Psychoacoustic Measures for UAM Noise in the Context of Ambient Sound

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Vertical Flight Society SF Bay Area Chapter

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Work supported by NASA RVLT

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

  - Realistic simulations using **auralization techniques**
  - Accurate modeling of **sound propagation** in the environment
  - Accurate simulation of **sound levels** and **spatial auditory cues**
  - 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:

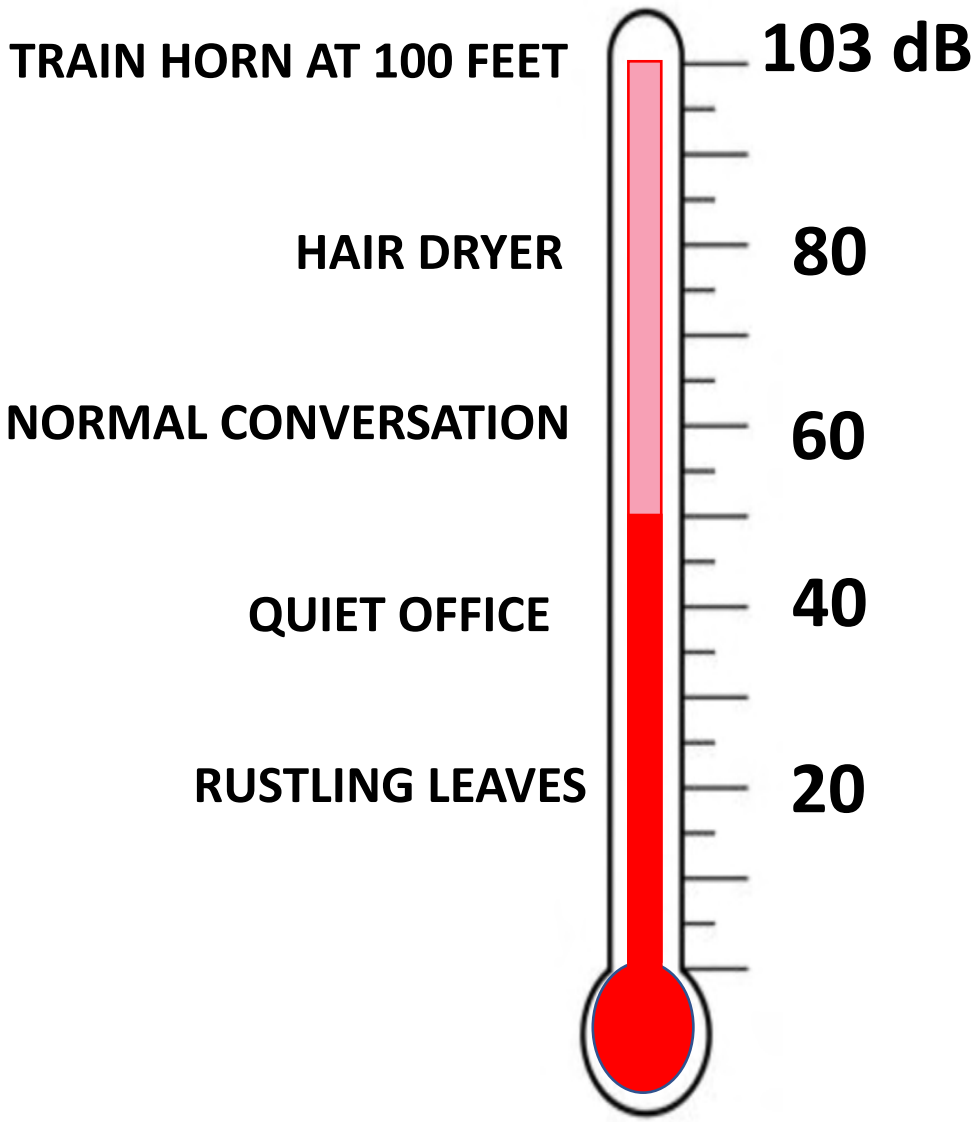
-LEVEL (“loudness”)

-FREQUENCY (”pitch”)

-MASKING

“DECIBEL THERMOMETER”
Decibels measure sound **level**

A 10 decibel increase equals a doubling of loudness



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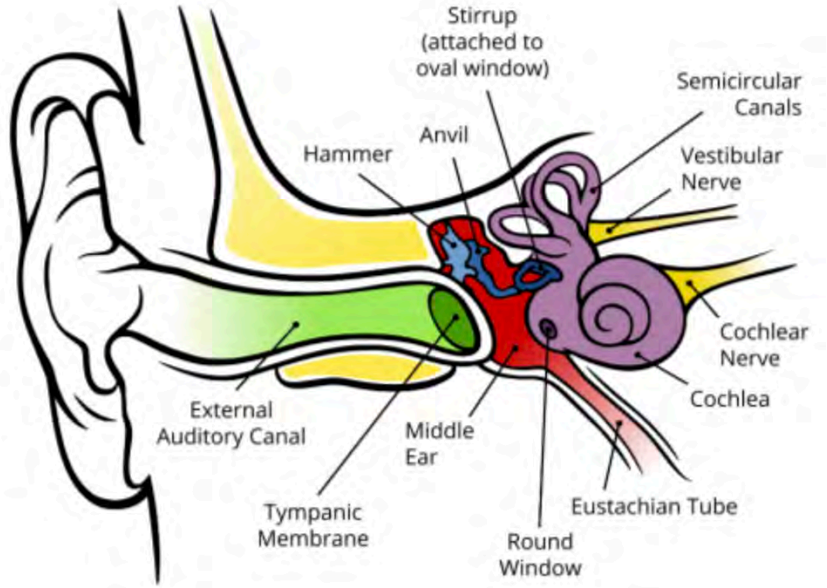
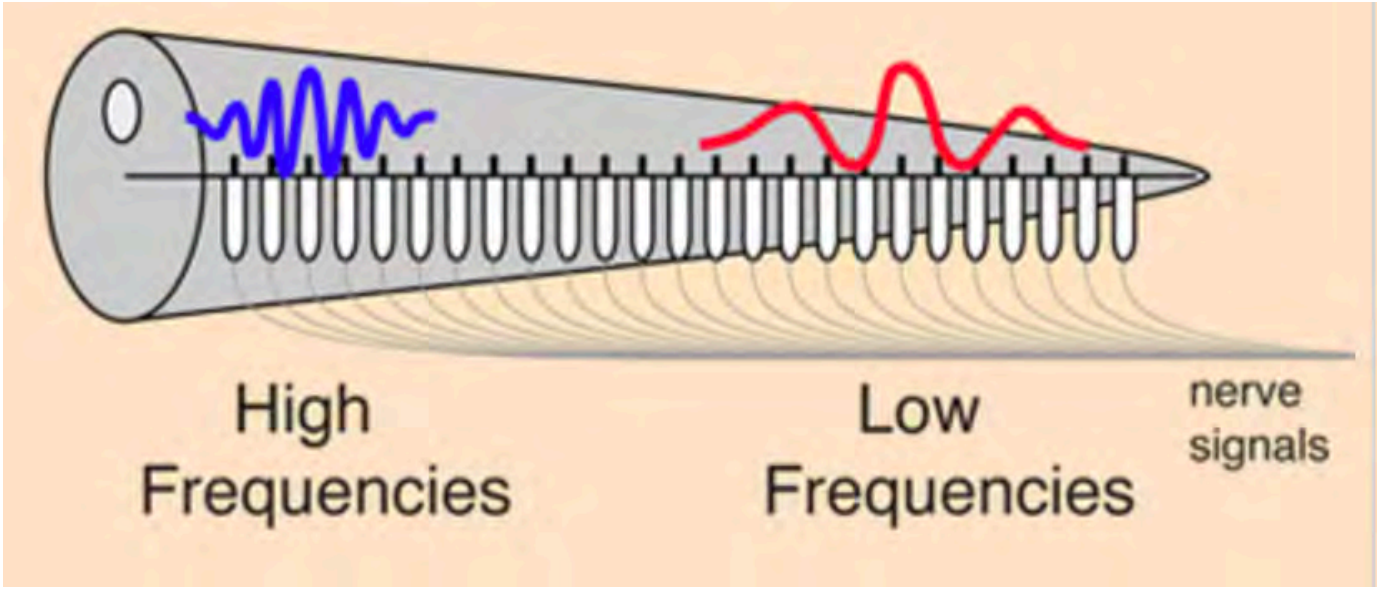
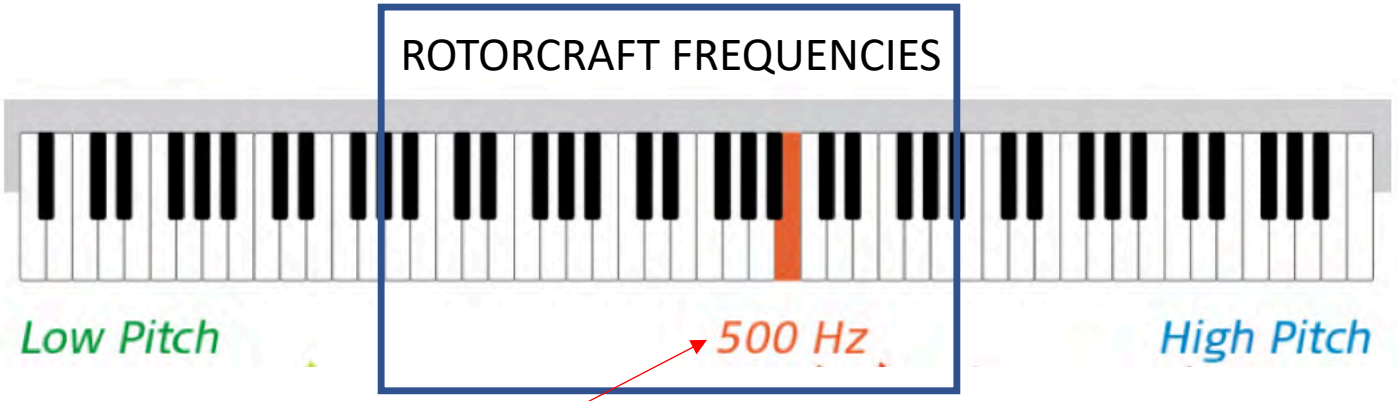






SIGNIFICANT TONE

THREE FACTS ABOUT SOUND:

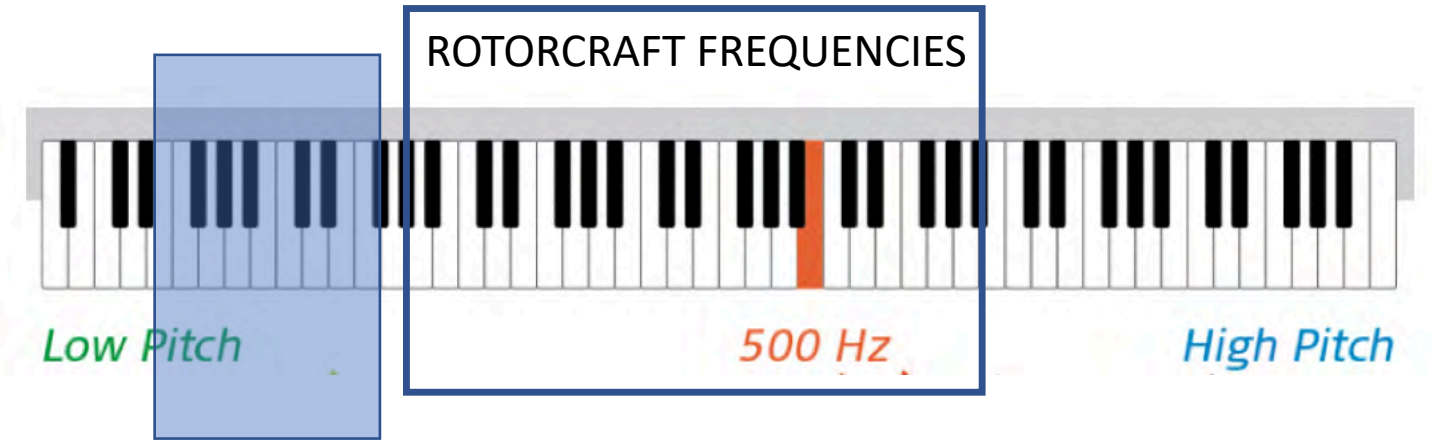
-LEVEL (“loudness”)

-FREQUENCY (”pitch”)

-MASKING:

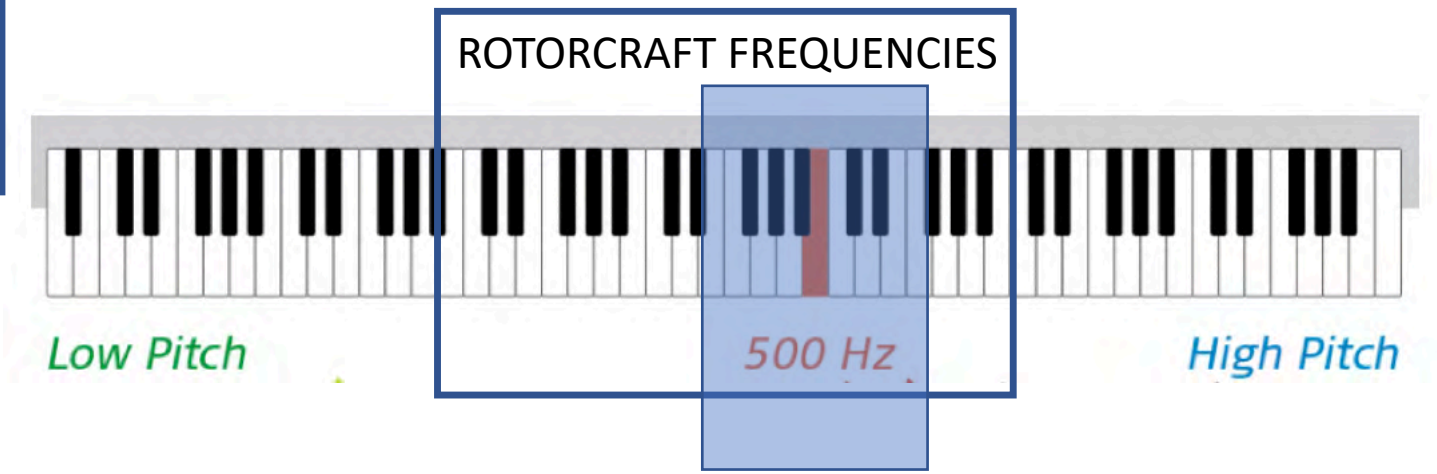
Noise is more effective at hiding (“masking”) a signal when their frequencies overlap

