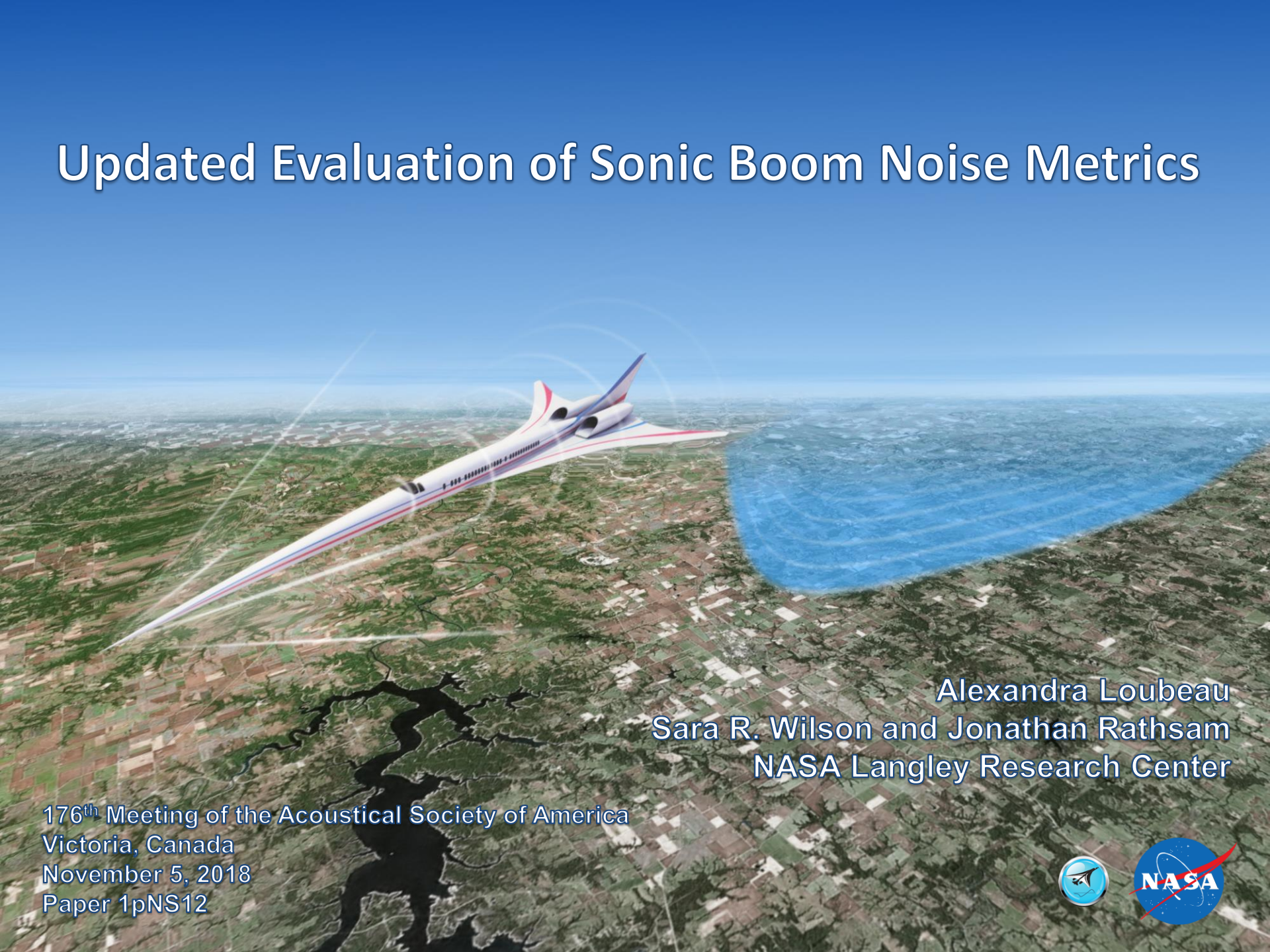
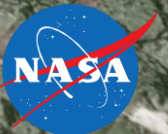


Updated Evaluation of Sonic Boom Noise Metrics



Alexandra Loubeau
Sara R. Wilson and Jonathan Rathsam
NASA Langley Research Center

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Introduction



- NASA goal to enable development of noise-based standard for commercial supersonic aircraft
- Need for a noise metric that predicts human perception of sonic booms experienced both outdoors and indoors
- Objective
 - Revise previous studies to evaluate noise metrics for predicting human perception of sonic booms
 - Use laboratory subjective data from various sources



Selection of Datasets



- Laboratory subjective studies of isolated sonic booms
 - Sufficient number of subjects
 - Variety of sonic boom sounds
 - High-fidelity stimulus acoustic data available
 - Variety of simulation laboratories
 - Include studies in which subjects experienced sonic booms indoors
 - Emphasize human perception of booms indoors with metrics computed on outdoor booms
- Identified seven existing datasets
 - Contain sonic boom waveforms and associated indoor and outdoor human response
 - Conducted in specialized labs at NASA Langley or Japan Aerospace Exploration Agency (JAXA)

List of Human Response Laboratory Studies



- Seven dose-response studies with shaped booms
 - NASA Outdoor (2003)
 - NASA Indoor (2013)
 - JAXA Indoor (2013)
 - JAXA Outdoor (2013)
 - NASA Indoor, with rattle (2013)
 - NASA Indoor, with vibration (2015)
 - NASA Indoor, with rattle (2017)



Naka (2013)





