Sound level recommendations for quiet sonic boom dose-response community surveys

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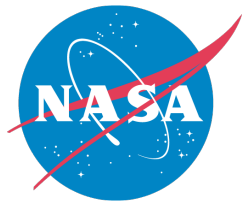
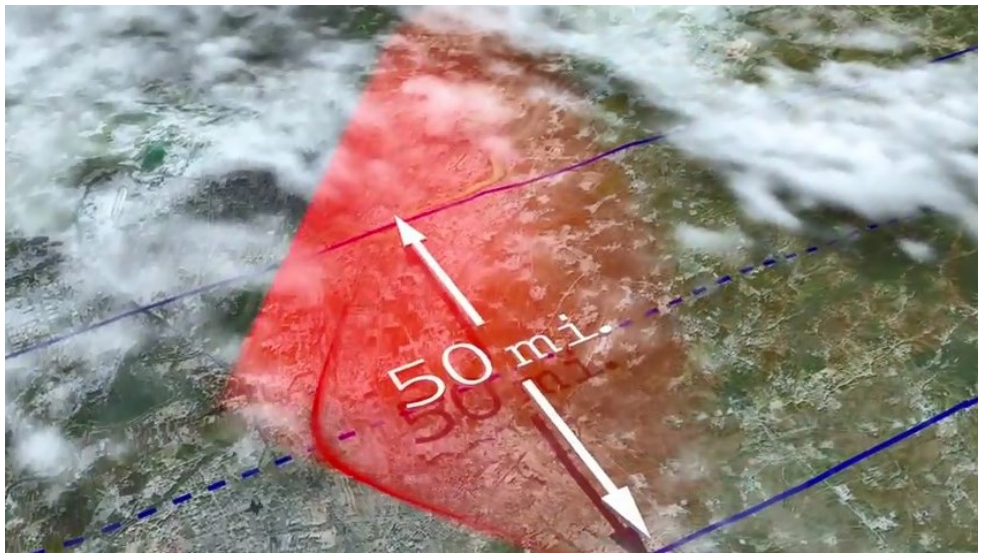


Background

- Traditional sonic booms are loud and startling
- Sonic booms can be heard up to 25 miles on either side of the flight path along the entire supersonic route



- In 1973, the FAA banned commercial overland supersonic flights
- What if sonic booms could be quiet enough to be publicly acceptable?

Motivation

- NASA has a two step plan:
  1. Make sonic booms as quiet as a thump by changing shape of aircraft
  2. Work with noise regulators to replace supersonic ban with a supersonic noise limit
- To determine the noise limit, we need to understand the relationship between noise levels and how communities react
- In order to do so, we need to conduct multiple community surveys for data collection

Motivation (continued)

