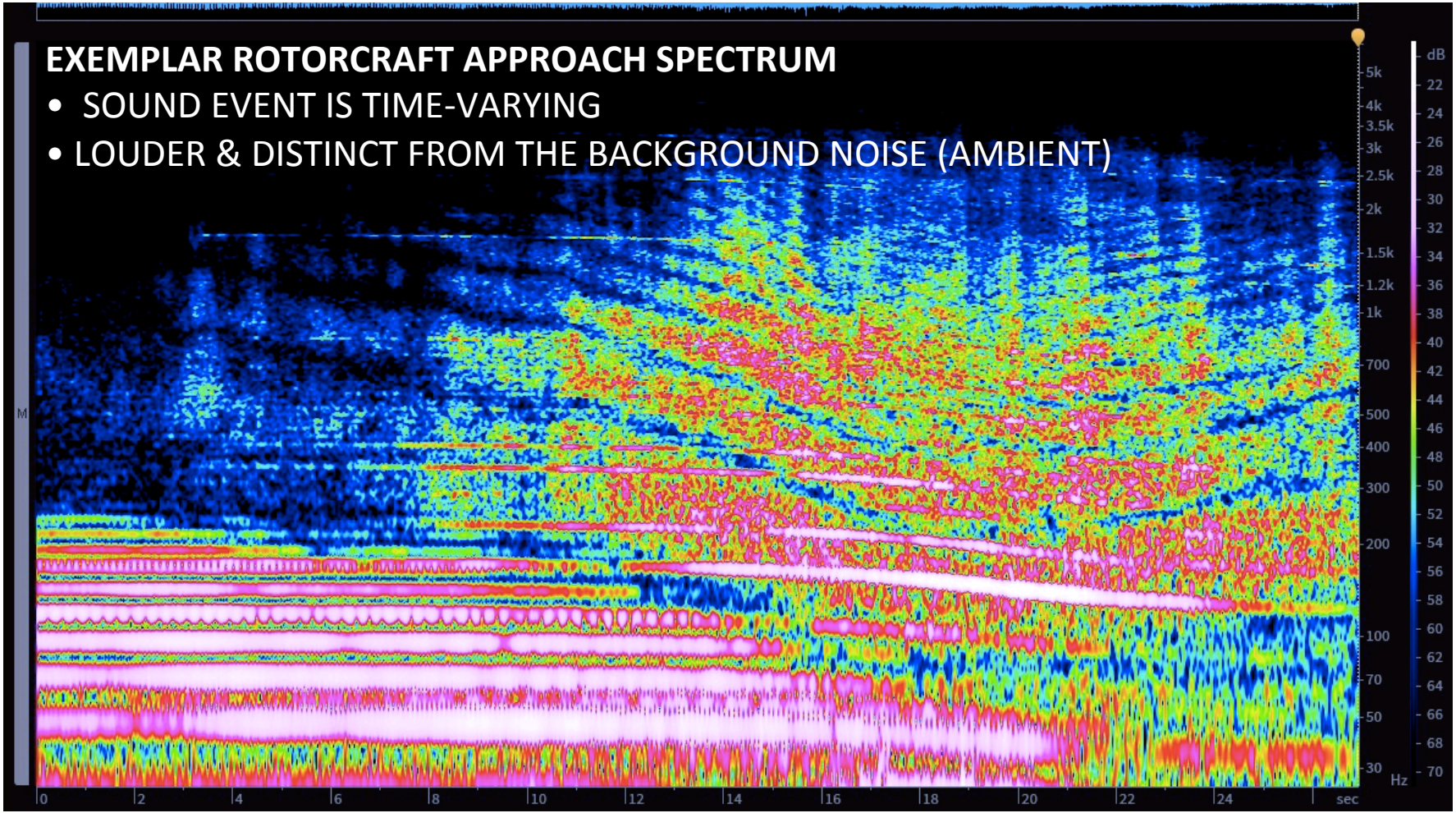
Overview of Metrics pertinent to Human Response to UAM Noise

Durand R. Begault PhD
durand.r.begault@nasa.gov

Advanced Controls & Displays Group
Human Systems Integration Research Division
NASA Ames Research Center
Moffett Field, California

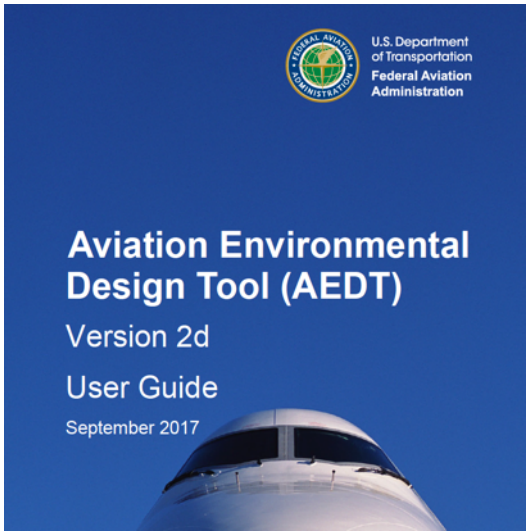
OUTLINE

- Noise dose metrics; DNL, CTL
- Statistical metrics; exemplar community noise ordinance
- Spectrum-based metrics
- Metrics based on event frequency
- Metrics based on partial loudness and detection


EXEMPLAR ROTORCRAFT APPROACH SPECTRUM
• SOUND EVENT IS TIME-VARYING
• LOUDER & DISTINCT FROM THE BACKGROUND NOISE (AMBIENT)
M
5k
4k
3.5k
3k
2.5k
2k
1.5k
1.2k
1k
700
500
400
300
200
100
70
50
30
Hz
dB
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
0
2
4
6
8
10
12
14
16
18
20
22
24
sec

AEDT ACOUSTIC PREDICTION METRICS

- Sound exposure level (dose-based)
- Average and Maximum levels
- Tone –corrected levels
- “Number above” levels (threshold-based)
- Time Audible (audibility above background)

