National Aeronautics and Space Administration

Estimates of residential floor vibration induced by sonic booms

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Acoustical Society of America
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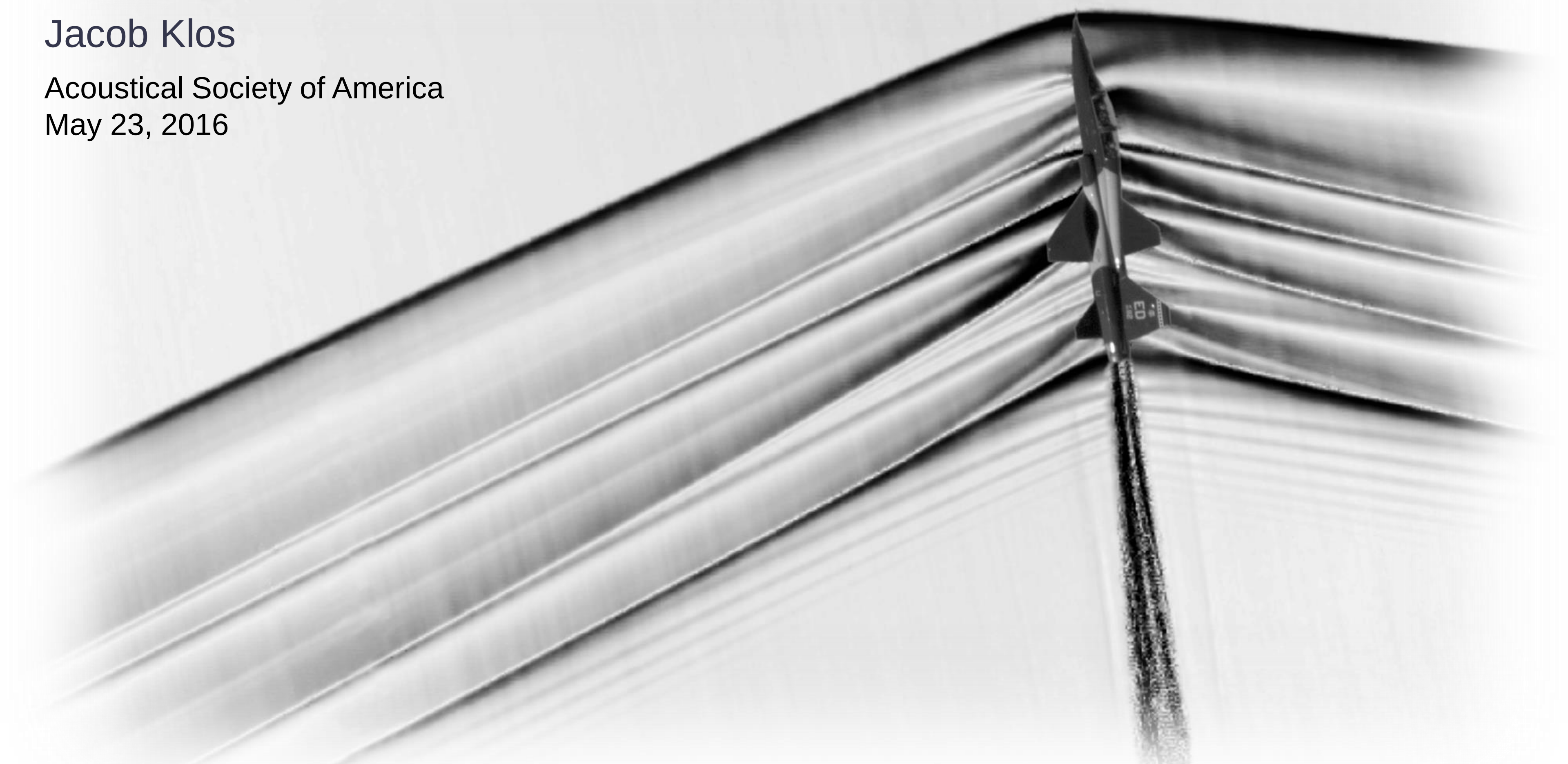
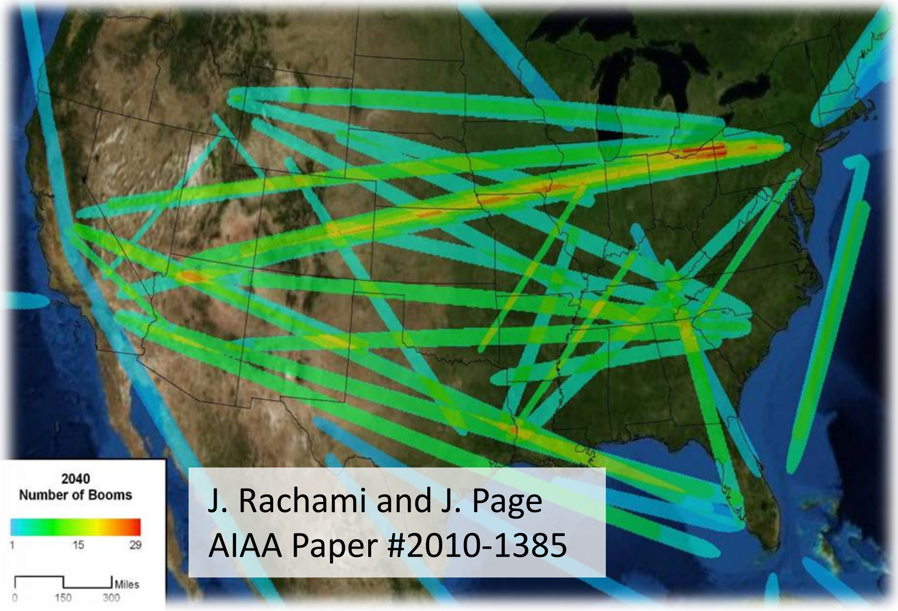


Image Source: http://www.nasa.gov/centers/armstrong/features/shock_and_awesome.html

Motivation and Outline

- Large area exposed
- Study people's subjective reaction to anticipated indoor exposure
- Need estimates of vibration exposure in residential homes



- Brief review of modeling approach
- Review a numerical design of experiment
- Illustrate histograms used to inform a psychoacoustic test
- Discuss comparison to experiments

Why Use Predictions

- Define likelihood of experiencing a particular level
- Relevant experimental data is limited
- Model response to aircraft that don’t yet exist
- Consider response quantities that are not in existing sonic boom literature

Modeling Approach

- Developed at Virginia Tech (PI: Ricardo Burdisso)
- Exterior loading: edge diffraction toolbox[1] (Peter Svensson)
- Structural response and interior acoustics: transient modal interaction model[2]
  - Formulated in terms of uncoupled Eigen solutions
  - Coupled indoor vibro-acoustic response
  - Structural envelope: Eigen solution of an in vacuo orthotropic plate[3] finite element model
  - Output is time domain interior pressure and/or structural vibration

[1] Edge Diffraction Toolbox: http://www.iet.ntnu.no/~svensson/software/

[2] **Remillieux, et. al.**, *Transmission of sonic booms into a rectangular room with a plaster–wood wall using a modal – interaction model*, **J. Sound and Vibration**, **327** (2009) pp 529–556.

