

National Aeronautics and Space Administration

The Quest for a Quiet Sonic Boom

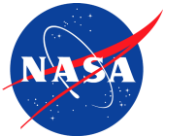
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Structural Acoustics Branch
NASA Langley Research Center

Ben-Gurion University
Departmental Seminar
February 26, 2014

A man with dark hair, wearing a dark flat cap and a dark and light grey striped sweater, is smiling at the camera. He is in a laboratory or workshop setting. In the background, there is a large, circular, silver-colored acoustic chamber or speaker with a black mesh grille. To the left of the man, there is a white, cylindrical object with a black mesh grille, possibly a microphone or a small speaker. The overall lighting is somewhat dim, and the background is slightly out of focus.

Hello!

- From San Diego, California
- Physics major from Grinnell College
- Ph.D. in Engineering (Acoustics) from University of Nebraska
- Postdoctoral Fellowship in Acoustics at Ben-Gurion University of the Negev (Israel)
- NASA since 2009



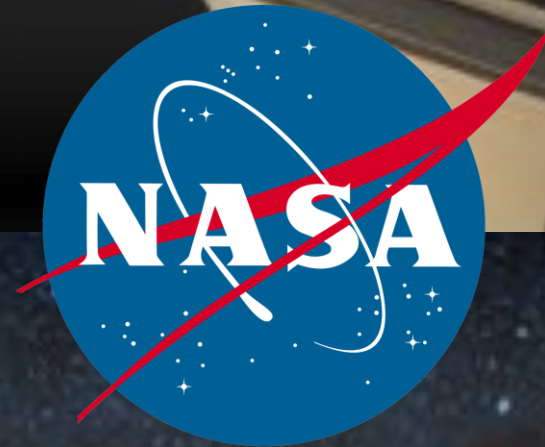
Today's Conversation

- About NASA
- About Supersonic Flight
- What is a Sonic Boom and why is it so loud?
- Working towards a “Quiet Sonic Boom”
 - Previous research
 - Current community & lab studies
- Future Work
- Q & A

Human Exploration
and Operations

Science

What does NASA do?



Aeronautics Research

Space
Technology

Where is NASA?



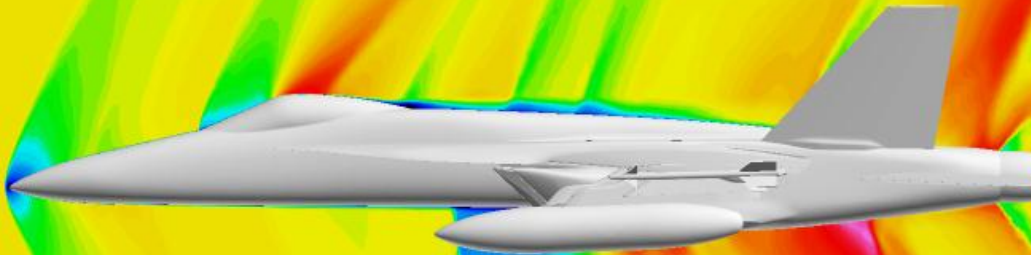
NASA Langley (Hampton, VA)

- Established in 1917
- ~3,500 Employees, annual budget ~\$750 Million



What is Supersonic Flight?

- Flying faster than the speed of sound
- Produces a shock wave in the air
- Sound of the shock wave is a sonic boom



Benefits of Supersonic Flight



- Supersonic flight over land enables large reduction in travel time
 - Business travelers, cargo shippers, traveling public
- Market potential has been validated in numerous studies
 - Business Aircraft: 350-500 units
 - Civil Airliners: 500+ units
- Opportunity for US to take the lead in new class of aircraft manufacturing
 - Maintains or increases aviation's place in US economy, high value employment



2020



~2025



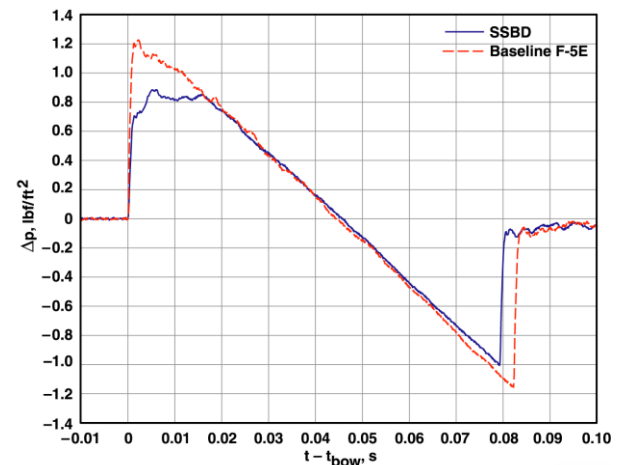
~2030

NASA investment in fundamental technology for supersonics enables continued US leadership in global commercial aviation