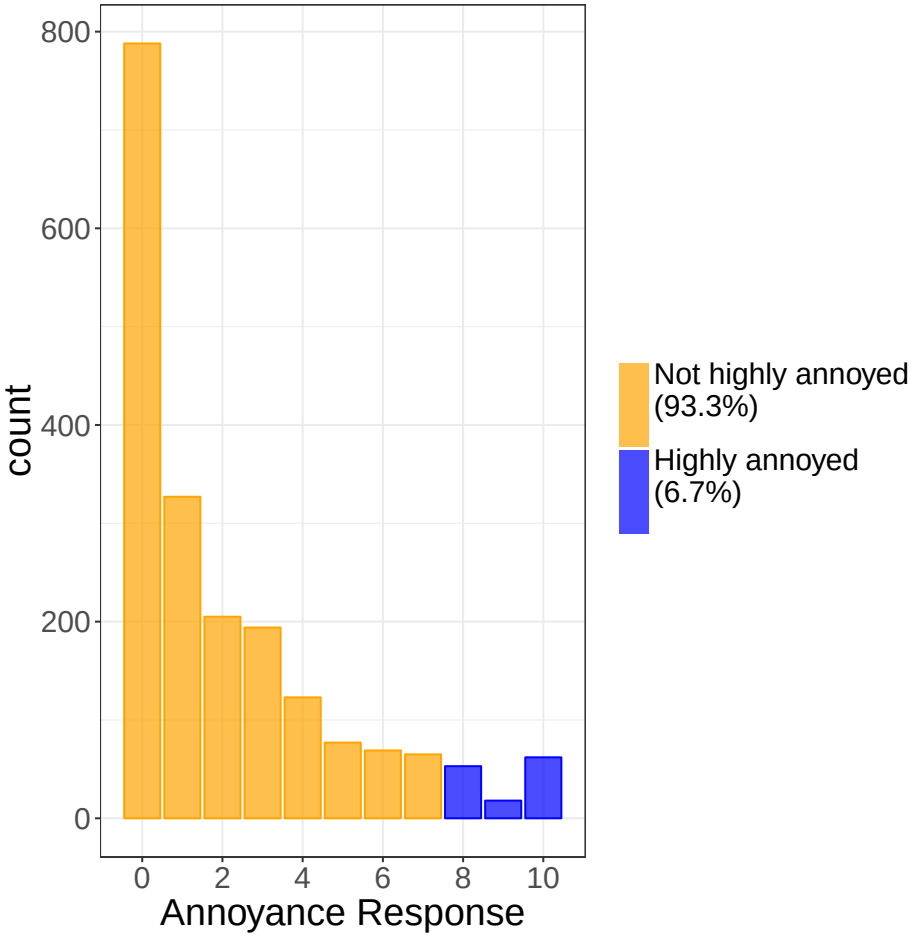
- The Low Boom Flight Demonstration aircraft (LBFD) is designed for quiet supersonic flight and expected to be complete in 2020's

- Data from a 2011 pilot study is used to develop methods and analysis techniques
  - Quiet low-booms were created from an F-18 dive maneuver

