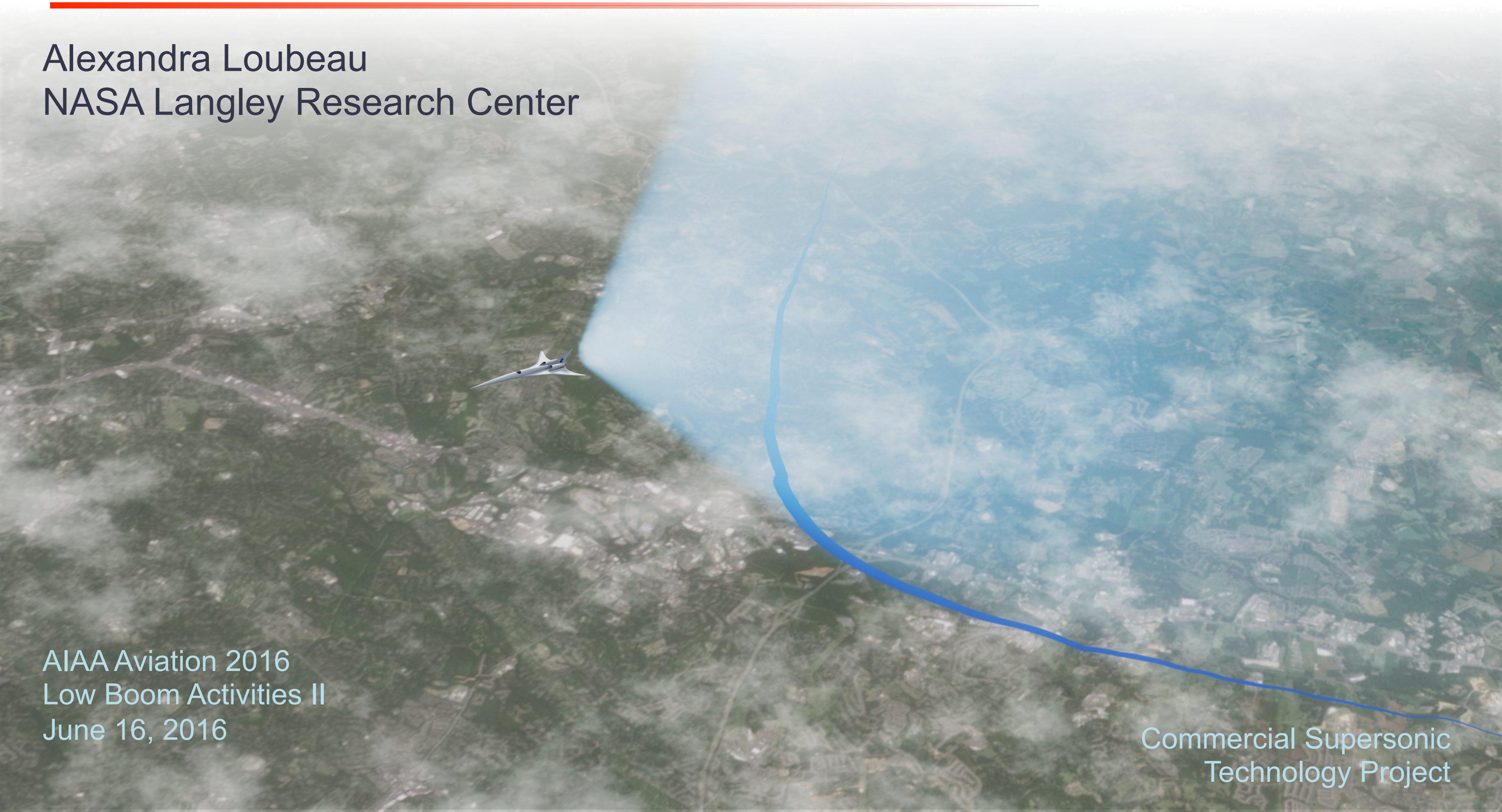
National Aeronautics and Space Administration

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



Alexandra Loubeau
NASA Langley Research Center

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Low Boom Activities II
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Commercial Supersonic Technology Project

Acknowledgments

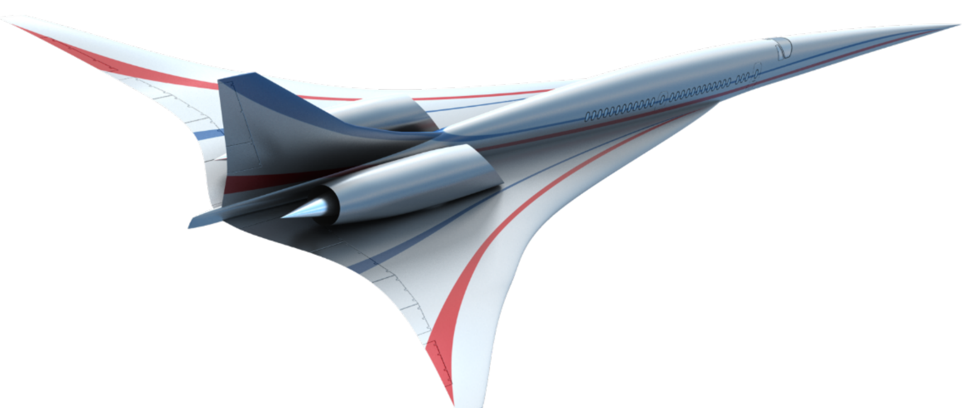
- Overland Supersonic Flight Sub-Project Manager: Brett Pauer