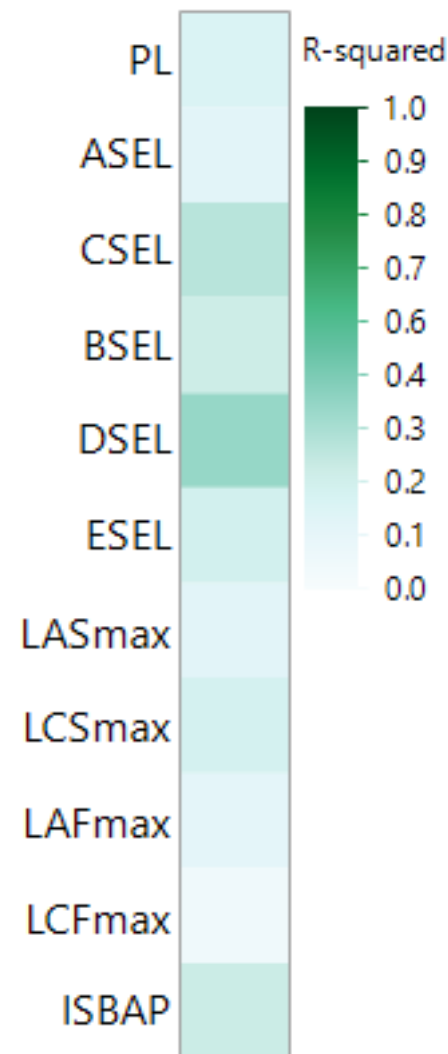
Methods for Metric Evaluation

- Three meta-analysis methodologies implemented to evaluate metrics:
 - 1) Meta-analysis with individual observations (indoor studies only)
 - Single step process using annoyance ratings from individual subjects in four indoor studies
 - 2) Meta-analysis with means (indoor studies only)
 - Single step process using mean annoyance ratings averaged across subjects from five indoor studies
 - 3) Meta-analysis with means (**indoor and outdoor studies**)
 - Multi-step process using mean annoyance ratings from five indoor and two outdoor studies treated separately
- All three methods use R^2 to quantify a metric's "goodness of fit" for effectively explaining human annoyance
 - Considered multiple criteria: R^2 , RMSE, Akaike Information Criteria
 - Results were similar and previous work used R^2
 - Thirteen metrics analyzed
 - PL, ASEL, BSEL, CSEL, DSEL, ESEL, LASmax, LAFmax, LCSmax, LCFmax, ISBAP, PNL, LLZ

1) Meta-Analysis with Individual Observations



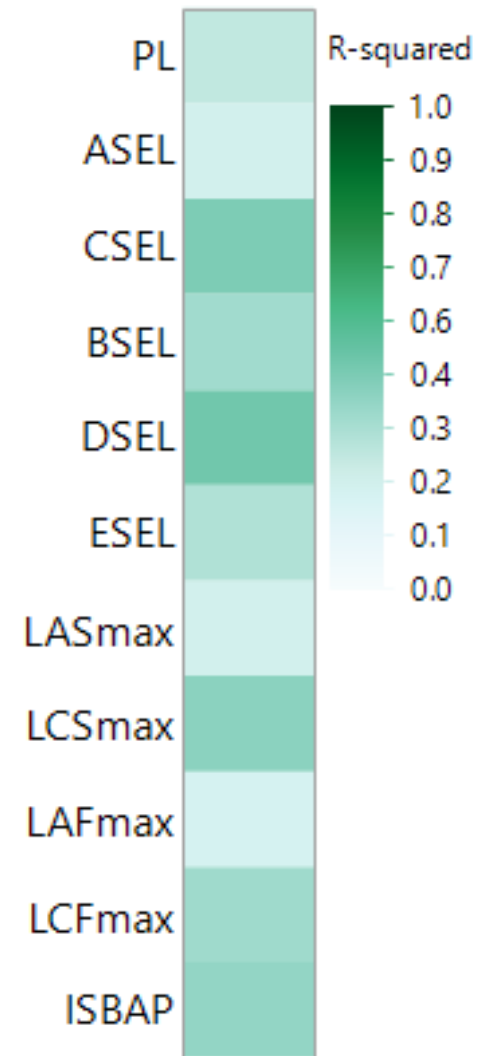
- Combined ratings from individual subjects in four indoor studies
- Compared R^2 across all data for set of metrics
- Results indicate subset of metrics with higher correlation to human annoyance
 - DSEL
 - CSEL
 - BSEL
 - ISBAP



