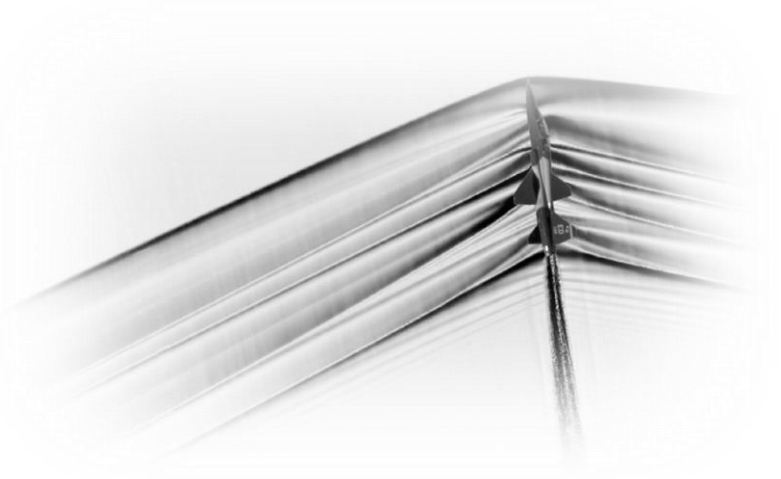


National Aeronautics and Space Administration

NASA

CELEBRATING 100 YEARS

NASA Langley Research Center 1917-2017

Psychoacoustics research at NASA
to enable quiet overland supersonic flight

Dr. Jonathan Rathsam, Research Aerospace Engineer, NASA Langley Research Center

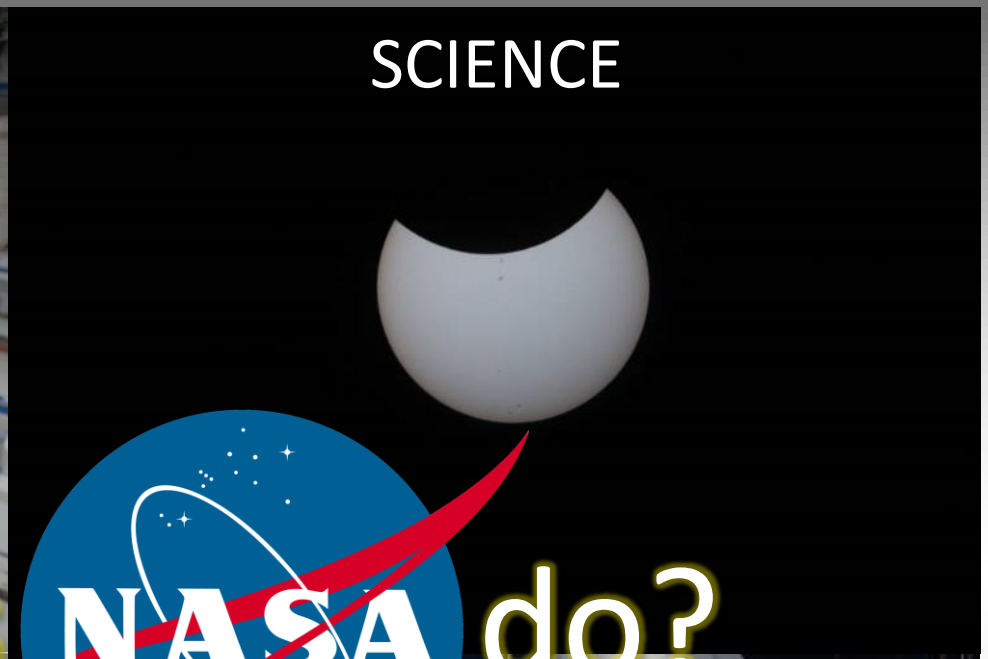
Psychology Department Brown Bag Talk, College of William & Mary

September 18, 2017

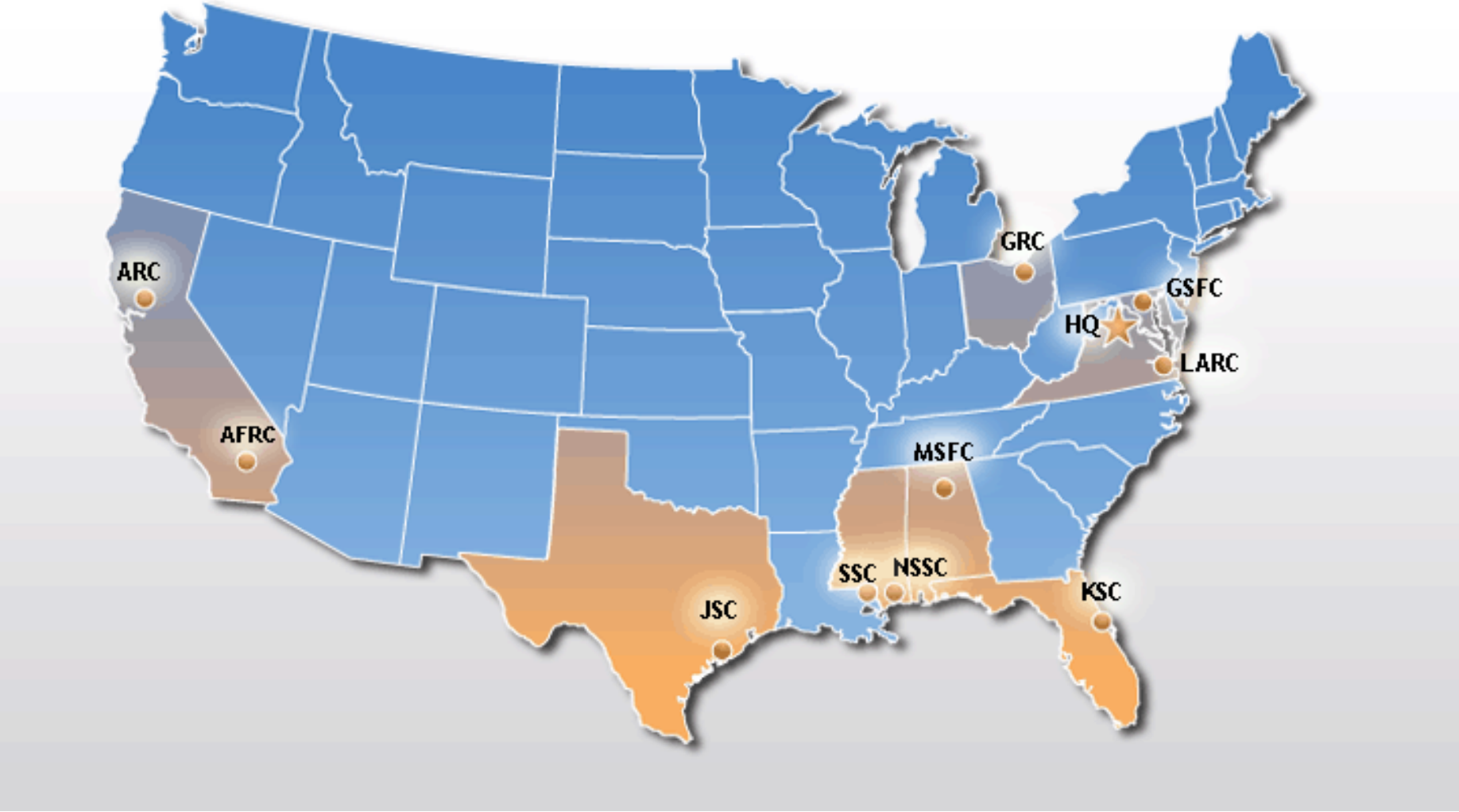
Today's Presentation

- About NASA
- NASA Internships
- Psychoacoustics & Aircraft Noise
- Quiet Supersonic Flight
  - History and Basics
  - Laboratory research
  - Field research

What does NASA do?



Where is NASA?