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

Introduction

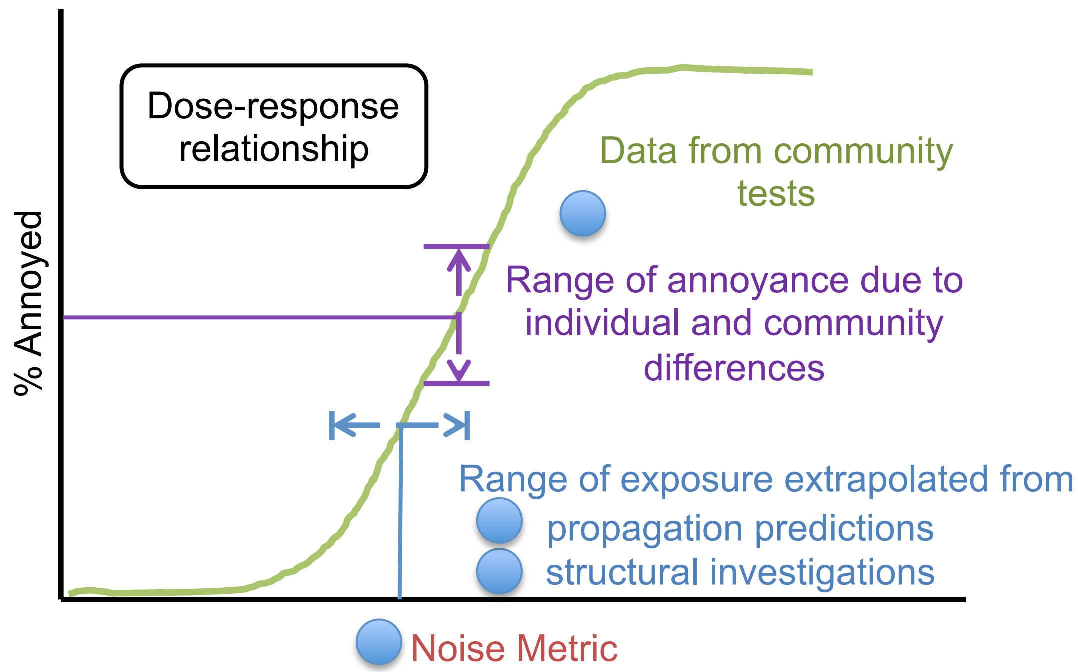
- Vision
  - A noise-based standard for aircraft certification to replace current prohibition of civil supersonic overland flight
  - Technologies that enable development of a new generation of supersonic aircraft
- Scope
  - Civil supersonic aircraft: business class to supersonic airliners
- NASA's 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