NOISE **DOESN’T** MASK THE ROTORCRAFT TONE



Noise

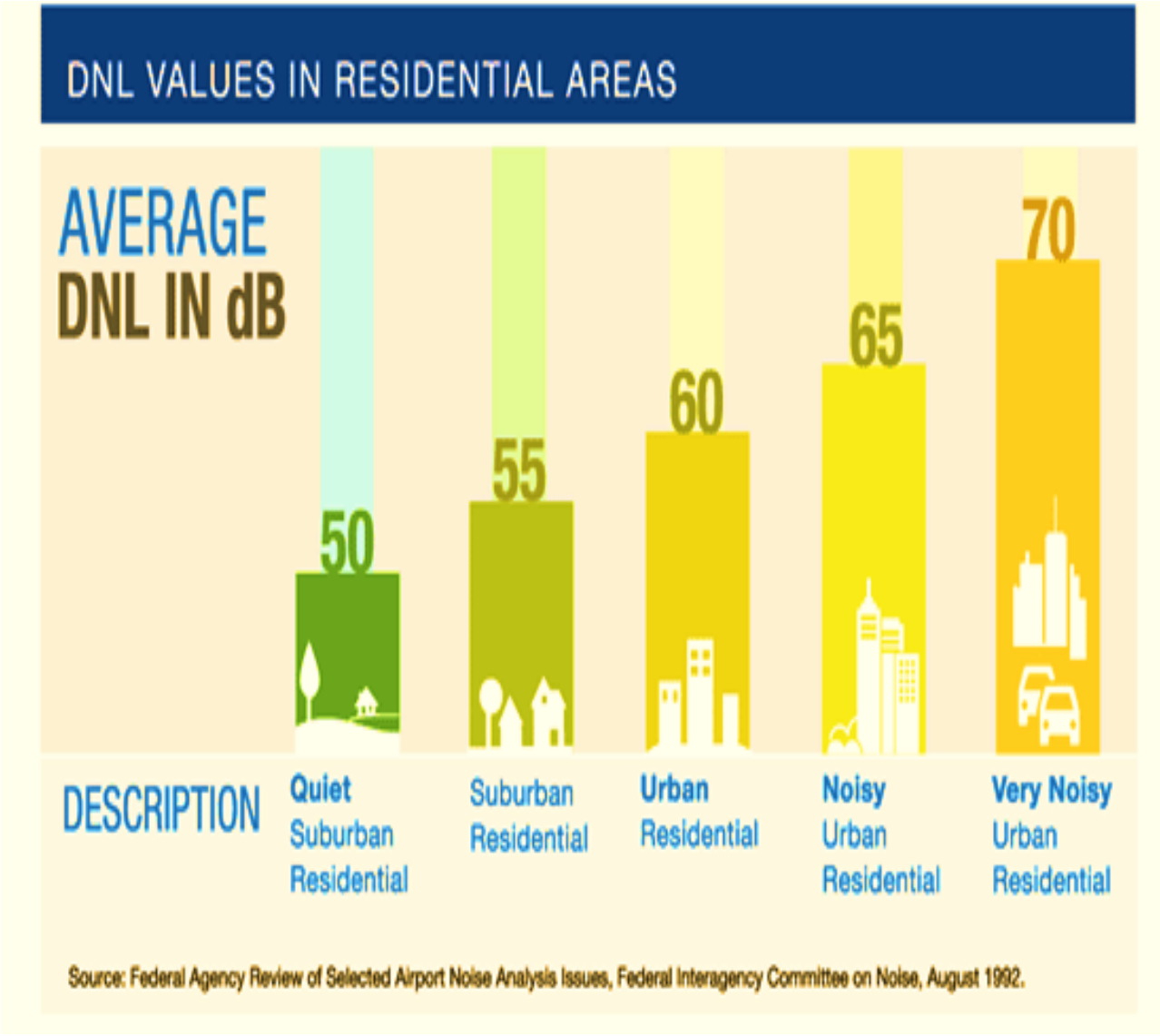
NOISE **DOES** MASK THE ROTORCRAFT TONE



Noise

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 (Leq_A) + 10* $\log_{10}$(duration)

- **SEL normalizes total sound energy to a <u>constant</u> time interval & level of 1 second**

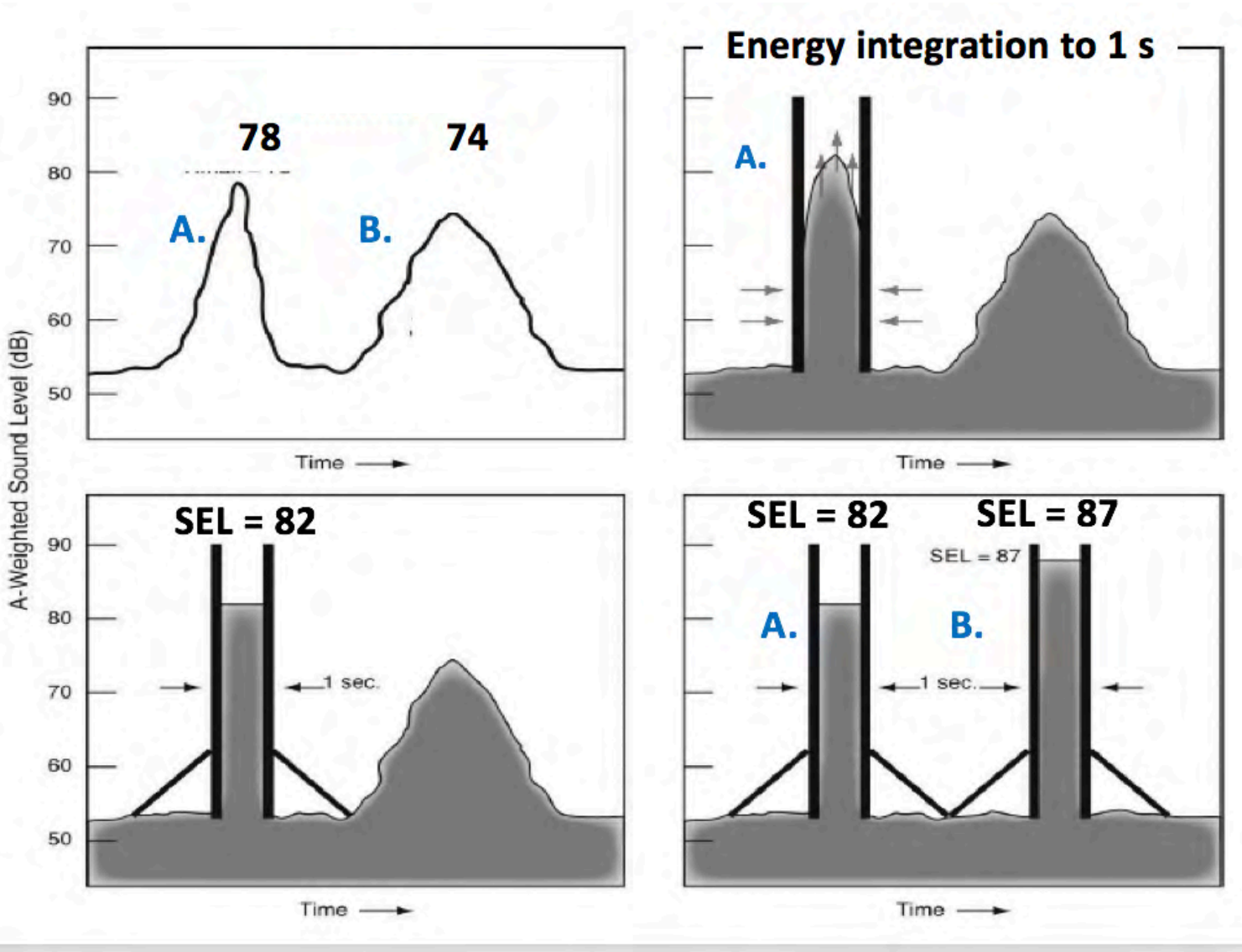
- The **longer** the duration of a a sound event, the **higher** the **SEL**

Example:

- **Flyover A has a <u>higher</u> maximum level than B**

but note that-

- **Flyover A has a <u>lower</u> SEL than B because its <u>duration</u> 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**

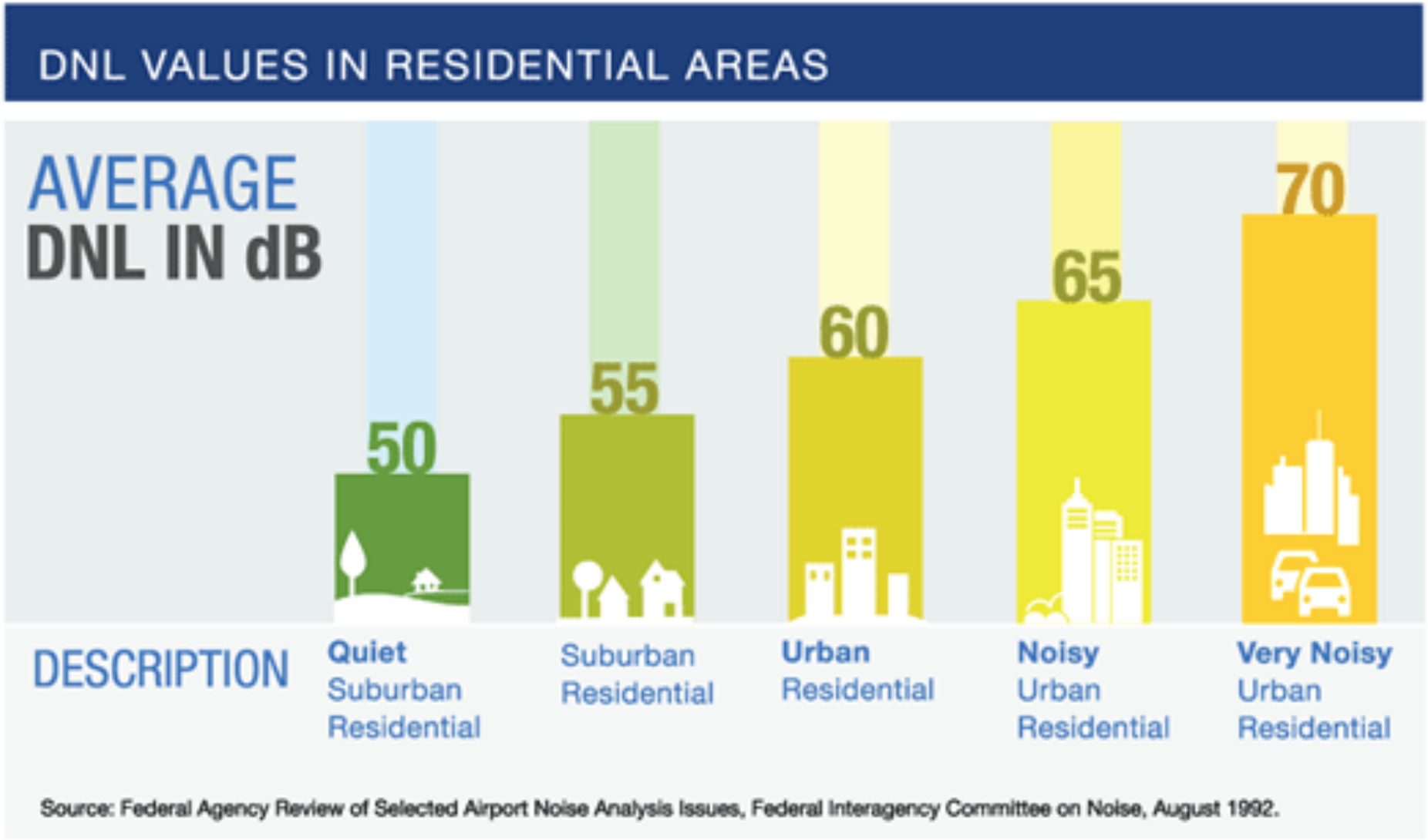
Time-energy dosage metric is not intuitive for communities responding to noise

