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Methodology for designing aircraft having optimal sound signatures

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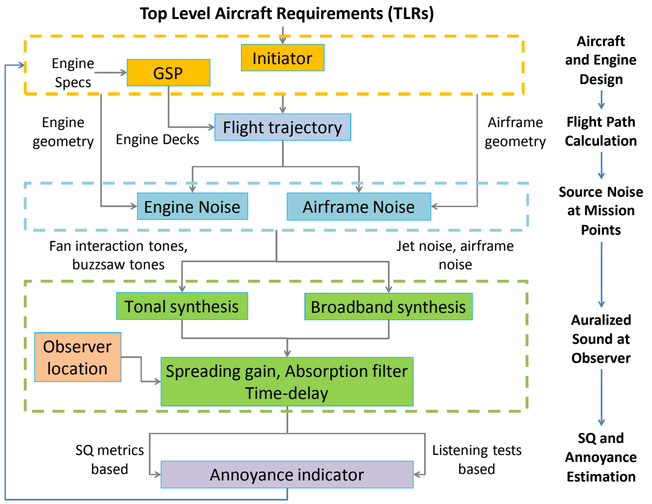
Background and Objective

- Research into aircraft noise has resulted in aircraft that have become quieter over the years, but the resistance and complaints against aircraft noise have not decreased.
- This is partly due to aircraft flying more frequently worldwide, but also partly because with the current aircraft configurations and engines being used, a limit exists towards how quiet aircraft can ultimately become.
- A sound does not necessarily have to be quieter for it to be judged less annoying, as shown by research from other industries [1], although loudness remains the most dominant factor affecting perceived aircraft noise annoyance . Other sound quality (SQ) based factors such as the strength of tonal content or tonality [2] and fast changes in noise intensity over time can also play a major role on annoyance perception.
- The goal here is to focus on the sound aircraft produce during the design stage and influence the perception of the sound towards lower annoyance, by modifying the aircraft’s design. This involves integration of a novel aircraft design-auralization-audio assessment chain.

Methodology

- The methodology used to design, auralize and assess aircraft for sound quality and annoyance is shown in Fig. 1. It can be seen that several tools need to be linked in order to produce aircraft sounds and modify them towards optimal signatures. The process begins with aircraft and engine design, done using the Initiator aircraft design software of TU Delft and with the Gas Turbine Simulation (GSP) program of Dutch NLR.
- The aircraft noise is then simulated using parametric models and auralized using signal processing techniques of additive synthesis for tonal noise and white noise based overlap-add technique for broadband noise. The resulting sound at the observer is then assessed in SQ and overall annoyance metrics [3] or rated through listening test results.



Top Level Aircraft Requirements (TLRs)

Initiator

Engine Specs

GSP

Engine geometry

Engine Decks

Flight trajectory

Airframe geometry

Engine Noise

Airframe Noise

Fan interaction tones, buzzsaw tones

Jet noise, airframe noise

Tonal synthesis

Broadband synthesis

Observer location

Spreading gain, Absorption filter
Time-delay

SQ metrics based

Listening tests based

Annoyance indicator

Aircraft and Engine Design

Flight Path Calculation

Source Noise at Mission Points

Auralized Sound at Observer

SQ and Annoyance Estimation

Figure 1: Methodology for aircraft design for optimal sound signatures

Results and discussion

- The novel toolchain has been applied to the design and SQ analysis of several conventional aircraft such as the Airbus A320, A330 and Boeing 747. The sound has been auralized for both departure and approach procedures, at representative observer locations near airports.
- Although each aircraft has a distinct spectral and temporal sound signature, individual SQ characteristics can be identified that dominate the annoyance perception for each aircraft. Table 1 shows the SQ and predicted modified Psychoacoustic Annoyance (PA_{mod}) metric as proposed by More et al [4]. It can be see that the B747 during departure is clearly louder than the A330 during approach. It also has an overall lower tonality due to more broadband noise surrounding the fan tones than the A330 during approach, as well as a rougher sound, due to strong buzzsaw noise produced during departure.

