TU Delft

Theme 4 Project:
Test, Analysis and Simulation

QUANTIFYING ANNOYANCE OF AIRCRAFT FLYOVERS USING DIFFERENT NOISE METRICS

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1. The 4th Thematic Project

1.1. The scope and objectives

The thematic projects in the Aerospace Engineering Bachelor Program aim to provide learning experiences that will enable you to better integrate the theoretical content of the courses in a practical, active setting. The projects are mandatory elements of the program. Each semester contains one thematic project.
The theme of the 4th semester is “test, analysis, and simulation”. The courses in this semester, in general, have this theme in common. This theme also is the focus in this 4th semester AE2223-I project.

1.2. Activities within the project

The project will run in the second semester of the second year. Table 1 gives an overview of the activities during the project.

The deadlines within the project are:

9 March 2018, 17:30	Hand in literature review for scientific reporting. You will be provided with the relevant instructions in the introductory lecture in week 3.1.
9 March 2018, 17:30	Hand in research plan to tutor. This research plan should contain the first research steps you intend to take. It will help you start the research. In addition, it allows your tutor to give to-the-point feedback.
30 March 2018, 17:30	Submit self-reflection report to the project supervisor. This self-reflection should not exceed 1 A4 and should reflect on your own contribution to the project: - How did it go so far? - What are your insights on your own functioning within a group? - What have you identified as your strengths? - What weaknesses need to be improved upon? - How do you intend to ensure these improvements?
18 May 2018, 17:30	Submit draft of scientific report for the peer review process
25 May 2018, 8:30	Submit peer review
15 June 2018, 17:30	Submit final version of scientific report to blackboard, tutor and scientific reporting teacher

1.3. Grading

You will be graded at the end of the project based on the following items:

1. The scientific report. A **group grade** will be given based on the technical quality of the report. Each group member should indicate what part of the report he/she has produced. This will be used for grading for the course Scientific Reporting.

2. Your attitude during the project. It is based on regular meetings with your tutor and your self-reflection, and is an **individual grade**.
3. The project ends with an oral exam. During this exam the tutor, together with one of the project coordinators or teaching assistants, will test your understanding with regards to the research, resulting in an **individual grade**.
4. You all will be asked to review the report of another group individually. The quality of the review will be accounted for as an **individual grade**. This grade is provided by the tutor of the group whose report is reviewed.

Partial grades will be rounded to 1 decimal and the final grade will be rounded to the nearest halve grade. The tutor grade holds for 4 ECTS and 1 additional ECTS is given by the Scientific Reporting tutor for the quality of the report.

In order to pass the project, the following needs to be fulfilled:

1. The whole project has been completed and all compensatory assignments have been completed successfully and,
2. No more than one grade is lower than 6.0 and all grades are 5.0 or higher,
3. All rules regarding absence are met.

If any of the above conditions are not met, a final grade of 1.0 is awarded for the project. If you fail the project you have to reregister to redo the project the following academic year.

Table 1. The project activities.

When	Activity
Week 3.1	- Introductory lecture - Kick-off: meeting with the tutor
Week 3.2	- **Scientific reporting coaching session 1** - Information literacy 2 course - Start literature survey
Week 3.3	- Literature survey
Week 3.4	- Finalize literature survey - Write research plan - Start with data analysis - Submit literature review (9/3/2018) - Submit research plan to tutor (9/3/2018)
Week 3.5	- Continue data analysis
Week 3.6	- Continue data analysis **- Scientific writing coaching session 2**
Week 3.7	- Continue data analysis - Work on scientific report - Submit the self-reflection report (30/3/2018)
Week 4.1	- Continue data analysis - Work on scientific report
Week 4.2	- **Scientific writing coaching session 3** - Continue data analysis - Work on scientific report

Week 4.3	- Continue data analysis - Work on scientific report
Week 4.4	- Continue data analysis - Work on scientific report - Draw conclusions - Submit draft of scientific report (18/5/2018)
Week 4.5	- **Scientific writing coaching session 4** - Peer review of scientific reports - Submit peer review report (25/5/2018)
Week 4.6	- Contact your scientific writing teacher for feedback and for questions regarding the implementation of the peer review comments - Implementation of the comments from the peer review and finalize data analysis - Work on scientific report
Week 4.7	- Contact your scientific writing teacher for feedback and for questions regarding the implementation of the peer review comments - Implementation of the comments from the peer review and finalize data analysis - Work on scientific report
Week 4.8	- Deliver final report (15/6/2018)
Week 4.9-4.11	- Oral exam - Grading

1.4. Required presence and absence rules

For each student group the project sessions will be scheduled and a project space assigned. Within each group a member needs to be assigned who is responsible for recording the presence. Presence during the project is compulsory and will be checked. The following rules hold:

1. A maximum of 2 project sessions per period (half semester) can be missed for the project itself;
2. Attendance at the instruction on information literacy is compulsory;
3. With respect to the course on scientific reporting, absence is allowed for maximally one session of this course. This session is not counted as a missed project session as mentioned under 1;
4. Being more than 20 min late counts as a missed session;
5. Arriving late (after 8:45 in the morning and 13:45 in the afternoon) 4 times will count as a missed session;
6. Leaving at any time during project sessions can also result in being registered as missed sessions;
7. Missed sessions must be compensated;
8. Attendance is required during the week in which the kick-off of the project takes place. Not being present in this week of the project results in exclusion from participation in the project in that academic year;
9. It is also not allowed to miss the last two sessions of the 1st period together with the 1st sessions of the 2nd period;
10. Absence for whatever reason for more than the allowed number of sessions or failure to make up for missed hours will mean that you cannot obtain a pass grade for the project;
11. In case of relevant extenuating circumstances one can turn to the academic counselors for guidance.

