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IMPACT ASSESSMENT OF AIRCRAFT NOISE WITH HIGH CONTENT IN COMPLEX TONES

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Future Aircraft Design and Noise Impact

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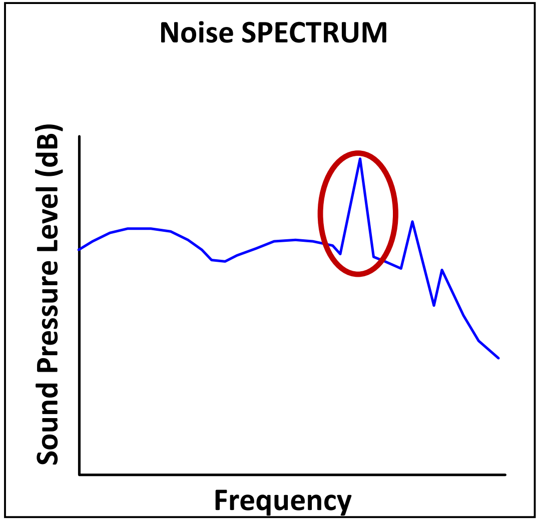
Effective Perceived Noise Level

- Effective Perceived Noise Level (EPNL) is the metric used to assess noise emissions from aircraft for regulatory purposes.

- EPNL:
    - Perceived Noise Level (PNL),
    - duration effects, and
    - tonal penalty based on the level of the strongest protruding tone.



Effective Perceived Noise Level

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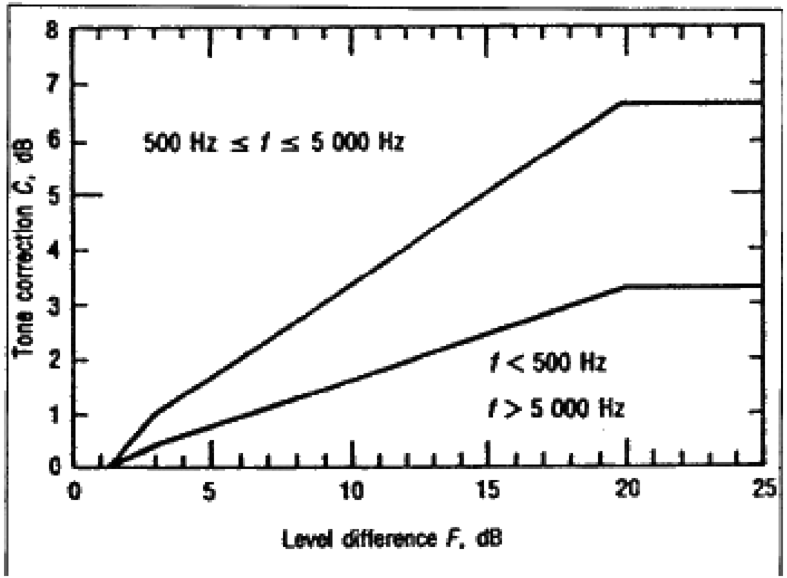
- EPNL Tone Correction:
  - position of the tone within the frequency spectrum
  - excess sound-level over adjacent third-octave frequency bands.



Level-difference (F) is transformed into a tonal correction factor (C) depending on the third-octave frequency band.