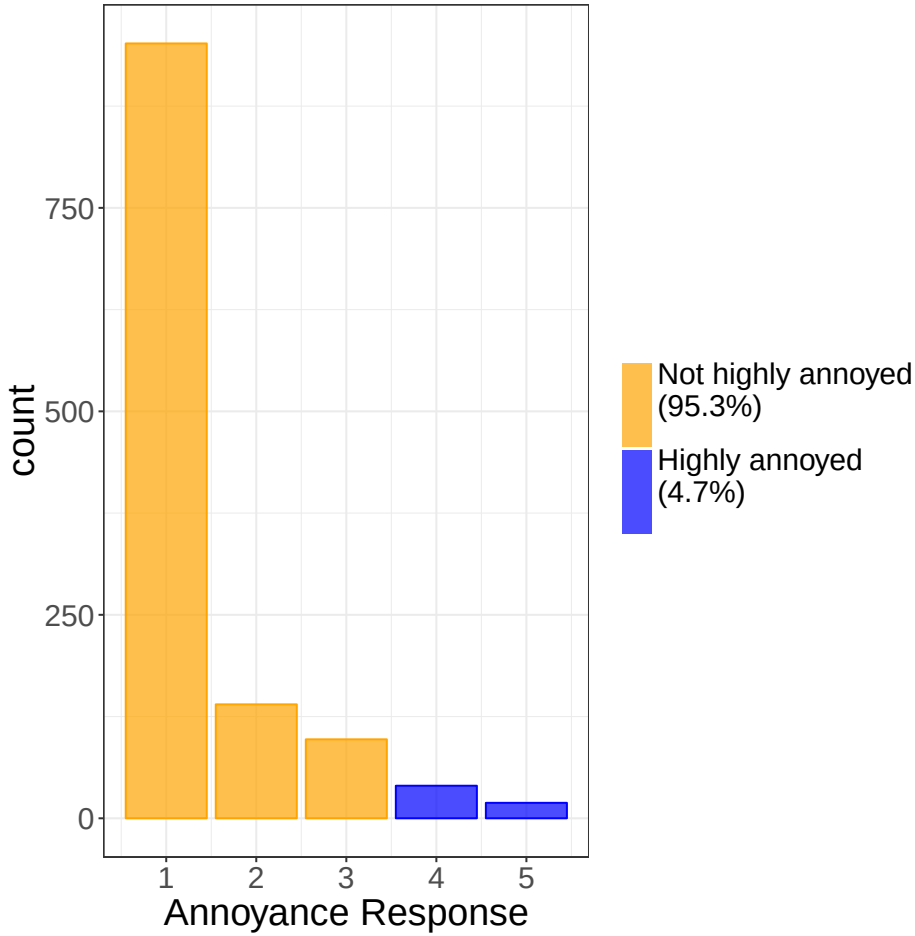
Data

- Panel data because each respondent responded multiple times
- Over a two-week period, with a total of 110 booms
- Combine two data subsets with different response scales
- Data validation
  - Reproduce results from analysis reports
  - We found some minor discrepancies but for methods development purposes, they are negligible

Data Summary



(a) 11-point scale survey



(b) 5-point scale survey

- Total of 97 respondents and 3229 responses
- Noise level range of sonic booms: 63-106 PLdB

Research Goals

