Psychoacoustic Measures for UAM Noise in the Context of Ambient Sound

Vertical Flight Society SF Bay Area Chapter

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FOCUS OF THE PRESENTATION

• Prediction of human response to EVTOL noise using psychoacoustic evaluation ("listening tests") that includes realistic Ambient Noise

• Ensure that such tests are ecologically valid: include
  
  o Realistic simulations using auralization techniques
  o Accurate modeling of sound propagation in the environment
  o Accurate simulation of sound levels and spatial auditory cues
  o Realistic signal-noise ratios (by including ambient sound)

• Enable evaluation & comparison of relevant metrics and criteria using multiple methods in the laboratory to establish psychometric data
• REVIEW OF BASIC CONCEPTS
  -Level, Frequency & Masking
  -Noise dose and DNL
THREE FACTS ABOUT SOUND:

- LEVEL ("loudness")
- FREQUENCY ("pitch")
- MASKING

“DECIBEL THERMOMETER”
Decibels measure sound level

A 10 decibel increase equals a doubling of loudness
THREE FACTS ABOUT SOUND:

- LEVEL ("loudness")
- FREQUENCY ("pitch")
- MASKING

ROTORCRAFT FREQUENCIES

SIGNIFICANT TONE
THREE FACTS ABOUT SOUND:

- LEVEL ("loudness")
- FREQUENCY ("pitch")
- MASKING:

Noise is more effective at hiding ("masking") a signal when their frequencies overlap.
Metrics based on NOISE DOSE

• A **noise dose** metric quantifies total acoustic energy over a period of time.

• Used for calculating permissible sound exposure to noise over a 8 hr. workday (“Dosage-Hearing Loss” relationship).

• Used for calculating the Day-Night Average Sound Level, **DNL**: a 24 hour noise dose.

• DNL widely used in environmental noise analysis
Sound Exposure Level (SEL): Average A-weighted level ($\text{Leq}_A$) + $10 \cdot \log_{10}(\text{duration})$

- SEL normalizes total sound energy to a constant time interval & level of 1 second
- The longer the duration of a sound event, the higher the SEL

**Example:**
- Flyover A has a higher maximum level than B but note that-
- Flyover A has a lower SEL than B because its duration is shorter
A single DNL value can result from different combinations of sound levels and event frequency.

These three examples are all equivalent to 65 DNL.

Time-energy dosage metric is not intuitive for communities responding to noise.
• FAA criteria for significance: at least 1.5 dB above 65 DNL

• Percentage of persons highly annoyed (%HA) by aircraft sound calculated by the DNL dosage-response relationship

- FAA criteria for significance: at least 1.5 dB above 65 DNL
- FICON (1992) predicts ~12% % HA @ 65 DNL
- ISO 1996.1 (2003) predicts ~27% HA at same DNL level
ANNOYANCE

BLEND (ACCEPTANCE)

DETECTION
HUMAN RESPONSE TO AIRCRAFT NOISE: “ANNOYANCE-NOISINESS ”
ca. 1950s-1960s

- **Current EPNL metric for certification uses NOY scale, tone-corrected PNL**
  - “Scaling Human Reactions to the Sound from Aircraft” Karl Kryter, JASA 1959
  - Judged Noisiness of a Band of Random Noise Containing an Audible Pure Tone Kryter & Pearsons JASA 1965

- TASK: “Assume that the noise would occur in your home 20 to 30 times during the day and night”
- MONAURAL SOUND
- PISTON vs JET AIRCRAFT or NOISE STIMULI
- PRESUMES NOISINESS SIMILAR TO LOUDNESS: annoyance is a perceptual attribute that is internally evaluated on a decibel RATIO SCALE

![TDH-39](image1)
![AR-1, KLH](image2)

![Fig. 14. Contours of equal loudness (after Stevens) and equal noisiness (Kryter)](image3)
"[In] low sound level settings, the loudness of the sound may play a less prominent role. Signal detection or audibility appears to be the most important factor in predicting annoyance."

