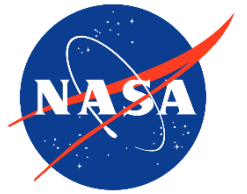

Statistical Considerations for the Design and Execution of NASA's Community Noise Surveys

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SAE 2022: Small Area Estimation, Surveys, and Data Science

University of Maryland, College Park

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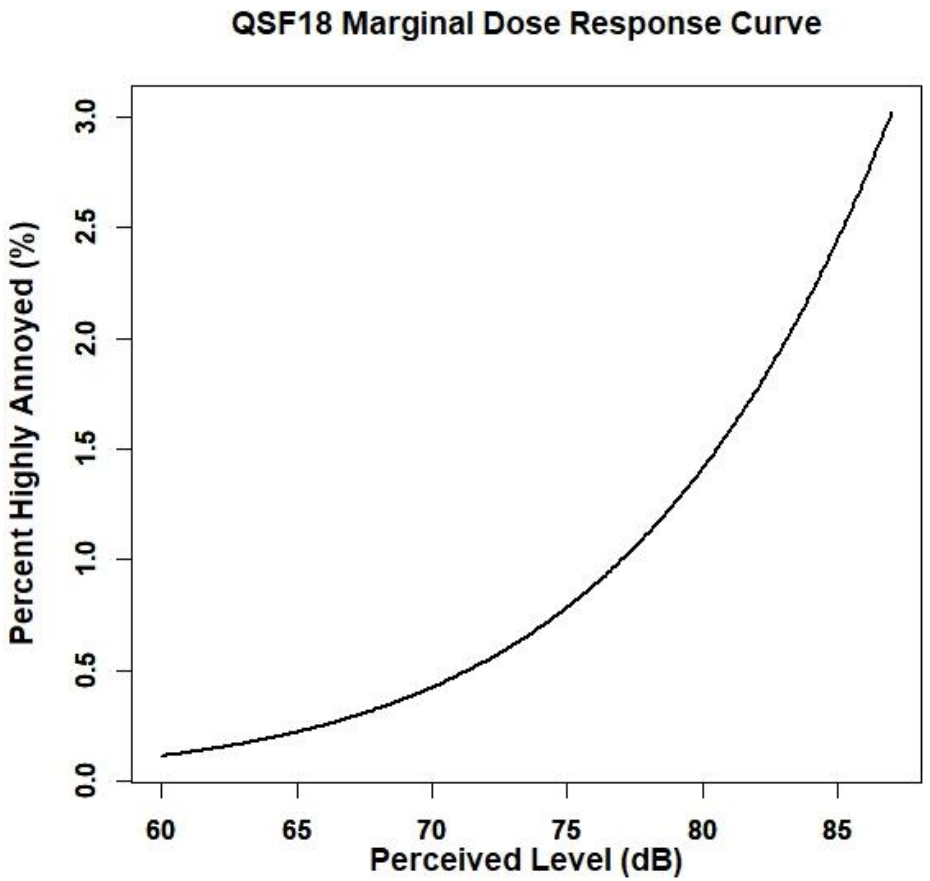
Thank you: Kate Ballard, Will Doebler, and Pete Parker

Presentation Outline



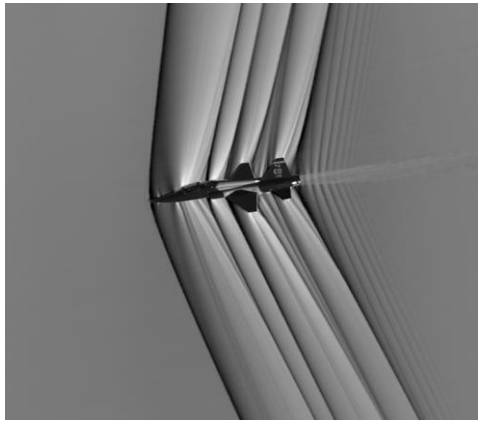
Outline

- Community noise and civilian supersonic flight
- Surveys and replicated analysis from past NASA risk reduction studies
- Future community response surveys: planning and challenges

Takeaways

- NASA is uniquely poised to contribute evidence for policy making
- Could a noise-based regulation replace the current ban on overland supersonic flight?