SEL = 114 dB
X 1 event

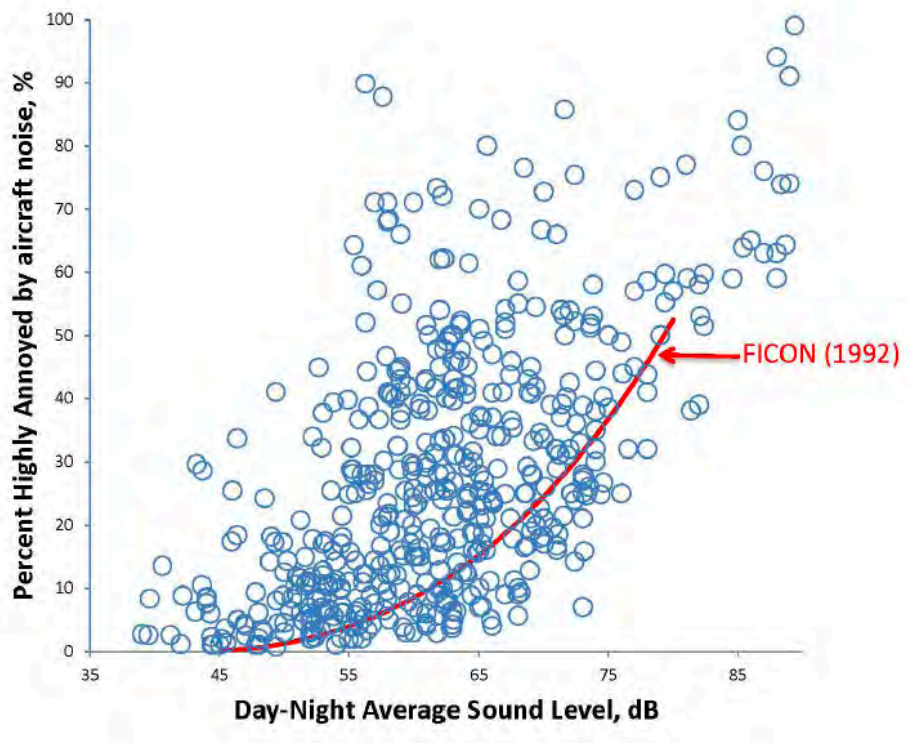
SEL = 104 dB
X 10 events

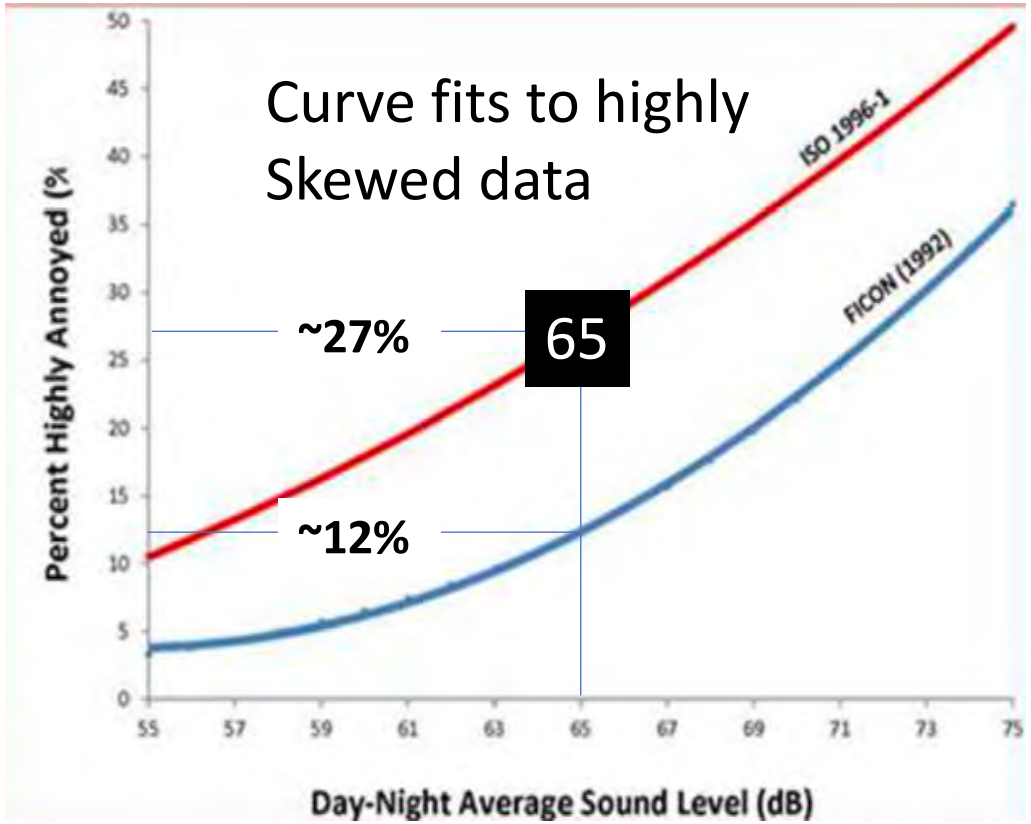
SEL = 94 dB
X 100 events

- **FAA criteria for significance: at least 1.5 dB above 65 DNL**

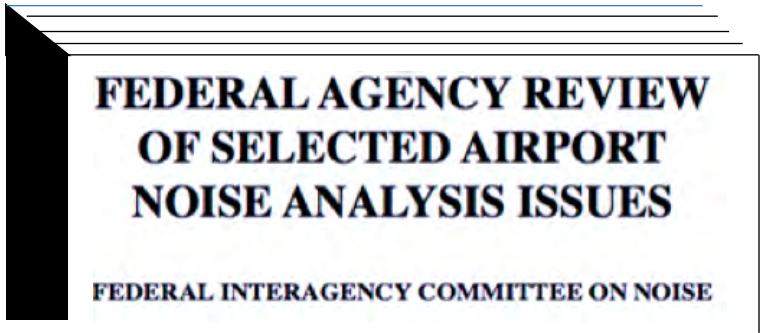


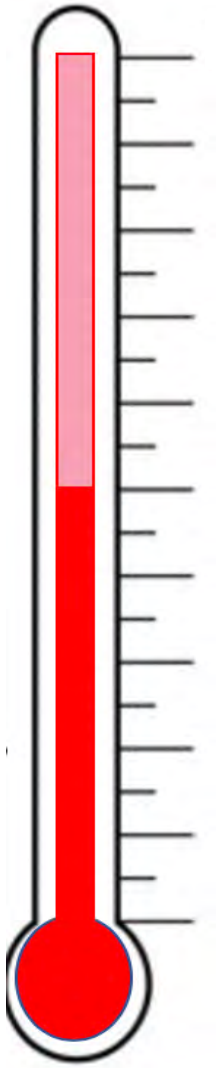
- Percentage of persons highly annoyed (**%HA**) by aircraft sound calculated by the **DNL** dosage-response relationship





- 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**

TDH-39

AR-1, KLH

• 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

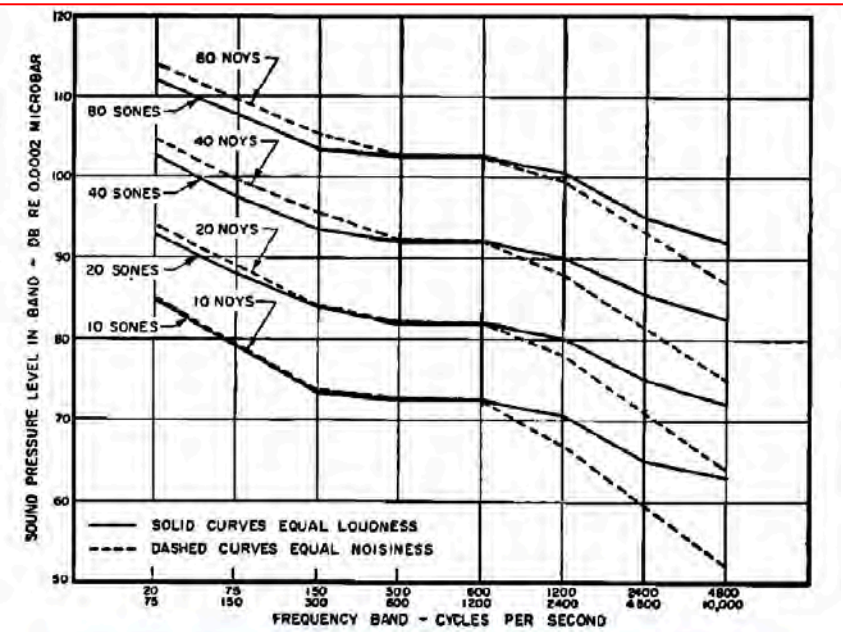


FIG. 14. Contours of equal loudness (after Stevens[7]) and equal noisiness (Kryter[5]).

HUMAN DETECTION TO AIRCRAFT NOISE: "DETECTION" NPS STUDIES ca. 1980s-1990s

NPOA Report No. 93-1 BBN Report No. 7197

EVALUATION OF THE EFFECTIVENESS OF SFAR 50-2 IN RESTORING NATURAL QUIET TO GRAND CANYON NATIONAL PARK

FINAL REPORT

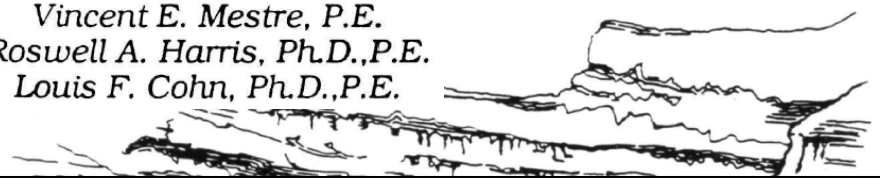
Sanford Fidell, Karl Pearsons, and Mathew Sneddon

METHODOLOGY FOR THE MEASUREMENT AND ANALYSIS OF AIRCRAFT SOUND LEVELS WITHIN NATIONAL PARKS

National Park Service

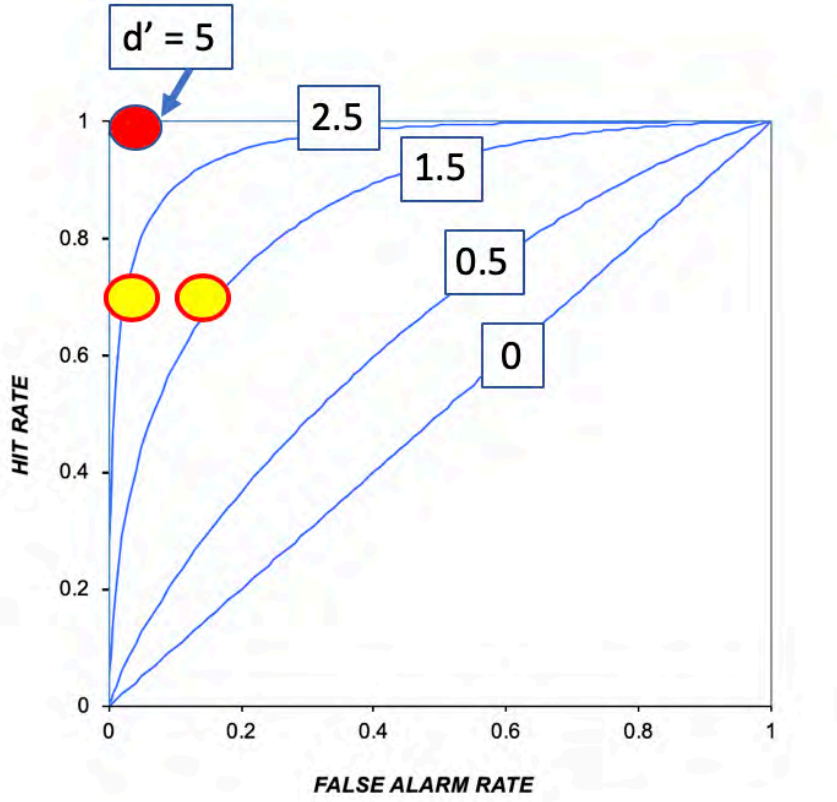
Final Report
March 1989

Paul H. Dunholter, P.E.
Vincent E. Mestre, P.E.
Roswell A. Harris, Ph.D.,P.E.
Louis F. Cohn, Ph.D.,P.E.



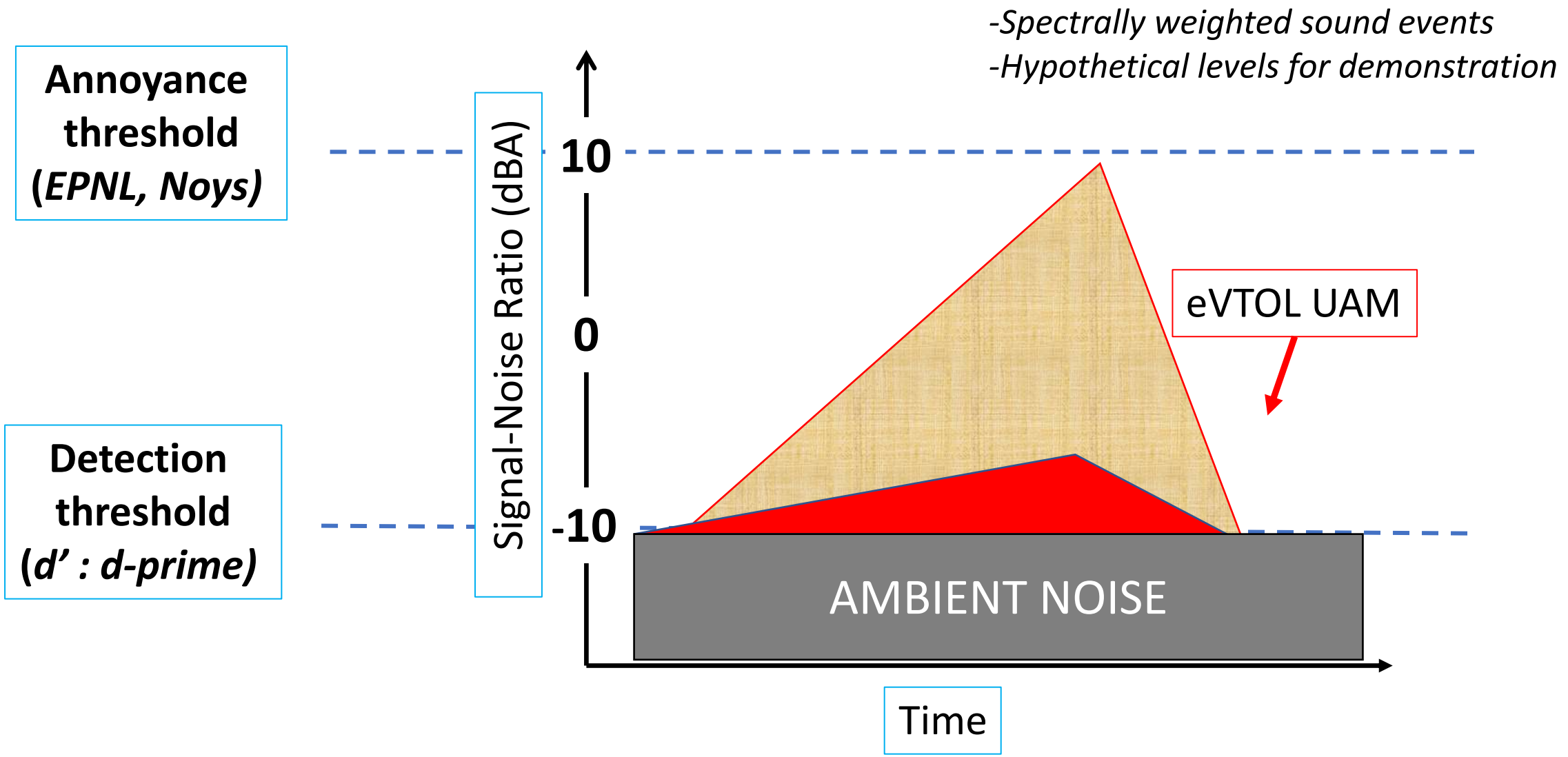
AKA "Audibility"

"[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.