Effective Perceived Noise Level

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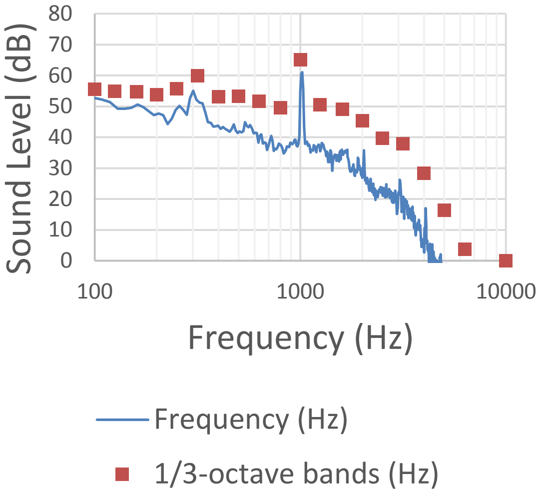
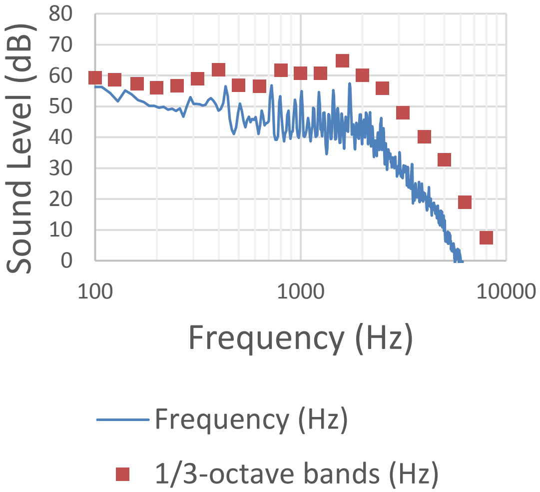
- Found to be reasonably effective for assessing aircraft noise annoyance (with presence of a single significant tone).
- Not able to account for the perceptual effect of complex tones.
  - 1/3-octave banding for tone detection.
  - Solely focused on strongest protruding tone.





Aures Tonality

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- Since introduction of EPNL more sophisticated tonality methods are available, e.g. Tonal Audibility (ISO 1996-2 C), DIN 45681, Aures Tonality.
- Aures Tonality:
    - Narrow-band FFT analysis
    - not limited to the maximum tonal emergence (takes into account presence of multiple tones)
    - applies weighting functions based on the bandwidth, centre frequency and prominence of each tonal component
    - also, accounts for the overall loudness of tone to noise ratio.

Objective

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⇨ This research investigates whether a more sophisticated tonality method such as Aures Tonality can improve the assessment of human response in relation to tonal content of contemporary aircraft.

Methodology: Stimuli

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- Sound recordings made during take-off at 900m from the end of the south runway of Heathrow airport (operating under westerly conditions).
- Six variants of aircraft engines (with significant differences in the tonal content) used for the analysis.
- Engine variants representative of
  - smaller aircraft: A320 (CEO and NEO) / 737 (800 and MAX)
  - larger aircraft: 757 / 767 / 777 / 787 (Dreamliner).

Methodology: Preference Rating

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- 35 participants were asked to rank by order of preference a series of test sounds.

- 2 reference samples used to obtain a subjective rating scale (Preference Rating).
- Preference Rating was assigned on the basis of equal spacing using an arbitrary magnitude of the reference samples.

Sample Order	Assigned Magnitude
Reference 1	60.0
Sample A	56.0
Sample B	52.0
Sample C	48.0
Sample D	44.0
Reference 2	40.0
Magnitude Range	100%

