# Developing Rationale for Experimental Designs Employed During Forthcoming NASA Quesst Mission Community Noise Campaigns

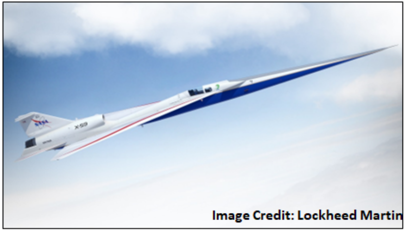
***Nathan B. Cruze**, *Aaron B. Vaughn, *Matthew A. Boucher, *Jacob Klos, +Scott Neuhoff, *Peter A. Parker

*NASA Langley Research Center, +NASA Ames Research Center

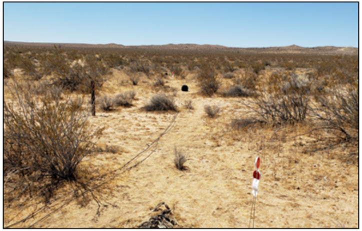
2024 Joint Statistical Meetings, Portland, Oregon
August 5th, 2024

**This work is supported by the NASA Commercial Supersonic Technology Project.**

# The Quesst mission will demonstrate the possibility of low-noise supersonic flight and produce dose-response regressions for use by regulators.




**Build and Test X-59**



**Acoustic Validation**

**Community Studies**

**Goal:** Collect representative community annoyance as function of dose (Rathsam et al., 2023)

# Community testing entails two simultaneous regression experiments.

**Single Event Dose**

- Perceived level, PL (dB) (Stevens, 1972)
- Nominal dose range: 70 to 87 dB
- Average level, not point-wise doses
- *Setpoint control is not absolute*

**Cumulative Dose**

- Day-night averaged sound level

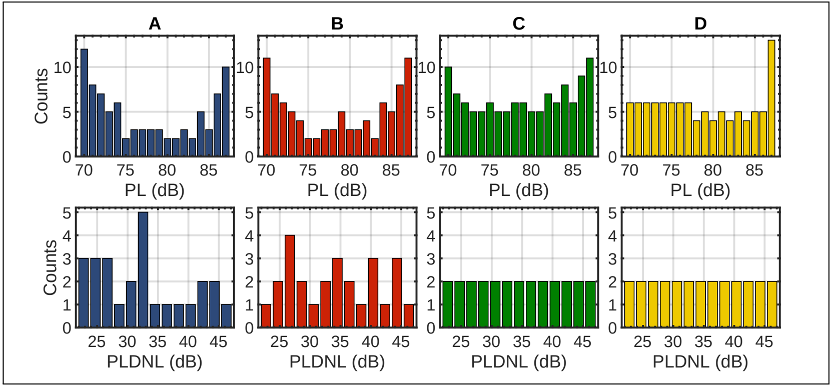
$$PLDNL = -49.4 + 10\log_{10}\left(\sum_{j=1}^{J} 10^{\frac{SE_j}{10}}\right)$$

# Initially proposed designs presumed fine control of setpoints anywhere in the nominal dose range and emphasized uniformity in dose histograms.

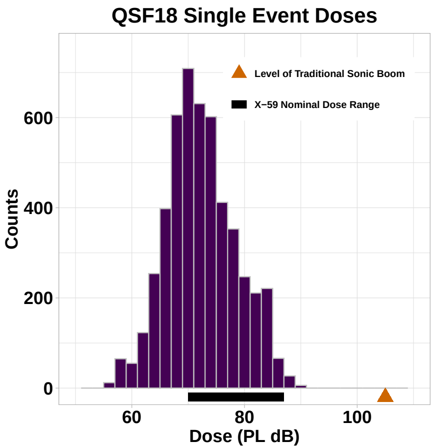
- Nominal, per-community tempo: ≈80 supersonic passes, 24-30 flight days over 4-6 weeks
- Scheduling tool rationale à la Horonjeff (2021); designs discussed in Vaughn et al. (2023)