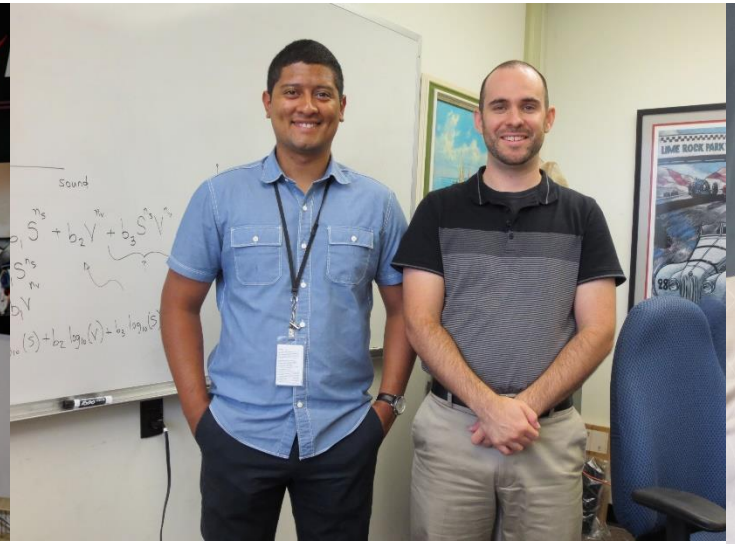
NASA Langley Research Center

- est. 1917
- $900 Million Annual Budget
- ~3000 employees

- Featured in 2016 20th Century Fox movie *Hidden Figures*

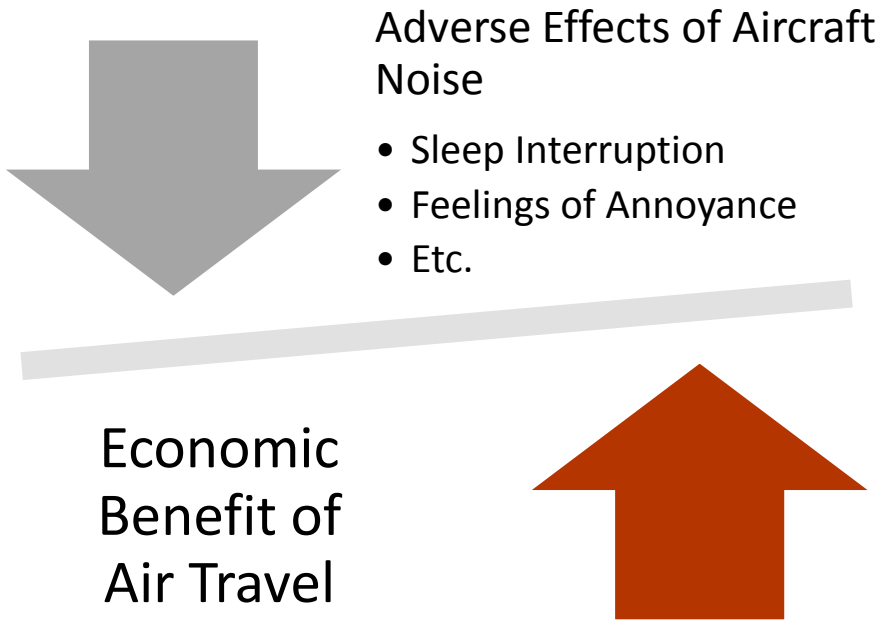
NASA Paid Internships

- Internships for U.S. Citizens in:
  - Science, Technology, Engineering, Mathematics (STEM)
  - Business, Communication, Marketing, other areas
- Spring, Summer, and Fall terms
- Sep 27 NIFS Virtual Career Summit: http://bit.ly/2x9oZJp



Why does NASA do Psychoacoustics?

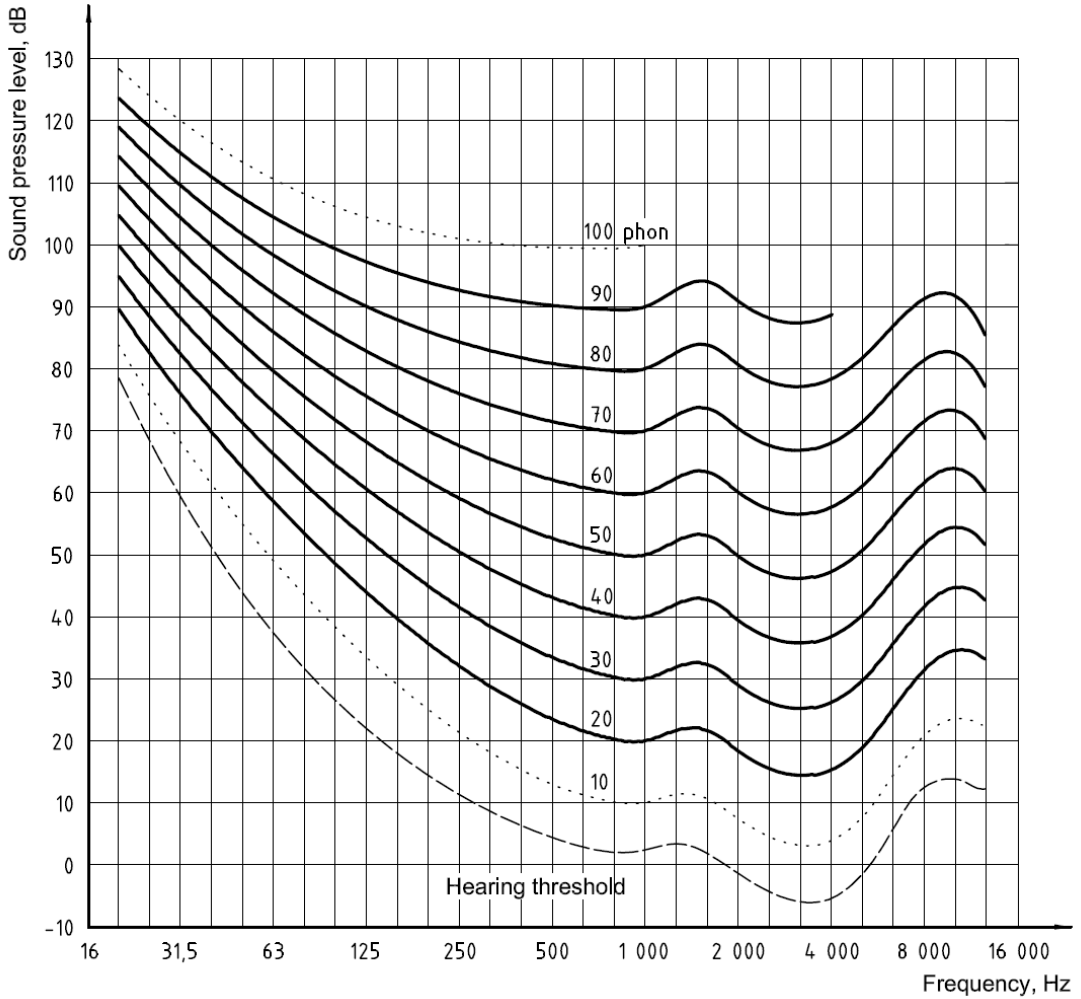
- NASA research informs government policy (space and aeronautics)



NASA psychoacoustics research aims to understand and reduce adverse effects of aircraft noise on people

