Development of Metrics and Models for Assessing Community Response to Supersonic En Route Noise

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Acknowledgments

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- Sonic Boom Community Response team
  - Larry Cliatt
  - Ed Haering
  - Jake Klos
  - Jonathan Rathsam
  - Jerry Rouse
  - Kevin Shepherd
Introduction

• Vision
  – A noise-based standard for aircraft certification to replace current prohibition of civil supersonic overland flight
  – Technologies that enable development of a new generation of supersonic aircraft

• Scope
  – Civil supersonic aircraft: business class to supersonic airliners

• NASA’s focus area
  – Develop tools and integrated concepts that will enable demonstration of overland supersonic flight with acceptable sonic boom

• Need for metrics and models for predicting community response to supersonic en route noise
Building a Dose-Response Relationship

- Proposed series of community studies in U.S.
  - Supersonic overflight of communities using a quiet supersonic technology aircraft
- Quantify estimated noise dose
- Survey residents on annoyance to sonic booms
  - Annoyance to single events (individual booms)
  - Annoyance over several events (daily)
- Combine data from different communities to build a dose-response relationship

![Graph showing dose-response relationship](image)
Atmospheric Propagation

Dose-response relationship

Range of exposure extrapolated from propagation predictions
Atmospheric Propagation

• Research on several effects that contribute to variations in sonic boom levels on the ground
  – Edge of the carpet (lateral cutoff)
  – Low Mach cutoff
  – Transition focus boom

• Current investigations
  – Atmospheric turbulence (Wyle)

• Proposed future research
  – Secondary sonic booms

• Research includes
  – Flight tests to compile specialized databases
  – Model development
  – Model validation
  – Application of models to shaped booms

POC: Ed Haering and Larry Cliatt
Community Exposure Models

Dose-response relationship

% Annoyed

Noise Metric

Range of exposure extrapolated from structural investigations
Community Exposure Models

- Recent advances in modeling and simulation to define what people would hear/experience in communities due to supersonic overflight

- Outdoors near buildings
  - Variations with location
  - Number of buildings
  - Incidence and azimuthal angle of sonic boom

- Inside buildings
  - Variations with building design
  - Number of buildings
  - Location inside building
  - Incidence and azimuthal angle of sonic boom

POC: Jake Klos and Jerry Rouse
Community Exposure Models

- Rural, suburban, and urban environments
  - Exterior loading, transmission, and interior acoustic field
  - Role of diffraction

- Prefer geometrical acoustics approach for computational efficiency

- Explore more complex methods to determine when diffraction effects are important

POC: Jake Klos and Jerry Rouse

Asheim and Svensson, JASA 2013
Urban Community Exposure Models

- Urban settings
  - Exterior environment and loading modeled using BEM
  - Exact wave-based method (includes diffraction)

\[ P_{total} - (P_{inc} + P_{images}) = P_{diffraction} \]

- Calculations have been verified with other methods
- Optimized by modifying elements to improve the rate of convergence

POC: Jerry Rouse
Urban Community Exposure Models

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POC: Jerry Rouse
Indoor Exposure Predictions

- Transmission indoors predicted with a transient modal interaction model
- Acoustics and vibration exposure inside houses is predicted
- Numerical design of experiment conducted to identify factors that contribute to variation in indoor exposure
  - 1.3 million house-source combinations
    - Floor plans
    - Construction details
    - Material properties
    - Rural vs. suburban (neighboring houses)
    - Aircraft concepts
    - Incidence azimuthal and elevation angles
  - Window construction and acoustic damping are significant

Variations of the physical properties of the houses
Variations in the exterior loading

POC: Jake Klos
Indoor Exposure Predictions

- Modeling of notional rural communities
  - Variation in PL between communities may be somewhat small (3 dB)
  - Variation in PL within a single community may be larger

<table>
<thead>
<tr>
<th>Community A vs. B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Community A:</strong></td>
</tr>
<tr>
<td>Rural, larger houses, sturdier construction, more heavily damped</td>
</tr>
<tr>
<td><strong>Community B:</strong></td>
</tr>
<tr>
<td>Rural, smaller houses, less sturdy construction, more lightly damped</td>
</tr>
</tbody>
</table>

- Differences in indoor levels between rural and suburban settings are small (< 1 dB on average)

POC: Jake Klos
Floor Vibration Exposure Predictions

- Estimated vibration exposure in houses for a variety of aircraft
  - Low boom exposure ranges from imperceptible to perceptible

- Favorable comparison of predictions to test of conventional military aircraft

- Floor vibration is likely higher than what a person would experience directly

POC: Jake Klos
Human Perception Research

Dose-response relationship

% Annoyed

Noise Metric
Human Perception Studies

- Understand how annoyance is related to sonic boom spectrum, level, rattle, and vibration

- Sonic boom simulators
  - Accurate reproduction of sonic boom noise
  - Consistent, repeatable test conditions
  - Wide variety of signature shapes and levels
  - Simulate sonic boom noise, rattle, and vibration