2) Meta-Analysis with Means



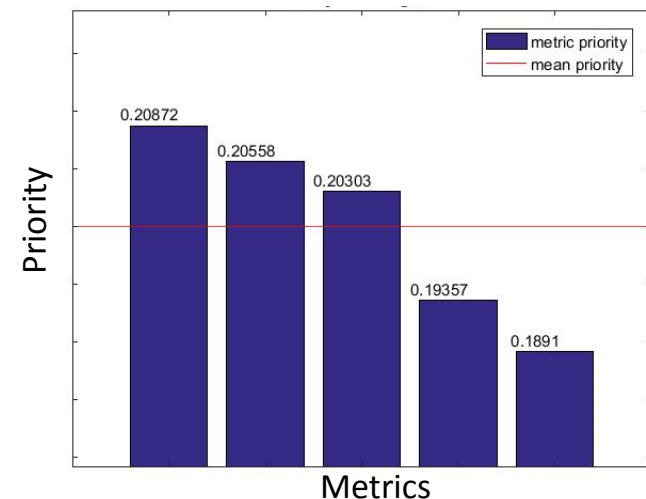
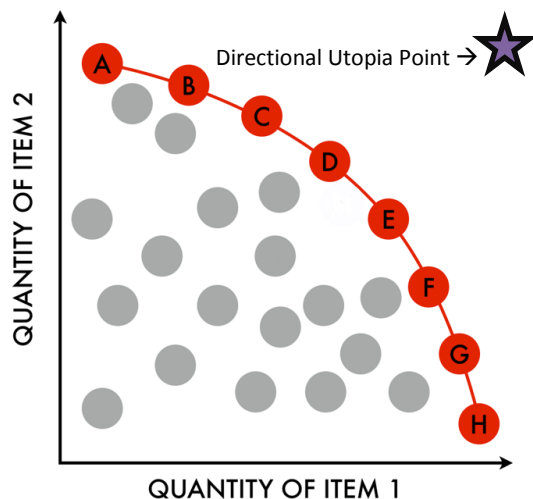
- Combined mean annoyance ratings from five indoor studies
 - Annoyance ratings for each signal averaged across subjects
- Compared R^2 across all data for set of metrics
- Results indicate subset of metrics with higher correlation to human annoyance
 - DSEL
 - CSEL
 - LCSmax
 - ISBAP



3) Meta-Analysis with Means in All Studies



- Used mean annoyance ratings from five indoor studies and two outdoor studies treated separately
 - Annoyance ratings for each signal averaged across subjects
- Multi-step process that uses R^2 for set of metrics (multiple criteria decision analysis)
- Pareto Efficiency Frontier
 - Allocates points such that it is impossible to make any item's criterion better off without making another item's criterion worse off
- Analytic Hierarchy Process (AHP)
 - Systematic paired comparisons to numerically rank each metric based on its explanatory power in all studies

