Developing a Sonic Boom Measurement System at JAXA

Figure 1. D-SEND No. 2 Test Model

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- Yusuke Naka, Japan Aerospace Exploratory Agency (JAXA) Supersonic Transport Team

The Challenge:
Capturing detailed multichannel sonic boom histories to validate aircraft design concepts that reduce sonic booms, which is necessary for next-generation supersonic transport.

The Solution:
Developing a real-time monitoring and data-logging system using NI PXI hardware and LabVIEW software that measures sonic booms indoors and outdoors as well as the resulting vibration of the windows and walls of the test building

Author(s):
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Japan Aerospace Exploration Agency (JAXA) is actively conducting supersonic transport research toward the realization of civil supersonic aircraft. Technology that precisely measures sonic booms is essential to demonstrating JAXA's sonic boom reduction concept in the planned drop test of a research aircraft. This is a part of the D-SEND Program (**D**rop Test for **S**implified **E** valuation of Non-Symmetrically **D**istributed sonic boom).

Figure 1. *D-SEND No. 2 Test Model*

Quiet supersonic flight over land appears increasingly viable, both technologically and economically, based on significant advancements in aircraft shape. JAXA has proposed some unique "low-boom" concepts that can reduce the sonic boom by half compared to the Concorde airliner. Efforts have been initiated to revise the rules prohibiting overland supersonic flight. To gain approval for overland flight operations, certification standards and criteria for acceptable supersonic overland flight need to be developed. Technology that can accurately measure sonic booms is key to getting these rules revised.

What Is a Sonic Boom?

A sonic boom is a shock wave created by an aircraft flying at supersonic speeds. It is an impulsive noise of less than 0.3 seconds, similar to an explosion. Supersonic flights over land are currently banned due to sonic booms.

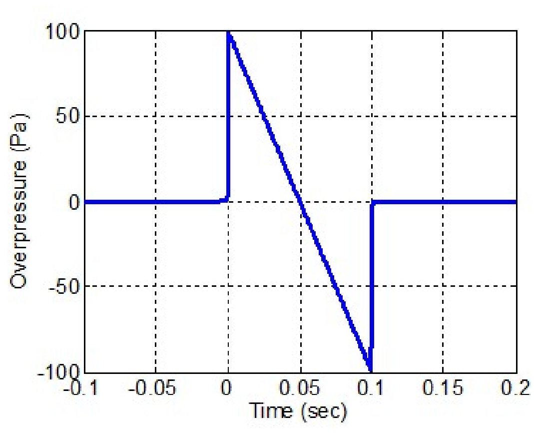

Figure 2. *Sonic Boom Signature*

The requirements for our sonic boom measurement system included accuracy, flexibility, reliability, and convenience. In terms of accuracy, we needed a system capable of handling the wide frequency and dynamic range of sonic booms. Sonic booms cover a wide frequency range with overall infrasonic components of less than 1 Hz and rapid pressure rises greater than 10 kHz. They also offer a wide dynamic range of over 200 Pa (140 dB SPL) and a small pressure fluctuation in "postboom noise" of less than 0.1 Pa (74 dB SPL). In addition, we needed a flexible, expandable instrumentation system to handle a variety of microphones and accelerometers with different setups for different channels. Reliability was very important because flight tests are costly, last up to one hour, require multiple simultaneously sampling channels, and need real-time monitoring and data review. The system also needed to be convenient to use. Postrecording data extraction and analysis were important because only a portion of the data recorded is useful and we needed to time stamp and align data obtained with different systems at different locations.

Hardware

We chose an NI PXI system with a variety of modules to meet our requirements. We chose the NI PXI-4472B dynamic signal acquisition (DSA) module to acquire data from the microphones and accelerometers due to its high resolution and wide dynamic range, low cut-off frequency (0.5 Hz for AC coupling) for recording infrasound, and software-configurable AC/DC coupling and integrated electronic piezoelectric (IEPE) conditioning. G.R.A.S Type 40AZ 1/2" free-field microphone systems used were customized for optimal frequency response in the infrasound range down to 0.09 Hz. The NI PXI-6682 timing and synchronization module provided synchronization via GPS, along with the NI PXI-6652, to the DSA modules. We also chose an NI controller to provide high-speed data streaming via a RAID 0 configuration as well as the high capacity needed for recording 16 channels for up to one hour.

