National Aeronautics and Space Administration

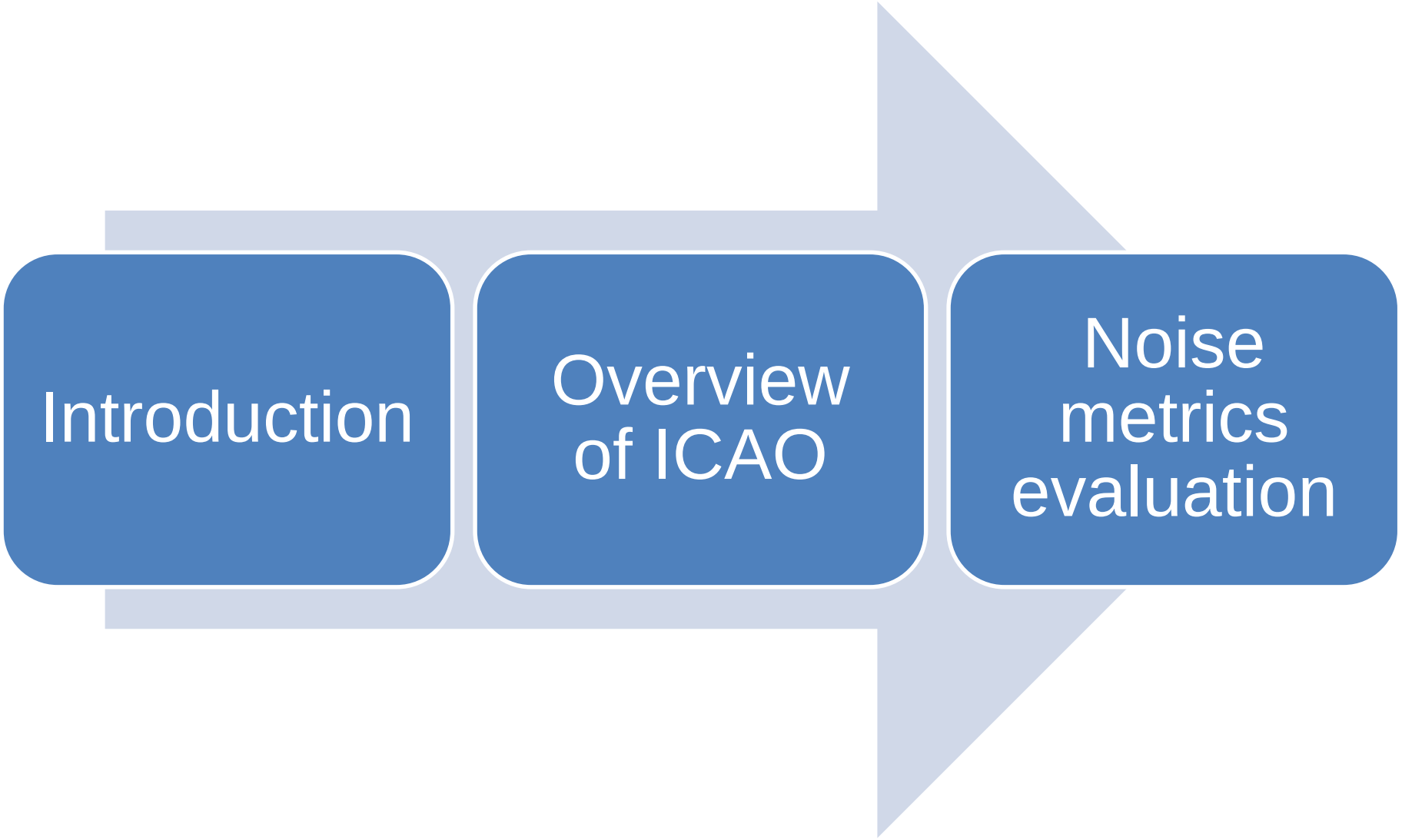
Supporting the FAA and ICAO in Developing Proposed Sonic Boom Standards