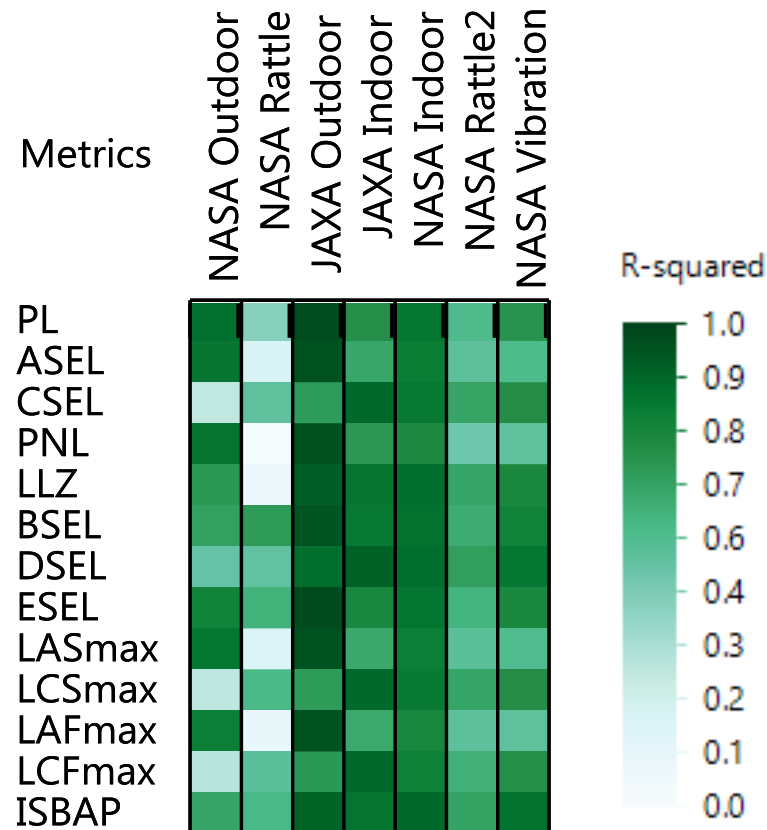


3) Comparison of Metrics Across Studies



- Graphical representation of R^2 values for each experiment

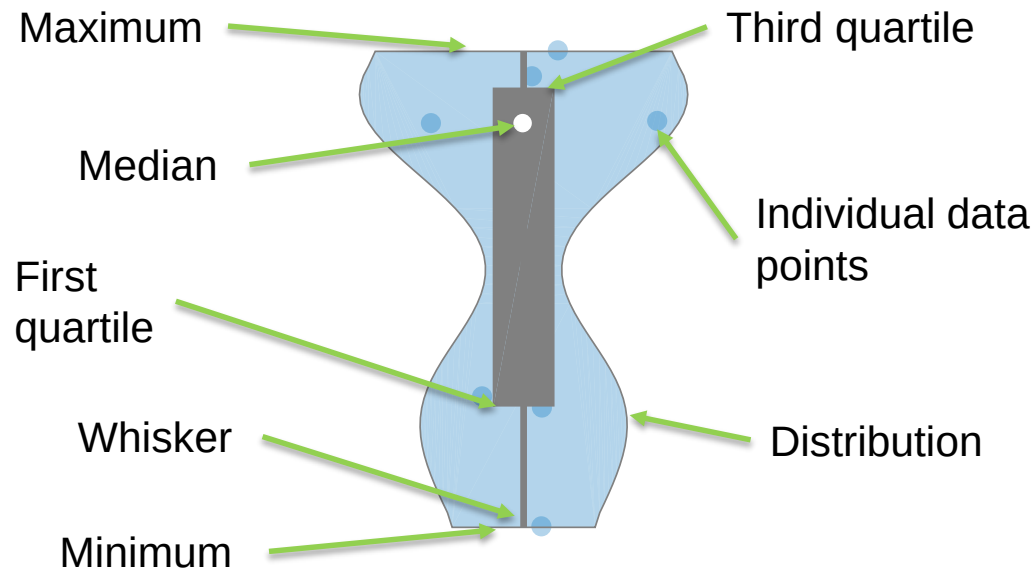
Cell Plot



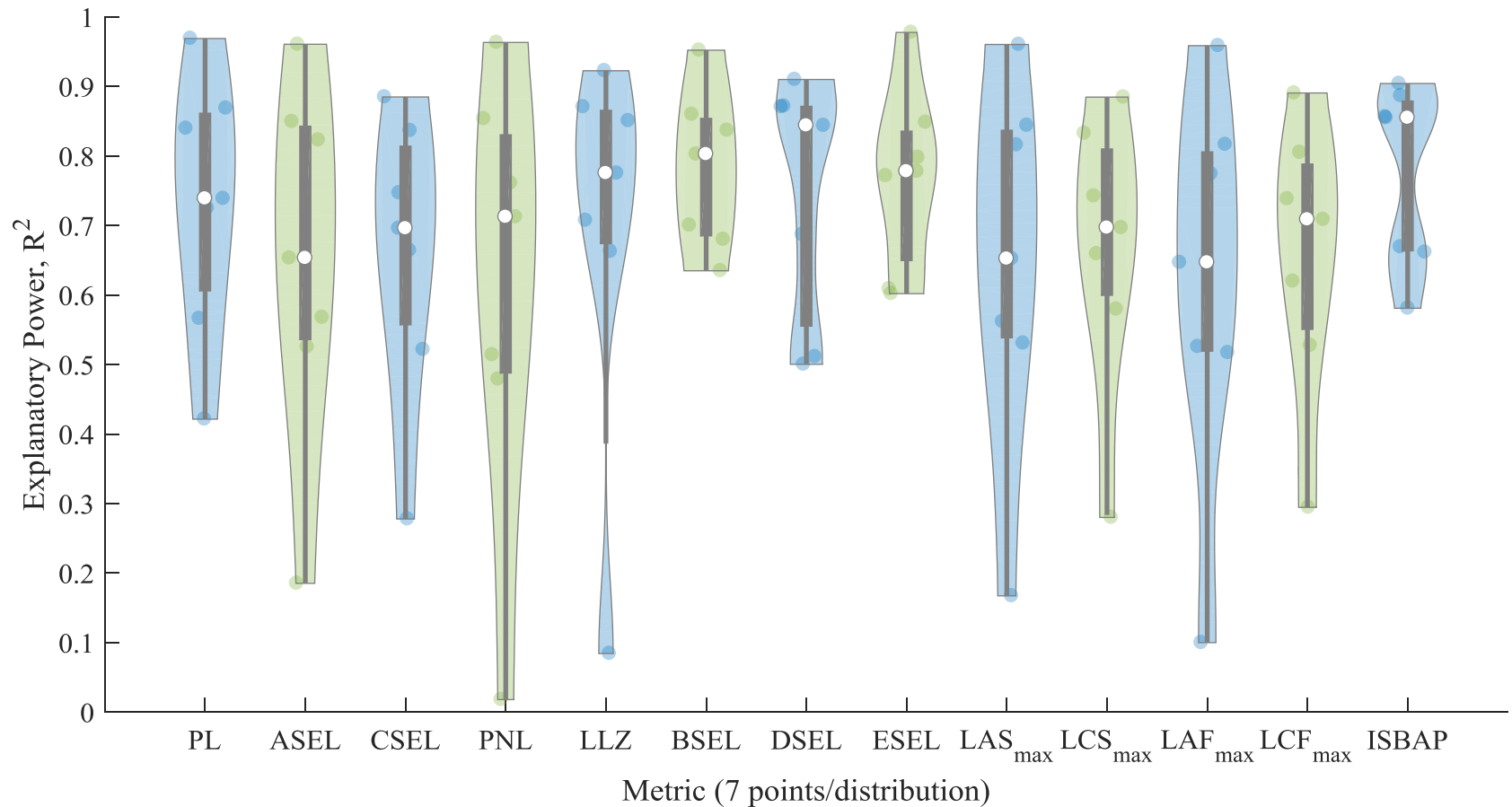
3) Summary Statistics



- Violin plots on following slides show distribution of data in addition to summary statistics
 - Only seven points per distribution representing the seven datasets