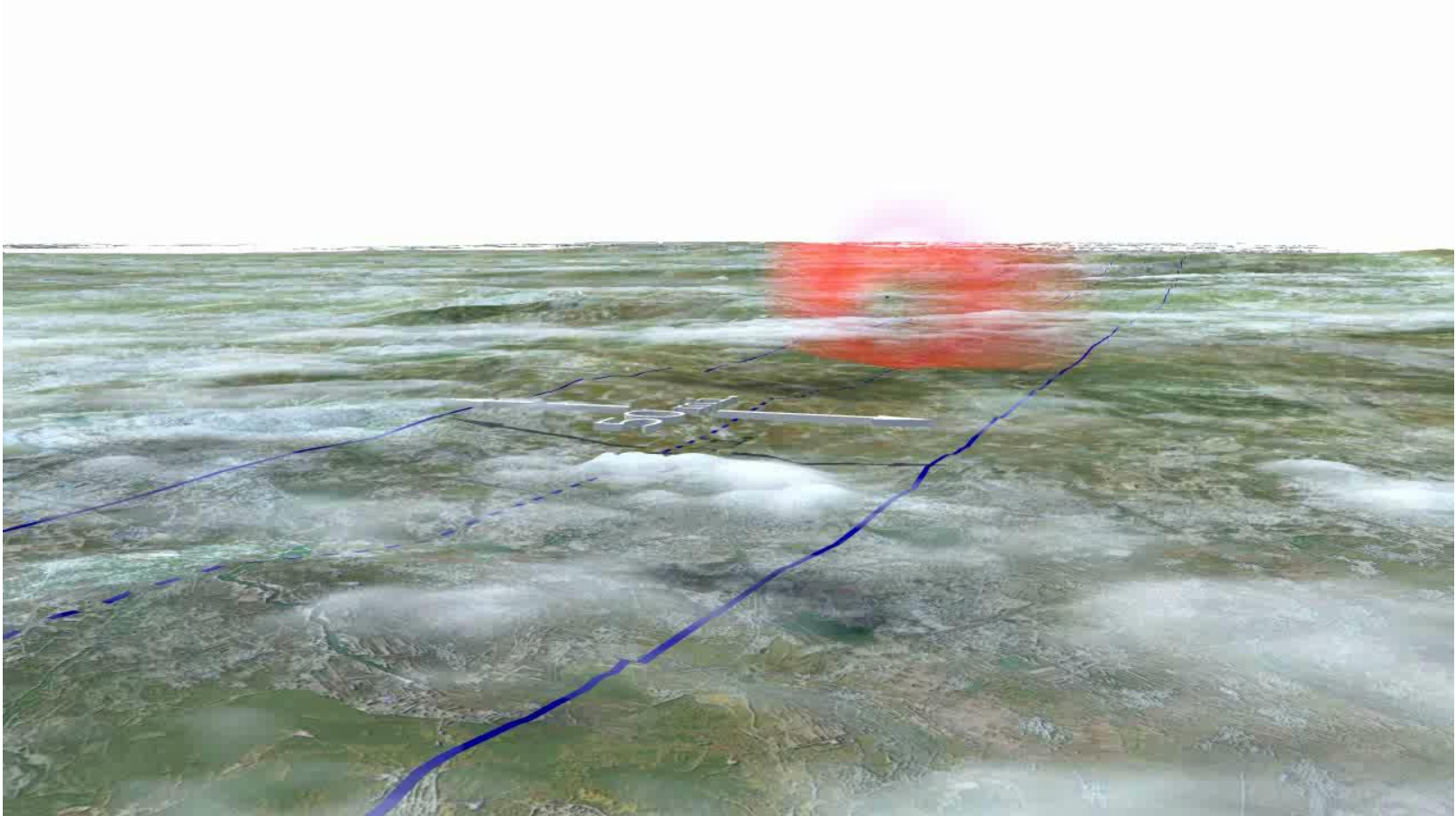
Historic sonic boom highlights



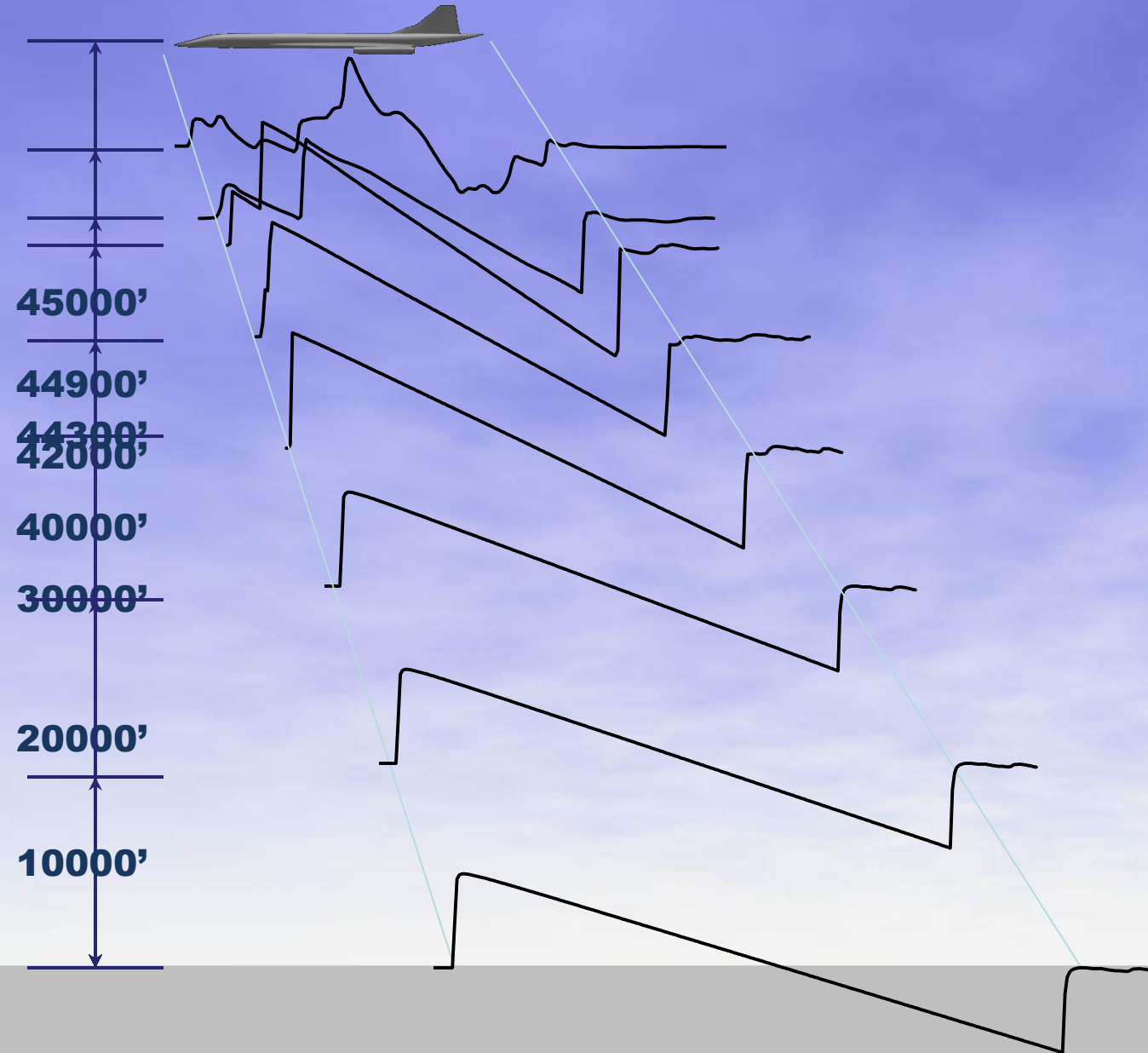
- 1947 Chuck Yeager first flies supersonically
- 1964 Sonic boom tests end early due to public complaints
- 1973 FAA forbids sonic booms over land
- 1976–2003 Concorde flies supersonically over Atlantic Ocean
- 1990s NASA High Speed Research Program
- 2003 Shaped Sonic Boom Demonstration



