



National Aeronautics and Space Administration

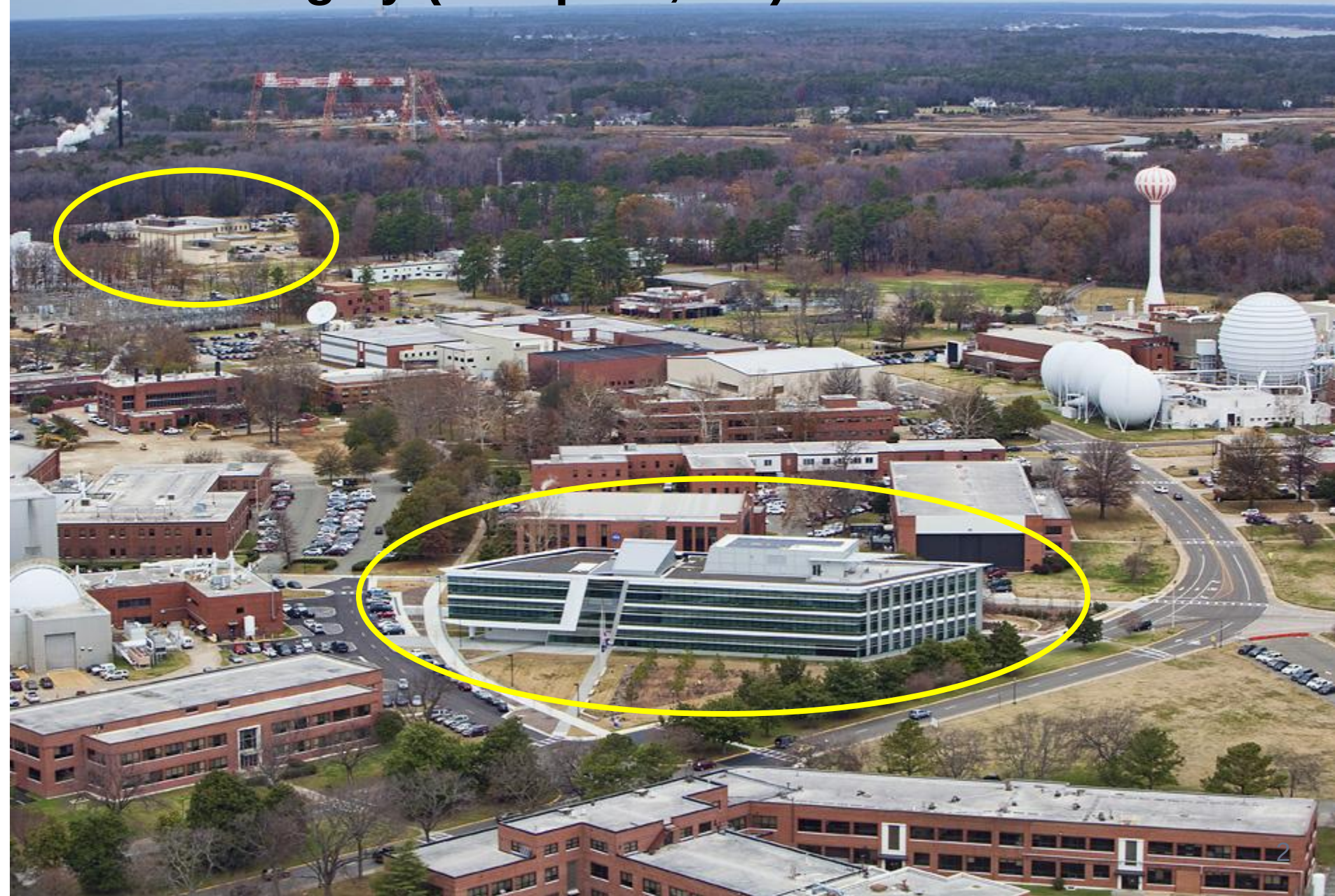
Update on Sonic Boom Research

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July 16, 2012
Omaha, Nebraska
www.nasa.gov

NASA Langley (Hampton, VA)

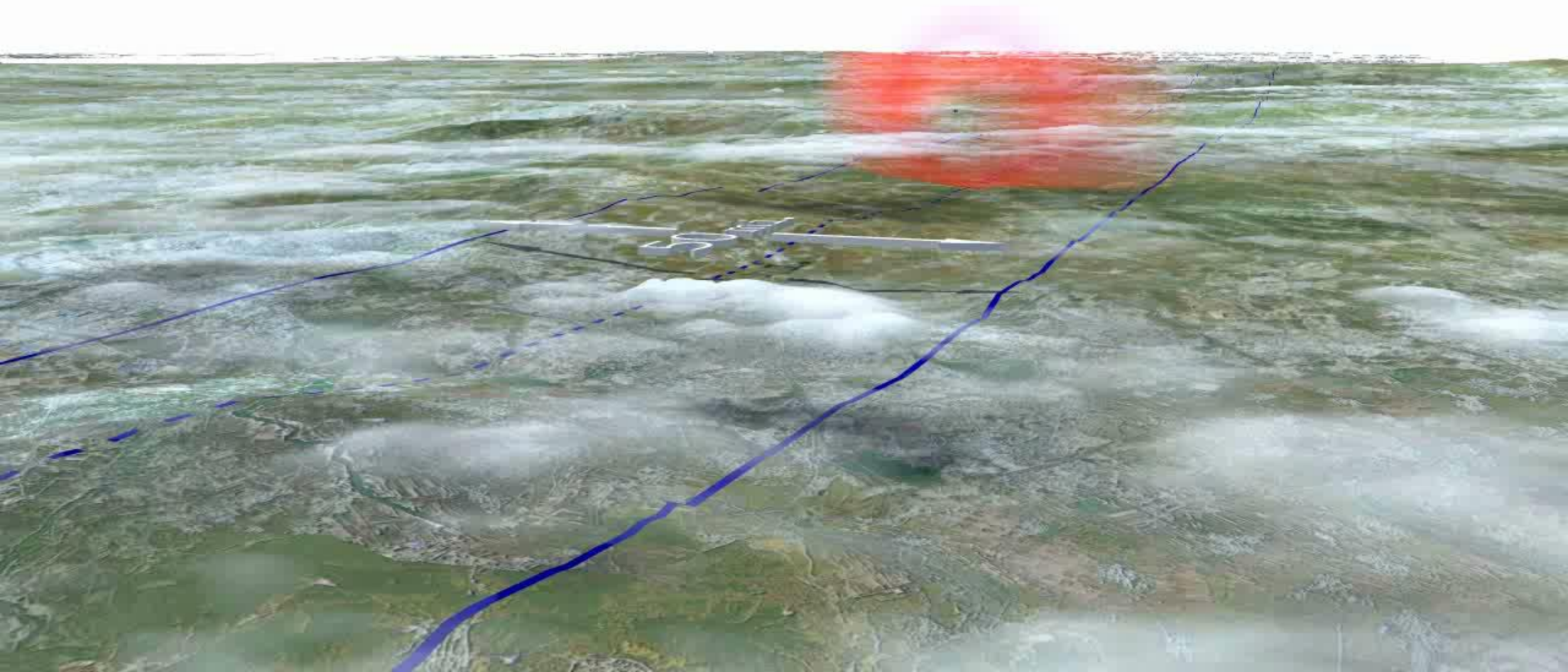


Outline



- Sonic Boom Basics
- Research Problem and Approach
- Field Tests
- Laboratory Study