Key results from Laboratory Research

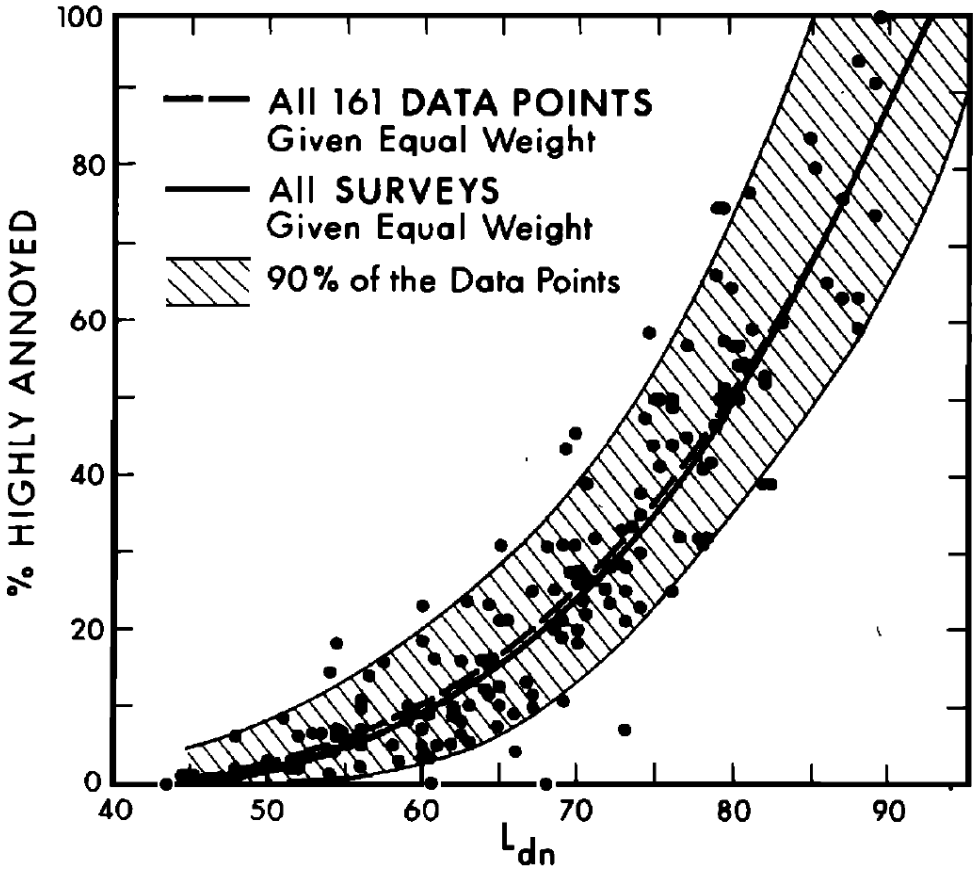
- Noise metrics developed to describe annoyance on the basis of physical sound measurements, accounting for:
  - Loudness (perceived sound intensity)
  - Pitch (perceived sound frequency)
  - Loudness summation across frequency
- Open question: how does annoyance from an individual noise event relate to annoyance from cumulative noise exposure (e.g. over a year)



Equal-Loudness Contours, Ref. 1

Key results from Field Research

- Dose-response relationships established between noise exposure and annoyance
- Enormous variation between surveys
  - Noise exposure accounts for < 50% of variation [Ref. 3]
  - Attitudinal variables describe additional variation [Ref. 4]
    - Fear of aircraft crashes
    - Noise sensitivity
    - Preventability
  - Demographic variables describe almost no variation [Ref. 4]
    - Age, sex, social status, income, education, home ownership, dwelling type, length of residence, receipt of benefits from noise source



Aggregate Dose-Response Curve, Ref. 2

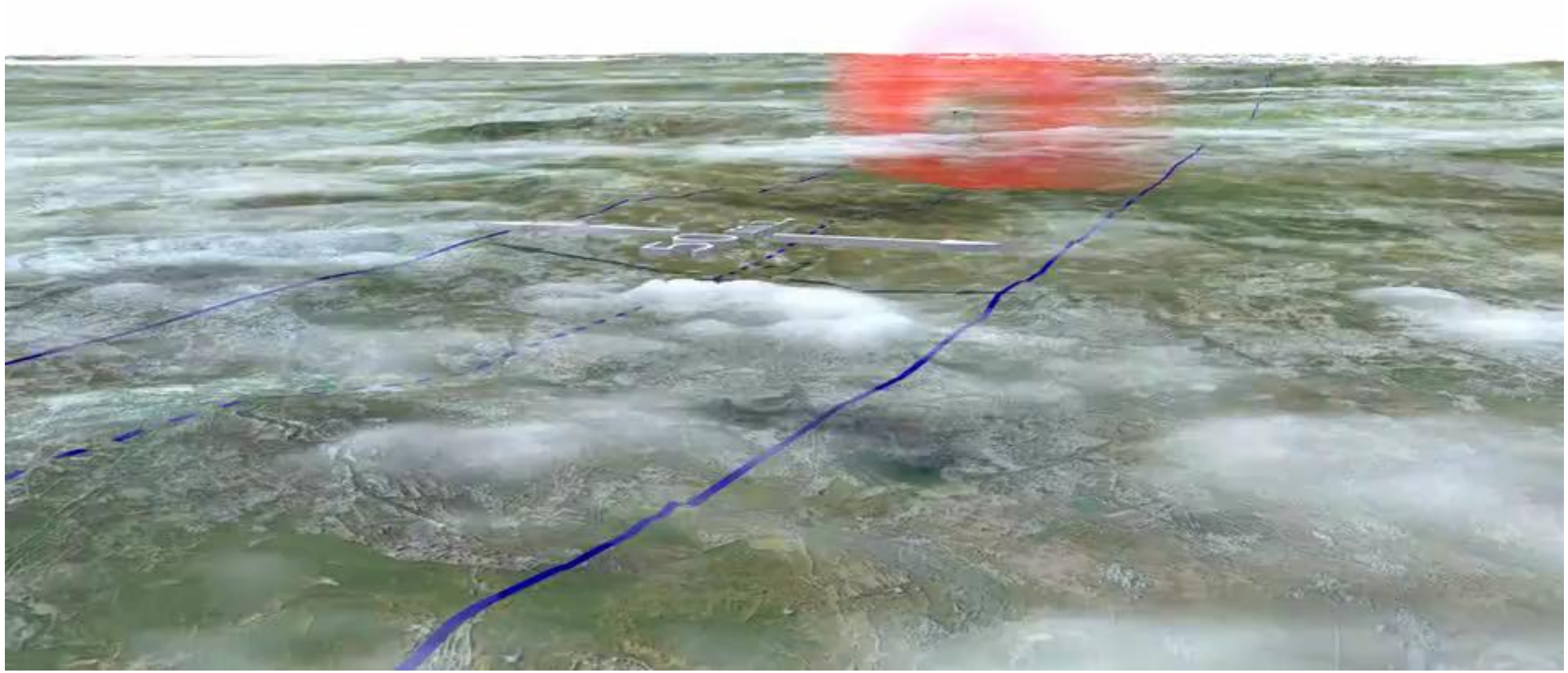
What Does Supersonic Mean?

Benefits of Supersonic Flight

- Reduced travel time
- Validated market potential
- Benefit to U.S. economy

- Why do we fly subsonically?