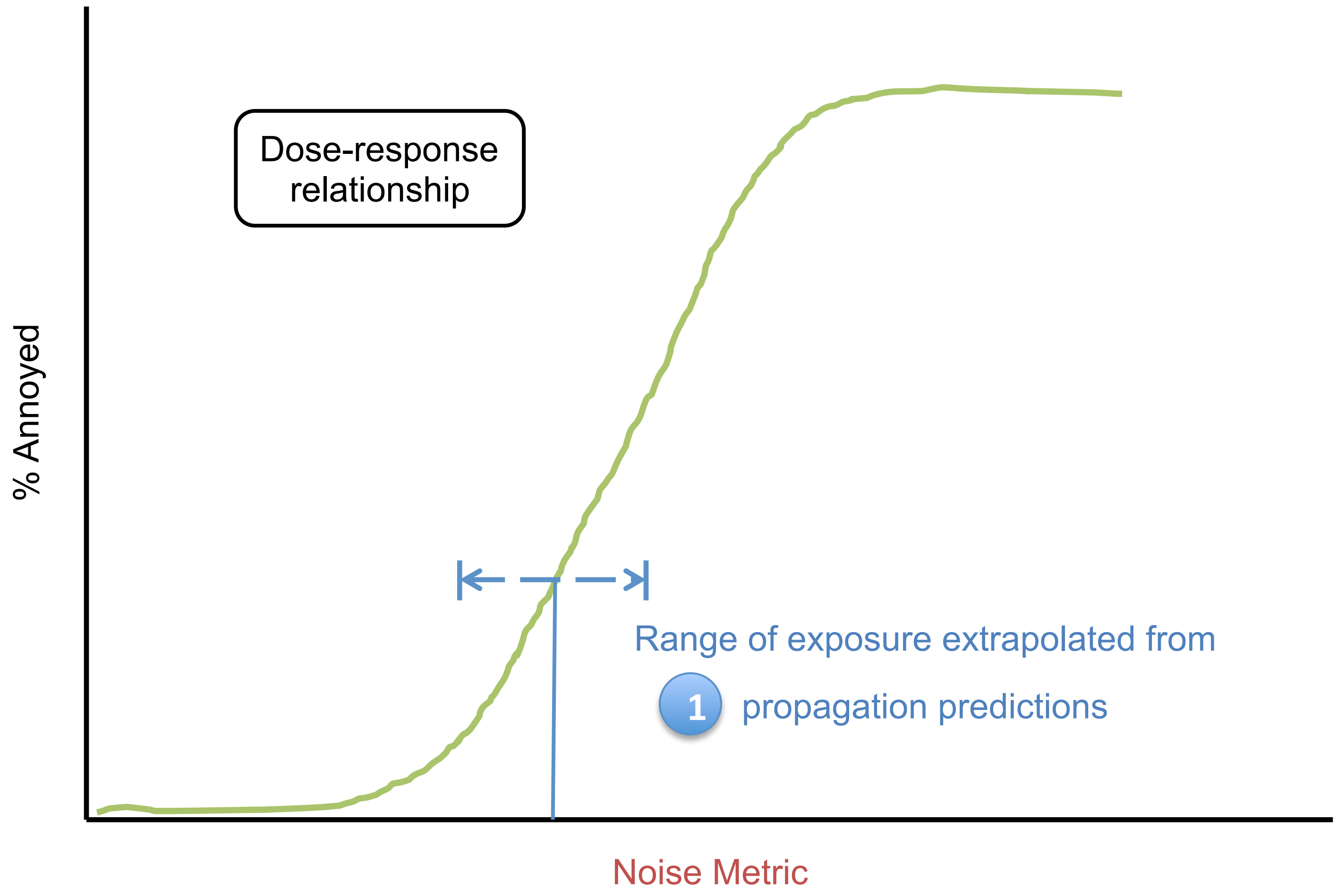


Building a Dose-Response Relationship

- 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

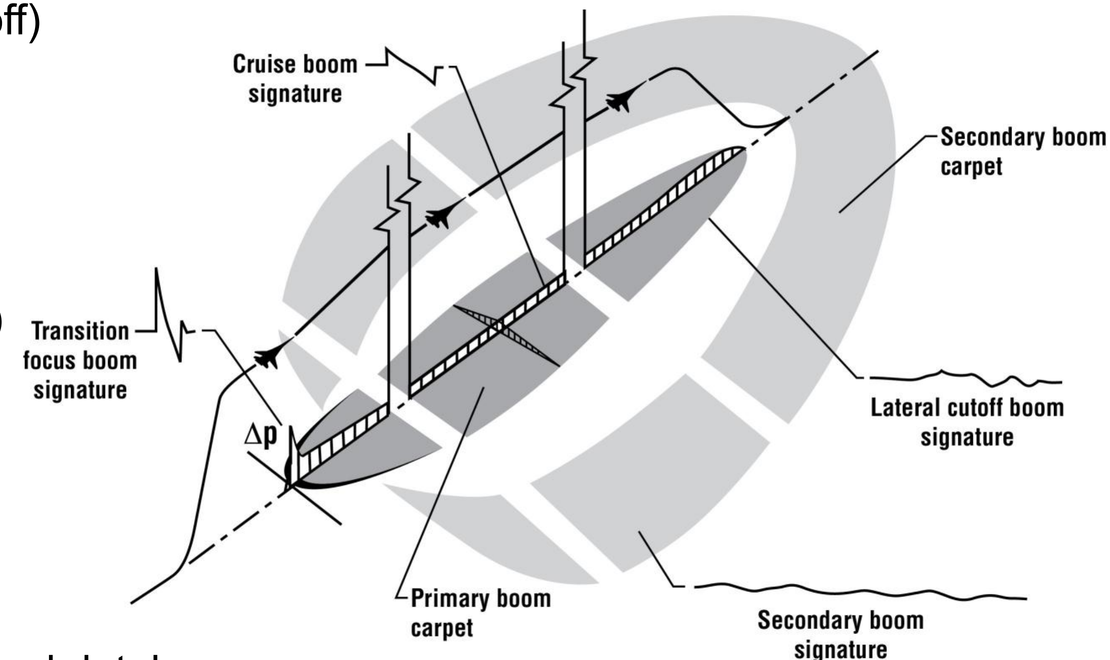


Atmospheric Propagation



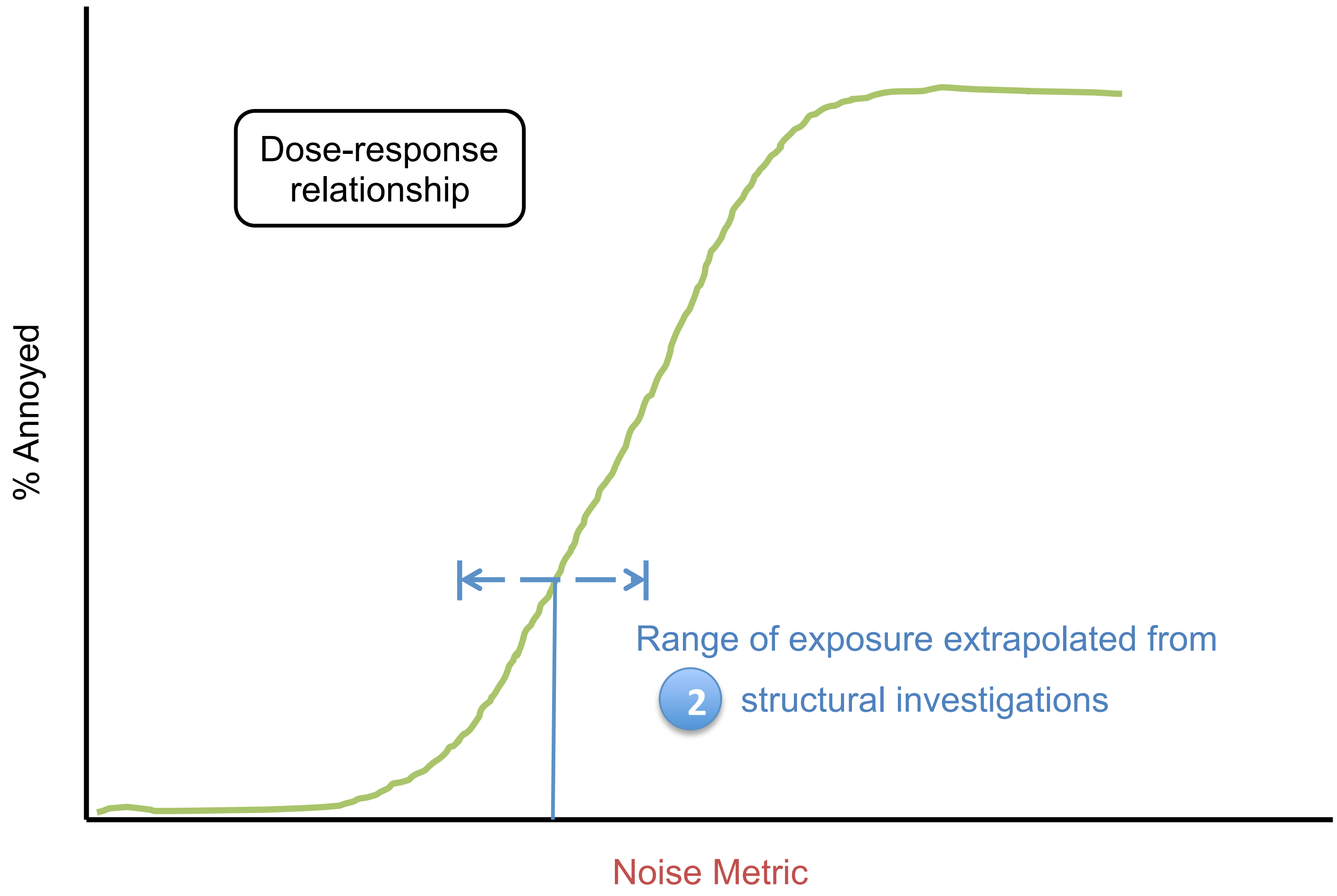
Atmospheric Propagation

- 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



Community Exposure Models

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

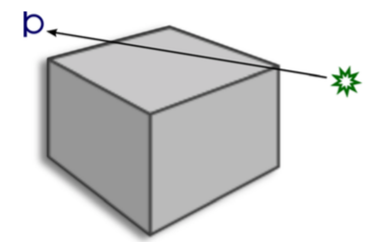
- Outdoors near buildings
  - Variations with location
  - Number of buildings
  - Incidence and azimuthal angle of sonic boom

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

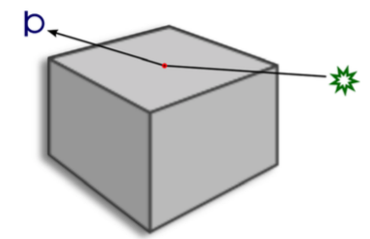
POC: Jake Klos and Jerry Rouse

Community Exposure Models

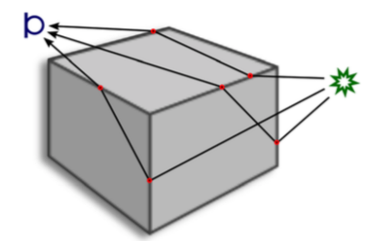
- Rural, suburban, and urban environments
  - Exterior loading, transmission, and interior acoustic field
  - Role of diffraction
- Prefer geometrical acoustics approach for computational efficiency
- Explore more complex methods to determine when diffraction effects are important