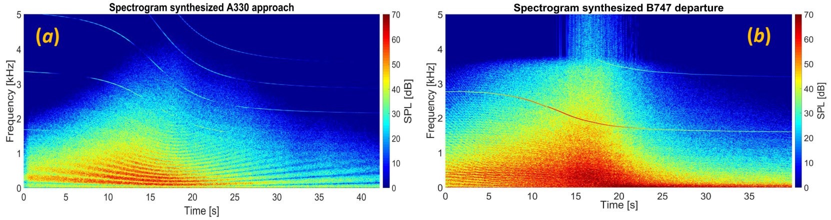


Figure 2: Synthesized spectrograms for an A330 approach (a) and B747 departure (b)

Table 1: Comparison of reference and low tonality aircraft variant sounds in sound quality metrics

Aircraft	Loudness [sone]	Tonality [-]	Roughness [asper]	Sharpness [acum]	PA_{mod} [-]
A330 approach	23.8	0.237	1.83	0.961	50.8
B747 departure	47.9	0.194	2.66	0.952	99.0

- Fig. 2 shows the spectrograms of the synthesized sound produced by both aircraft, for which the SQ metric as well as PA_{mod} values are shown in Table 1. The B747 during takeoff will thus be judged more annoying than the A330 during approach. Reducing the loudness would result in the most significant reduction of annoyance, followed by roughness for the B747. For the A330 during approach, the tonality is the strongest characteristic and would require the fan tonal noise to be reduced or the broadband noise surrounding the tones to be increased. Increasing low frequency airframe or broadband jet noise may also reduce the tonality due to increased masking effects from low frequency noise on higher frequency fan noise.
- Trends seen from previous studies by the authors [5] show that larger engines are relatively quieter but more tonal. They are also more likely to produce lower buzzsaw noise and hence have lower roughness values.

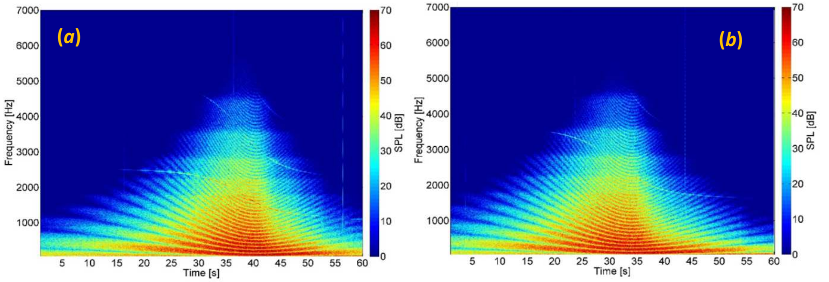


Figure 3: Audio spectrograms of an A320 approaching an airport – (a) Reference aircraft, (b) Low tonality aircraft variant [5]

Table 2: SQ comparison of reference and low tonality aircraft variant sounds

Aircraft – A320	Loudness [sone]	Tonality [-]	Roughness [asper]	Sharpness [acum]	PA_{mod} [-]
Reference	20.4	0.283	2.18	0.938	47.8
Low tonality	19.2	0.236	2.23	0.934	45.2
Difference	-5.9%	-16.6%	+2.3%	-0.4%	-5.4%

- Although providing an automated feedback of the annoyance indication, based either on sound quality or results of listening tests, has not yet been completed, Fig. 3 shows what a potential optimization for minimal tonal impact, in this case for the A320 during approach would sound like.
- The reference A320 approach spectrogram is shown in Fig. 3 (a) and the low-tonality design variant is shown in Fig. 3 (b). It can be seen that the relatively high tonality of the reference A320 aircraft during approach is reduced by 17%, along with a slight reduction in loudness. The optimized aircraft does this by shifting the fan tones to higher frequencies and increasing the broadband noise through a larger wing and slightly smaller engine. The fundamental fan tone intensity itself is also reduced in excess of 5 dB.
- Initial listening test results indicate a general preference for the low-tonality sound by listeners. Although the PA_{mod} metric accounts for tonality, it is still heavily dominated by loudness. An improved annoyance indicator may thus still be required.

Conclusions and future work

- The authors demonstrate the application of a novel aircraft design-auralization-audio assessment toolchain to design and auralize aircraft at representative ground locations, where they can be assessed for their sound quality and impact on perception.
- It is shown that each aircraft has specific SQ characteristics that dominate their annoyance perception, for which the aircraft can be optimized using generally observed trends for all aircraft designs.
- Future work shall involve an automated feedback of the annoyance indication for design optimization, further sensitivity studies of design changes on SQ and annoyance, as well as listening tests for validation.

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