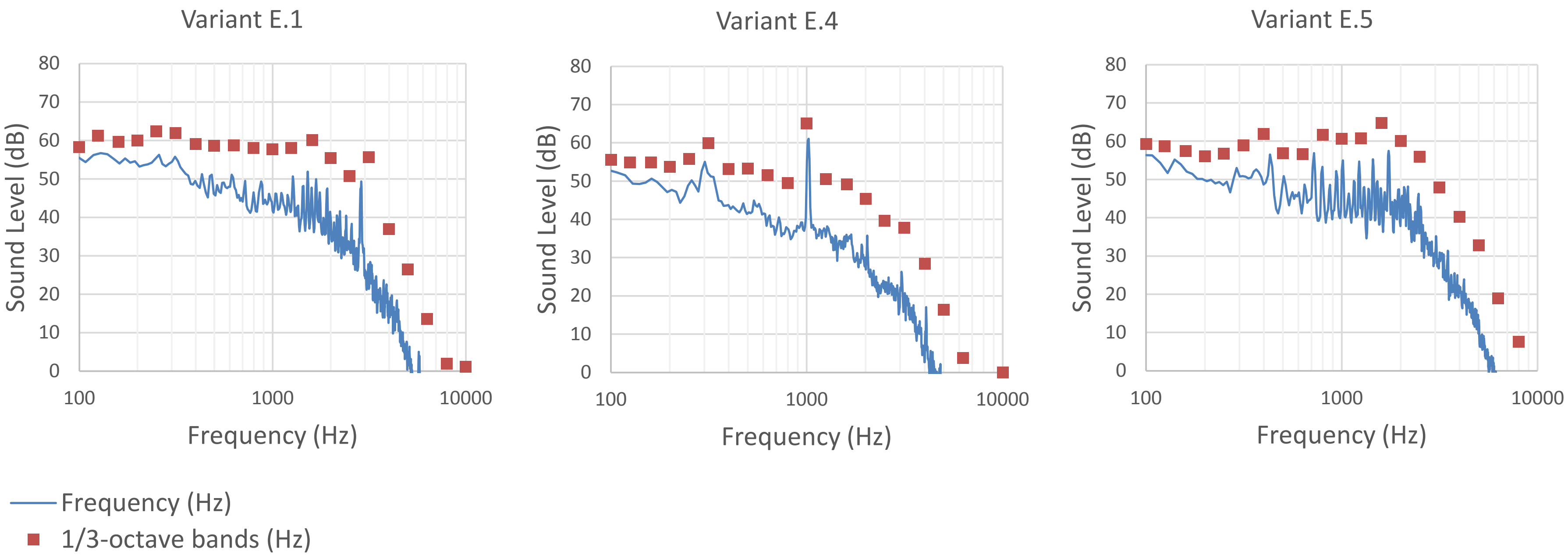
Sample Order	Assigned Magnitude
Sample A	65.0
Reference 1	60.0
Sample B	55.0
Sample C	50.0
Sample D	45.0
Reference 2	40.0
Magnitude Range	125%

Sample Order	Assigned Magnitude
Sample A	66.7
Reference 1	60.0
Sample B	53.3
Sample C	46.7
Reference 2	40.0
Sample D	33.3
Magnitude Range	167%

Sample Order	Assigned Magnitude
Sample A	70
Reference 1	60
Sample B	50
Reference 2	40
Sample C	30
Sample D	20
Magnitude Range	250%

Sample Order	Assigned Magnitude
Sample A	100
Sample B	80
Reference 1	60
Reference 2	40
Sample C	20
Sample D	0
Magnitude Range	500%

Results


Variant E.1
Variant E.4
Variant E.5
Sound Level (dB)
Frequency (Hz)
0
10
20
30
40
50
60
70
80
100
1000
10000
Frequency (Hz)
1/3-octave bands (Hz)