Direct Path



Reflection



Diffraction

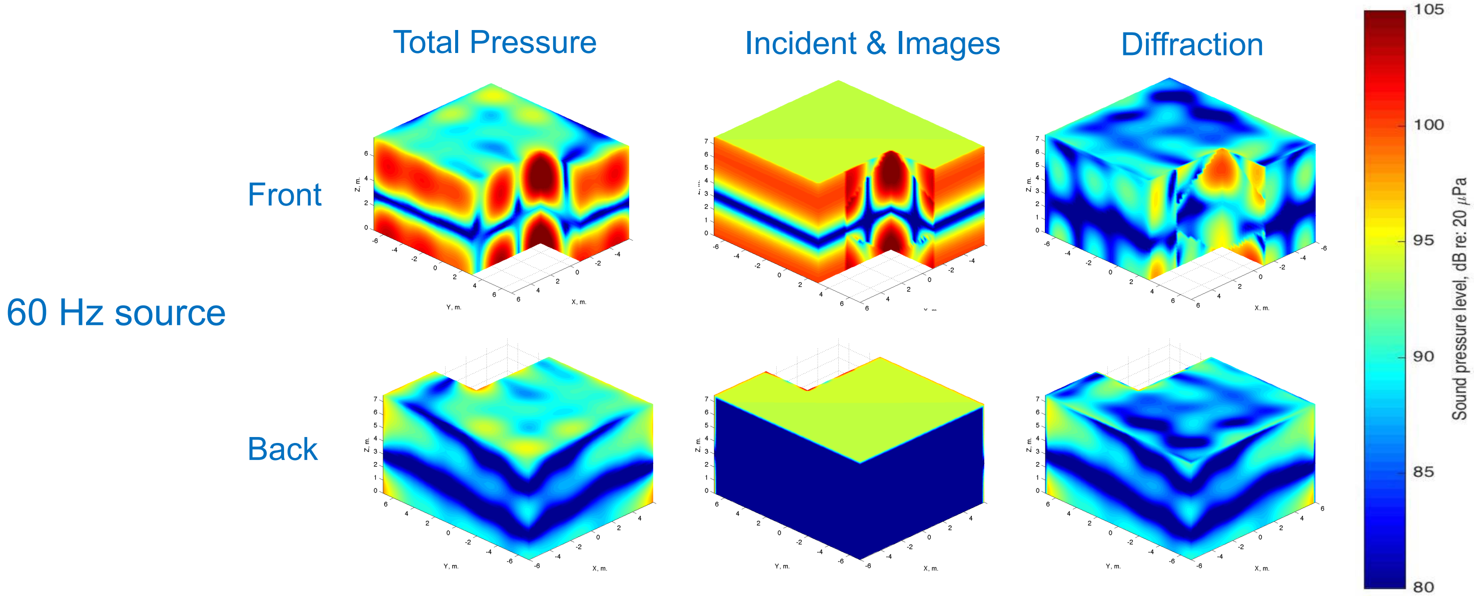
Asheim and Svensson, JASA 2013

POC: Jake Klos and Jerry Rouse

Urban Community Exposure Models

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

$$p_{total} - \left(p_{inc} + p_{images}\right) = p_{diffraction}$$



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

POC: Jerry Rouse

Urban Community Exposure Models

- Urban settings
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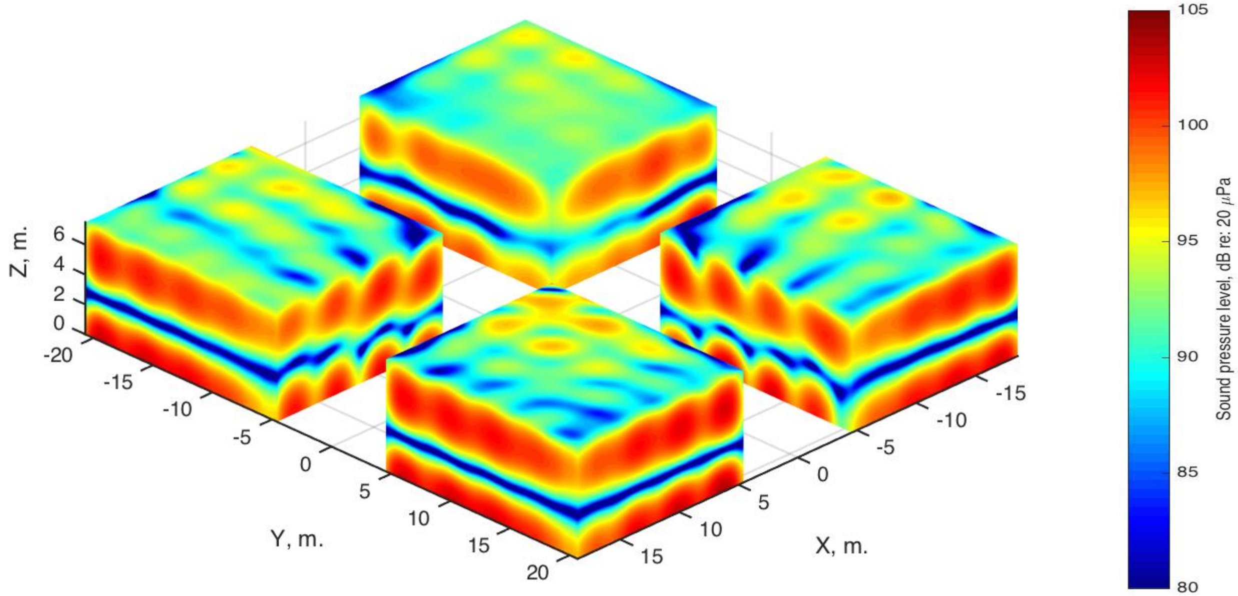
Total Pressure

60 Hz source



  - Calculations have been verified with other methods
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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

    Variations of the physical properties of the houses

    - Rural vs. suburban (neighboring houses)
    - Aircraft concepts
    - Incidence azimuthal and elevation angles

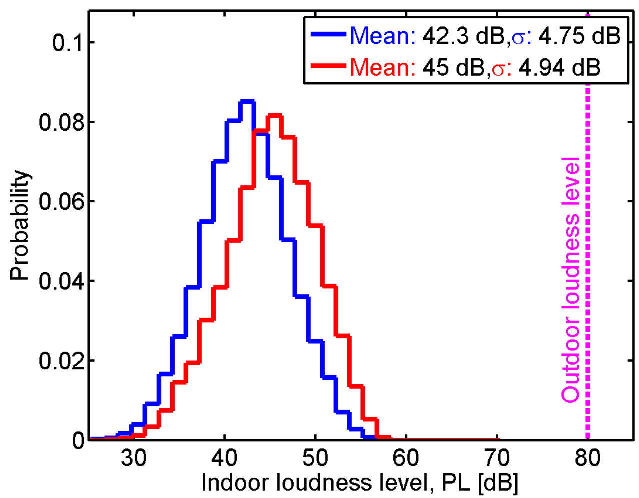
    Variations in the exterior loading
  - Window construction and acoustic damping are significant

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

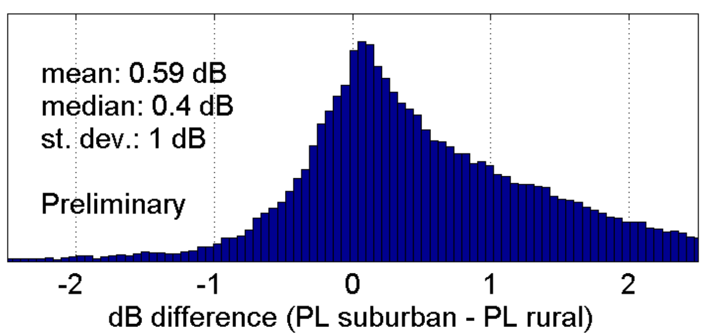
Community A vs. B



Community A:
Rural, larger houses, sturdier construction, more heavily damped

Community B:
Rural, smaller houses, less sturdy construction, more lightly damped

