Development of a Sonic Boom Measurement System at JAXA

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Agenda

• Background
• Requirements for Measurement System
• Development of Measurement System
• Flight Test
• Summary
Supersonic Transport Research at JAXA

NEXST (National Experimental SST) Tech. R&D Program


S-cube (Silent SuperSonic) Tech. R&D Program

S3TD (Silent Supersonic Technology Demonstrator)

D-SEND (Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom)

1st Drop Test (D-SEND #1)

2nd Drop Test (D-SEND #2)

Feasibility Study

Development

Planning of New Flight Demonstration Project

Cancelled

Jet-Powered T/O and Land

Jet-Powered Air Launch

NEXST-1

NEXST-2

Non-powered Rocket Launch

Planning of New Flight Demonstration Project

Modification/Improvements

First Trial – Failure

Second Trial - Success

Technologies for Economically Viable and Environmentally Friendly

ni.com
D-SEND Program

- **Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom**

- **Objective**
  - To validate JAXA’s aircraft design concepts for sonic boom mitigation.

- **Test Procedure**
  - Drop test models with and without “low-boom” design
  - Measure sonic booms on and above the ground
D-SEND #1 (Spring, 2011)
D-SEND #2 Test Model

- $W = 1000 \text{ kg}$
- $L \times \text{Dia.} \times \text{Span} = 7.7 \text{ m} \times 0.48 \text{ m} \times 3.5 \text{ m}$
- $\text{Span} = 3.5 \text{ m}$
- $CL = 0.12 \ (M = 1.4, \ H = 8 \text{ km})$
- $\text{Swing} = 4.92 \text{ m}^2$
- EGI (INS+GPS)
D-SEND #2 (Summer, 2013)
Measuring Sonic Booms

- Accurate measurement of sonic boom
  - Key technology for D-SEND Program

- Special requirements for measurement system
  - Unique acoustic characteristics of sonic booms
What is a Sonic Boom?

• Shock wave created from aircraft flying at a supersonic speed

• Impulsive, loud noise similar to explosion

• Supersonic flights over land currently banned due to sonic booms

• Reduction of sonic booms be necessary for next-gen. SST
Acoustic Properties of Sonic Boom

• Wide Frequency Range
  - Overall infrasonic components < 1 Hz
  - Rapid pressure rises > 10 kHz

• Wide Dynamic Range
  - Large pressure > 200 Pa (140 dB SPL)
  - Small pressure fluctuation in “post-boom noise” < 0.1 Pa (74 dB SPL)

• Transient Noise
  - Short duration < 0.3 sec
Requirements for Sonic-Boom Measurement System

- Accuracy
- Flexibility
- Reliability
- Convenience
Requirement: Accuracy

- Need to capture sonic-boom pressure time histories in detail
  - Wide range of frequency
    - 0.5 – 10,000 Hz
  - Wide dynamic range
    - 0.1 – 200 Pa
Requirement: Flexibility

• Need to use various types of transducers
  ▪ Microphones and accelerometers
  ▪ Different set-ups for different channels
    • AC- and DC-couplings
    • With and without IEPE excitation
  ▪ Ability to increase the number of channels
Requirement: Reliability

- Need to record sonic booms without fail
  - Flight test be costly
  - Long continuous recording
    - Up to 1 hr
  - Multiple channels with simultaneous sampling
    - 16 ch, 48-kHz sampling rate
  - Real-time monitoring
  - Quick review of recorded data
Requirement: Convenience

• Need to use/analyze recorded data afterward
  ▪ Post-recording data extraction and analysis
    • Only a portion of recorded data is useful
  ▪ Time stamping
    • Time alignment with data obtained with different systems set at different locations, e.g. aircraft position data.
Solution: Hardware

- NI PXI System
  - Wide variety of modules to meet requirements
    - NI 8353
    - NI PXI-1044
    - NI PXI-8360
    - NI PXI-6652
    - NI PXI-6682
    - NI PXI-4472B
Hardware Solution: Input Module

- NI PXI-4472B
  - High resolution: 24-bit ADCs
  - Wide dynamic range: 110 dB
  - Low cut-off frequency: 0.5 Hz for AC coupling
  - Software-configurable AC/DC coupling and IEPE conditioning
Hardware Solution: Timing Modules

- NI PXI-6652 & NI PXI-6682
  - Synchronize PXI systems using GPS antenna
Hardware Solution: Controller & Interface

- **NI 8353**
  - High-speed data streaming: RAID 0 configuration
  - Large-capacity storage: 4 x 250 GB HDD

- **NI PXI-PCIe8362**
  - MXI 4 High-throughput: Up to 160 MB/s
Software Solution: LabVIEW

- **Set-up**
  - Detailed set-up for each channel
  - Transducer information
- **Control Measurement**
  - Effective binary format of TDMS suitable for multi-channel, long recording
- **Real-time monitoring**
Software Solution: LabVIEW

• Quick review of recorded data
  ▪ Can check recorded data right after each flight.
  ▪ Can modify flight/measurement conditions for the next trial.

• Post-recording data analysis
  ▪ Variety of analysis functions of Sound and Vibration add-on.
Preliminary Flight Test

• Overview
  ▪ Measured sonic booms of actual supersonic aircraft (i.e. not research aircraft/model)
  ▪ September, 2009 in Sweden.

• Objectives
  ▪ To verify preliminary sonic-boom measurement system
  ▪ To identify appropriate transducers and set-ups

• Flights
  ▪ 5 flyovers
  ▪ 3 flight conditions
Flight Test: Measurement Scheme

• On the ground, measured:
  ▪ Sonic booms outdoors
  ▪ Sonic booms indoors
  ▪ Vibration of windows and walls of building

• Above the ground, measured:
  ▪ Sonic booms at altitude of 3,300 ft
Flight Test: Instruments Set-Up
Flight Test: Measured Data

![Graphs showing measurements of overpressure and acceleration over time.](image-url)
Summary

• Sonic boom measurement system has been developed at JAXA.

• The system is based on NI PXI system and LabVIEW.

• Preliminary measurement system has been validated in flight test.
Summary

• NI PXI system and LabVIEW chosen because of their:
  ▪ Accuracy
  ▪ Flexibility
  ▪ Reliability
  ▪ Convenience
  ▪ Cost effectiveness

• System developed with close relationship with NI staff
  ▪ Consulting by specialist in sound and vibration applications
  ▪ Knowledge and know-how from world-wide network
  ▪ On-site technical support in software development
Future Test Schedule

• 2nd preliminary flight test (September 2010)

• D-SEND #1 (Spring 2011)

• D-SEND #2 (Summer 2013)
Expansion Plan

• Apply NI products to aerial measurement
  - New input module in development
    • Suitable for sonic boom measurement
      ▪ 0.12 Hz cut-off for AC-coupling
      ▪ 24-bit resolution
    • Suitable for aerial measurement
      ▪ Compact and light-weight
      ▪ No external power supply needed. (USB bus-powered)
  - Low Frequency Microphone: GRAS 40 AZ-S1
    • 0.09 Hz cut-off
    • IEPE-type microphone
Tentative Expansion Plan

- Compact, stand-alone systems distributed.
- Executable LabVIEW program in each PC.
- Controlled via wireless LAN.
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