



New Reference Day Atmosphere for Analyses of Quiet Supersonic Overflight

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Enable development of noise-based standard for commercial supersonic aircraft

- **Two regulatory noise issues for civil supersonic flight**
 - Limiting airport noise during subsonic flight
 - Limiting sonic boom noise during [en route supersonic](#) flight
- **Development of international standard**
 - Noise-based certification standard for supersonic en route (sonic boom) noise
 - Certification standard would include noise metric, [test procedures](#), and noise limits
- **Required characteristics of atmosphere definition in test procedures**
 - Relate field measurements to a common reference atmosphere to provide uniformity in method across applicants for noise certification
 - Well-defined with use of existing standards, where applicable
 - Robust to apply in real-world situations

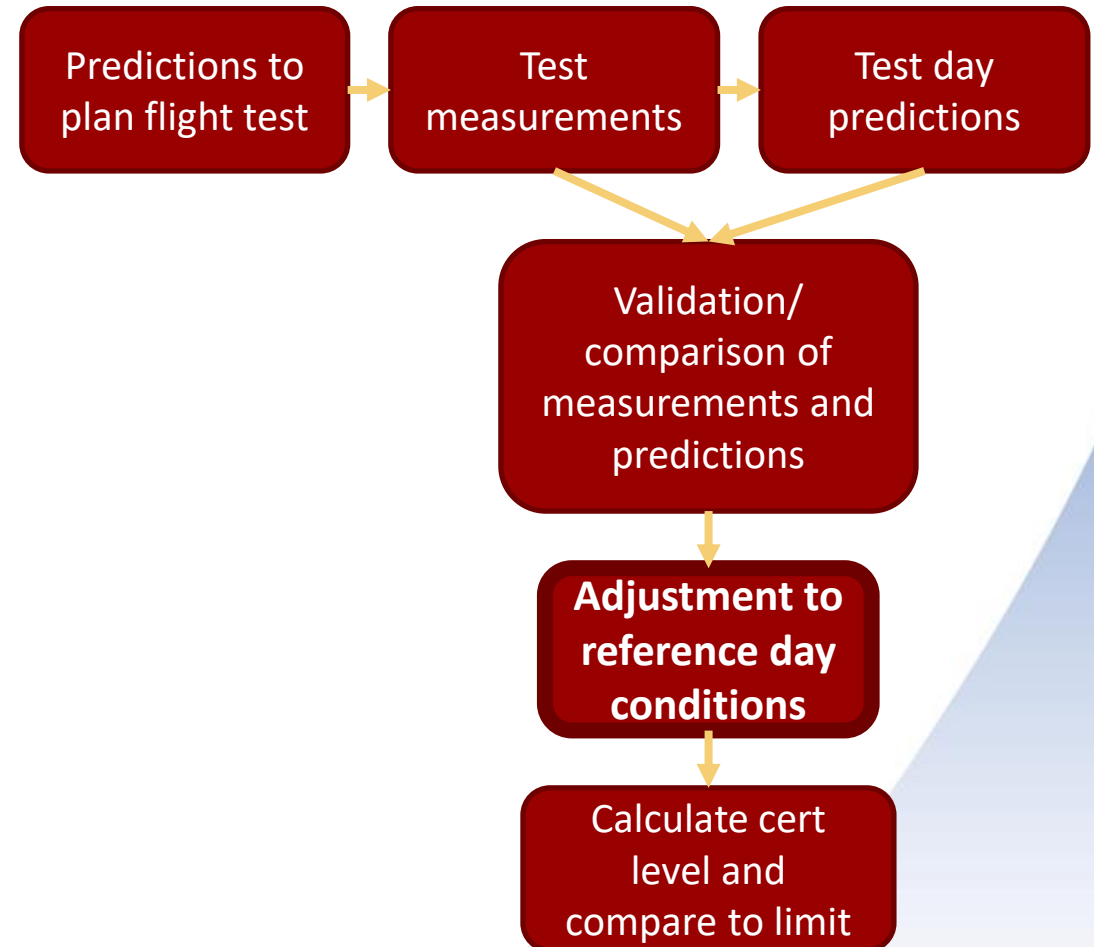
Notional Certification Procedure



- **Procedure must characterize noise performance at reference conditions**
- Concept of fairness (“level playing field”)
 - Procedure is not finalized yet
 - No mutually agreed-upon reference day profile existed beforehand