Sonic Boom



Historic sonic boom highlights

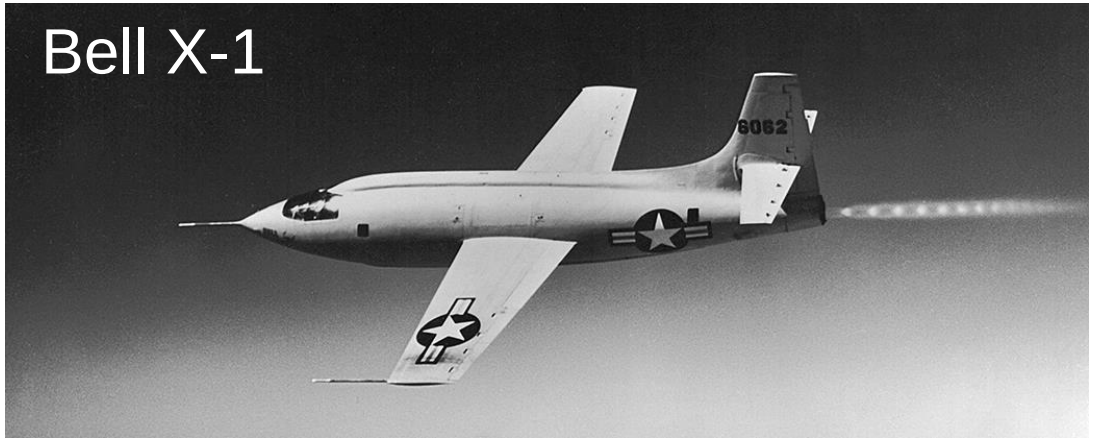
1947 – Supersonic flight

1964 – Community study

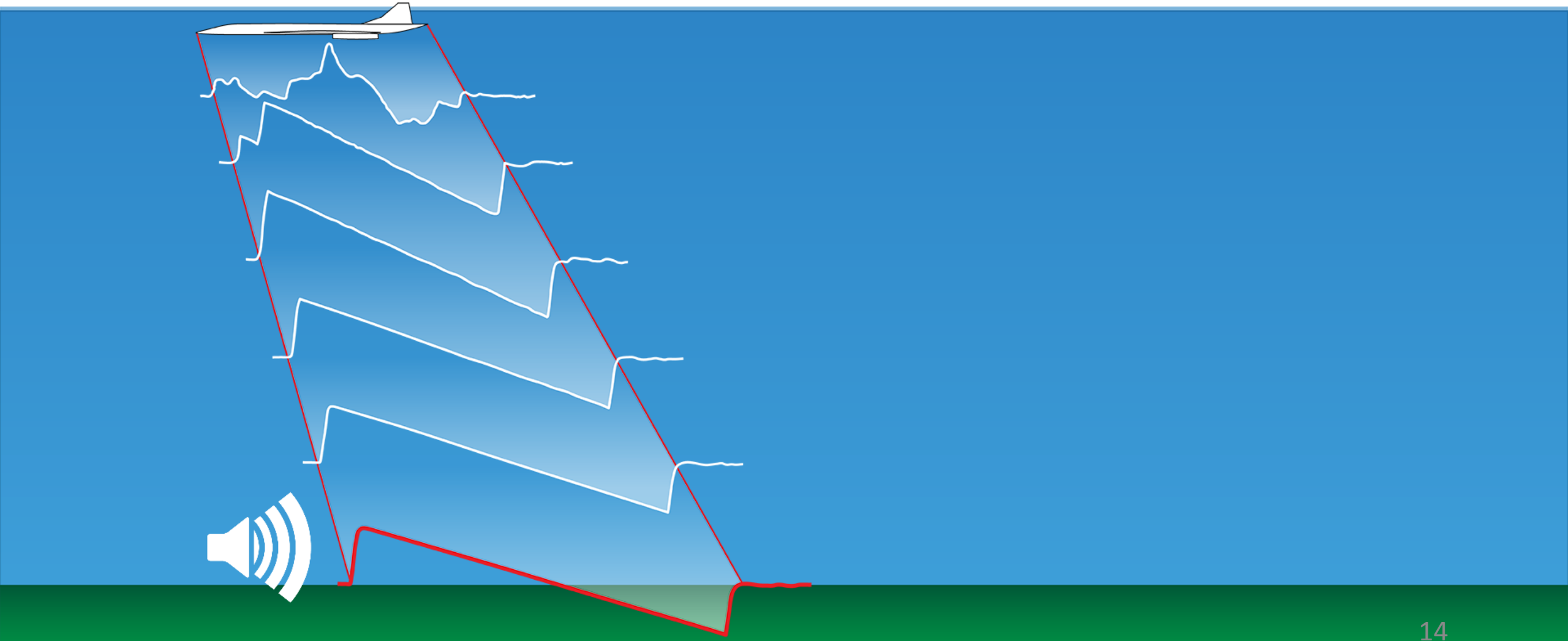
1973 – Federal ban

2003 – Demonstration

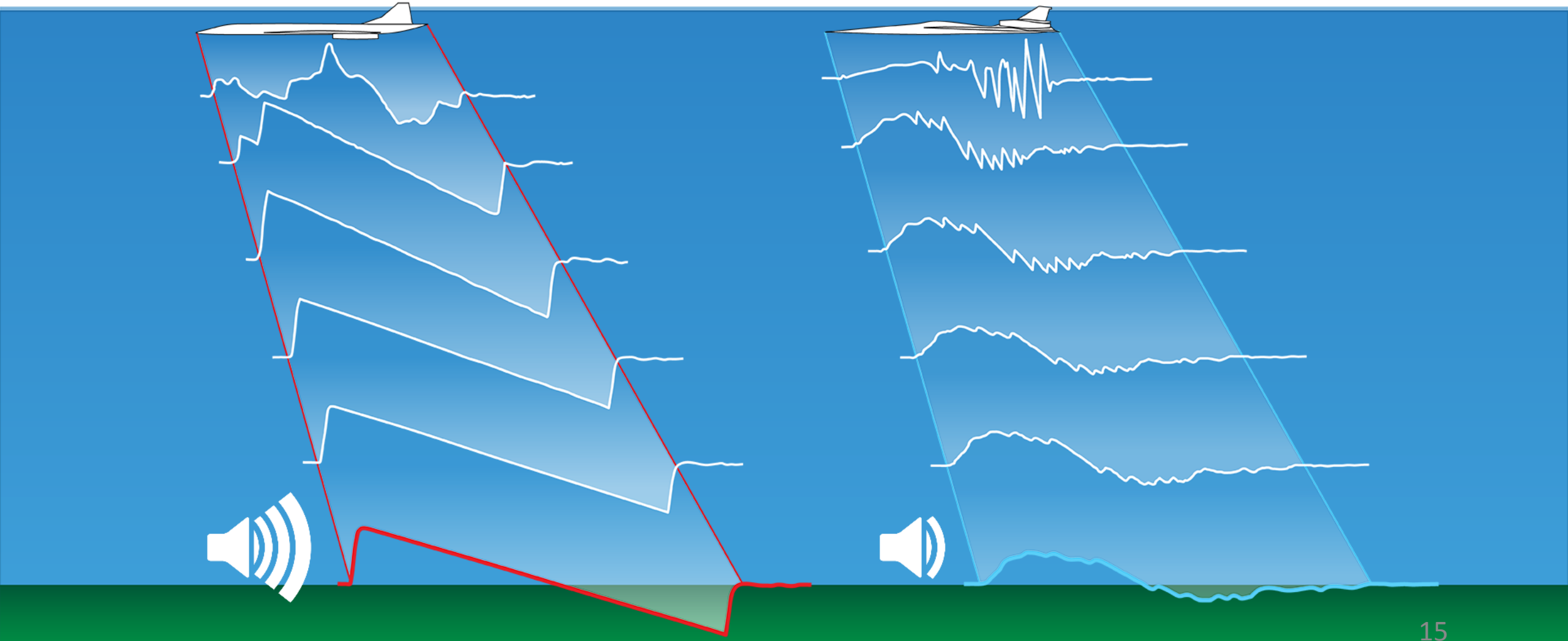
2016 – Design of Supersonic X-plane



How is the Boom Quieted?



How is the Boom Quieted?



Hear the difference

How is annoyance studied?

