NASA'S QUIET AIRCRAFT TECHNOLOGY PROJECT

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Abstract

NASA's Quiet Aircraft Technology Project is developing physics-based understanding, models and concepts to discover and realize technology that will, when implemented, achieve the goals of a reduction of one-half in perceived community noise (relative to 1997) by 2007 and a further one-half in the far term. Noise sources generated by both the engine and the airframe are considered, and the effects of engine/airframe integration are accounted for through the propulsion airframe aeroacoustics element. Assessments of the contribution of individual source noise reductions to the reduction in community noise are developed to guide the work and the development of new tools for evaluation of unconventional aircraft is underway. Life in the real world is taken into account with the development of more accurate airport noise models and flight guidance methodology, and in addition, technology is being developed that will further reduce interior noise at current weight levels or enable the use of lighter-weight structures at current noise levels.

1 Introduction

NASA's community noise reduction goals, which are intended to improve the quality of life of those people impacted by aircraft noise, are challenging. They are stated as follows: '… the Aeronautics Technology Theme will research, develop and transfer technologies that: By 2007, enable a reduction in community noise due to aircraft by half, based on the 1997 state of the art; Beyond 2007, continue technology development to reduce community noise due to aircraft by a factor of four'. The Quiet Aircraft Technology Project (QAT) was formed in 2001 as the means by which these goals should be achieved, building on the success of its predecessor, the Noise Reduction element of the Advanced Subsonic Transport Program (which came to an end in 2001).

To achieve the goals, QAT conducts research in the areas of aircraft source noise reduction (engine sources, airframe sources, effects of installation); community noise impact reduction (real world effects, flight path modifications) and, because the traveling public are also part of the community, interior noise reduction. In all areas, the emphasis is on 'physics-based' modeling to enable the assessment of noise from aircraft that are unconventional when compared to the familiar 'tubes with wings' for which a large quantity of data is available.

2 Aircraft Source Noise

2.1 The Overall Problem

Figure 1 illustrates the potential sources of noise for a commercial aircraft on approach. In addition to the engine sources – fan, compressor, turbine, core combustor and jet exhaust, we have sources related to the 'dirty' configuration of the airframe – landing gear (both main and nose), high lift devices – slats and flaps, and sources relating to the installation of the engine on the airframe – propulsion airframe aeroacoustics.