[3] **Harne, et. al.**, *Structural-acoustic aspects in the modeling of sandwich structures and computation of equivalent elasticity parameters*, **Thin-Walled Structures**, **56** (2012) pp 1-8.

Numerical Design of Experiment

- Ten factors were analyzed

- An ensemble of 5832 houses
  - Houses had a wood framed floor with crawl space
  - Only considered limp siding material (e.g. no brick or stucco in the present analysis)
  - Windows were closed
  - Doors were not included in the structural model

Factors Influencing Exterior Loading

- Incident waveform: aircraft configurations

  7 low boom aircraft concepts ▌ 2 conventional military aircraft

- Source incidence azimuthal angle

  12 equally spaced angles (30 degree increment)

- Source incidence elevation angle

  30 degrees ▌ 45 degrees

Factors Influencing Physical Properties

- Different floor plans

  Four generic floor plans ▌Edwards ranch ▌Edwards two story

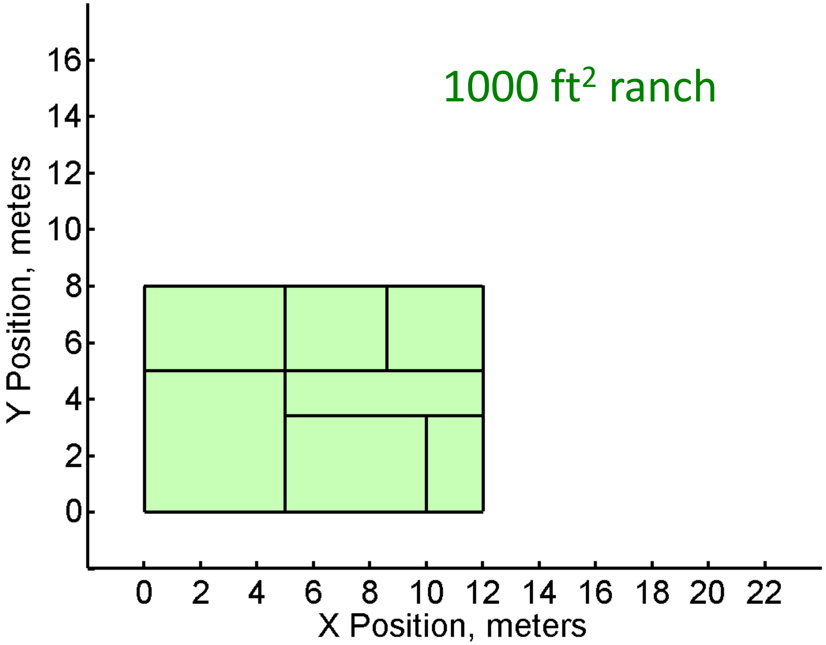
- Exterior wall construction
- Floor joist depth
- Window construction

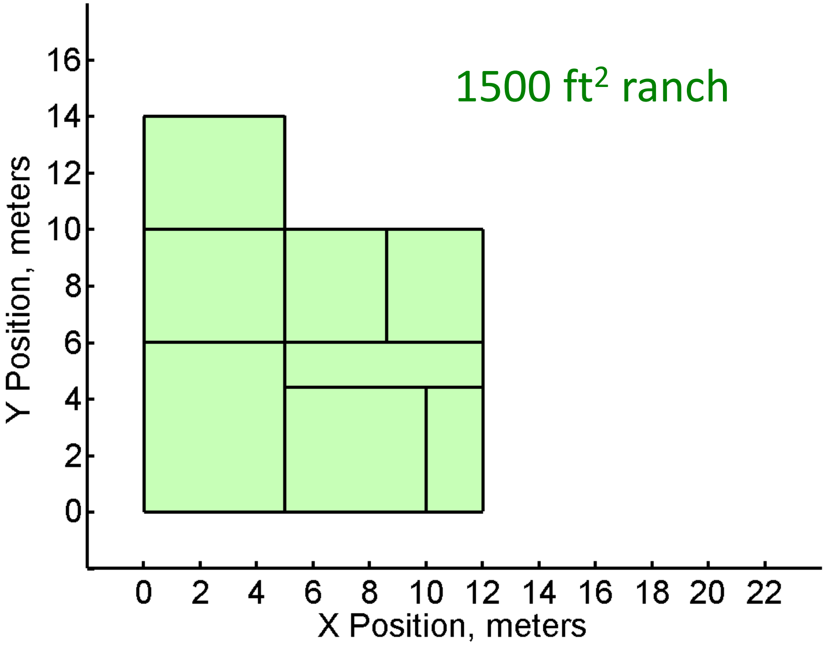
  } Construction

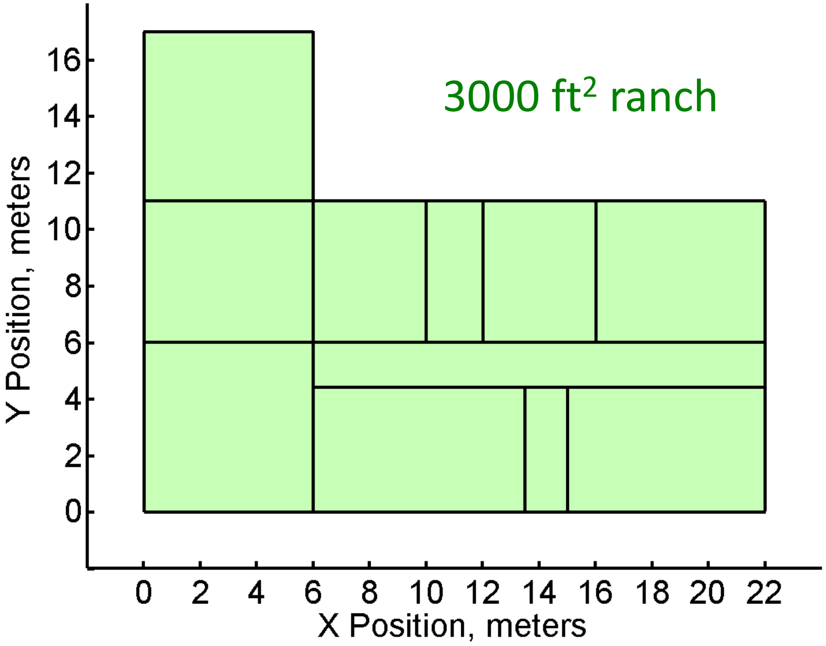
- Structural damping
- Acoustic damping
- Structural stiffness to mass ratio