Designing a First-of-Kind Study for Evidence-Based Policy

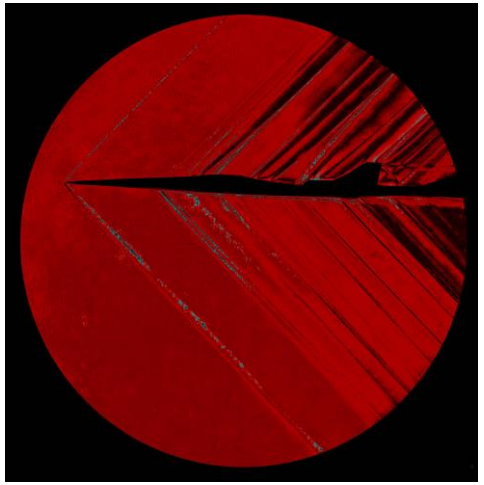


Sonic booms occur when objects travel faster than speed of sound

- The sound of a shockwave or pressure disturbance
- More than six decades of study; see Maglieri et al. (2014)
- New design choices can shape sonic booms—"sonic thump"

Policy and regulatory authorities

- Federal Aviation Administration
  - Prohibition enacted in 1973 and codified in 14 CFR 91.817-Civil Aircraft Sonic Boom
  - FAA Reauthorization Act of 2018 Sec. 181—FAA Leadership on Civil Supersonic Aircraft
- International Civil Aviation Organization (ICAO)



National scope and international importance

Sources: https://technology.nasa.gov/patent/TOP2-271
https://www.nasa.gov/image-feature/x-59-wind-tunnel-testing-at-nasa-glenn

Select Literature and Efforts on Noise and Sonic Boom

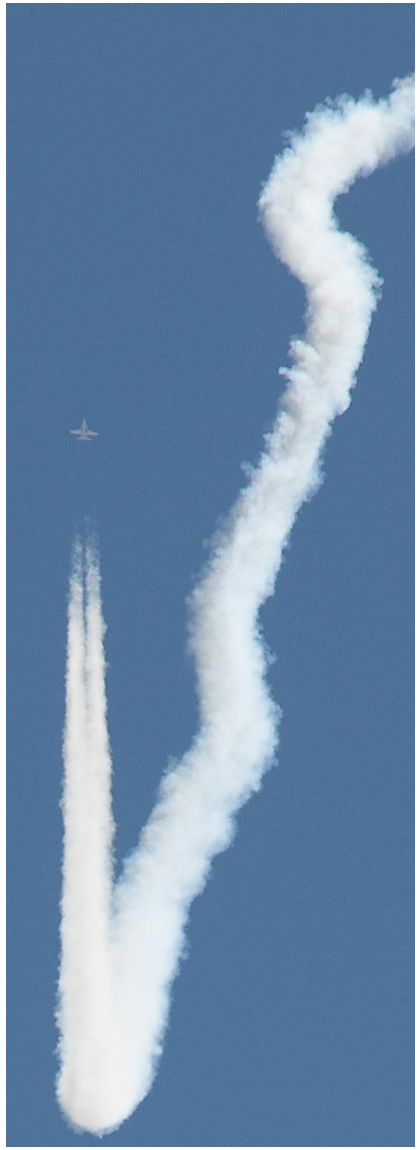
- **Fields and Shepherd (2001)—*An Updated Catalog of 521 Social Surveys of Residents' Reactions to Environmental Noise (1943-2000)***

- ***1961 St. Louis Sonic Boom Study*—N=1,157 respondents; 1,043 reinterviewed. Measured overpressures. See, e.g., Nixon and Borsky (1966)**

- ***1964 Oklahoma City Sonic Boom Study*—N=3,200 respondents and 8,997 interviews. Measured overpressures. See, e.g., Borsky (1965)**

- **Miller et al. (2021)—*Analysis of the Neighborhood Environmental Survey***
  - Conducted on behalf of Federal Aviation Administration
  - Balanced sample of 20 airports; N=10,000 respondents by mail with 40% response rate
  - Noise data collected near airports and *nationally representative Dose-Response curve* produced