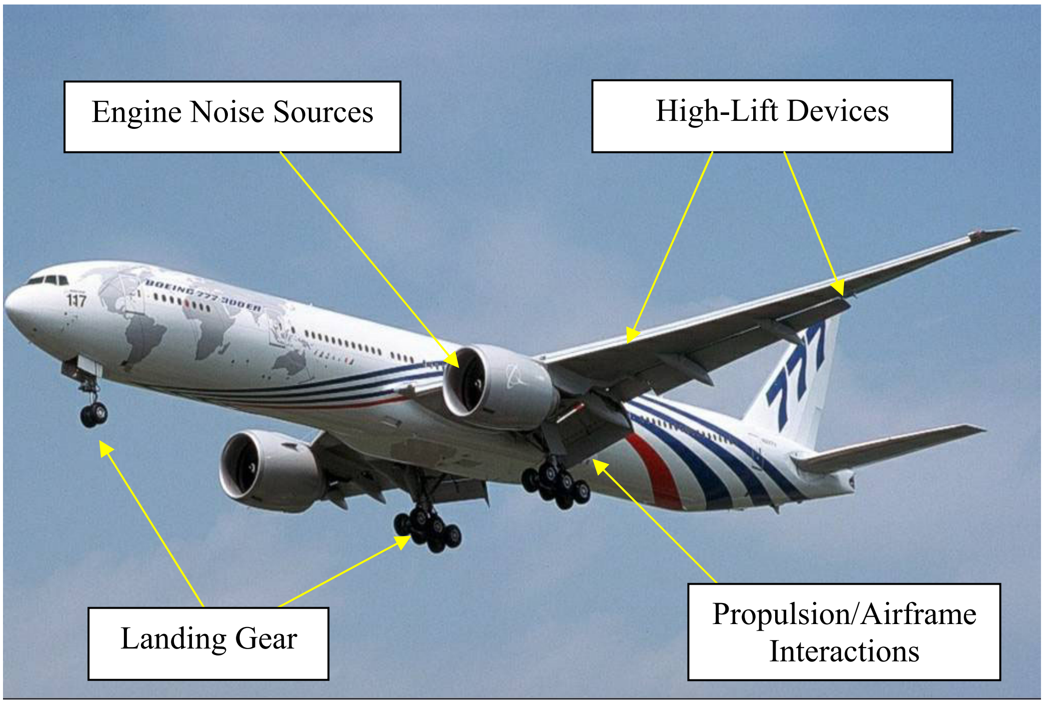


Fig. 1: Noise sources for an aircraft on approach

Aircraft noise is a system problem, and in order to determine which areas promise greatest potential for noise reduction of the aircraft as a whole, a system prediction is performed at those observer locations corresponding to the standard noise certification points. From those results the following areas of effort have emerged. In each case, a brief description is followed by some examples of progress in understanding, noise reduction or both.

2.2 Engine System Noise

Figure 2 shows the noise sources that have been identified for a typical commercial high bypass ratio turbofan engine. System analysis shows that the most important noise source at takeoff is the jet, closely followed by the fan exhaust and fan inlet. At approach, fan inlet noise, fan exhaust and jet noise are important.

2.2.1 Jet Exhaust Noise

For many years, it was believed that the only way to reduce jet noise without incurring a

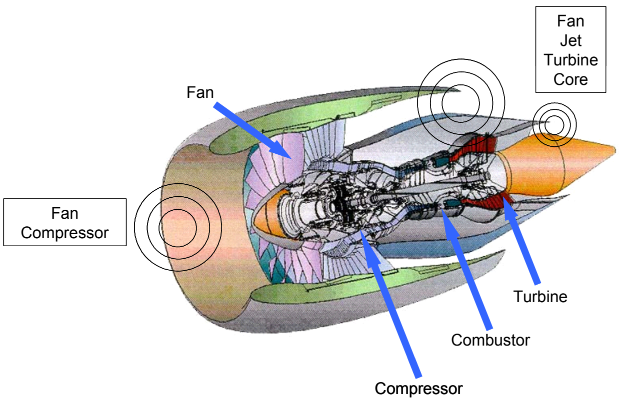


Fig. 2: Typical high bypass ratio turbofan noise sources

major performance penalty was to reduce jet velocity. Jet noise scales with the 8^{th} power of velocity; hence reducing the jet velocity is a powerful tool in noise reduction.

More recently, chevrons (devices that protrude slightly into the flow at the exhaust nozzle exit) have been developed that reduce jet noise significantly while delivering an acceptable reduction in performance.

In order to understand the effects of chevrons on the jet flowfield – and hence on the noise – efforts are underway in the areas of hot jet aerodynamic measurements and CFD, together with acoustic modeling. Successful prediction of jet noise from CFD results requires knowledge of turbulence quantities within the flowfield. It thus becomes necessary to measure these quantities in a hot jet for comparison with prediction in order to improve the turbulence model. Recent advances have demonstrated greatly improved agreement between predicted and measured jet plumes – and also between predicted and measured jet noise.

2.2.2 Fan Noise

Fan noise has been studied for many years, but (as with jet noise) recent advances in CFD, together with enhanced diagnostic measurement capabilities and the development of new materials and manufacturing techniques are giving increased insight into fan noise generation, propagation and potential opportunities for its reduction. Much insight has been gained through source diagnostic tests using scale model fan rigs. A major enhancement has been the development of a fan rig that has no support struts behind the fan – the nacelle is mounted on the wall of the tunnel – enabling diagnostic tests of the fan rotor alone.

In addition to tests and modeling, fan noise reduction concepts have been developed. The more extreme include: fan trailing edge blowing (designed to fill in the blade wake, thus reducing rotor/stator interactions), while the forward-swept fan and its appropriately designed stator are intended to reduce rotor noise at high rotational speeds.

2.2.3 Acoustic Liners and Duct Propagation

Strictly speaking, liners do not form part of 'source noise'. However, their objective is to reduce engine source noise before it is able to radiate, hence their inclusion here. Liners have been studied for many years, but it is only recently that their design and performance have ceased to be a black art and have become a science. Computer modeling now provides physics-based insight into how liner performance can be improved, without additional weight penalty, and innovative means (e.g. active/passive liner designs) are under consideration for improved liner performance.