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



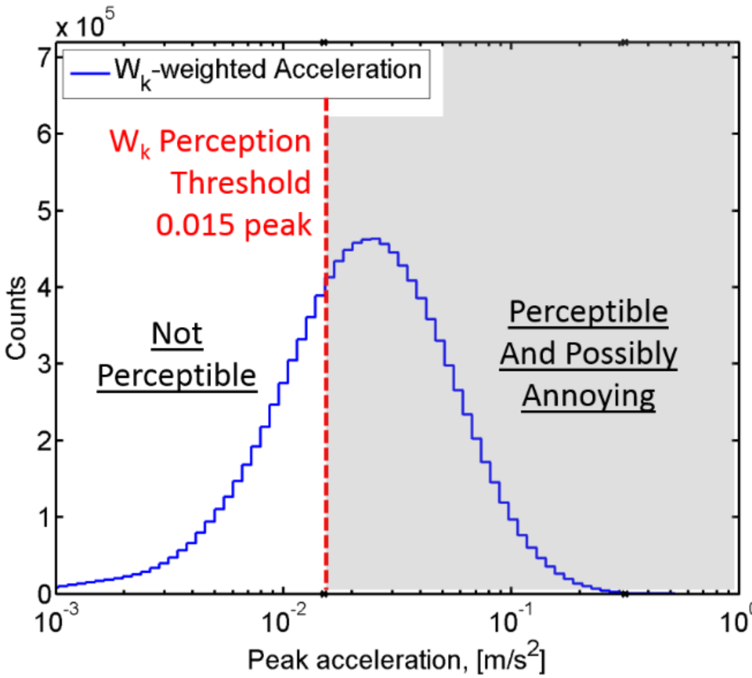
POC: Jake Klos

Floor Vibration Exposure Predictions

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

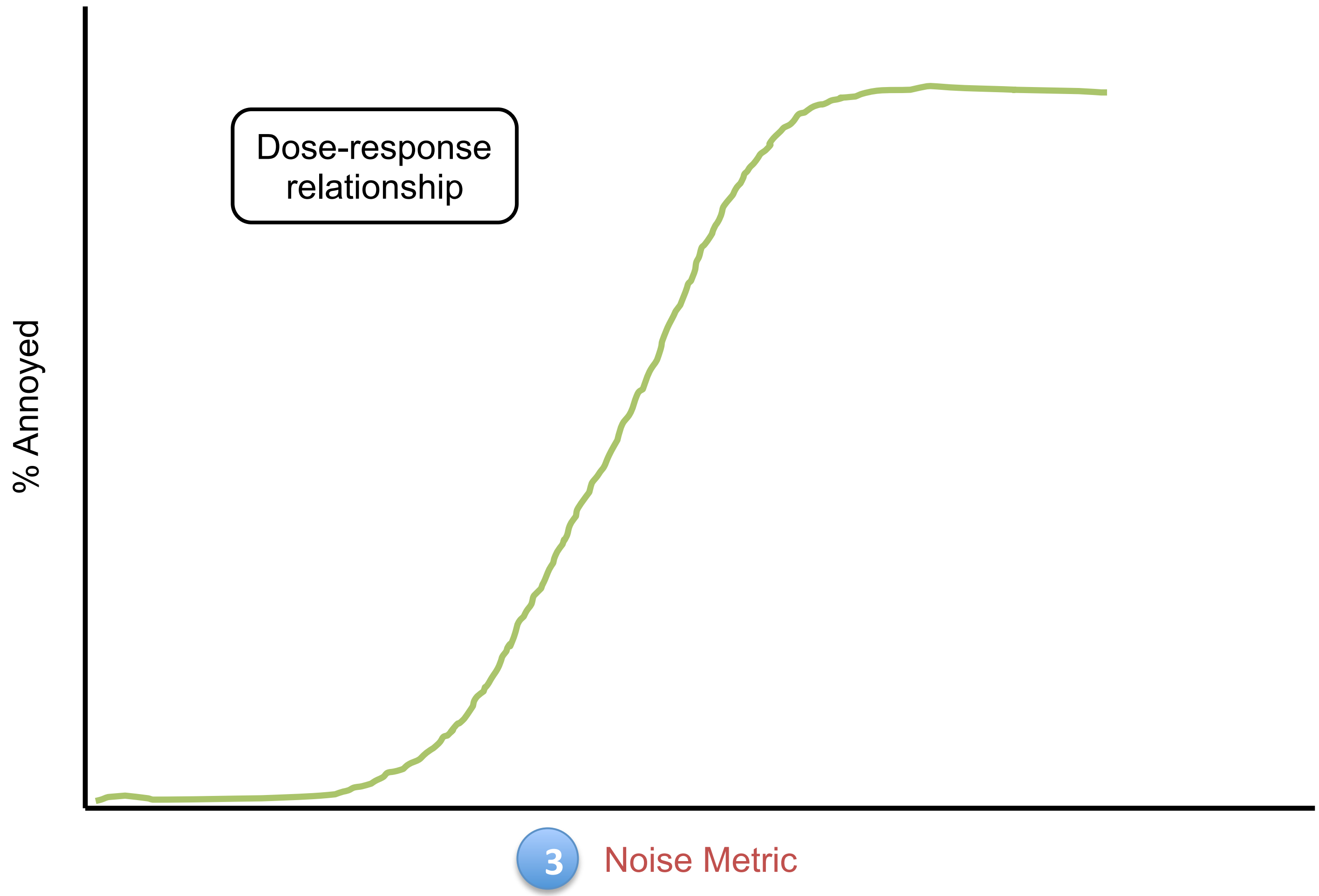
- Favorable comparison of predictions to test of conventional military aircraft

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



POC: Jake Klos

Human Perception Research



Human Perception Studies

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

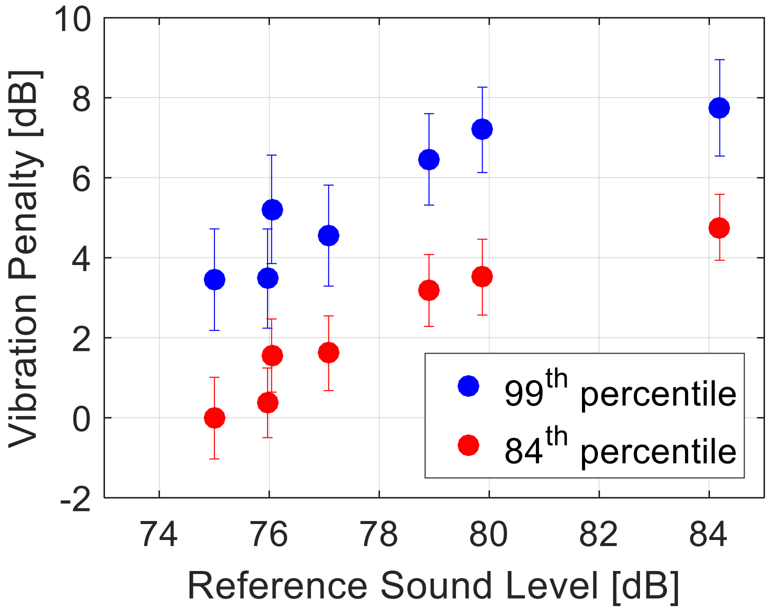
- Sonic boom simulators
  - Accurate reproduction of sonic boom noise
  - Consistent, repeatable test conditions
  - Wide variety of signature shapes and levels
  - Simulate sonic boom noise, rattle, and vibration