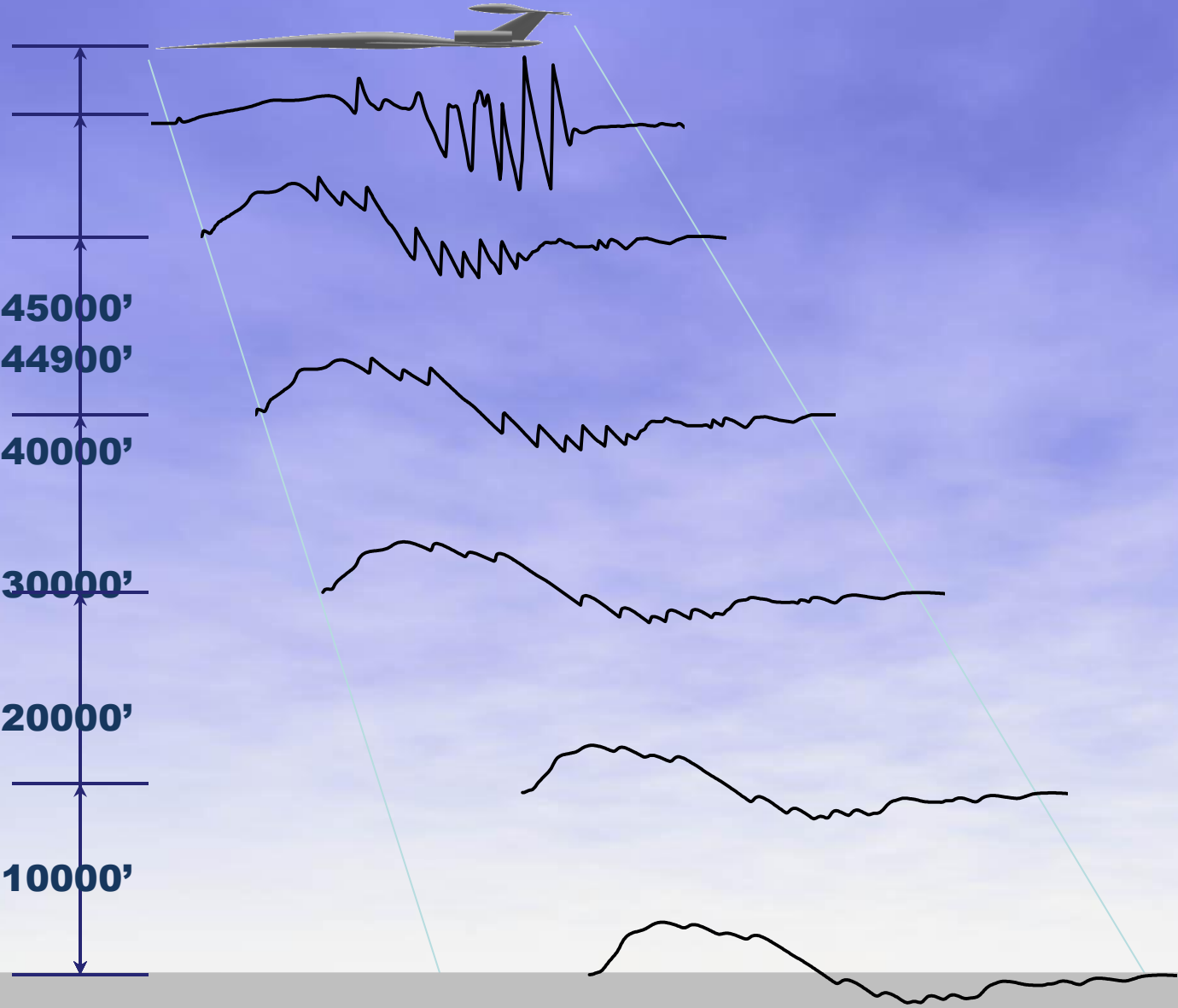
Sonic Boom Basics



Conventional N-wave Sonic Boom



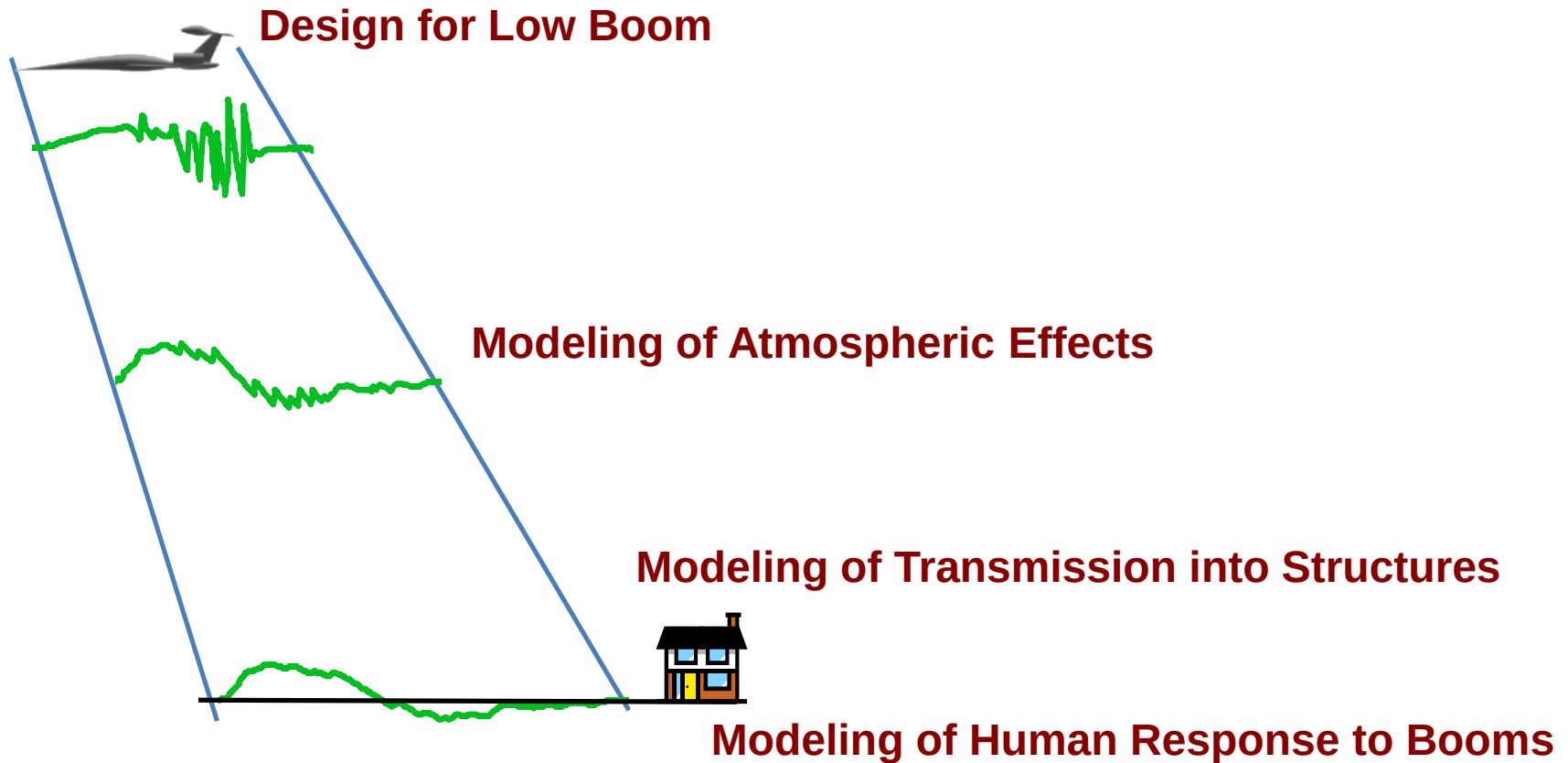
Quiet Sonic Boom



Sonic Boom - Reduction and Response



Understand and overcome the environmental barrier of sonic booms to civil supersonic flight. Improve understanding of the impact of reduced sonic boom noise on community residents.



How do We Measure Response?

1 – Sonic Boom Simulators



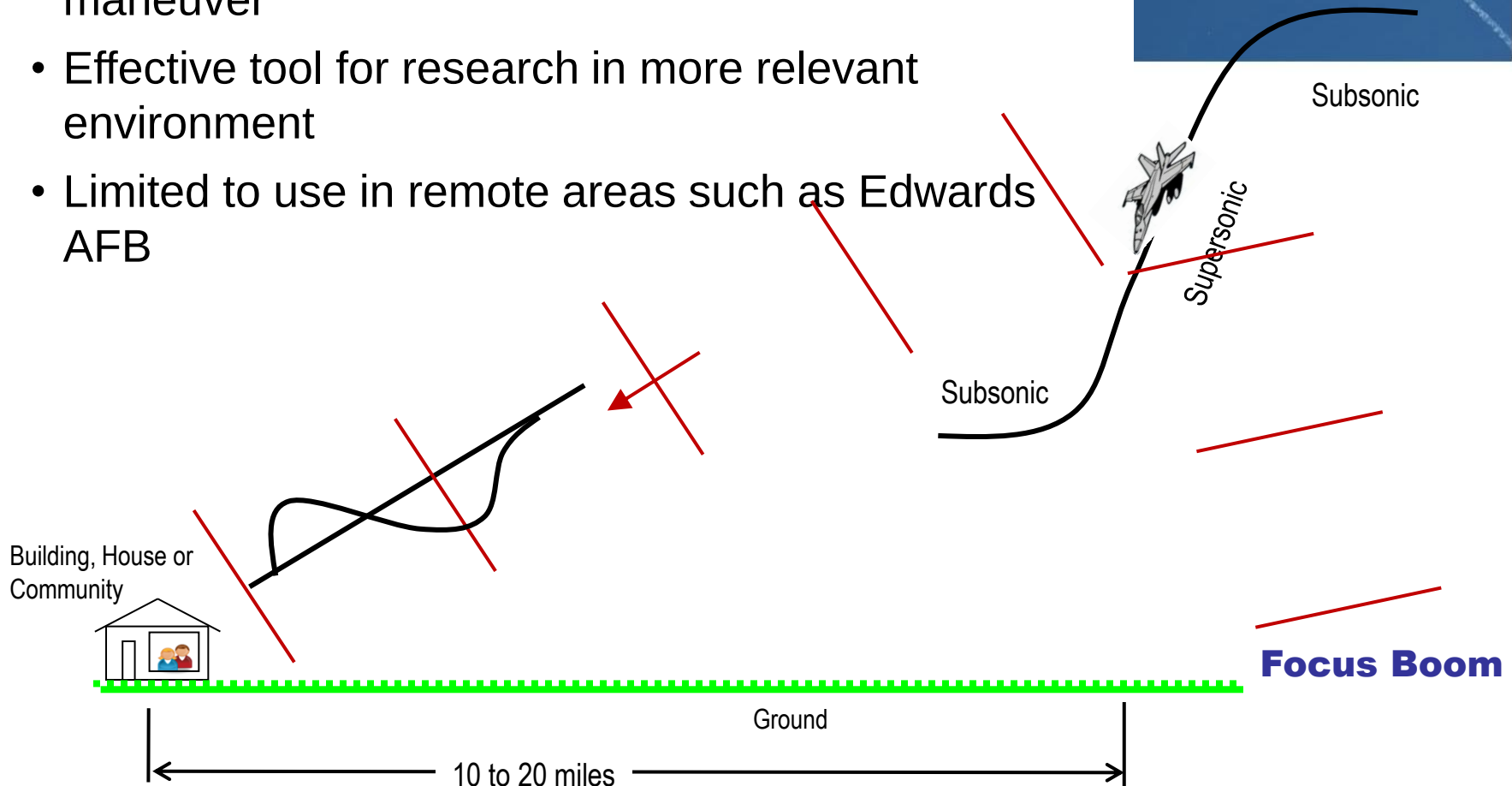
Simulation of boom heard outdoors



Simulation of boom heard indoors

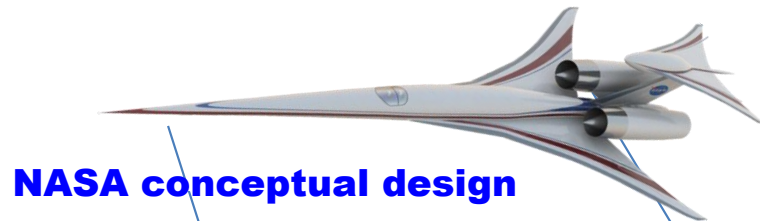
- Sophisticated boom simulators
 - Unique national capability
- Accurate reproduction of sonic boom noise
 - Repeatable test conditions
 - Wide variety of signatures
- Study elements of boom that create annoyance
 - Goal: Understand how annoyance is related to waveform, level, rattle, vibration

-
- The graph displays a white line on a blue background. The white line starts at a low value on the left, rises sharply to a peak, and then gradually declines towards the right. Below this white line, there is a thick black curve that starts at a low value on the left and rises to a peak before declining.



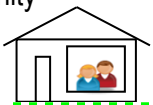
How do We Measure Response?

3 – Quiet Boom Demonstrator Aircraft



- Only completely realistic way to measure response
- Flights conducted over any community
 - Particularly those without prior exposure to boom
- Valuable research platform
- Viewed as critical step by regulators

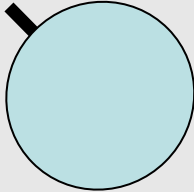
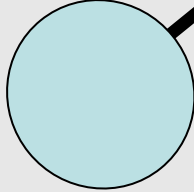
Community



Psychoacoustic Testing



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

Field Test	Laboratory Test
Realism Control 	Realism Control 
-Address cumulative annoyance over days/weeks -Demonstrator aircraft over population centers	-Isolate annoyance contribution of: -loudness -perceived vibration -presence of rattle -room acoustics -Relative rather than absolute levels