NASA Risk Reduction Studies

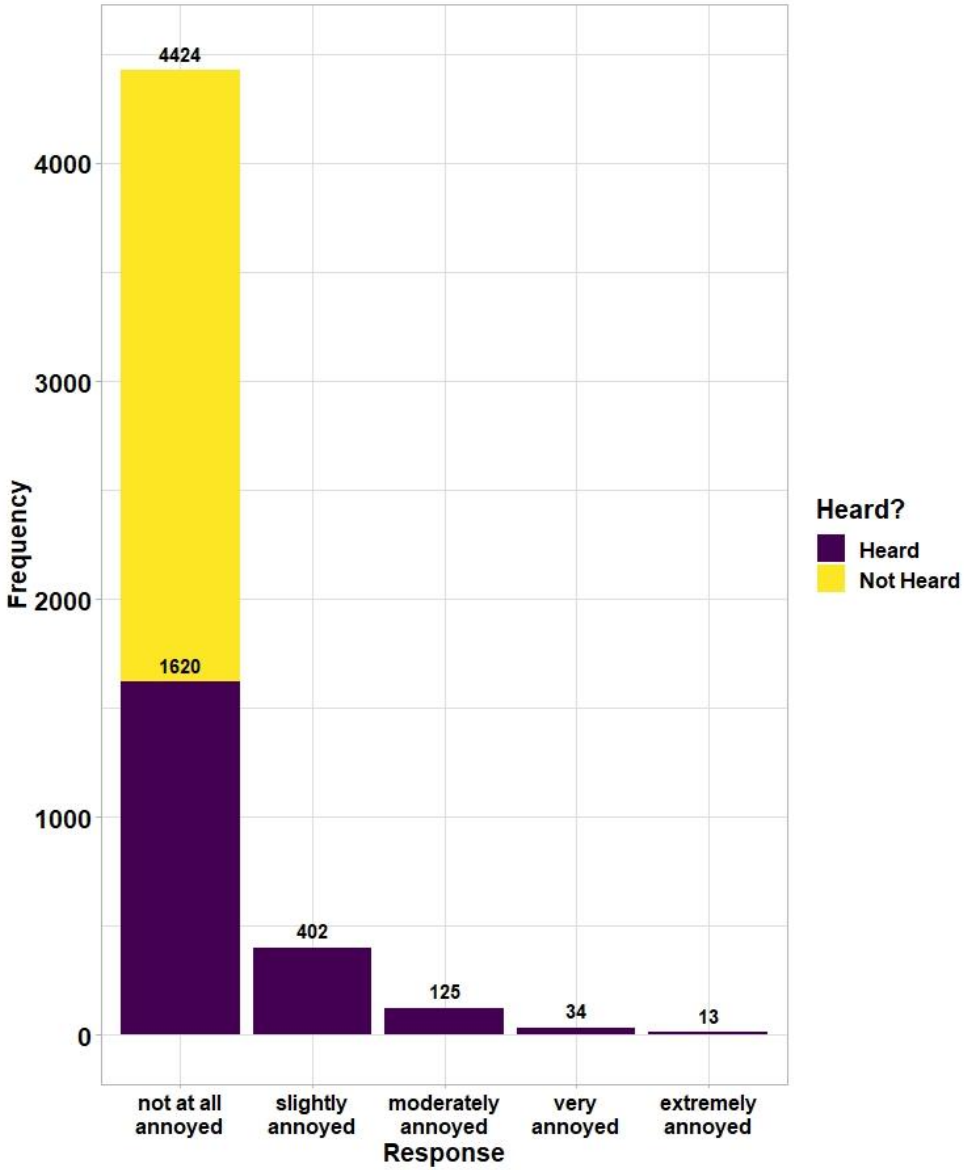


- **Simulated sonic thump with F-18 dive maneuver (Haering et al. 2006)**
- **Experimentation with survey modes and ordinal annoyance scales**
- ***Single event and daily summary questionnaires***
- ***QSF18 Citizen science: https://www.nasa.gov/qsfscientist***

