

High Channel-Count Aircraft Noise Mapping Applications

Kurt Veggeberg, National Instruments, Austin, Texas

Modular instrumentation is being widely used in noise and vibration measurement systems that demand higher channel counts and the wider dynamic range that 24-bit delta-sigma ADCs make available at lower costs. This is an overview on how flexible modular instrumentation based on PXI (PCI extensions for instrumentation), employing a distributed hardware and software architecture is being used in noise mapping applications. This example will concentrate on the efforts by NASA and Boeing to test and validate aircraft noise-reducing technologies. In this application, higher sampling rates, higher channel counts, increased dynamic range, and distributed architectures were used in a system designed to be easily scalable and extensible.

NASA, Boeing and aerospace industry partners are flight testing new technologies to make aircraft quieter on takeoff and landing. They assess and test actual hardware at a test facility in Glasgow, MT, as well as at other facilities. In early tests in 2001, they deployed an “acoustic camera” for flyover noise mapping as a part of their Quiet Technology Demonstrator (QTD). The goal of the Quiet-Aircraft Technology Project is to reduce perceived aircraft noise by 50% in 10 years and by 75% in 25 years using 1997 levels as the baseline.¹

Over the years, aircraft engine noise has been consistently reduced by various techniques, drawing more attention to airframe noise issues. Engine noise, including jet, fan and combustion is dominant on takeoff and important on approach. Airframe noise, including slats, flaps and landing gear is dominant on approach.

Acoustic beam forming can be used for aircraft fly-by noise tests to measure and distinguish engine and airframe noise sources in addition to testing quieter flight operation procedures. The use of phased arrays of microphones in the study of noise sources is being more widely used and should increase as the cost of instrumentation goes down. When properly used, arrays can be used to extract noise source distributions on full-scale and wind tunnel models.²

With more channels, Boeing has been able to get increased dynamic range and higher resolution to distinguish noise sources. This information can be used to make design or operational changes. Their ultimate goal is to increase the channel count to more than 1,000 channels. The flyover noise map based on data from a phased array “acoustic camera” identifies opportunities for noise source reductions and distinguishes between engine and airframe sources.

In the first stage of the project in 2001, Boeing deployed a system that could handle a microphone array up to 264 channels. They ran into channel bandwidth limitations in the total number of channels that their system architecture allowed. The system required a centralized data system architecture where all the chassis had to be co-located; this required more than 30 miles of cable. They also faced challenges in synchronizing multiple instrumentation chassis, the cost per channel, the dynamic range as well as the data turnaround (time to retrieve acquired data).

In the second stage of the project, conducted in August of 2005, Boeing tested the Quiet Technology Demonstrator 2 (QTD2), which is based on the 777-300ER. In these tests, several advanced noise-reduction concepts were validated. These included chevrons on the engine exhaust ducts and new acoustic treatment for the engine inlet (see Figure 1). They also tested noise-reducing aerodynamic fairings for the main landing gear.

The acoustic camera requirements were increased to allow no more than $\pm 1^\circ$ of phase mismatch at 90 kHz across all channels with a distributed architecture to allow rapid access to the sampled data



Figure 1. QTD2 engine and landing gear treatment.

and unconstrained scalability. They introduced a new instrumentation system that allowed them to increase the channel count to 456 in 2005. This has since been expanded to 824 channels. This yielded higher resolution while only requiring approximately 3 miles of microphone cable. They also were able to achieve a better than 2 \times reduction in cost per channel over their existing system while achieving significant improvement in capability.

Since then, multiple and varied test installations have been done using the same basic architecture. These include a full-scale static engine test with 395 channels sampling at 102.4 kS/sec and 412 channels at 204.8 kS/sec with a scale model of the 787 in the QinetiQ pressurized wind tunnel. The higher sampling rates are necessary for scale models, since the noise frequencies of a scale model are inversely proportional to the size of the model.

Architecture

High-channel count dynamic signal acquisition applications have some important issues to consider, including data throughput, streaming to disk, data processing, user display and network activity. Depending on the requirements of the system, trade-offs can be made to optimize one performance vector over another.

For scalable systems from 400 to more than 1000 channels, a system architecture using multiple PC-based controllers and multiple chassis was proposed for this application. In this architecture, a master chassis controls timing and triggering. To synchronize dynamic signal acquisition devices (DSA) in a PC-based architecture such as PXI, you typically need to be able to provide three timing signals. Two of the signals are triggers. One is the sync pulse, which resets the device's internal counters and analog-to-digital converters (ADCs). The other is the start trigger, which begins an acquisition.