Results

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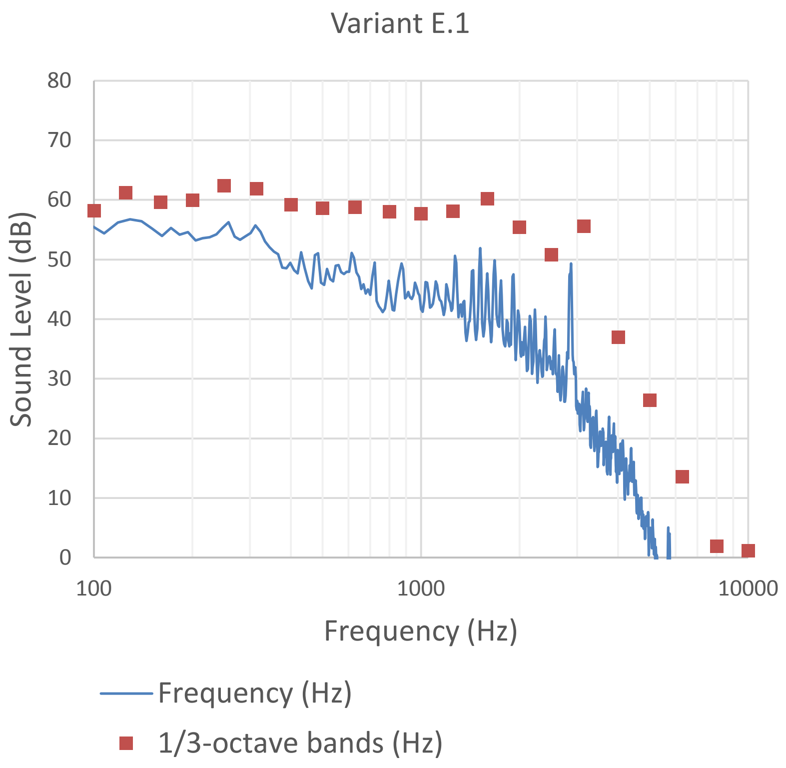