	Waveforms and Sonic Boom Perception and Response (WSPR)	Quiet Supersonic Flights 2018 (QSF18)
Year	2011, 10 flight days	2018, 9 flight days
Location	Edwards Air Force Base, California	Galveston, Texas
Panel	49 volunteers in EAFB community	Recruitment by mail; enrollment capped at 500
Modes	Web, smartphone, and paper	Web and smartphone
Area	1 square mile	60 square miles
# Booms	89 planned booms; 14 adventitious	52 planned booms
Scale	11-point scale ranging from 0 to 10	5-point verbal scale
References	Lee et al. (2019); Page et al. (2014)	Lee et al. (2020); Page et al. (2020)
Data	https://ntrs.nasa.gov/citations/20190002702	Supplemental files at https://doi.org/10.1121/10.0001021

Source: https://www.nasa.gov/feature/nasa-goes-quiet-over-galveston-for-flight-series

QSF18: Conditional Dose-Response Relationship



- **Reproducing Bayesian Random Intercept Logistic Regression of Lee et al. (2020)**

- $i \in \{1, 2, \ldots, 371\}$ individuals
- $j \in \{1, 2, \ldots, n_i\}$ booms
- H_{ij}, indicator of High Annoyance
- p_{ij}, probability of High Annoyance
- x_{ij}, dose, in PL dB
- u_i, individual intercept
- $\beta_0, \beta_1, \sigma_u^2$, parameters

$$
\begin{aligned}
H_{ij}|p_{ij} &\sim Bernoulli(p_{ij}) \\
p_{ij}|\beta_0, \beta_1, u_i &= logit^{-1}\left((\beta_0 + u_i) + \beta_1 x_{ij}\right) \\
u_i|\sigma_u^2 &\sim N\left(0, \sigma_u^2\right) \\
\beta_0 &\sim N\left(0, 100\right) \\
\beta_1 &\sim N\left(0, 100\right) \\
\sigma_u^2 &\sim IG\left(0.01, 0.01\right)
\end{aligned}
$$

Parameter	Estimate	Lower 95% CI	Upper 95% CI	$\hat{R}$
$\hat{\beta}_0$	-19.0	-24.02	-14.25	1.00
$\hat{\beta}_1$	0.15	0.10	0.21	1.00
$\hat{\sigma}_u$	2.62	1.75	3.86	1.00

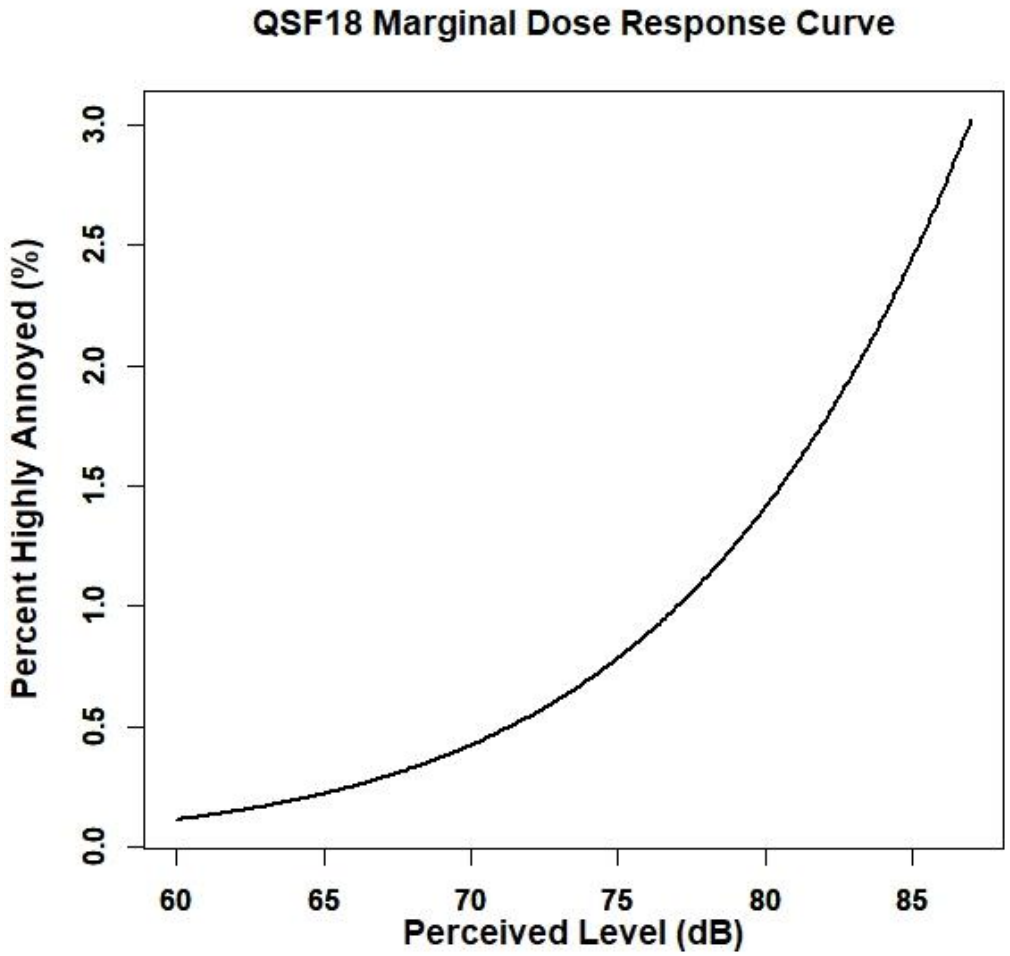
- **Estimates for 371 subject-specific intercepts; family of individual dose-response curves**