The third signal is a 10-MHz clock. The DSA device will phase lock loop (PLL) its internal clock to this 10-MHz signal. The master chassis creates and distributes the timing signals and the slave chassis propagate them on the backplane. Slaves distribute clocks to modules within them, control local acquisition, and store data to disk. A central CPU serves as a master data storage (moving data over Ethernet) and analysis engine. This allows local acquisition, analysis and data storage with a single host used for remote monitoring via Ethernet and centralized timing and synchronization.

In the Boeing flyover application during a typical test cycle, the aircraft would fly past the target approximately every six minutes. The system had to be capable of uploading the data acquired to

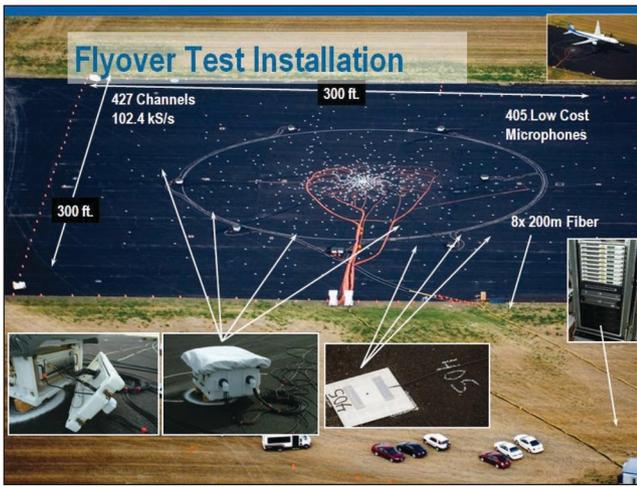


Figure 2. Flyover test installation components.

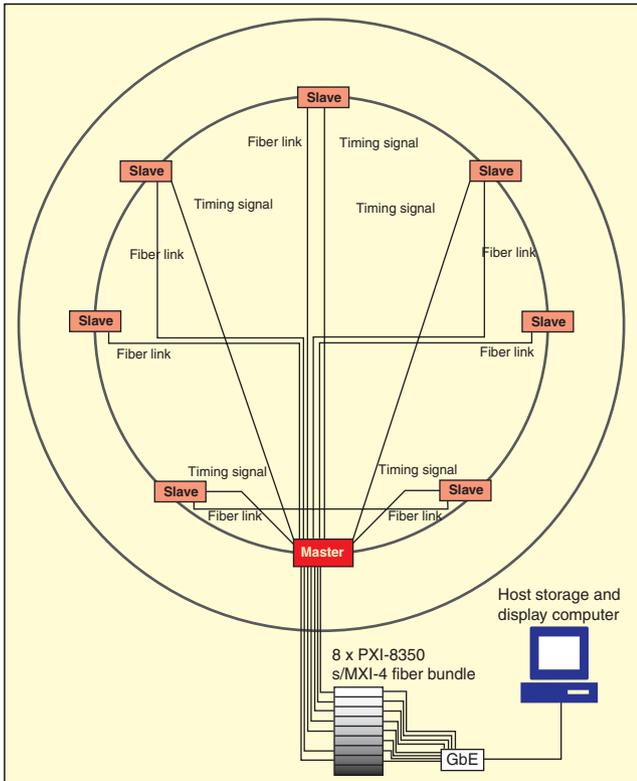


Figure 3. Architectural diagram of instrumentation.

the master data storage engine and be ready to acquire more data. During the test sequence in 2005, they conducted over 300 tests comprising 78 minutes of data and more than 1 terabyte of data.

The multiple PC and multiple chassis architectures allowed Boeing to distribute their digitizers in several clusters closely around the microphone array, while the controllers for the digitizers were located in a trailer connected by a MXI (mainframe extension) fiber-optic link up to 300 meters away. The controllers chosen were 1U rack-mounted PXI controllers with a chipset with multiple PCI buses. These are basically 19 in., rack-optimized, server-class computers bundled with an MXI link for remote control of a PXI system. Based on commercial off-the-shelf hardware, the SATA RAID drives installed are capable of streaming over 50 MB/sec to disk. With an MXI link, they were able to transparently control a PXI system from the server computer. All PXI modules in the system appear to the user as if they were PCI boards within the computer itself (see Figure 2).

The microphone array had a diameter of approximately 250 feet, which is larger than the wingspan of the aircraft. The ability to distribute the data acquisition versus a centralized system, cut the cable length needed from 30 miles to closer to 3 miles. (Figure 3)



Figure 4. Pressurized wind tunnel test installation.



Figure 5. PXI Instrumentation in cases on the tarmac.

