DOI: 10.61782/fa.2025.0782

FORUM ACUSTICUM EURONOISE 2025

# Sound Characteristics and Perception Study of new Generation of Turbofan Aircraft

**Roalt Aalmoes**[1*] **Naomi Sieben**[1] **Stijn Nolet**[1]
[1] Sustainability and Environmental Department, Royal Netherlands Aerospace Centre NLR, The Netherlands

**ABSTRACT**

Ongoing development for more efficient and more silent aircraft resulted in the introduction of a new generation of turbofan aircraft for air transport. This new generation promises to be quieter and more efficient than existing generations. Examples are the Boeing 737MAX and the Embraer E-Jet E2 family. Some communities claim these benefits do not translate into less annoyance and for this reason, research has been performed to examine claimed benefits for noise and to examine whether reductions of noise also reduce annoyance by conducting a perception study. Participants rate simulated flyover events of prior and new generations of aircraft. A virtual reality environment provides both sound and visual stimuli for these events. Subsequently, participants rate these events on their perceived loudness, annoyance, sharpness, and tonality. In addition, psycho-acoustic differences between generations are examined to provide further insight into expected benefits for communities near airports. Results show that the Embraer E195-E2 is less annoying than the older E190. On the other hand, the newer generation Boeing 737 MAX aircraft is not less annoying than the older generation Boeing 737. When the sounds are corrected for loudness, the B737MAX is significantly more annoying than the older B737.

**Keywords:** *noise annoyance, aircraft noise, psycho-acoustics, perception study, virtual reality*

## 1. INTRODUCTION

Since the world of aircraft development moved from a pioneering stage towards a full-grown transport industry, and despite its positive effect it had on people's way of travelling, more and more emphasis is also put on the negative aspects of aviation. Initially, the increase of air traffic and loud (jet) aircrafts led to an increase of noise annoyance for communities living close to an airport. Already in the 1960s, a commission was formed in the Netherlands to advice the Dutch government on new regulations related to aircraft annoyance [1], but aircraft noise annoyance became a problem elsewhere as well. International organizations like WHO nowadays provide guidelines how to deal with noise annoyance, including aircraft noise [2], and the aviation industry is focused on reducing noise annoyance as much as possible. Additional concerns associated with the growth of aviation are related to emissions that cause climate change or adverse health effects for humans living close to the airport. Both noise and emission impact concerns are, next to efficiency improvements, important drivers to optimize aircraft technologies.

Ongoing development for more efficient and more silent aircraft resulted in the introduction of a new generation of turbofan aircraft for air transport. With the adaptation of novel aeroacoustic design, application of new and lighter materials, and the latest generation of high bypass combustion engines, this new generation promises to be more quiet and more efficient than existing generations. Examples are the Boeing 737MAX and the Embraer E-Jet E2 family.

Though airliners and aircraft manufacturers emphasize these benefits for reduction of carbon emissions and noise, some communities claim these benefits do not translate into less annoyance [3]. The authors suggest three possible reasons why there may be differences between claimed reductions and perceived reductions of noise. First, these differences may not only relate to measured sound exposure that is different between the earlier and newer aircraft models, but also to *perceived*

[*] ***Corresponding author**: roalt.aalmoes@nlr.nl.*

noise reduction. From what is known from human acoustics research, a reduction in sound pressure of 50% can be translated towards a 3 dB(A) measured reduction, but will not be perceived as a 50% reduction of noise. Instead, prior research indicates that a 10 dB(A) reduction is needed in order to be perceived as a reduction by 50% of the noise. Second, not only sound pressure could be different between these generations or aircraft, but also sound characteristics can be different due to different engine design and/or differences in thrust and fan rotation (RPMs). Whether there are sound characteristics differences has only partly been reported: there are, for instance, some adverse noise effects in the newer engines of the Embraer E-Jet E2 aircraft during landing, also known as the 'whale sound' [4,5]. Comparing sound characteristics could help explain why reducing sound pressure alone may or may not be sufficient to reduce perceived noise, or whether factors like tonality and sharpness also contribute to this. Third, the flight performance (flight path) of different aircraft may be different as well. As the authors do not foresee significant differences between the take-off flight profiles of these different generations, this third reason is not further examined in this study.
This leads to the following research questions that we wanted to examine:

1. In what way are the newer generation of aircraft perceived as less annoying than the older generation?
2. Are there differences in sound characteristics of the newer generation of aircraft and how do they relate to the reduction of loudness during a flyover?
3. Are there additional psycho-acoustic indicators, next to loudness, that influence the annoyance of this newer generation of aircraft?