Notional Certification Procedure Steps



Atmospheric Properties



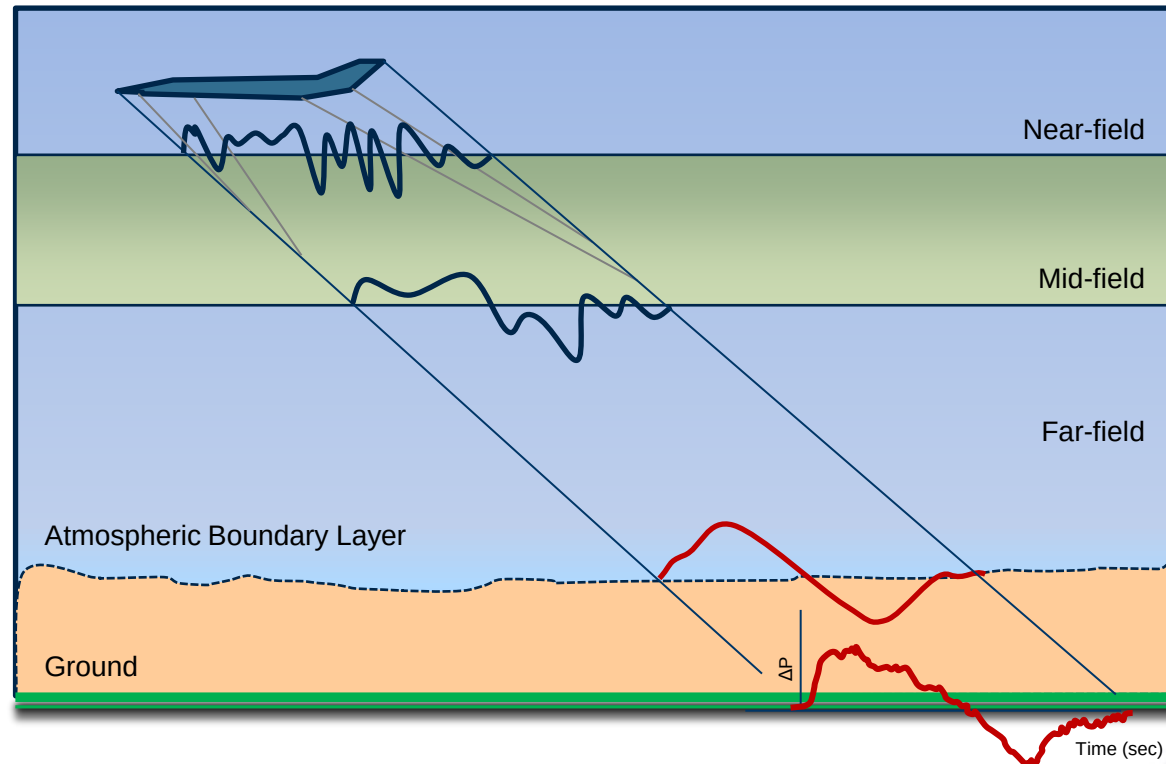
➤ Long propagation distance between aircraft flight altitude and ground

- Certification measurements can be substantially affected by the atmosphere
- Profiles as a function of altitude needed

➤ Atmospheric properties that vary with altitude

- Pressure
- Temperature
- Humidity
- Wind
- Atmospheric turbulence

➤ Wind and turbulence set to zero for reference day



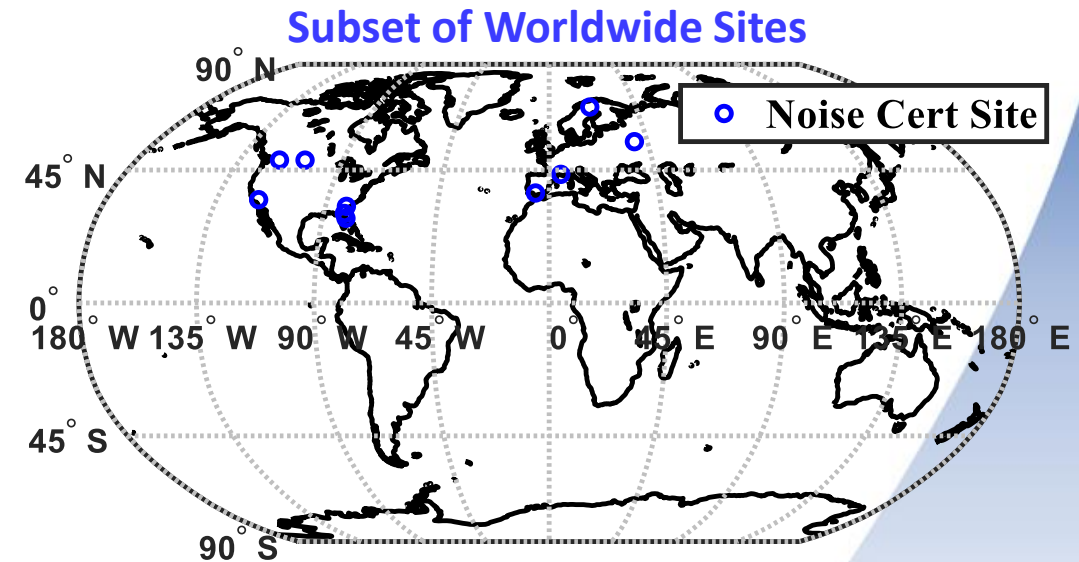
Identify reference atmosphere that minimizes required adjustment to certification test measurements