- 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 84th and 99th 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



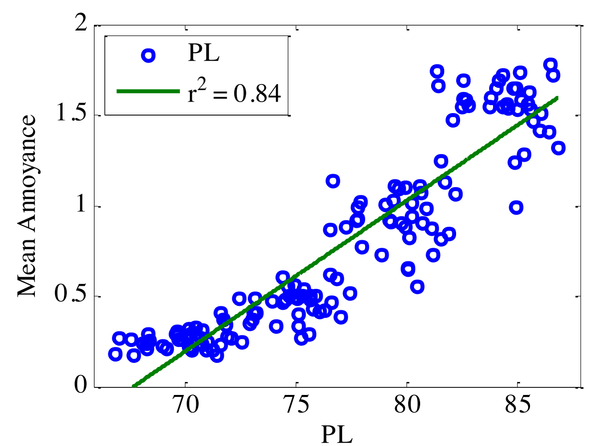
POC: Jonathan Rathsam

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 <u>indoors</u> with metrics computed on <u>outdoor</u> booms
- Compiled an exhaustive list of metrics from standards and literature
- Chose 25 metrics for quantitative analysis

Metric Name	NASA Indoor	NASA Outdoor	JAXA Full Data	JAXA Indoor Subset
ISBAP	0.89	0.66	0.95	0.85
BSEL	0.86	0.68	0.96	0.84
ESEL	0.85	0.80	0.97	0.78
PL	0.84	0.87	0.95	0.74
ASEL	0.82	0.85	0.96	0.65
L_{ASMAX}	0.82	0.84	0.96	0.65
L_{AFMAX}	0.77	0.82	0.95	0.65
PNL	0.76	0.85	0.94	0.71