For these questions, a study has been performed to examine the claimed benefits for noise reduction. We also examine, first, whether reductions of noise also reduce annoyance, and second, whether changes in noise characteristics of different generation of aircraft also change noise perception, either positively or negatively. This study has been conducted as a human perception study using a noise and visual aircraft flyover simulator. Additionally, to explain the results found in this study, a psycho-acoustics analysis is conducted to objectively examine differences in the aircraft sounds, as demonstrated in other studies [6,7].

## 2. METHOD AND MATERIALS

### 2.1 Study set-up

The NLR Virtual Community Noise Simulator (VCNS) [8] was used to provide participants of the study with auditory and visual stimuli to evaluate. The VCNS consists of a Meta Quest Pro Virtual Reality (VR) headset connected to a powerful Alienware m17 R5 laptop via a tethered USB cable. The laptop ran the VCNS simulation software that had been configured to show different aircraft flyovers in a pre-recorded (using a 360 degrees video camera) outdoor environment. The chosen outdoor environment was a rural area with minimal environmental sounds. This simulation facility ensures all participants of the study experience the same sound and visual stimuli. It is also easier to control than, for instance, actual flyovers of aircraft as there is a lot of variation of sound exposure level due to differences in operations, weather, airliner's preferences for flight operations, and so on. Also, an experiment using a simulator is much easier to organize and can be conducted in different locations as the VCNS system is mobile. And, although this study focuses on experienced sound, adding the visual simulation makes the simulation more realistic (immersive) to experience for the participants than a sole auditory simulation system. Instead of using the onboard audio of the VR headset, that does not mask other sounds in the room, a separate over-ear Bose QuietComfort headset was used connected with a DragonFly Cobalt USB-audio device. Prior experience has shown that using a separate USB-audio device helps with more stable output levels (needed for calibration requirements) than the internal audio device that may vary per laptop-model.

### 2.2 Stimuli

A list of sound events was composed that contained all tested events for the study. Initial take-off sounds were selected since engine sounds are more audible during take-off than during landing because of the higher thrust while taking off. The aircraft sounds were recorded using a Brüel & Kjær (B&K) Class 1 microphone placed in a residential backyard underneath a departure route of Schiphol Airport. The recording location was situated at a distance of approximately 9 km along the lateral flight path from the start of the runway. Time of recordings were two days in June 2024 with comparable weather circumstances with similar wind (51° with 5 m/s and 55° with 4 m/s) and maximum temperatures (28 °C and 29 °C). Aircraft used in the study were the (older generation) Boeing B737-800 and (newer generation) B737 MAX, and the (older generation) Embraer E190 and (newer generation) Embraer E195-E2. For the selected aircraft different take-offs were recorded and only considered for selection if there were sufficiently "clean", i.e. no other dominating environmental sounds recorded as well, such as birds, playing children, or road traffic during the main part of the flyover sound (the peak). Although initially also Airbus A320/A321 (NEO) were considered to be used, they were ultimately not included as none of the recorded flights were sufficiently "clean" in the recorded period. As a paired comparison would take place between the older and newer generation aircraft, the flying distance to destination was checked and ensured that the distances did not differ too much: as aircraft that fly further away are considered heavier due to the amount of fuel needed for these flights. This is important to consider as heavier aircraft will use more thrust and make more noise and equal conditions should be considered when doing an honest comparison.

To compare sound characteristics of the older generation of aircraft with the newer generation of aircraft, a simple comparison can be done by replaying the sound using their pre-recorded level, and this has been used in this study. But since we know loudness has dominating influence on people's perception of noise, the authors also wanted to compare these aircraft in a way that loudness was excluded from the equation. For this purpose, the (louder) older generation aircraft sounds were adjusted by reducing their loudness and made equal to the loudness of the (quieter) newer generation aircraft. The loudness method of ISO 532-1:2017 [9] was used for this purpose, and the N5 metric was chosen indicated the loudness level that was exceeded five percent of the time of the full length (55s) of the event. To correct for the loudness, a value was chosen of 76.7 phon. This is the average measured loudness value of the sounds of the B737MAX and the E195-E2, and allows for a better comparison between the four aircraft. Although there is still a limited difference in loudness, it allows for a better four-way comparison between the newer generation aircraft sounds and the two sounds that were adjusted. These two additional sound samples were added to the list of stimuli and were called *B737-quiet* and *E190-quiet*. A full list of loudness values can be found in Table 1.