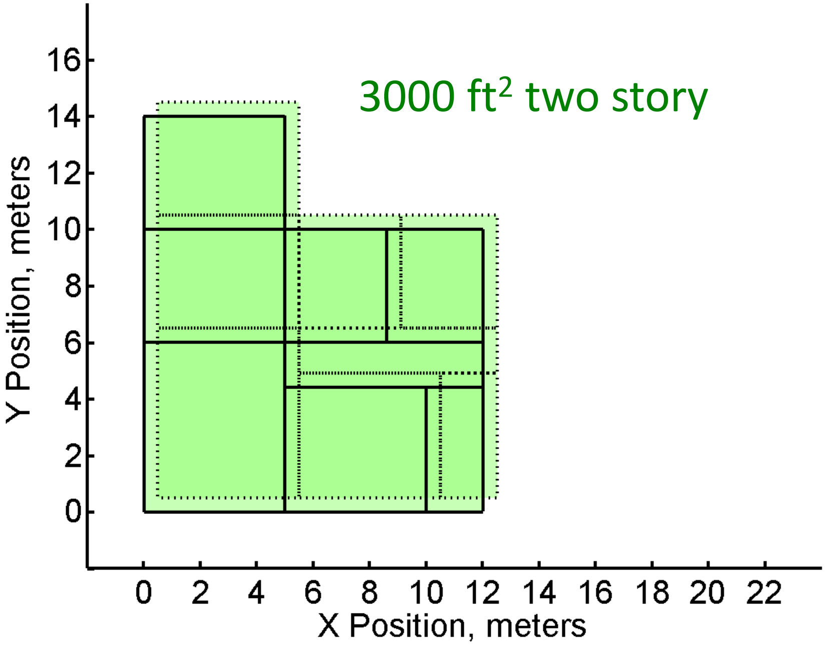
  } Resonances

- Full factorial analysis:
  - 1,259,712 house-source combinations
  - Each with about 100 virtual accelerometers on the floor
  - Analysis took 2 weeks to complete