Indoor Sonic Boom Simulator



Indoor Sonic Boom Simulator

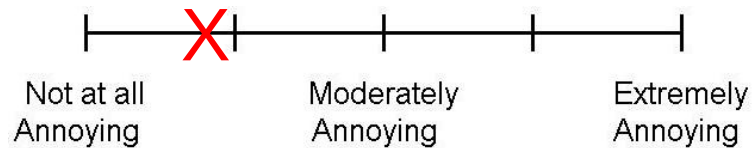


Laboratory Study



Test Details

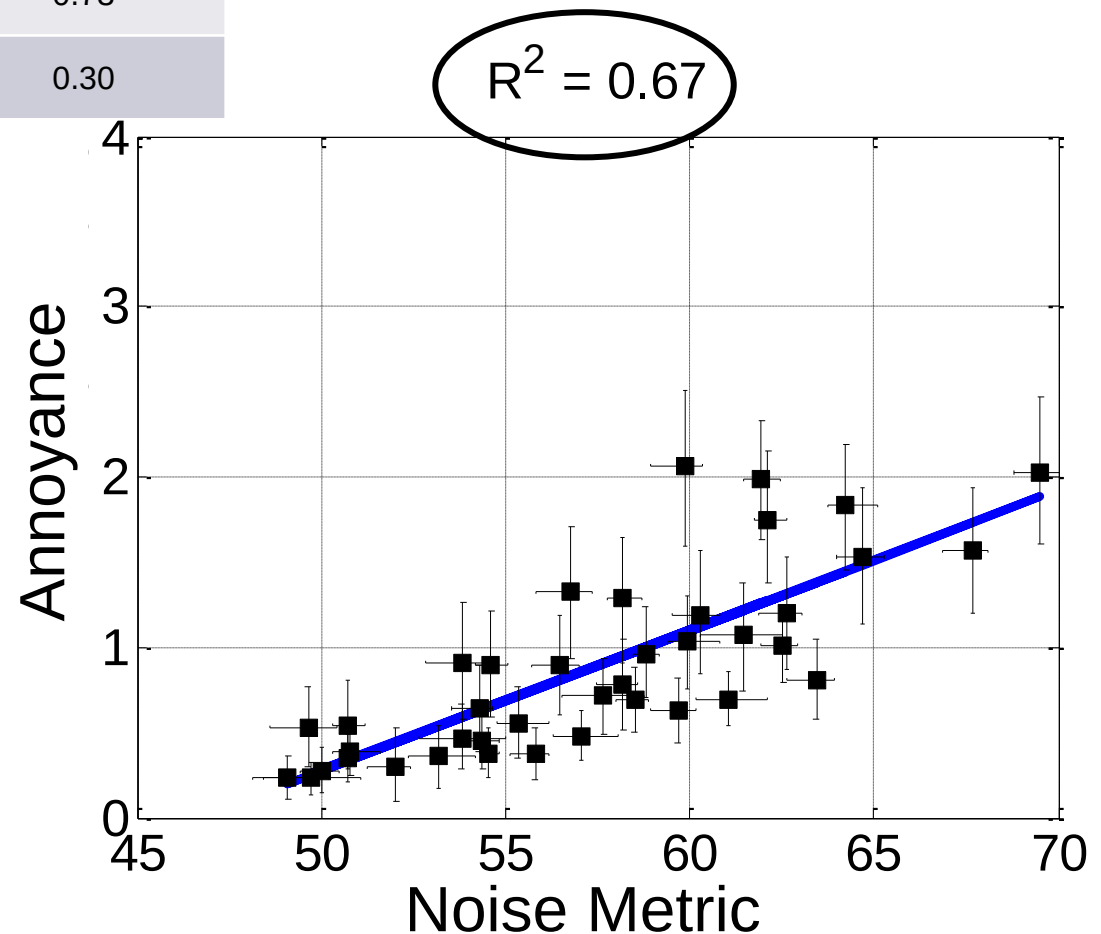
- 33 subjects, tested in groups of 3
- 207 sounds (fully randomized for each group)



Sample Data



Metric	Fit (0 to 1)
Existing	0.67
Proposed A	0.73
Proposed B	0.30



Community Test



Low Boom Community Response Testing



Objective

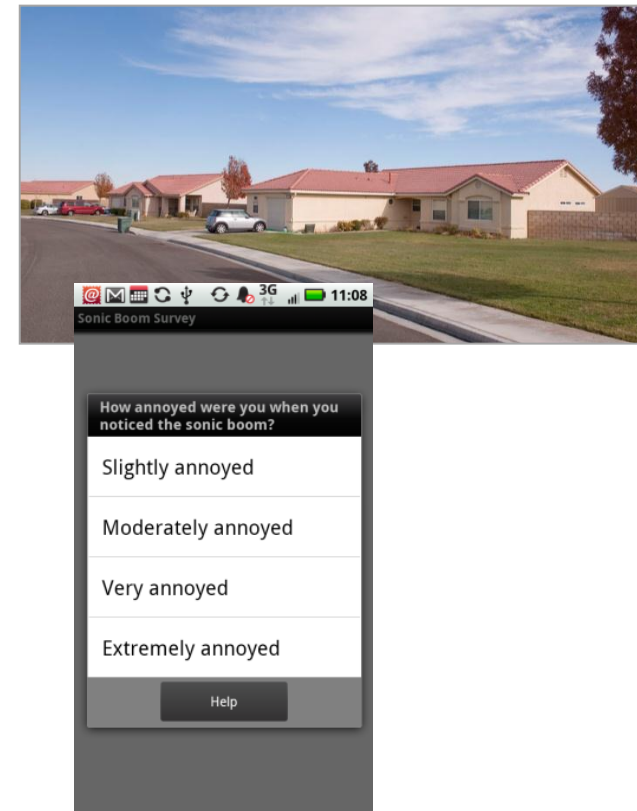
- Pilot test to prepare for future sonic boom community response studies
- Develop experimental methodologies
 - Noise exposure design
 - Sonic boom data acquisition
 - Subjective data collection methods
 - Analysis methods

Approach

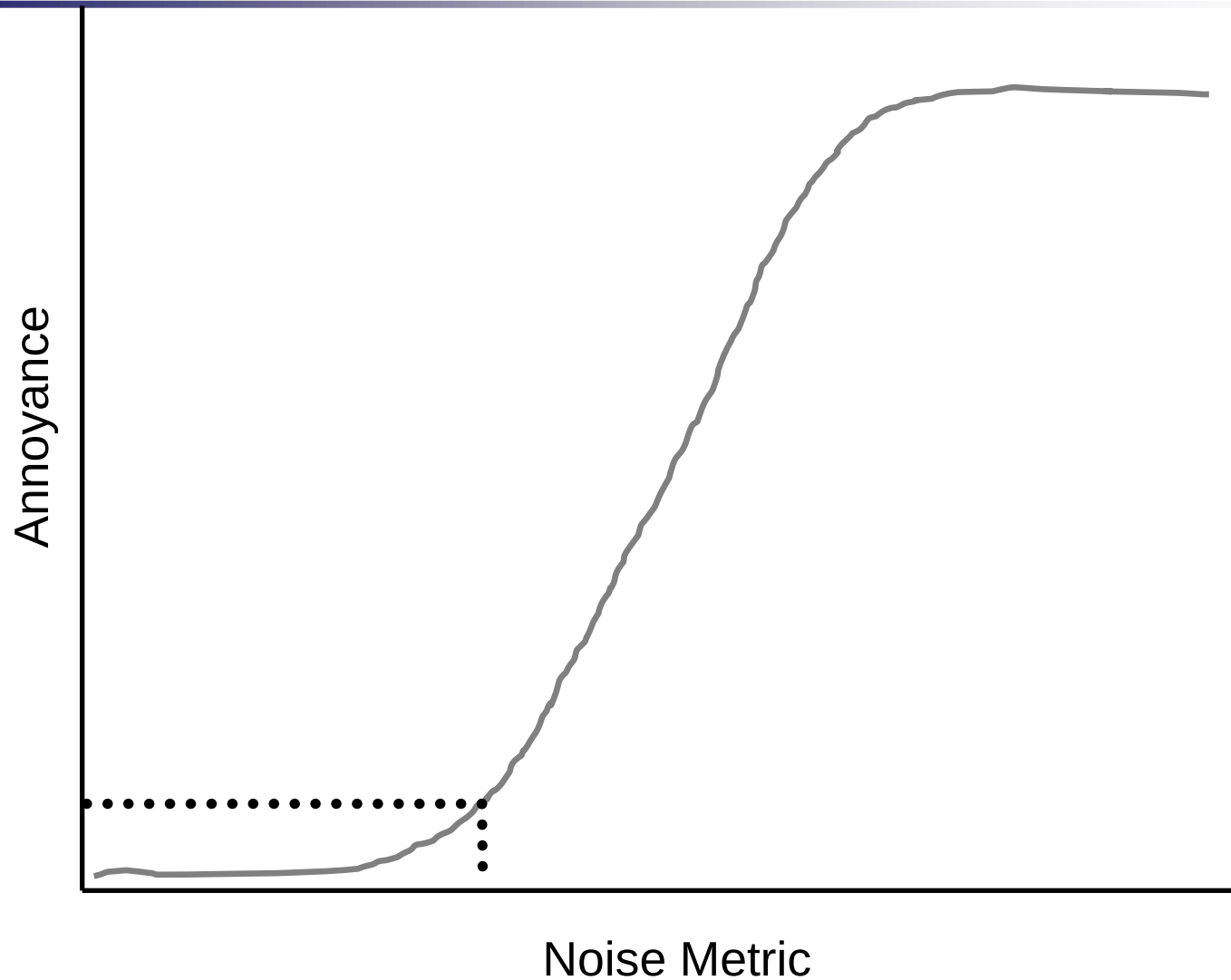
- Exposed Edwards Air Force Base housing area to low-amplitude sonic booms over a two-week test period (Nov. 2011)
- Recruited over 100 residents at home during the day most days
- Range of boom amplitudes and number of booms/day
- Custom-designed sonic boom monitors placed throughout community