Laboratory Simulators

Psychoacoustic Testing

Laboratory Simulator

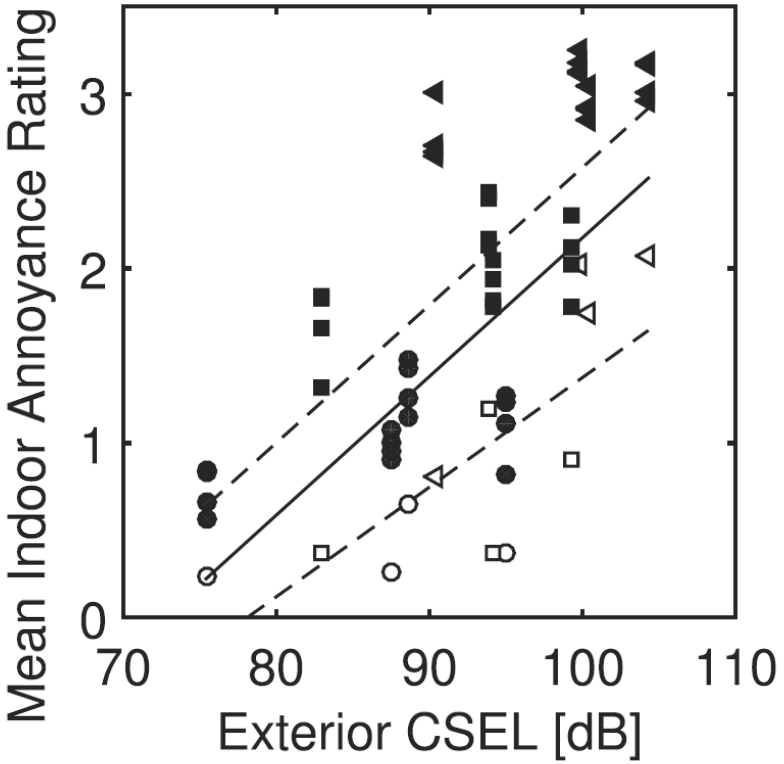
Laboratory Research Objectives

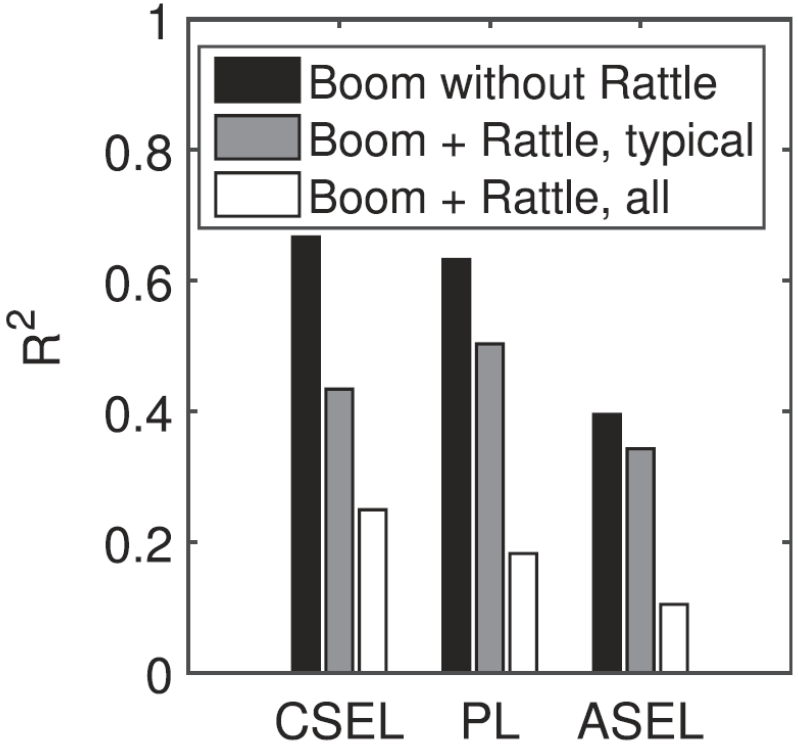
- Identify noise metrics that best describe annoyance for regulating supersonic aircraft
- Quantify effects of rattle and vibration on annoyance

Videos of Rattle Study and Vibration Study

- Rattle study
- Vibration study

Laboratory Study: Noise Metrics [Ref. 1]





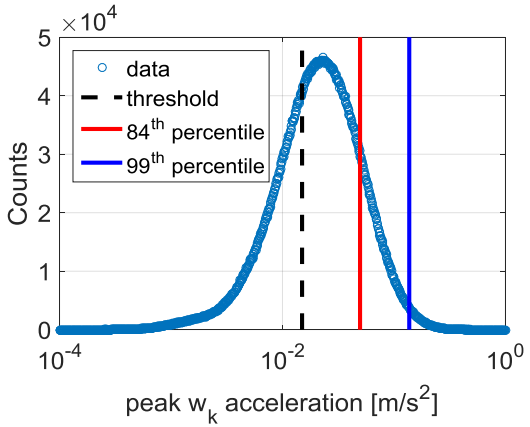
- Meta-analysis underway, combining results of multiple lab studies.

Laboratory Study: Effect of Vibration

- **Research Questions:** Is there a "vibration penalty"? By how much does indoor low boom annoyance increase if structural vibrations are felt directly? How can vibration penalty be modeled?

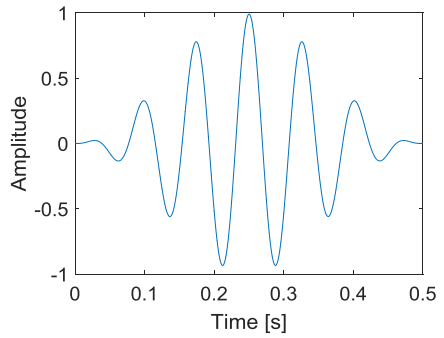
Signature	Exterior PL [dB]	Peak w_k acceleration [m/s^2]	
		84th percentile	99th percentile
Small Airliner	75	0.017	0.045
Large Airliner	76	0.016	0.047
Business Jet (A)	77	0.023	0.061
Business Jet (B)	79	0.037	0.115
X-plane (B)	80	0.050	0.138
X-plane (C)	84	0.050	0.128

Test Matrix



Simulated vibration exposure

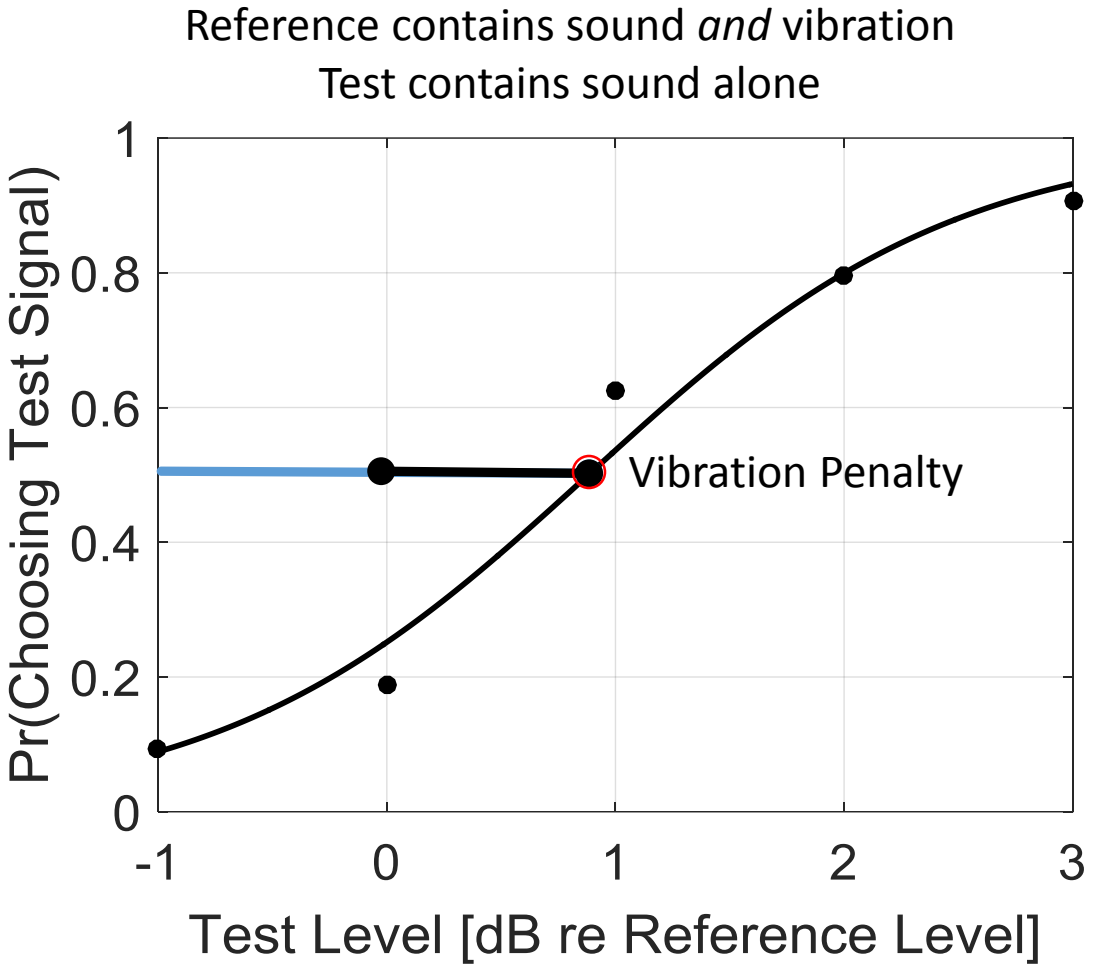
Vibration excited by underseat shaker



Vibration waveform (13 Hz sine pulse)