1000 ft² ranch
Y Position, meters
X Position, meters

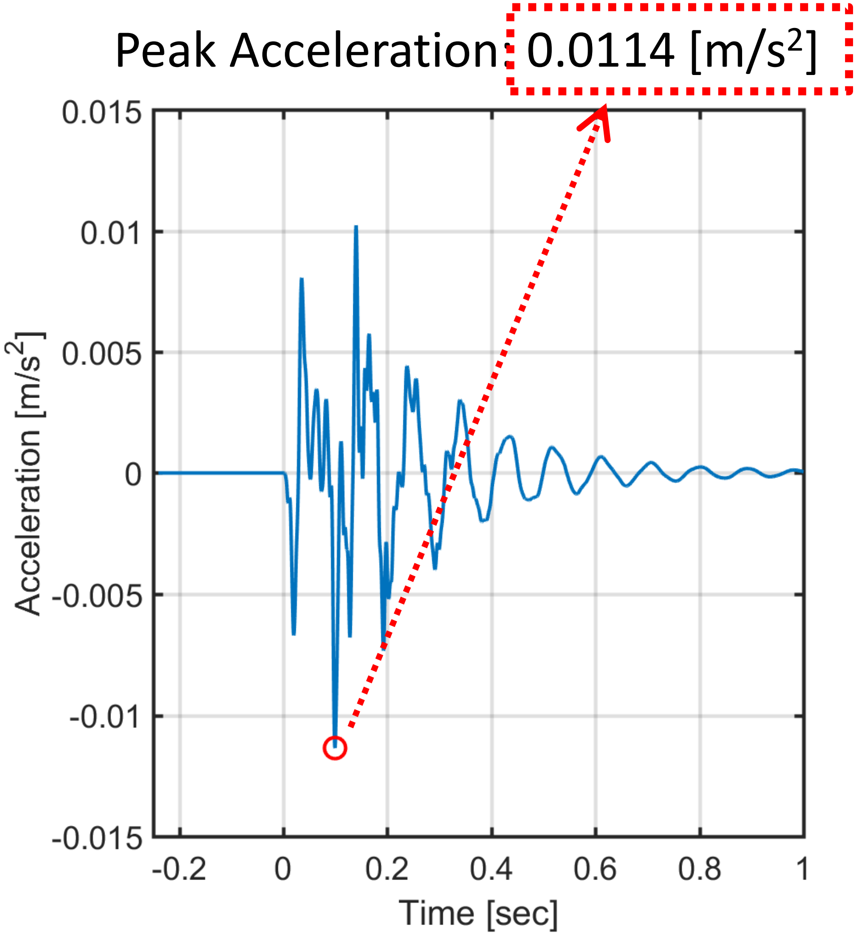

1500 ft² ranch
Y Position, meters
X Position, meters

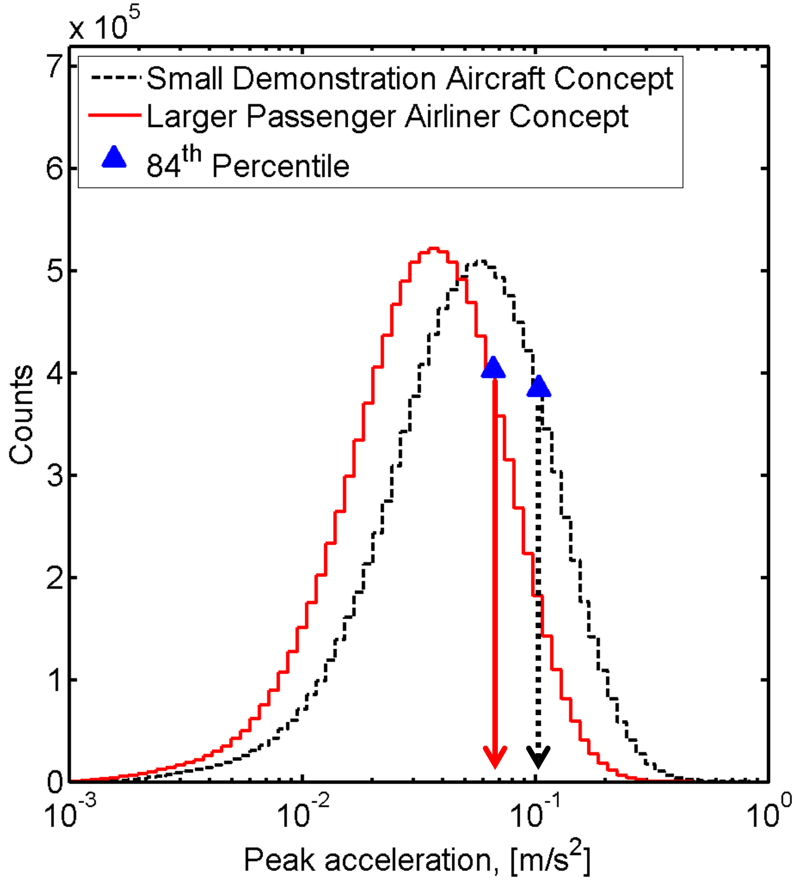

3000 ft² ranch
Y Position, meters
X Position, meters


3000 ft² two story
Y Position, meters
X Position, meters

Example Vibration Distributions

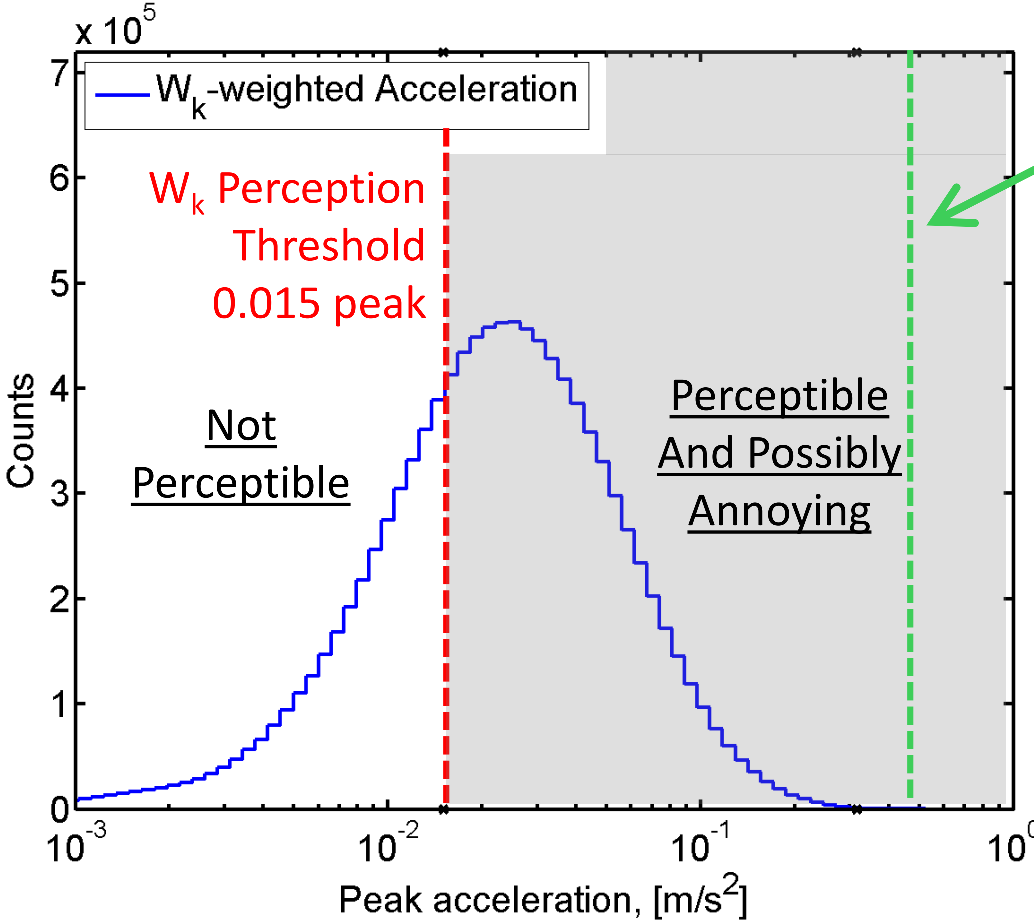
- Fixed outdoor loudness level of 80 dB [perceived level]
- Binned the peak floor acceleration
- Different low boom aircraft concepts





W_k Weighted Peak Acceleration

- ISO 2631 parts 1 and 2 – whole body vibration
