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
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

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

(b) 5-point scale survey

- Not highly annoyed (95.3%)
- Highly annoyed (4.7%)
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

![Graph showing estimates of percent highly annoyed given different levels of PL (dB)].

- Full range fit
- Reduced range fit
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


Backup
Results
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

<table>
<thead>
<tr>
<th>PL (dB)</th>
<th>Estimates (%)</th>
<th>Conf. Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>0.79</td>
<td>(0.53, 1.18)</td>
</tr>
<tr>
<td>75</td>
<td>1.36</td>
<td>(0.98, 1.88)</td>
</tr>
<tr>
<td>80</td>
<td>2.33</td>
<td>(1.80, 3.00)</td>
</tr>
</tbody>
</table>

Table 1: Estimates for full range fit

<table>
<thead>
<tr>
<th>PL (dB)</th>
<th>Estimates (%)</th>
<th>Conf. Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>0.17</td>
<td>(0.02, 1.89)</td>
</tr>
<tr>
<td>75</td>
<td>0.61</td>
<td>(0.22, 1.73)</td>
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<tr>
<td>80</td>
<td>2.2</td>
<td>(0.94, 5.05)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Perc. HA</th>
<th>Estimates</th>
<th>Conf. Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>65.79</td>
<td>(61.50, 70.07)</td>
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<tr>
<td>1</td>
<td>72.16</td>
<td>(68.76, 75.56)</td>
</tr>
<tr>
<td>2</td>
<td>78.58</td>
<td>(76.03, 81.14)</td>
</tr>
</tbody>
</table>

Table 3: Estimates for full range fit

<table>
<thead>
<tr>
<th>Perc. HA</th>
<th>Estimates</th>
<th>Conf. Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>74.2</td>
<td>(69.35, 79.05)</td>
</tr>
<tr>
<td>1</td>
<td>76.9</td>
<td>(74.33, 79.48)</td>
</tr>
<tr>
<td>2</td>
<td>79.63</td>
<td>(76.58, 82.68)</td>
</tr>
</tbody>
</table>

Table 4: Estimates for reduced range fit

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Casella & Berger (2002)