Results & Significance

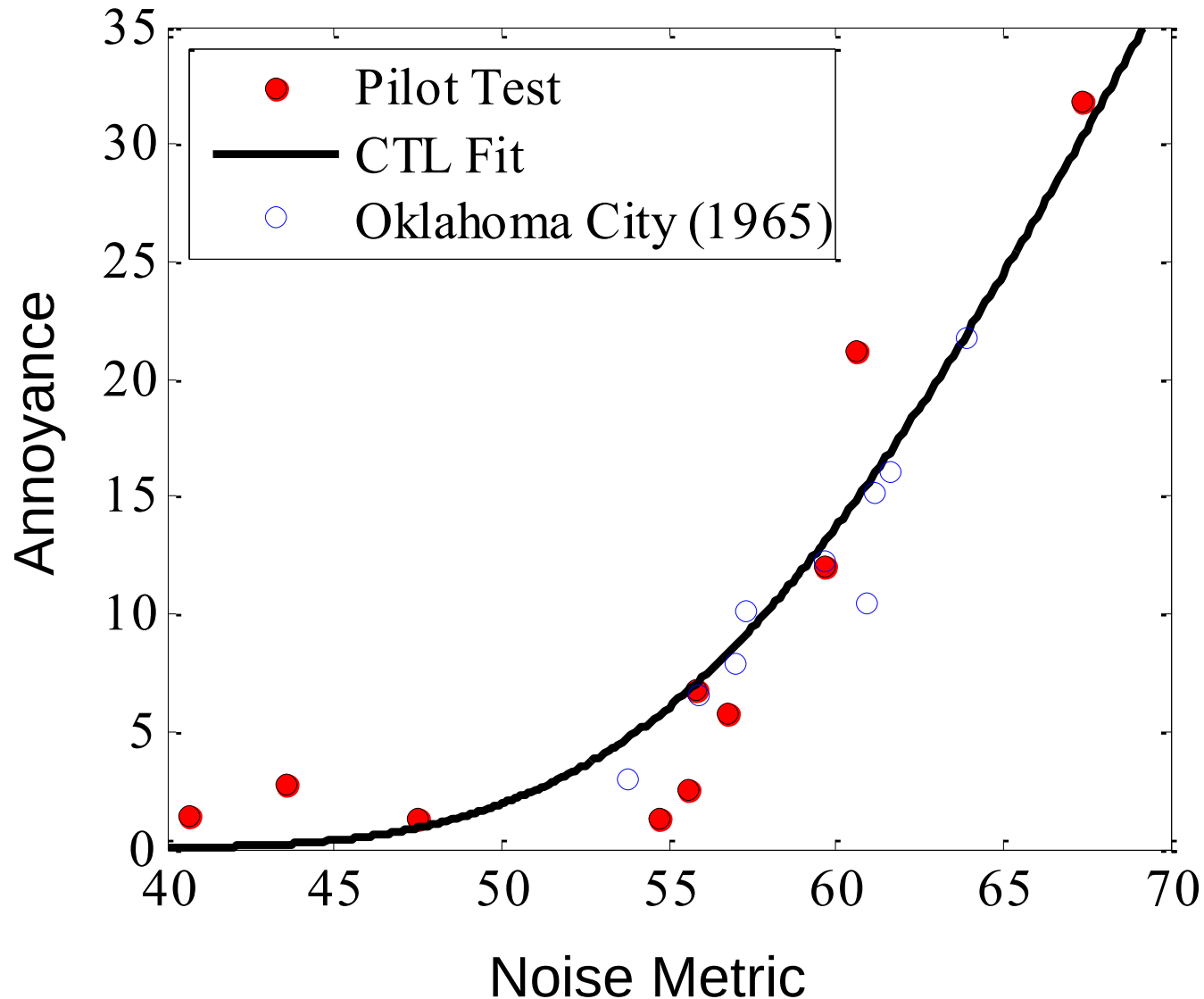
- Three data reporting methods (paper, web, smartphone successful)
- Expected trends in annoyance data with minimal annoyance to the lowest amplitude booms
- Lessons learned will be used to help design future studies with LBFD



Research goal: dose-response relationship



Community Test Data



Future Work



- NASA is funding conceptual design of a quiet supersonic aircraft
- In the coming years we hope to build it and demonstrate quiet sonic booms in communities around the country