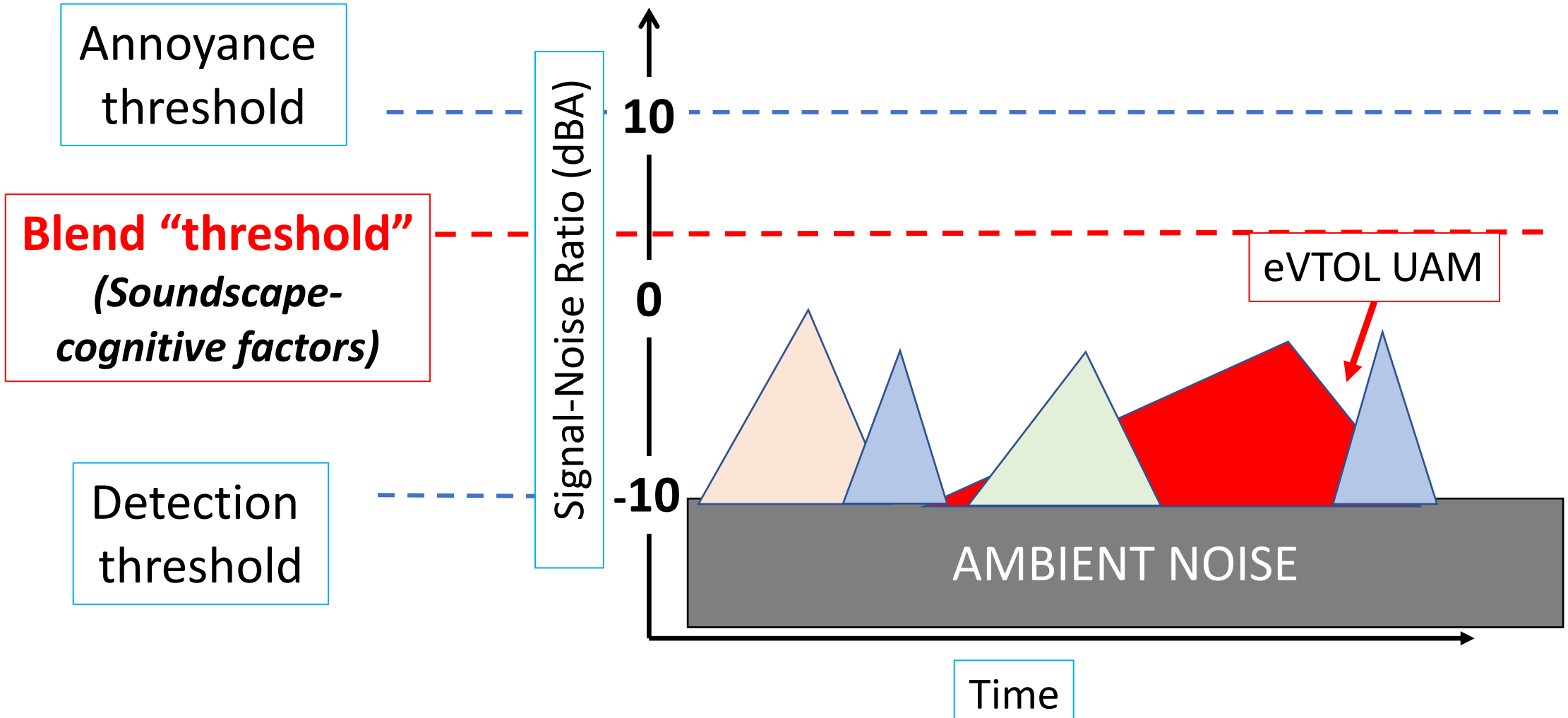
AEDT **TAUD** (time audible) METRIC

- **ANNOYANCE and DETECTION: "Extreme" signal-noise endpoints**

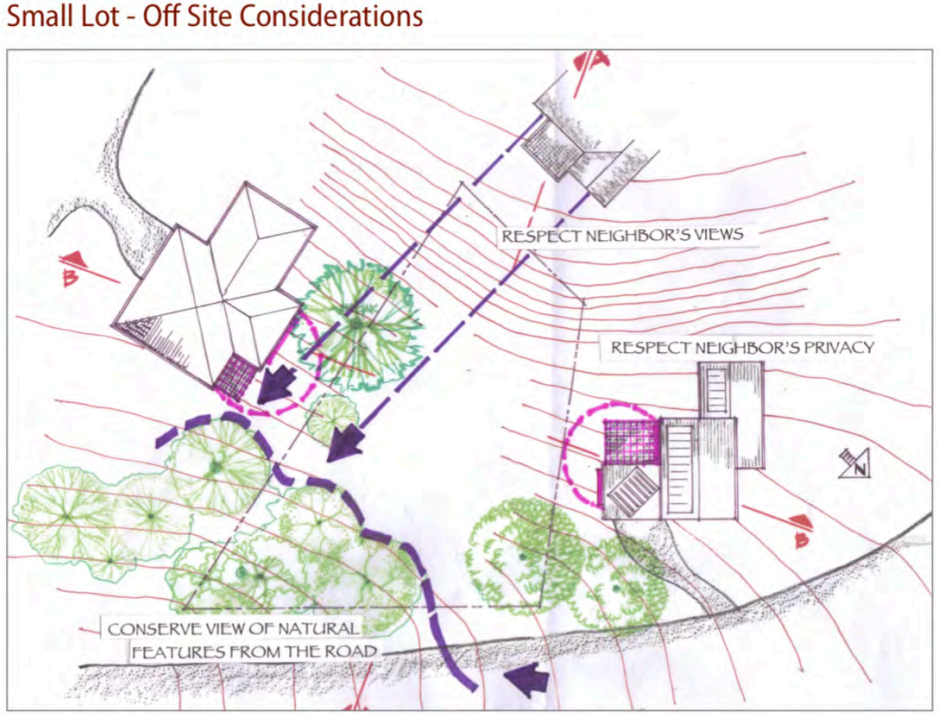


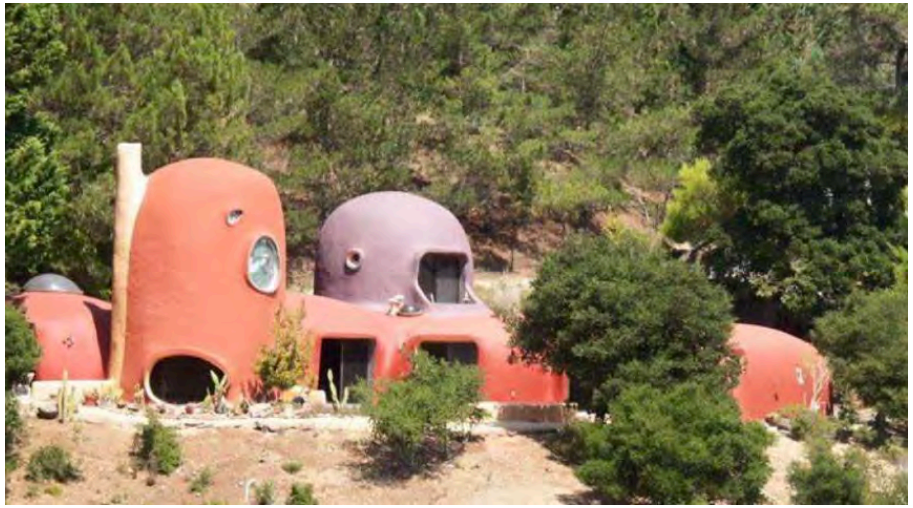
- **BLEND METRIC:** Signal-Noise region where UAM noise **does not dominate** other ambient sound sources

- *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**

TIME VARYING AMBIENT

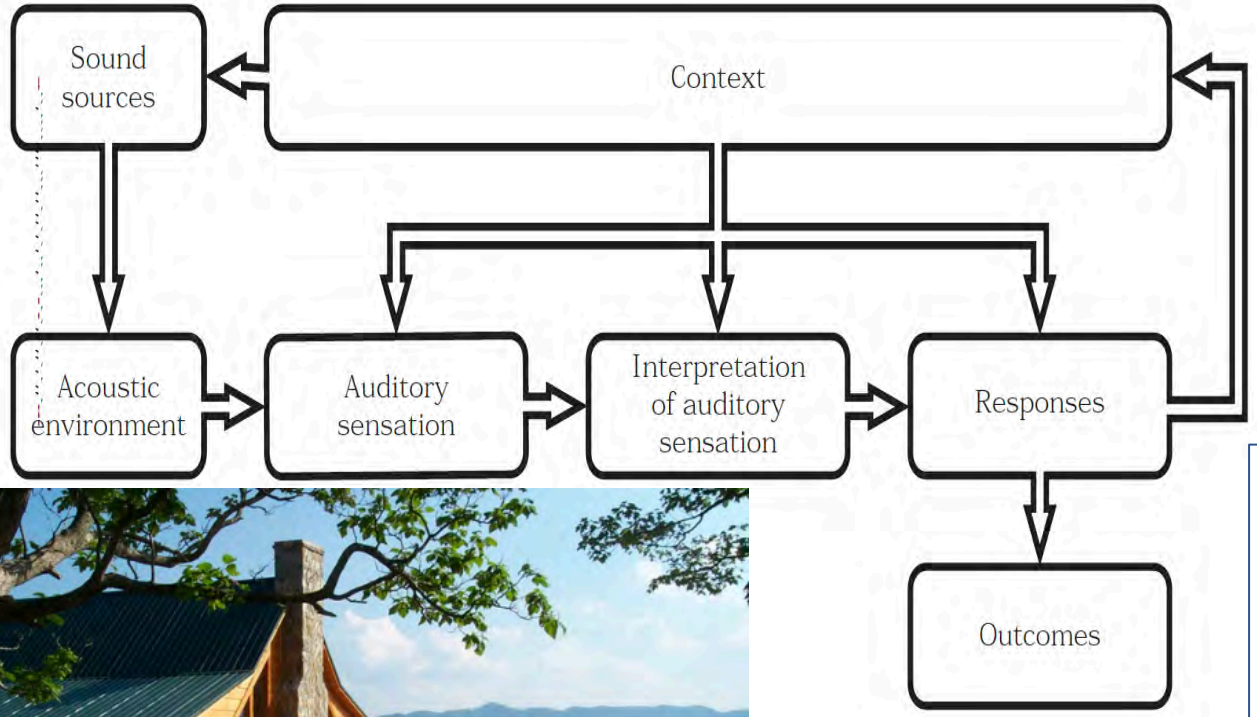
TIME VARYING SIGNAL

AUDITORY SCENE ANALYSIS

PERCEIVED SOUNDSCAPE

BLEND THRESHOLD

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**



INTERNATIONAL STANDARD **ISO 12913-1**

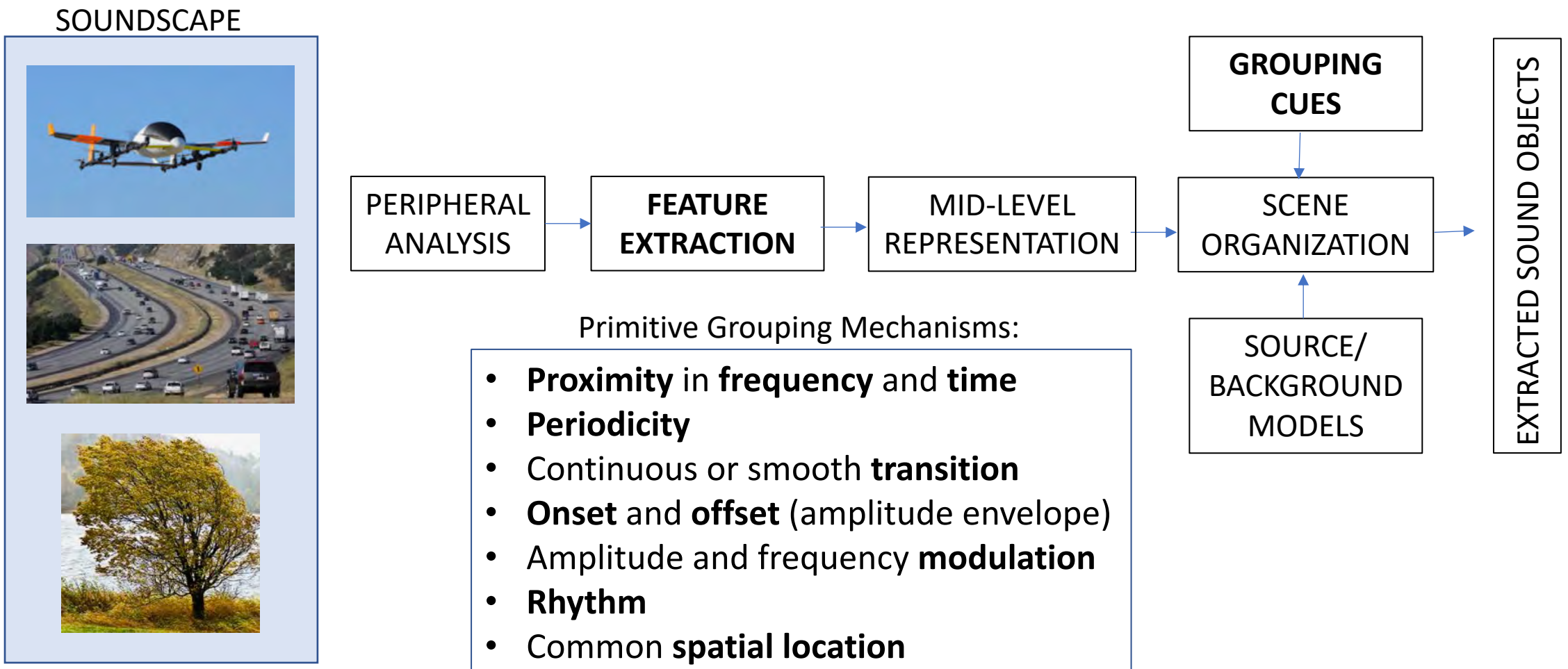
First edition
2014-09-01

Acoustics — Soundscape —

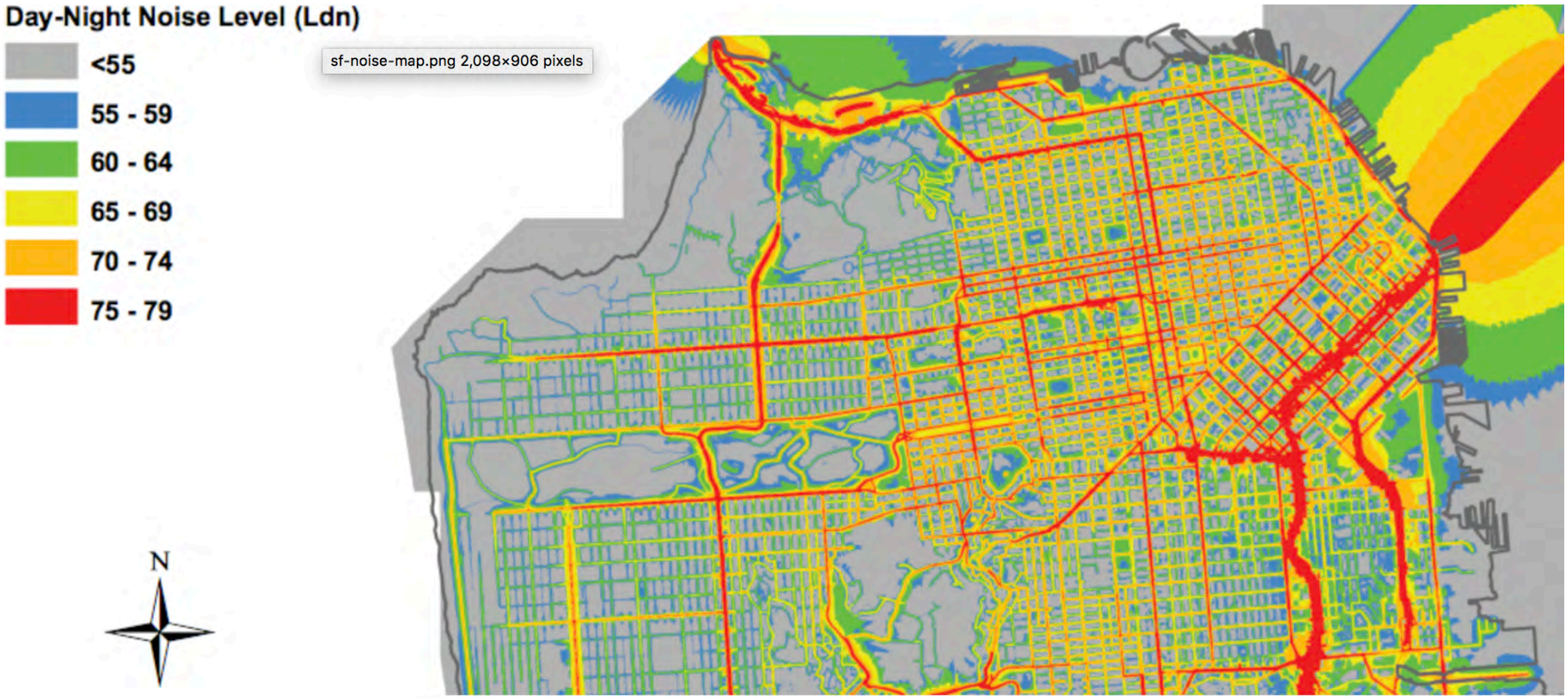
Part 1:
Definition and conceptual framework

I am listening to a soundscape at night compromised of crickets, ocean waves crashing, and two ban 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**



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

EXTERIOR NOISE LIMITS

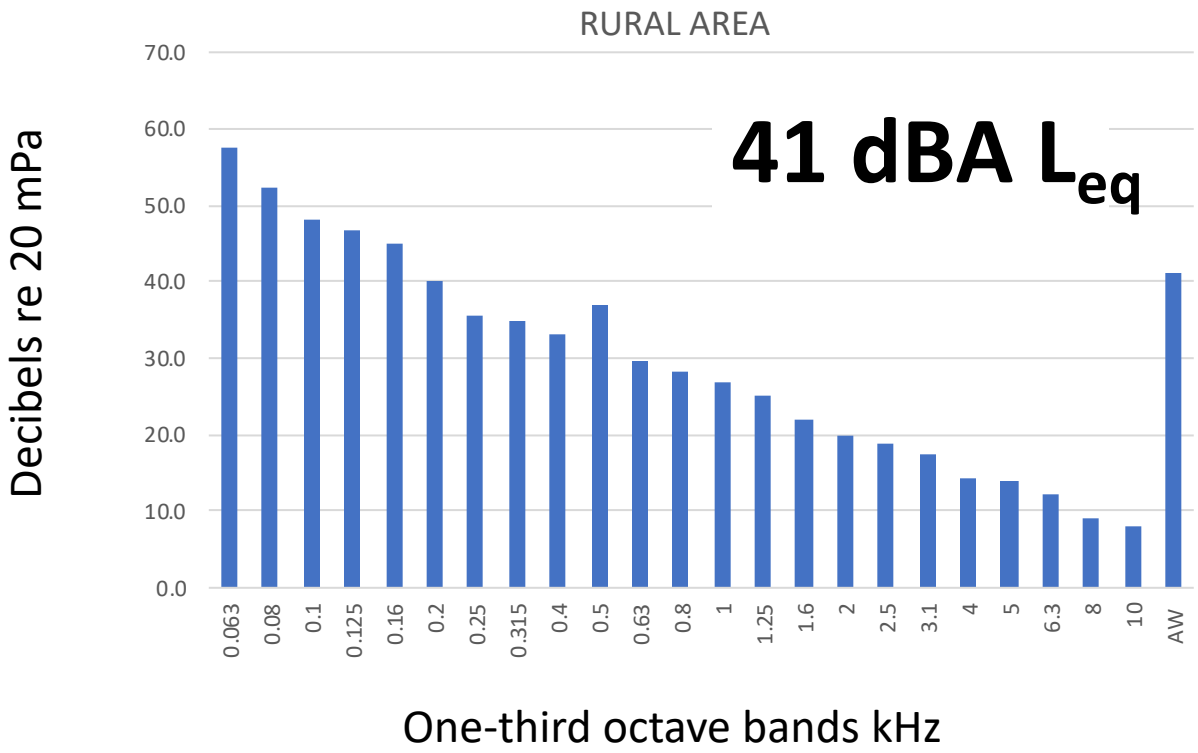
(Levels Not To Be Exceeded More Than 30 Minutes In Any Hour)