Test Method

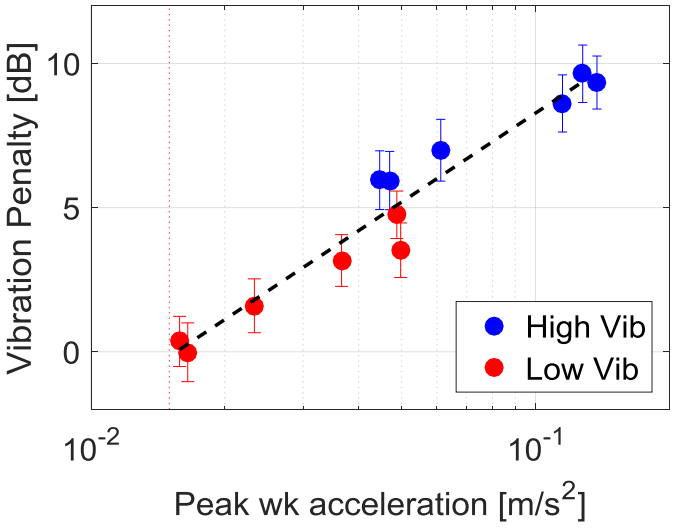

First
Second
Which event is more annoying?

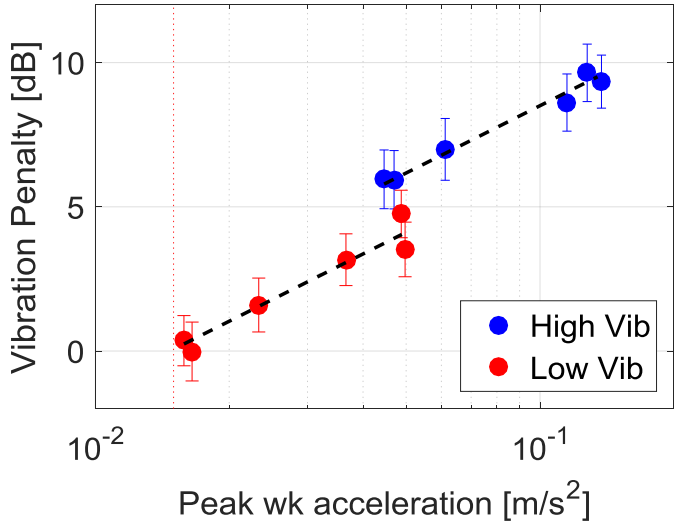

Reference contains sound *and* vibration
Test contains sound alone
Pr(Choosing Test Signal)
0
0.2
0.4
0.6
0.8
1
-1
0
1
2
3
Test Level [dB re Reference Level]
Vibration Penalty

Laboratory Results: Effect of Vibration

- **Research Questions:**
  - Is there a "vibration penalty"? How big?
    - Yes, 0-10 dB
  - How might we model vibration penalty?
    - Based on peak floor acceleration, see below

Model 1 fit is not as good, but model is simpler





Model 2 fit is improved, but requires multiple intercepts

	Model	R^2	F-Test, p-value	RMSE
1	$VibrationPenalty = \beta_0 + \beta_1 PeakAccel + \varepsilon$	0.936	$161.6_{1,10}$, <0.001	0.85
2	$VibrationPenalty = \beta_0 + \beta_1 PeakAccel + \beta_2 VibrationLevel + \varepsilon$	**0.9864**	$399.7_{2,9}$, <0.001	**0.39**

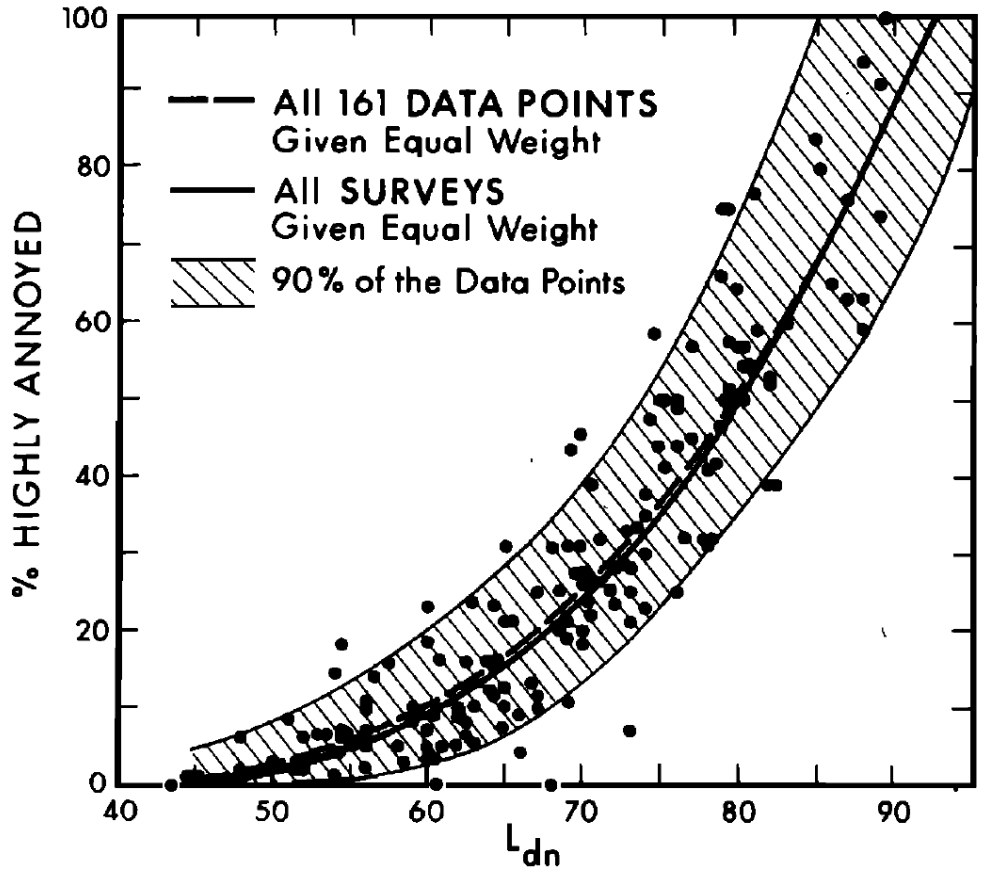
Field Studies: Social Surveys

F-18 Dive Maneuver

X-Plane

Field Research Objectives

1) Collect defensible data indicating degree of public acceptability of quiet supersonic flight