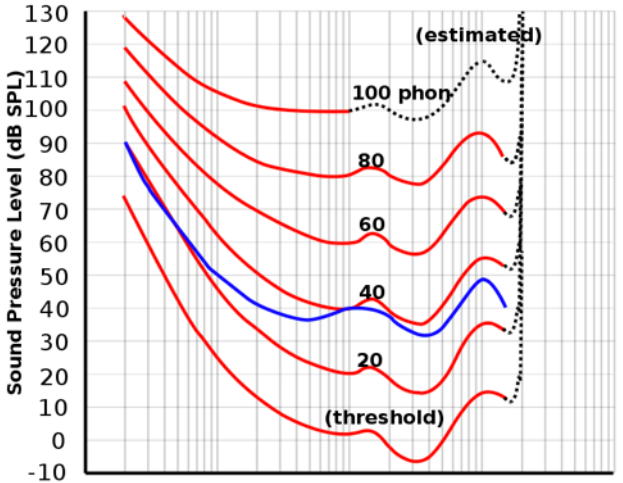


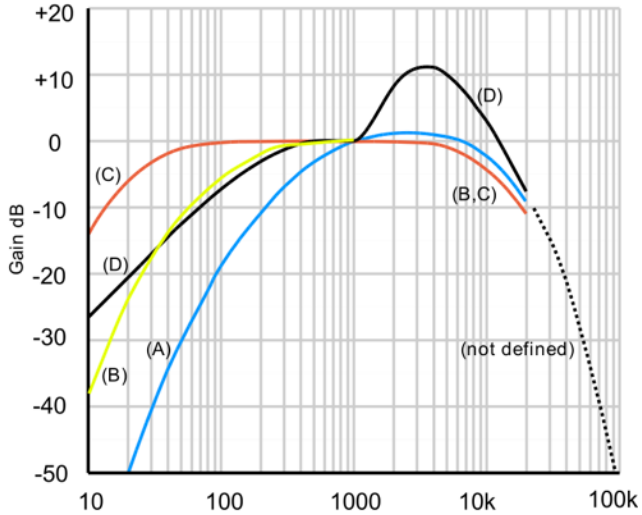
Metric Type	AEDT Name	Standard Name	Definition/Full Name
A-Weighted Noise Metrics			
Exposure	SEL	L_{AE}	A-Weighted Sound Exposure Level
	DNL	L_{dn}	Day Night Average Sound Level
	CNEL	L_{den}	Community Noise Equivalent Level
	LAEQ	L_{AeqT}	Equivalent Sound Level
	LAEQD	L_{d}	Day-average noise level
	LAEQN	L_{n}	Night-average noise level
Maximum Level	LAMAX	L_{ASmx}	A-Weighted Maximum Sound Level
Time-Above	TALA	TA_{LA}	Time-Above A-Weighted Level
Time-Audible	TAUD	T_{Aau}	Time-Audible
	TAUDSC	T_{AudSC}	Time-Audible with Overlapping Events Method (Statistical Compresion)
	TAUDP	T_{AudP}	Time-Audible Percent
	TAUDPSC	T_{AudPSC}	Time-Audible Percent with Overlapping Events Method (Statistical Compresion)
C-Weighted Noise Metrics			
Exposure	CEXP	L_{CE}	C-Weighted Sound Exposure Level
	CDNL	L_{Cdn}	C-Weighted Day Night Average Sound Level
Maximum Level	LCMAX	L_{CSmx}	C-Weighted Maximum Sound Level
Time-Above	TALC	TA_{LC}	Time-Above C-Weighted Level
Tone-Corrected Perceived Noise Metrics			
Exposure	EPNL	L_{EPN}	Effective Perceived Noise Level
	NEF	L_{NEL}	Noise Exposure Forecast
	WECPNL	L_{WECPN}	Weighted Equivalent Continuous Perceived Noise Level
Maximum Level	PNLTM	L_{PNTSmx}	Tone-Corrected Maximum Perceived Noise Level
Time-Above	TAPNL	TA_{PNL}	Time-Above Perceived Noise Level
Number Above Noise Level Metric			
Number Above Noise Level	NANL	NANL	Number Above Noise Level

Weightings applied to acoustical measurements

- **Time Weighting**
  - Instantaneous levels (“peak”)
  - Integration of sound energy over specific time period (125 ms “fast”; 1 s “slow”)

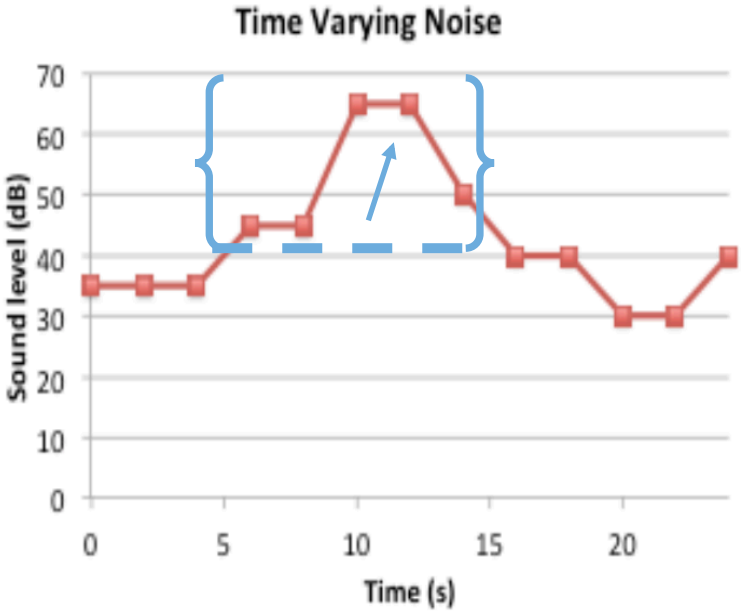
- **Frequency Weighting**
  - **A-weighting** (loudness as a function of frequency, at one sound level)
  - Unweighted (“Z” weighting)
  - ”C” weighting, “B”, “D”…….





Average, Statistical and Maximum Levels

- L_{eq}: equivalent continuous sound pressure level (average level over a period of time)
- L_{max}: maximum level
- L_{pk}: Peak sound pressure level
- L_{90}: Ninetieth Percentile Sound Level (L90) (level exceeded 90% of a time period)



Sound Exposure Level (SEL):
Normalization of sound energy to a constant time interval

- The sound energy within the duration of a **sound event** (e.g. a jet flyover) is normalized by integration to a **fixed duration**, e.g., 1 second.