The PXI-665X timing and synchronization control module was used in each chassis. This allows tight synchronization between modules in a single chassis and extends timing and synchronization to multiple chassis. The PXI-665x modules use the trigger bus, star trigger, and system reference clock features of PXI to implement advanced multidevice or multichassis synchronization. In this example, by using a combination of master modules (PXI-6653) with slave modules, multiple PXI chassis all operate off the same high-precision clock. The timing signal is distributed throughout the system by simple coaxial cables, which allow up to 200 m of separation of the chassis while still maintaining tight synchronization between the digitizers. The hardware specification for interchannel phase mismatch between any two channels in the system is 0.1° or less when the input signal is a 1 kHz sine wave. In practical use, they have experienced no more than $\pm 0.3^\circ$ of phase mismatch as a worse case up to 92 kHz.

Data Acquisition

For this application, Boeing was interested in a system that could be used for a broad range of applications, from full-scale tests to scale-model tests in a wind tunnel. They were interested in a system that had higher sampling rates and increased dynamic range than the older system. As a result, they chose the PXI-4462 data acquisition module. Each module has four simultaneously sampled input channels that digitize signals from DC to 92 kHz with anti-aliasing protection and differential input.

For full-scale tests, the frequency of interest would typically be no higher than 6 kHz, which doesn't require such a high sampling rate. In a wind tunnel test with a scale model, the higher sampling rates are needed. The module provides power for the microphones

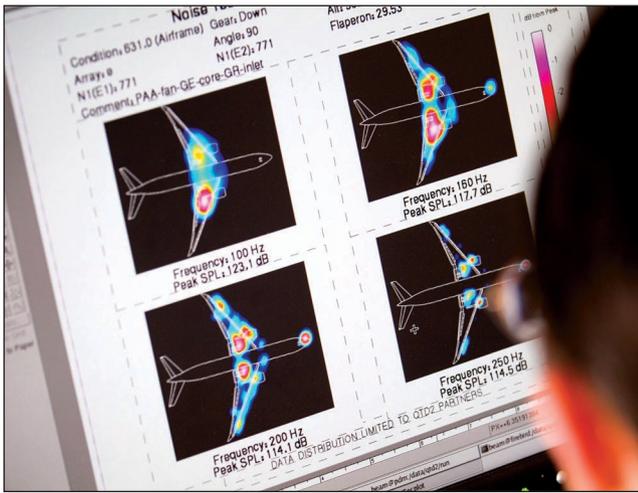


Figure 6. Noise maps from tests on QTD2 (Boeing).

and uses 24 bit sigma-delta technology to deliver better than 118 dB of dynamic range, which closely matches the dynamic range of their microphones compared to their older 16 bit system. The IEPE (integrated current source) in the modules also allowed them significant reductions in the cost and complexity of their instrumentation for some of their applications with specialized sensors (see Figure 4).

The fiber-optic link allowed them to place the instrumentation inside the pressurized QinetiQ wind tunnel and place the controllers inside the control room via a fiber optic patch panel. This proved quite useful in this application, because the conduit between the pressure plenum and the control room was not wide enough to accommodate more than 400 cables.

The system can also be broken up for lower channel count applications due to its modular nature (Figure 5). This makes it easier for them to deploy the instrumentation in other applications. Full-

scale model tests normally occur at longer intervals. The versatility of having instrumentation that can be adjusted for varying channel counts makes it more cost effective.

Conclusion

We showed how flexible modular instrumentation is being used in making demanding advanced noise mapping measurements to demonstrate advanced noise reduction concepts that are finding their way into new aircraft. Based on the improved results from the more detailed noise maps they were able to obtain (See Figure 6), Boeing is planning to increase the channel count for future tests as a part of their commitment to further improvements on their aircraft. By careful design and implementation, Boeing was able to develop a high-end, low-cost data acquisition system with virtually unlimited channel expansion capability. This type of instrumentation helps them make good on their commitment to reduce noise emissions on existing and new airplanes. This same type of distributed architecture can be used for making measurements on a variety of large structures where the sampling rates are often much lower.

Acknowledgement

Special thanks to James R. Underbrink, Boeing technical fellow, for feedback on the test system.

References

1. Wallace, James, "Boeing Makes 'Quiet' Advances: Noise Reduction Efforts Pay Off at Remote Airfield in Montana," *Seattle Post-Intelligencer*, August 11, 2005.
2. Brooks, Thomas F., "A Deconvolution Approach for the Mapping of Acoustic Sources (DAMAS) Determined from Phased Microphone Arrays," AIAA-2004-2954, 10th AIAA/CEAS Aeroacoustics Conference, Manchester, UK, May 10-12, 2004.
3. Underbrink, James R., "Hardware Architectures and Applications for a Distributed, High Bandwidth, High Channel Count Acoustic Data Acquisition System," *NI Week*, 2007. 

The author can be reached at: kurt.veggeberg@ni.com.