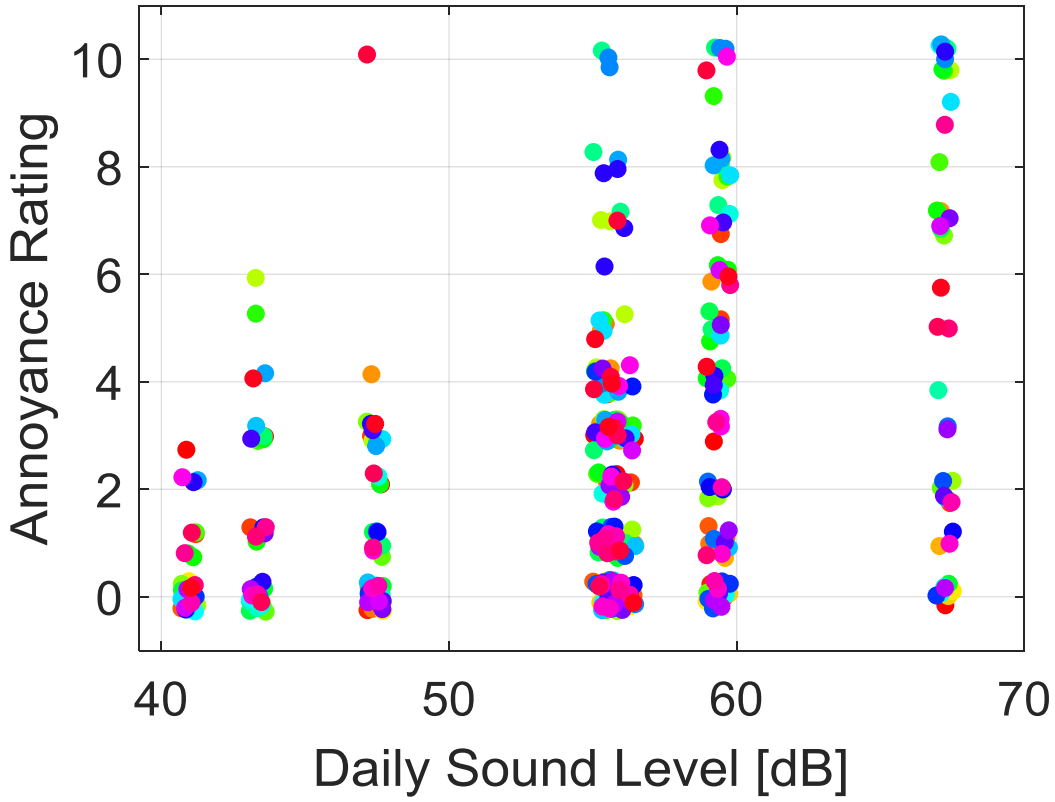


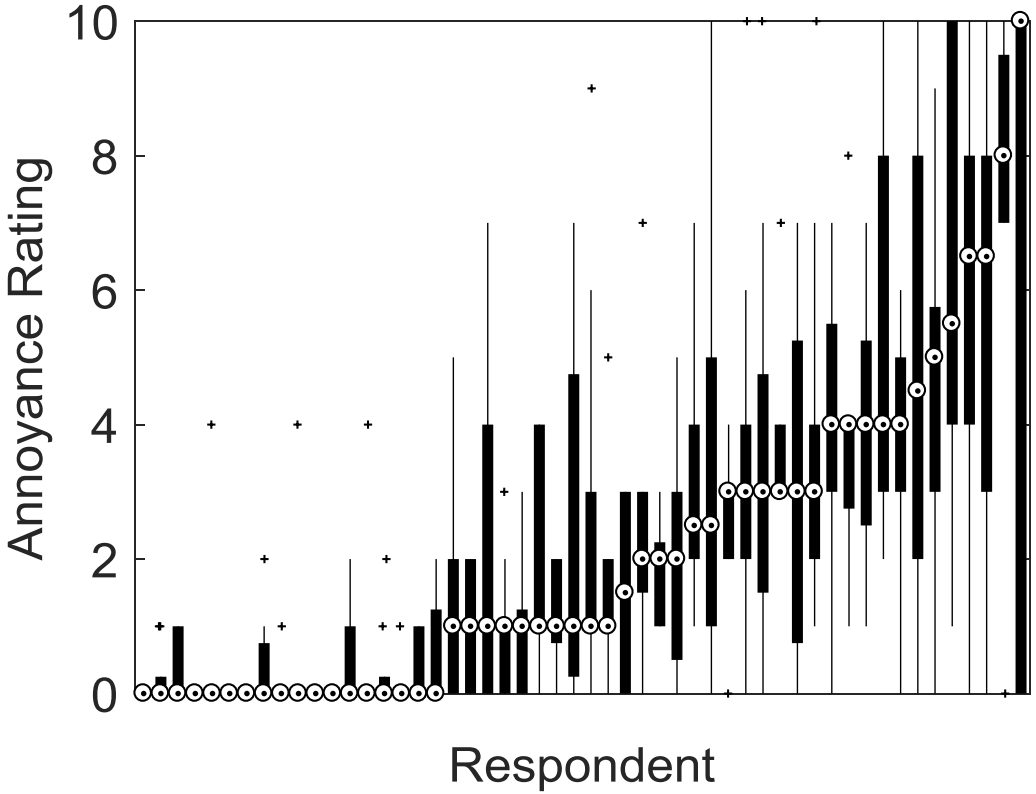
Ref. 2

Relevant research [Adapted from Ref. 6]

Survey Location	Year	Study Lead	Number of Subjects	Number of flights/ booms	Notes
Historic Boom Studies					
St. Louis	1961	FAA	1150	76	Only study with nighttime exposures
Oklahoma City	1964	FAA	3200	1225	A cautionary tale for community engagement
Edwards AFB	1966	NSBEO	800	569	Research driven study
6 Major US Cities	1967	FAA NASA Tracor	6400*	~300	Urban environments * No. of interviews
Edwards AFB/ Nellis AFB	1992 / 1995	NASA	1400	Variable	Long term response to boom from training flights
Recent Studies					
Edwards AFB	2011	NASA	100	21 flights 110 booms	Low noise booms from F-18 dive maneuver, normal booms
5-6 near 2 bases	2008 - 2012	ERDC - CERL	100 - 1400	3 months	Random telephone interviews and panel surveys
20 large US airports	2015 - 2016	FAA	10000	~ 1 year 6 ”waves”	Mainly mail surveys of recruited subjects. Some phone surveys

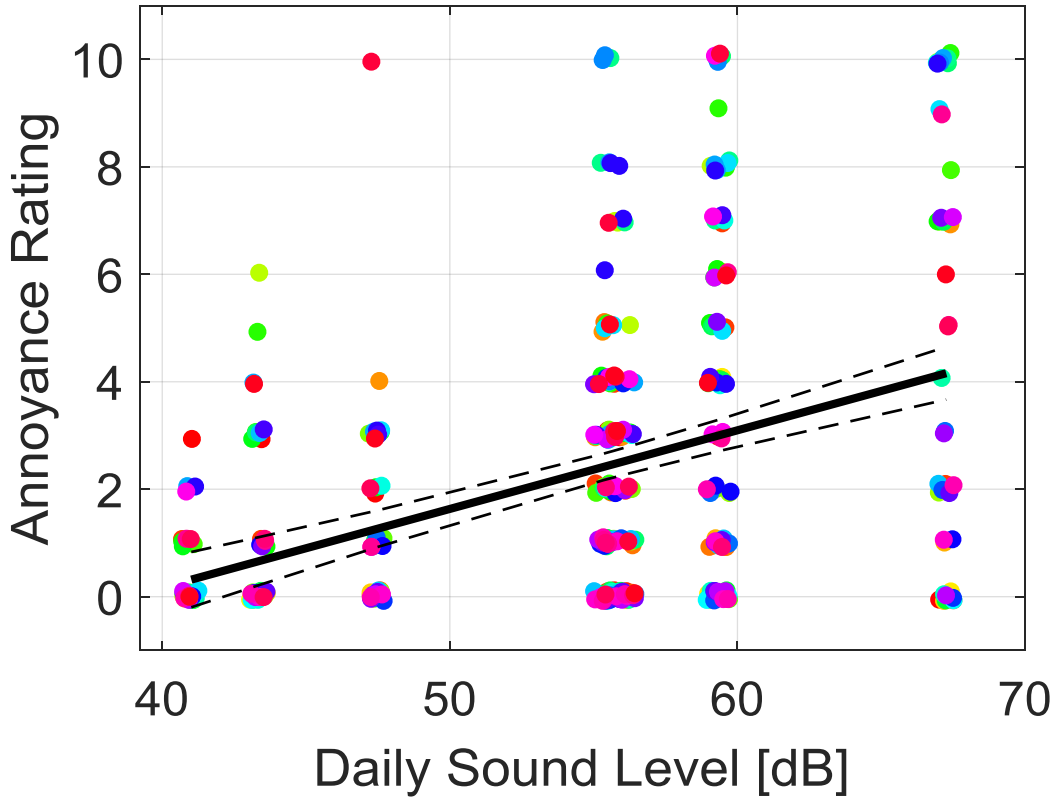
Field Data


Annoyance Rating
10
8
6
4
2
0
40
50
60
70
Daily Sound Level [dB]