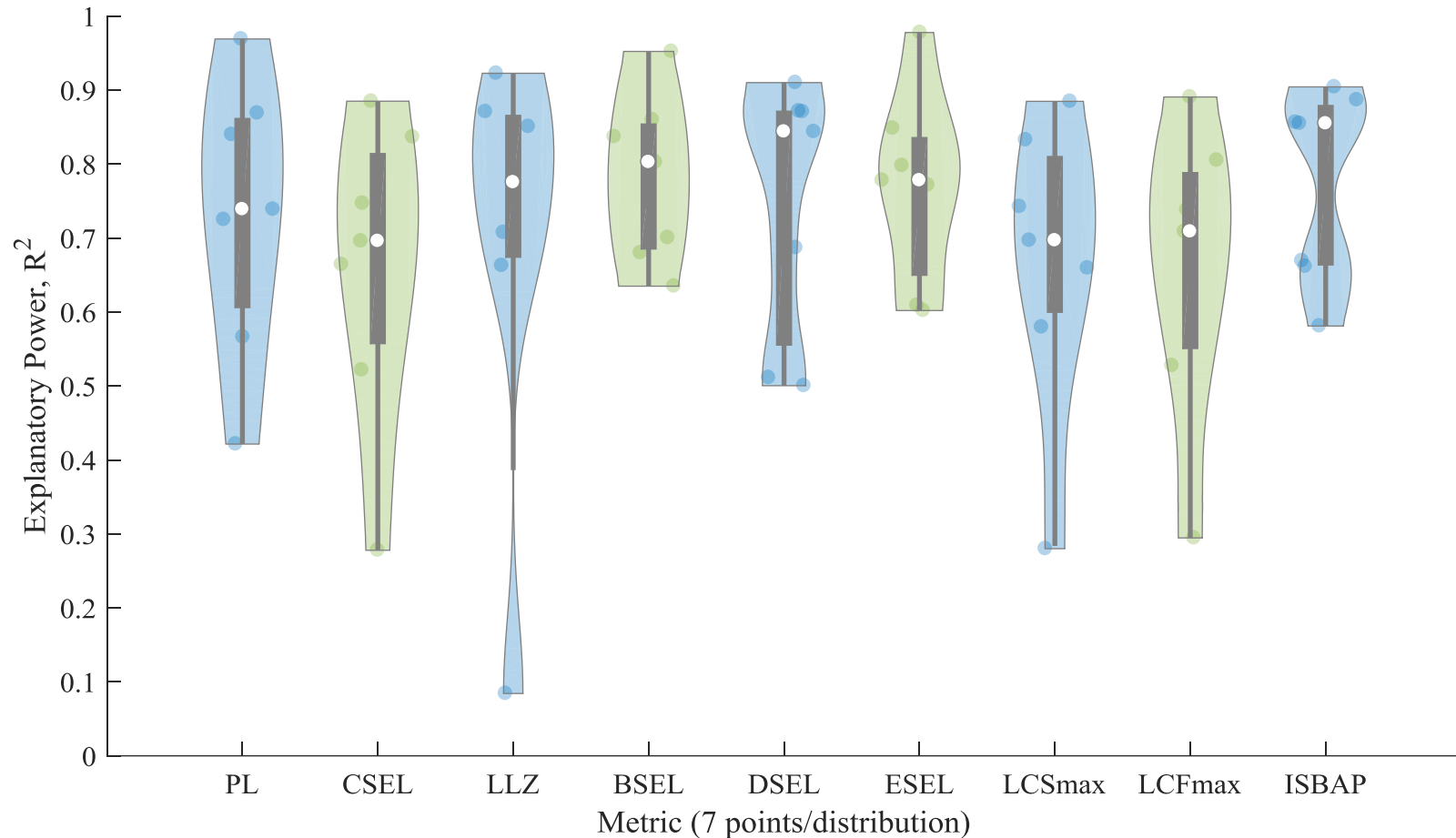
3) Comparison of Metrics Distributions



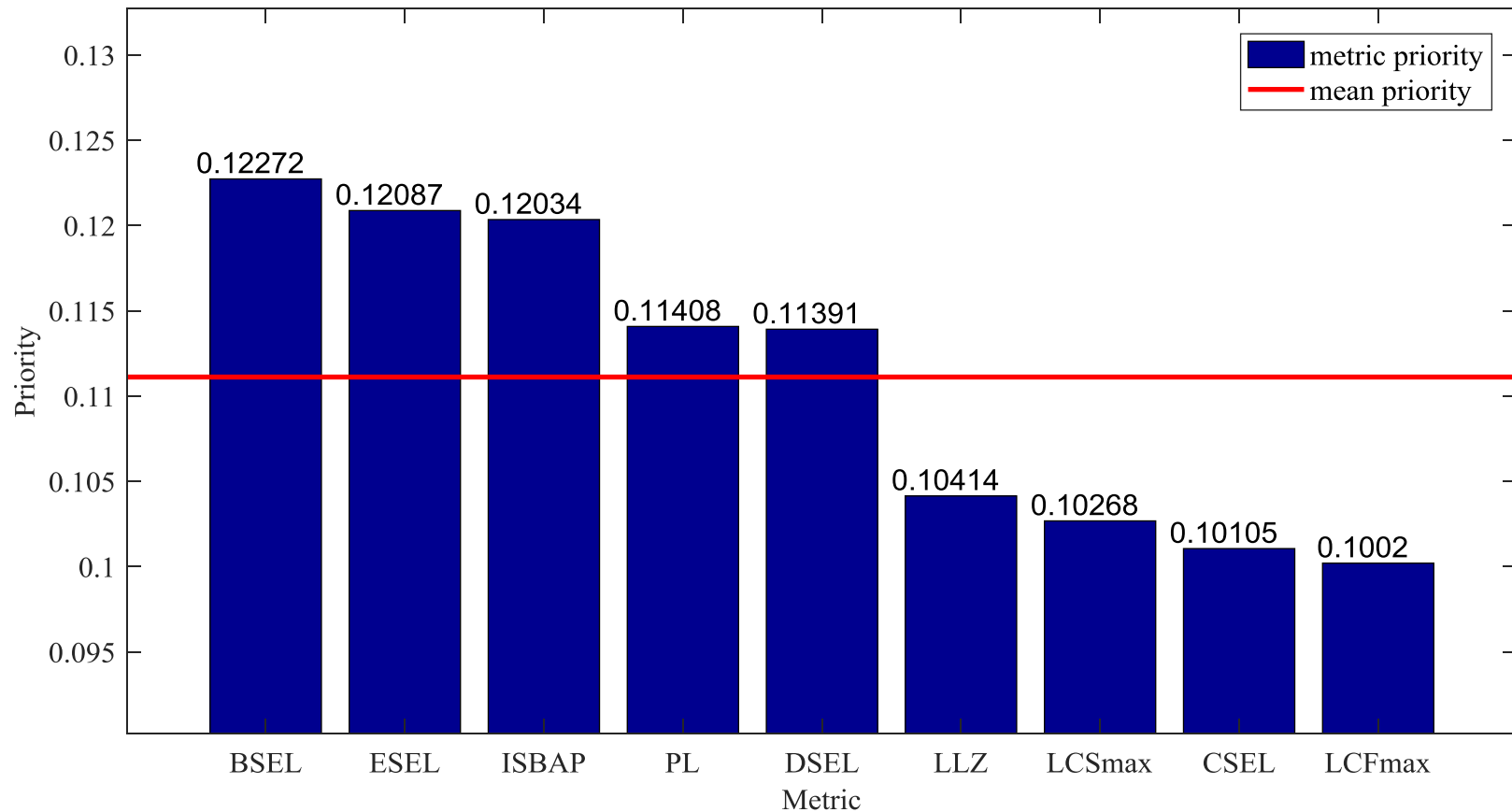
3) Comparison after Pareto Analysis



- PNL and A-weighted metrics are eliminated through Pareto analysis



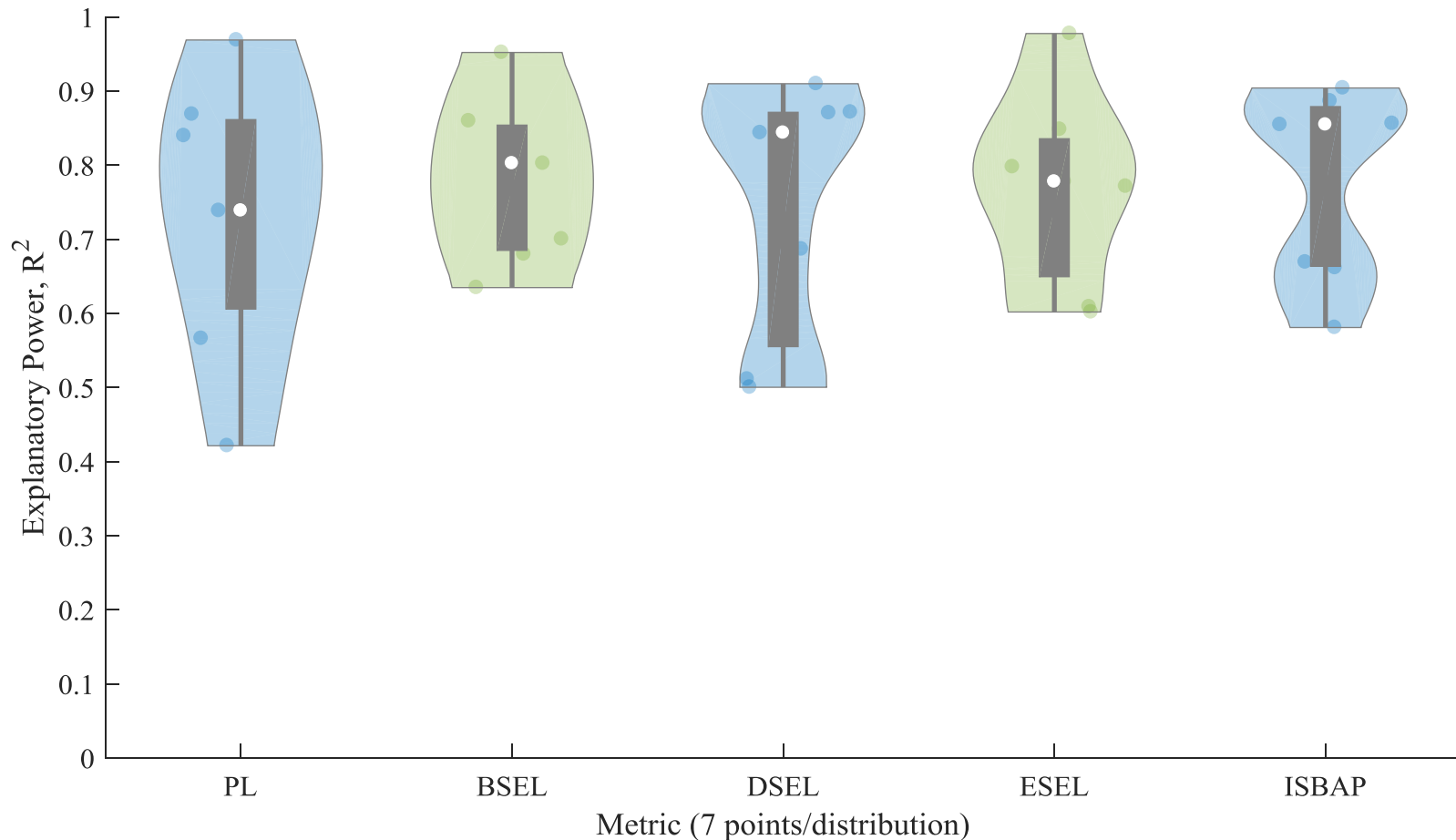
3) Results of AHP Analysis



3) Comparison after AHP Analysis



- LLZ and C-weighted metrics are eliminated through AHP analysis
- Metrics subset remains unchanged from previous analysis (DeGolia & Loubeau, 2017)
 - Additional study did not change conclusions