➤ Predictions of propagation through atmospheres for overflight of quiet supersonic aircraft to quantify expected worldwide variation

- NASA C25P concept (Mach 1.6 at 15.8 km altitude)
- Atmospheric data from 666 sites across the world
 - ERA5¹ and IGRA² databases
 - Subset of 10 noise certification sites
- Atmospheric data from several candidate reference atmospheres
 - ICAO 7488/3 used for temperature and pressure profiles in all cases³
 - Six humidity model candidates

➤ Compared ground loudness levels

- Six noise metrics identified in previous work^{4,5}

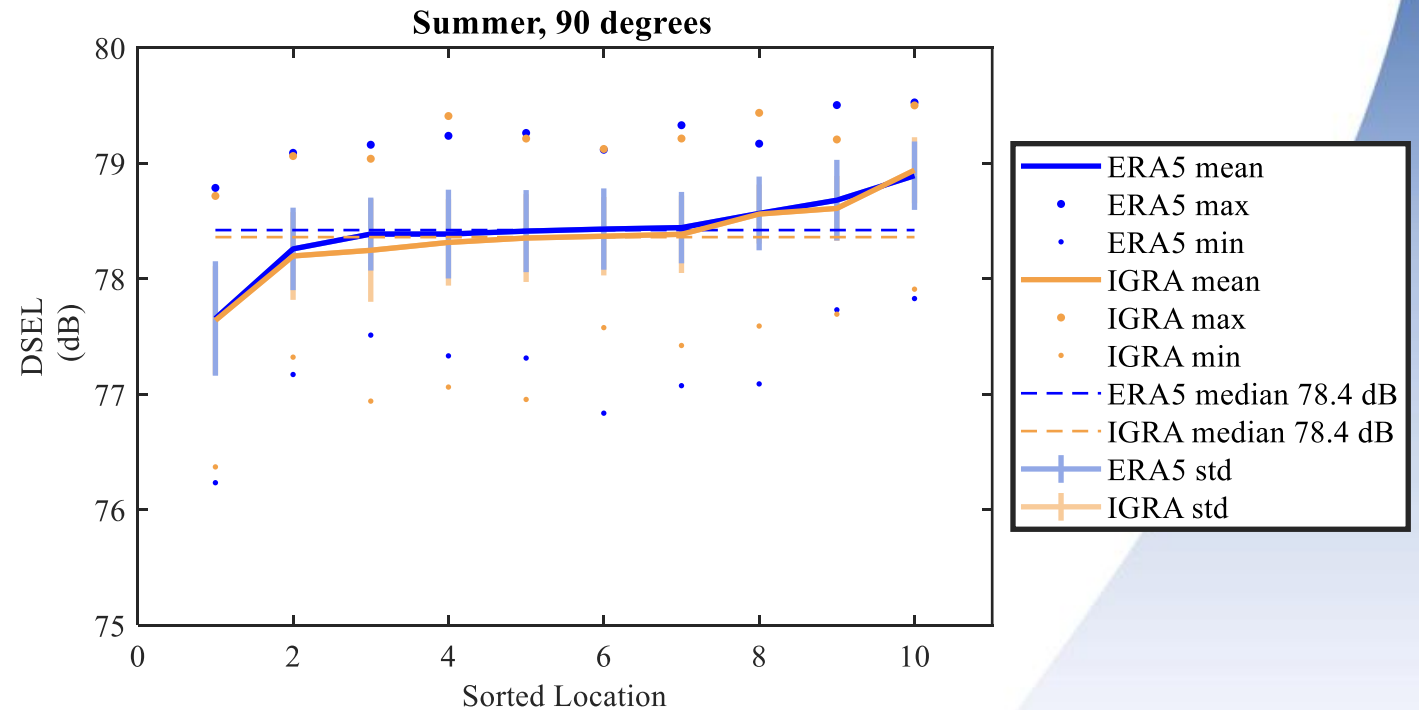
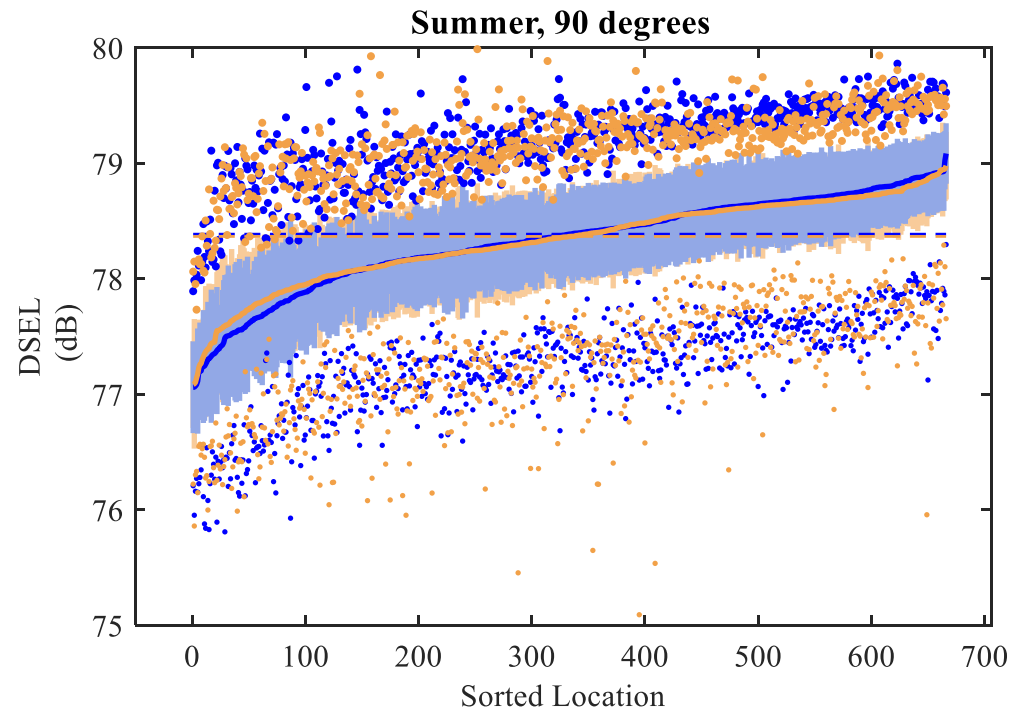