QSF18: Marginal Dose Response Relationship

- Want population average relationship, rather than subject-specific curves
- Vaughn et al. (2021) compare Bayesian and GEE approaches to obtain marginal models
- Integrate over (prior) distribution of random effects (Pavlou et al. 2015)

$$P\left(H_{ij}=1|X_{ij}=x_{ij}\right)=\int_{\infty}^{\infty}\frac{1}{1+exp\left(-\left[u-19.0+0.15x_{ij}\right]\right)}f(u)du$$

where f(u) denotes a normal density with mean zero and variance 2.62^2



Future Community Response Surveys Featuring X-59

- **Phase I—Build the X-59**
  - Aircraft is currently undergoing extensive ground testing
  - First flight anticipated in late 2022
- **Phase II—Test Flights and Acoustic Validation**
- **Phase III—Execution of Community Response Surveys in up to five locations (2024-2026)**

- **Before conducting surveys, government agencies post notifications and obtain clearances**
  - Office of Management and Budget and Institutional Review Board approvals
  - Federal Register Notice of intent to collect data currently posted

- **Survey test activities are planned (without X-59 overflight)**
  - Test internet and smartphone applications and survey instruments
  - Additional information about potential response rates, understanding of questionnaires

Future Community Response Surveys: Survey Modes

- **Administer several surveys: recruitment and background surveys; multiple single event surveys, daily summary surveys each day; end-of-test survey**
  - Recruiting and retaining a panel is more practical than a cross-sectional study design
- **Paper modes don't meet near-real-time need, especially for single event survey**
  - Experimental conditions may change within the half hour; require prompt response
- **Fidell and Horonjeff (2019) noted low completion rates for telephone surveys without callbacks—consideration of interactive voice recording (IVR)**
- **Internet and custom smartphone applications as modes**
  - Meets near-real-time requirement
  - Mapping interface allows user to indicate location at point in time—solves significant linkage issue
  - Simplifies nonresponse follow up

Future Community Response Surveys: Site Selection

- **Thousands of airfields nationwide**
  - Limited number of airfields for X-59
  - Some sites near one another
  - Study aims require one month
  - Resources for up to five sites

- **Purposive selection of test sites**
  - Demographic considerations
  - Climate factors (Doebler et al. 2022a)
  - Explore between-site variability

Source: https://www.energy.gov/eere/buildings/building-america-climate-specific-guidance

Future Community Response Surveys: Sample Selection

- **All in community will be dosed, only a portion will be surveyed**

- **Challenge: Multicriteria decision in placement of 20 NM x 30 NM "reliable region" at site**
  - Operational necessities for takeoff/landing, fuel capacity, deploying recording instruments
  - Sample must be recruited from within this region