- Model the relationship between noise levels and percent highly annoyed as a dose-response relationship
- We expect a limited noise level range that the LBFD can achieve (i.e., [70, 80] PLdB)
- Research question: what are the implications of testing in a limited range of noise levels?

Logistic Regression

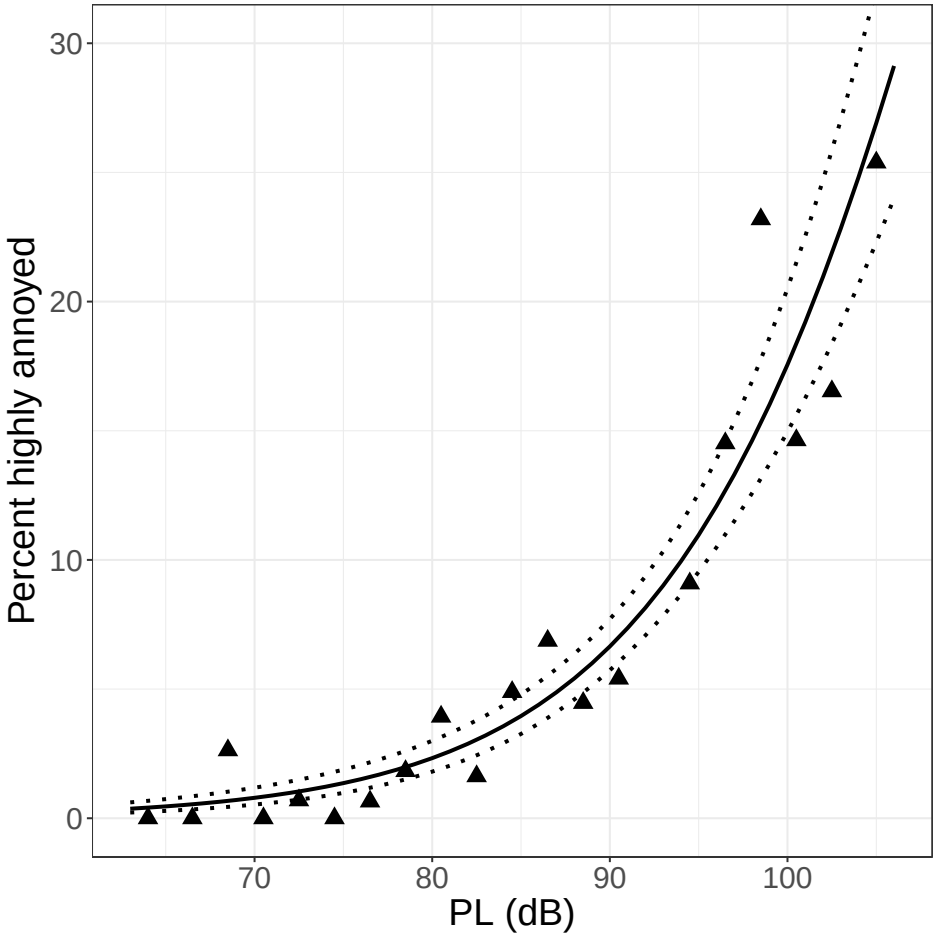
- A common model for dose-response relationship
- Explanatory variable: sound metric Perceived Level (PL) in dB
- Response variable: binary response Y_i where

$$Y_i = \begin{cases} 1 & \text{if respondent is highly annoyed} \\ 0 & \text{otherwise} \end{cases}$$