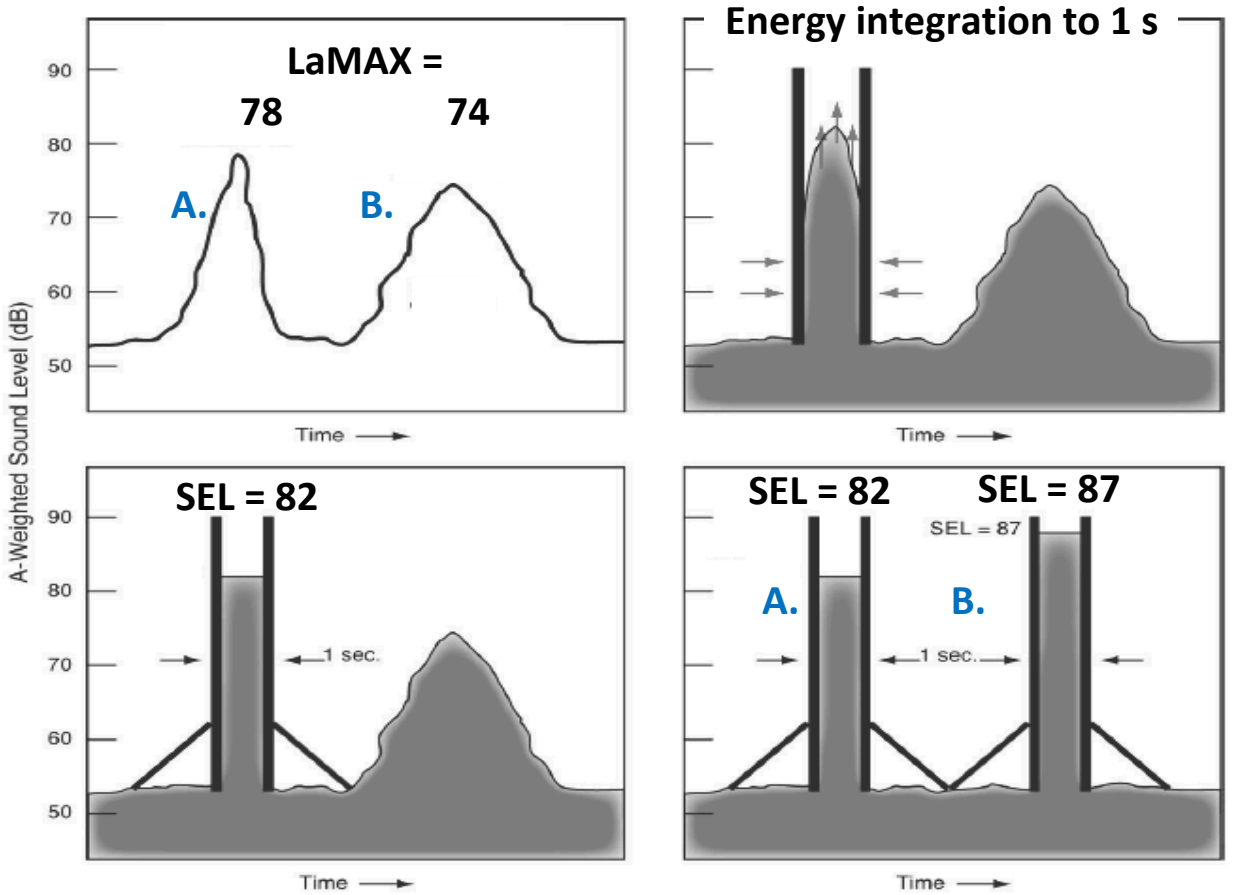
- The energy integration starts & ends re to a peak level (e.g., 10 dB a single aircraft flyover re the maximum level).

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

- **SEL** = Average A-weighted level (**LeqA**) + 10* log10(duration)

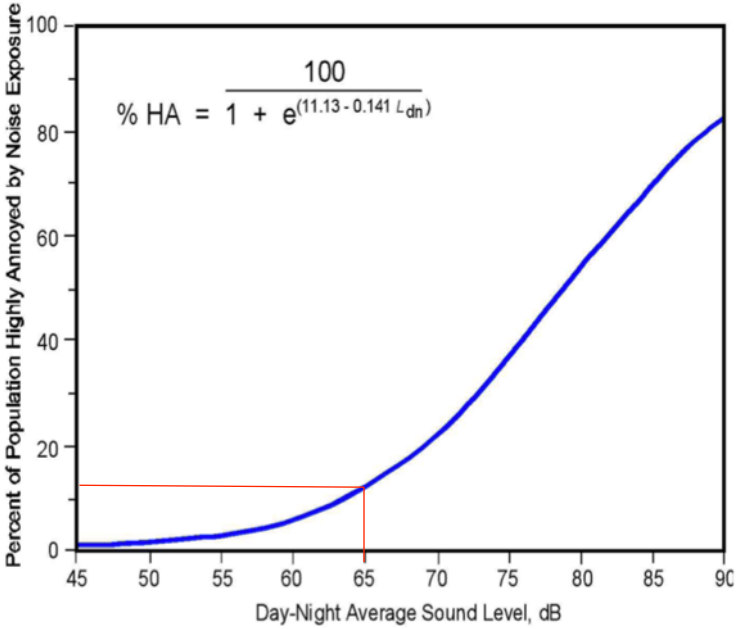
Two Sound Events (aircraft flyovers) A and B

- A has a higher maximum level than B
- But A has a lower SEL than B because its duration is shorter
- SEL calculates a normalization of total sound energy to a constant time interval

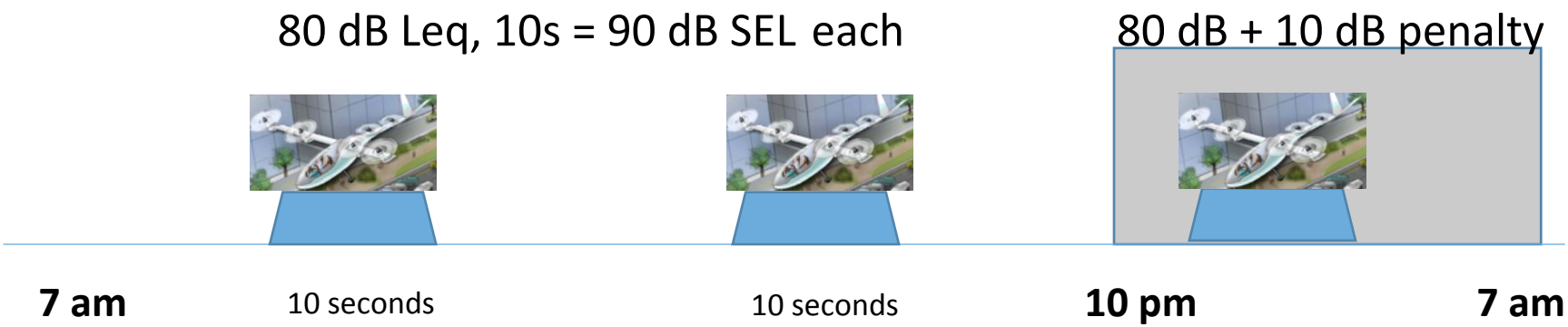


Metrics based on SOUND DOSE (SOUND EXPOSURE LEVEL: SEL)

- Used for hearing conservation (e.g., OSHA) – calculating permissible sound exposure to noise over a workday (“dosage-HL” relationship).
- A-weighted frequency typically applied
- Used for calculating the Day-Night Average Sound Level, or **DNL**, a community noise exposure metric.
- Percentage of persons highly annoyed (**%HA**) by aircraft sound can be calculated by a dosage-response relationship.



- **DNL metric (L_{dn}) sums energy across multiple SELs**
- **10 dB penalty for nighttime hours**
- **Effectively, a 24 hour noise dose**



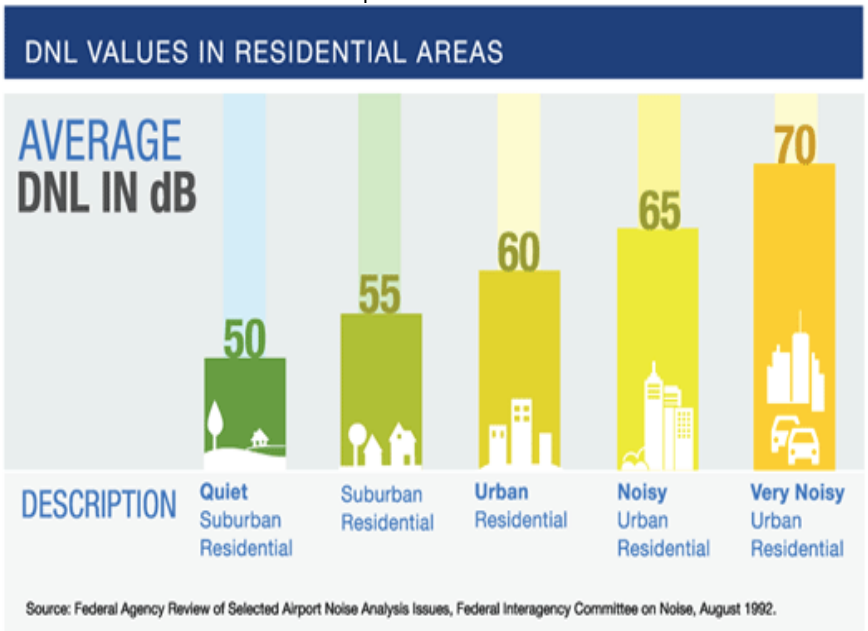
Example:

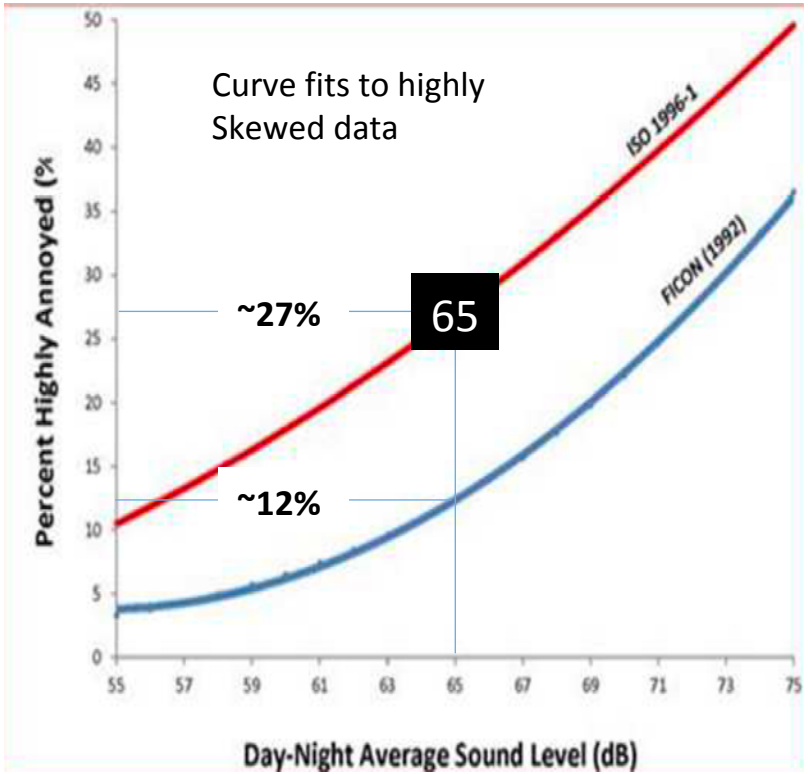
- **Two VTOL flyovers during the day, average level** (Leq) **80 dB**
- **One flyover at night = 10 daytime flyovers (due to 10 dB penalty)**
- **Duration of overflight = 10 s (90 dB SEL for daytime flights)**
- **Sound exposures summed and adjusted for a 24 hour period**
- **Resulting DNL = 51.4**

- **FAA criteria for significance: at least 1.5 dB above 65 DNL**
- **FICON (1992)** predicts **~12% highly annoyed @ 65 DNL**
- **ISO 1996.1 (2003)** predicts **~27% highly annoyed**

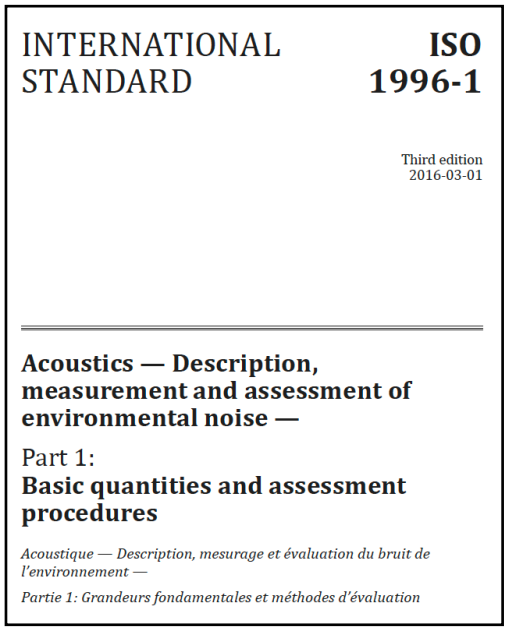
FEDERAL AGENCY REVIEW OF SELECTED AIRPORT NOISE ANALYSIS ISSUES

FEDERAL INTERAGENCY COMMITTEE ON NOISE





CTL (community tolerance level, L_{ct}) : ISO 1996-1



INTERNATIONAL STANDARD

ISO 1996-1

Third edition
2016-03-01

Acoustics — Description, measurement and assessment of environmental noise —

Part 1:
Basic quantities and assessment procedures

Acoustique — Description, mesurage et évaluation du bruit de l'environnement —

Partie 1: Grandeurs fondamentales et méthodes d'évaluation

- **L_{ct} = DNL** level at which 50 % of the people in a **particular community** are predicted to be highly annoyed (**%HA**) by noise exposure
- Calculates %HA and DNL for a **specific community** as opposed to hypothetical "average"
- The variation in sensitivity between different communities can be wide-ranging

EXEMPLAR URBAN RESIDENTIAL NOISE ORDINANCE (SAN FRANCISCO)

- The levels and metrics cited in community noise ordinances could affect expectations and sensitivity

EXEMPLAR URBAN RESIDENTIAL NOISE ORDINANCE (SAN FRANCISCO)

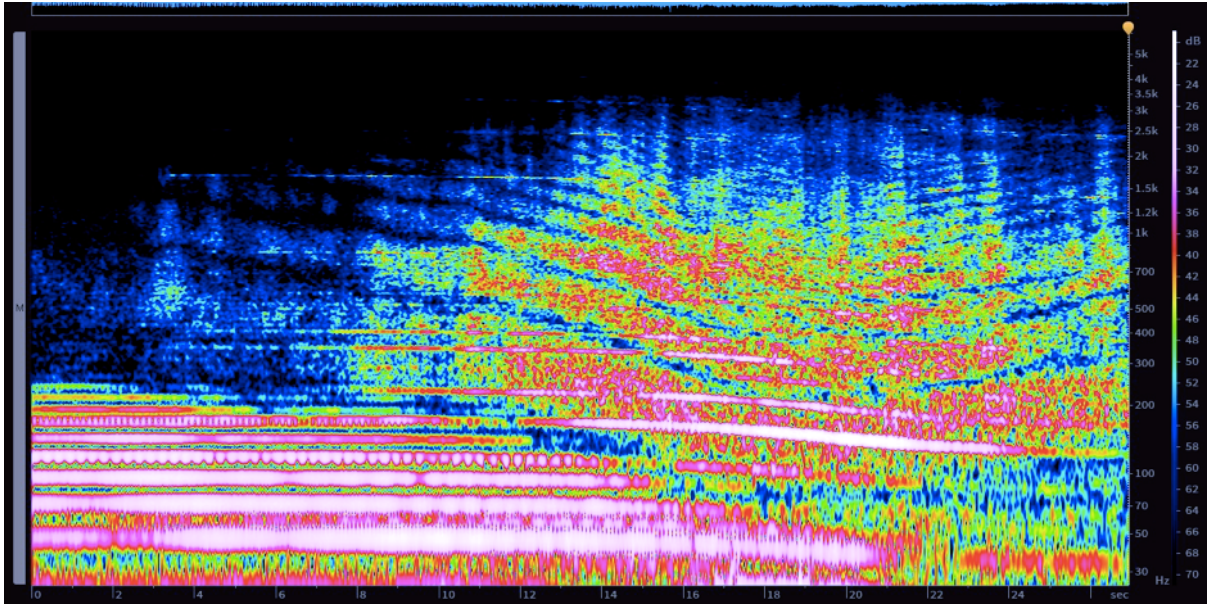
Maximum allowable interior noise :
45 dBA between 10:00 p.m. - 7:00 a.m.
55 dBA between 7:00 a.m. to 10:00p.m.
from a source outside of a dwelling….