AKA “Audibility”

AEDT TAUD (time audible) METRIC
• ANNOYANCE and DETECTION: “Extreme” signal-noise endpoints

- Spectrally weighted sound events
- Hypothetical levels for demonstration

Annoyance threshold (EPNL, Noys)

Detection threshold (d’ : d-prime)

Signal-Noise Ratio (dBA)

Time

eVTOL UAM

Ambient Noise
**BLEND METRIC:** Signal-Noise region where UAM noise 
**does not dominate** other ambient sound sources

*Blend metric is a practical compromise between detection and annoyance*
Architectural review boards: visual blend
Q: What would be an ideal characteristic for aircraft noise?

A: The noise blends into the ambient; i.e., the soundscape

- The blend threshold is a hypothetical concept representing all attributes of a sound that cause it to not dominate over the ambient.

- We can determine a blend threshold via auditory scene analysis.
**Soundscape**: “The acoustic environment as perceived or experienced and/or understood by a person or people, in context” (ISO 12913): i.e., the perceived ambient

I am listening to a soundscape at night compromised of crickets, ocean waves crashing, and two barn owls hooting. I have no road traffic in the ambient. An aircraft flyover occurs infrequently and when it does it does not obscure the soundscape. It has a tonal and time character that allows me to ID it but it is easy to ignore. It seems to be in relatively far distance, hard to localize. It is not out of the ordinary.
- **Auditory Scene Analysis**: perception of *soundscape* as multiple *sound objects*
- Sound objects **blend** to the degree sound object separation **fails**
- Sound objects are identified by perceptual **grouping mechanisms**

**Primitive Grouping Mechanisms:**
- **Proximity** in frequency and time
- **Periodicity**
- Continuous or smooth **transition**
- **Onset** and offset (amplitude envelope)
- Amplitude and frequency **modulation**
- **Rhythm**
- Common **spatial location**
EXEMPLAR URBAN RESIDENTIAL NOISE ORDINANCE (SAN FRANCISCO)
**EXEMPLAR URBAN RESIDENTIAL NOISE ORDINANCE** (SAN FRANCISCO)

*indoor*

Section 2909 (d), Fixed Residential Interior Noise Limits
This section sets the maximum allowable interior noise within a dwelling unit......**45 dBA between the hours of 10:00 p.m. to 7:00 a.m. and 55 dBA**
between the hours of 7:00 a.m. to 10:00p.m

*outdoor*

Article 29 of the Police Code **defines “Ambient” as the lowest sound level repeating itself during a minimum ten-minute period**. The minimum sound level shall be determined with the noise source at issue silent, and in the same location as the measurement of the noise level of the source or sources at issue...
Noise ordinances reflect an averaged level, NOT a noise dose

<table>
<thead>
<tr>
<th>Receiving Land Use Category</th>
<th>Time Period</th>
<th>Noise Level (dBA)</th>
<th>Noise Zone Classification (1)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Rural Suburban</td>
<td>Suburban</td>
</tr>
<tr>
<td>One &amp; Two Family Residential</td>
<td>10 pm-7 am</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>7 am-10 pm</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Multiple Dwelling Residential Public Space</td>
<td>10 pm-7 am</td>
<td>45</td>
<td>50</td>
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<tr>
<td></td>
<td>7 am-10 pm</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Limited Commercial Some Multiple Dwellings</td>
<td>10 pm-7 am</td>
<td></td>
<td>55</td>
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<tr>
<td></td>
<td>7 am-10 pm</td>
<td>60</td>
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<tr>
<td>Commercial</td>
<td>10 pm-7 am</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>7 am-10 pm</td>
<td>65</td>
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<tr>
<td>Light Industrial</td>
<td>Any Time</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>Heavy Industrial</td>
<td>Any Time</td>
<td></td>
<td>75</td>
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</tbody>
</table>
• EXAMPLE SOUNDSCAPES;
AMBIENT SOUND LEVELS
RE POTENTIAL UAM SOUND
RURAL- PARK AREA (17:00)

*Soundscape: dominated by wind through trees, birds, ocean and fog horn*

41 dBA $L_{eq}$

One-third octave bands kHz
**INDUSTRIAL PARK – MULTIFAMILY HOUSING NEAR FREEWAY (10:00)**

**Soundscape:** dominated by freeway traffic noise, motorcycle-truck single events

+ 23 dBA increase compared to last example
MULTIFAMILY HOUSING NEAR CALTRAIN LINE (10:00)