Example Propagation Results for World Sites



➤ Worldwide results with full set and subset of 10 locations

- Results from ERA5 model match well with IGRA balloon data, for all metrics
- Metrics for subset are representative of full set
- Median value used for comparison to reference day results



Humidity Model Candidates

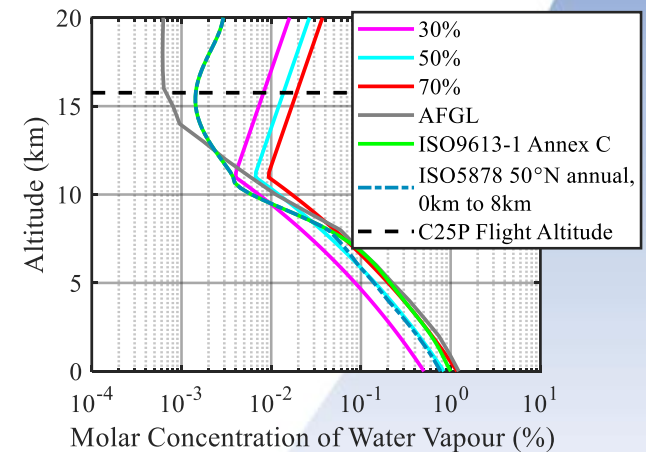
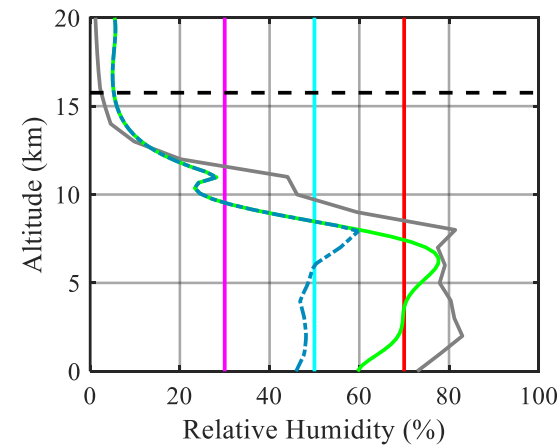
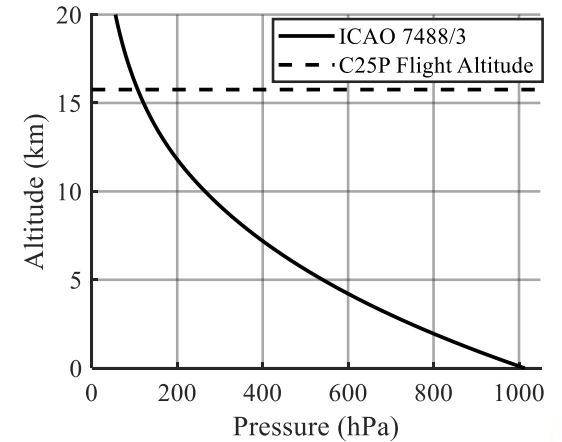
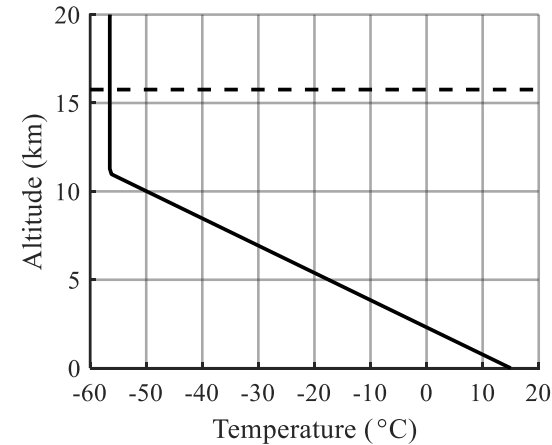