**Table 1**. N5 Loudness levels used in the study, measured of the full length of the flyover event.

| Flyover event | N5 |
|---|---|
| B737 | 84.3 |
| B737-quiet | 76.7 |
| B737MAX | 77.2 |
| E190 | 81.3 |
| E190-quiet | 76.7 |
| E195-E2 | 76.2 |

To make a closer one-on-one comparison possible, additional toggling events were added as well, effectively allowing a classic A/B-testing experiment to take place. This means that the two different aircraft sound that needed to be compared were toggled every five seconds. Except for the sound, also the colour of the aircraft model was toggled between an orange and green colour, and a text appeared on the screen with the displayed colour*. This method allowed a direct comparison of two events that sound very similar. Participants had to indicate which state of the event (green or orange) was louder or more annoying. This method was first successfully used in a previous study [10] where two different rotor blade sounds were compared.

The full list of events that were tested per participant is shown in Table 2. The order of events was randomized to prevent bias based on order of events, although the toggle events were always presented either before or after the other (single) events. To let participants get acquainted with the simulation and the controls for answering the questions, two example flyovers were added before the measured events. These two example flyovers were a B737 played at a 10 dB(A) lower sound level and a E195-E2 played at a 10 dB(A) higher sound level than recorded.

### 2.3 Questionnaires

After each event, participants had to answer four questions related to the sound that they experienced. These questions were displayed in the Virtual Reality environment, so participants did not need to take-off their headset to answer them. They were instructed to use a handheld controller to select and confirm their answer.

* Showing a text that stated either 'orange' or 'green' in the Virtual Reality environment was not only an additional indication which aircraft was being heard, it also helped in case participants had colour blindness, a condition that was not asked from, nor tested for, the participants.

For the single sound events, the following questions were asked:

1. How much did the sound of this aircraft bother, disturb or annoy you in this environment?
2. How loud did you perceive the sound of this aircraft?
3. Did you hear one (or more) distinctive tone(s) in this sound?
4. How would you describe the sharpness (high frequency component) of this sound?

**Table 2**. Test event list for the experiment

| no | Flyover event | vehicle | type |
|---|---|---|---|
| 1 | B737 | B737 | single |
| 2 | B737-quiet | B737 | single |
| 3 | B737MAX | B737 | single |
| 4 | E190 | B190 | single |
| 5 | E190-quiet | B190 | single |
| 6 | E195-E2 | E195-E2 | single |
| 7 | Embraer-toggle | E190 and E195-E2 | toggle |
| 8 | Embraer-quiet-toggle | E190-quiet and E195-E2 | toggle |
| 9 | B737-toggle | B737 and B737MAX | toggle |
| 10 | B737-quiet-toggle | B737-quiet and B737MAX | toggle |

All questions should be answered according to an 11-point Likert scale from "not at all" (leftmost) to "extremely" (rightmost). The first question relates to the annoyance question in general, and the second to fourth questions relate to the psycho-acoustic subjectively perceived notion of loudness, tonality, and sharpness, respectively.

Similar questions were asked for the toggle events, where a choice was made between two different aircraft sounds. These questions were:

1. Which aircraft sound did you perceive as more bothering, disturbing or annoying?
2. Which aircraft sound did you perceive as louder?
3. In which aircraft sound did you perceive more distinctive tone(s)?
4. Which aircraft sound did you perceive as sharper (higher frequencies)?

Here the participants could also answer on a 11-point scale, but the leftmost position stated "Green aircraft" , while the rightmost position stated "Orange aircraft". If no differences were heard, the middle position could be chosen.

### 2.4 Statistical methods

To measure differences between the aircraft types, paired-Samples T Tests were used. For the A/B tests where the aircrafts alternated within one event, Wilcoxon rank tests were performed. All the statistical tests were run in the statistical package IBM SPSS Statistics 25.

### 2.5 Participants

Participants for the perception study were gathered from personal circles of the involved researchers and did not get a monetary reward for participation. Individuals who had worked or studied in aviation-related fields (such as NLR employees) were excluded to prevent prior biases. Before the study started, participants filled in a consent form that indicated their rights and the use of the data. Measured data was anonymized and could not be traced back to the individual participants because of privacy regulations. A total number of 23 people participated in the study

### 2.6 Ethical approval

The study was executed with the same approach as a previous study [11] that was approved by the Utrecht University ethical committee, so additional approval was not required.