Acknowledgements



Jacob Klos, Alexandra Loubeau, Peter Coen

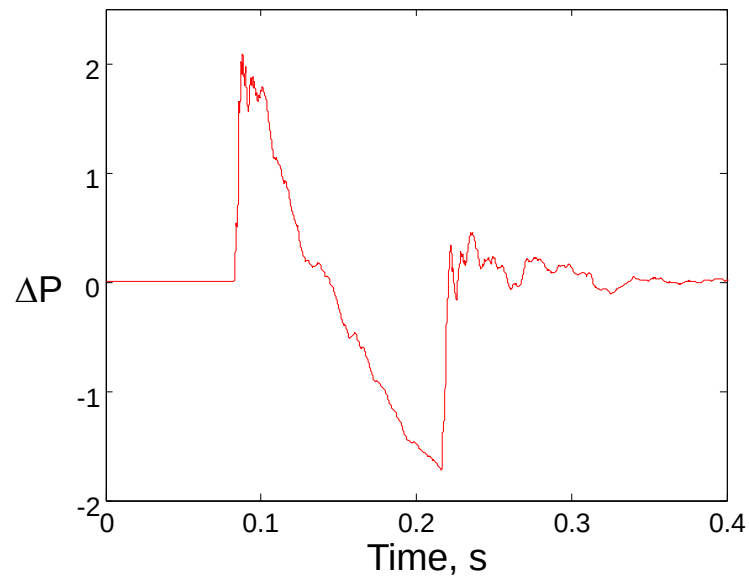
Backup Slides



Sonic Boom Basics: The N-Wave



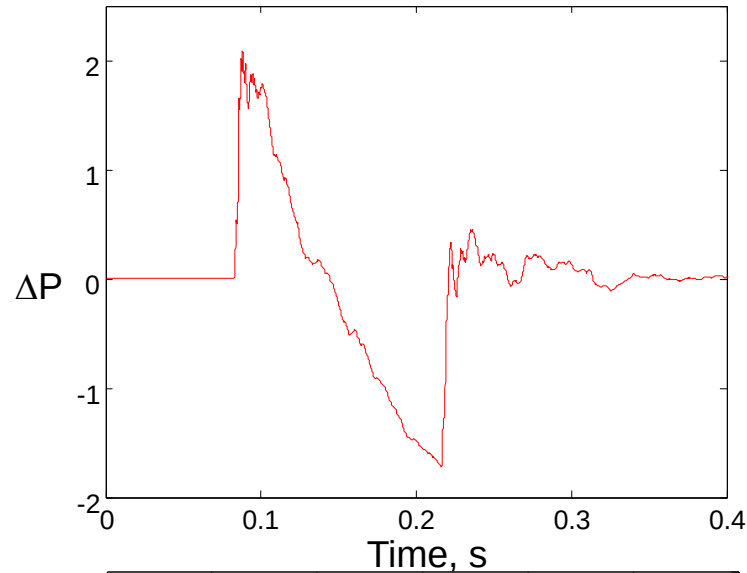
Measured Sonic Boom



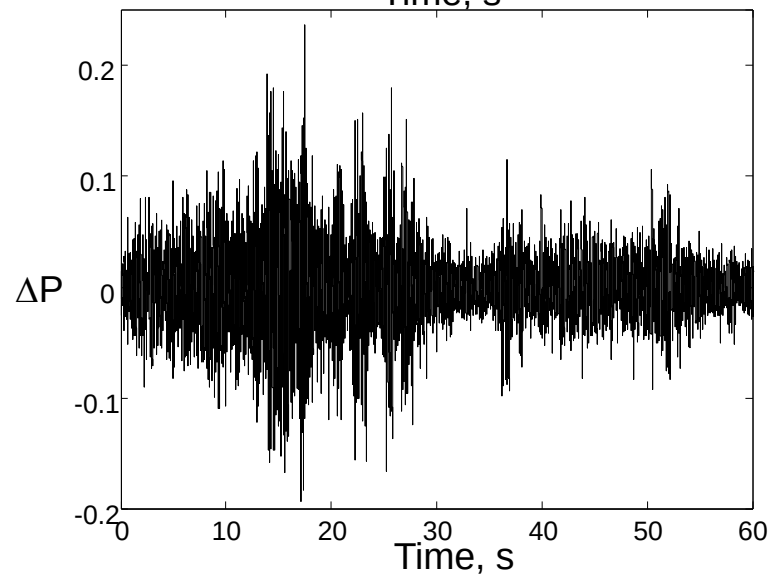
Sonic Boom Basics: The N-Wave



Measured Sonic Boom



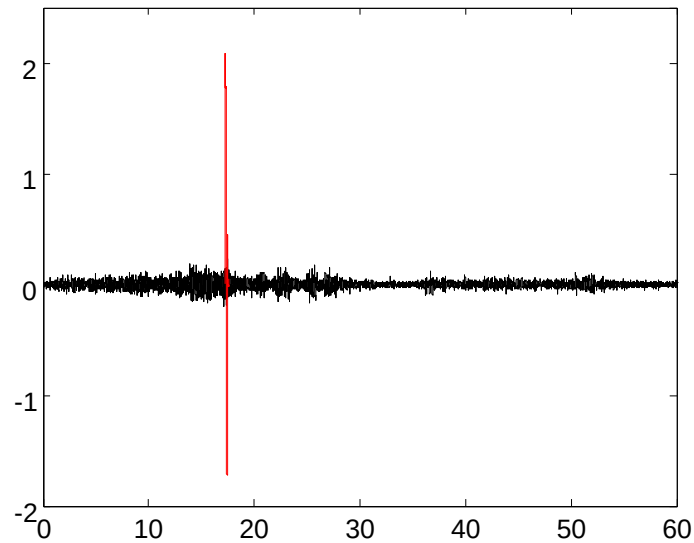
**Measured
Commercial Aircraft**



Sonic Boom Basics: The N-Wave



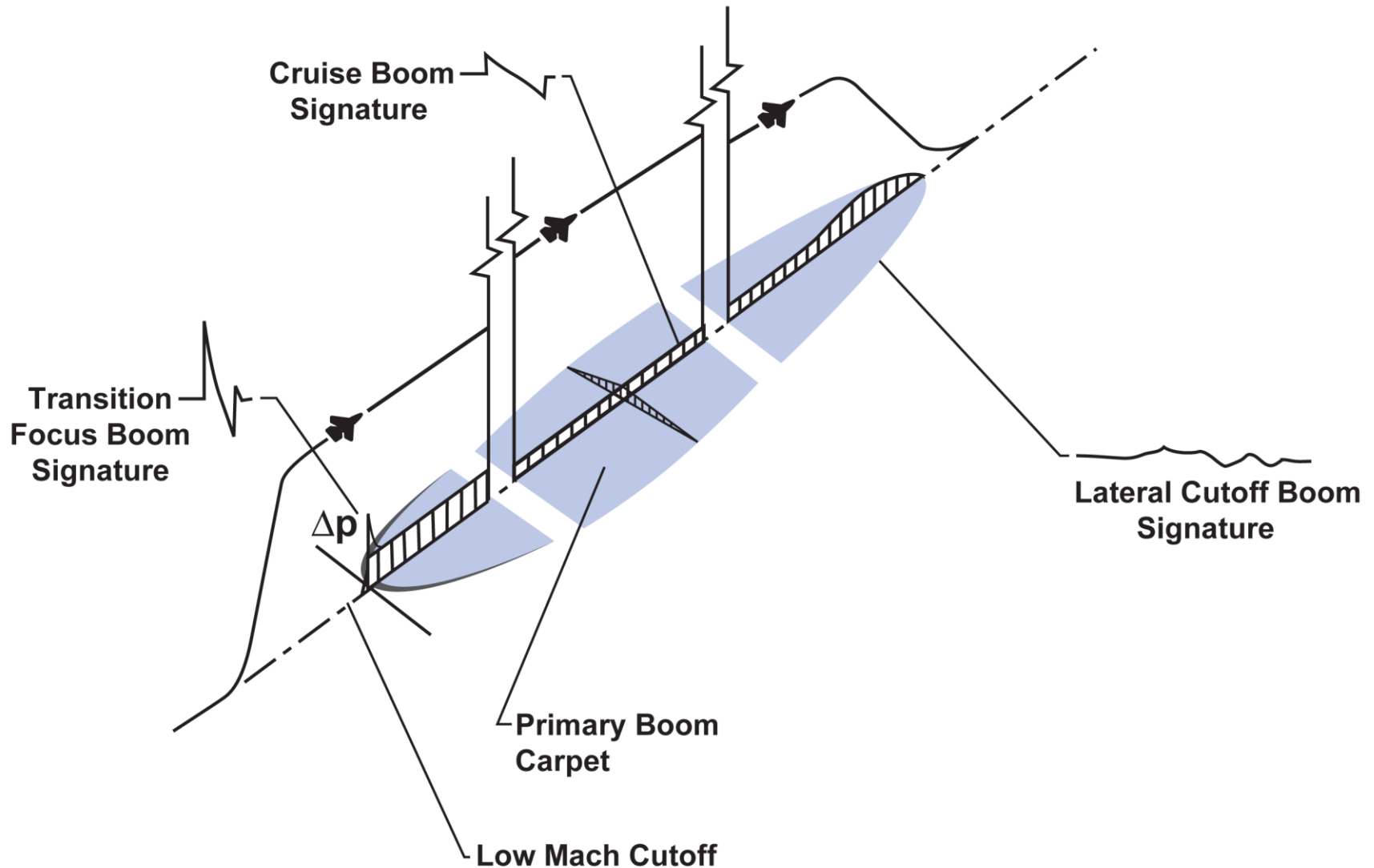
.. To the same scale