Alexandra Loubeau
Technical Lead, Sonic Boom Effects Modeling
NASA Langley Research Center

Acoustics Technical Working Group Meeting
Hampton, VA
April 22, 2015

Commercial Supersonic Technology Project

Presentation Outline



Introduction

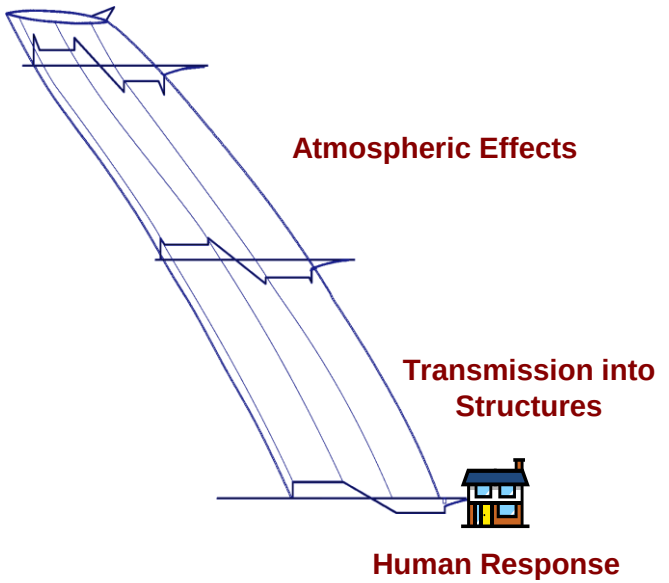
What are we trying to do?

Understand the impact of sonic booms from new low-boom aircraft designs on community residents

What is our approach?

- **Atmospheric Propagation**
- **Indoor & Outdoor Acoustics**
- **Human Response**
- **Support of ICAO SSTG Activities**

- Work cooperatively with regulators (FAA, ICAO) and other researchers (industry, academia, JAXA, others)



What are the payoffs if we are successful?

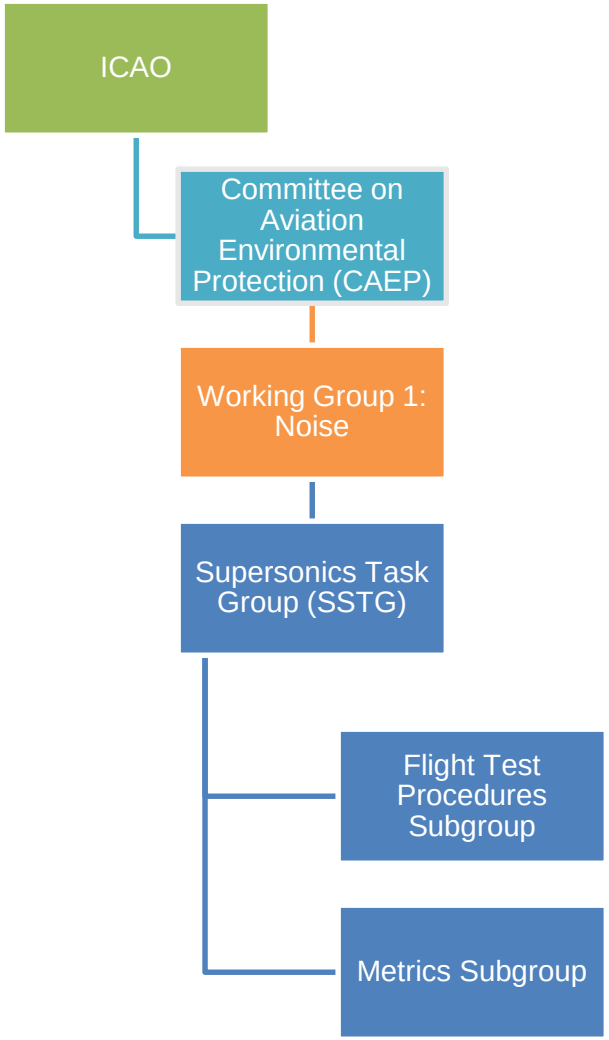
- Replace current prohibition of civil supersonic overland flight with a noise-based standard for aircraft certification
- Open the door for development of a new generation of supersonic civil transport aircraft

