significantly altered by modifying the approach profile. The 1995 test also showed that there really is no noise problem for tilt-rotor take-offs. The 1997 test utilized a 37 microphone large area array (2000 feet wide by 9000 feet long) to measure the noise footprints for approaches to hover. The variable airspeed, nacelle angle, and glide slope approaches blended handling quality requirements with noise reduction to assure realistic IFR approaches

5. Military aeroacoustics applications

Two important military noise control applications are STOVL ground environment improvement and weapons bay noise suppression. STOVL ground impingement noise is of concern because of possible sonic fatigue failure of aircraft structures and ground personnel on aircraft carriers being exposed to high acoustic levels. The weapons bay aeroacoustic program aims to reduce acoustic loads in weapons bays with a view to reducing


(a)

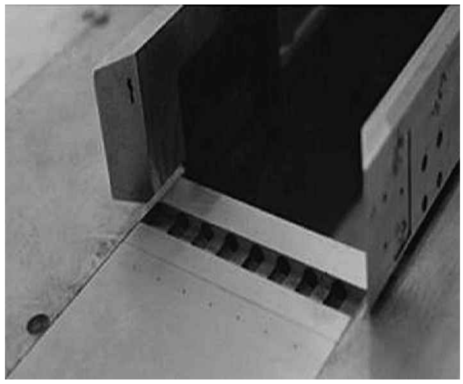

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Figure 6. Photographs of Boeing/IIT integrated powered resonance tube actuators installed in a DERA (UK) weapons bay cavity in the ARA (UK) wind tunnel. (a) Photo of the model in the ARA wind tunnel. (b) Photograph of actuator installed in the DERA model.

structural fatigue and improving weapons delivery. The US Air Force Research Laboratories (AFRL), Air Force Office of Scientific Research (AFOSR), Naval Air Weapons Center (NAWC), and DERA (UK) have all initiated new coordinated weapons bay aeroacoustic control programs to enhance the ability to dispense weapons over a larger flight envelope without fatigue failure. New experiments have been conducted, a number of simulation efforts are in place using LES methodology, and flight tests are planned for the near future. A consortium entitled Active Robust ConTrol of Internal Cavities (ARCTIC) made up of the government agencies listed, and including major airframe contractors, small companies, and universities, was developed to help focus efforts and enhance coordination. Figure 6 shows a picture of the DERA weapons bay model in the ARA wind tunnel (see Stanek et al. [6] and Raman et al. [7] for details). The Boeing/IIT powered resonance tube actuator tested in this facility was successful in suppressing cavity noise at M = 1.19 by about 30 dB.

Acknowledgements

The authors thank all those who contributed and graciously consented to the reproduction of illustrations. Excerpts from Ref [1] and photographs from NASA NP-1998-10-242-HQ [4] also appear in this article.

References

1. *Raman, G. and McLaughlin, D.K. 1999 Highlights of Aeroacoustics Research in the U.S. Journal of Sound and Vibration, Vol. 228(3), pp. 589–610.*

2. *R.P. Woodward, D.M. Elliott, C.E. Hughes and J.J. Berton 1999 American Institute of Aeronautics and Astronautics Paper 99-0479. Benefits of swept and leaned stators for fan noise reduction.*

3. *E. Envia, D.L. Huff and C.R. Morrison 1996 American Institute of Aeronautics and Astronautics Paper 96-1791 Analytical assessment of stator sweep and lean in reducing rotor-stator tone noise.*

4. *Aeronautics and Space Transportation Technology, Three Pillars for Success. NASA Annual Progress Report 1997–1998. Publication of the NASA Office of Aeronautics and Space Transportation Technology, Code R, NASA HQ, NP-1998-10-242-HQ.*

5. *Stanek, M., Raman, G., Kibens, V., Ross, J., Peto, J. & Odedra, J. 2000 Cavity tone suppression using high frequency excitation. AIAA Paper 2000–1905.*

6. *Raman, G., Kibens, V., Cain, A. & Lepicovsky, J. 2000 Advanced actuator concepts for active aeroacoustic control. AIAA Paper 2000–1930.*