## 3. RESULTS

### 3.1 Differences between the B737 and B737MAX

No significant difference was found in annoyance scores for the B737 (M=5.78, SD =1.81) and B737MAX (M=5.57, SD=1.85) when they were presented at the original (recorded) sound level, where the B737 was louder ($t(22)$ = -0.53 $p$ = .603).

A significant difference in sharpness is found between B737 (M=4.78, SD=2.22) and B737MAX (M=6.90, SD=1.87) where the B737MAX was perceived sharper (t(22) =3.64, p = .001). No significant difference was found for tonality.

A significant difference in annoyance was found when the B737MAX and the B737 were presented at the same loudness level ($t(22)$ = -3.49 $p$ = .002). The annoyance scores for the B737MAX were higher ($M$ = 5.57, $SD$ = 1.85) than for the B737 ($M$ = 4.39, $SD$ = 1.90). There was also a significant sharper sound reported ($t(22) = 4.60, p < .001$) for the B737MAX (M = 6.90, SD = 1.87) than for the B737 ($M$ = 4.39, $SD$ = 1.92), but no significant difference in reported tonality.

Similar results for perceived loudness were found as for perceived annoyance by the participants.

*3.1.1 A/B test differences between the B737 and B737MAX*

The A/B test analysed with a one sample Wilcoxon rank test shows that the B737 and B737MAX did not differ in annoyance ratings when presenting at the original sound level, where the B737 was louder than the B737MAX ($z$ = 1.69, $p$ = .091).

The A/B test, analysed with a one sample Wilcoxon rank test revealed that the annoyance for a B737MAX was significantly higher than the B737 at the same loudness level ($z$ = 2.64, $p$ = .008). The median score on the 11-point Likert scale item was 7, whereas a value of 5, that translates to middle value of the slider, would indicate no difference in annoyance between the B737 and B737MAX.

### 3.2 Differences between the E190 and E195-E2

When comparing the E190 at its original recorded sound level with the E192-E2, a significant difference was found in annoyance ($t(22) = 3.83$ $p$ = .001). Here, the E190 was more annoying ($M$ = 6.09, $SD$ = 1.91) than the E195-E2 ($M$ = 4.57, $SD$ = 2.48). No differences were found in perceived sharpness or tonality. When presented at the similar N5 loudness level, no difference in annoyance was found ($t(22) = -.381$, $p$ = .707). A significant difference was found for sharpness between the E190-quiet (M = 4.52, SD = 1.88), and the E195-E2 (M = 5.70, SD = 2.16), where the E195-E2 was rated as sharper (t(22) = 2.55, p < .018). No significant differences in tonality was found between the E190-quiet and the E195-E2.

*3.2.1 A/B test differences between the E190 and E195-E2*

A/B test differences between the E190 and E195-E2 analysed with a one sample Wilcoxon rank test revealed the annoyance for the E190 was significantly higher than the E195-E2 when presented at the original sound level, where the E190 was louder than the E195-E2 ($z$ = 3.62, $p$ < .001). The median score on the 11-point scale item was 8, whereas a score of 5 would indicate no difference in annoyance between the E190 and E195-E2.

The A/B test analysed with a one sample Wilcoxon rank test shows that the E190 and E195-E2 did not differ in annoyance ratings when presenting at the similar N5 Loudness level ($z$ = 1.58, $p$ = .113).

### 3.3 Differences between B737 and E190

No difference was found (t(22) < 0.01, p = 1.00) between the reported annoyance of the B737 (M = 4.39, SD = 1.90) and the E190 aircraft (M = 4.39, SD = 1.64), even though there was a difference in measured N5 loudness of 84.3 (B737) and 81.3 (E190), as shown in Table 1. No difference was found between the B737-quiet events and the E190-quiet events where loudness was normalized. Also reported loudness, tonality and sharpness were not significantly different. Note that no additional toggle event was done in this study between these aircraft.

### 3.4 Differences between B737MAX and E195-E2

A significant difference in annoyance was found where the B737MAX ($M$ = 5.57, $SD$ = 1.85) was found more annoying than the E195-E2 ($M$ = 4.57, $SD$ = 2.48) with $t(22)$ = 2.32, $p$ = .030. This is also true for perceived loudness, t(22) = 2.26, p = .034, where the B737MAX (M = 5.74, SD = 1.60) was rated as louder than the E195-E2 (M = 4.78, SD = 2.09). Also, a significant difference was found in the subjective sharpness evaluation between the B737MAX and E195-E2, $t(22) = 2.62$, $p$ = .016, where the B737MAX ($M$ = 6.70, $SD$ = 1.87) was rated as sharper than the E195-E2 ($M$ = 5.70, $SD$ = 2.16). No significance difference was found for tonality.