A computational tool has been developed that enables immediate assessment of liner effectiveness.

In the past, the use of a lined splitter in the aft fan duct of an engine was welcome as a means for increasing liner area – but was discarded on the grounds of increased weight and performance loss. Advances in CFD design methods for the duct and in materials for the splitter have made this option a distinct possibility, leading to potential reductions in aft-radiated fan noise.

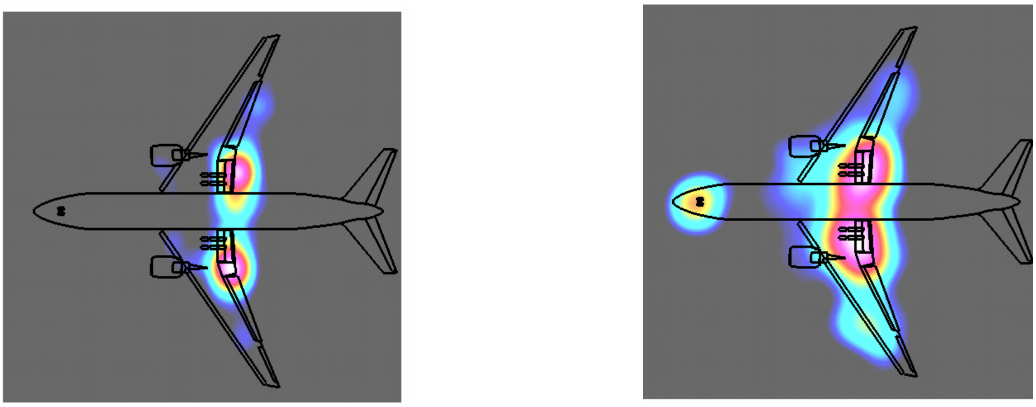
2.3 Airframe System Noise

Sources of airframe noise have been identified in a series of tests (ranging from flight to a 6.3% scale model) through the use of microphone array technology.

Fig. 1 shows (at one frequency) noise 'hot spots' from a large twin-jet aircraft. It can be seen that the main areas of concern are the landing gear (main and nose) and the high-lift system (leading edge slats, trailing edge flaps). Efforts are underway in all these areas to develop models based on the physics of the problem in order to acquire understanding of the mechanisms involved in the noise generation and concepts for noise reduction.

2.3.1 Landing Gear Noise

It has been stated that aircraft landing gear exist in order to re-use the airframe. When deployed, they consist in essentials of a collection of wheels mounted on a frame, connected to the main body of the aircraft by a strut. This arrangement can immediately be perceived to have the potential for noise generation. Added to this is the necessity for these structures to remain concealed within the body of the aircraft (for drag reduction purposes) until required, whereupon hydraulics come into play via a myriad of smaller diameter lines as the entire assembly unfolds and locks into place. Indeed, the hydraulic lines form another noise source!



a) Landing gear up　　　　　　　　　　b) Landing gear down

Fig. 1: Sample airframe noise data from flight test (courtesy Boeing)

Landing gear are being studied extensively, both via computational tools and through experiments. Concepts for noise reduction are under investigation, with a prime requirement being the capability for implementation of the concept given the deployment and retraction environment of the gear.

2.3.2 High Lift System Noise

The high lift system of an aircraft is generally regarded as the wing leading edge slats and trailing edge flaps. They are deployed under low-speed operating conditions to modify the wing shape and thus enhance its lift capability. By their nature, as seen in Fig. 1, they are also sources of aerodynamic noise. Again, the approach followed is that of gaining fundamental understanding through extensive use of CFD combined with computational acoustics, together with experiments to acquire fundamental acoustic and flowfield information using models of differing degrees of complexity. Once the understanding of the noise generation mechanisms is in place, concepts for noise reduction are developed, bearing in mind (as with the landing gear above) that deployment capability is of prime concern, together with the requirement that aerodynamic performance of the high lift system be uncompromised.