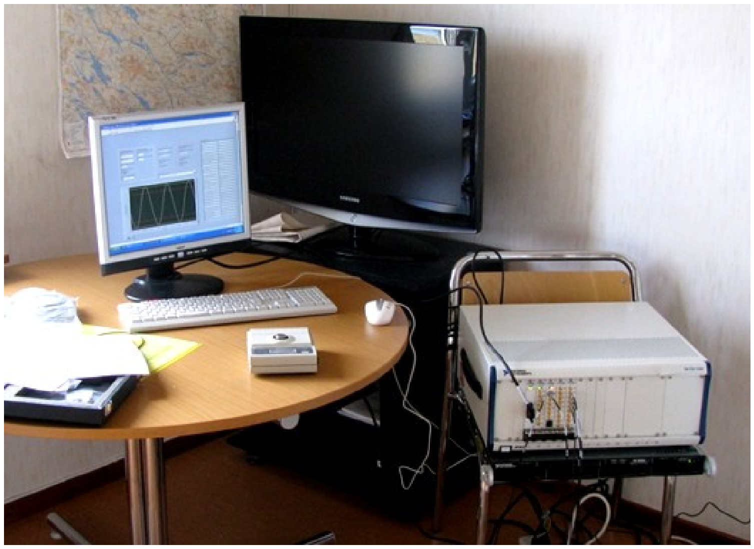

Figure 3. *PXI System in Test Building*

Software

LabVIEW and the NI Sound and Vibration Measurement Suite provided an effective tool for developing our solution. The system provided quick setup, data logging, real-time monitoring, and data review. The setup screen tab provided a detailed setup for each channel along with transducer information. We chose to use Technical Data Management Streaming (TDMS) as the most effective binary format suitable for multichannel long recording. We used TDMS to quickly review data right after each test and modify flight/measurement conditions for the next trial.

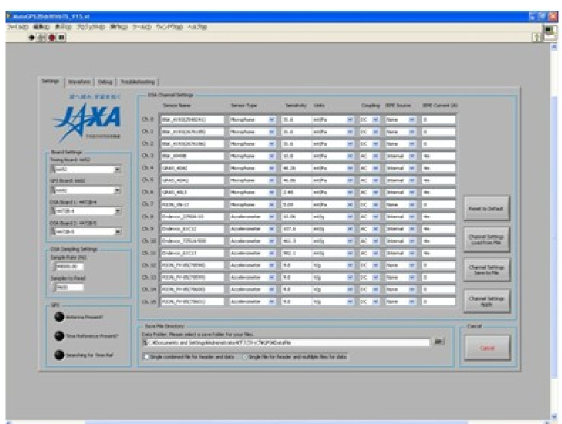

Figure 4. *Channel Setup Tab*

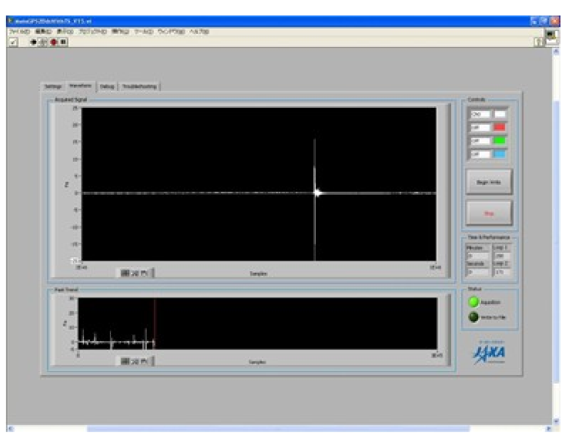

Figure 5. *Real-Time Monitoring Tab*

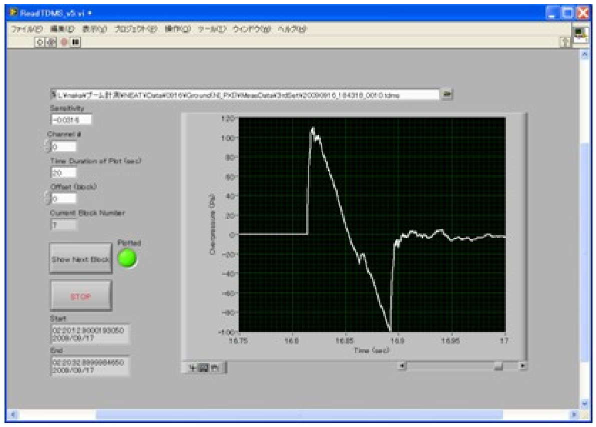

Figure 6. *Quick Review of TDMS Data*

We validated the system by measuring actual sonic booms from supersonic aircraft at the Northern European Aerospace Test range in Sweden in September 2009. The objectives were to verify the measurement system and identify appropriate transducers and setups during five flyovers and three flight conditions. For the tests, the aircraft flew at a maximum altitude of 14 km (approximately 46,000 ft) and a minimum of 6 km (approximately 20,000 ft). The overpressure of the sonic boom heard inside the test building was about one-fourth of that heard outside. Recent research shows that the sonic boom from current aircraft heard inside a building can cause significant annoyance because of the rattling noise and building vibration. After experiencing the noise and vibration, we recognized that we must further study the effects of sonic booms not only outdoors but indoors as well.