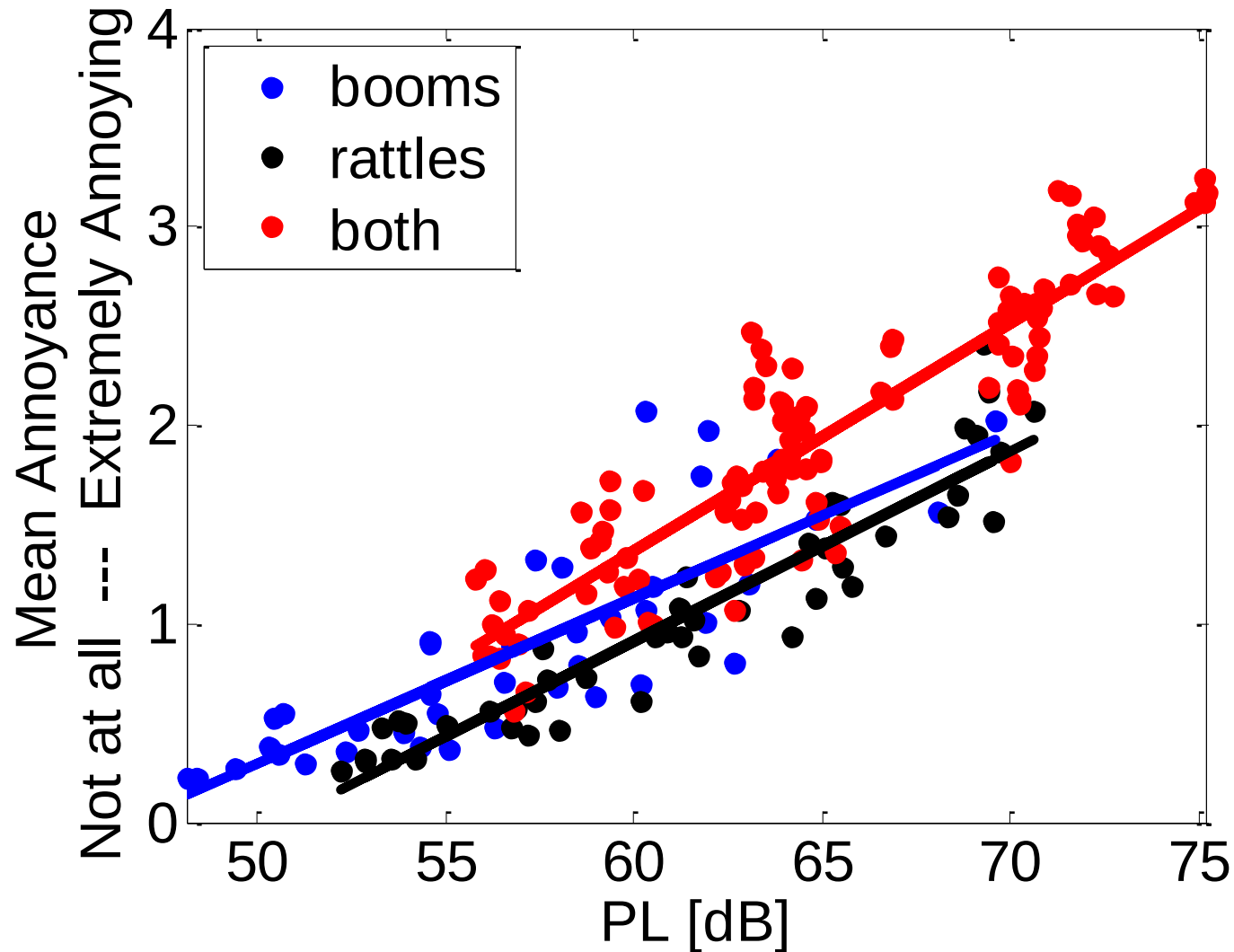
Sonic Boom Simulator



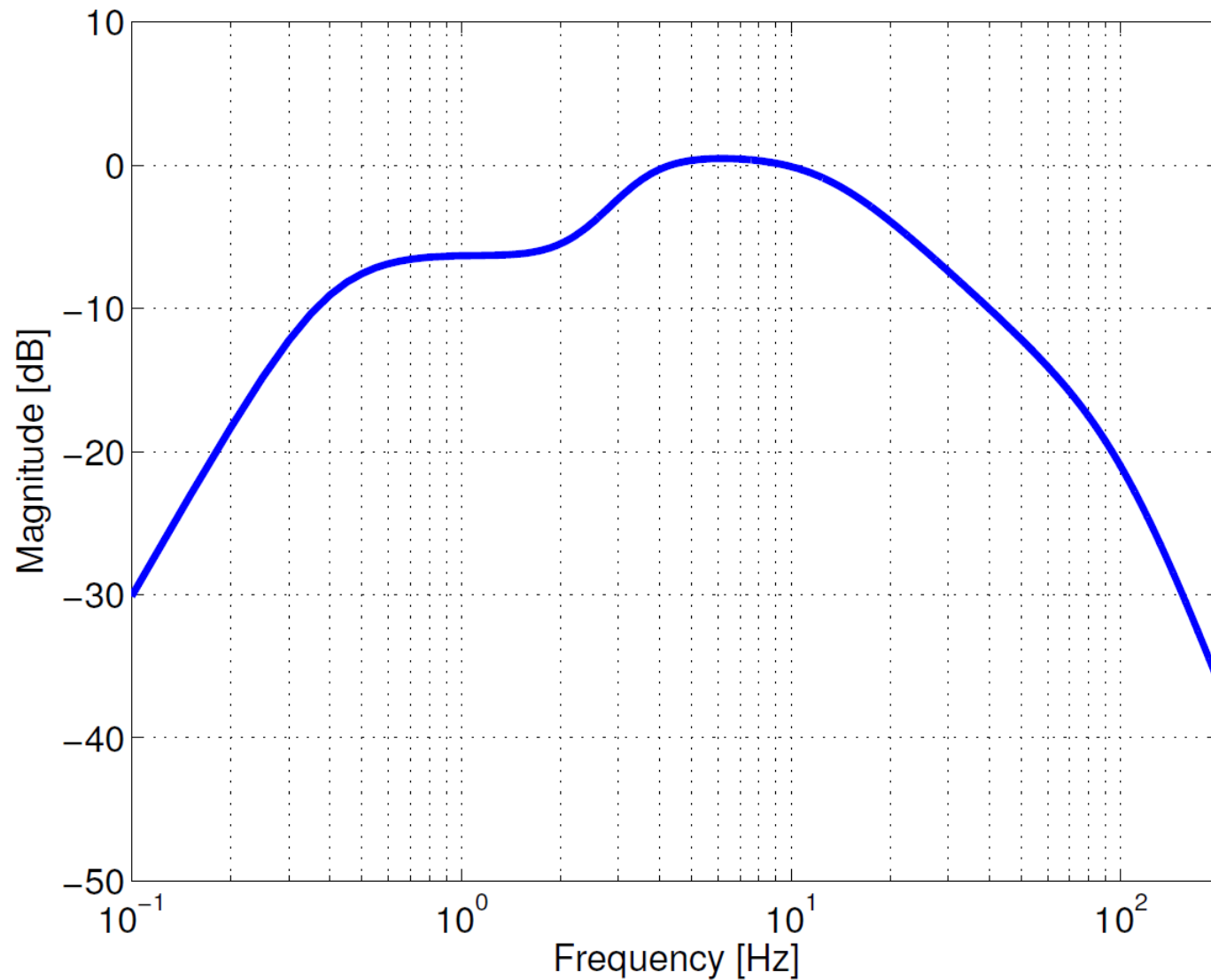
Atmospheric Propagation



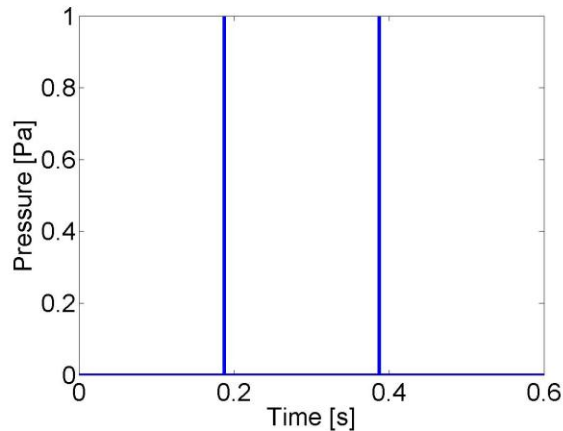
Laboratory Test: Results



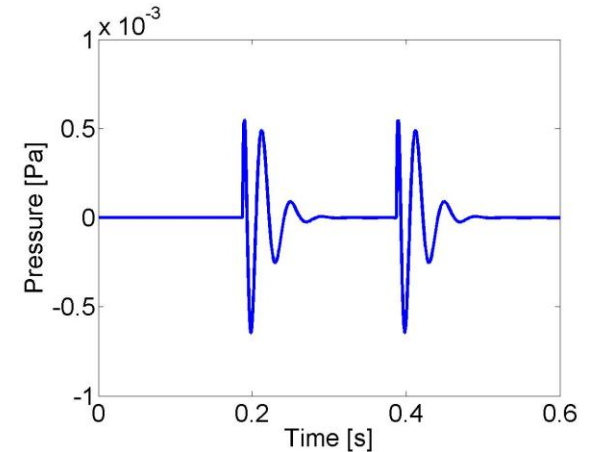
w_k -weighting function for acceleration



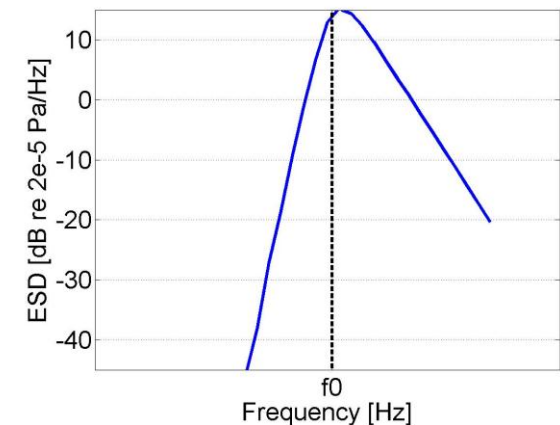
Objective 1: Synthetic sounds, spectrally varied



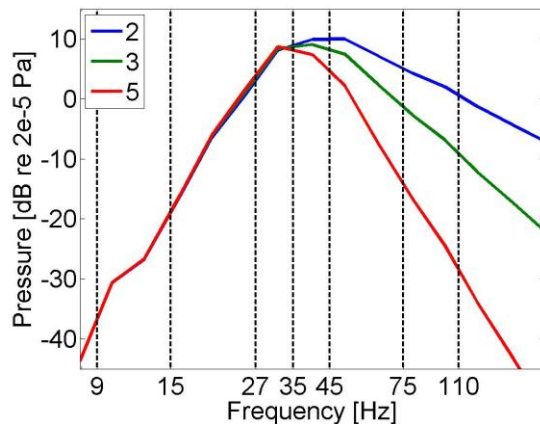
Band Pass Filter



FFT

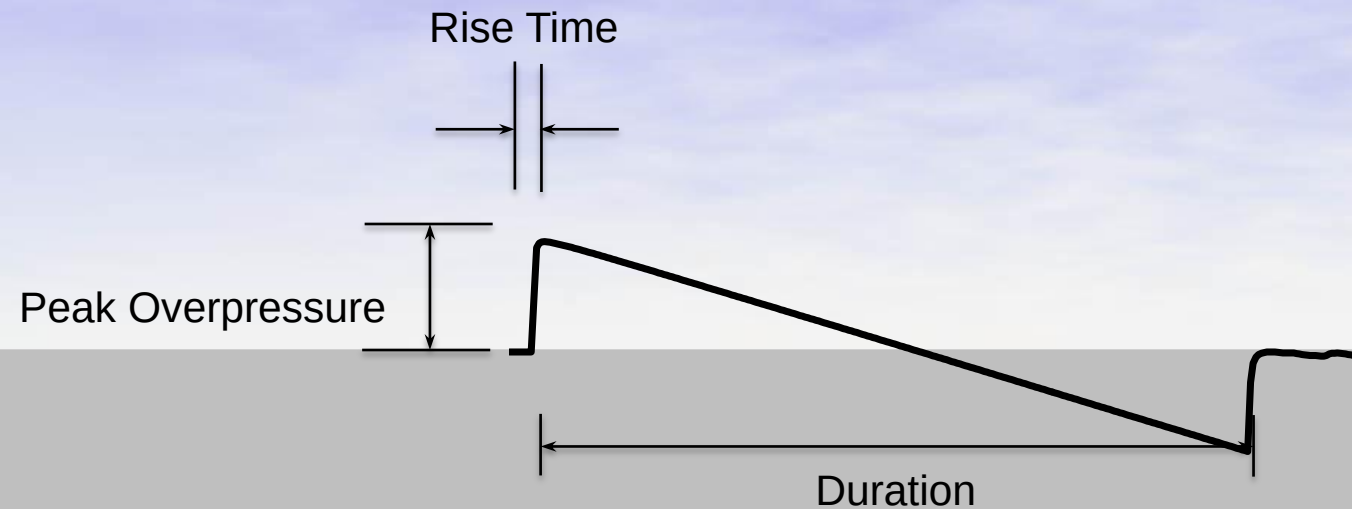


(Repeat)