➤ Candidates considered

- Constant relative humidity (30%, 50%, 70%)
- ISO 9613-1 Annex C (atm absorption standard)⁶
- Air Force Geophysics Laboratory (AFGL) Atmospheric Constituent Profiles⁷
- ISO 5878 with extension⁸

➤ Lower altitude values of molar concentration of water vapor are very low for 30% relative humidity

➤ All constant relative humidity options have unrealistic linearly increasing values of molar concentration of water vapor above 11 km



Humidity Model Propagation Results



- Undertrack metrics for C25P signature propagated through 6 atmospheres
- PCBoom and sBOOM results similar to within a few tenths of a dB

Reference Atmosphere Humidity Model	ASEL (dB)	BSEL (dB)	DSEL (dB)	ESEL (dB)	PL (dB)	ISBAP (dB)
30%	58.2	74.5	78.2	69.4	73.0	86.6
50%	59.4	75.1	78.4	70.2	74.2	87.4
70%	60.2	75.4	78.6	70.6	75.0	87.8
AFGL	61.2	75.9	78.9	71.3	75.9	88.4
ISO 9613-1 Annex C	61.2	75.9	78.8	71.3	75.8	88.4
ISO 5878 w/extension	59.8	75.4	78.6	70.5	74.6	87.6

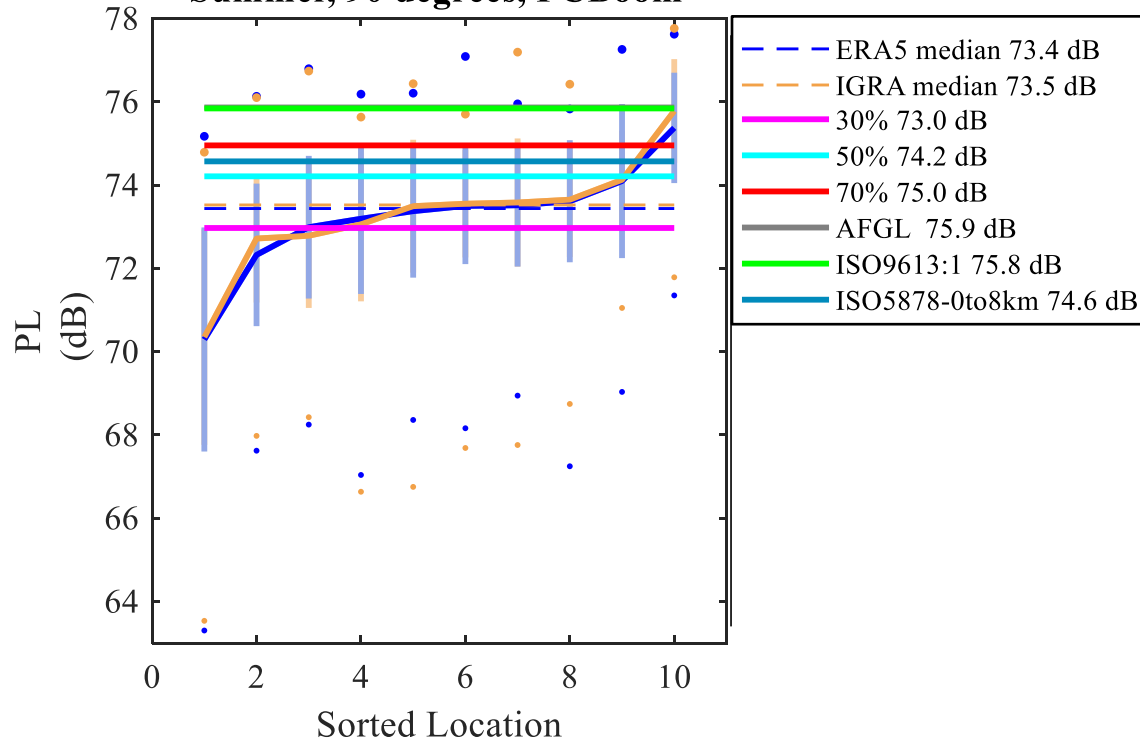
Comparison of World Sites and Ref Day Humidity Options