- Let the probability of highly annoyed at PL_i be p_i
- $Y_i \sim Bernoulli(p_i)$, where $p_i = logit^{-1}(\beta_0 + \beta_1 PL_i) = \frac{e^{\beta_0+\beta_1 PL_i}}{1+e^{\beta_0+\beta_1 PL_i}}$

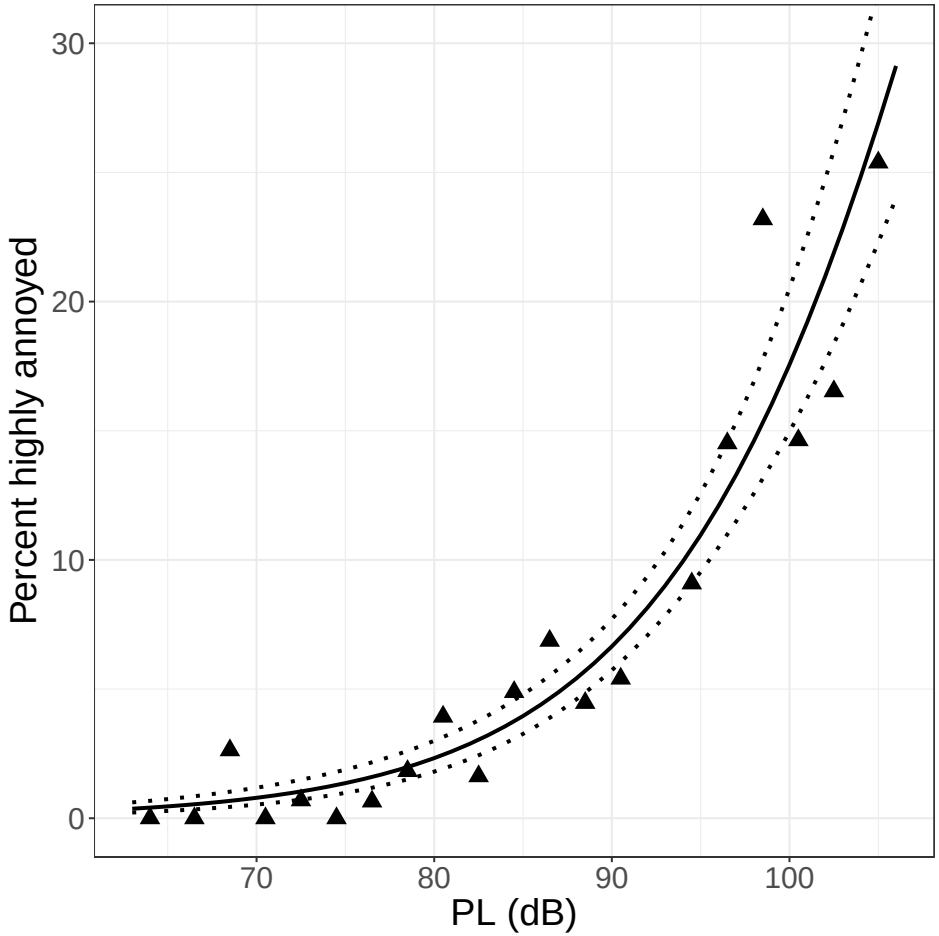
- Quantities of interest include:
  - Estimates and confidence intervals for percent highly annoyed given PLdB
  - Estimates and confidence intervals for PLdB given percent highly annoyed