Maximum allowable exterior noise :
5 dBA above the ambient at any point outside of the property plane...or three feet from any wall between dwellings (apartments, condos, etc.)

Article 29 of the Police Code **defines "Ambient"** as **the lowest sound level repeating itself during a minimum ten-minute period**…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…**the L90 (the level of noise exceeded 90% of the time) is a conservative representation of the ambient**…. In no case shall the ambient level be considered to be **less than 35 dBA for interior** residential measurements and **45 dBA** in all other locations.

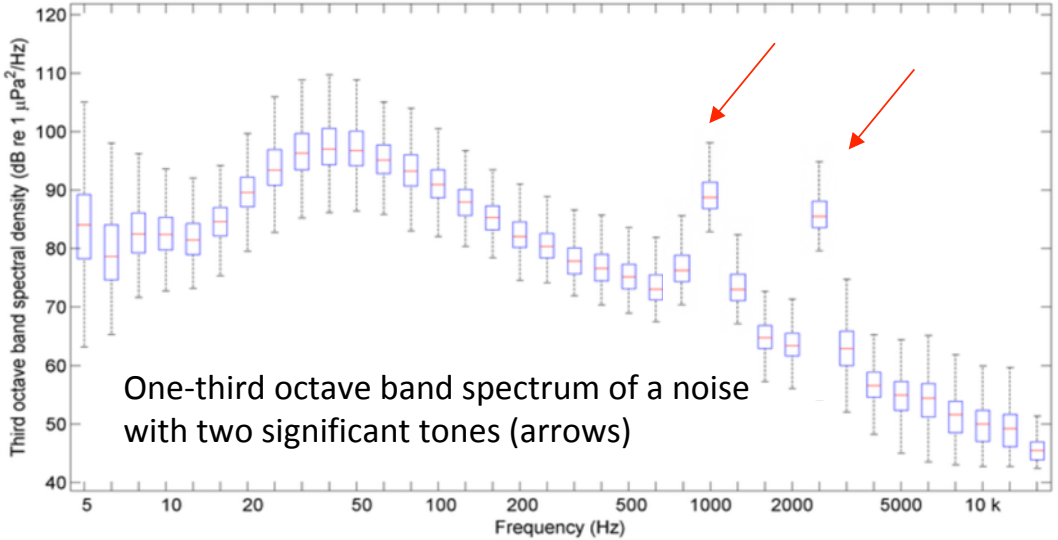
SPECTRUM BASED METRICS

consideration of level and frequency

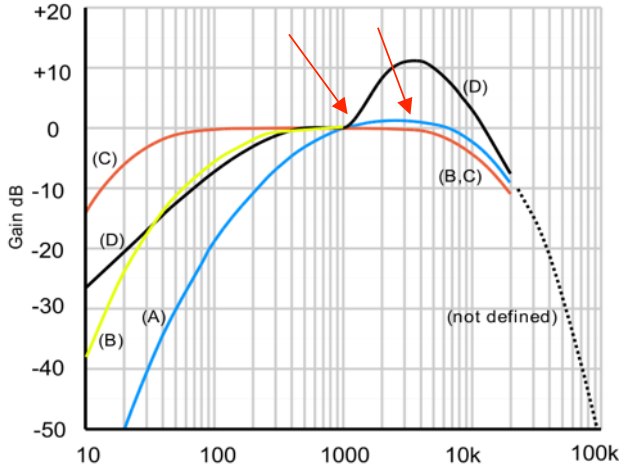


Tonal Correction metrics

- Applied in many community noise ordinances
- Accounts for the relative increase in noise loudness when individual tones are predominant within an overall spectrum
- Examples of sources: motors, blade passage frequency, electrical “buzz”
- The presence of tones can add 5-8 dB to measured sound source as a penalty (e.g., $\mathbf{L_{PNT}}$–Tone-corrected Perceived Noise Level- for aircraft certification).



One-third octave band spectrum of a noise with two significant tones (arrows)

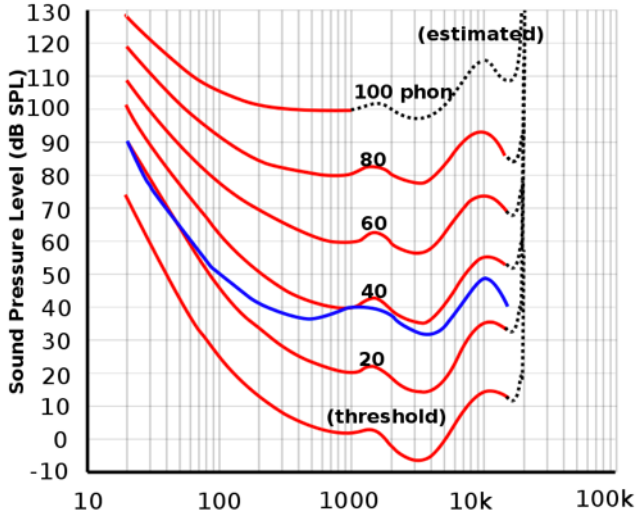


Loudness adjusted sound exposure level: LLSEL

- Described in annex to ANSI S12.9 part 4
- Use of ISO 226 equal loudness contours instead of A-weighting:
  based on level and frequency (but averages over time)
- Applies penalties for types of sound (characteristic, impulsiveness)
- Tonal penalties: 5 dB exceedance in adjacent 1/3 octave bands from
  500 Hz- 10 kHz, 8 dB for 160-400 Hz

AMERICAN NATIONAL STANDARD

QUANTITIES AND PROCEDURES FOR DESCRIPTION AND MEASUREMENT OF ENVIRONMENTAL SOUND— PART 4: NOISE ASSESSMENT AND PREDICTION OF LONG-TERM COMMUNITY RESPONSE



- **Metrics based on NUMBER OF EVENTS above a threshold**

Sky Posse Palo Alto

#4 THE CONCENTRATION OF ROUTES TO IMPACT THE SAME NEIGHBORHOODS REPEATEDLY IS UNFAIR

NextGen's precision routing technologies could in fact dramatically improve the situation to the benefit of both the flying and the residential public. When used unwisely, as they are now, they dramatically worsen it. It's misleading to call NextGen's "net noise reduction" policy noise reduction when it reduces the aviation noise for some by severely increasing it for others. This unfair distribution of the noise burden calls for alternate designs that consider the population on the ground.