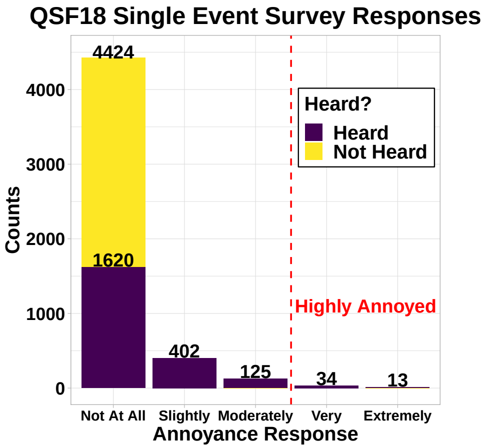
Single Event

Cumulative



# Data from past risk reduction studies may have features like the X-59 shaped sonic boom data.



# Logistic (GLM) regression experiments suffer from design dependence.

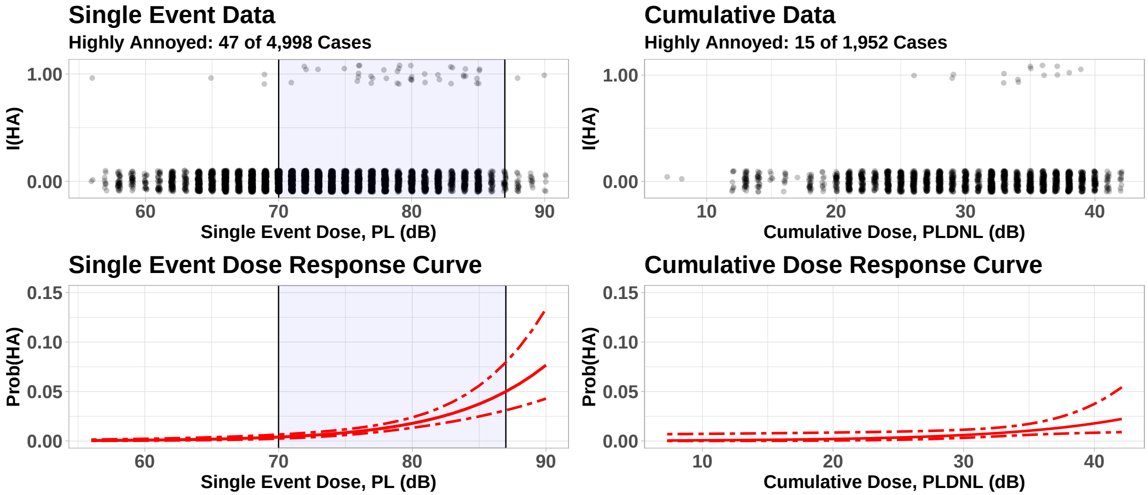
Following Khuri et al. (2006), good designs minimize

$$\mathbf{MSE}\left[\widehat{\mu}\left(\boldsymbol{x}\right)\right] = \boldsymbol{E}\left[\widehat{\mu}\left(\boldsymbol{x}\right) - \mu\left(\boldsymbol{x}\right)\right]^2 = \mathbf{Var}\left[\widehat{\mu}\left(\boldsymbol{x}\right)\right] + \left\{\mathbf{Bias}\left[\widehat{\mu}\left(\boldsymbol{x}\right)\right]\right\}$$

- Linear predictor: $\eta\left(\boldsymbol{x}\right) = \boldsymbol{f}^T\left(\boldsymbol{x}\right)\boldsymbol{\beta}$ $\left(\boldsymbol{\beta}^T \equiv \left(\text{intercept}, \text{slope}\right)^T\right)$
- Mean response at $\boldsymbol{x}$: $\mu\left(\boldsymbol{x}\right) = h\left[\boldsymbol{f}^T\left(\boldsymbol{x}\right)\boldsymbol{\beta}\right] = h\left[\eta\left(\boldsymbol{x}\right)\right]$ $\left(h \equiv \text{logit}^{-1}\left(\cdot\right)\right)$

**Upon literature review: specificity, points of support, use of previous information**

# By its design, the X-59 should reduce annoyance, and the binary annoyance outcome is expected to be rare within the range of factors tested.



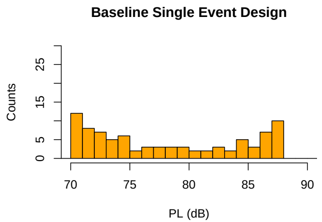
# Concerns about setpoint control and sparsity of highly annoyed responses in the limited dose range motivated discussion of single-event designs.