## 4. PSCYHO-ACOUSTICS ANALYSIS

To analyse the sound characteristics of the flyover movements, psycho-acoustics metrices were used to objectively calculate the values for loudness, sharpness, fluctuation strength, roughness, and tonality. We call this *objectively*, as the perceived characteristics of sharpness, tonality and loudness were already *subjectively* asked from the participants during the perception study. The *open source* toolkit SQAT [12], was used for this purpose. For the psycho-acoustic analysis, only the main part of the flyover event (35s) was analysed in the event. An earlier analysis for the whole event showed higher sharpness values that were contributed to some bird sounds at the beginning of some events. During the main part of the event, such sounds do not occur. For this reason the reported loudness values differ from the earlier found values in Table 1. Results of this analysis are found in Table 3. Both the B737 and B737MAX have a higher sharpness than the other sounds. The newer generation aircraft B737MAX and E195-E2 have a higher tonality than the other sounds. The Embraer aircraft has a higher fluctuation strength than the Boeing aircraft. Note that this analysis was only based on the sound samples used in this study. Differences that may occur between aircraft sounds of the same aircraft type are not examined.

**Table 3**. Psycho-acoustic analysis of main part of the sound event (35s). N5= 5% highest loudness, S5=5% highest sharpness, R5=5% highest roughness, K5=5% highest tonality, FS5 = 5% highest fluctuation strength.

| Aircraft | N5 *phon* | S5 *acum* | R5 *asper* | K5 *t.u.* | FS5 *vacil* |
|---|---|---|---|---|---|
| B737 | 85.21 | 1.16 | 0.07 | 0.07 | 0.28 |
| B737 MAX | 77.87 | 1.15 | 0.06 | 0.10 | 0.19 |
| B737-quiet | 77.69 | 1.05 | 0.06 | 0.07 | 0.23 |
| E190 | 82.13 | 1.06 | 0.06 | 0.07 | 0.45 |
| E195-E2 | 77.04 | 1.09 | 0.05 | 0.10 | 0.46 |
| E190-quiet | 77.54 | 0.98 | 0.06 | 0.07 | 0.39 |

## 5. DISCUSSION

The outcome of the comparison between the B737 and the B737MAX show a remarkable result: while it would be expected that the quieter B737MAX, due to lower certified noise levels and also due to lower measured noise levels, would be rated as significantly less annoying, this is not the case. On the other hand, if the loudness is compensated, the B737MAX is rated as significantly more annoying than the B737. This would indicate that sound characteristics of the B737MAX negatively affects people's noise perception in comparison with the B737. It could be argued that the corrected loudness of the B737-quiet (76.7) is lower than the B737MAX (77.2). However, this limited difference could not fully explain the result, as the loudness difference of 0.5 is difficult to perceive, according to the authors. Psycho-acoustic analysis may explain these unexpected results, as higher measured tonality and sharpness for the B737MAX could influence perceived annoyance (Table 3).
For the comparison between the E190 and the E195-E2, results were as expected, where the E195-E2 is considered less annoying than the E190 at the recorded sound level. When corrected for the difference in loudness, no difference can be found, so reduction of annoyance can be related to reduction in loudness for the newer generation aircraft. It should be noted that the distinct 'whale sound' is a sound has only been reported during landing operations, so the occurrence of this phenomenon for the E195-E2 has not been evaluated in this study. A comparison between the B737MAX and the E195-E2 also rate the B737MAX as more annoying than the E195-E2. According to the participants this can be contributed to the a higher perceived sharpness, also calculated in the psycho-acoustic analysis. The higher fluctuation strength of the E195-E2 compared to the B737MAX does not seem to have a negative influence.
It should be noted that this was a study with a limited number of participants (23) and only single recordings of aircraft flyovers. A validation study with a representative group of people living close to the airport with a larger sample size of aircraft sounds, also including landing phases, would therefore be useful to verify the outcomes of this study. What also should be considered is that this new generation of aircraft and their associated sounds may need some time for local residents near airport to get used to. Studies near airports where these aircraft fly for a longer period may help to prove or disprove this hypothesis.
If these results are confirmed and prolong after a customization period, alternative certification measures should be considered that not only include noise measures that consider loudness and (limited) tonality, such as EPNL, but also include additional psycho-acoustic metrics to better estimate human annoyance towards aircraft noise.