- **After flight path and orientation of reliable region determined, more standard sampling problem akin to recruiting a probability-based internet panel**
  - Sampling frame is a list of postal addresses
  - Primary sampling unit (variance unit) is a household
  - Within-household sampling to go from household to person level (Rizzo, Brick, and Park 2004)
  - *In contrast to WSPR, QSF18, survey weights derived for individual respondents*

Future Community Response Surveys: Dose Uncertainty

- **Study of measurement error in logistic regression and in generalized linear mixed models**
  - Attenuation of predicted probabilities—"…underestimate the…probability for high-risk cases and overestimate for low-risk cases" (Stefanski and Carroll 1985, p. 1336)
    - If overestimated, policy may be unduly stringent on aircraft manufacturers
    - If underestimated, policy may subject public to unacceptable levels of noise
  - Of recent interest in the acoustics literature; Doebler et al. (2022)

- **Challenge: Dose must be *estimated* across a 20 NM x 30 NM region**
  - Forthcoming study will estimate dose by combining sonic boom propagation models with measurements from sparse network of monitors in a 20 NM x 30 NM region
  - Discussions about means of data fusion used to estimate dose and quantify uncertainty are ongoing; see Klos (2020) for one example

Future Community Response Surveys: Pooling Data

- **Many papers in acoustics literature seek to pool or combine data from distinct studies or from multiple noise sources**

- **Two years from collecting live data at any site—what will final analysis model look like?**
  - Categorical outcome, with regulatory emphasis on binary concept of “Highly Annoyed” or not
  - Repeated measurements through panel survey of respondents
  - Need for national, marginal dose-response relationships (single event and cumulative) from up to five distinct sites

- **A candidate: multilevel regression with poststratification (Gelman and Little 1997)**
  - Divide population into many categories (poststrata)
  - Probability sample allows us to estimate the number of individuals in defined poststrata
  - Averaging across dose-response relationships for poststrata, weighted in proportion to size in *population*

Conclusions

- **Discussed features of survey data collected during a past risk reduction studies and demonstrated techniques pertinent for producing a marginal dose-response curve**

- **Opportunity to design study for the purpose of assessing attitude toward “sonic thumps”**
  - Noted several unique challenges

- **NASA to contribute a body of evidence for policymaking on commercial supersonic flight**
  - Results of the study to be provided to ICAO for use in the Committee on Aviation Environmental Protection rule making cycle in 2028