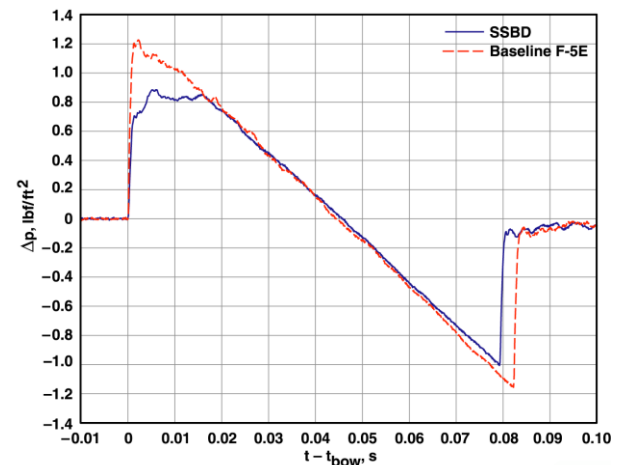
Sonic boom



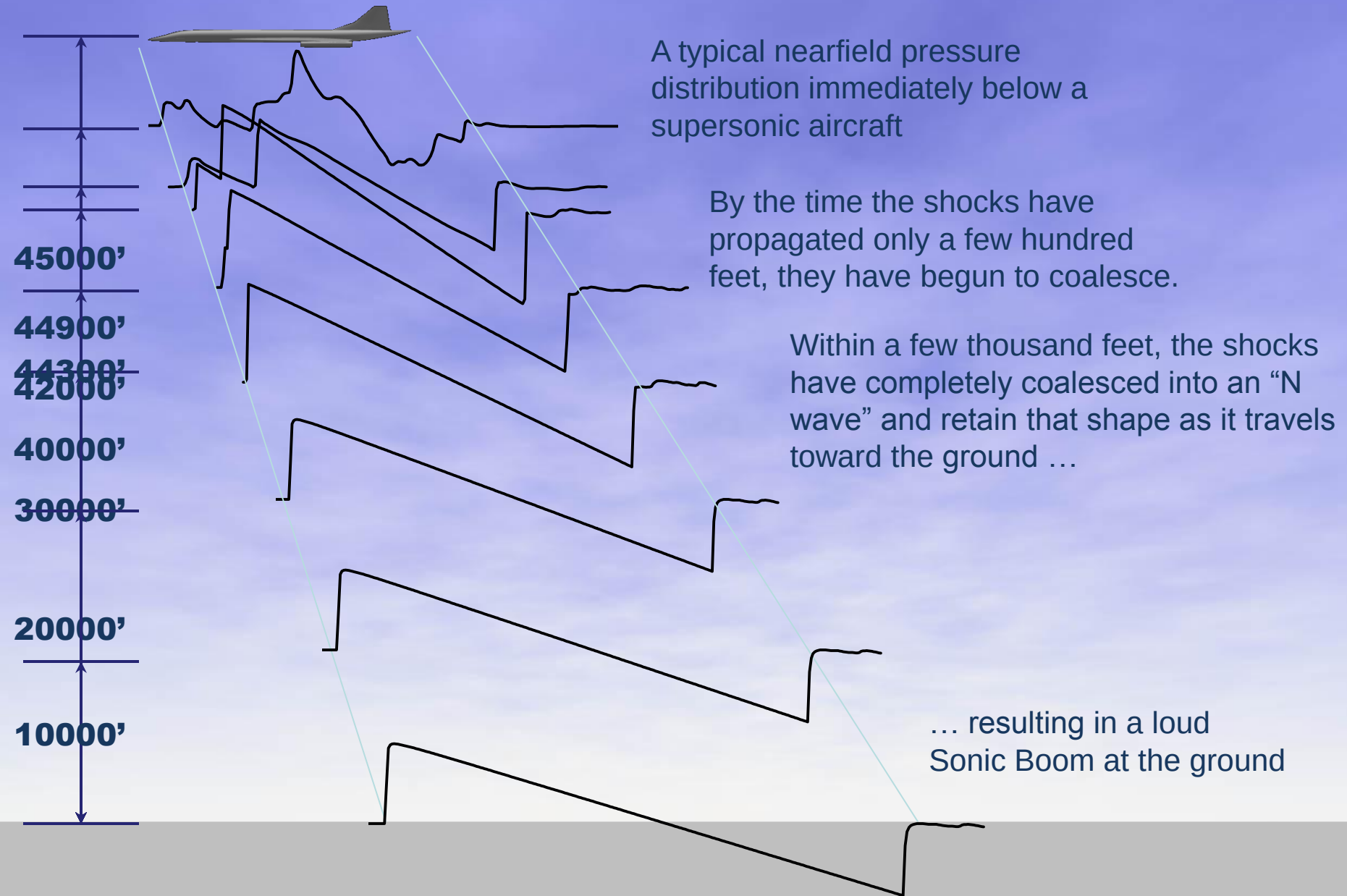
Historic sonic boom highlights



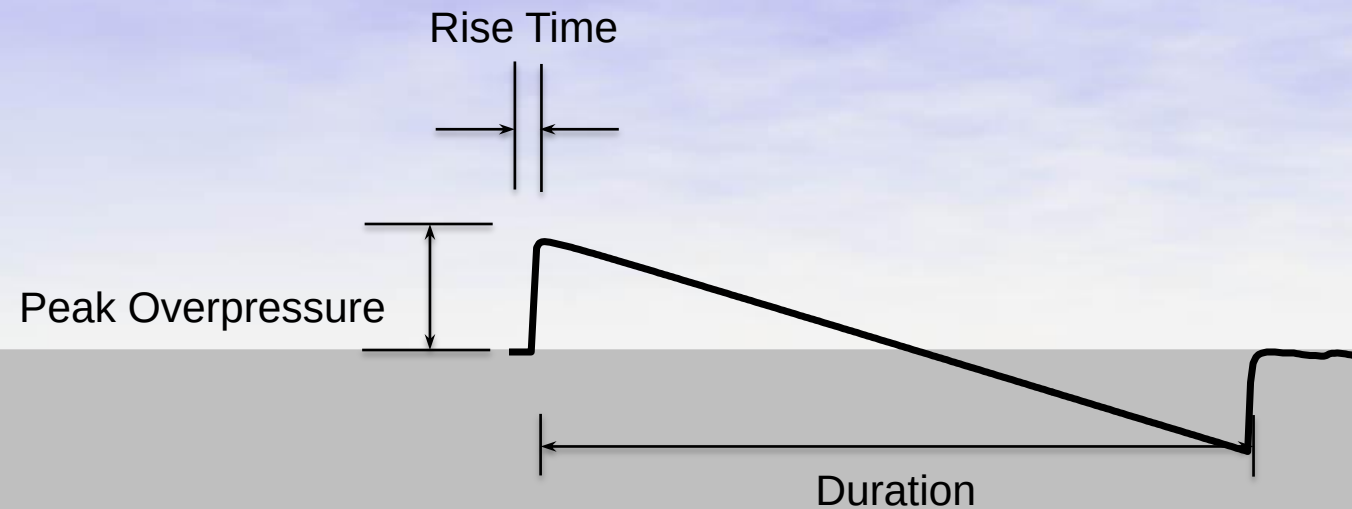
- 1947 Chuck Yeager first flies supersonically
- 1964 Sonic boom tests in OK end prematurely due to negative public reaction
- 1976 – 2003 Concorde flies supersonically over Atlantic Ocean
- 1990s NASA High Speed Research Program
- 2003 Shaped sonic boom demonstration



