BOEING

Backgrounder

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Boeing Quiet Noise Technology Initiatives

The Boeing Company has been developing and implementing noise reduction features on its jetliners for more than 40 years. As a result, each generation of Boeing airplanes has become quieter than its predecessor, while also becoming cleaner, safer and more affordable. With the global commercial fleet expected to double in the next 20 years, Boeing and others in the industry are working collaboratively to ensure the trend of declining noise continues well into the future.

One of our most recent efforts in the area of noise reduction technology has been the Quiet Technology Demonstrator (QTD) program. The first QTD program was conducted in partnership with Rolls-Royce, using a newly built Boeing 777 on loan from American Airlines. Building on the success of the initial QTD program, Boeing successfully conducted a follow-on effort -- QTD2 -- in the summer of 2005, which further validated additional advanced noise-reduction concepts. QTD2 was accomplished in conjunction with several key industry partners including Goodrich, GE Aircraft Engines and NASA. ANA (All Nippon Airways) provided the use of a 777 for this flight test series. Several of the tested technologies during QTD2 included chevrons on the engine exhaust ducts, new acoustic treatment for the engine inlet and landing gear noise reduction features. The test program was designed to validate technologies to lower noise for both communities that live around airports and also for passengers and crews in the cabin.

Background on Airplane Noise

Noise can best be described as pressure fluctuations in the air. Pressure fluctuations cause our ear drums to vibrate and we hear it as noise. The source of airplane noise is always something that creates pressure fluctuations. In most cases, it is some form of flow distortion or turbulent flow.

Noise heard on the ground is composed of engine noise and airframe noise. During take-offs, engine noise is dominant and the airframe noise is not as important. This is partly due to the fact that the landing gears are stowed and the flaps are only deployed to a small deflection.

During aircraft landings, both engine noise and airframe noise are important, while on most contemporary airplanes, the generated engine noise is still a bit more than the airframe noise.

To sort out and develop noise technology, engineers distinguish various sources as follows:

Engine noise

1. Jet noise: noise due to mixing of air streams in a turbulent manner. This happens between the hot core efflux, the fan (or bypass) exhaust flow and the ambient (or free stream air). Jet noise is most dominant during take-off.
2. Fan noise: The fan within the engine makes noise that escapes both from the front of the engine and from the back. This noise consists of both tones or single frequency noise components and broad-band noise. Broadband noise sounds like a water fall for example. Fan noise is usually controlled by engine design features and by including acoustically absorbent surfaces in the engine nacelle. Nacelles are the ducts you see in front and back of the engine, and are typically produced by companies other than the engine manufacturer. For example, on 777 airplanes, Boeing designs and manufactures the nacelles for all three engine options (Rolls Royce, General Electric, and Pratt and Whitney). In principle, fan noise is very important during both take-off and landing.
3. Turbine Noise: The noise made by the turbine is heard mostly in the rearward portion of the engine. This noise tends to be most important during landing depending on the engine make and model.
4. Compressor Noise: This is usually made up of several tones and is heard in the frontal portion of the engine. Some of the compressor noise is absorbed by the acoustic lining in the inlet.

5. Buzz-saw Noise: This is a particular fan noise source that occurs when the tips of the fan blades are traveling close to the speed of sound. In modern high bypass engines, this happens during take-off. A good acoustic lining in the area forward of the fan can effectively attenuate this noise source.

Airframe noise

1. Wing Noise: Noise due to turbulence produces at flaps, slats and other flow discontinuities. Boeing has conducted research for the past decade to better understand how to minimize this noise within design constraints.
2. Landing Gear Noise: Both main landing gear and nose landing gear create turbulence and therefore noise.

Chevrons

Chevrons reduce the jet noise component of the engine noise. Since jet noise is important during take-off, the benefit of chevrons is best realized during that portion of a commercial flight.

Chevrons are zigzag or saw-tooth shapes at the end of the nacelle, with tips that are bent very slightly into the flow. This creates vortices that form at each chevron, enhancing the mixing rate of the adjacent flow streams. As previously mentioned, the jet noise is due to turbulent mixing between jets and the noise generation mechanism is very complex. When the chevrons enhance mixing by the right amount, the total jet noise reduces. If the mixing is too much, the chevrons make the noise go up. If the mixing is too little, no noise reduction benefits are realized.

Chevron designs began with running flow analysis computer programs know as computational fluid dynamics. Based on these results, several small models in multiple variations were built and tested in the Boeing acoustic wind tunnel and, at the conclusion of extensive testing, the best designs were selected for building full-scale hardware for the 777 airplane. Due to the cost of flight-worthy hardware, the QTD flight test included one fan chevron design and two core nozzle chevron designs.

The chevron design was successful, with a reduction of up to 4 decibels of noise at the peak frequency and noisiest location was achieved.

