Recent Progress on Sonic Boom Modeling Research at NASA

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NASA Langley

NASA Dryden
What are we trying to do?
Understand the impact of sonic booms from new low-boom aircraft designs on community residents

What is our approach?
- **Atmospheric Propagation**: Develop more accurate sonic boom propagation models
- **Structural Response & Modeling**: Examine sonic boom transmission into small and large structures
- **Human Response & Modeling**: Develop psychoacoustic model of human response to low booms (both outdoors and indoors) for single and multiple events
- Work cooperatively with regulators (FAA, ICAO) and other researchers (industry, academia, JAXA, others)

What are the payoffs if we are successful?
- Replace current prohibition of civil supersonic overland flight with a noise-based standard for aircraft certification
## Research Activities

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<td>FY07</td>
<td>SonicBOBS I</td>
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### Flight Tests
- LASB
- Rattle
- Struct Tx

### Other Field Tests
- IER Design
- IER Construction
- Operational IER
- IVT
- BLT
- IER Tests
- GNBRT 1-3
- Rattle Mod
- Val High Freq Bldg Tx Model
- Val Low Freq Bldg Tx Model
- SB Prop Mod
- Val Full Freq Bldg Tx Model
- Val SB Prop Mod
- Predictive Capability for SB Impact

### Laboratory Tests
- Val PsychoAcs Mod for Single SB
- Struct Comm Model
- Prelim Mod for Comm Resp Low Booms
- Val Mod for Comm Resp Low Booms

### Model Dev.
- SB Bldg Vib and Acs Database
- Val Low Freq Bldg Tx Model
- SB Prop Mod
- Val Full Freq Bldg Tx Model
- Val SB Prop Mod
- Predictive Capability for SB Impact
Technical Highlights

- Focus Boom Flight Test
- Interior Effects Room (IER) Subjective Tests
- Community Response Flight Test
- Structural Response & Modeling
Focus Boom Flight Test
SCAMP Introduction

- **Superboom Caustic Analysis and Measurement Project**
  - Objective: Validate models for prediction of focus booms
  - NRA award to Wyle Laboratories in 2010
  - Flight test May 9-20, 2011
  - F-18 performing acceleration and dive maneuvers
  - Large ground microphone array (81 mics) in remote desert location
  - Microphones on TG-14 motorized glider and tethered blimp
  - Weather data

- Extensive collaborative work
  - 11 NASA/Industry teams on site for acoustic measurements
What is a focus boom?

- Focusing of sound rays
- Due to accelerations or other maneuvers

Why do we care?

- Boom amplitude much higher than from cruise
- Unavoidable during accel to supersonic speed
- Need to evaluate focus boom from future low-boom aircraft
- Acceptability of overland supersonic flight
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Test Results

- 2 weeks of testing
- 13 Flights, 70 array passes
- 37 focus booms recorded
- $P_{\text{max}} = 7-8$ psf ($\sim 4P_{\text{max}}$ cruise boom)

Example Data

Uptrack

Focus

Downtack
Preliminary Predictions

- Comparisons of flight data to 1st generation predictions from 4 codes this week
- Final versions of codes in Summer 2012
- Predictions of focus booms from low-boom vehicle designs
Interior Effects Room (IER) Subjective Tests
Psychoacoustic Testing

Develop psychoacoustic model of human response to low booms (both outdoors and indoors) for single and multiple events.

<table>
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<th>Field Test</th>
<th>Laboratory Test</th>
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<td>Realism</td>
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<td>Control</td>
<td>Control</td>
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- **Realistic boom exposure**
  - Levels
  - Time period
- **People in real communities**
- **Absolute annoyance**

- **Isolate effects of**
  - loudness
  - rattle
  - vibration
  - room acoustics
  - visual cues
  - ambient noise

- **Relative rather than absolute annoyance**
Objective

• Assess human response to sonic booms experienced indoors

• Investigate response to simulated booms from new low-boom aircraft designs

Approach

• Controlled and repeatable tests

• Realistic living room environment

• Realistic low-frequency reproduction and transmission of sonic booms

Significance

• Will ultimately lead to a psychoacoustic model of human response to single sonic booms indoors