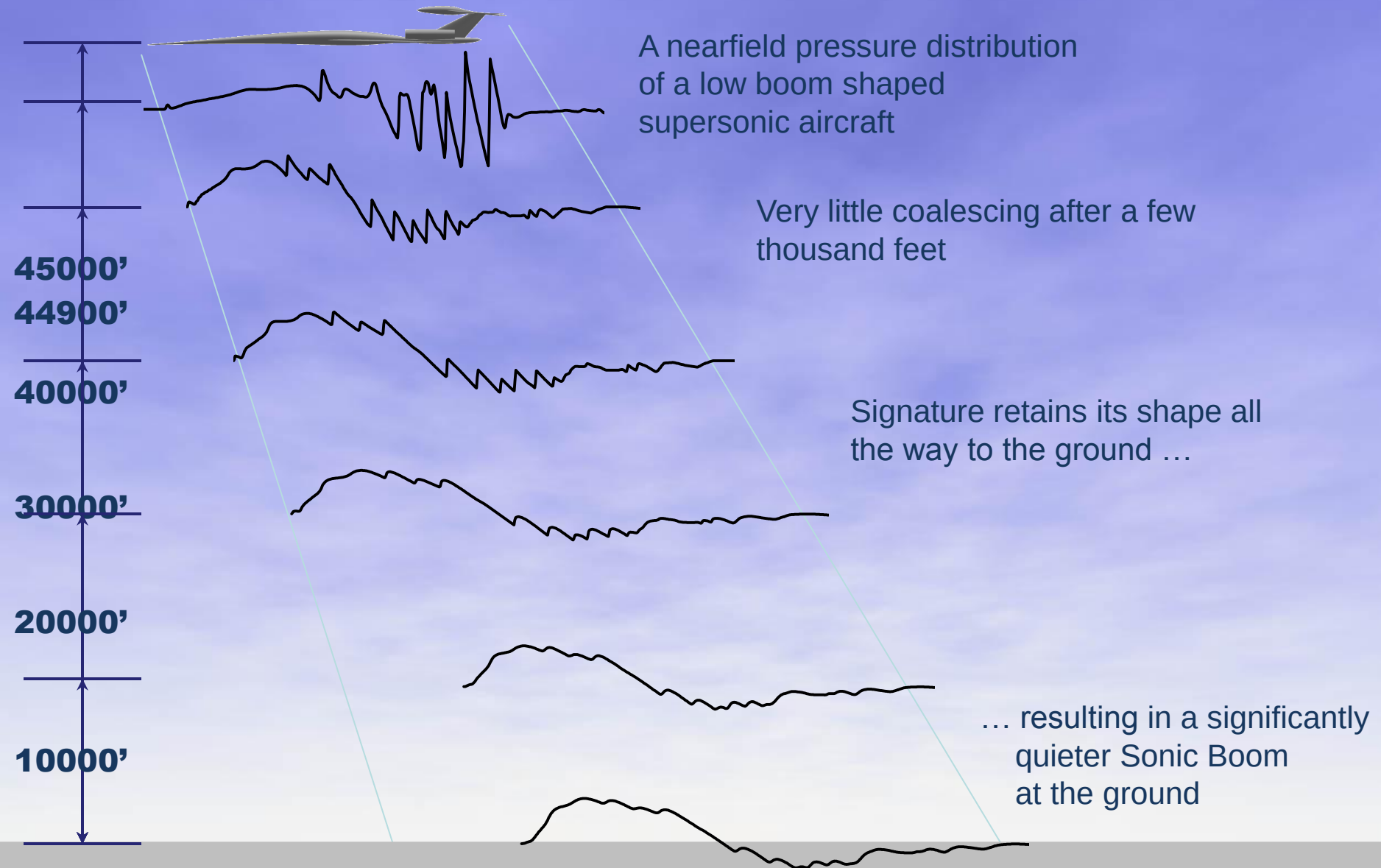
Sonic boom basics: N-wave



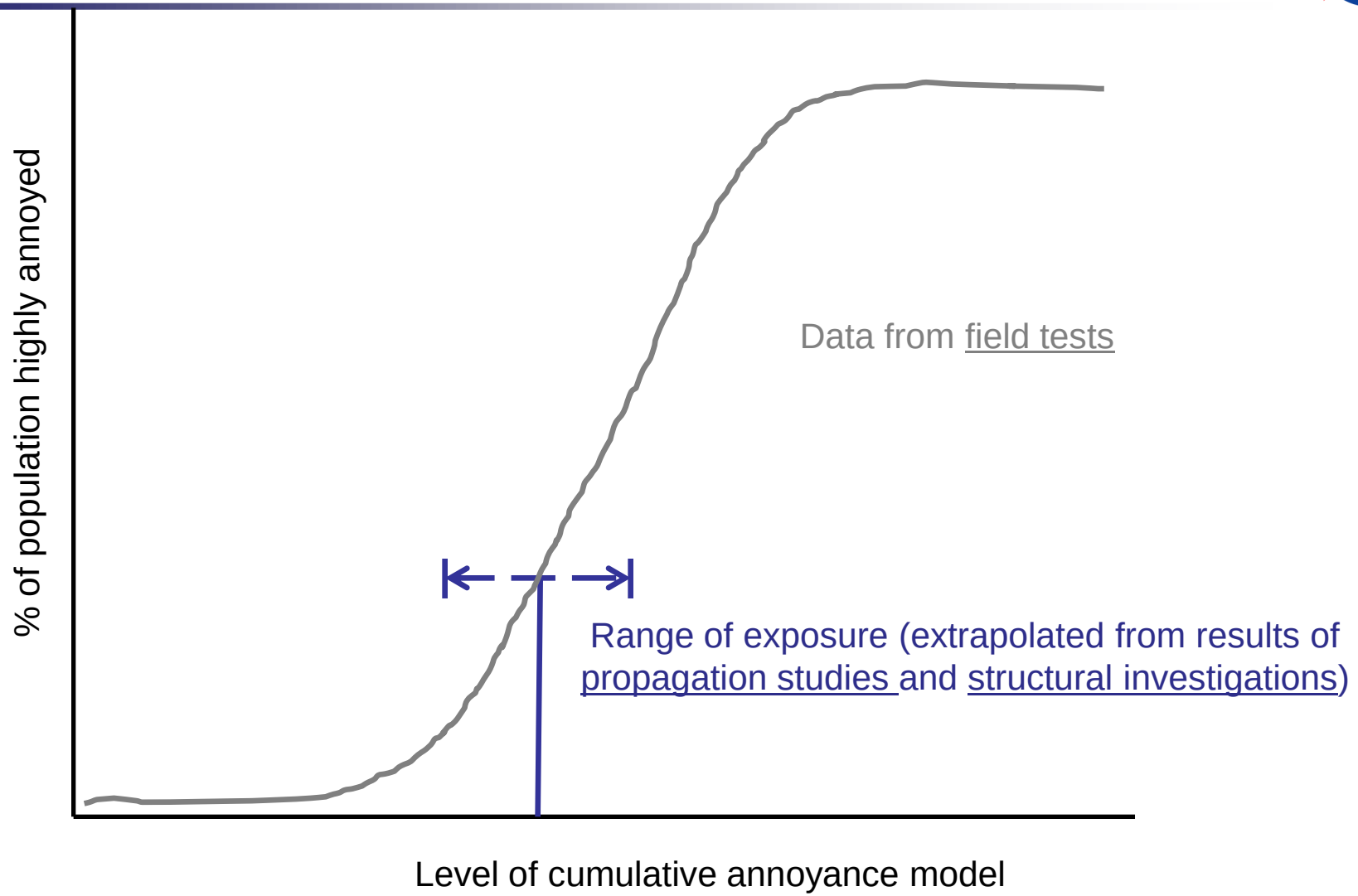
Sonic boom basics: factors affecting loudness