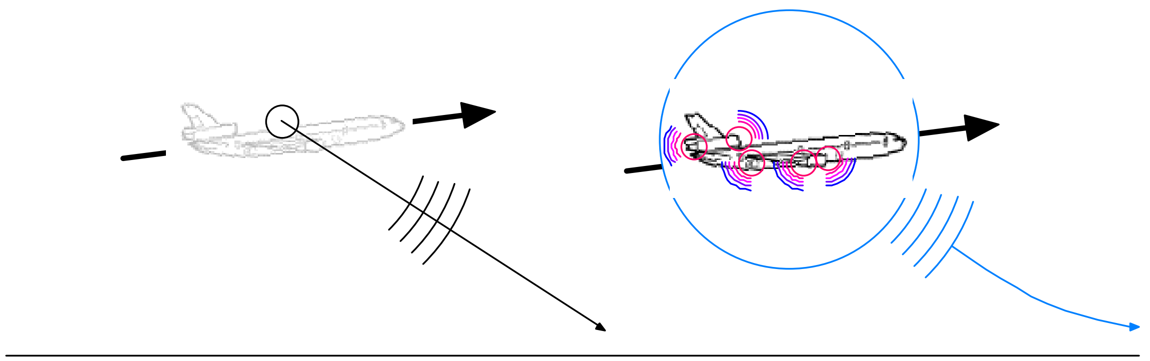
2.3.3 Propulsion Airframe Aeroacoustics (PAA)

So far, we have looked at (skimmed over) the various sources of aircraft noise – both engine and airframe. They do not act in isolation, nor, indeed, independently. The concept of propulsion airframe integration is not new in performance circles, though historically the acoustic implications of the installation of the propulsion system on the airframe have been gleaned from past experience. Within QAT we are addressing PAA in a systematic fashion.

A simple example follows from the earlier discussion of engine jet noise and the benefit of chevrons. Many of the initial studies of chevrons were performed using simple, circular nozzles. Now, engines on aircraft do not have simple circular nozzles. They are installed (on conventional aircraft) via mounting pylons which extend through the outer (fan) duct, possibly with a further bifurcation on the opposite side of the core. This pylon can also be seen to extend significantly beyond the exit of both the fan and core nozzles in a conventional under-the-wing installation. Not surprisingly, the presence of the pylon affects the jet flowfield at the engine exit relative to a circular nozzle – and thus modifies the noise generated. Effects of chevrons are also changed. Within PAA, tools are being developed to predict the flowfield of a non-axisymmetric hot jet – and its noise.

In addition to the modification of engine source noise as a result of installation, the presence of the airframe affects the radiated sound. Again, to use the under-wing mounted jet as an example, noise generated in the jet plume will be reflected off the underside of the wing. In a tail-mounted configuration, fan inlet radiation will reflect off the fuselage, and may even be reflected from the top surface of the wing, shielding the community below.

Understanding acoustic effects of installation through PAA is regarded as an essential step along the way to using the aircraft configuration as a design parameter in the search for noise reduction.



a) Current model (ANOPP) b) Future model (AVATAR)

Fig. 2: Improvements needed in system noise modeling to enable prediction of unconventional configurations

2.4 Community Noise Impact and Modeling

Thus far we have described areas of opportunity for aircraft noise reduction at the source. Aircraft noise is a complex topic, and reduction in one component of the source does not of itself guarantee a reduction in the noise perceived in the community. Indeed, such are the vagaries of acoustic arithmetic, a major reduction in source noise can result in an increase in the community noise metric!

It is necessary, therefore, to assess the benefit to the community of noise reduction concepts developed under QAT and thus progress towards the noise goals outlined earlier. Two aircraft were defined by the QAT community as representing the 1997 state of the art baselines: the Boeing 777-200 powered by twin GE90-94B high bypass ratio turbofans, and the Bombardier CRJ-700 powered by GE CF34 engines. These aircraft are good representatives of the current fleet mix, being a 'large twin' and a 'regional jet'. NASA's aircraft noise prediction program (ANOPP) is used for these assessments.

It is believed that the long term goal, described earlier, of reducing perceived noise due to aircraft by a factor of 4 relative to 1997 levels will require more than an incremental approach. Current aircraft system noise prediction tools (such as ANOPP) rely on current knowledge. Their ability to extrapolate to unconventional configurations is not to be trusted. As a part of this element of QAT, a new computational tool (AVATAR) is under development that will account for engine placement, individual airframe components and non-standard atmospheric conditions (e.g. gradients, wind) for the propagation of sound from the aircraft to the ground. This tool is illustrated in

a) Current model (ANOPP)
b) Future model (AVATAR)

, above.