- W_k-weighting filter (Psycho-physical metric)



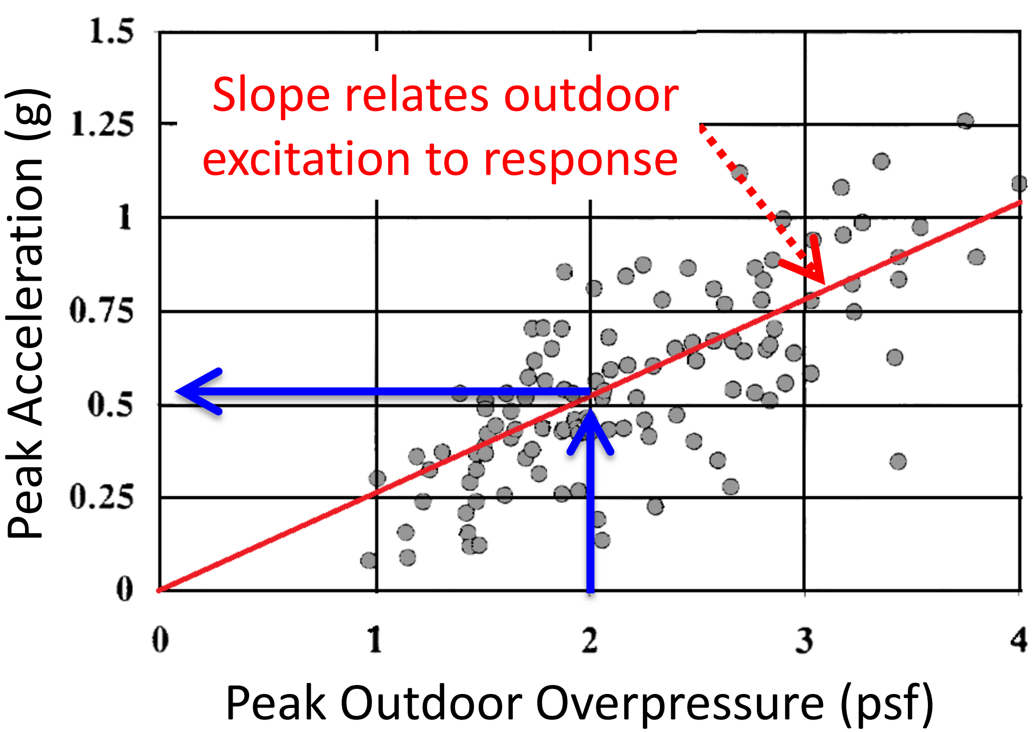
Passenger Ride Discomfort Threshold*
0.315 [m/s^2 RMS]
0.450 [m/s^2 Peak]

* For reference only, not applicable to vibration in buildings

Edwards (1966) Test Data

- USAF and NASA study in 1966 on two purpose built homes
  - Homes had wood framed floors with crawl spaces
  - N-wave excitations from a B-58 and a F-104 military aircraft
- Analysis by Sutherland and Czech (NASA CR #189584, 1992)

Transducer # 311 (Wall Mounted Accel)



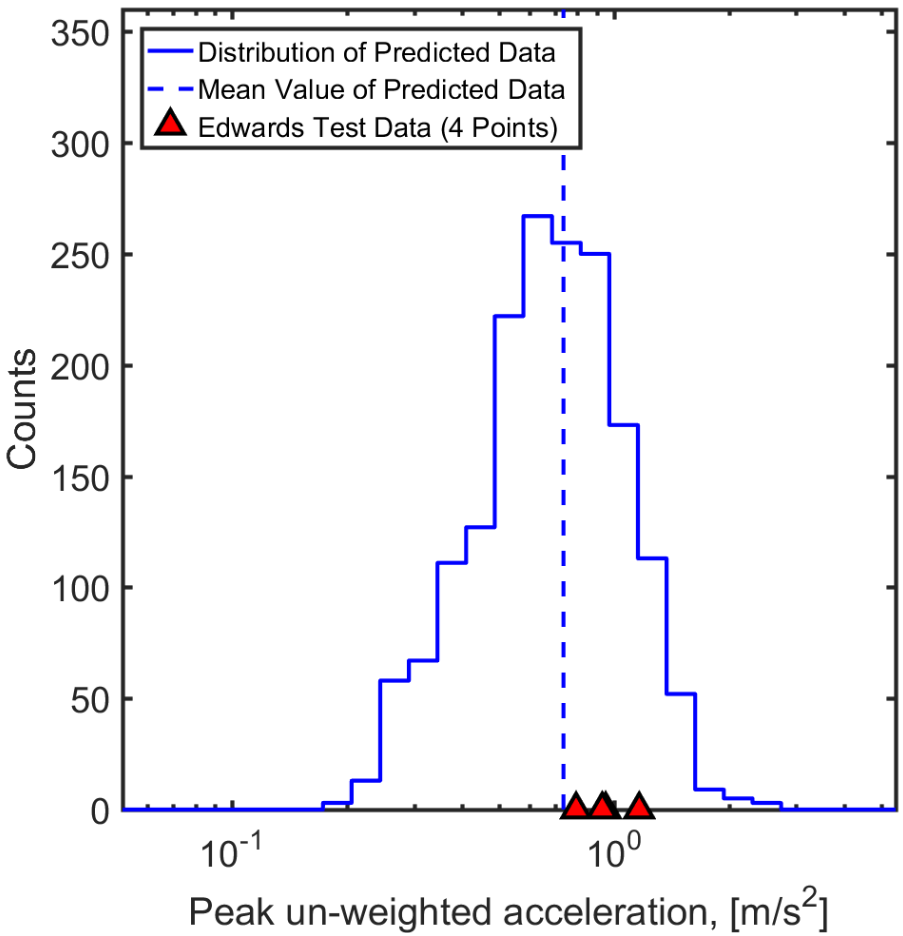
Slopes for floor accels [g/psf]