Sonic boom basics: shaped sonic boom

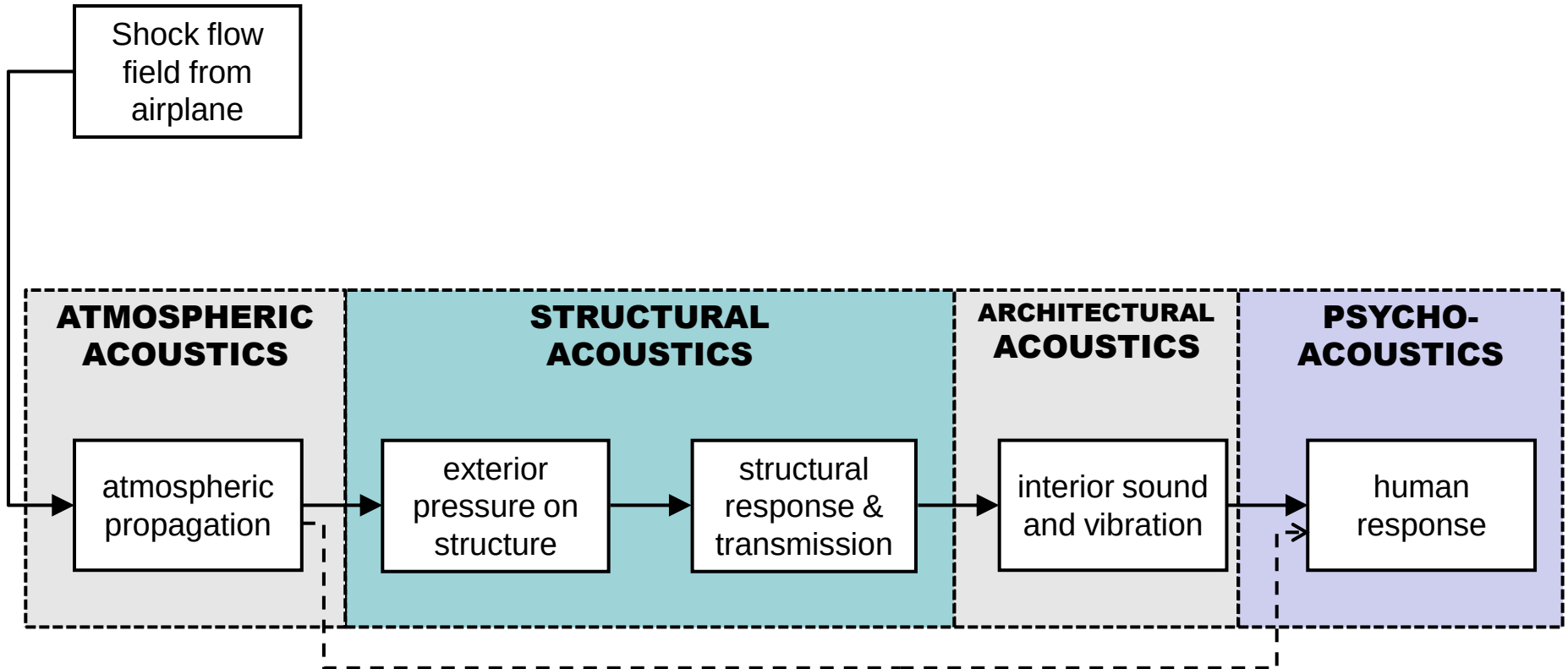


Research goal: dose-response relationship



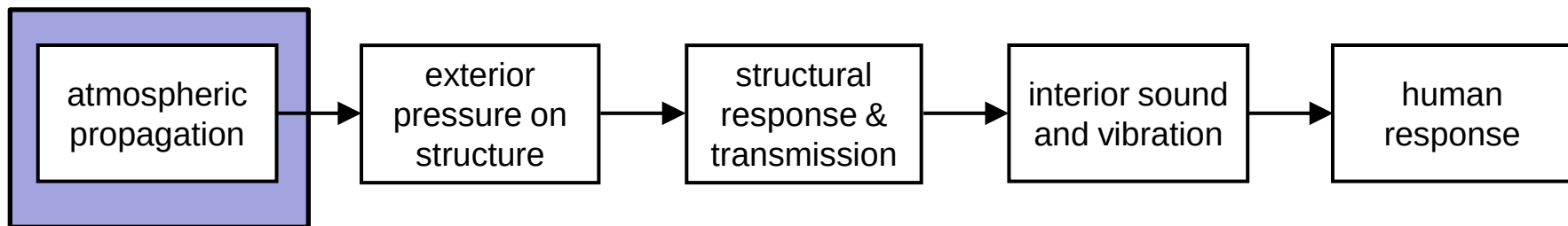
(based on single-event model from lab studies and energy addition theory)

Research approach



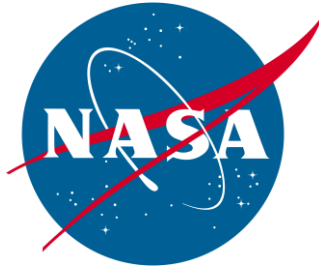
- Goal: develop validated models for each block
- Methods: theory, lab experiments, field experiments

Field Test 1 (May 2011)



Partners

- NASA Langley, NASA Dryden



Dryden
Langley
Marshall



- Boeing
- Northrop Grumman
- Penn State University
- Cessna
- Nagoya University, Japan



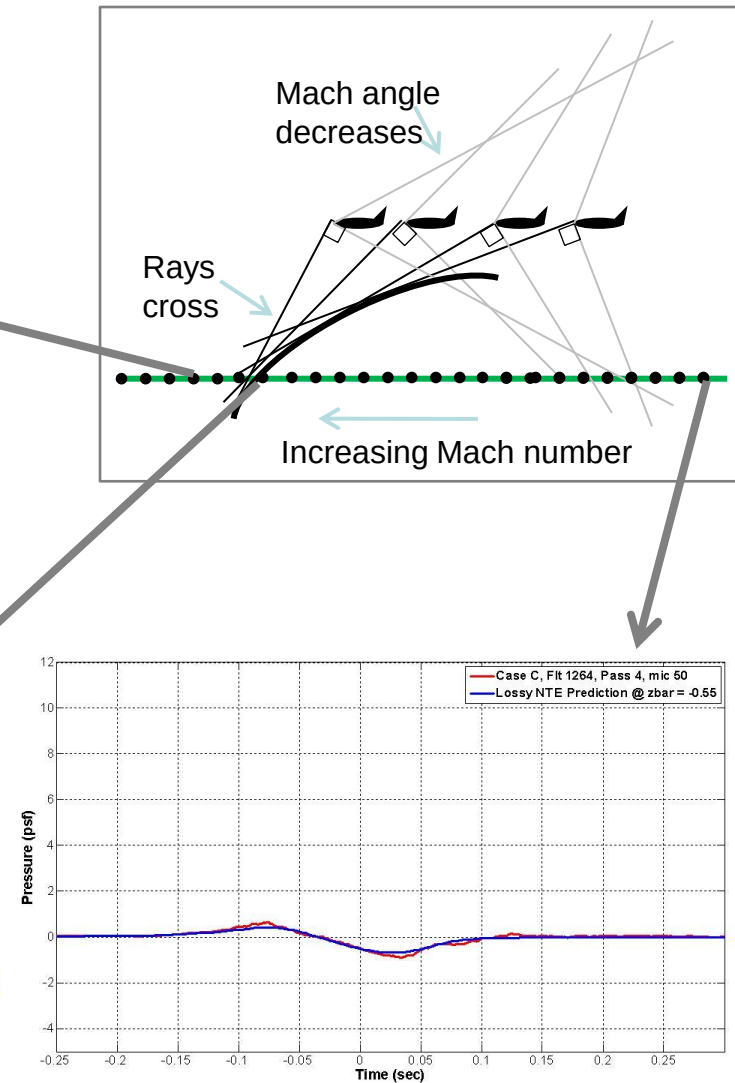
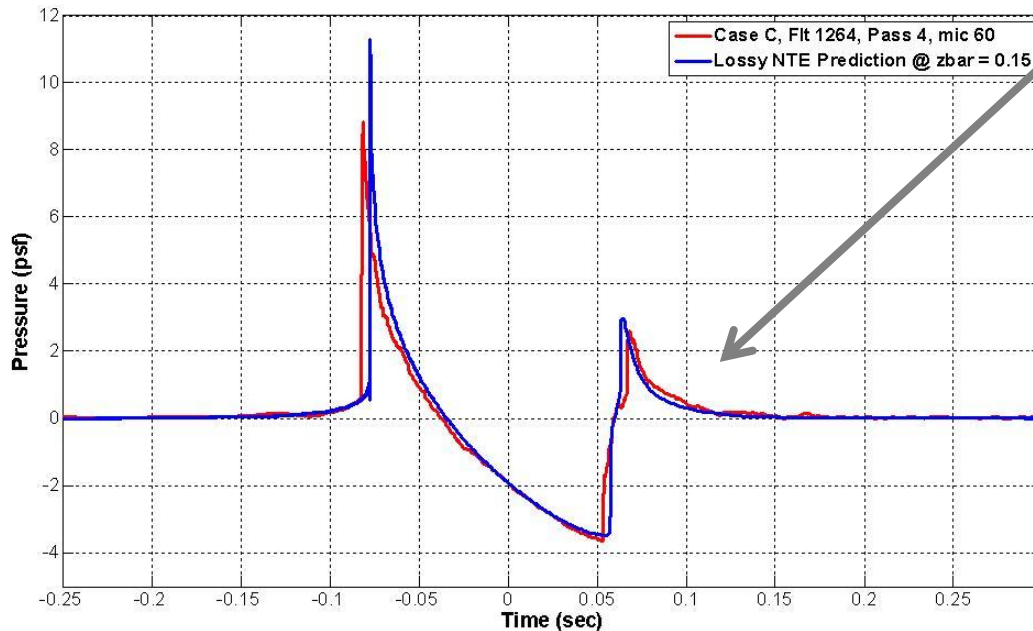
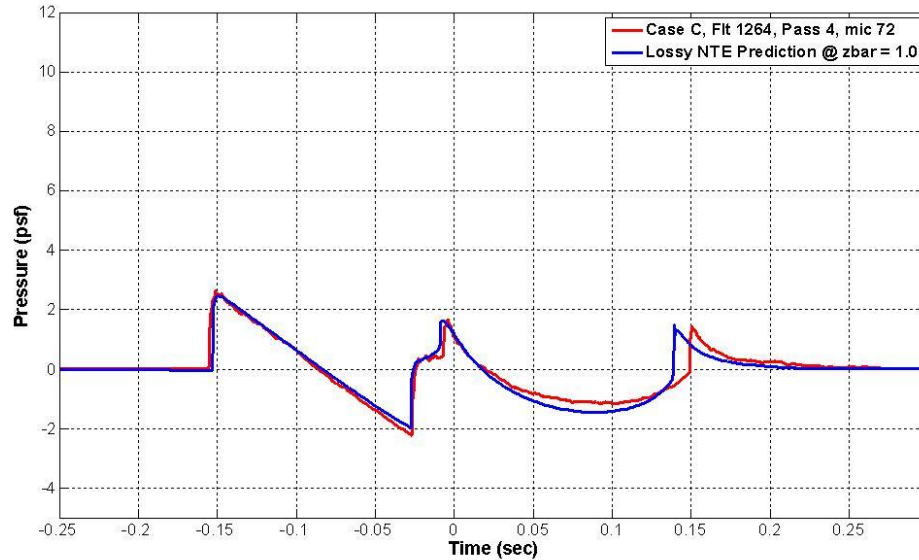
NORTHROP GRUMMAN