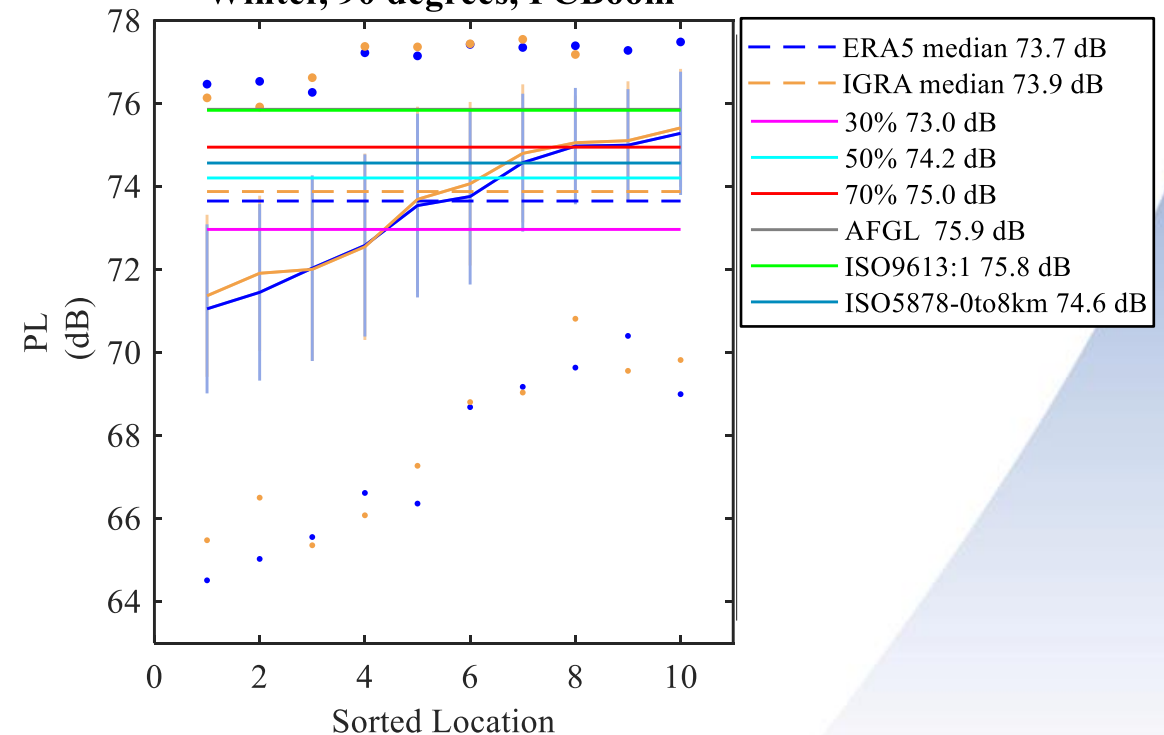
➤ Example of Summer and Winter seasons with 90-degree heading

- Ref day humidity model closest to worldwide median is 30% relative humidity
- 50% relative humidity and ISO 5878 with extension are also close
- ISO 9613:1 has the largest (positive) offset

Summer, 90 degrees, PCBoom



Winter, 90 degrees, PCBoom



Comparison Summary



➤ Mean difference and 90% CI between candidate reference day options and worldwide medians for all six metrics

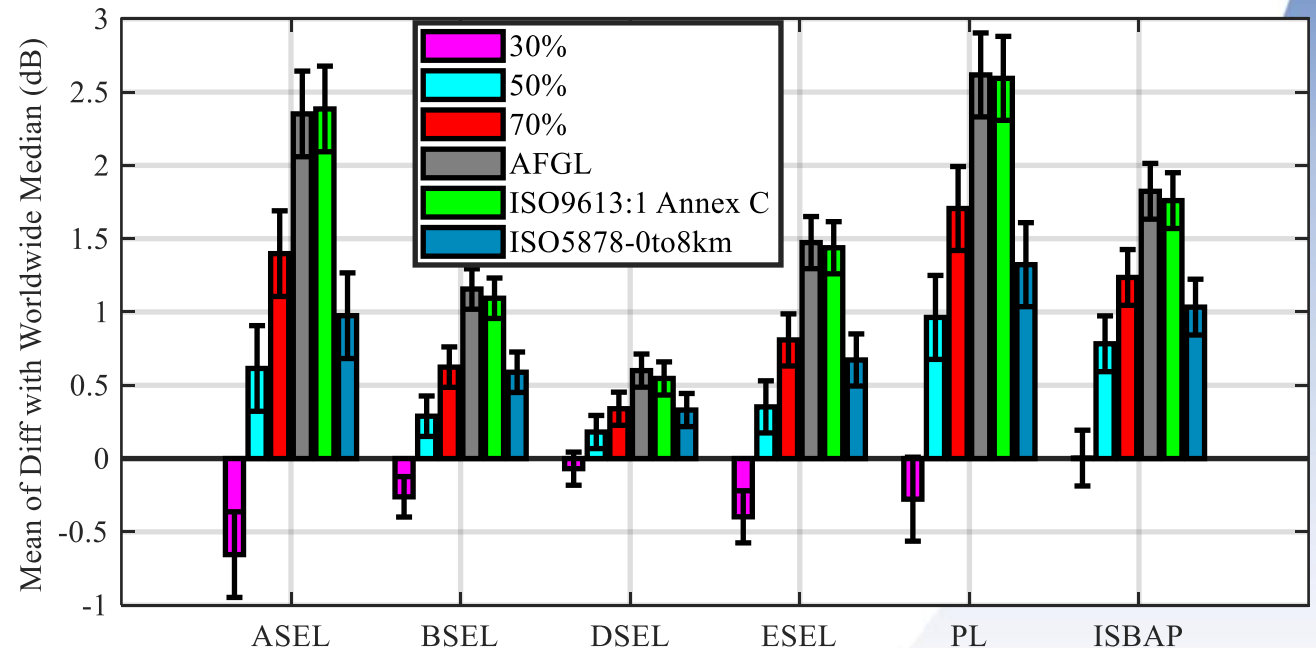
- All seasons, headings, and subset locations included
- All reference day options have mean difference $< 2.6 \pm 0.3$ dB
 - Smaller differences for BSEL, DSEL, and ESEL
 - Worst case metric with highest sensitivity is PL