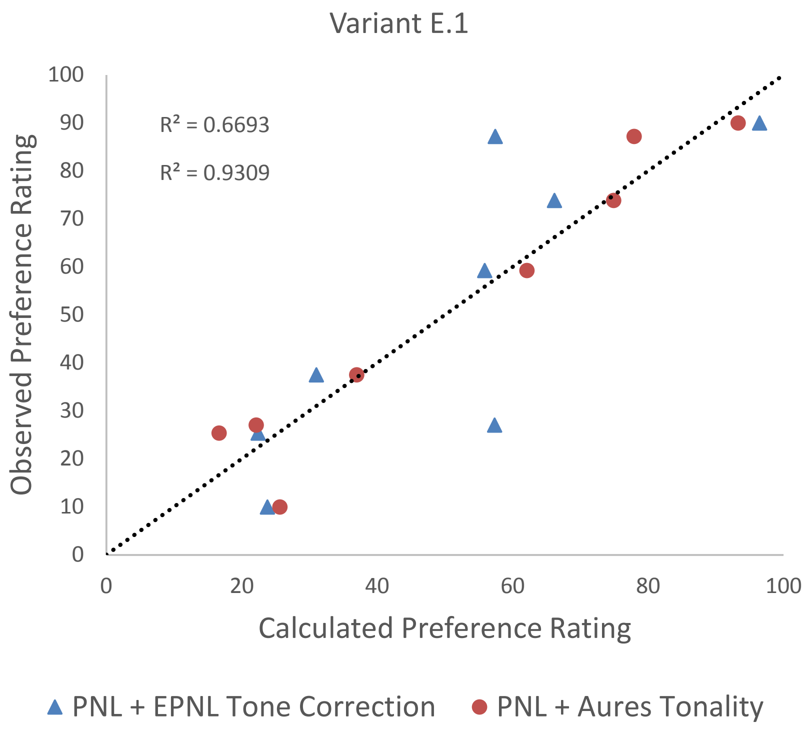
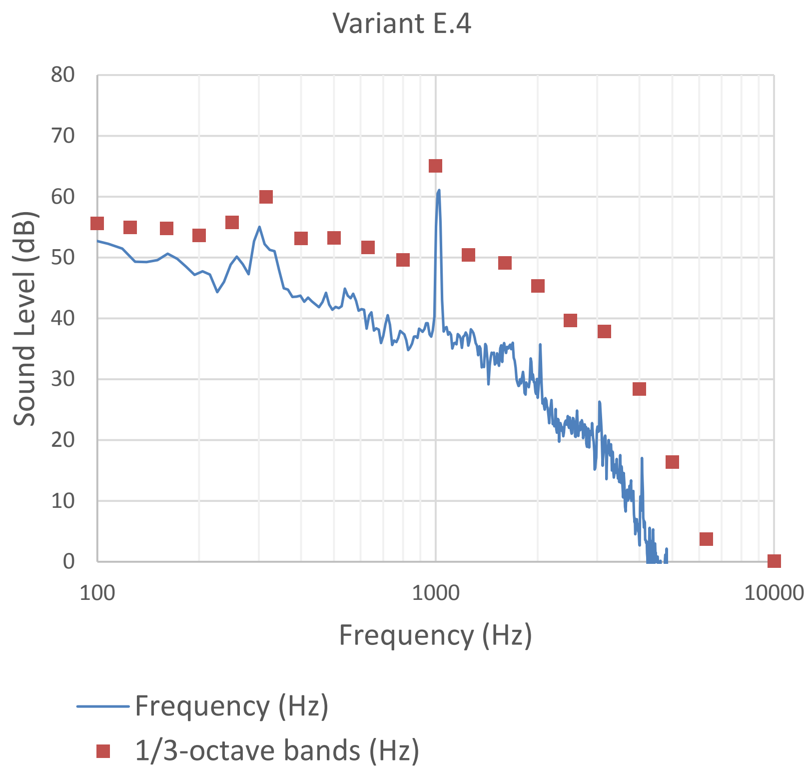
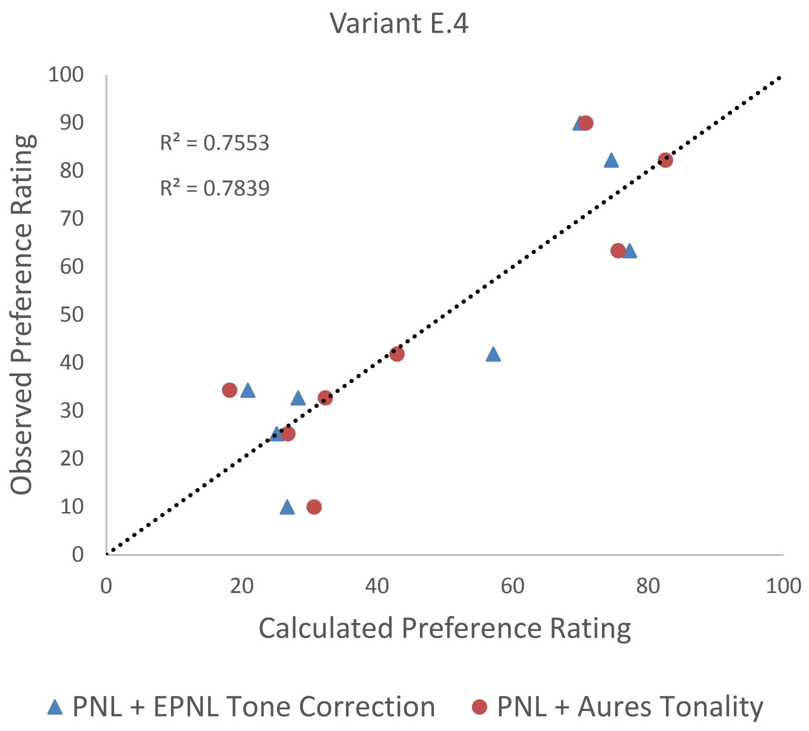