Other equipment support: AFRL, NASA Marshall

Other Collaborators: Metro Laser, Seismic Warning Systems

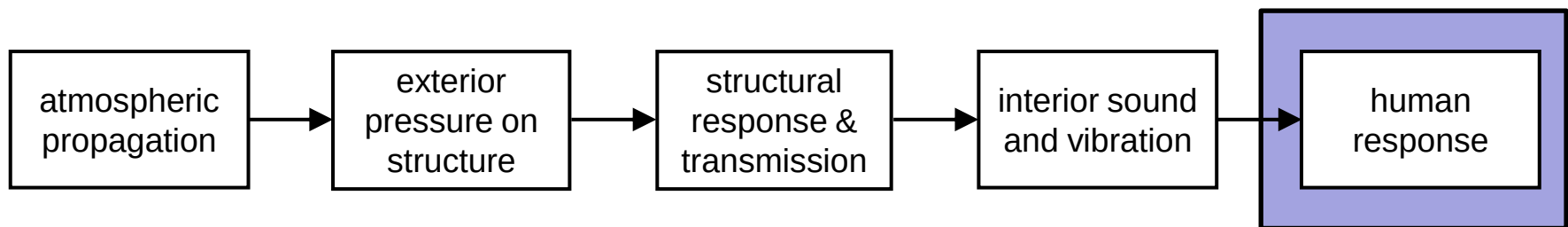
Validate propagation model for focus boom



Pictures from Field Test 1



Field Test 2 (Nov 2011)



Partners



Sonic boom monitors

PENNSTATE



ARL

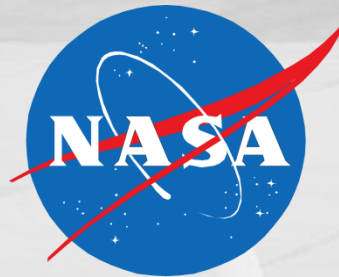
Noise exposure design
Statistical data analysis

**Fidell
Associates**

Smartphone study

wyle
laboratories

NRA leadership & integration
Sonic boom data analysis



**Langley
Dryden**



Recruitment
coordination



TETRA TECH

Subject Recruitment
Coordination with EAFB
Subjective data collection

Gulfstream
A GENERAL DYNAMICS COMPANY

Sonic boom monitors

Field Test 2



- Research Goal: a pilot test to develop community sonic boom test methods
 - objective data acquisition
 - subjective data collection
 - analysis methods

WEB

The screenshot shows a web browser window displaying the "NASA Sonic Boom Study" form. The form includes a scale from 0 to 10 for rating vibration and rattle. The scale is labeled "None" at 0 and "A great deal" at 10. The form also includes a "Back" button and a "Next" button.