		Aircraft Type	
		B-58	F-104
Ranch House	Floor Accel #1	0.069	0.090
	Floor Accel #2	0.043	0.062
	Floor Accel #3	0.052	0.058
Two Story House	Floor Accel #1	0.048	0.049
	Floor Accel #2	0.041	0.060

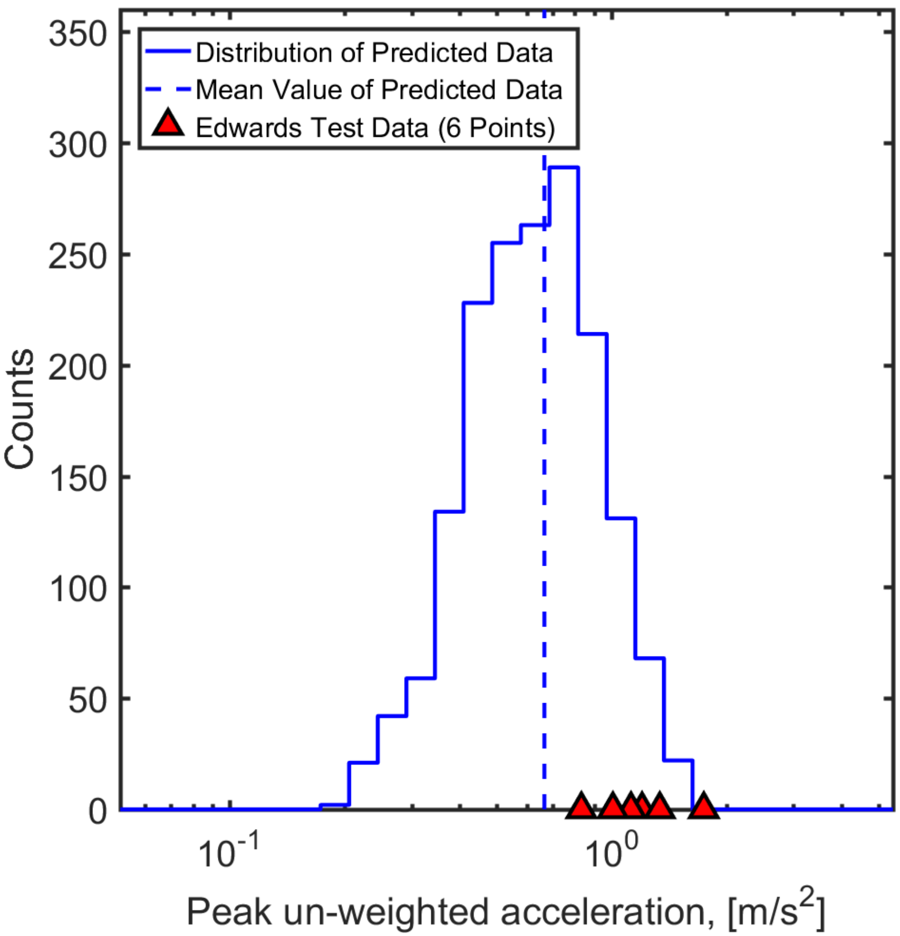
Predicted Vs. Measured Floor Vibration

- Modeled response to a 2 psf N-wave from two military aircraft

Edwards Two Story House

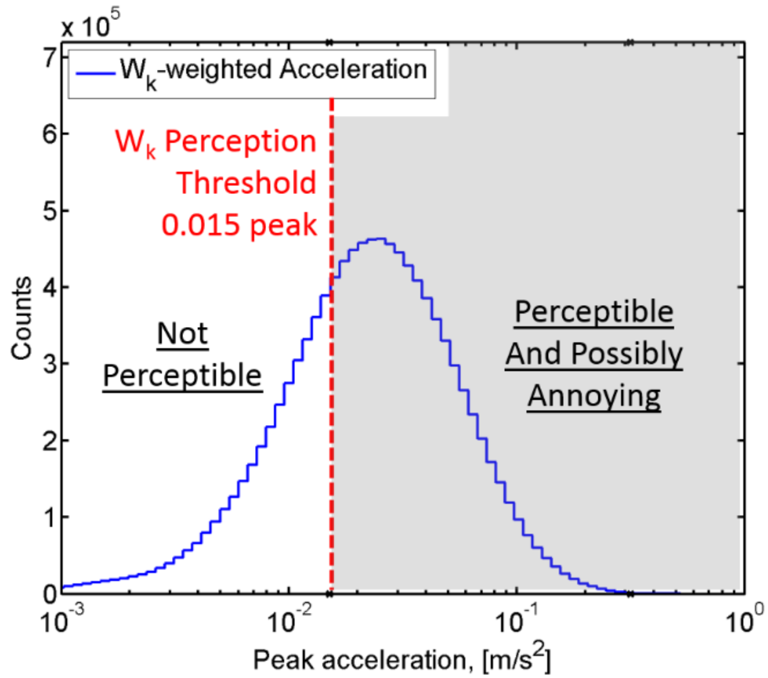


Edwards Ranch House



Summary

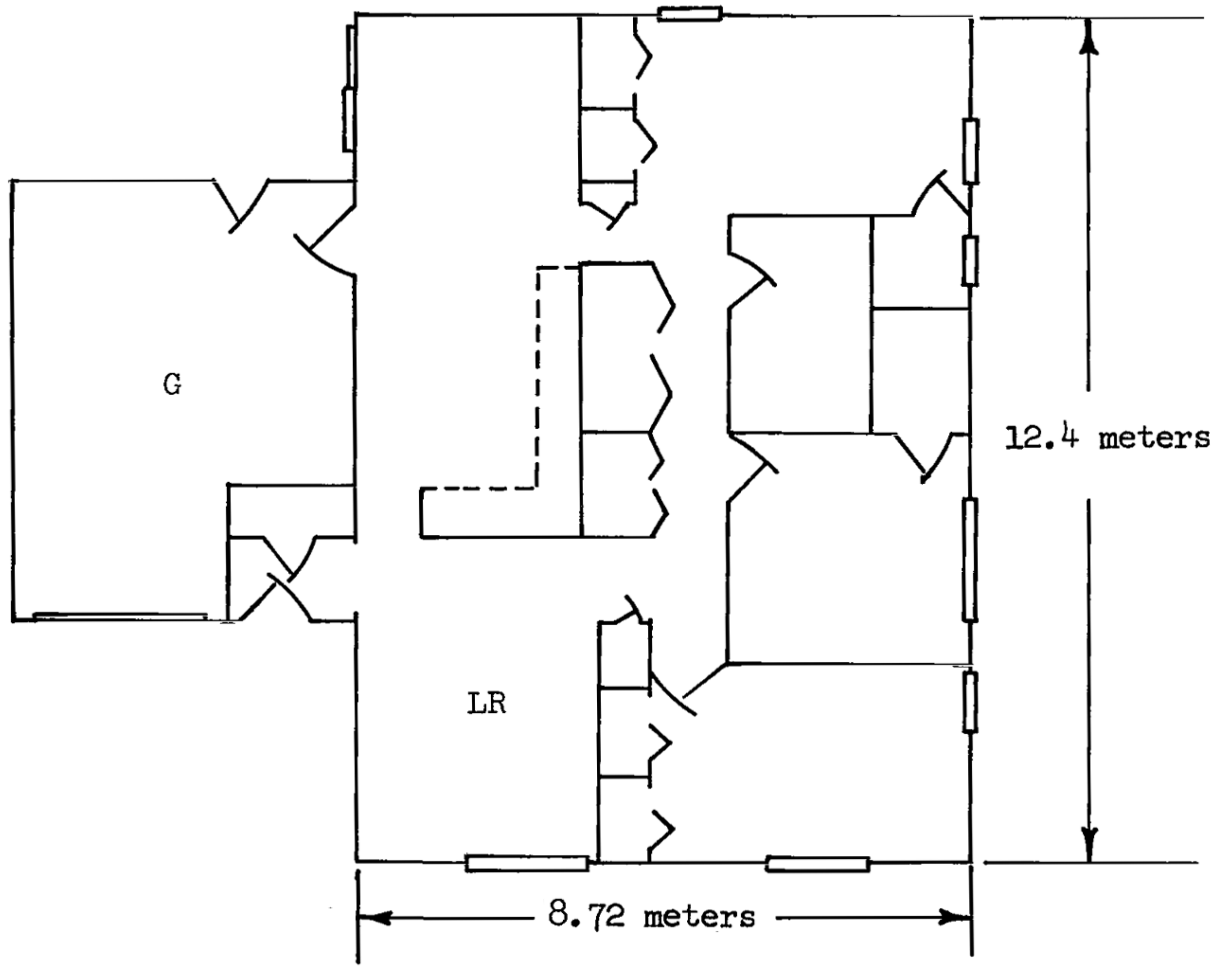
- Estimated vibration exposure in homes for a variety of aircraft
  - Low boom exposure ranges from imperceptible to perceptible
  - Need to study how subjective annoyance varies with anticipated range in levels



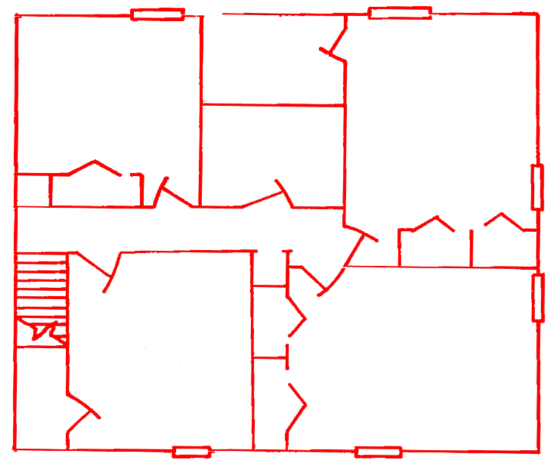
- Favorable comparison of predictions to test for conventional military aircraft
- Floor vibration is a conservative exposure estimate

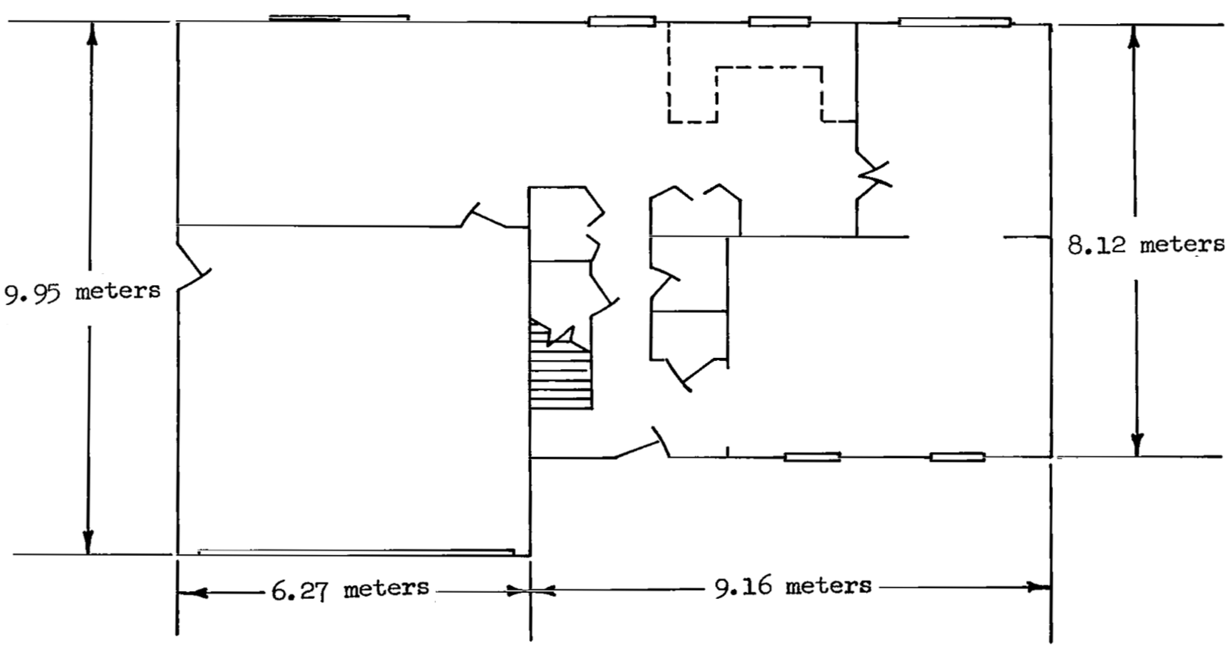
Backup Slides

Edwards Test Houses (1966, Ranch House)



Edwards Test Houses (1966, Two Story House)