2.4.1 Airport Noise Modeling

Everything described above is concerned with modeling and reduction of noise resulting from a single event – one takeoff, one approach (or landing). Airport operators, and the general public, are concerned with the total impact of many events and thus an element of QAT is directed towards improved modeling of the noise around airports in the 'real world'. Airport noise is typically predicted using government-approved codes such as the FAA's Integrated Noise Model. Such codes are intended for use at all airports and incorporate several simplifying assumptions regarding sound generation and propagation. Modeling improvements conducted under QAT are based on both theoretical and empirical studies and will include real-world effects of weather on sound propagation and airline flight procedures. The improved model will be validated through field measurement studies conducted at various airports.

2.4.2 Approach Aids

Still in the real world, it is no surprise to learn that the perceived noise from an airplane is a function of distance. The further away the source, the lower the noise. When an aircraft takes off, it leaps into the air and climbs rapidly away from the community. The excess thrust provided by the engines of a 'large twin' aircraft (and required for safety) enables a rapid reduction in perceived noise. Approach is more complex. The pilot must control the aircraft at low speed, as directed by air traffic control, with the major noise producing (drag generating) devices deployed. In general, this involves flying at constant, fairly low, altitude until the three degree glide slope is intercepted – which is then followed to the ground. If it is possible to keep the aircraft at greater altitude for longer, there is a benefit to the community, and the so-called 'Constant Descent Approach' or CDA illustrated in Fig. 3 is gaining support. Within QAT we are working on means to implement this technique that are acceptable to pilots, air traffic controllers, and regulatory bodies.

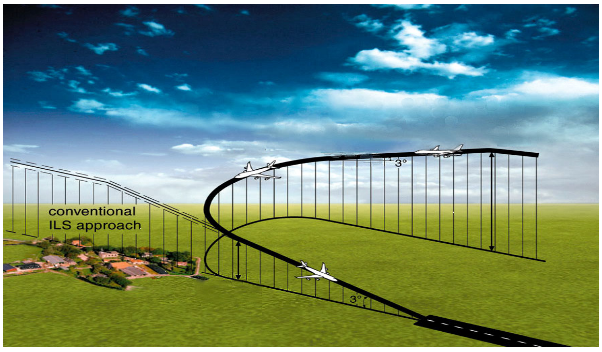


Fig. 3: Continuous Descent Approach (avoiding community) compared with conventional approach

2.5 Passenger / Crew Environment (Interior Noise)

Everything described above has concentrated on noise perceived by the community. There is another group, however, known as the traveling public, who in conjunction with the crew of a passenger transport are concerned about levels of noise within the cabin and cockpit. In the past, the solution to the problem has been to add mass to the fuselage structure. This attenuates noise that results from the engines and the fuselage boundary layer. In these days of high operating costs and emissions goals, however, adding non-structurally required weight is a bad thing. There are major efforts afoot to reduce the weight of aircraft, thus we are working on means to maintain current noise levels within the cabin given a weight reduction of 30%. In essentials, this requires the definition of lightweight concepts for increasing transmission loss, both for fuselage sections and for windows. In addition, as with all noise sources described and concepts proposed, the goal is to proceed from an understanding of the physics of the problem. Instrumentation is under development to make this possible.

3 Concluding Remarks

NASA's Quiet Aircraft Technology Project is developing physics-based understanding, models and concepts to discover and realize technology that will, when implemented, achieve the goals of a reduction of one-half in perceived community noise (relative to 1997) by 2007 and a further one-half in the far term. Noise sources generated by both the engine and the airframe are considered, and the effects of engine/airframe integration are accounted for through the propulsion airframe aeroacoustics element. Assessments of the contribution of individual source noise reductions to the reduction in community noise are developed to guide the work and the development of new tools for evaluation of unconventional aircraft is underway. Life in the real world is taken into account with the development of more accurate airport noise models and flight guidance methodology, and in addition, technology is being developed that will further reduce interior noise at current weight levels or enable the use of lighter-weight structures at current noise levels.

4 Acknowledgements

The author would like to express her thanks to all members of the Quiet Aircraft Technology team.