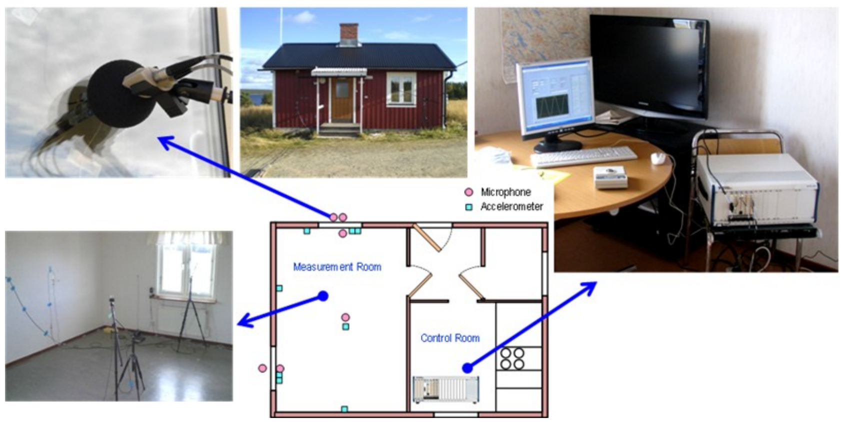

Figure 7. *Test Setup for Sonic Boom Ground Test*

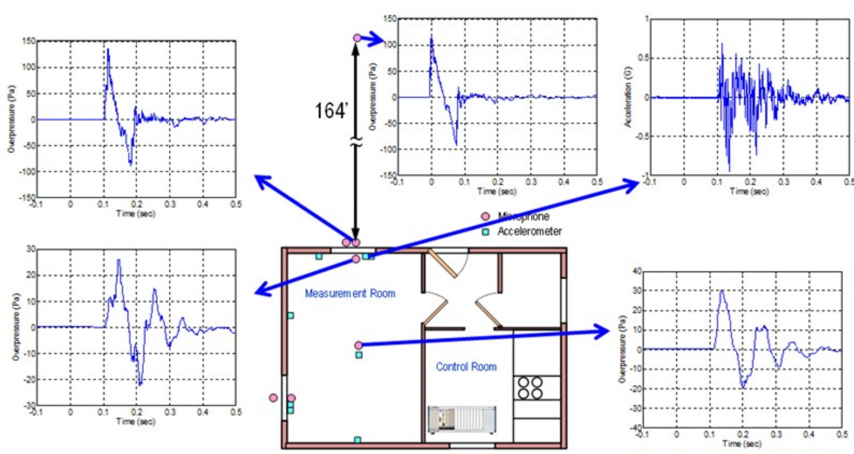

Figure 8. Measured Data From Flight Tests

Our tests in Sweden validated that the measurement system can measure sonic booms and works well with a variety of microphones optimized for infrasound measurements.

We chose LabVIEW and PXI because of their accuracy, flexibility, reliability, convenience, and cost-effectiveness. We worked closely with National Instruments sound and vibration specialists to develop the system and with onsite technical support to develop the software. The ground-based measurement system will be expanded to include an aerial measurement system distributed at altitudes up to 1,000 m to reduce the effects of atmospheric turbulence. This system will be based on stand-alone computers controlled via wireless LAN distributed aloft with a 4-channel NI USB-9234 C Series DSA module for making high-accuracy audio frequency measurements. We hope to accelerate the development of civil supersonic aircraft by demonstrating the low-boom design technology in our planned drop test.

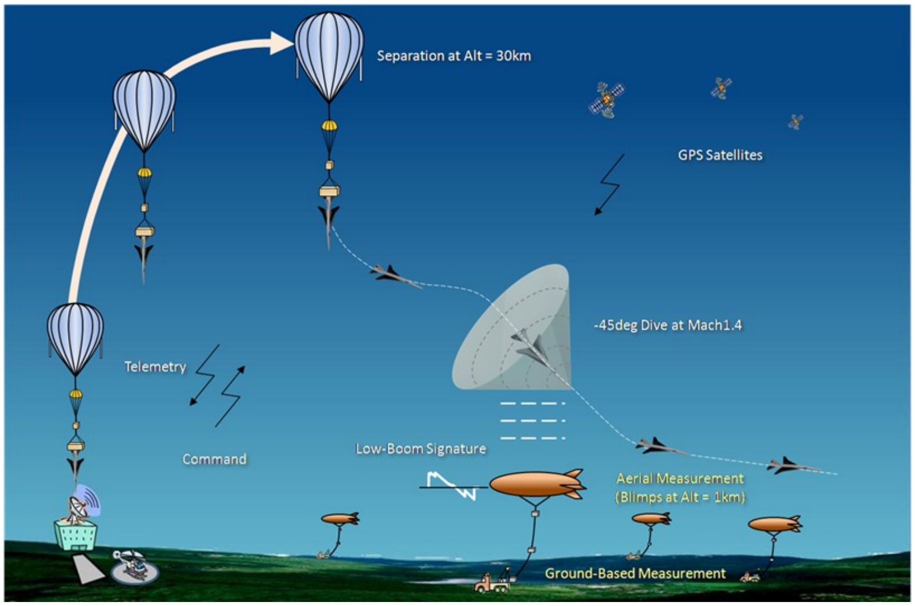

Figure 9. *Test Setup for Drop Testing With Validated Instrumentation System*

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Figure 1. D-SEND No. 2 Test Model

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