International Civil Aviation Organization

- ICAO is a specialized agency of the United Nations
  - Coordinates and regulates international air travel
  - Standards organization for international air navigation
- Convention on International Civil Aviation
  - Rules on airspace, aircraft registration, and safety
  - Contains 19 annexes of standards and recommended practices
    - Including Annex 16, Environmental Protection
      - Aircraft noise
      - Aircraft engine emissions

- Committee on Aviation Environmental Protection (CAEP)
  - In U.S., supported by FAA Office of Environment and Energy
  - NASA serves as technical advisor to the FAA
  - In addition to regulators, industry groups are represented
  - Operates on 3-year cycles (current cycle ends in 2016)

ICAO Supersonics Task Group



- SSTG
  - Monitor sonic boom research
  - Standards development for supersonic transport (SST) aircraft*
  - SST airspace coordination
  - Monitor SST projects
- Flight Test Procedures Subgroup
  - Develop flight test procedures for en-route sonic boom noise
  - Develop test requirements for boom measurement/instrumentation
- Metrics Subgroup
  - Recommend sonic boom metric for certification standard
- Ad-hoc groups
  - Lead development of technical elements

*Amendments for Annex 16, Volume I - Aircraft Noise - Chapter 12 for supersonic jet aeroplanes

Flight Test Procedures Overview

- Identify test conditions and locations for sonic boom measurements
  - Transition focus
  - Intermediate supersonic conditions
  - Supersonic cruise
- Consider use of prediction codes to support certification procedures
- Outline a work plan for developing specifications related to instrumentation
  - Identify unique elements that differ from conventional aircraft noise measurement
  - Instrumentation and analysis system
    - Dynamic range and frequency range of entire measurement system
    - Microphone characteristics
    - Number and locations of microphones
    - Recording system
    - Possible correction or adjustment methods
  - Measurements of aircraft flight path
  - Atmospheric conditions
    - Measurement vs. height
    - Determination of acceptability for test day conditions

Peter Coen, Jake Klos

Metrics Overview

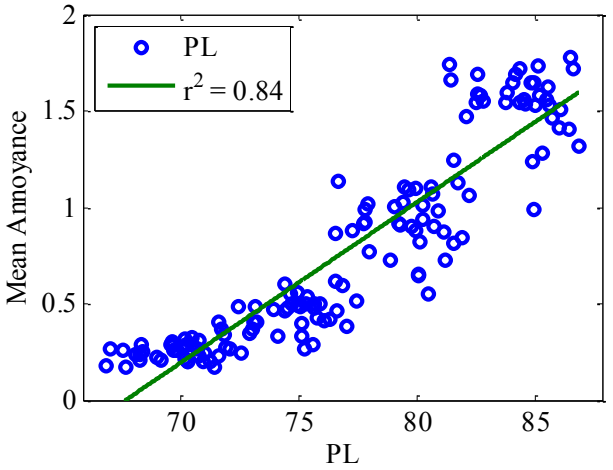
- Developed a catalog of 70 noise metrics for evaluation
- Developed 12 criteria for evaluation of noise metrics
  - Certification will require a boom measurement outdoors
- Performed crosscheck study to verify results across different organizations
  - Eight waveforms identified and shared with group
  - Calculated noise metrics
  - Compared results
  - Adjusted calculations
- Evaluated suitability of metrics for predicting human response
  - Identified and released three existing datasets containing sonic boom waveforms and associated human response (laboratory studies of isolated booms)
  - Calculated noise metrics for exterior booms
  - Calculated linear correlation of objective and subjective data (r^2)
  - Rank ordered the data for each study

Noise Metrics Evaluation

Facilities

Subjective studies

Correlation analysis and results



NASA Outdoor Boom Study

- 2003 Sonic Boom Simulator (SBS) study
- Simulates booms in an outdoor environment