12. All students are required to be present during the weekly meetings with the tutor and summarize (3/4 students) the work done.

In case a group member is absent, he/she has to make a plan in cooperation with his/her group on how to make up for the absence. The result has to be communicated to the supervisor and its realization is based upon the supervisor’s approval. Absence at a scientific reporting session needs to be reported to the scientific reporting teacher. A compensatory assignment will be provided. The student is responsible for fulfilling the compensatory assignment, at a time or within a time limit set by the responsible lecturer (this also applies to supporting courses). The quality of the compensatory assignment is assessed by the responsible lecturer. Not finishing the assignment within the allocated time and/or with sufficient quality, results in failing the project.

2. The Assignment

2.1. Introduction

Aircraft have become quieter over the last decades, but the continuous expansion of airports close to populated areas and the growing of air traffic still makes aircraft noise a topical problem.

The most common certification metrics used today were developed in the 60s and designed for the typical aircraft at the time. The acoustic signature of an aircraft is different nowadays, and with the reduction of jet noise other noise components gained importance.

Therefore it is important to assess annoyance differently, taking into consideration actual aircraft and which types of sounds are more disturbing to human ear. Psychoacoustics based Sound Quality (SQ) metrics are a step further in quantifying aircraft annoyance.

In this work, the most common metrics will be compared with the SQ metrics in order to check if both metrics indicate the same aircraft as the most annoying, in a large dataset with different aircraft models.

2.2. Experimental setup

Measuring aircraft noise is a difficult task, as it requires knowledge not only of the noise level but also an accurate position and velocity of the aircraft. An acoustic camera (Fig. 1) of 64 microphones in a spiral configuration was used to collect the flyover measurements used in this work.

Figure 1: Acoustic camera used in the experiments.

This type of array distribution it is possible to identify the individual components of noise (e.g. engine, trailing edge, landing gear) using beamforming methods. In this project, the focus is on the total level of noise. Thus, data from only one microphone is provided.

The experimental campaign took place at the Schiphol Airport at runway position 18C, illustrated in Fig. 2. In the days of the measurements most of the measurements were of landing aircraft due to the direction of the wind.

Figure 2: Runway of the Schiphol airport were the measurements were performed.

2.3. Parameters Measured

Acoustic pressure in a microphone of the array

The acoustic pressure [Pa] measured by a single microphone during the duration of the flyover. The signal was band filtered by the data acquisition system (0.2 – 25 kHz). The sampling frequency in all the measurements is 50 kHz. Each file corresponds to a flyover measurement and can be open using MATLAB.

Position and velocity of the aircraft

The landing trajectories do not vary much because the landing were all in the same runway, however, depending on the aircraft model there are differences especially in the velocity. The aircraft position and velocity relative to the source are essential to the calculation of propagation effect and to account for the Doppler effect. This information was obtained with the optical camera and with an ADS-B (Automatic Dependent Surveillance-Broadcast) receiver. The position of the aircraft, the velocity and the overhead time will be provided to the students for each flyover.

Atmospheric conditions

The atmospheric pressure, temperature and humidity were also measured in order to improve the accuracy of the calculations. Such data will also be provided to the students.

2.4. Procedure

The provided acoustic pressure data is a time domain data. However, aircraft noise analysis in the frequency domain is also relevant. A spectrogram of each flyover provides a good link between the time and frequency domain analysis. This can be made by applying a Fast

Fourier Transform (FFT) to each flyover. In a spectrogram it is possible to observe the Blade Passage Frequency (BPF) of the fan and ground reflections, for example.

All the data is at the receiver (microphone) so it has to be propagated back to the source (aircraft) taking into consideration propagation effects (Doppler effect, geometrical spreading, atmospheric absorption, etc.) see [2, 4]. After the correction there is a visible difference between the spectrograms at the source and at the receiver. The spectrogram will help grouping the different models of aircraft.