Nacelle inlet acoustic treatments

The inlet nacelle surface is usually made of an acoustically absorbent surface. The acoustic absorber (called the acoustic lining) usually consists of a perforated sheet at the surface. Behind the surface is a layer of honeycomb core material. Finally, there is a final non-porous back sheet. The depth of the honey comb core and the properties of the perforated face sheet (hole diameter, sheet thickness, core depth, etc.) decide what frequency of sound is absorbed (tuning frequency). Essentially, the deeper the liner, the lower the frequency of sound that is absorbed. The effectiveness of the acoustic lining extends to a small frequency range around the tuning frequency. In most instances, to make the frequency over which the sound is absorbed wider, typical engine inlet liners have an additional perforated sheet in between the face sheet and the back sheet. This is called a double layer liner.

The inlets for airplanes such as the 777 get very large (about 3.5 m in diameter). During manufacturing the acoustic linings are built in a few segments and attached together. This creates joints without acoustic perforations. These joints reduce effectiveness of the acoustic lining in two ways. First, the effective area available for sound absorption is reduced. Secondly, at each discontinuity, the sound bounces off – called scattering. This is analogous to car headlights creating blinding scattering when your car windshield is wet with rain drops.

During QTD, and using a manufacturing technology called AMAX, Boeing successfully reduced the joint widths dramatically. As part of the QTD 2 flight test program, we eliminated the joints altogether by building a one-piece acoustic barrel and observed that this indeed was superior in further reducing noise.

Q: When will Boeing begin to implement joint-less inlet acoustic liners?

Boeing is implementing the joint-less acoustic liners on the 787 Dreamliner scheduled to enter commercial service in 2008. The joint-less liner inlet is also implemented on the Boeing 747-8 airplane scheduled to enter service in 2009.

Q: Are acoustic liners used only in the inlet nacelle?

No. Extensive use of double-layer acoustic liner can be seen in the fan exhaust inner surface of all Boeing airplanes. Also, the inner walls of the engine, both forward and aft of the fan blades, have acoustic treatment. On some airplanes, sound absorption liners also are included in the hot core exhaust duct to muffle the noise from the turbine. Both of the QTD programs to date have included the study of the acoustic liner in the engine case just forward of the fane blades.

Reducing airframe noise

Boeing has tested scale models of most models in its airliner family in its acoustic wind tunnel in Seattle to better understand the sources of airframe noise. Recently in cooperation with NASA, Boeing tested a large 26-percent model of the 777 wing and landing gear in the NASA wind tunnel to map, in detail, the noise-generating locations and elements on wings and landing gear.

During the QTD flight test program, Boeing deployed a large number of microphones on the ground to form a phased array or an acoustic camera. As the airplane flies over the microphones, the sound signals reach each microphone at a slightly different time. Computer algorithms take this phase delayed information and deduce the location of the noise sources on the airplane surface. In effect a noise photo is created. In addition, the Boeing Research and Technology Europe located in Madrid, Spain, sponsored the National Aeronautical Laboratory of The Netherlands to deploy phased arrays at the end of runway 06 at Amsterdam Schiphol Airport. Noise maps pin pointing noise sources were acquired from approximately 500 flights covering just about every airplane in commercial flight today.

Boeing is now using the data to understand how some airliner designs are quieter than others. During the development phase of new airplanes such as the Boeing 787, a larger number of wind tunnel tests were employed to optimize wing and flap system design. During these tests, it became standard practice to include the phased array on the wind tunnel walls. Thus, the noise characteristics of the airframe are available together with the aerodynamic characteristics, allowing Boeing to identify quieter airframe noise configurations.

Q: When will Boeing begin to implement Chevrons?

Boeing is implementing chevrons on the fan nacelle cowl of the 787 Dreamliner scheduled to enter commercial service in 2008. Both fan nacelle cowl chevrons and hot core nozzle chevrons are implemented on the 747-8 airplane scheduled to enter service in 2009.

Q: What else did you implement based on the QTD test program?

During the QTD test program using the phased array we identified that some one-inch diameter holes located along the leading edge of the wing, on the lower surface were whistling (like blowing across a coke bottle mouth). These holes are present to exhaust wing leading edge anti-ice air. Following QTD we did a series of wind tunnel tests and developed rectangular slotted-hole designs that don’t whistle. As a result, all 777 in production now have rectangular slots for discharging anti-ice air.

Q: What are the next steps toward further reducing airliner noise?

The month-long QTD2 flight test program effectively tested newer low-noise designs. Data from unique advance noise reduction features were successfully tested aboard the 777 airplane including low-noise concepts for landing gear, variable geometry chevrons that morph automatically to different immersion for take-off and cruise, a joint-less acoustic liner in the inlet nacelle and an acoustic liner that goes from very near the fan to the very front of the inlet.

Testing involved the use of more than 1200 microphones, including 600 on the ground and another 200 aboard the airplane to obtain detailed airport noise and cabin noise measurements. A QTD3 Flight test program is currently being planned to test even more advanced noise reduction technologies.

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