Results From Three Methods

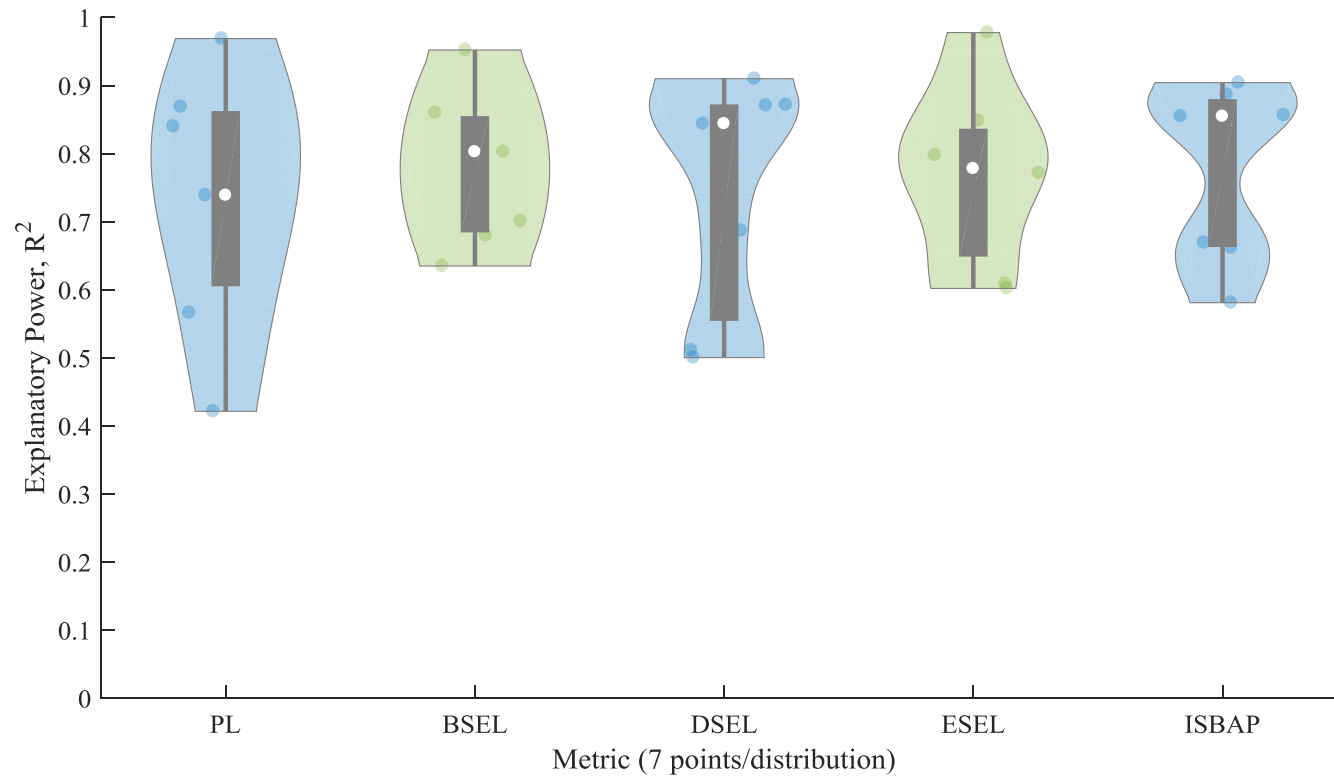
Analysis Metric	Individual Observations (Indoor)	Means (Indoor)	Means (Indoor and Outdoor)
PL			X
BSEL	X		X
DSEL	X	X	X
ESEL			X
ISBAP	X	X	X
CSEL	X	X	
LCSmax		X	

- No one clear winning metric
- Recommend same 5 metrics as in previous work
- Including outdoor studies eliminates the C-weighted metrics that perform well for indoors only
- A-weighted metrics do not appear in the results for any of the methods

Summary



- Several years of laboratory testing and summary meta-analysis enabled comprehensive evaluation of sonic boom metrics
- Three meta-analysis methods applied to metrics evaluation
 - Results are robust to differences in use of mean vs. individual rating data
- Five metrics are suggested for further study
 - Predict human response to sonic booms experienced both outdoors and indoors
 - Additional two metrics included if only indoor studies are considered
- Community studies will also be needed
 - Gather data in a realistic environment
 - Verify metric(s) selected from laboratory data analysis
 - This data will be given to regulators to choose a metric limit for noise certification