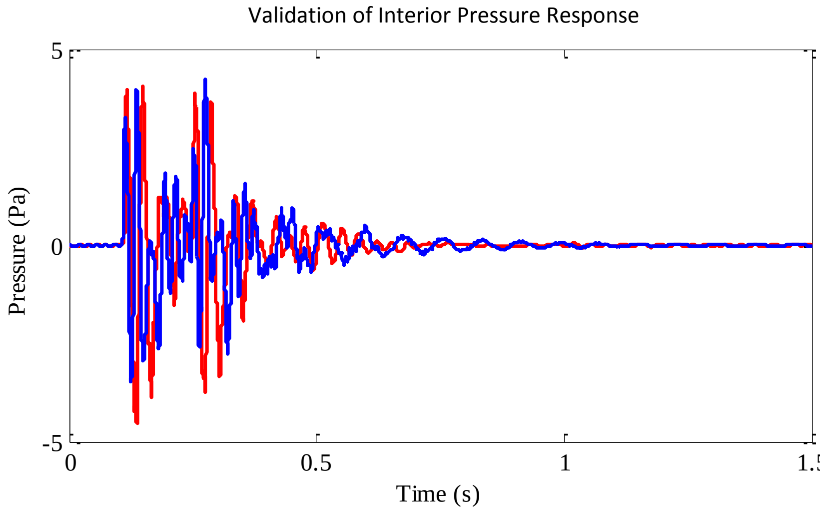


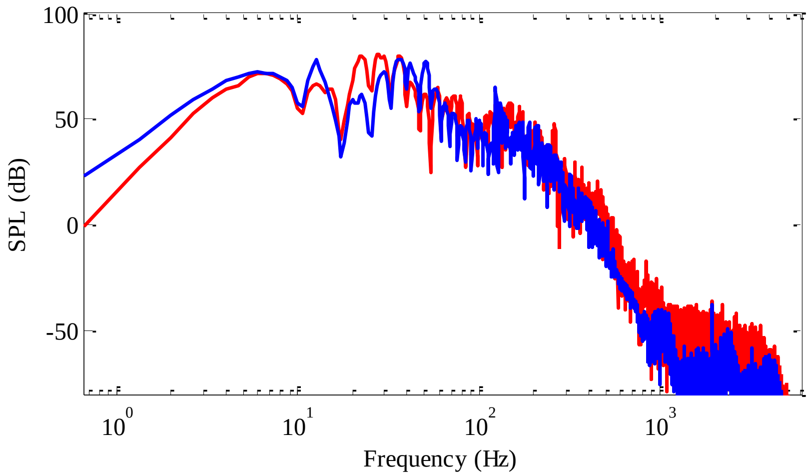
Experimental Validation: Interior Pressure

- Comparisons between measurements in the IER and predictions using VA Tech code were made
  - Microphone time histories and spectra were compared
  - Typical microphone response is shown to the right
- Loudness level inside the IER

Mic #	Perceived Level (dB)	
	Measured	***Predicted***
1	73.8	74.2
2	75.3	76.1
3	75.9	75.7
4	73.5	72.1
5	73.0	73.7

- Good agreement between experiment and VARS was obtained





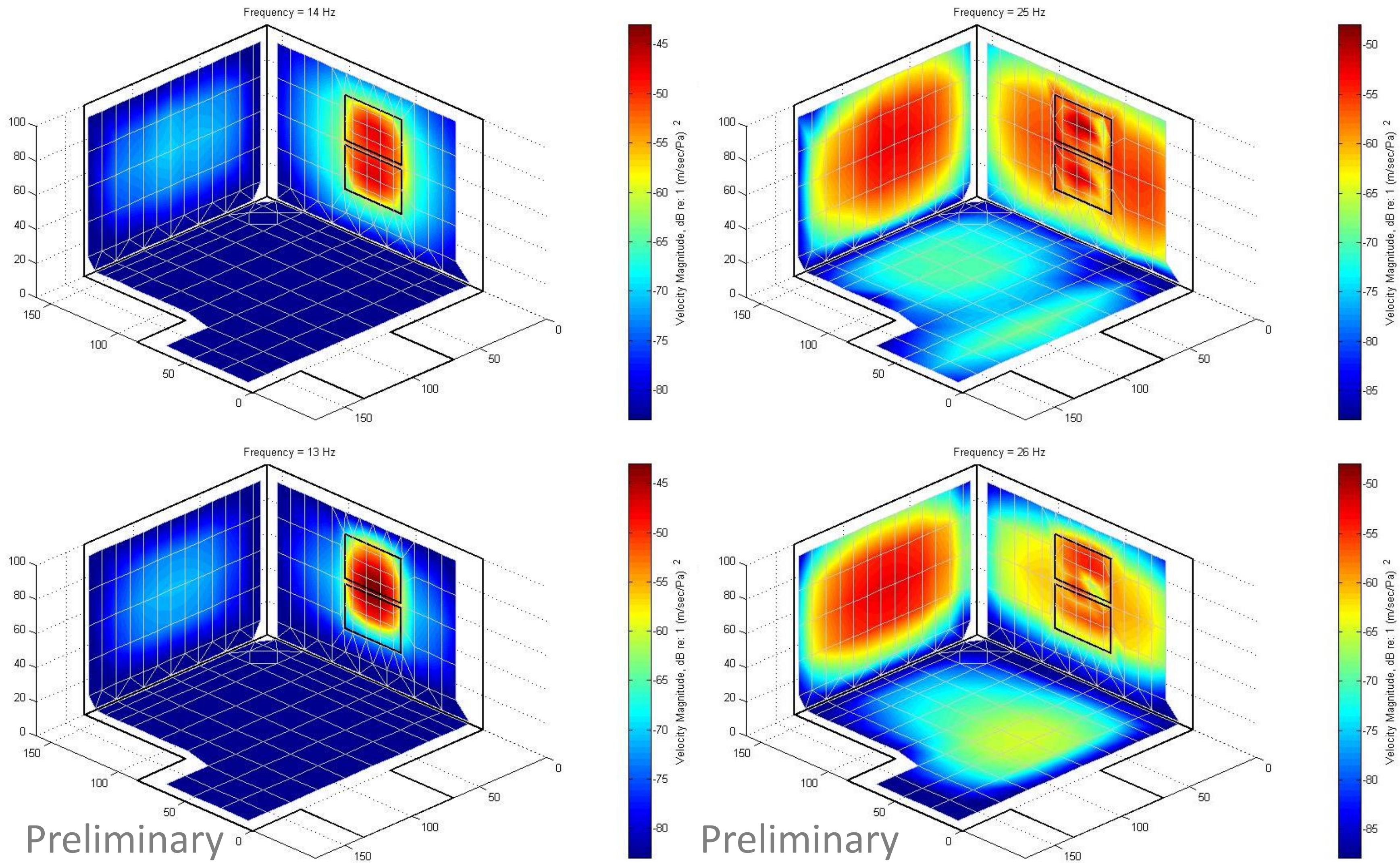
Measured vs. predicted structural mode shapes (pink noise excitation, low frequency)