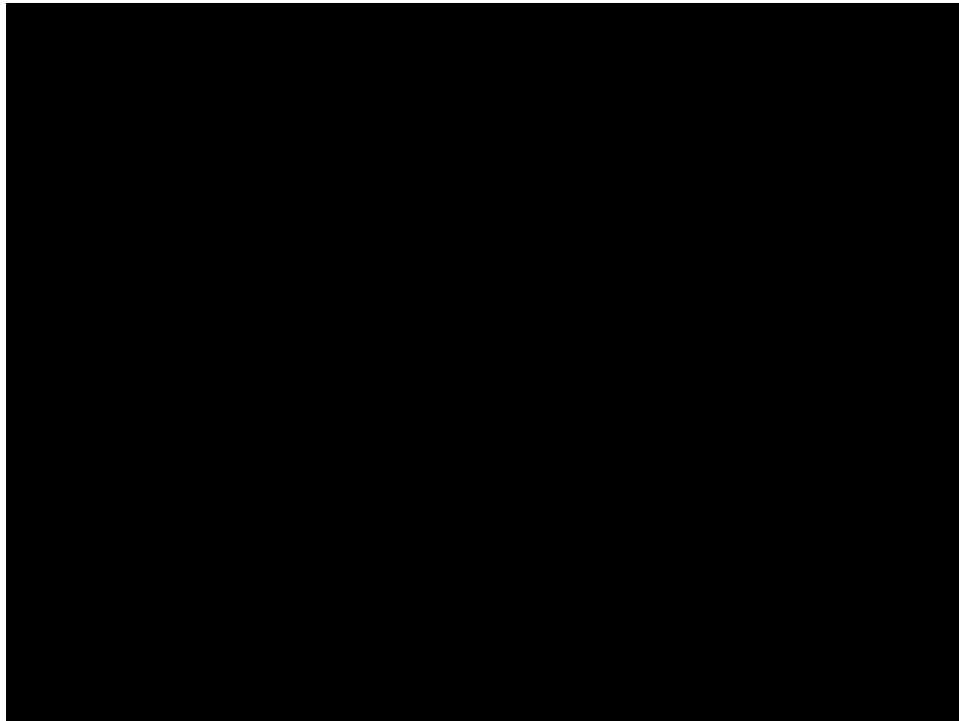
PAPER



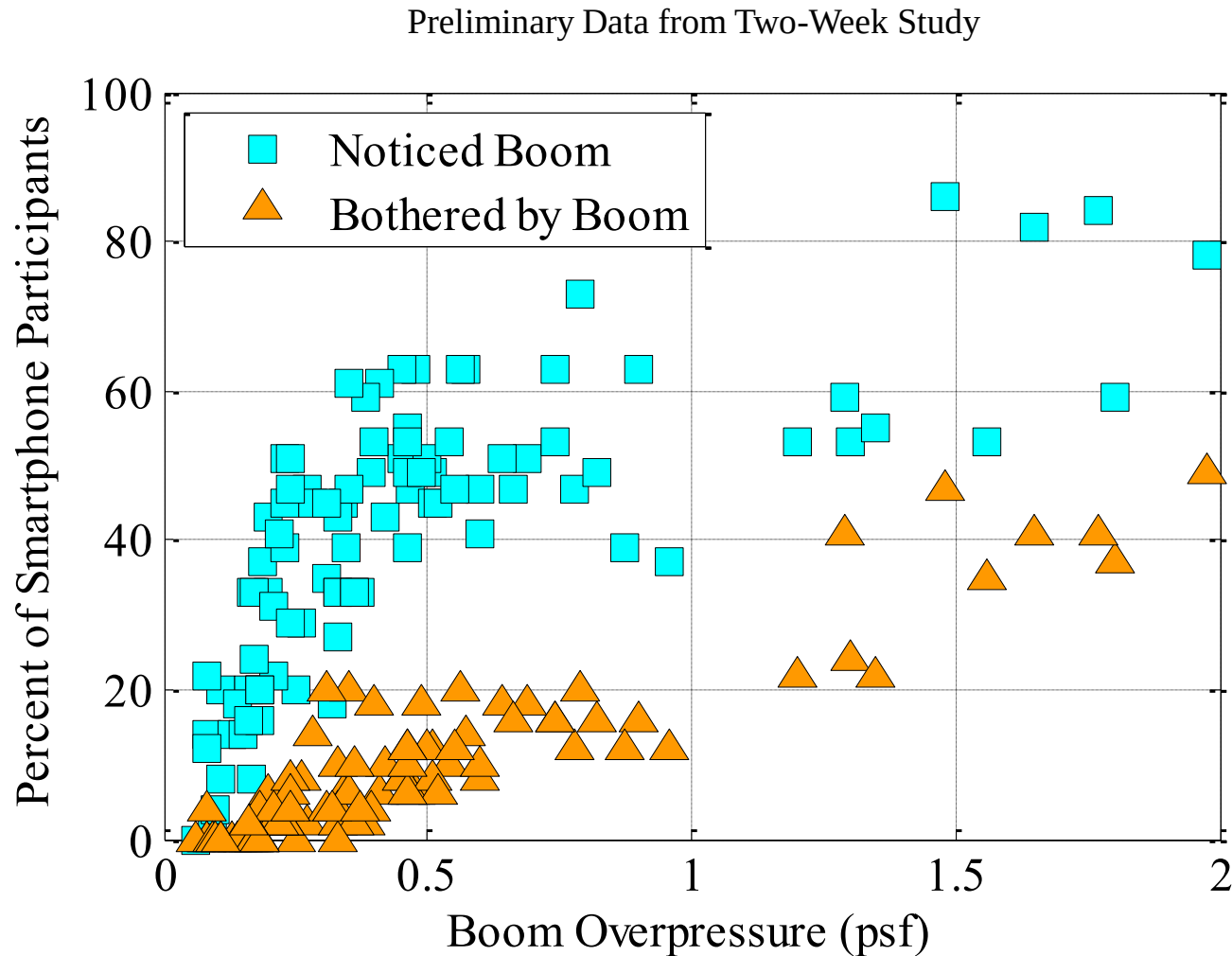
SMARTPHONE

The screenshot shows a smartphone screen displaying the "NASA Sonic Boom Study" app. The app includes a scale from 0 to 10 for rating vibration and rattle. The scale is labeled "None" at 0 and "A great deal" at 10. The app also includes a "Back" button and an "Okay" button. The current value is set to 3, and the slider is positioned at 3. The app is titled "Wyle" and includes the text "Waveforms and Sonicboom Perception and Response".

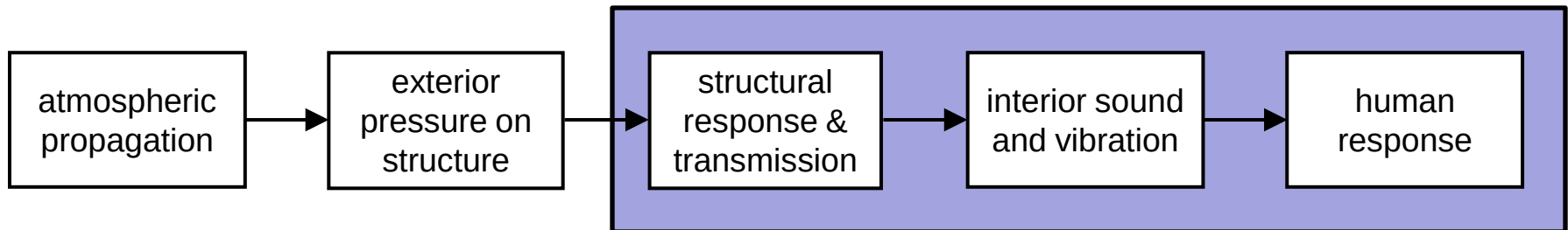
Field Test 2: Video



Field Test 2: Results



Laboratory: Interior Effects Room (IER)