## 6. CONCLUSION

A noise study was conducted to evaluate different generation of jet aircraft sounds during a take-off operation near an airport. Recordings were made near Schiphol airport and these were selected on comparable route and destination distance, to prevent differences in recording distance or take-off weight, respectively. Results show that the newer generation Boeing 737MAX aircraft is not less annoying than the older generation Boeing 737 during the measured take-off phase. If the sounds are corrected for loudness, as the B737MAX is quieter than the B737, the B737MAX is perceived as significantly more annoying than the older B737. This is a remarkable result, and demonstrates that single noise metrics on loudness do not always capture perceived annoyance. On the other hand, a comparison between the older generation Embraer E190 and the newer generation E195-E2 show that reduction of loudness also reduces perceived annoyance. Both these results were found using two different methods. First, a single flyover sound that was rated individually, and second, a toggling event where participants compared two flyover sounds directly. The use of both methods in one study strengthens the belief that both these methods contribute to the evaluation of aircraft sounds in such perception studies.

## 7. ACKNOWLEDGMENTS

The authors would like to thank their internship student Ariaan Aberan Tabrizi from the faculty of Applied Cognitive Psychology of the Utrecht University who helped set up and execute part of the experiment.

## 8. CONFLICTS OF INTERESTS

This research was conducted with NLR internal funding. The authors declare no conflict of interest.

## 9. REFERENCES

1. Kosten CW, Zwaan GW de, Steenbergen MH, Falkenhagen CAF, Jonge JAC de, Os GJ van. Geluidhinder door vliegtuigen. Delft: Adviescommissie geluidhinder door vliegtuigen; 1967 Jun. Report No.: (01730) 31900-242.

2. World Health Organization. Regional Office for Europe. Environmental noise guidelines for the European Region [Internet]. Copenhagen: World Health Organization. Regional Office for Europe; 2018. Available from: https://apps.who.int/iris/handle/10665/279952

3. Staat van de luchtvaart 2023 [Internet]. Inspectie Leefomgeving en Transport; 2024 Apr [cited 2025 Apr 1]. Available from: https://www.ilent.nl/documenten/transport/luchtvaart/luchthavens/rapporten/staat-van-de-luchtvaart-2023

4. Nold C, Haklay M, Walker T, Doherty J, Morris M, Boon G. Citizen Science Study of Overflight Noise from New and Old Generation Aircraft at London City Airport. Community Science [Internet]. 2023; Available from: https://oro.open.ac.uk/94037/

5. Zurich residents complain about whale-like sounds coming from passing Swiss A220 jets [Internet]. 2018 [cited 2025 Mar 28]. Available from: https://www.gatechecked.com/zurich-residents-complain-whale-like-sounds-swiss-a220-689

6. Green N, Ramos-Romero C, Torija AJ. Comparison of the noise perception of conventional aircraft and Unmanned Aircraft Systems. INTER-NOISE and NOISE-CON Congress and Conference Proceedings. 2024 Oct 4;270(4):7419–30.

7. Boucher M, Rafaelof M, Begault D, Christian A, Krishnamurthy S, Rizzi S. A Psychoacoustic Test for Urban Air Mobility Vehicle Sound Quality. 2023 May 8;

8. Aalmoes R, Boer M den, Veerbeek H. Virtual Reality Aircraft Noise Simulation for Community Engagement. In: INTER-NOISE and NOISE-CON Congress and Conference Proceedings. Chicago, IL: Institute of Noise Control Engineering; 2018. p. 1559–66.

9. ISO 532-1:2017 Acoustics — Methods for calculating loudness [Internet]. 2017. Available from: https://www.iso.org/standard/63077.html

10. Aalmoes R, Knepper K, Sieben N, Haan, de W, Margalida G, Sinnige T. Sound Perception Study of Auralized Novel Propeller Design for Future Electrical Air Mobility Platforms. In Rome, Italy; 2024.

11. Aalmoes R, Bruijn B de, Sieben N. The Influence of Contextual Non-Auditory Factors on Drone Sound Perception. In SAE International; 2023.

12. Felix Greco G, Merino-Martinez R, Osses A, Langer S. SQAT: a MATLAB-based toolbox for quantitative sound quality analysis. 2023.