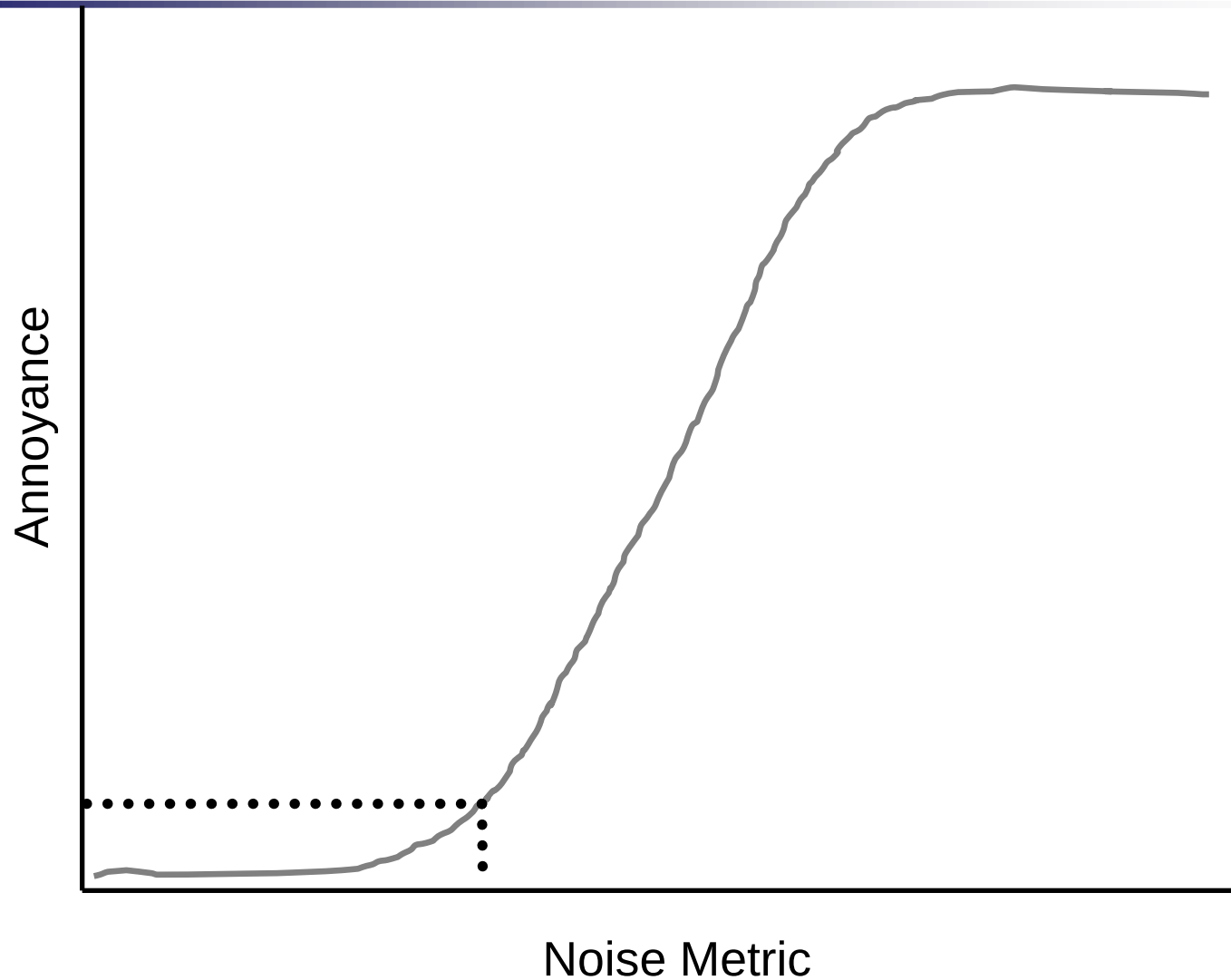


Signals have sonic-boom character and varied spectral content

Factors affecting loudness



Research goal: dose-response relationship



Human and Community Response



Specialized
simulation facilities



Community tests



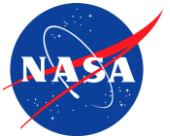
Jury tests



Noise Metrics

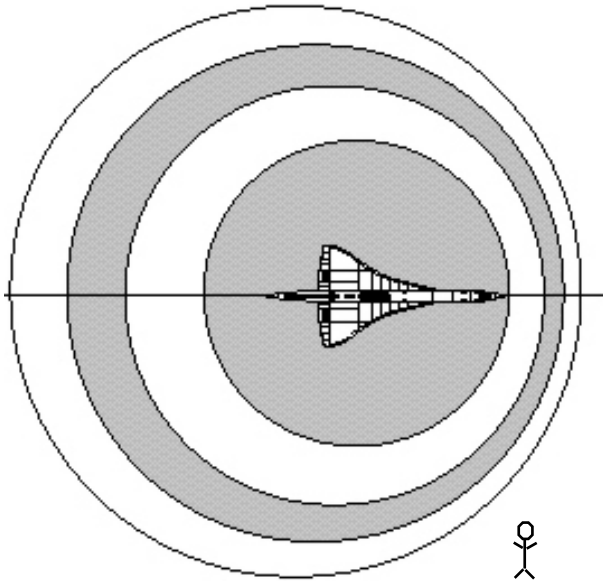


Metric	Description
PL	Perceived Level (Stevens Mk VII, Shepherd & Sullivan)
MGSLp	Moore & Glasberg Stationary Loudness (phons)
dSTL	Time derivative of short-term loudness
CSEL-ASEL	Difference in weighted sound exposure levels, a.k.a. “heaviness” (Vos 2001)
LAFmax	Maximum output of sound-level meter
w_k-weighted peak acceleration	Measured at subjects’ feet (subjects not present)

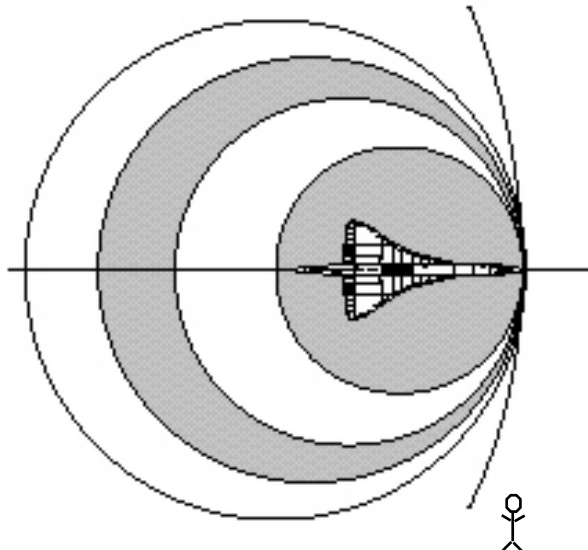


-
- SCAMP
 - <http://www.youtube.com/watch?v=aJPHysqJo6M> (5:10)

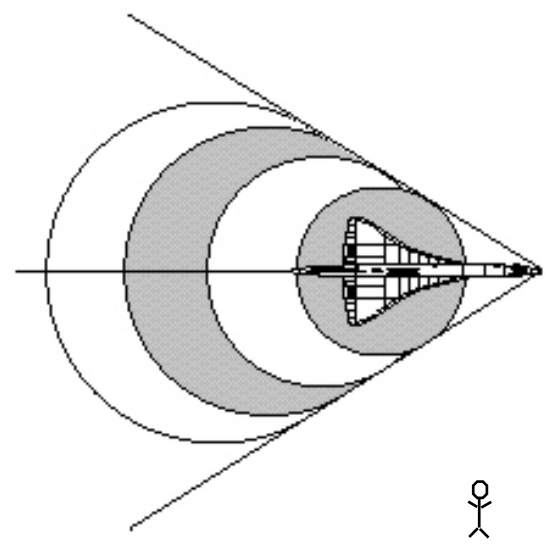
Sonic Boom Basics



- Speed < Speed of Sound (< Mach 1)
- Pressure disturbance (sound) precedes aircraft



- Speed = Speed of Sound = Mach 1
- Aircraft Speed = Speed of Pressure Disturbance



- Speed > Speed of Sound > Mach 1
- Aircraft precedes pressure disturbance
- Entire disturbance passes observer instantaneously

Sonic Boom is NOT the sound of an aircraft “breaking the sound barrier”
Sonic Boom is created as long as the aircraft is flying faster than Mach 1.0



Sound is a pressure disturbance

Animation

Sonic Boom - Reduction and Response



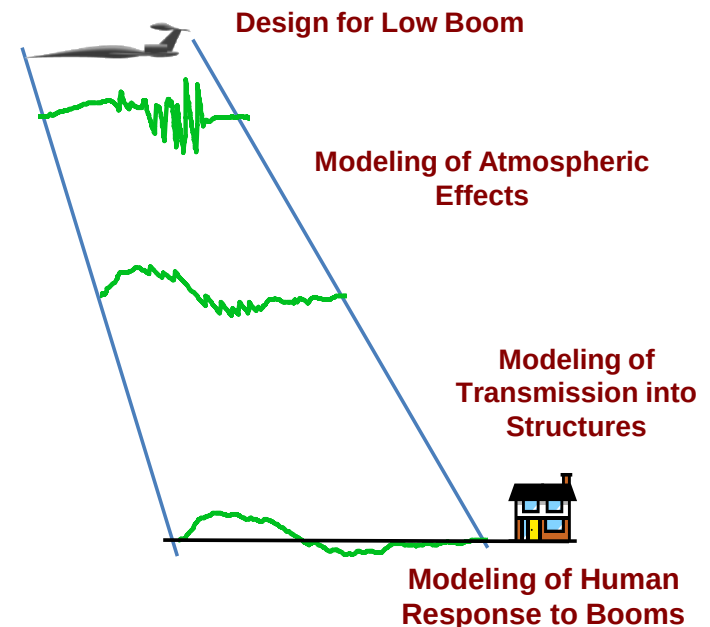
Understand and overcome the environmental barrier of sonic booms to civil supersonic flight. Improve understanding of the impact of reduced sonic boom noise on community residents.

Design for Boom Reduction

- Quiet sonic boom design techniques
- Multi-discipline tools for practical application
- Flight validation approaches

Response to Quiet Sonic Boom

- Effects of atmosphere
- Structural response & modeling
- Human response & modeling
- Community exposure testing
- Extrapolation to general population



In-house activities and integrated contracted and cooperative effort with a diverse group from Universities, Industry and Government