Palo Alto online

TOWN SQUARE

POST A NEW TOPIC

209

Here is what happens when you actually measure airplane noise

Original post made by Peter Carpenter, Atherton, on Jun 25, 2015

- **CURRENT METRIC: 65 dB CNEL (BASED ON OBJECTIVE SOUND PRESSURE LEVEL IN COMMUNITY FOR CERTIFIED AIRCRAFT)**
- **DESPITE LARGE INCREASE IN COMPLAINTS FROM ATHERTON FROM NEXTGEN FLIGHT RE-ROUTING, CNEL AVERAGE MEASURED ~49 dB CNEL**
- **COMMUNITY ACCEPTANCE NOT SUCCESSFULLY PREDICTED BY CURRENT METRIC**

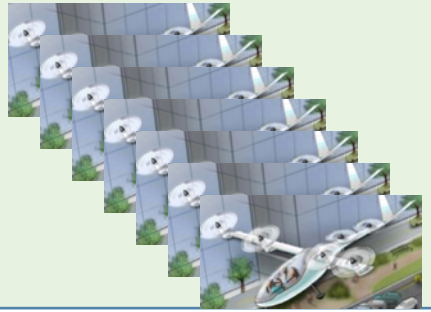
A single DNL value can result from different combinations of sound levels and event frequency

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

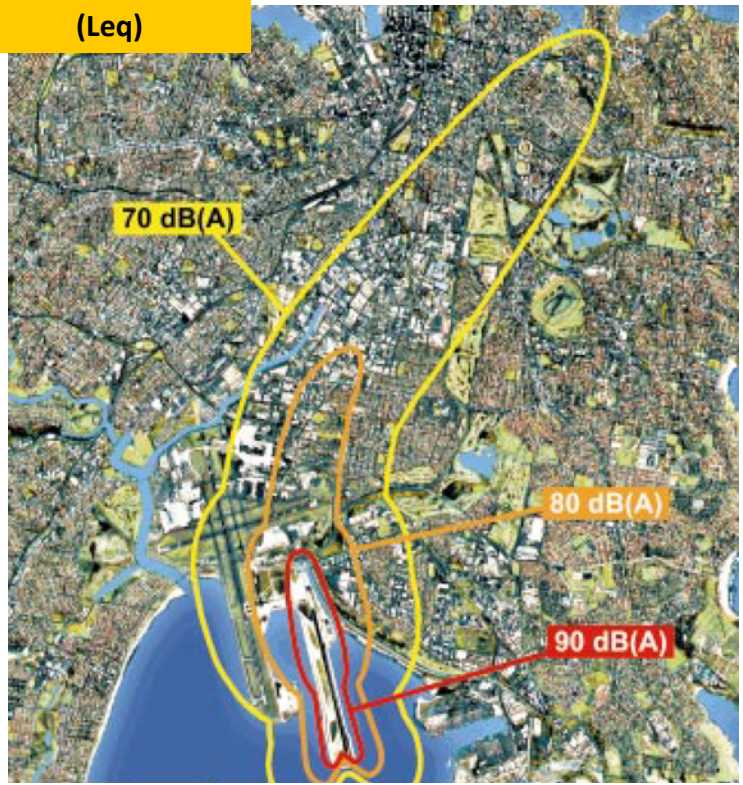
SEL = 104 dB
X 10 events



SEL = 94 dB
X 100 events

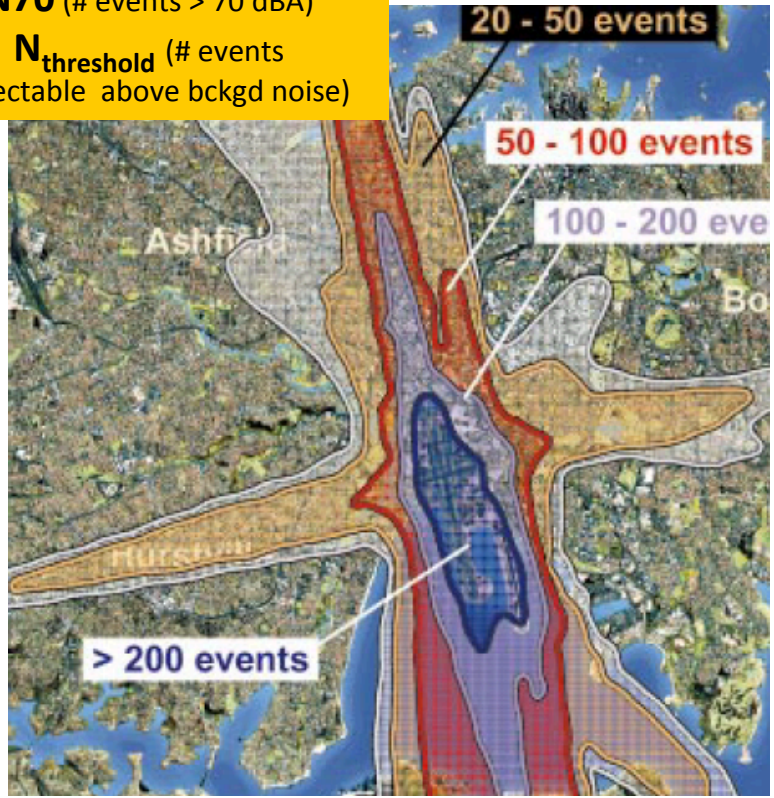
Event Frequency compared to Noise Contours

Noise contours (Leq)



N70 (# events > 70 dBA)

$N_{threshold}$ (# events detectable above bckgd noise)



Example event frequency metrics

- **TALA** time above A-weighted SEL
- **TALC** time above C-weighted SEL
- **TAPNL** time above PNL-weighted SEL
- **NANL** number above noise level
- Number of events above auditory threshold