Receiving Land Use Category	Time Period	Noise Level (dBA)		
		Noise Zone Classification (1)		
		Rural Suburban	Suburban	Urban
One & Two Family Residential	10 pm- 7 am 7 am-10 pm	40 50	45 55	50 60
Multiple Dwelling Residential Public Space	10 pm- 7 am 7 am-10 pm	45 50	50 55	55 60
Limited Commercial Some Multiple Dwellings	10 pm- 7 am 7 am-10 pm	55 60		
Commercial	10 pm- 7 am 7 am-10 pm	60 65		
Light Industrial	Any Time	70		
Heavy Industrial	Any Time	75		

- EXAMPLE SOUNDSCAPES;
  AMBIENT SOUND LEVELS
  RE POTENTIAL UAM SOUND

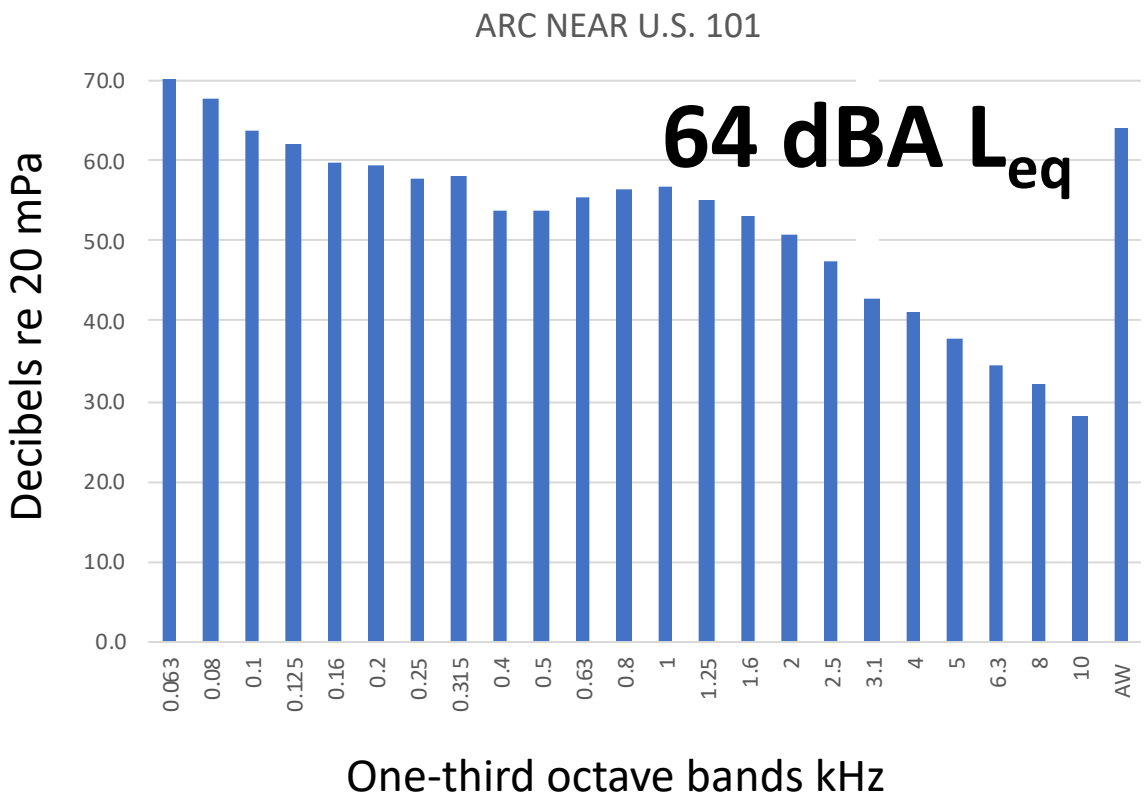
RURAL- PARK AREA (17:00)

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



INDUSTRIAL PARK – MULTIFAMILY HOUSING NEAR FREEWAY (10:00)

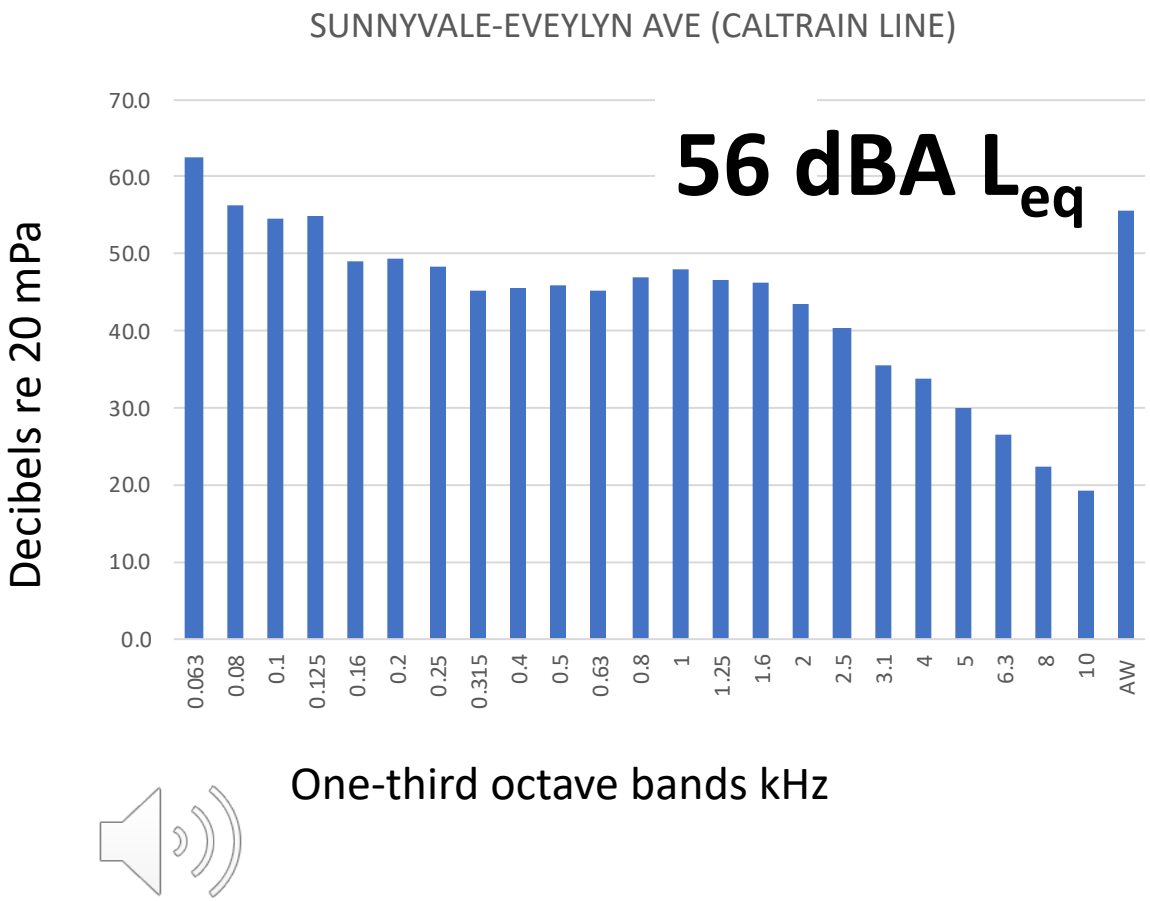
Soundscape: dominated by freeway traffic noise, motorcycle-truck single events



+ 23 dBA increase compared to last example

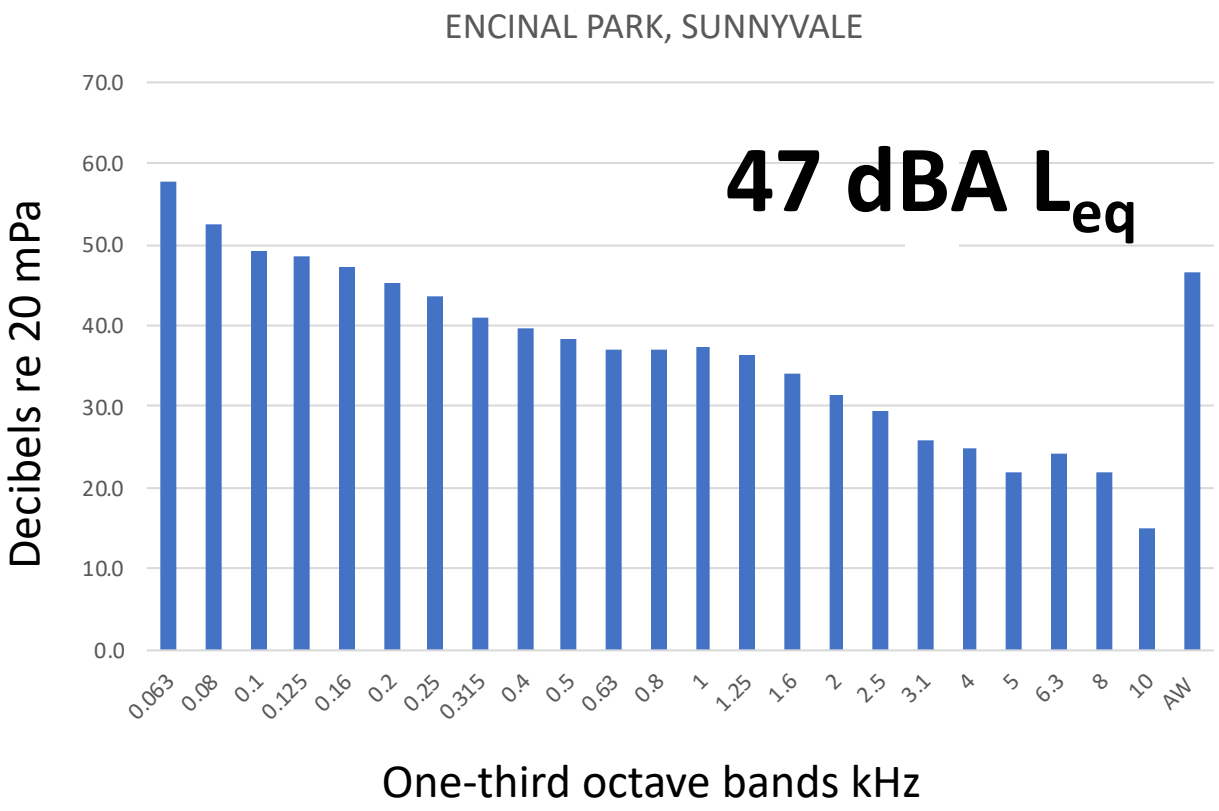
MULTIFAMILY HOUSING NEAR CALTRAIN LINE (10:00)

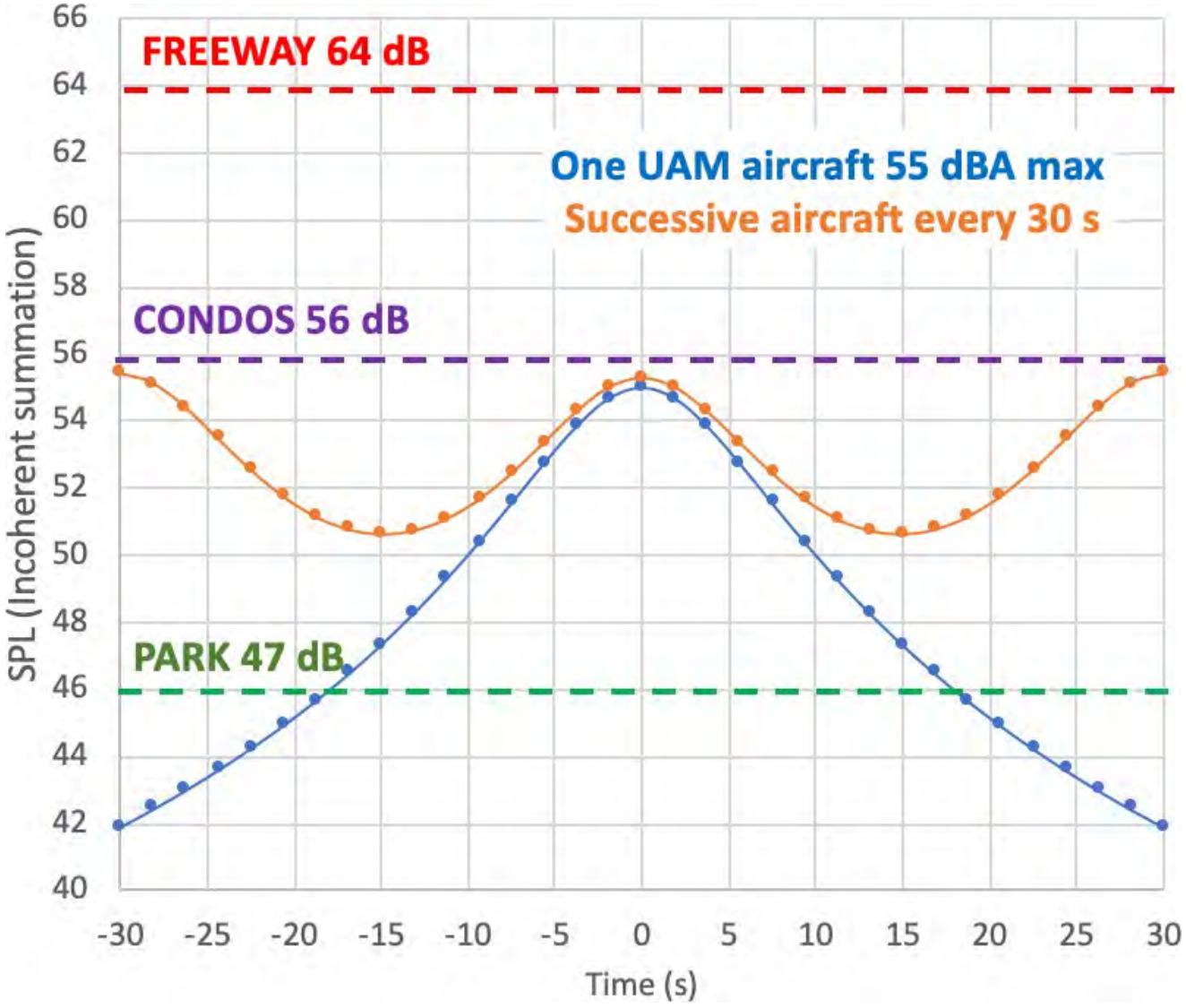
Soundscape: road traffic single events, power tools, distant highway