➤ Top 2 candidates

- 50% relative humidity (1.0 ± 0.3 dB)
- ISO 5878 with extension (1.3 ± 0.3 dB)

➤ Trends observed similar regardless of:

- Full data or subset
- Propagation code
- Season
- Heading
- Metric



Reference Day Definition Summary



- **Performed analysis to define common reference day atmosphere that will be used for supersonic aircraft en route noise certification**
- **The existing ICAO 7488/3 profiles for temperature and pressure, combined with a modified ISO 5878 humidity profile, were found to offer the best results**
 - ISO 5878 with extension preferred because provides results close to worldwide median and is physically realizable at altitudes above 11 km
- **Using this reference day definition is expected to minimize corrections between measured sonic boom certification levels and the predicted reference day level**
- **New reference day, including humidity profile, will be available in a forthcoming publication for adoption by both sonic boom researchers and applicants for supersonic aircraft noise certification**

Assumptions and Applicability



➤ Assumptions of analysis

- Single aircraft concept
- Single flight altitude
- Single flight condition
- Set of atmospheres from 2 weather databases over the span of one year
- Undertrack sonic booms only
- No atmospheric turbulence

➤ However, expect applicability of results to future supersonic aircraft

- NASA analysis of X-59 simulations across USA gave similar statistics (diff aircraft, flight conditions, locations, atmospheric profiles)⁹



1. **Hersbach et al. The ERA5 global reanalysis. *Q J R Meteorol Soc.* 146:1999–2049, 2020.**
2. **Durre et al. Overview of the Integrated Global Radiosonde Archive. *J. Climate* 19(1), 2006.**
3. **International Civil Aviation Organization. Manual of the ICAO Standard Atmosphere Extended to 80 kilometres (262 500 feet). Tech. Rep. 7488/3, 1993.**
4. **American National Standards Institute. Design response of weighting networks for acoustical measurements. ANSI/ASA S1.42-2020, 2020.**
5. **Loubeau et al. Updated evaluation of sonic boom noise metrics. *J. Acoust. Soc. Am.*, 144: 1706, 2018.**
6. **International Standards Organization. Acoustics - Attenuation of Sound During Propagation Outdoors - Part 1: Calculation of the Absorption of Sound by the Atmosphere, Annex C. Tech. Rep. ISO 9613-1:1993(E), 1993.**
7. **Anderson et al. AFGL Atmospheric Constituent Profiles (0-120 km). Tech. Rep. AFGL-TR-86-0110, Air Force Geophysics Laboratory, 1986.**
8. **International Standards Organization. Reference Atmospheres for Aerospace Use, Addendum 2: Air Humidity in the Northern Hemisphere. Tech. Rep. ISO 5878-1982/Add.2-1983(E), 1983.**
9. **Doebler et al. Simulation and Regression Modeling of NASA's X-59 Low-boom Carpets across the USA. *AIAA J. Aircraft* 60(2): 509-520, 2023.**