- **Metrics based on DETECTION and TIME-VARYING PARTIAL LOUDNESS**

AFAPL-TR-71-37

NOISE DETECTABILITY PREDICTION METHOD FOR LOW TIP SPEED PROPELLERS

FRANK W. BARRY
BERNARD MAGLIOZZI
HAMILTON STANDARD

TECHNICAL REPORT AFAPL-TR- 71-37
JUNE 1971

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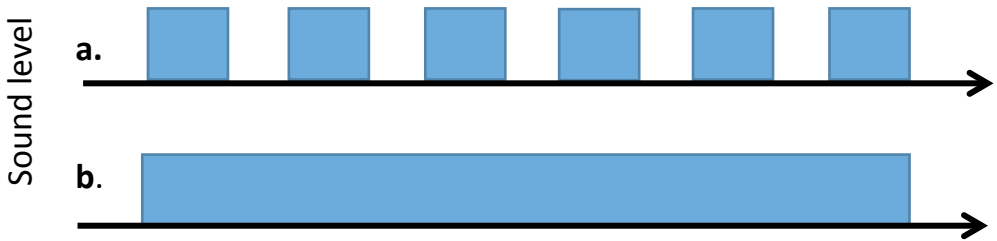
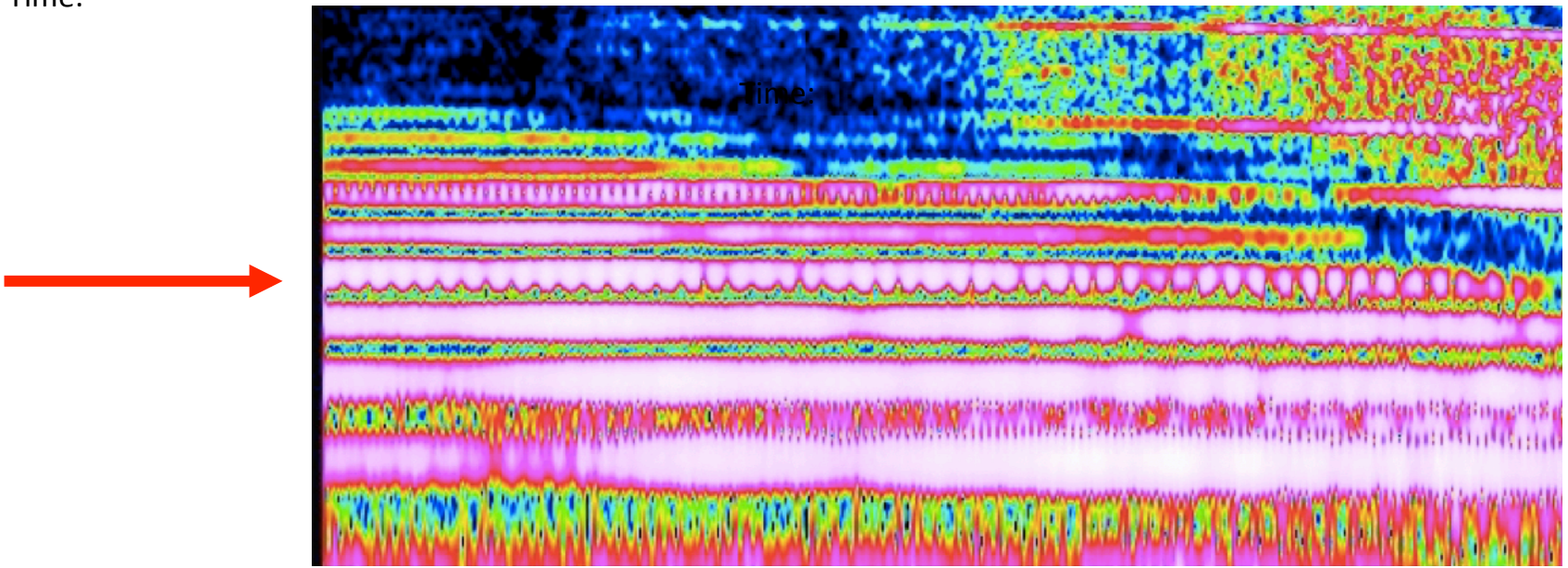
Loudness is affected by its variance over time (intermittency)



Given the same A-weighted level, intermittent sound is louder and more detectable

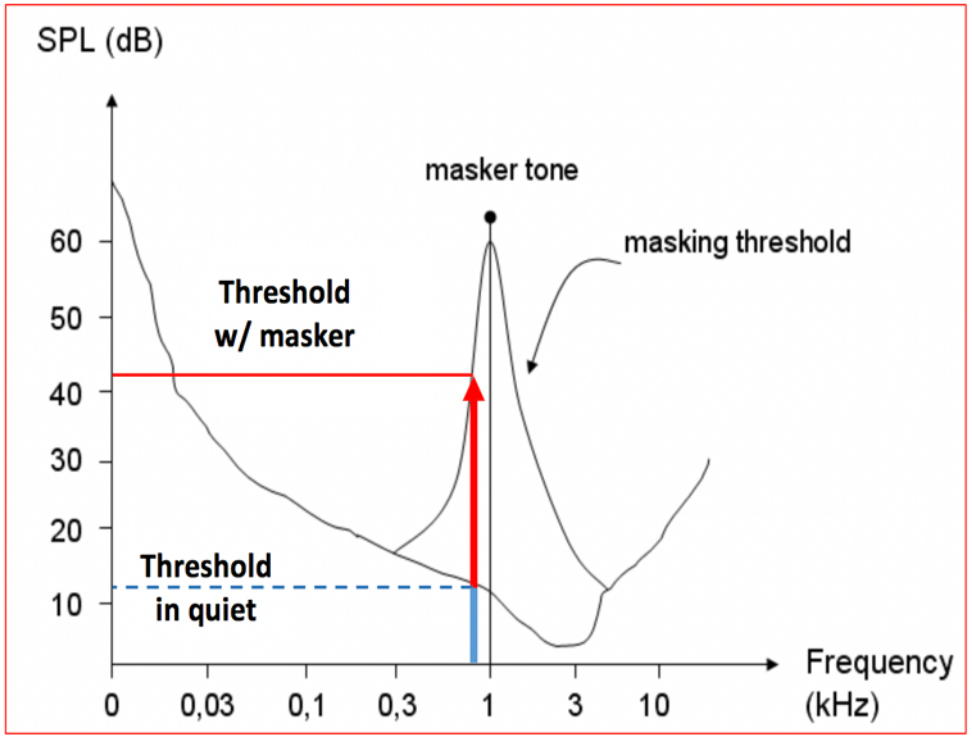


Loudness is affected by the phenomenon of masking: how one sound can affect the perception of another sound

Two tones that are close in frequency can interact such that a quieter tone is made inaudible. This is termed the "masking threshold"

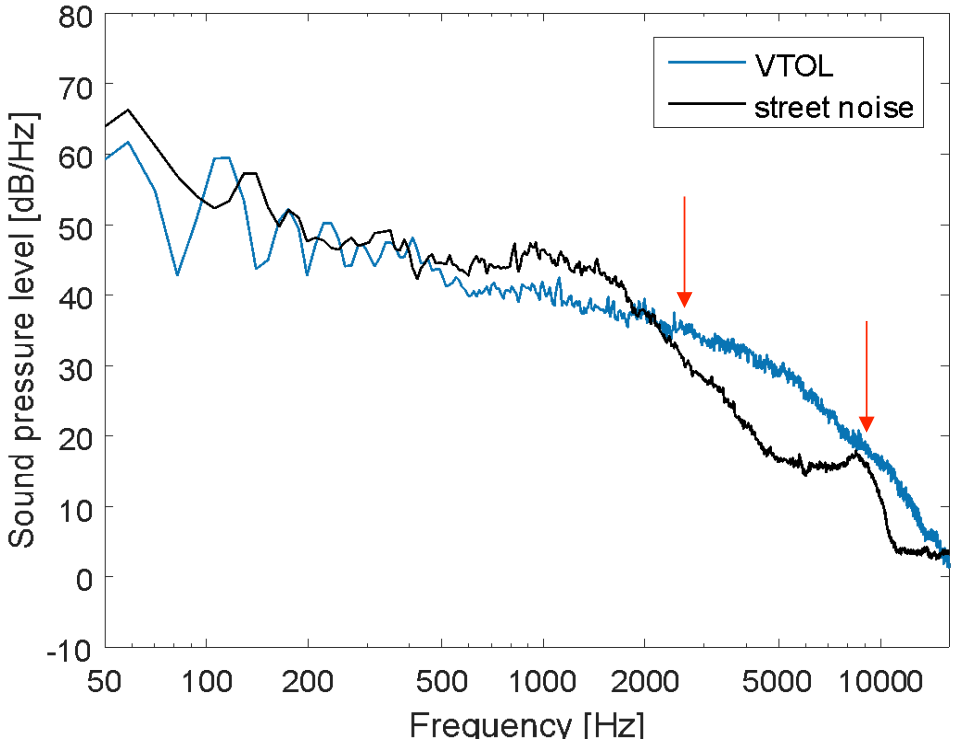
This figure shows a masking tone at 1000 Hertz with a **second tone** (blue-red arrow) slightly lower in frequency