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



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

POC: Alexandra Loubeau

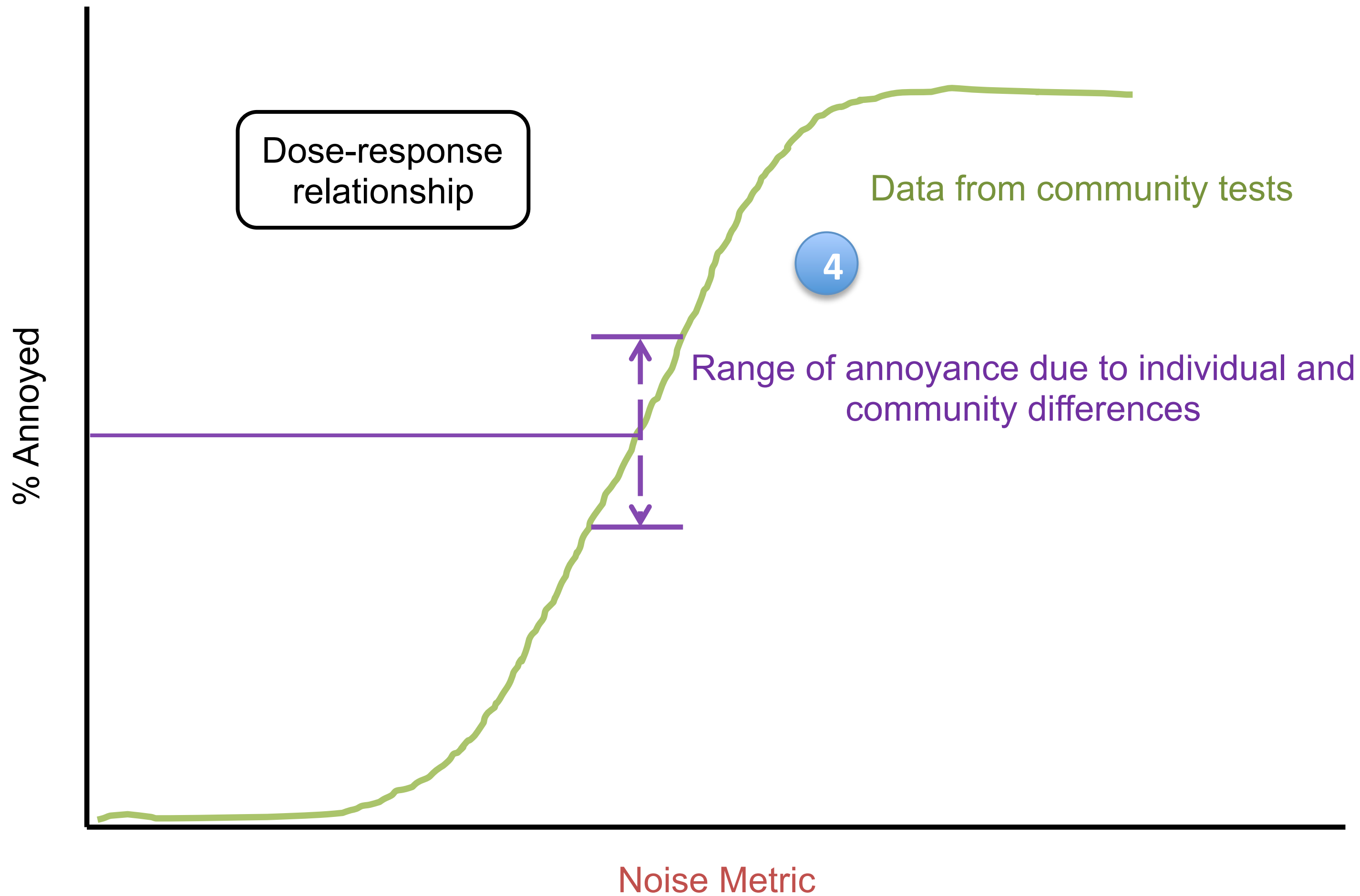
Noise Metrics Evaluation

- 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

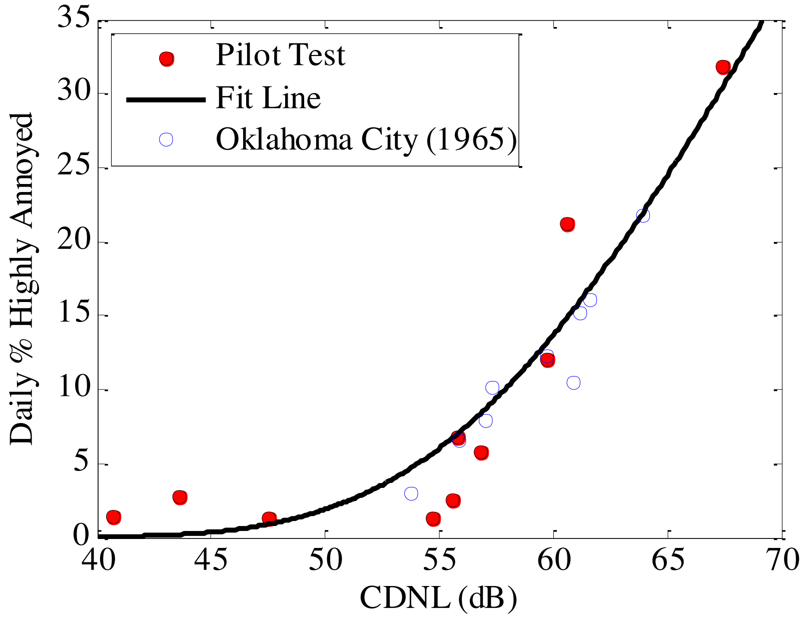
POC: Alexandra Loubeau

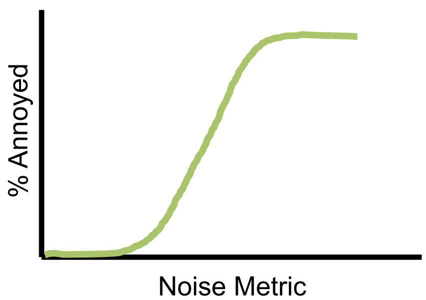
Community Response Research



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





Loubeau, POMA 2013

POC: Alexandra Loubeau and Kevin Shepherd

Community Response Research

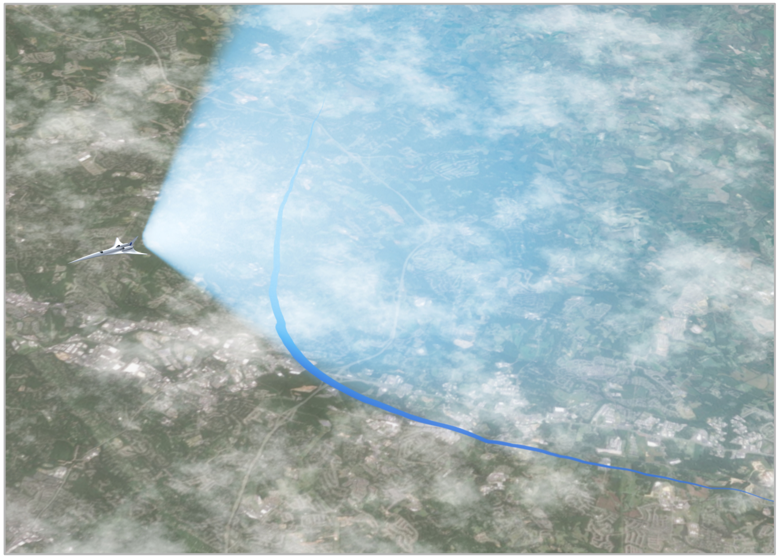
- Two contractor teams established to help plan future studies
  - Applied Physical Sciences (APS) and Fidell Associates

- 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



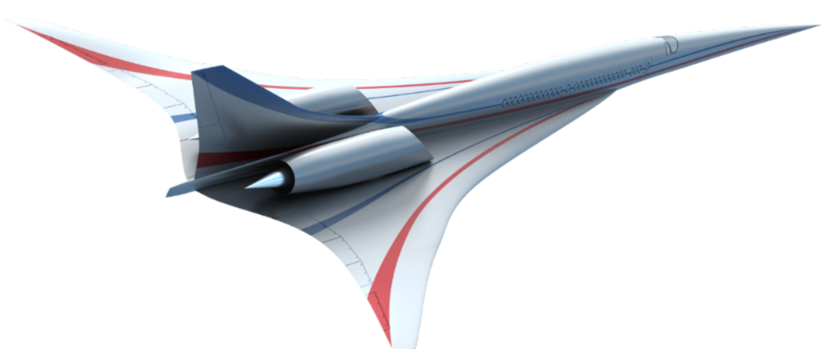
- Address several risk items
  - Improve objective and subjective data collection methods and analyses
  - Site selection
  - Regulatory processes and approval
  - Public/media education and legislative approvals

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



Alexandra Loubeau
a.loubeau@nasa.gov