Results

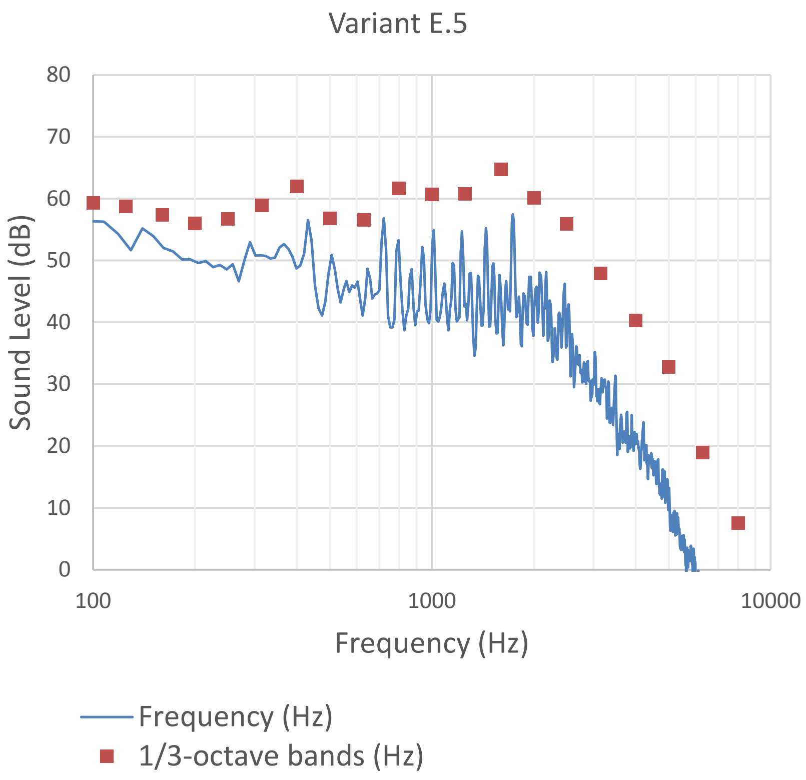


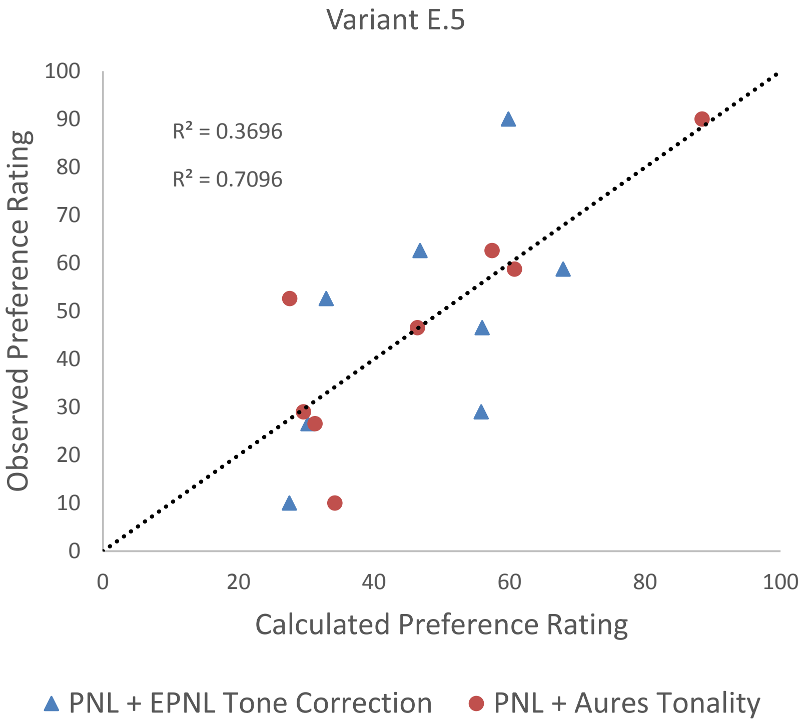
Variant E.4
Sound Level (dB)
80
70
60
50
40
30
20
10
0
100
1000
10000
Frequency (Hz)
Frequency (Hz)
1/3-octave bands (Hz)



Variant E.4
Observed Preference Rating
100
90
80
70
60
50
40
30
20
10
0
R² = 0.7553
R² = 0.7839
0
20
40
60
80
100
Calculated Preference Rating
PNL + EPNL Tone Correction
PNL + Aures Tonality

Results


Variant E.5
80
70
60
50
40
30
20
10
0
100
1000
10000
Sound Level (dB)
Frequency (Hz)
Frequency (Hz)
1/3-octave bands (Hz)


Variant E.5
R² = 0.3696
R² = 0.7096
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
Observed Preference Rating
Calculated Preference Rating
PNL + EPNL Tone Correction
PNL + Aures Tonality

Discussion & Further Work

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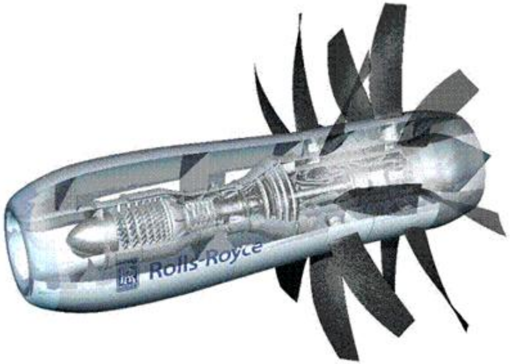
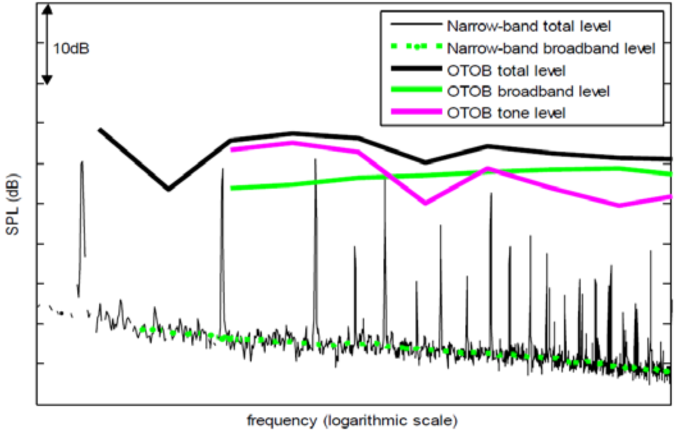
- Aures Tonality is able to account for perceptual effect of tonal content of tested sounds, but still some limitations are observed:
  - Aircraft sounds that contains series of complex tones spaced evenly across the frequency spectrum with relatively even sound-levels.
- Possible improvements:
  - Interaction between complex tones.
    - Auditory Roughness.
  - Perceived pitch of complex tones.
    - Terhardt's Virtual Pitch Theory.
  - 'High pitch' sound.
    - Total Energy of Tonal Components in the high critical bands.