PUBLIC PARK NEAR MULTIFAMILY HOUSING AND TWO FREEWAYS (14:00)

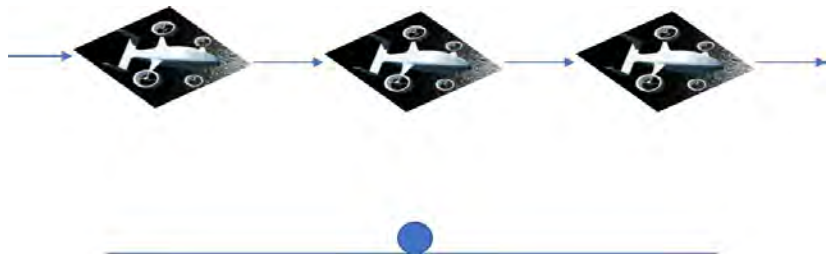
Soundscape: distant highway noise, birds, people, park activity

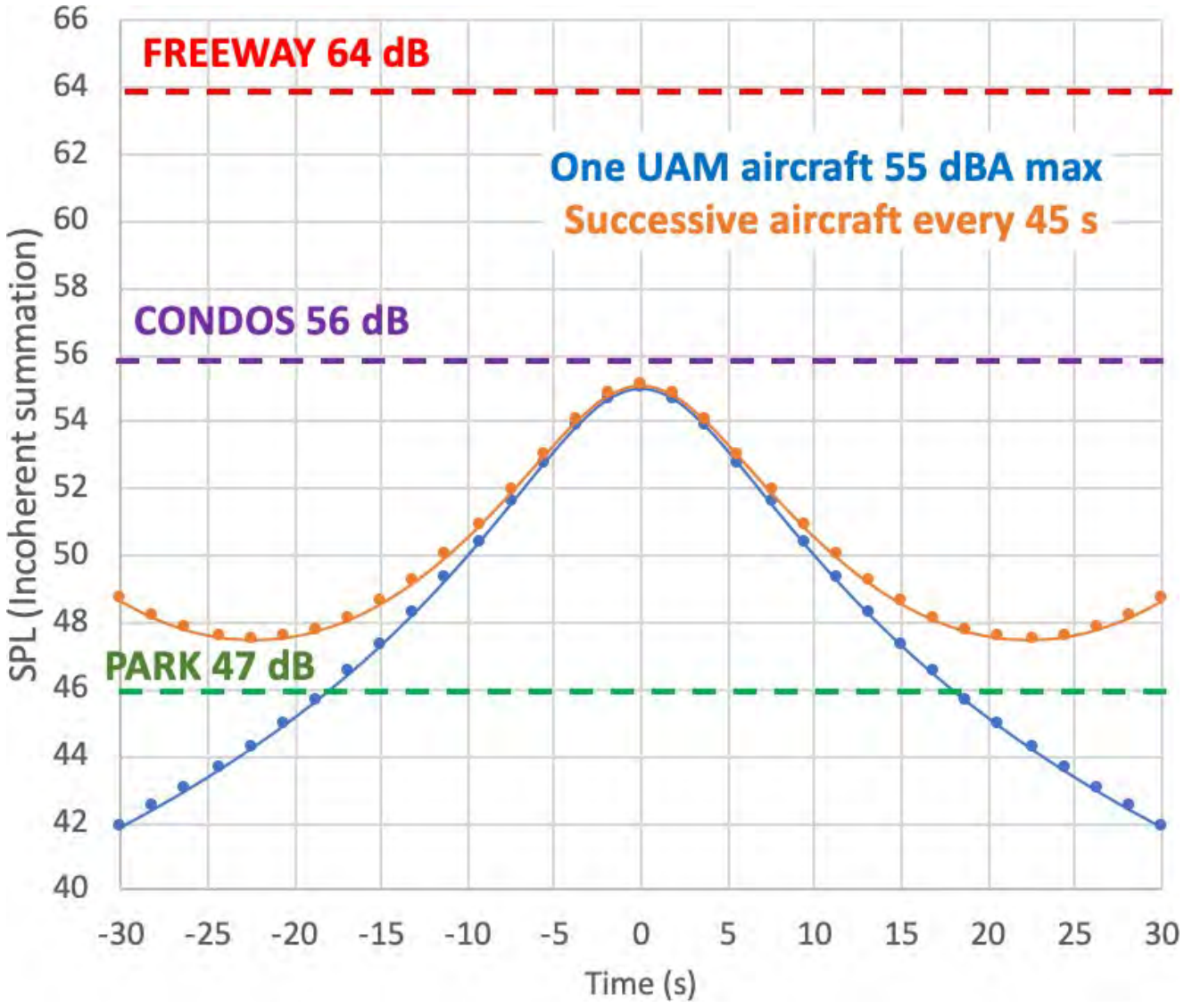




Elevation = 1000 ft
Velocity = 100 mph (147 ft/s)
Rate = 30 s

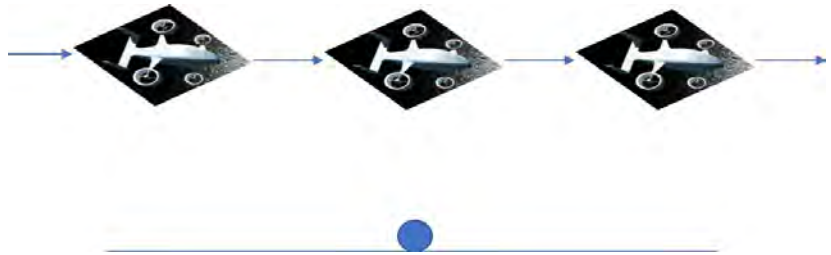
Amplitude Modulation 30 s(.033 Hz):
= 4.5 dB

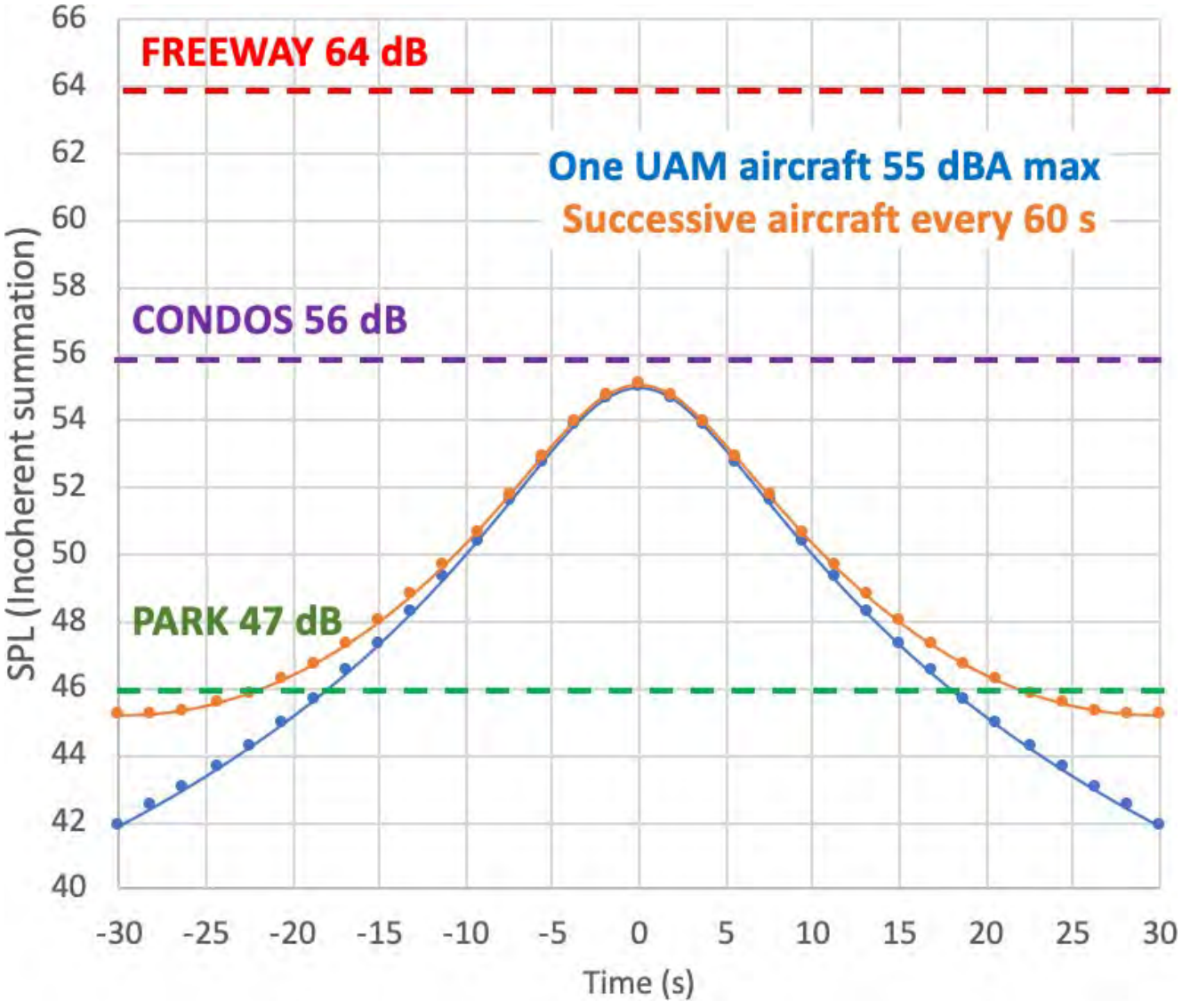




Elevation = 1000 ft
Velocity = 100 mph (147 ft/s)
Rate = 45 s

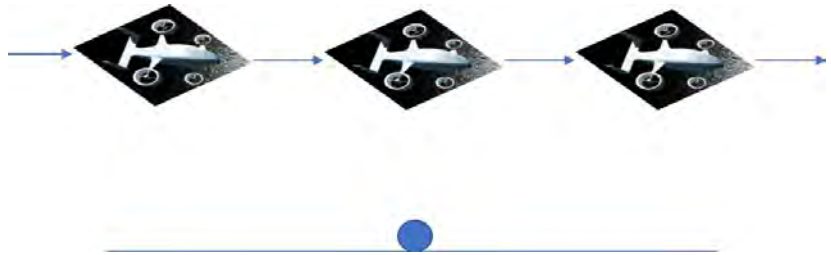
Amplitude Modulation 45s (.022 Hz) = ~7 dB





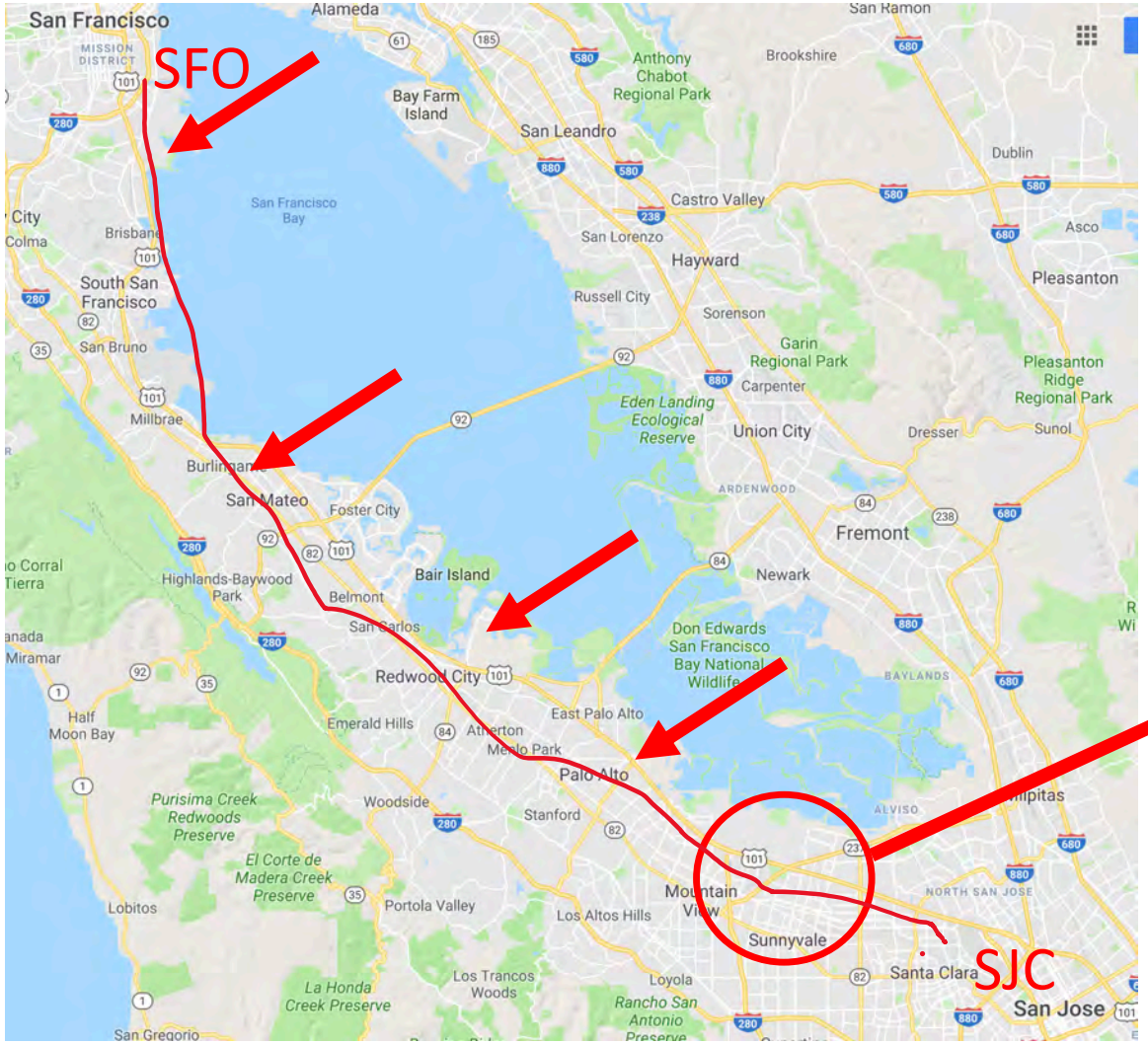
Elevation = 1000 ft
Velocity = 100 mph (147 ft/s)
Rate = 60 s