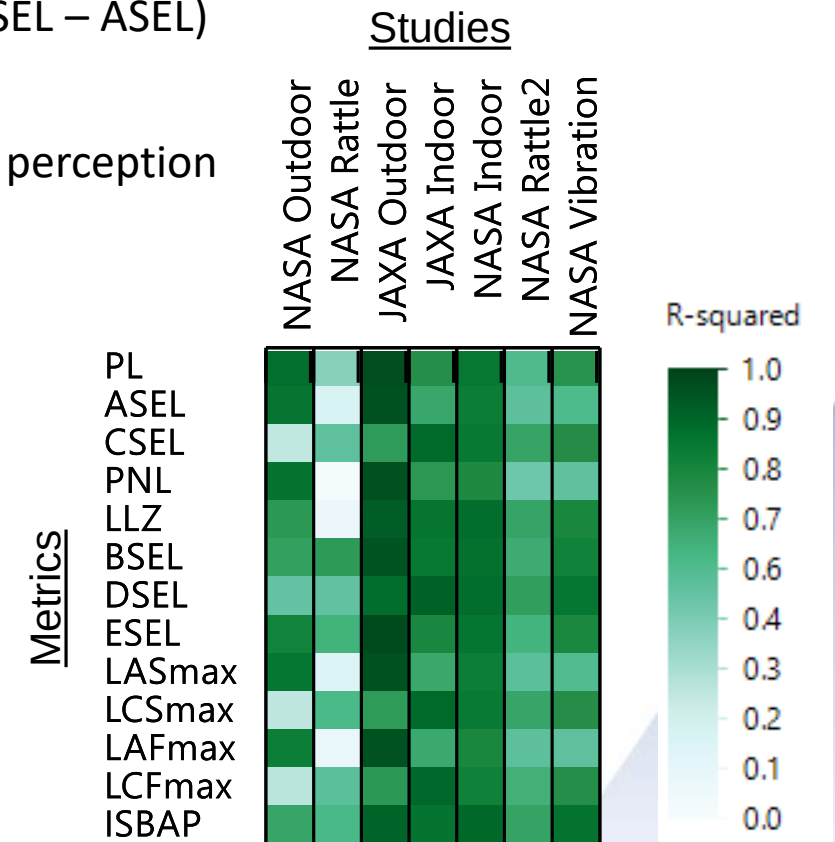
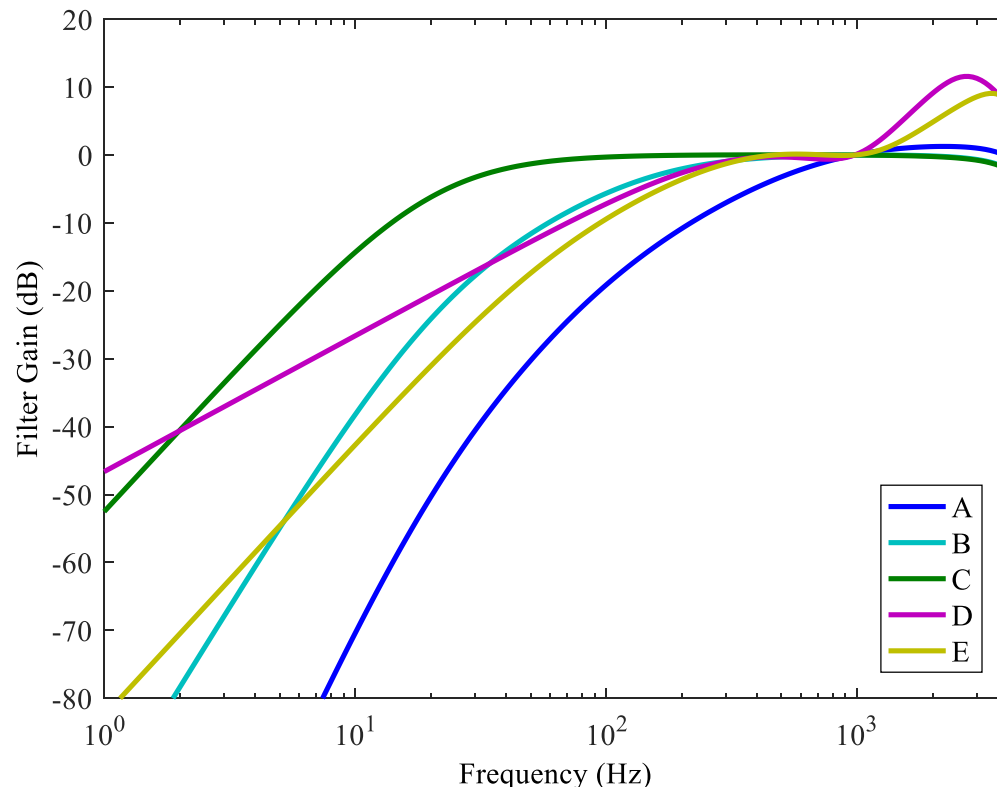
Backup Slides

Sonic Boom Noise Metrics: Human Perception



➤ Six noise metrics identified in previous work^{4,5}

- ASEL, BSEL, DSEL, ESEL, PL, ISBAP
 - Indoor Sonic Boom Annoyance Predictor = ISBAP = PL + 0.4201 (CSEL – ASEL)
- No clearly preferred metric
 - PL has been used often because of good correlation with outdoor perception



Graphical representation of
R² values for each experiment

Sonic Boom Noise Metrics: Human Perception



➤ Meta-analysis

- Comprehensive evaluation of metrics
- Several years of laboratory testing data (7 tests) at NASA and JAXA

➤ Five metrics correlate well with human response outdoors and indoors⁵

- Sixth metric (ASEL) retained for historical reasons