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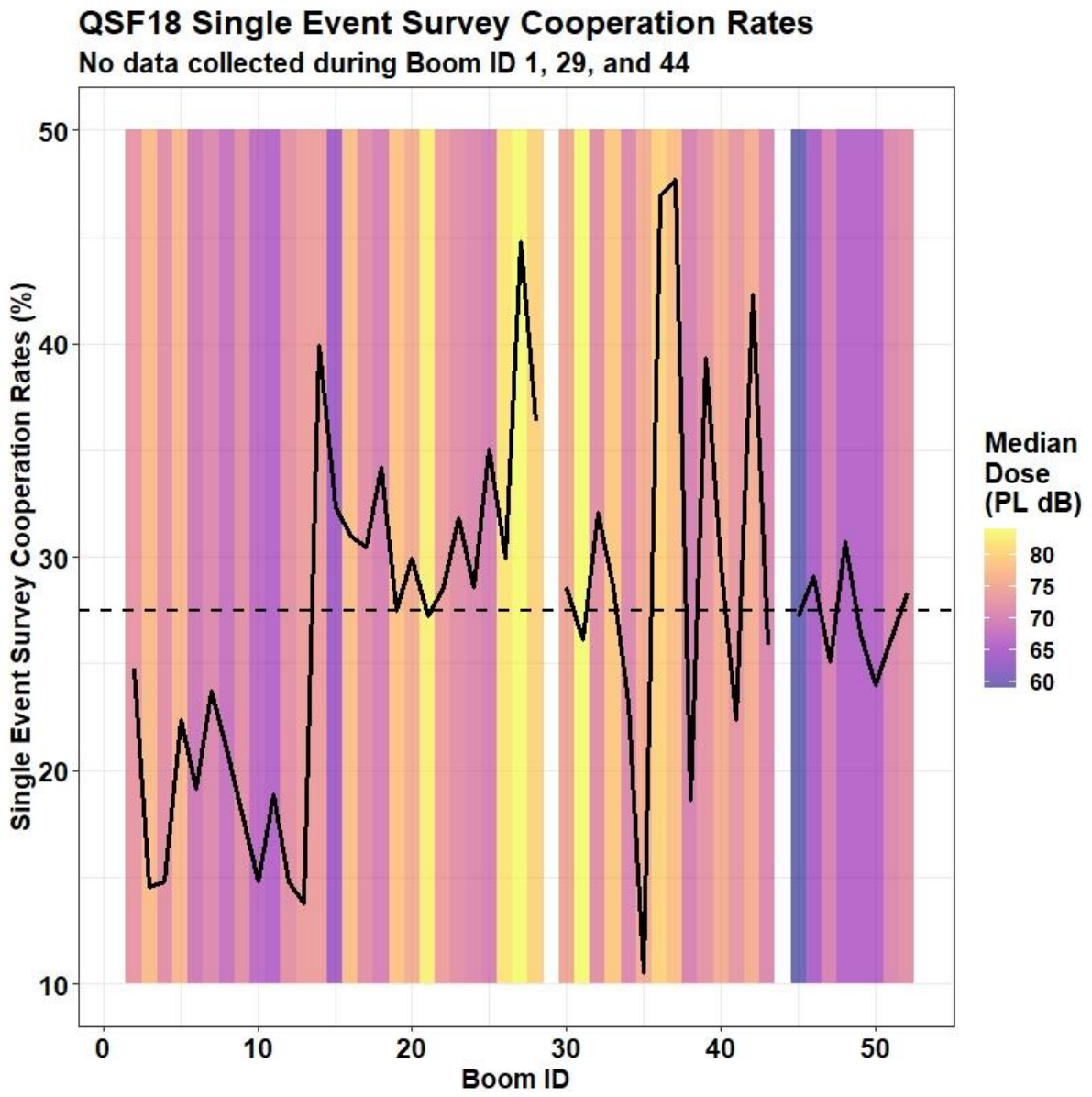
Supplemental Slides

QSF18: Single Event Survey Response Rates

- **371/500 (74.2%) completed at least one single event survey over duration of study**
- **Define cooperation rate for any single event survey as percent responding out of 371. (Med. coop. rate=27.5%)**
- **No data for Boom ID 1, 29, 44**
  - Learning, safety, and “go/no-go” criteria (Page et al. 2020, p. 36)



BRMS Code and Example Output

```
#### Assumes user has tidyverse, brms, parallel, and dependencies
library(tidyverse)
library(brms)

#### User downloads "SuppPub1.csv" at:
#### https://asa.scitation.org/doi/suppl/10.1121/10.0001021
#### Download to the directory you rename here:
setwd("C:/Your/Directory/Here/")

#### Note case sensitivity in csv name upon download from asa site
qsf_dat=read.csv("SuppPub1.csv",header=T)

#### Recode to create binary "High Annoyance" variable
qsf_dat=mutate(qsf_dat,HA=annoy>=4)
table(qsf_dat$HA)

#### Responses by participant over study duration
qsf_dat %>% group_by(PARTICIPANT_ID) %>% summarize(count = n())

#### Responses by boom event
qsf_dat %>% group_by(BOOM_ID) %>% summarize(count = n())

#### Replicate Lee et al. (2020) analysis in Stan using "brms"
options(mc.cores = parallel::detectCores())
dose_response <- brm(HA ~ dose + (1|PARTICIPANT_ID),
                     data = qsf_dat,
                     family = bernoulli(link = "logit"),
                     prior = c(prior(normal(0, 10), class = Intercept),
                               prior(normal(0, 10), class = b, coef="dose"),
                               prior(inv_gamma(.01, .01), class = sd)),
                     warmup = 5000,
                     iter = 10000,
                     chains = 4,
                     init = "0",
                     cores = 4,
                     seed = 123)

#### Compare to Lee et al (2020), Table 1
summary(dose_response)

#### Bayesian--Each parameter has a distribution
#### Output of "fit" includes estimates of random intercepts
dose_response$fit

#### Plots emphasizing posterior distributions
pairs(dose_response)
plot(dose_response)
```