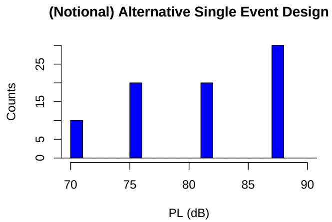
Factorial Experimentation

- Single-event dose as primary factor and treatment
- Imperfect setpoint control $\rightarrow$ reduce points of support

Replication

- Fixed ‘budget’ of $\approx$80 supersonic passes
- Fewer points of support $\rightarrow$ increased replication per point
- Sparse response $\rightarrow$ greater emphasis on high doses



# Blocking strategies may add robustness against testing interruptions.

(Notional) Blocking according to uniform risk assessment, assuming five weeks of testing

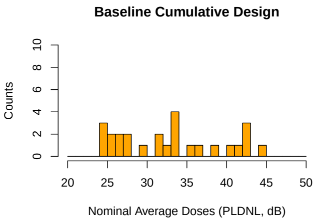
| Nominal Level (PL, dB) | Counts Each Week | Total |
|---|---|---|
| 70 | 2 | 10 |
| 75 | 4 | 20 |
| 81 | 4 | 20 |
| 87 | 6 | 30 |
| Total | 16 | 80 |

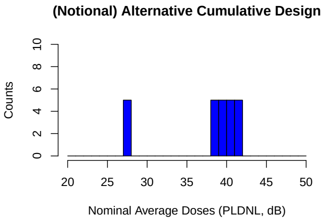
(Notional) Blocking to prioritize high doses in initial and final weeks of testing

| Nominal Level (PL, dB) | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Total |
|---|---|---|---|---|---|---|
| 70 | 0 | 3 | 3 | 3 | 1 | 10 |
| 75 | 3 | 3 | 5 | 6 | 3 | 20 |
| 81 | 5 | 4 | 4 | 3 | 4 | 20 |
| 87 | 8 | 6 | 4 | 4 | 8 | 30 |
| Total | 16 | 16 | 16 | 16 | 16 | 80 |

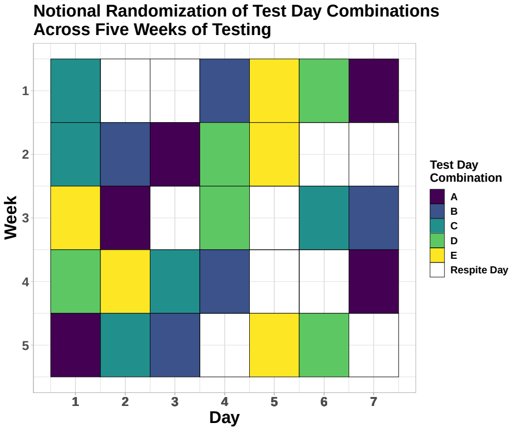
# Arrangement of supersonic passes into same-day testing is necessary to determine treatment levels for cumulative dose design.

| Test Day | No. Passes | Single-Event Doses (PL, dB) | Cumulative Dose (PLDNL, dB) |
|---|---|---|---|
| A | 3 | 70, 70, 75 | 27.7 |
| B | 4 | 75, 75, 81, 87 | 39.0 |
| C | 3 | 81, 81, 87 | 39.3 |
| D | 3 | 75, 87, 87 | 40.8 |
| E | 3 | 81, 87, 87 | 41.1 |



# Randomization is used to remove effects due to remaining nuisance factors.




Examples

- Random sampling of experimental units ($\approx$ 1,000 people) within community
- Assigning nominal test day combinations into blocks (weeks)
- Randomize time of delivery, order of nominal levels of supersonic passes

Numerous operational constraints exist!

# Community testing with X-59 is an extraordinarily complex undertaking!

Conclusions

1. Setpoint control and other considerations motivated reevaluation of proposed test designs.
2. The basics of design of experiments bolster the rationale for community testing plans.
3. Notional experimental designs emphasize the loudest levels produced by the quiet X-59.

QUESST

https://www.nasa.gov/mission/quesst/

# References I


Abdelbasit, K. M. & Plackett, R. L. (1983). Experimental design for binary data. *Journal of the American Statistical Association*, 78(381), 90–98. http://www.jstor.org/stable/2287114

Chaloner, K. (1984). Optimal Bayesian Experimental Design for Linear Models. *The Annals of Statistics*, 12(1), 283 – 300. https://doi.org/10.1214/aos/1176346407

Chaloner, K. & Larntz, K. (1989). Optimal Bayesian Design Applied to Logistic Regression Experiments. *Journal of Statistical Planning and Inference*, 21(2), 191–208. https://doi.org/10.1016/0378-3758(89)90004-9

Freeman, P. R. (1970). Optimal bayesian sequential estimation of the median effective dose. *Biometrika*, 57(1), 79–89. http://www.jstor.org/stable/2334938