IER animation

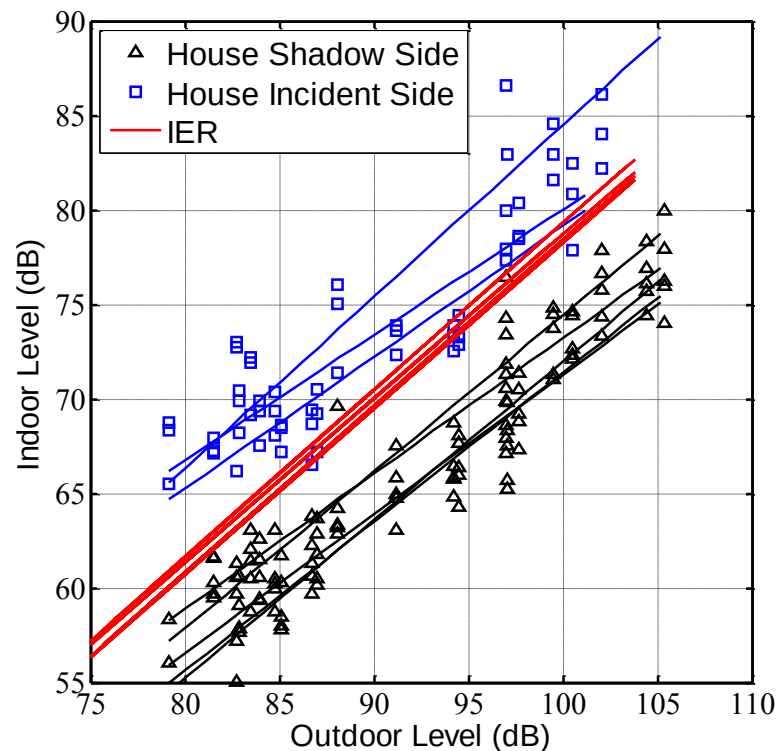


Characteristics of the IER

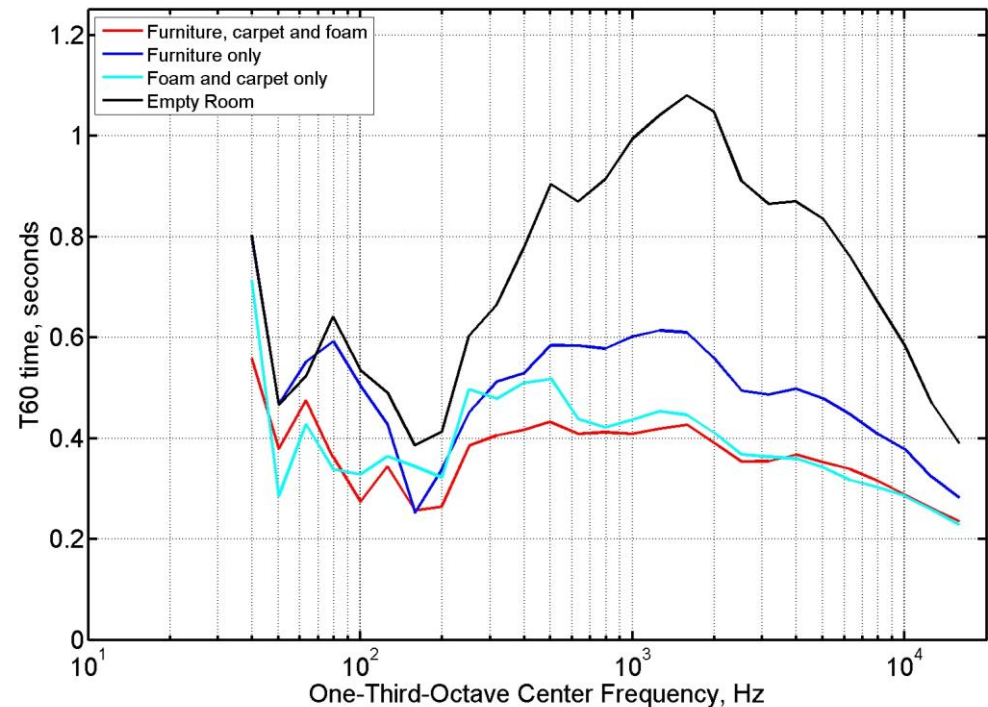


- IER response similar to field data
- Indoor reverberation can be manipulated above 200 Hz

Indoor vs. Outdoor Level



IER Reverberation Time



Uncertainty analysis



- Uncertainty $\equiv$ range of measured values attributable to quantity being measured
- Not *whether* there is uncertainty, but *how much*
- Uncertainty necessary for data comparison
 - within a single lab
 - among labs
 - between lab data and field data



Microphone locations inside IER

Uncertainty procedure (ISO GUM)



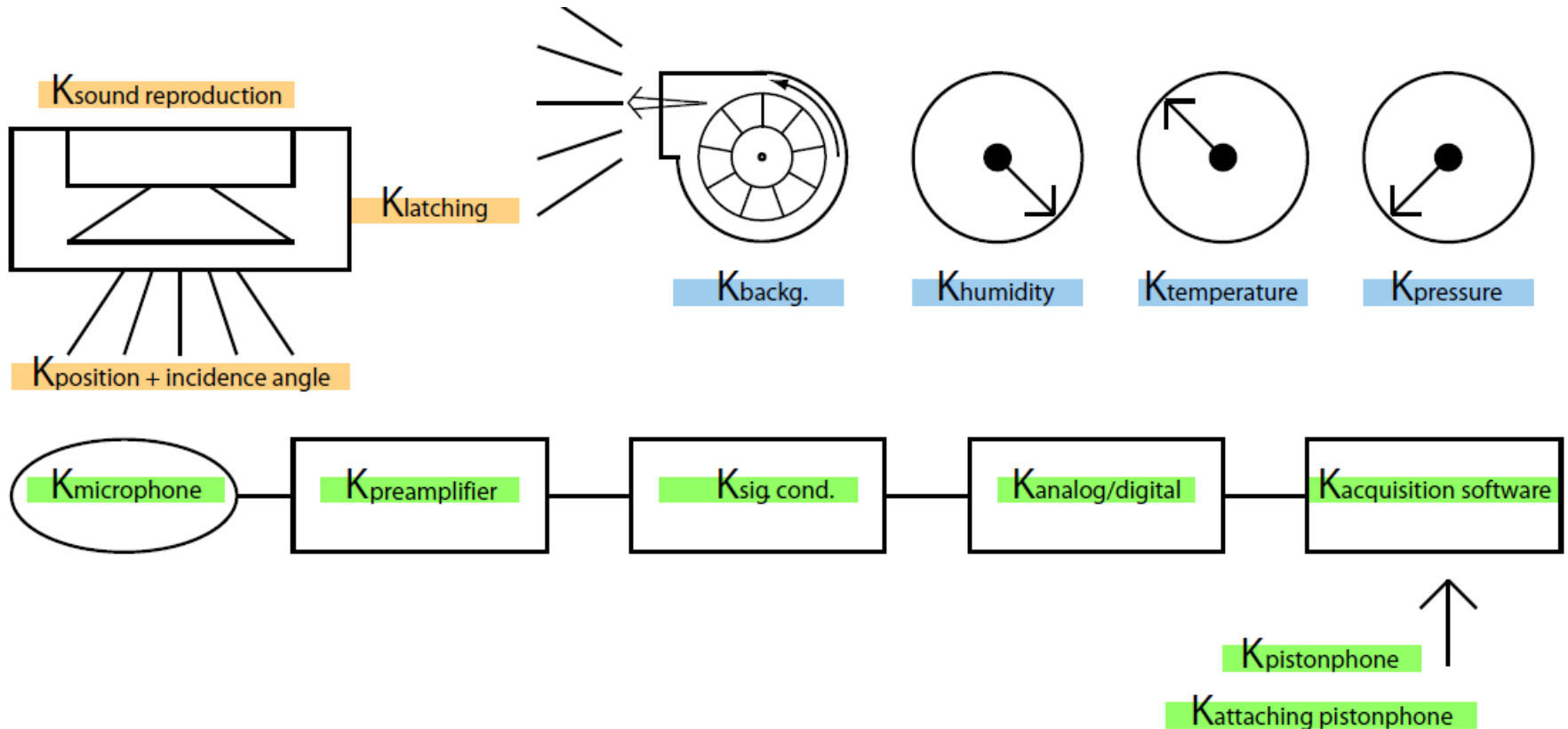
$$Y = f(X_1, X_2, \dots, X_N) \quad u(Y) = \sqrt{\sum_{i=1}^N \left[\frac{\partial f}{\partial X_i} u(X_i) \right]^2}$$

$$v = \frac{d}{t} \left[\frac{\text{m}}{\text{s}} \right]$$

$$u(v) = \sqrt{\left(\frac{1}{t} \right)^2 u^2(d) + \left(\frac{-d}{t^2} \right)^2 u^2(t)} \left[\frac{\text{m}}{\text{s}} \right]$$