• Complement community studies and previous lab tests
Two IER Subjective Tests

Objectives

1) Systematically vary spectral content of sonic boom test sounds
2) Does indoor annoyance increase with loudness?
3) Is rise time inversely related to annoyance indoors?
4) What is acoustical variation across listener locations?
5) Evaluate performance of loudness/sound quality metrics to predict indoor annoyance to sonic booms
Test Method

• 30 subjects for each test
  – 3 subjects tested at a time
  – All subjects repeated test at all 3 locations in Test 1
• Test signals
  – Synthesized waveforms
  – Field measurements
• Paired comparison to a reference
  – Each pair presented in two orders A-B and B-A
  – Signal levels varied
  – Level of each signal equally annoying as reference

If the first sound is more annoying depress the button labeled 'First'.
If the second sound is more annoying depress the button labeled 'Second'.

First
Second

X
IER Test Summary

1) New method devised to design boom-like sounds with varied spectral content

2) Does indoor annoyance increase with loudness? Yes

3) Is rise time inversely related to annoyance indoors? Yes

4) What is variation in loudness across listener locations? ≤7 dB
   - Test method must account for variation or locations must be changed to decrease variation
   - Listener locations 1-4-5 give more uniform exposure than 1-2-3

5) Evaluate performance of loudness/sound quality metrics: best metrics identified
   - No loudness metric predicts annoyance to indoor signals better than PL

6) Vibration contributes to annoyance

New facility validated as a laboratory research tool for studying indoor human response to sonic booms
Community Response Flight Test
WSPR Introduction

Pilot test of community response to multiple low-boom events using F-18 dive maneuver and residents accustomed to booms

- **Waveforms and Sonic boom Perception and Response**
  - 2 NRA Contract awards: Wyle Laboratories and Fidell
  - Design and execute an experiment at EAFB to gather data relating the impact of sonic boom exposure to EAFB community residents

- Develop experimental methodologies
  - Annoyance survey methods
  - Acoustic data acquisition
  - Analysis methods

- Prepare for future community studies
Test Design

- Experimental design
  - Noise exposure
  - 100+ residents at EAFB
  - Subjective survey methods
    - Paper/pencil
    - Website
    - Smartphone
- Data collection
  - Sonic boom measurements throughout community
  - Residents fill out a survey each time they hear a boom
  - Residents fill out a daily survey
- Two weeks in Nov. 2011
- 3 low-boom target levels: 0.1, 0.3, 0.5 psf
- 3-10 booms/day
  - Morning and afternoon
Structural Response & Modeling
Daily Sonic Boom Exposure in 2040 (Wyle)
Path Towards Regulation Change

Relating indoors to outdoors:

**Indoor Annoyance Model**

- Notional

**Indoor Exposure**

- Notional

**Going from indoors to outdoors:**

**NASA**
- Defining exposure probability density function (structural acoustic problem)
- Defining indoor (and outdoor) metrics (psychoacoustic problem)

**Regulators**
- Defining an acceptable indoor level
- Defining an acceptable indoor exposure probability

Different buildings respond differently.
Structural Response Research Goal

Validate and use prediction tools to create a probability density function representing indoor community exposure.
Key FY12 Activities

- Atmospheric Propagation
  - Analysis of focus boom flight test and model development (SCAMP)

- Structural Response & Modeling
  - Apply structural models to IER

- Human Response & Modeling
  - Low boom community response test (WSPR), Nov 2011
  - Additional subjective tests in Interior Effects Room
Backup Slides
Low-Boom Dive Maneuver

- Sonic boom is generated during supersonic dive of an F/A 18 aircraft (Dryden operated)
- Boom propagates very far, attenuating before reaching the building
- Boom amplitude is adjusted by moving dive location relative to the building

NASA Dryden low boom maneuver

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