Hooshangifar, M., Talebi, H., & Poursina, D. (2022). D-Optimal Design for Logistic Model Based on More Precise Approximation. *Communications in Statistics - Theory and Methods*, 51(7), 1975–1992. https://doi.org/10.1080/03610926.2021.1957482

Horonjeff, R. D. (2021). An Examination of Dose Uncertainty and Dose Distribution Effects on Community Noise Attitudinal Survey Outcomes. *The Journal of the Acoustical Society of America*, 150(3), 1691–1701. https://doi.org/10.1121/10.0005949

Khan, M. (1988). Optimal bayesian estimation of the median effective dose. *Journal of Statistical Planning and Inference*, 18(1), 69–81. https://doi.org/10.1016/0378-3758(88)90017-1

# References II


Khuri, A. I., Mukherjee, B., Sinha, B. K., & Ghosh, M. (2006). Design Issues for Generalized Linear Models: A Review. *Statistical Science*, 21(3), 376 – 399. https://doi.org/10.1214/088342306000000105

Lawless, J. F. (1977). Discussion of: Asymptotically Optimum Over Stress Tests to Estimate the Survival Probability at a Condition with a Low Expected Failure Probability. *Technometrics*, 19(4), 401–404. https://doi.org/10.1080/00401706.1977.10489578

Lee, J., Rathsam, J., & Wilson, A. (2020). Bayesian Statistical Models for Community Annoyance Survey Data. *The Journal of the Acoustical Society of America*, 147(4), 2222–2234. https://doi.org/10.1121/10.0001021

Mathew, T. & Sinha, B. K. (2001). Optimal Designs for Binary Data Under Logistic Regression. *Journal of Statistical Planning and Inference*, 93(1), 295–307. https://doi.org/10.1016/S0378-3758(00)00173-7

Meeker, W. Q. & Hahn, G. J. (1977). Asymptotically Optimum Over-Stress Tests to Estimate the Survival Probability at a Condition with a Low Expected Failure Probability. *Technometrics*, 19(4), 381–399. http://www.jstor.org/stable/1267877

Moerbeek, M., Breukelen, G. J. P. V., & Berger, M. P. F. (2001). Optimal Experimental Designs for Multilevel Logistic Models. *Journal of the Royal Statistical Society. Series D (The Statistician)*, 50(1), 17–30. http://www.jstor.org/stable/2681154

O'Brien, T. E. & Silcox, J. (2021). Efficient experimental design for dose response modelling. *Journal of Applied Statistics*, 48(13-15), 2864–2888. PMID: 35707079. https://doi.org/10.1080/02664763.2021.1880556

# References III


Rathsam, J., Coen, P., Loubeau, A., Ozoroski, L., & Shah, G. (2023). Scope and Goals of NASA's Quesst Community Test Campaign with the X-59 Aircraft. *Proceedings of the Fourteenth ICBEN Congress on Noise as a Public Health Problem*. https://ntrs.nasa.gov/citations/20230004142

Stevens, S. S. (1972). Perceived Level of Noise by Mark VII and Decibels (E). *The Journal of the Acoustical Society of America*, 51(2B), 575–601. https://doi.org/10.1121/1.1912880

Telford, J. K. (2007). A Brief Introduction to Deisgn of Experiements. *Johns Hopkins APL Technical Digest*, 27(3), 224–232. https://secwww.jhuapl.edu/techdigest/Content/techdigest/pdf/V27-N03/27-03-Telford.pdf

Tsutakawa, R. K. (1972). Design of experiment for bioassay. *Journal of the American Statistical Association*, 67(339), 584–590. https://doi.org/10.1080/01621459.1972.10481253

Tsutakawa, R. K. (1980). Selection of dose levels for estimating a percentage point of a logistic quantal response curve. *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, 29(1), 25–33. http://www.jstor.org/stable/2346406

Vaughn, A. B. & Christian, A. W. (2024). A Generalized Cumulative Noise Exposure Metric for Community Response Analysis. *The Journal of the Acoustical Society of America*, 155(2), 1272–1284. https://doi.org/10.1121/10.0024765

Vaughn, A. B., Doebler, W. J., & Christian, A. W. (2023). Cumulative Noise Metric Design Considerations for the NASA Quesst Community Test Campaign With the X-59 Aircraft. *Proceedings of Inter-Noise 2023 Conference*. https://ntrs.nasa.gov/citations/20230006837