Alexandra Loubeau
a.loubeau@nasa.gov

Backup Slides



References

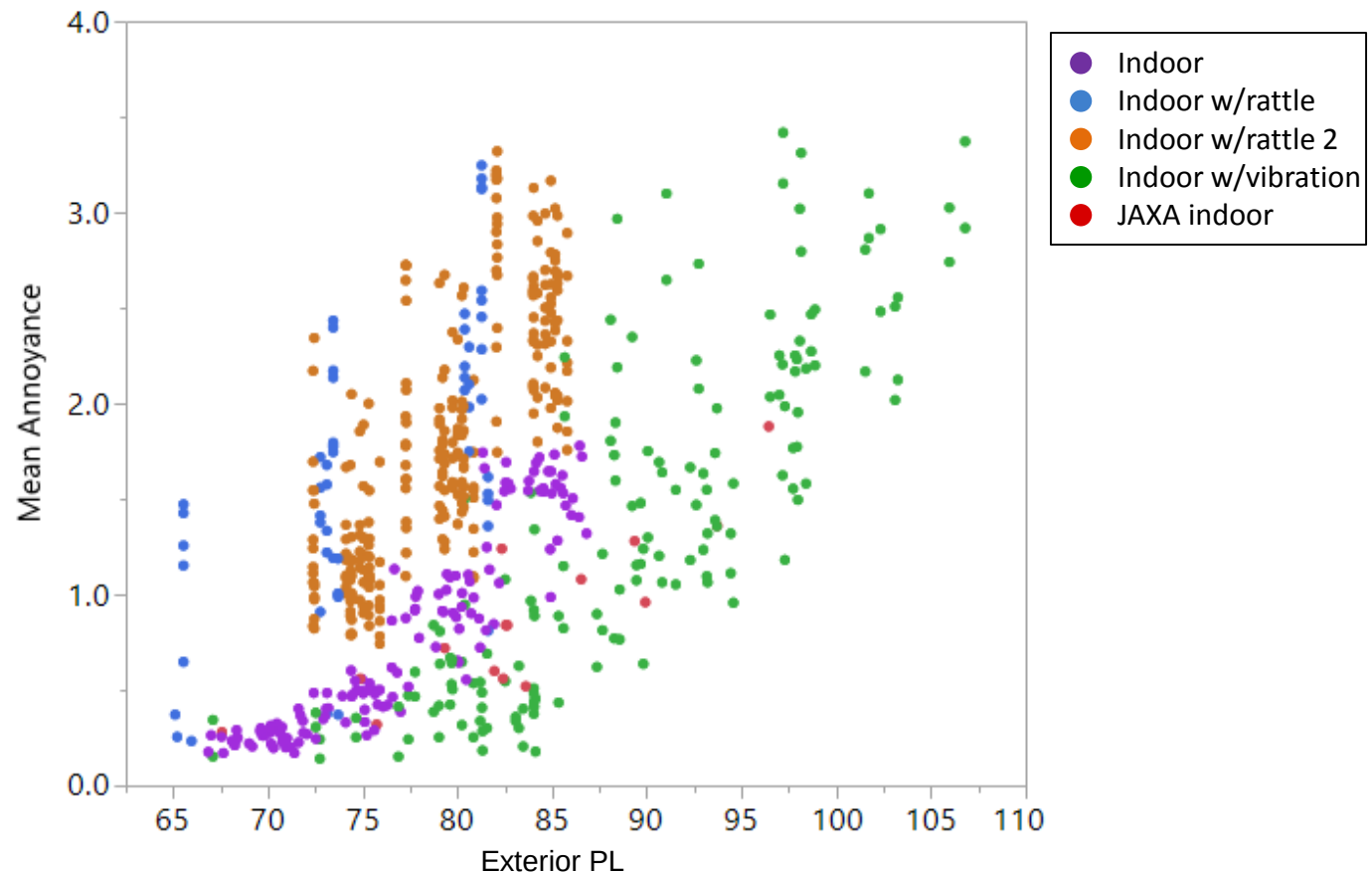


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Comparison of Indoor Mean Annoyance Data



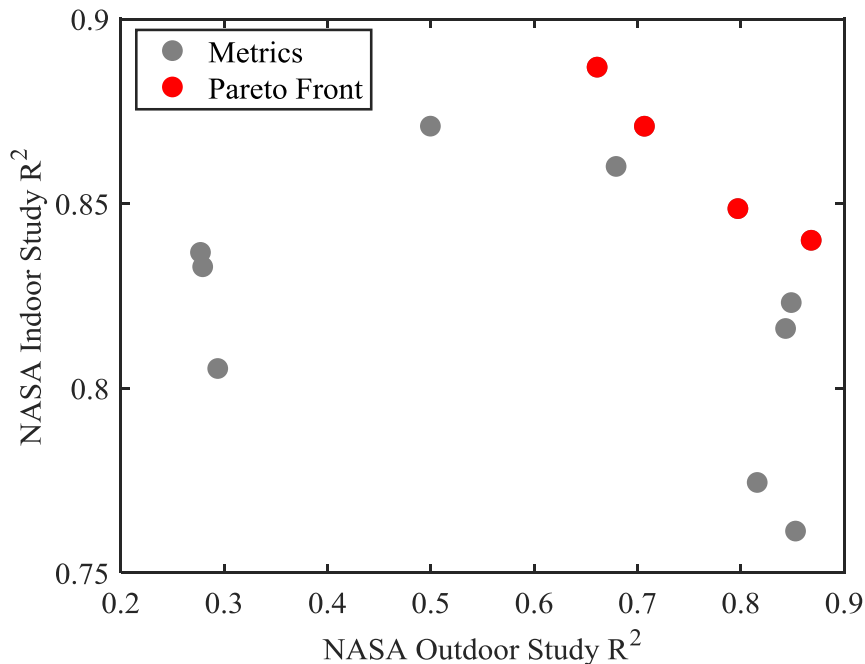
- Differences between studies
 - Exterior PL range
 - Annoyance range
 - Number of test points



Pareto and AHP Methods

First Step

- Example Pareto front with 2 studies is shown below



- Final analysis is expanded to 7 dimensions for the 7 datasets

Second Step

- AHP is used in group decision making
- Systematic paired comparisons
- Allows assignment of weight to criteria (lab studies)
- Numerical priorities calculated for each decision alternative (metric)
- Results in a ranking and prioritization