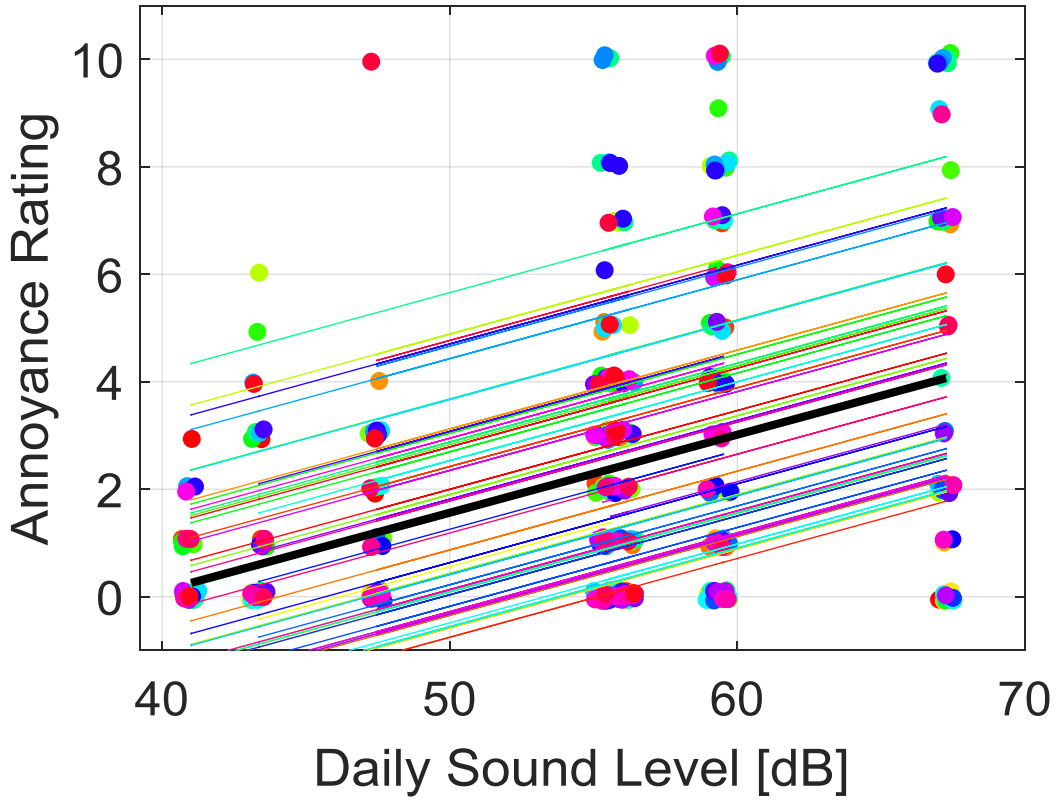

Annoyance Rating
10
8
6
4
2
0
Respondent

Linear Regression vs. Multilevel Analysis

$$Daily\ Annoyance_i = \gamma_0 + \gamma_1 CDNL + \varepsilon_i$$



$$Daily\ Annoyance_{ij} = \gamma_{00} + u_{0j} + \gamma_{10} CDNL + \varepsilon_{ij}$$

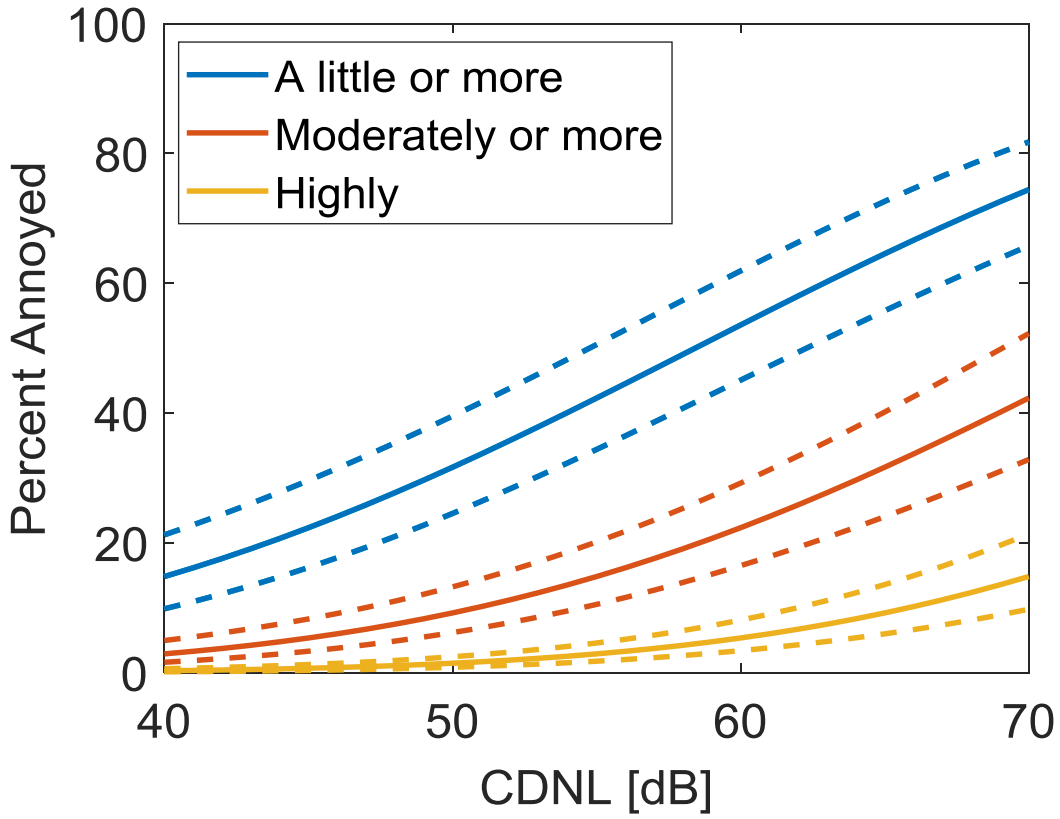


Dose-Response Analysis [Ref. 7]

$$Daily\ Annoyance_{ij} = \gamma_{00} + u_{0j} + \gamma_{10} CDNL + \varepsilon_{ij}$$

parameter	estimate (SE)
γ_{00}	-5.769 (0.71)
γ_{10}	0.1467 (0.012)
σ_{u0}^2	3.382
σ_e^2	3.686

$$p_c(CDNL) = \left(1 - \phi\left(\frac{C - \gamma_{00} - \gamma_{10} \times CDNL}{\sqrt{\sigma_{u0}^2 + \sigma_\varepsilon^2}}\right)\right)$$



Upcoming social surveys

- 2018 Test
  - F-18 dive maneuver off-base
  - Location TBD
  - Challenges: maximizing response rate, determining noise dose
- X-Plane community studies
  - Timeframe, 2022 – 2024
  - Locations TBD
  - Challenges: experimental design, site selection

Conclusions

- The main barrier to supersonic commercial flight is noise
- NASA and its partners are developing quiet supersonic technology
- NASA is working to demonstrate public acceptability of quiet supersonic flight through psychoacoustics research in the laboratory and field

- NASA offers paid internships in STEM and other fields
  - https://intern.nasa.gov/

References

1. ISO 226:2003 Acoustics – Normal equal-loudness contours (2003).
2. T. Schultz, “Synthesis of social surveys on noise annoyance,” J. Acoust. Soc. Am. 64, 377-405 (1978).
3. J.M. Fields, “Effect of personal and situational variables on noise annoyance in residential areas” J. Acoust. Soc. Am, **93** 5 (1993).
4. S. Fidell and L. Silvati, “Parsimouious alterantives to regression analysis for characterizing prevalence rates of aircraft noise annoyance” Noise Control Eng. J. 52, 56-68 (2004).
5. J. Rathsam, A. Loubeau, J. Klos, “Effects of indoor rattle sounds on annoyance caused by sonic booms,” J. Acoust. Soc. Am. 138, EL43 – EL48 (2015).
6. P. Coen, A. Loubeau, B. Pauer, “NASA’s Low Boom Flight Demonstration: Assessing Community Response to Supersonic Overflight of Quiet Supersonic Aircraft,” J. Acoust. Soc. Am. 141, 3624 (2017).
7. C. Groothuis-Oudshoorn and H. Miedema, “Multilevel grouped regression for analyzing self-reported health in relation to environmental factors: the model and its application,” Biometrical Journal 48 1, 67-82 (2006).