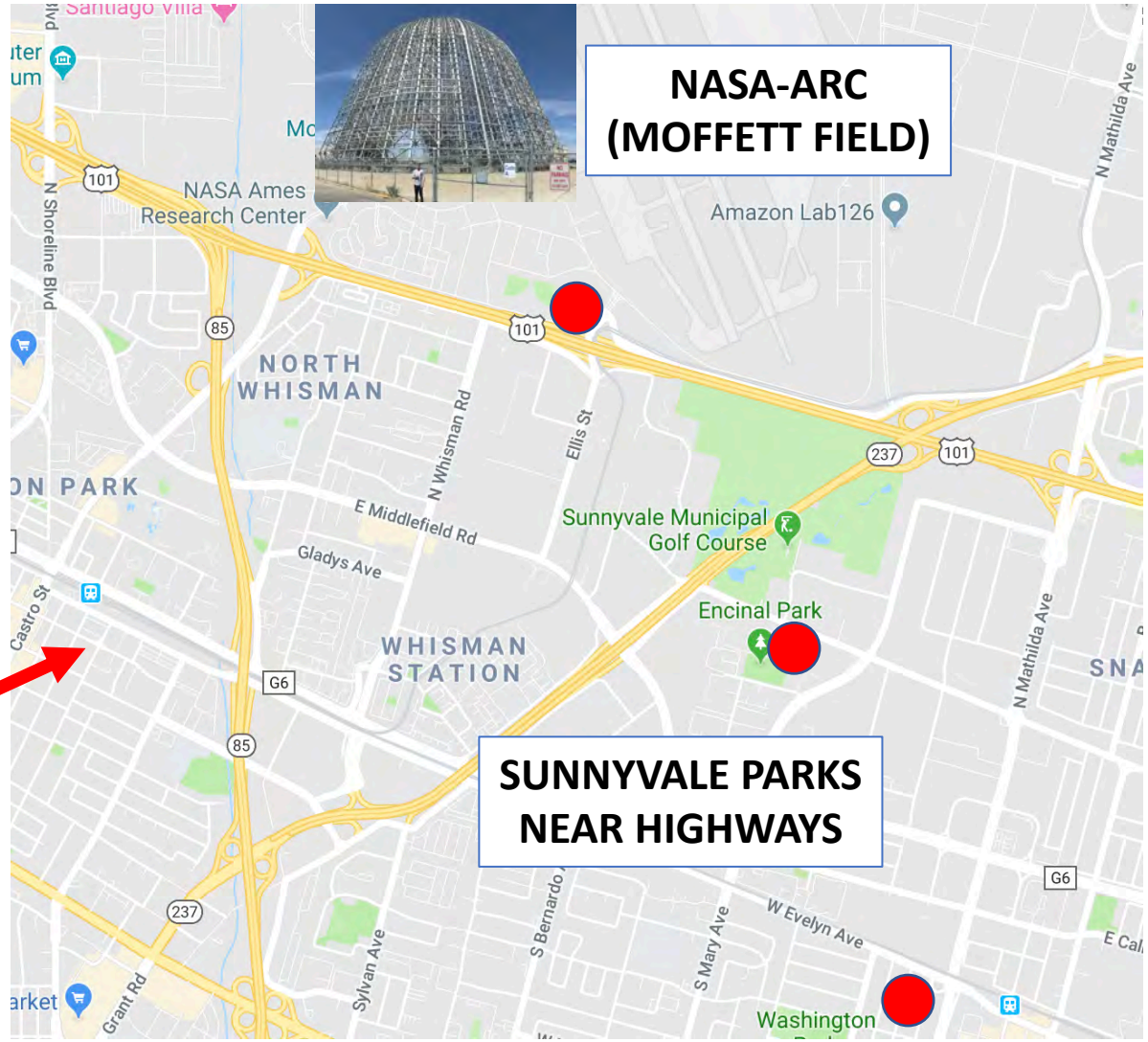
Amplitude Modulation (.016 Hz):
= ~10 dB



- PSYCHOACOUSTIC TESTS AT NASA

RECORD AMBIENT AT POTENTIAL VERTIPORT LOCATIONS AND UAM ROUTES (SF PENINSULA)

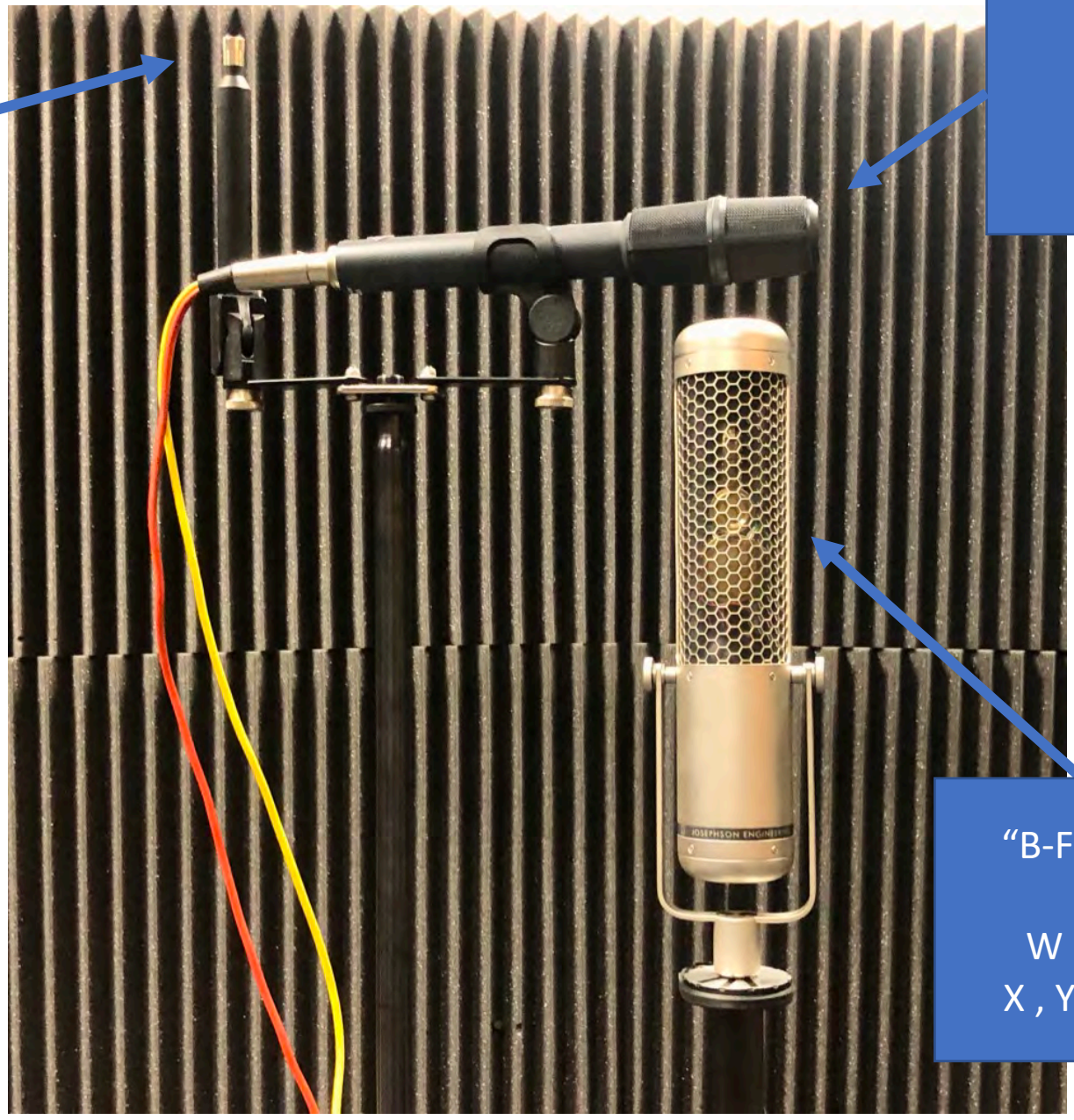


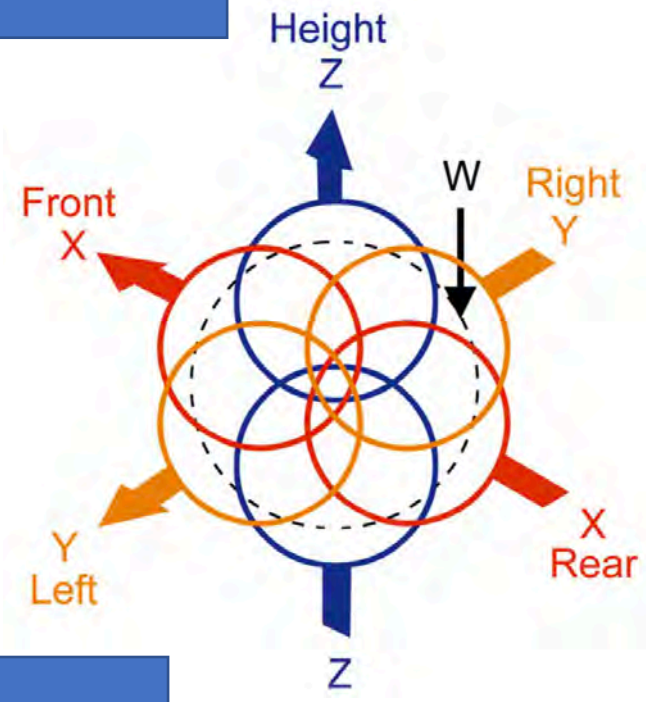


MICROPHONE CONFIGURATION FOR AMBIENT FIELD RECORDING

LOW-NOISE SPL CALIBRATION MICROPHONE (ANSI Type 1)

Z: DIPOLE





RECORDED WITH BATTERY POWERED 4 CHANNEL DIGITAL RECORDER & MIC PREAMPLIFIERS

192 kHz SRATE
24 BIT DYNAMIC RANGE

BINAURAL “DUMMY HEAD” MIC OPTIONAL FOR HEADPHPONE PLAYBACK

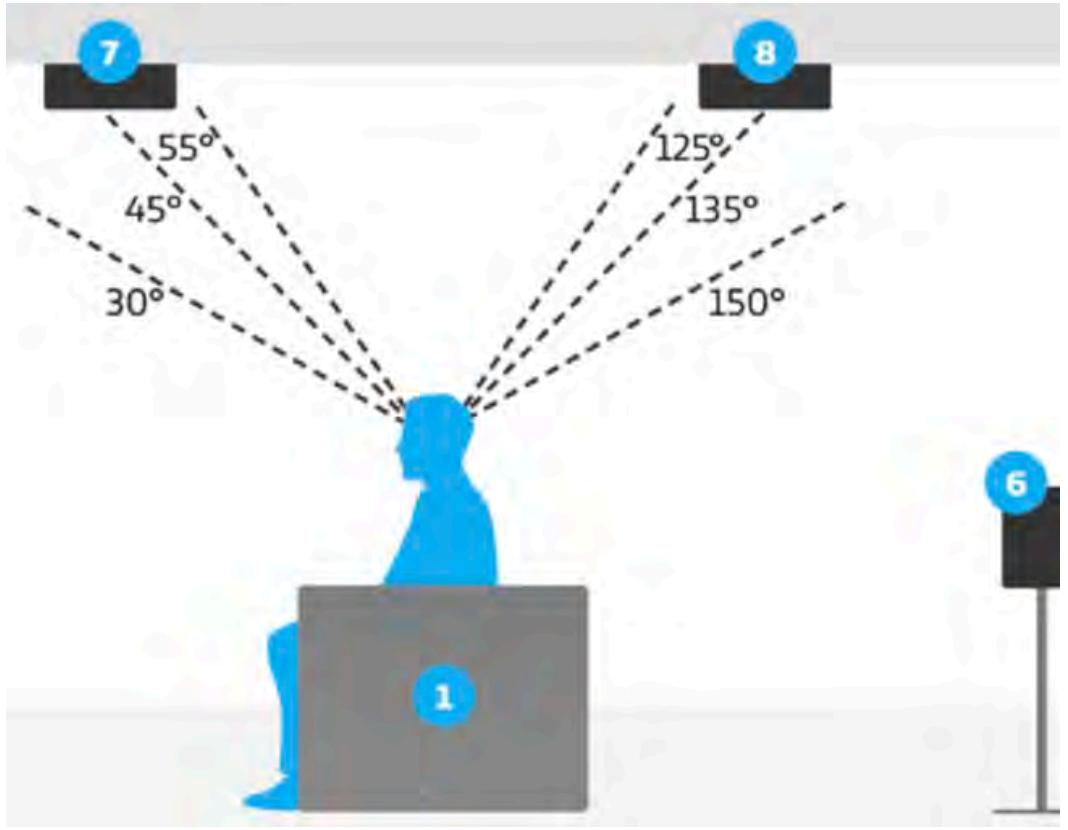
“B-FORMAT”

W : OMNI
X , Y: DIPOLE

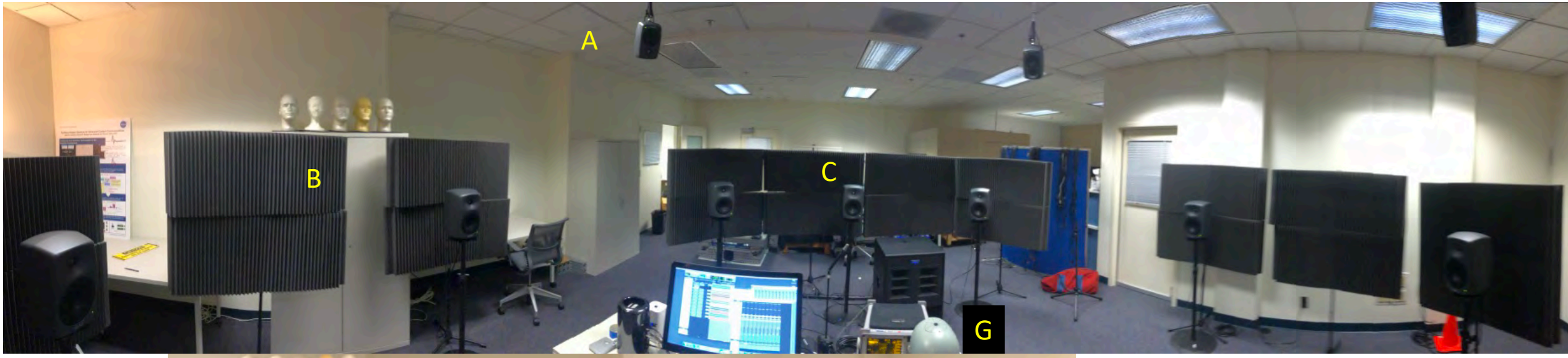
AURALIZATION LOUDSPEAKER SYSTEM: 7.1.4 ATMOS (DOLBY MULTICHANNEL)