NASA Outdoor Boom Study

- Included predicted waveforms for candidate low-boom aircraft designs and classic N-waves
  - 135 total booms
  - Asymmetric and symmetric waveforms
  - PL = 70-90 dB
- 40 subjects recruited from Hampton Roads
- Subjects rated **loudness** of each boom relative to a reference boom
  - Magnitude estimation method
  - Ratings averaged for each boom
- Correlations of outdoor annoyance with outdoor booms

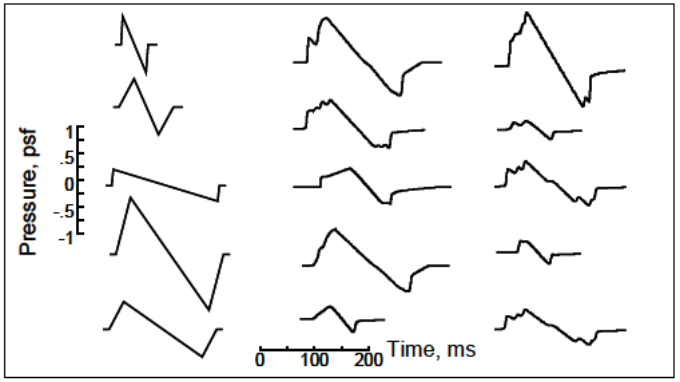


Fig 4 - Sample boom waveforms from Low-Intensity Boom study

NASA Indoor Boom Study

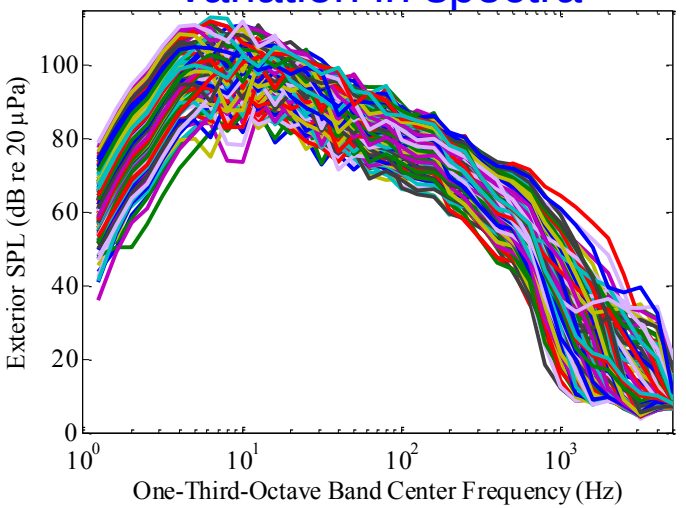
- 2013 Interior Effects Room (IER) study
- Indoor sonic boom simulator
  - Single-room psychoacoustic facility configured as a living room
  - Reproduces exterior boom with two loudspeaker arrays
  - Exterior boom transmits through facility wall to interior of structure

NASA Indoor Boom Study

- Predicted ground sonic booms for shaped low-boom aircraft designs
- 4 categories of sonic booms based on aircraft class
- 35 unique boom shapes provided by partners*
- Each boom shape presented at 4 levels
  - Loudness levels (PL) ranging from ~ 70-85 dB
- 140 total booms