The second tone in quiet is audible at the blue level (10 dB).
With the masking tone present,
Its level must be at the red level (42 dB) to be audible



Partial loudness: Loudness of a VTOL in the presence of another sound

- Red arrows indicate frequencies that would be audible (not masked)



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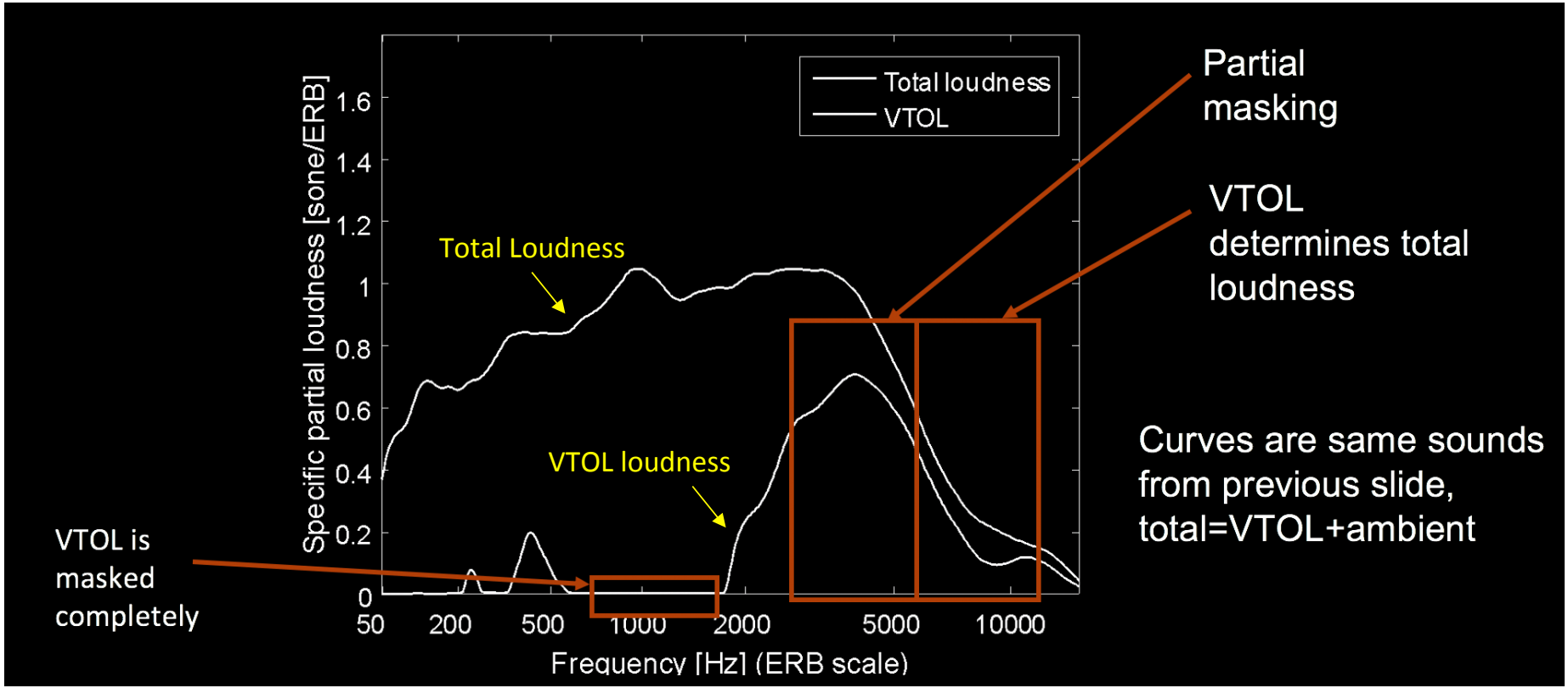
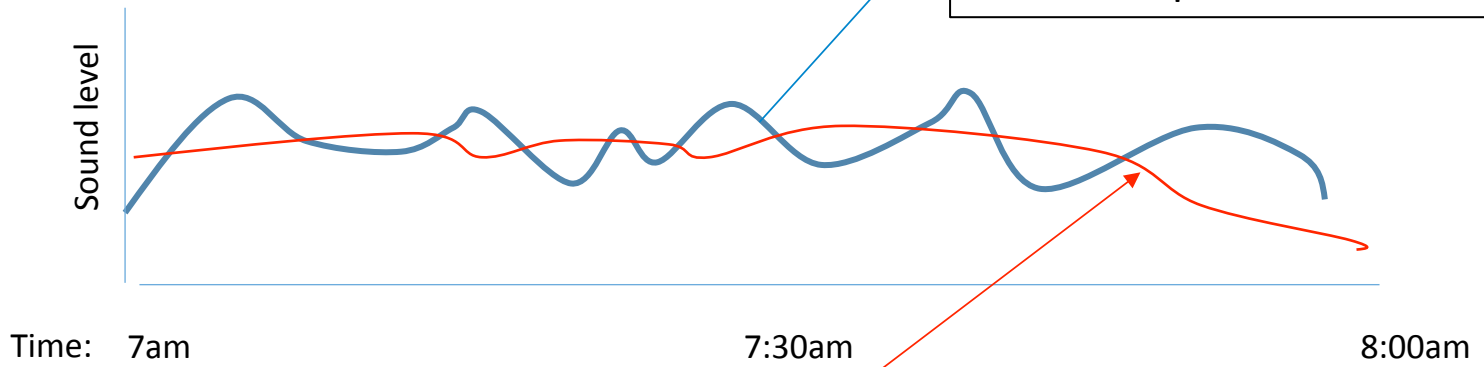


Time-varying partial loudness approach (future ISO 532.3, 532.4)

1. Characterize background noise in terms of standardized time-varying loudness spectra



2. Determine the time-varying partial loudness of a VTOL to determine its **level of detection** for that hour

Overview of Metrics pertinent to Human Response to UAM Noise

Durand R. Begault PhD
durand.r.begault@nasa.gov

Advanced Controls & Displays Group
Human Systems Integration Research Division
NASA Ames Research Center
Moffett Field, California