- Studies to-date
  - Characteristics of waveform that contribute to indoor annoyance
  - Rattle is an important factor
  - Vibration also affects response
  - Aircraft size is not a significant factor (for boom alone, without rattle or vibration)

POC: Alexandra Loubeau and Jonathan Rathsam
Vibration Effects

- Two studies on effect of vibration on annoyance
- Vibration signal
  - Actuated by shakers mounted below chair seats
  - Levels chosen from 84\textsuperscript{th} and 99\textsuperscript{th} percentile vibration level predictions for a cross-section of houses
- “Vibration Penalty”: increment in sound level that yields same annoyance as including realistic vibration
  - 0-5 dB for lower vibration and 4-8 dB for higher vibration

POC: Jonathan Rathsam
Noise Metrics Evaluation

• Need for a noise metric that predicts human perception of booms experienced both outdoors and indoors
  – Conducted a study to evaluate noise metrics using existing data
  – Conducted in specialized labs at NASA Langley and JAXA
  – Emphasize human perception of booms indoors with metrics computed on outdoor booms

• Compiled an exhaustive list of metrics from standards and literature
• Chose 25 metrics for quantitative analysis

<table>
<thead>
<tr>
<th>Metric Name</th>
<th>NASA Indoor</th>
<th>NASA Outdoor</th>
<th>JAXA Full Data</th>
<th>JAXA Indoor Subset</th>
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</thead>
<tbody>
<tr>
<td>ISBAP</td>
<td>0.89</td>
<td>0.66</td>
<td>0.95</td>
<td>0.85</td>
</tr>
<tr>
<td>BSEL</td>
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<td>0.68</td>
<td>0.96</td>
<td>0.84</td>
</tr>
<tr>
<td>ESEL</td>
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<td>0.80</td>
<td>0.97</td>
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<tr>
<td>PL</td>
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<td>0.87</td>
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<td>0.74</td>
</tr>
<tr>
<td>ASEL</td>
<td>0.82</td>
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<td>0.96</td>
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<tr>
<td>$L_{ASMAX}$</td>
<td>0.82</td>
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<tr>
<td>PNL</td>
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<td>0.85</td>
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<td>0.71</td>
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</tbody>
</table>

* ISBAP = $a_0 + a_1 PL + a_2 (CSEL-ASEL)

Loubeau, Naka, Cook, Sparrow, Morgenstern, ISNA 2015

POC: Alexandra Loubeau
Noise Metrics Evaluation

• Collaborative effort has enabled comprehensive evaluation of sonic boom metrics

• Eight metrics are suggested for further study
  – Predict human response to sonic booms experienced both outdoor and indoors
  – Confirmed notion that outdoor metric can be used to predict human response indoors

• Plan to continue noise metrics evaluations
  – Additional analyses
  – Additional datasets may be needed
    • Studies that include secondary rattle sounds and vibration
  – New or modified metrics for better prediction of human perception are being developed

• Community studies will also be needed
  – Gather data in a realistic environment
  – Verify metric(s) selected from laboratory data analysis
  – This data can be given to regulators to choose a metric limit for certification

POC: Alexandra Loubeau
Community Response Research

Dose-response relationship

Data from community tests

Range of annoyance due to individual and community differences

% Annoyed

Noise Metric
Community Response Testing

- Community response data from a low-boom flight demonstration research program are needed to support international regulation.
- Conducted a preliminary test (2011) to develop and assess experimental methodologies, including noise exposure design, sonic boom data acquisition, subjective data collection, and data analysis.
- We have lessons learned from pilot study, but there is still more preparation needed.

POC: Alexandra Loubeau and Kevin Shepherd
Community Response Research

- Two contractor teams established to help plan future studies
  - Applied Physical Sciences (APS) and Fidell Associates

- Objectives
  - Conceptualize a sonic boom community response test campaign with a low-boom flight demonstration vehicle
  - Identify key risk and development requirements associated with the envisioned test
  - Propose risk reduction activities in priority areas that require further understanding or risk mitigation

POC: Alexandra Loubeau and Kevin Shepherd
Potential Near-Term Activities

- Conduct study in a non-acclimated community
  - Possibly use F-18 surrogate aircraft in low-boom dive maneuver

- Address several risk items
  - Improve objective and subjective data collection methods and analyses
  - Site selection
  - Regulatory processes and approval
  - Public/media education and legislative approvals

POC: Alexandra Loubeau and Kevin Shepherd
Summary

• Research is being conducted in several areas to develop the building blocks for a dose-response relationship
• Collaborations are contributing to efforts to estimate community response
• Current research will facilitate proposed future testing with low-boom aircraft in communities not familiar with sonic booms
• Predict potential impact of low-amplitude shaped booms on communities
• Critical element in support of goal of enabling overland supersonic flight
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