- Sonic booms measured at exterior of structure

Variation in spectra



D **Demonstrators**

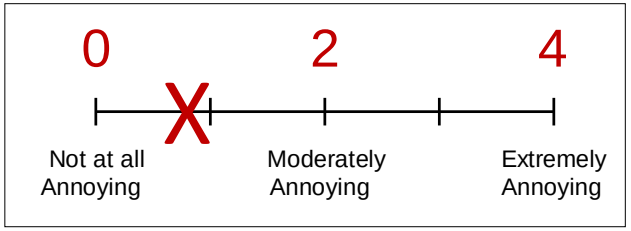
1 **Business Jets**

2 **Small Supersonic Airliners**

3 **Larger Multi-Mach Aircraft**

NASA Indoor Boom Study

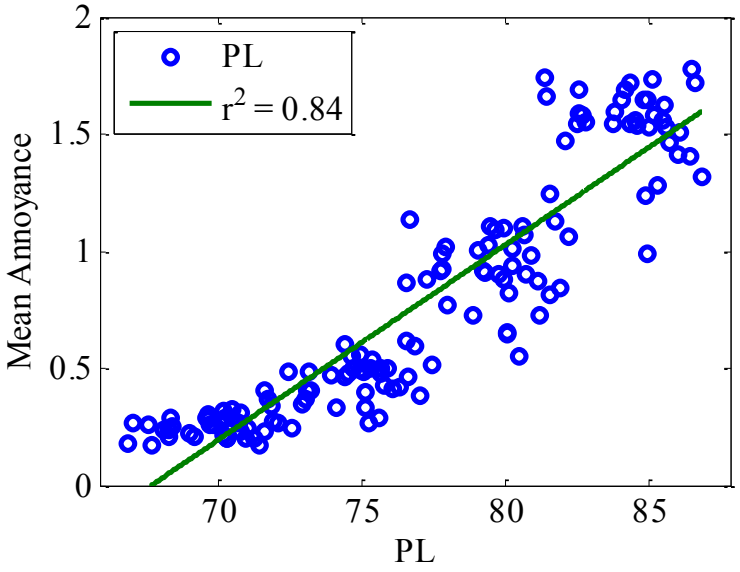
- 30 subjects recruited from Hampton Roads
- Subjects rated **annoyance** to each boom on a category line scale



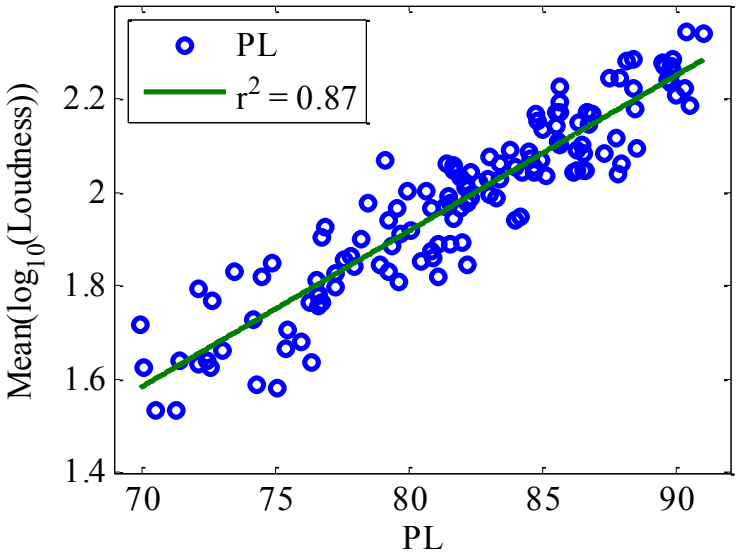
- Ratings converted to numerical scale (0-4) and averaged for each boom
- Correlations of indoor annoyance with outdoor booms