Discussion & Further Work



Courtesy of Rolls-Royce plc - Advanced open rotor concept



Source: Kingan (2014)

Courtesy of NASA - Sceptor project

Annoyance model for DEP using Loudness, Roughness and Aures Tonality as predictors (Rizzi et al., 2017)

Discussion & Further Work

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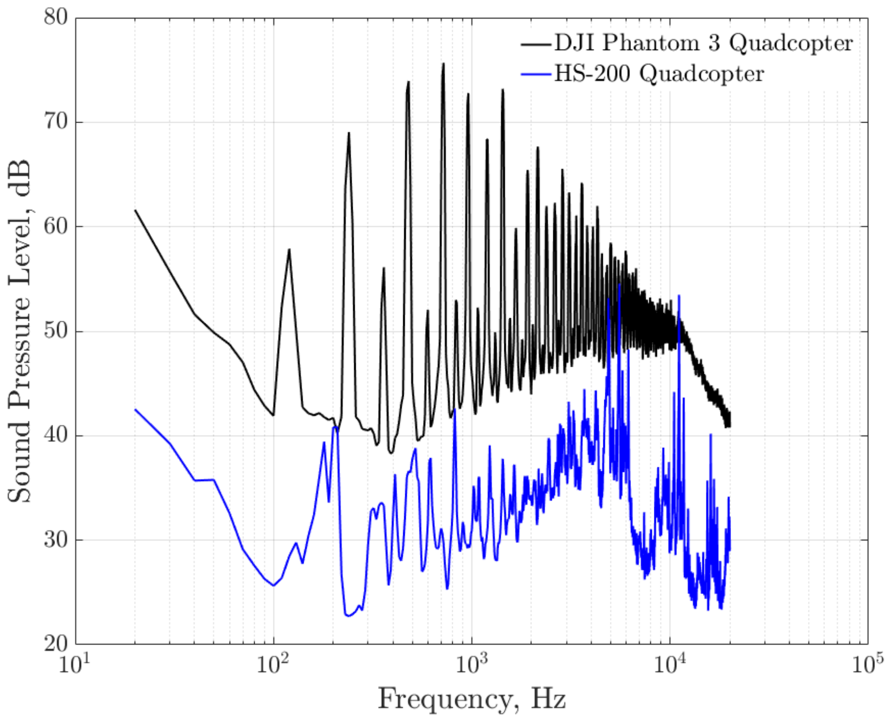
- Small-size quadcopters (DJI Phantom and HS-200): Multiple complex tones distributed across the whole spectrum (significant content in high frequency).
- Drone noise certification: More sophisticated tonality methods needed.



Conclusions

1. EPNL Tone Correction: reliable metric with a single physically dominant tone.
2. Aures Tonality improves on the EPNL Tone Correction assessing the subjective response to the tonal content of contemporary aircraft noise.
3. Aures Tonality is able to account for the perceptual effect of complex tonal content in aircraft noise,

   but, some limitations and potential improvements are discussed.
4. The research presented can contribute to the development of novel noise metrics for assessing subjective response to novel aircraft designs (e.g. CROR and DEP) and drones.

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Thank you very much for your attention

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