Results

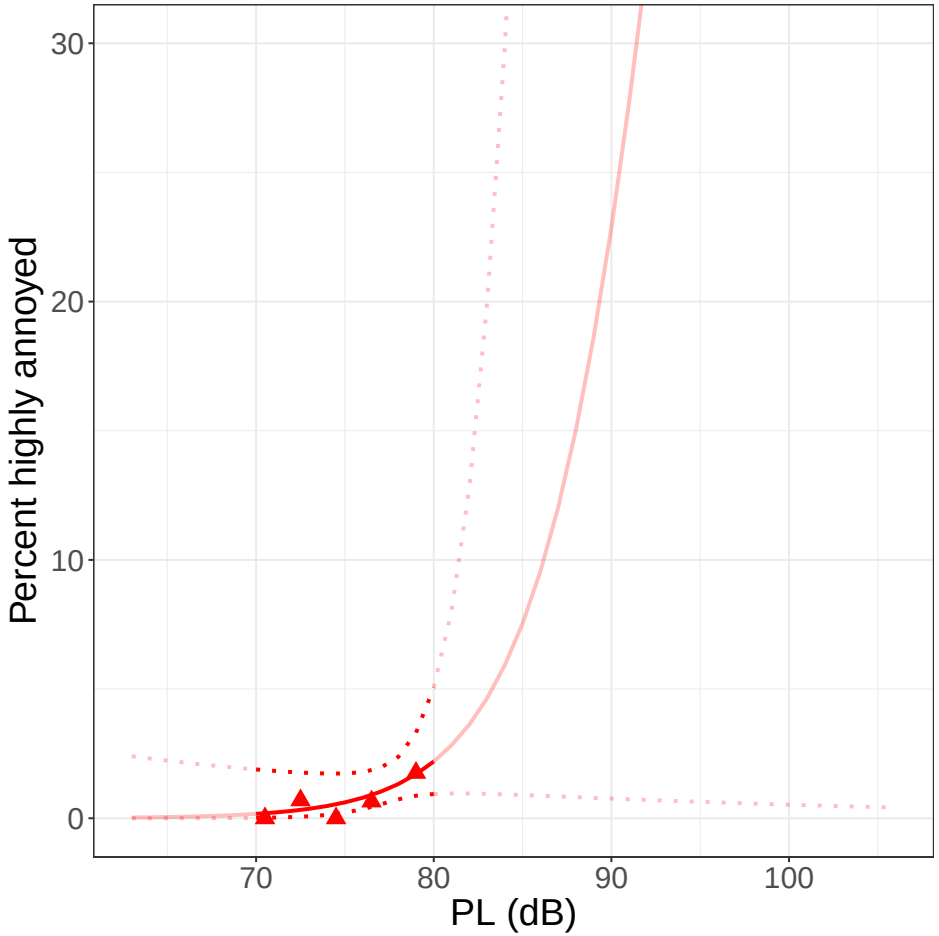


(a) Full range fit

Results



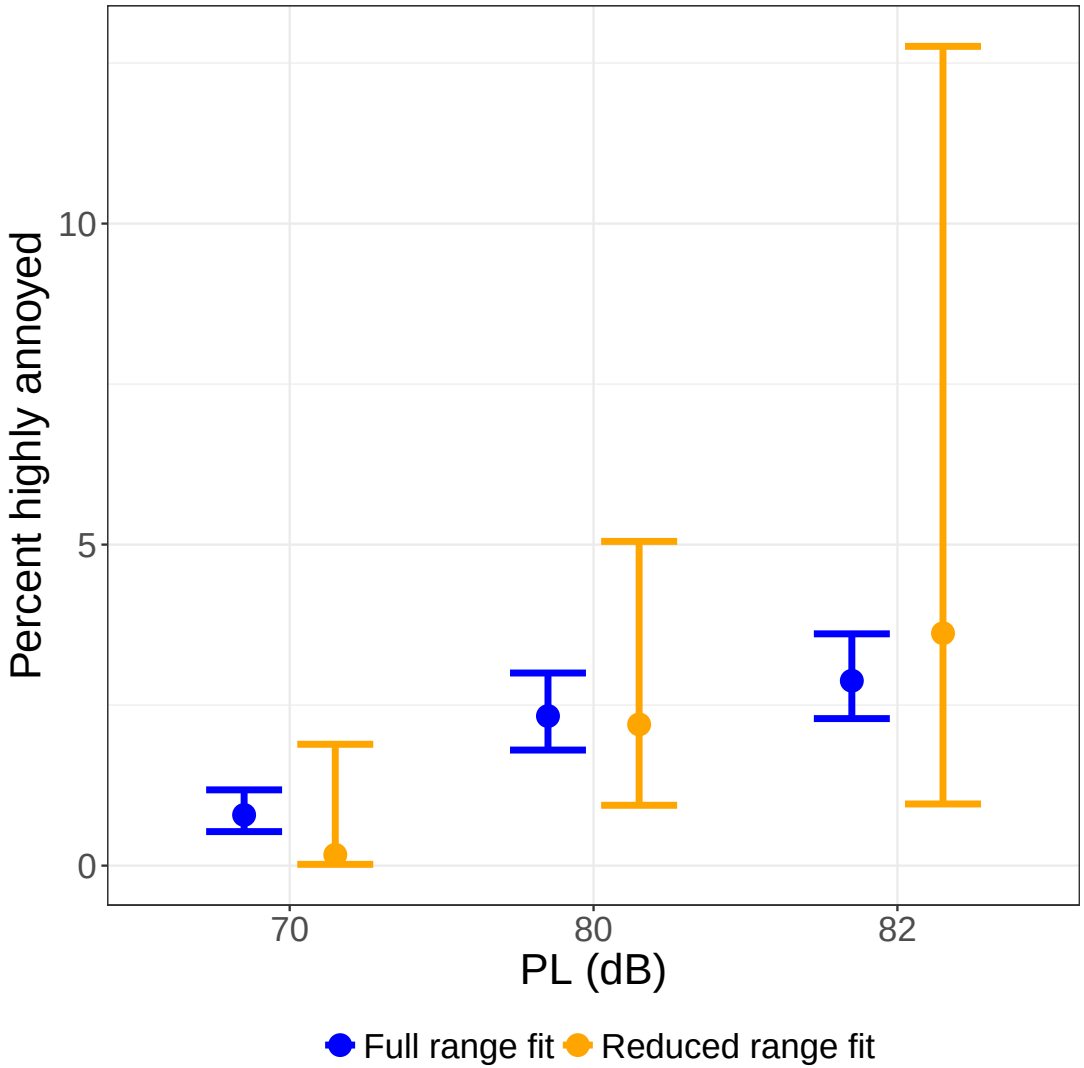
(a) Full range fit



(b) Reduced range fit

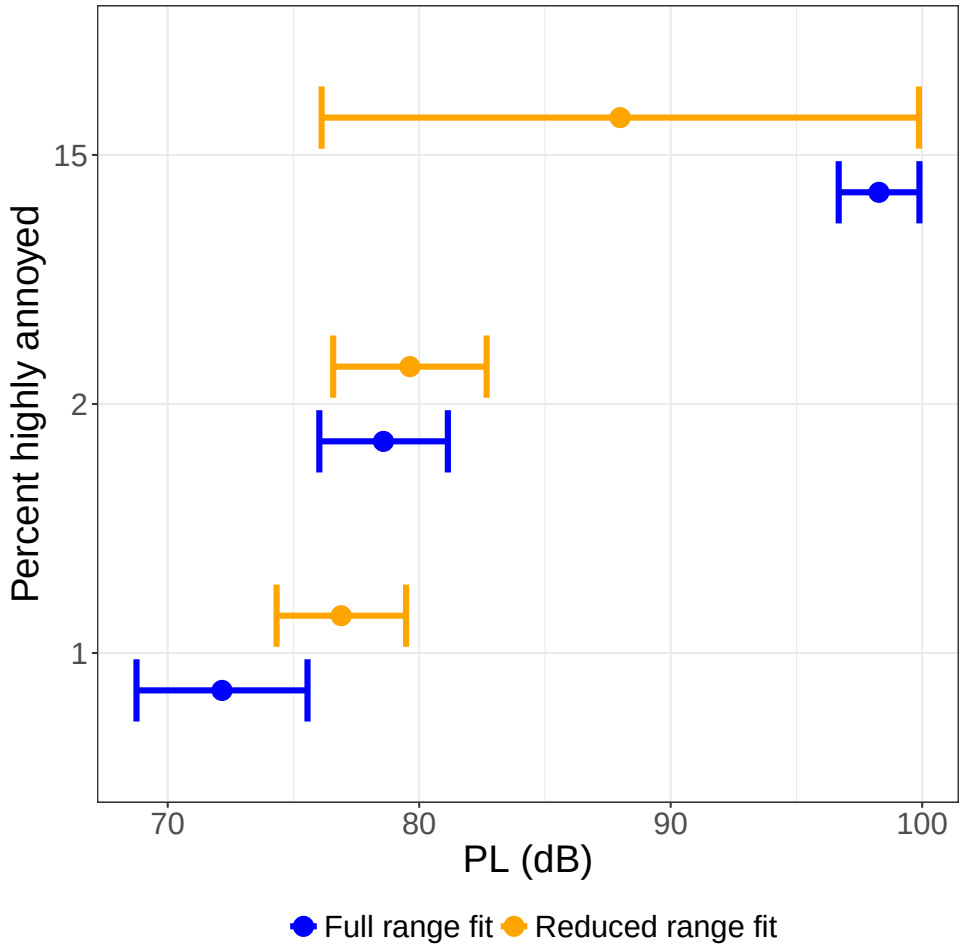
Estimates of quantities of interest

- Percent highly annoyed given PL



Estimates of quantities of interest (continued)

- PL given percent highly annoyed
  - Confidence intervals are calculated using Delta Method [1]



[1] Casella & Berger (2002)

Conclusions

- For reduced range fit:
  - estimated quantities within reduced range data have higher precision,
  - extrapolated quantities beyond reduced range have high uncertainty
- For LBFD tests, if the range tested does not include the future noise limit, estimates will have high uncertainty

Continuing work

- Evaluate and compare candidate models
- Logistic regression model assumes:
  - probability of highly annoyed, p_i, for every individual is the same, and
  - independence in Y_i, ignoring longitudinal nature of data
- Other candidate models:
  - multilevel models[2] to take into account of different individuals' probability of high annoyance
  - first-principles based model[3] from psychoacoustics literature
- How many responses (observations) are necessary for LBFD surveys?

[2] Groothuis-Oudshoorn & Miedema (2006)
[3] Fidell et al. (2011)