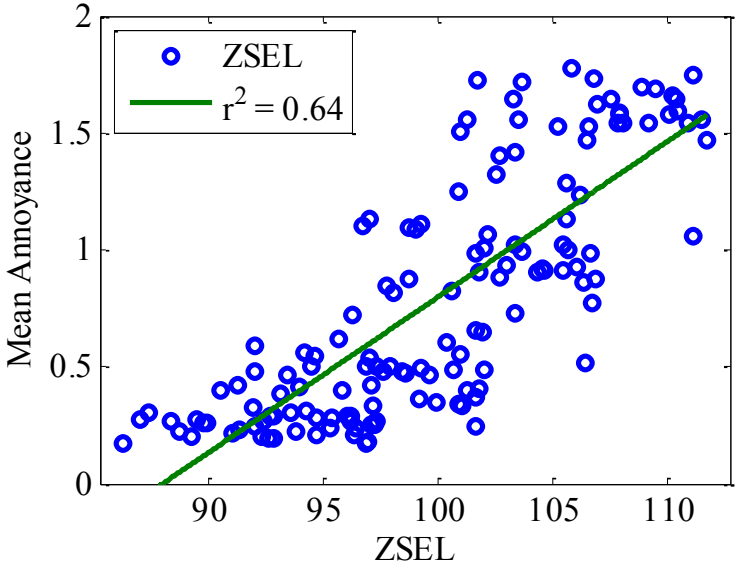
Linear Correlation Examples

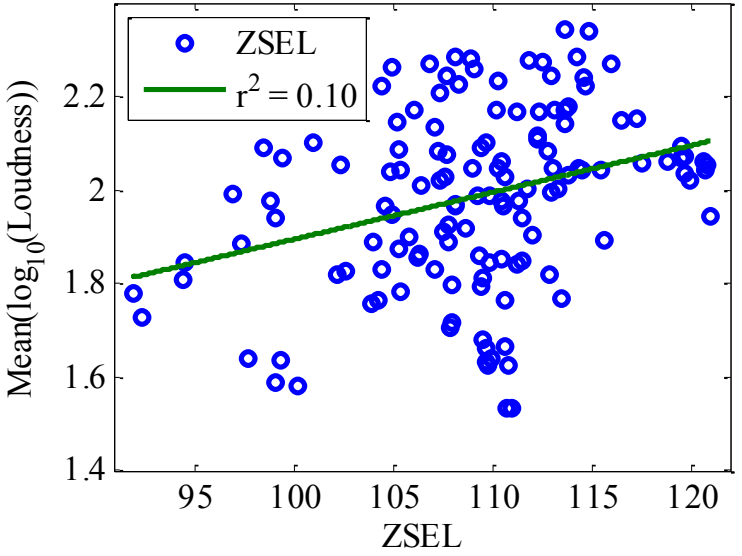
Indoor Annoyance



Outdoor Loudness Rating







Linear Correlation Results

Metric Name	Indoor Study r^2	Metric Name	Outdoor Study r^2
PL+H*	0.89	PL	0.87
DSEL	0.87	PNL	0.85
LLZ	0.87	DIN45631	0.85
BSEL	0.86	ASEL	0.85
ESEL	0.85	LASMAX	0.84
PL	0.84	TVLZmax	0.82
CSEL	0.84	LAFMAX	0.82
LCSMAX	0.83	ESEL	0.80
ASEL	0.82	MGSL	0.76
LASMAX	0.82	LLZ	0.71
LCFMAX	0.81	BSEL	0.68
HEAD	0.79	PL+H	0.66
DIN45631	0.78	(dΔp/dt)max	0.61
LAFMAX	0.77	DSEL	0.50
EQL	0.77	EQL	0.45
PNL	0.76	TVLGMImax	0.32
TVLZmax	0.75	LCFMAX	0.29
MGSL	0.73	LCSMAX	0.28
ZSEL	0.64	CSEL	0.28
(dΔp/dt)max	0.58	TVLGMSmax	0.26
dLmax	0.58	TVLGMLmax	0.25
TVLGMImax	0.23	HEAD	0.24
TVLGMSmax	0.13	dLmax	0.17
TVLGMLmax	0.10	ZSEL	0.10

* PL+H=PL+(CSEL-ASEL)

- Metrics calculated for exterior boom in both cases
- Metric correlations with indoor and outdoor perception differ
  - Indoor environment has less high-frequency energy due to transmission loss
- Several metrics have poor performance, especially for predicting outdoor loudness ratings
- However, no one metric clearly outperforms others
- Further analyses are being discussed

Summary and Next Steps

- NASA's support of FAA and ICAO has enabled advances in standards development for supersonic aircraft

- Specifications of certification procedures for measurement of sonic booms will continue to be developed
- Noise metrics evaluations will continue
  - Recommend a preliminary group of metrics for further consideration
  - Additional datasets may be needed
  - New or modified metrics for better prediction of human perception may still be proposed for evaluation

- Community studies will be needed to gather noise dose-response relationships
  - Regulators will use this data to choose a metric limit for certification