Window fundamental ↓

Wall fundamental ↓

Measured →

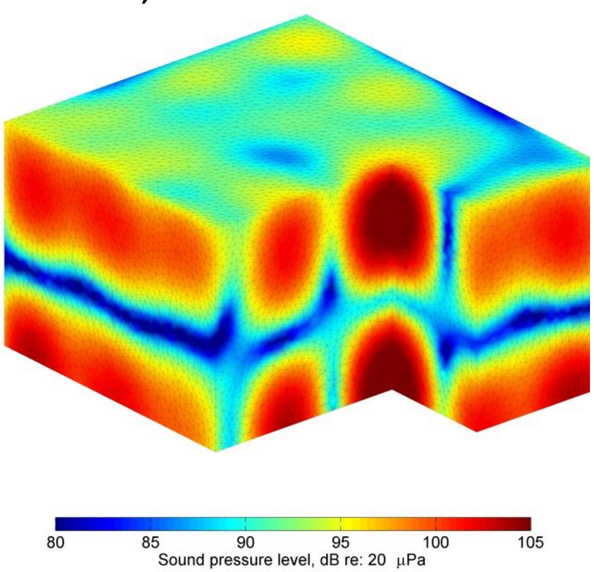
Predicted →



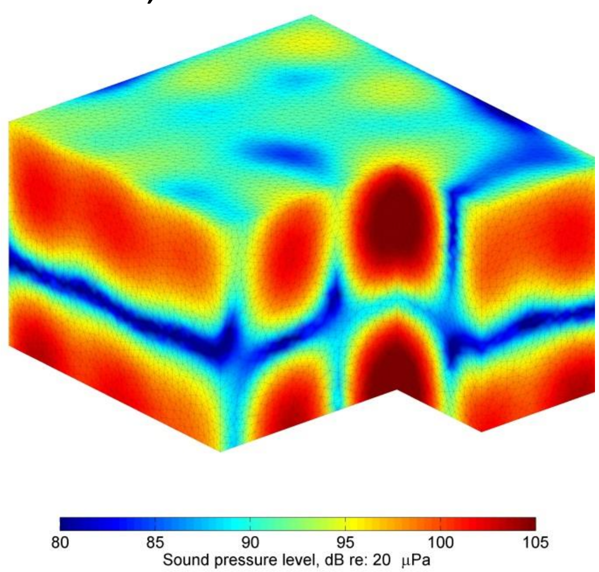
Edge Diffraction vs. Boundary Element

- Edge diffraction toolbox
  - Written by Peter Svensson at the Norwegian University of Science and Technology
  - Incorporated into VARS to predict exterior loading
- Compared frequency domain BEM to edge diffraction toolbox predictions
- Spatial distribution of sound pressure level at 60 Hz is shown, incident side
- Good agreement comparing all three methods

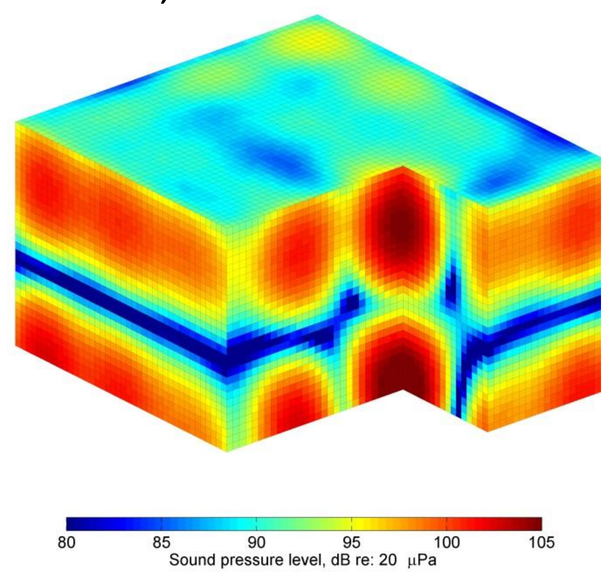
BEM, Plane Wave Source



BEM, Distant Point Source



VARS, Distant Point Source

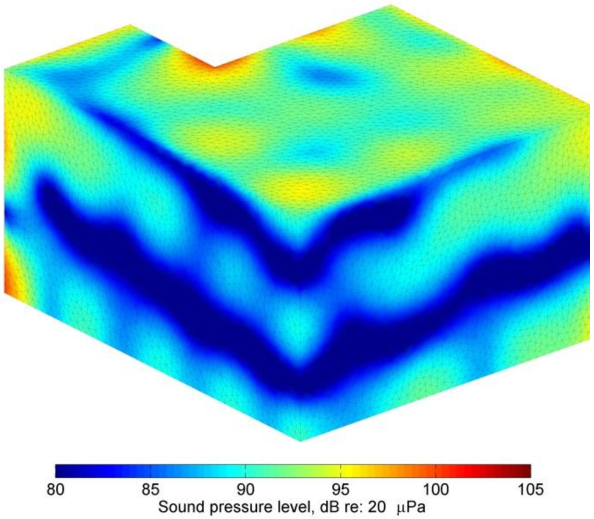


Nominal level on the ground in absence of the building is 94 dB (light green)

Edge Diffraction vs. Boundary Element (60 Hz)

- Spatial distribution of sound pressure level at 60 Hz is shown
- Shadow side of the building
- Nominal level on the ground in absence of the building is 94 dB (light green)
- Good agreement in level comparing all three methods
- VARS lack some fine detail due to limited diffraction order (2nd order was used)

BEM, Plane Wave Source



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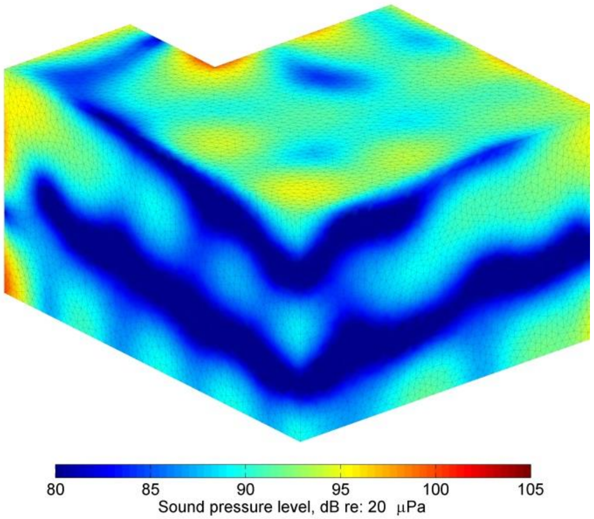
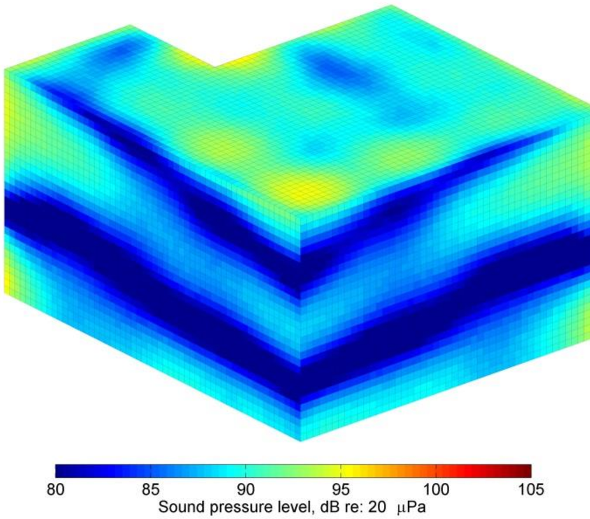


VARS, Distant Point Source



Nominal level on the ground in absence of the building is 94 dB (light green)