$$Y = f(Y', K_1, K_2, \dots, K_N) = Y' - K_1 - K_2 - \dots - K_N$$

Uncertainty components



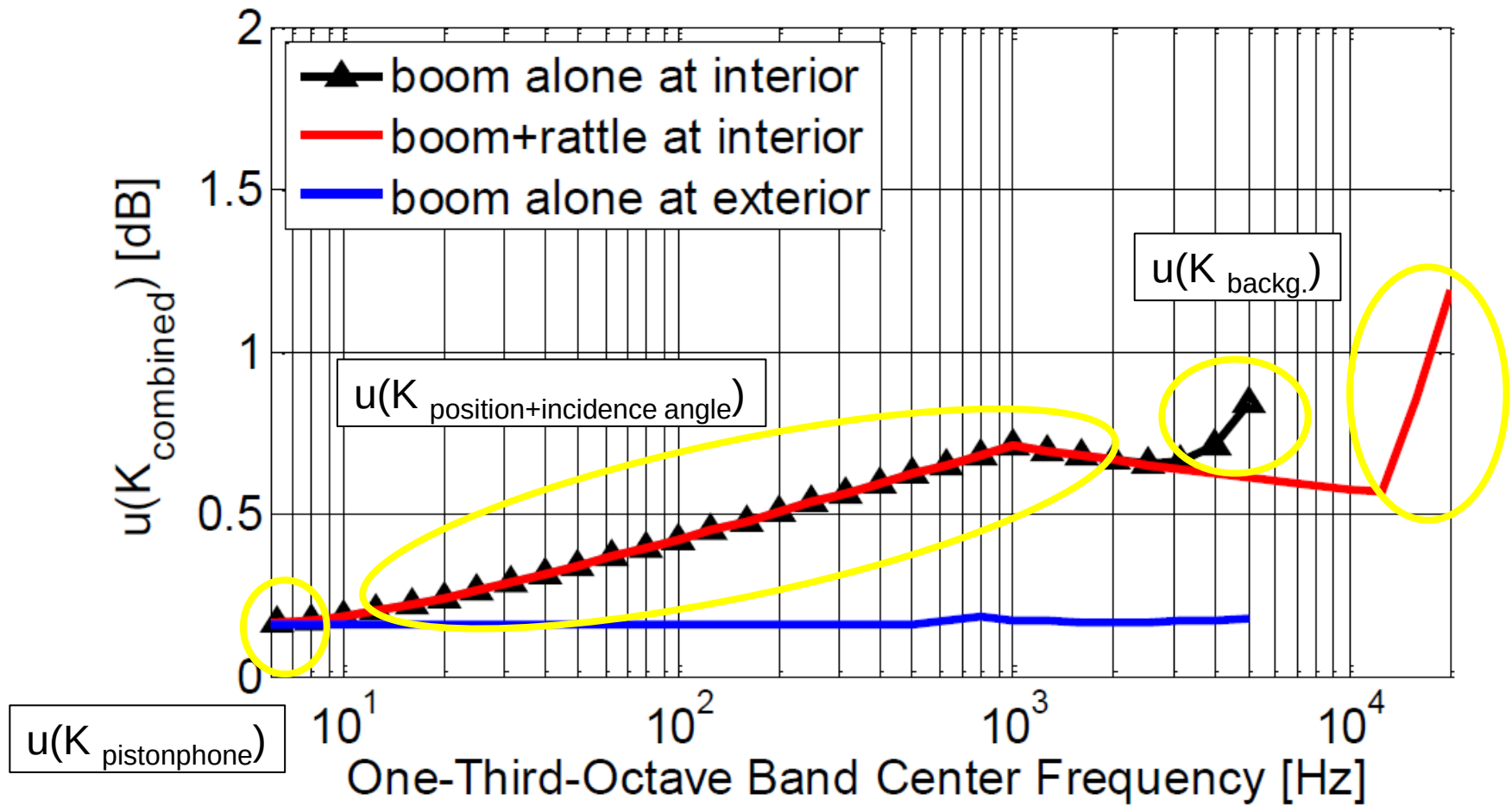
$$L_p = L'_p - K_{\text{met}} - K_{\text{backg.}} - K_{\text{mic+preamp}} - K_{\text{sig. cond.}} - K_{\text{A/D}} - K_{\text{acquisition software}} - K_{\text{sound reproduction}} - K_{\text{latching}} - K_{\text{position+incidence angle}} \text{ [dB]}$$

Uncertainty budget

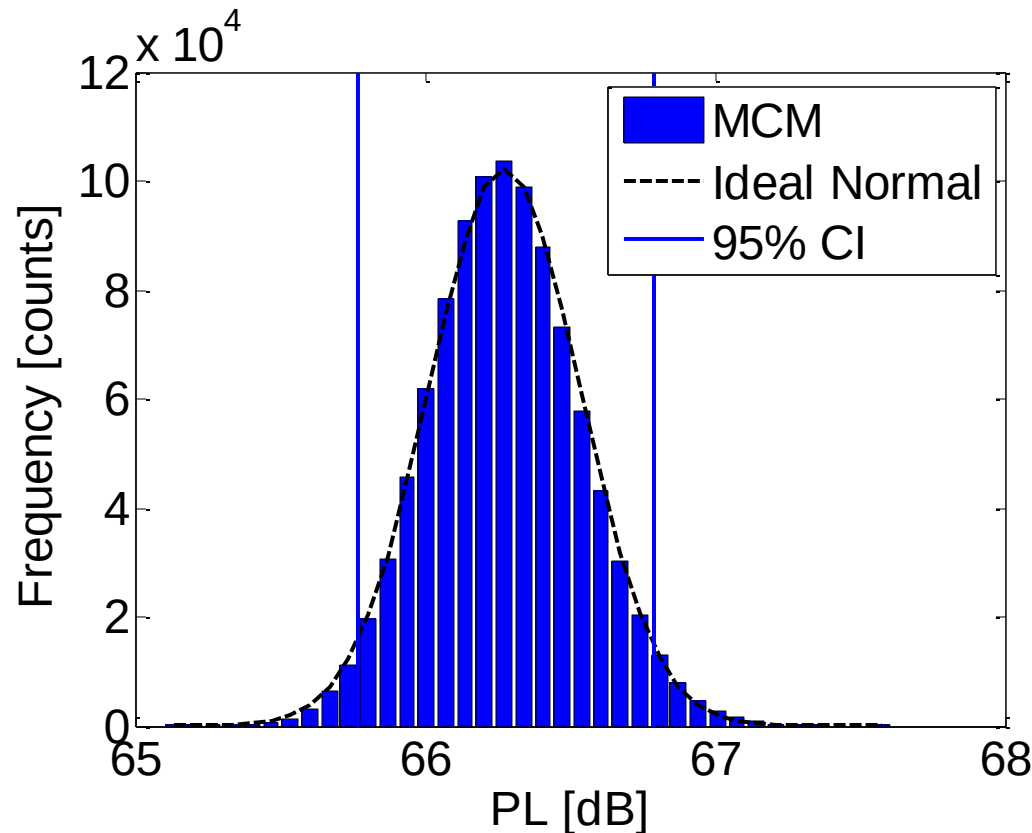


Correction Component		Distribution	Analysis Type	Uncertainty (1σ) For Type 4193 Microphone ^A
Environmental Factors				
Sound Radiation	Temperature	Uniform $\bar{x} = 22\text{ }^{\circ}\text{C}$ $\sigma = 5.8\text{ }^{\circ}\text{C}$, estimated	B	0.09 dB ¹¹
	Pressure	Normal $\bar{x} = 1013.25\text{ hPa}$ $\sigma = 8.07\text{ hPa}$ ⁶	B	0.08 dB ¹¹
	Humidity	Uniform $\bar{x} = 50\%$ $\sigma = 29\%$, estimated	B	0.015 dB ¹¹
	Background	Normal, varies with frequency	A	depends on signal to noise ratio
	Door	Normal	A	(Not applicable)
Measurement Equipment				
Microphone	Frequency Response actuator calibration, including preamplifier	Normal, varies with frequency	A	0 - 0.185 dB ⁷ before interpolation
	Temperature	(see above)	B	(Sensitivity coefficient 0.002 dB/ $^{\circ}\text{C}$ ¹¹) 0.012 dB
	Pressure	(see above)	B	(Sensitivity coefficient -0.005 dB/kPa ¹¹) 0.004 dB
	Humidity	(see above)	B	Negligible ¹¹
	Signal Conditioning Amp	Uniform	B	0.050 dB ⁸
	Analog/Digital Converter	Uniform	B	0.0035 dB ⁹
	Attaching Pistonphone	Normal	A	0.01 dB
	Pistonphone (and Acquisition Software)	Normal	A	Random error $\sim 0.007\text{ dB}$
		Uniform	B	Systematic error $\sim 0.15\text{ dB}$ ¹⁰
Measurement Setup				
	Sound Reproduction	Normal, varies with frequency	A	$\leq 0.045\text{ dB}$
	Latching	Normal, varies with frequency	A	$\leq 0.03\text{ dB}$ (interior) $\leq 0.08\text{ dB}$ (exterior)
	Position and Incidence Angle (interior only)	Normal, varies with frequency	A	$\leq 0.69\text{ dB}$ (envelope)

Combined uncertainty of sound levels (1σ)



Uncertainty propagated to noise metric



- Uncertainty (2σ) based on Monte Carlo Method (MCM) procedure
 - interior (boom alone): 0.6 [dB PL]
 - interior (boom + rattle): 0.5 [dB PL]
 - exterior: 0.2 [dB PL]

Summary



- Field Test 1: Focus boom model validation



- Field Test 2: Community response pilot test



- Lab Study: Uncertainty analysis





Thank You



Acknowledgements: Jacob Klos, Alexandra Loubeau, and Jeffry Ely

Backup Slides



Sonic Boom Simulator