Soundscape: road traffic single events, power tools, distant highway

SUNNYVALE-EVEYLYN AVE (CALTRAIN LINE)

56 dBA $L_{eq}$

Decibels re 20 mPa

One-third octave bands kHz
PUBLIC PARK NEAR MULTIFAMILY HOUSING AND TWO FREEWAYS (14:00)

Soundscape: distant highway noise, birds, people, park activity

ENCINAL PARK, SUNNYVALE

47 dBA $L_{eq}$

One-third octave bands kHz
Elevation = 1000 ft
Velocity = 100 mph (147 ft/s)
Rate = 30 s

Amplitude Modulation 30 s (.033 Hz):
= 4.5 dB
Elevation = 1000 ft
Velocity = 100 mph (147 ft/s)
Rate = 45 s
Amplitude Modulation 45s (.022 Hz)
= ~7 dB
Elevation = 1000 ft
Velocity = 100 mph (147 ft/s)
Rate = 60 s

Amplitude Modulation (.016 Hz):
= ~10 dB
• PSYCHOACOUSTIC TESTS AT NASA
RECORD AMBIENT AT POTENTIAL VERTIPORT LOCATIONS AND UAM ROUTES (SF PENINSULA)
MICROPHONE CONFIGURATION FOR AMBIENT FIELD RECORDING

LOW-NOISE SPL CALIBRATION MICROPHONE (ANSI Type 1)

RECORDED WITH BATTERY POWERED 4 CHANNEL DIGITAL RECORDER & MIC PREAMPLIFIERS

192 kHz SRATE
24 BIT DYNAMIC RANGE

BINAURAL “DUMMY HEAD” MIC OPTIONAL FOR HEADPHONES PLAYBACK

“B-FORMAT”

W : OMNI
X , Y: DIPOLE
AURALIZATION LOUDSPEAKER SYSTEM: 7.1.4 ATMOS (DOLBY MULTICHANNEL)

- SEVEN SURROUND LOUDSPEAKERS (L, C, R, LSS, RSS, LSR, RSR) + SUBWOOFER
- FOUR OVERHEAD LOUDSPEAKERS
A: OVERHEAD LOUDSPEAKER
B: ABSORPTIVE PANEL
C: EAR-LEVEL LOUDSPEAKERS
D: REAL TIME ANALYZER & CALIBRATION MIC (RED)
E: SUBJECT RESPONSE DEVICE
F: MULTI-AXIS VIBRATION PLATFORM
G: DUMMY HEAD MIC FOR CALIBRATION AT SUBJECT SEAT
NASA LaRC NAF

AURALIZATION OF
CONCEPT EVTOL

INDEPENDENT VARIABLE PROCESSING
- Level
- Spectrum
- Trajectory
- Ambient

MULTICHANNEL AMBIENT RECORDINGS

Bed Audio + Object Audio + Dolby Atmos Metadata = Dolby Atmos

ATMOS PANNING MODULE WITHIN PROTOOLS

Source-Receiver Trajectory vs Time

Waypoints

NASA LaRC NAF
AURALIZATION OF CONCEPT EVTOL
**Annoyance**:
- Is the UAM sound annoying enough that you would complain?
- (2 yes = decrease)
- 70.7% threshold (+/- 2 dB)

**Blend**:
- Does the UAM sound dominate the ambient (=YES) or is it either about the same or inaudible (= NO) (2 yes = decrease)

**Detection**:
- Click ASAP when you clearly hear a UAM sound within the ambient
- 20+ signal (S+N) trial responses ("ideal subject")
- Random intermix with 20 noise (N) trials
- 2 yes = decrease
- FA count (no Correct Rejection count)
- Timing for HIT stimuli

**Signal Duration**
- 50% trial duration

**Trial Soundfile**
- 5 "N" files in ambient
- 30 "S" files in 2 dB increments

**YES or NO responses (single interval, 2AFC)**
- 70.7% threshold level (2 down, 1 up)

**Trial Duration**
- 8-16 s TBD

**Detection trials** include N only

* Detection trials include N only
Judgments as a function of LEVEL (signal-noise ratio) ("informed routing")

Judgments as a function of TONE ATTENUATION ("informed design")

Difference in time varying loudness with significant tone attenuated
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