References

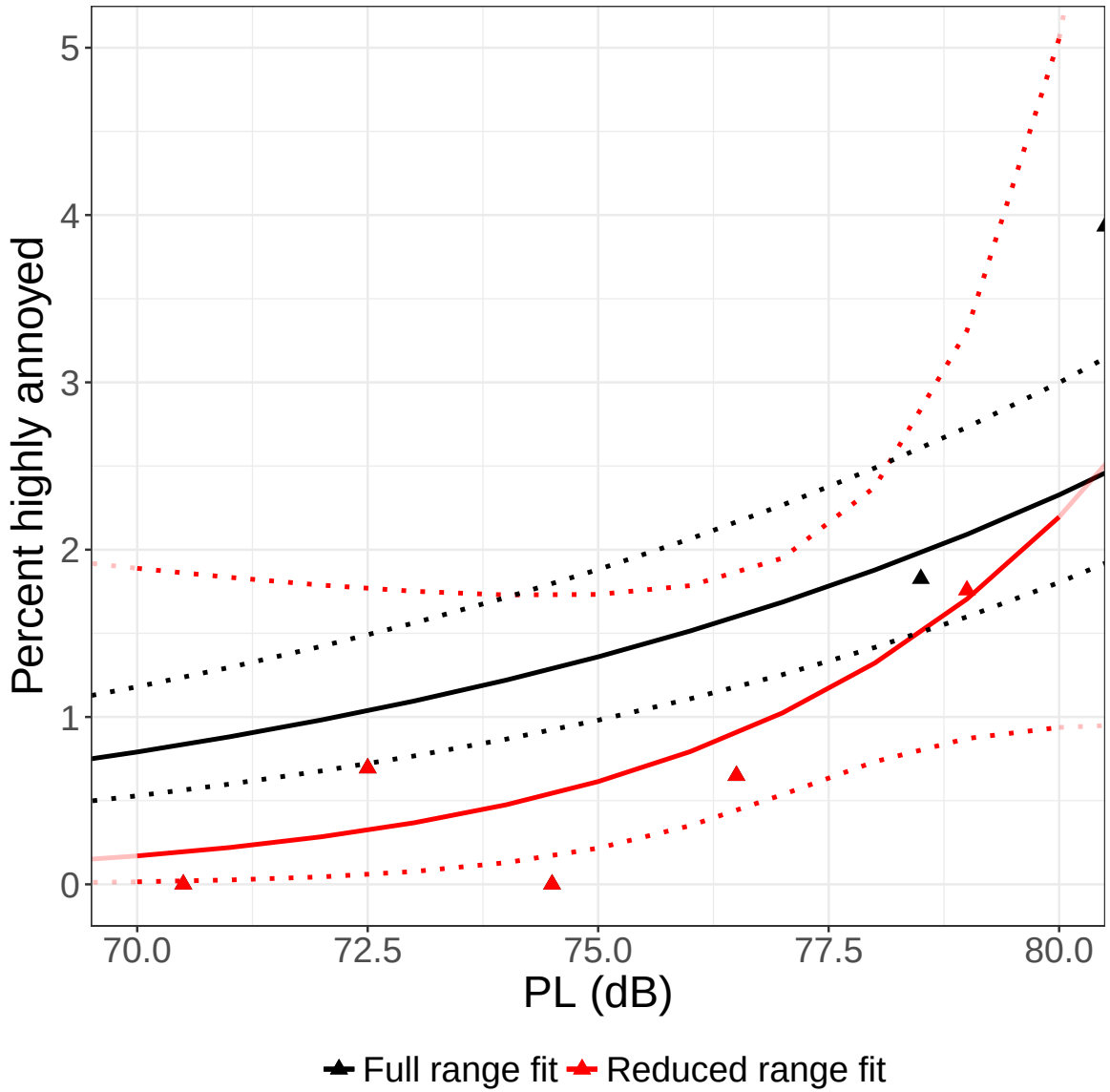
Casella, G., & Berger, R. L. (2002). *Statistical inference* (Vol. 2). Pacific Grove, CA: Thomas Learning.

Fidell, S., Mestre, V., Schomer, P., Berry, B., Gjestland, T., Vallet, M., & Reid, T. (2011). A first-principles model for estimating the prevalence of annoyance with aircraft noise exposure. *The Journal of the Acoustical Society of America*, *130*(2), 791-806. doi: 10.1121/1.3605673

Groothuis-Oudshoorn, C. G. M., & Miedema, H. M. E. (2006). Multilevel grouped regression for analyzing self-reported health in relation to environmental factors: the model and its application. *Biometrical Journal*, *48*(1), 67–82. doi: 10.1002/bimj.200410172

Backup

Results


Percent highly annoyed
0
1
2
3
4
5
70.0
72.5
75.0
77.5
80.0
PL (dB)
Full range fit
Reduced range fit

Comparison of estimates and confidence intervals

- Percent highly annoyed given PL
  - Confidence intervals for reduced range are about two times wider than those for full range

PL (dB)	Estimates (%)	Conf. Intervals
70	0.79	(0.53, 1.18)
75	1.36	(0.98, 1.88)
80	2.33	(1.80, 3.00)

Table 1: Estimates for full range fit

PL (dB)	Estimates (%)	Conf. Intervals
70	0.17	(0.02, 1.89)
75	0.61	(0.22, 1.73)
80	2.2	(0.94, 5.05)

Table 2: Estimates for reduced range fit

Comparison of estimates and confidence intervals (continued)

- PL given percent highly annoyed
  - Confidence intervals are calculated using Delta Method [4]

Perc. HA	Estimates	Conf. Intervals
0.5	65.79	(61.50, 70.07)
1	72.16	(68.76, 75.56)
2	78.58	(76.03, 81.14)

Table 3: Estimates for full range fit

Perc. HA	Estimates	Conf. Intervals
0.5	74.2	(69.35, 79.05)
1	76.9	(74.33, 79.48)
2	79.63	(76.58, 82.68)

Table 4: Estimates for reduced range fit

[4] Casella & Berger (2002)