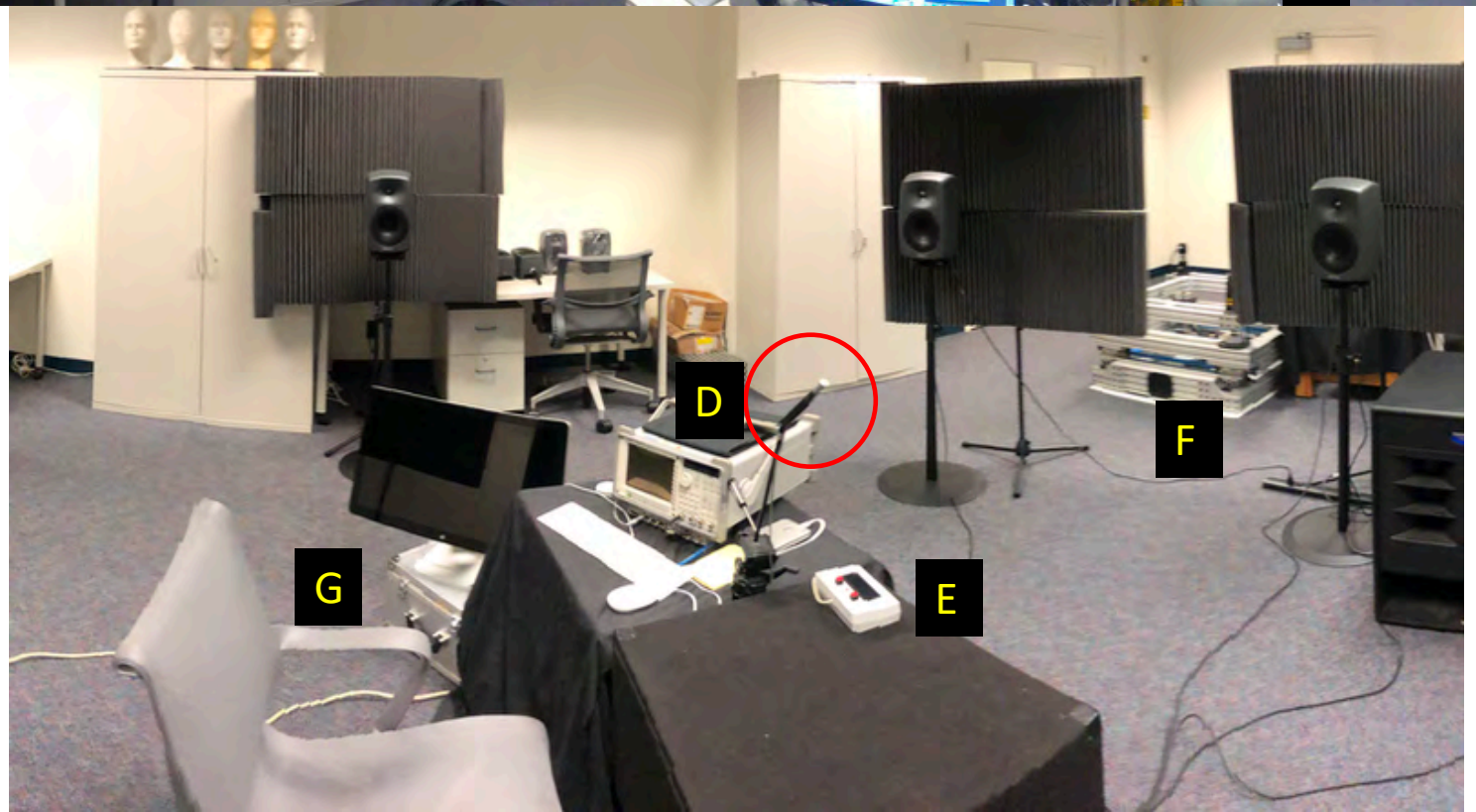
PERSPECTIVE

SECTION



- **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

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

INDEPENDENT VARIABLE PROCESSING
- Level
- Spectrum
- Trajectory
- Ambient

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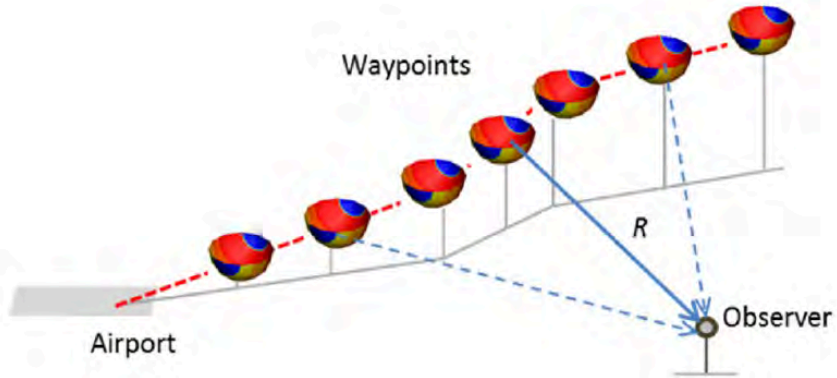
ATMOS PANNING MODULE WITHIN PROTOOLS

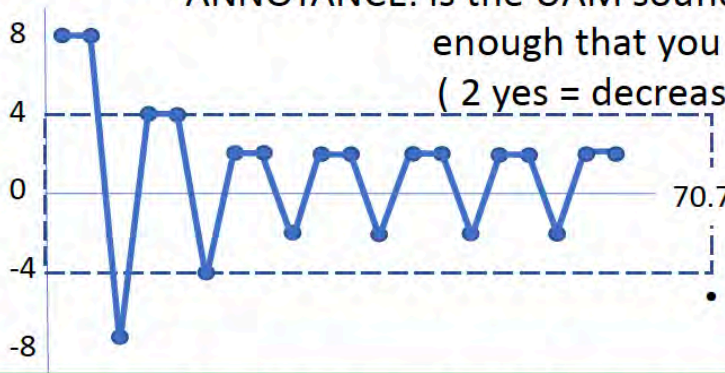
Source-Receiver Trajectory vs Time

MULTICHANNEL AMBIENT RECORDINGS



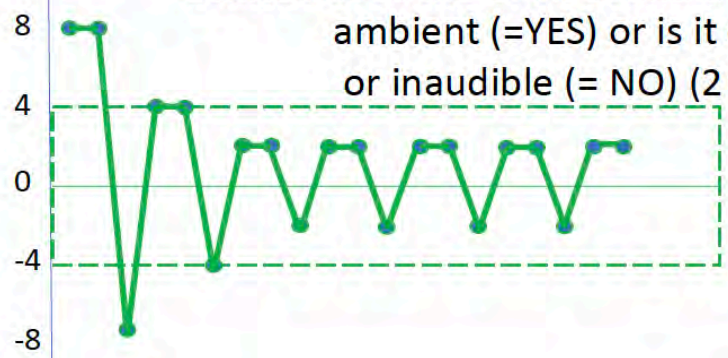
NASA LaRC NAF AURALIZATION OF CONCEPT EVTOL

ANNOYANCE: is the UAM sound annoying enough
enough that you would complain?
(2 yes = decrease)



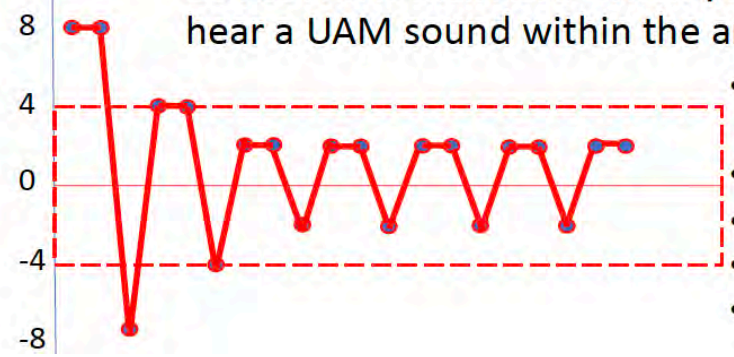
- 20+ signal (S+N) trial responses (“ideal subject”)

BLEND: does the UAM sound dominate the
ambient (=YES) or is it either about the same
or inaudible (= NO) (2 yes = decrease)



- 20+ signal (S+N) trial responses (“ideal subject”)

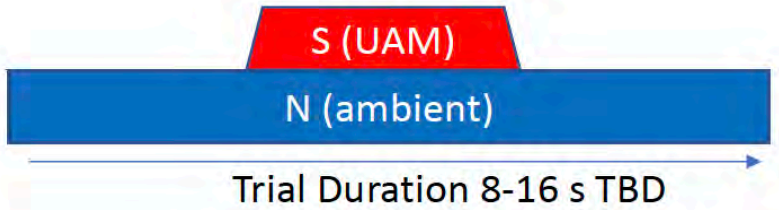
DETECTION: click ASAP when you clearly
hear a UAM sound within the ambient

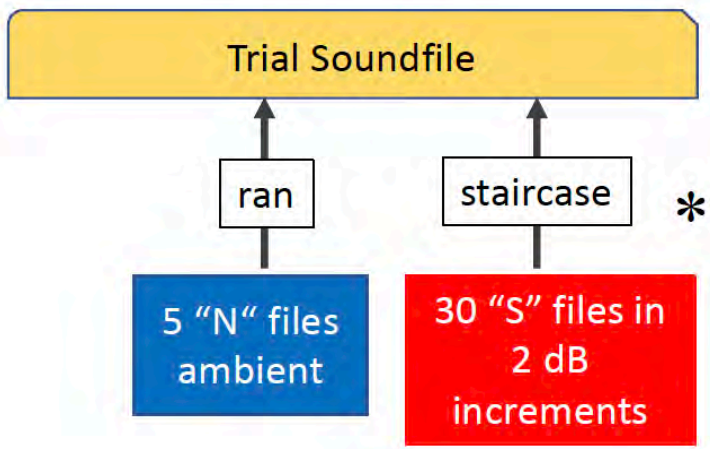


- 20+ signal (S+N) trial responses (“ideal subject”)
- random intermix with 20 noise (N) trials
- 2 yes =decrease
- FA count (no Correct Rejection count)
- Timing for HIT stimuli

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

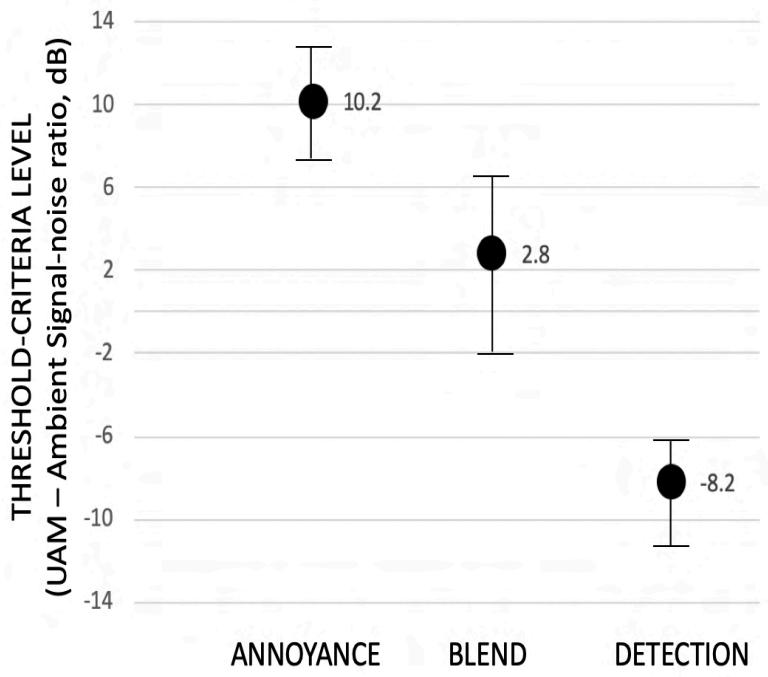
Signal Duration 50% trial duration



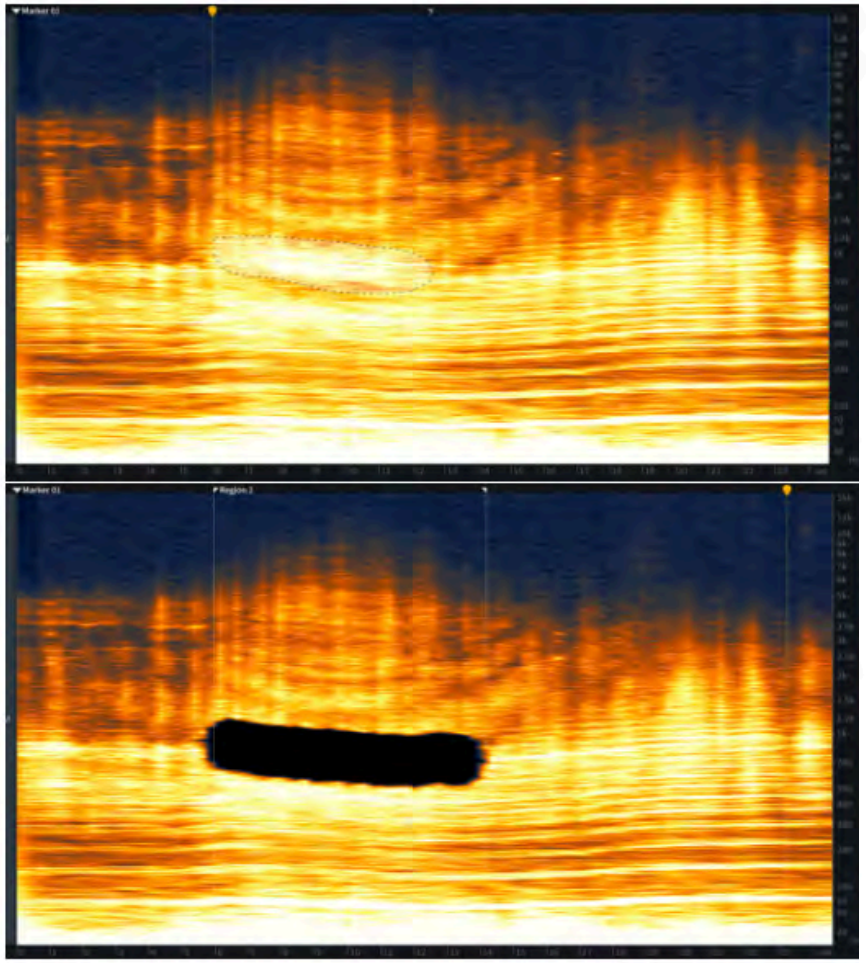


* Detection trials include N only

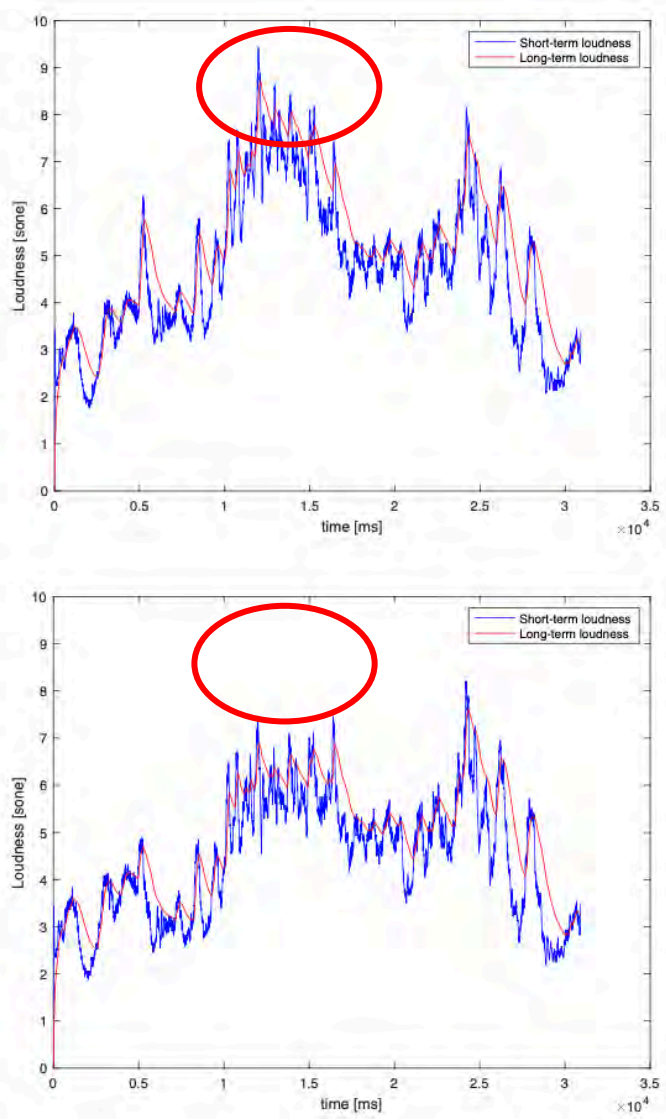
Judgments as a function of LEVEL (signal-noise ratio) (”informed routing”)



Judgments as a function of TONE ATTENUATION (“informed design”)



Difference in time varying loudness with significant tone attenuated



Psychoacoustic Measures for UAM Noise in the Context of Ambient Sound

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