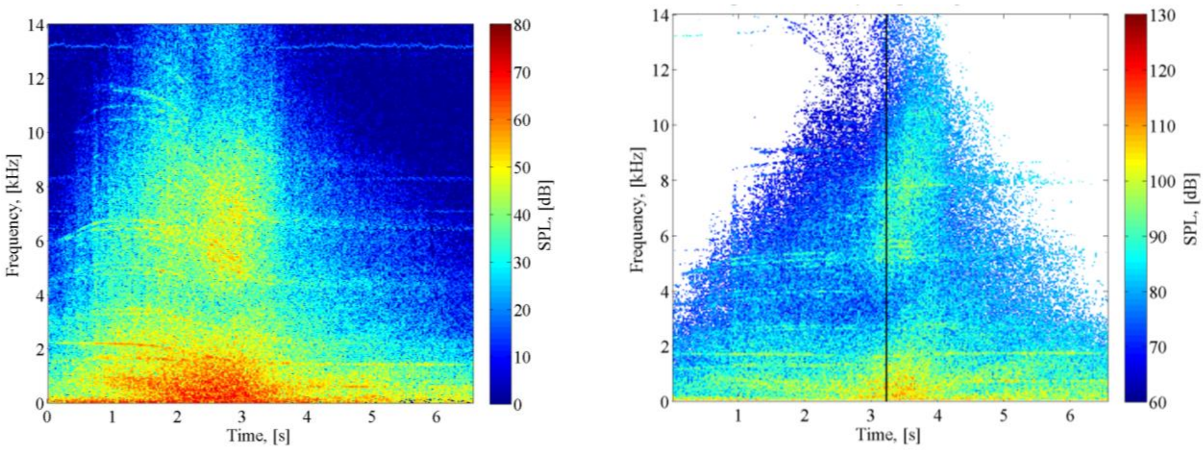

Figure 3: Example of an spectrogram of the sound received at the array (left) and of the sound emitted at the source (right). [2]

Different metrics should be calculated in order to assess the annoyance of each aircraft model, in this work the following are recommended,

- Maximum Sound Pressure Level (SPL_{max}) [9],
- Maximum A-weighted Sound Pressure Level , ($L_{A,max}$) [9],
- Sound Exposure Level (SEL) – [9],
- Perceived Noise Level (PNL) [8],
- Perceived Noise Level + Tone Correction (PNLT) [8],
- Effective Perceived Noise Level (EPNL) [8],
- Stationary loudness (ISO532B) [11],
- Sharpness (Bismarck) [11],
- Tonality (Aures) [11],
- Psychoacoustic Annoyance (PA) [12].

2.5.Research Questions

Note: These are some example research questions. Students have freedom to modify the provided questions or come up with new research questions.

- What are the values of the different metrics applied to each flyover?
- Is it possible to identify similar aircraft using the metrics and the spectrograms? If so, group the flyovers by aircraft type or model.

- Is it possible to pinpoint sources of noise in the spectrograms? When the metrics are applied, what could possibly be the most annoying component of a landing aircraft?
- Are the traditional metrics in agreement with the SQ metrics? (e.g. do EPNL and PA have the maximum and minimum value for the same flyover?).

3. The project tutor

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4. Relevant courses

- Programming & Scientific Computing in Python for AE1 (AE1205)
- Physics (AE1240)
- Calculus I (WI1421LR)
- Probability and Statistics (WI2180LR-II)
- Basic signal processing

5. References/reading material

Reviewed papers

[1] Zwicker, E. et al., *Program for calculating loudness according to DIN 45631 (ISO 532B)* J. Acoust. Soc. Jpn (E)12, 1, 1991.

[2] Snellen, M., Merino-Martinez, R. and Simons D.G., "*Assessment of noise variability of landing aircraft using phased microphone array*," Journal of Aircraft, Vol. 54, No. 6, pp 2173-2183. November-December 2017

[3] Simons, D.G., Snellen, M., Midden, B., Arntzen, M. and Bergmans D.H.T., "*Assessment of noise level variations of aircraft fly-overs using acoustic arrays*," Journal of Aircraft, Vol. 52, No. 5, pp 1625-1633. September-October 2015

[4] Howell, G.P., Bradley, A.J., McCormick M.A. and Brown J.D., "*De-Dopplerization and acoustic imaging of aircraft flyover noise measurements,*" Journal of Sound and Vibration, No. 105, pp 151-167. 1986.

Conference papers and others

[5] Snellen, M., Merino-Martinez, R. and Simons D.G., "*Assessment of aircraft noise sources variability using an acoustic camera*," 5th CEAS Air & Space Conference. Challenges in European Aerospace. 7-11 September 2015. Delft, Netherlands.

[6] HEAD acoustics – Loudness and Sharpness calculation with ArtemiS. Application note – Psychoacoustic Analyses I.

[7] HEAD acoustics – Psychoacoustic Analyses in ArtemiS II. Application note – Psychoacoustic Analyses II.

[8] Hreinsson, G.S., Aircraft Noise. (1993)

Books

[9] Ruijgrok, G.J.J. - *ELEMENTS OF AVIATION ACOUSTICS* (TU Delft) (1993)

[10] Brandt, A. – *NOISE AND VIBRATION ANALYSIS*. Wiley and Sons. (2011)

[11] Sahai, A.K. – Consideration of Aircraft Noise Annoyance during Conceptual Aircraft Design (2016, PhD thesis). **Focus on chapter 6**.

[12] More, S.R. – Aircraft noise characteristics and metrics (2011, PhD thesis)