Parameter estimation: a key ingredient for the application of sonAIR

Olivier Schwab (olivier.schwab@empa.ch)

Empa, Laboratory for Acoustics / Noise Control

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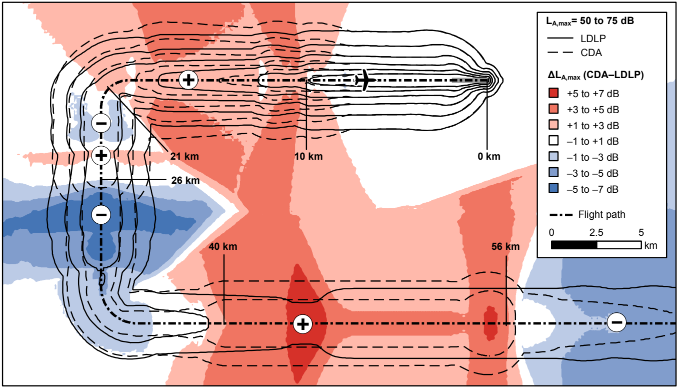
Introduction: a quick recap on sonAIR

An emission model for the accurate simulation of single flights

- The emission model accounts for both engine and airframe noise
- Considers the most important effects based on physics
  - Directivity (θ, φ)
  - Engine power ($N1$, $N1^2$)
  - Aeroacoustic sources (Ma, ρ)
  - Configuration (LG, FH, SB)
  - Interactions (e.g. change of directivity with engine power)
- Spectral model in $1/3$ octave bands, between 25 Hz – 5 kHz

Application in current and future aircraft noise topics

- Increased accuracy for standard applications
  - Calculation of noise maps for yearly traffic
- Unique new applications
  - Assessment and optimization of noise abatement procedures



Zellmann *et al.* (2018), Aircraft Noise Emission Model Accounting for Aircraft Flight Parameters, Journal of Aircraft

Motivation: the need for a parameter estimation

Engine and airframe input parameters are needed

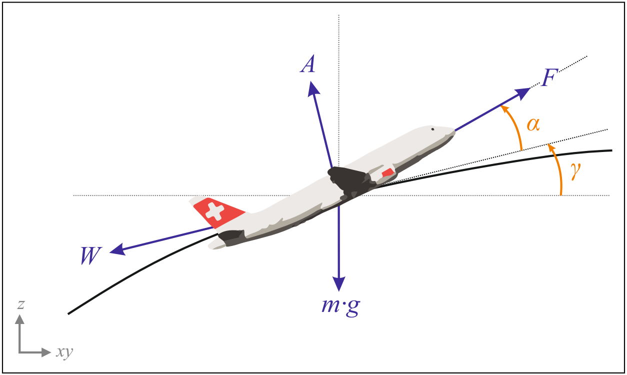
- Commonly available inputs:
  - Radar data: $x(t), y(t), z(t)$
  - List of movements: aircraft type, date, time, [mass], destination, ...
- Required sonAIR inputs:
  - Directivity $(\theta, \varphi) \rightarrow$ from geometry ✓
  - Engine power $(N1, N1^2) \rightarrow$ ✗
  - Aeroacoustic sources $(Ma, \rho) \rightarrow$ from geometry and ISA ✓
  - Configuration $(LG, FH, SB) \rightarrow$ ✗

→ For the application of sonAIR, it is essential to determine the missing engine and airframe parameters: $N1$ and configuration

Is a solution by calculation possible?

Problem: estimate $N1$ ($\leftarrow F$), flap handle ($\leftarrow A$), landing gear ($\leftarrow W$)

$$\begin{cases} m \cdot a_{xy} = F \cdot \cos(\gamma + \alpha) - W \cdot \cos\gamma + A \cdot \cos\left(\frac{\pi}{2} + \gamma\right) \\ m \cdot a_z = F \cdot \sin(\gamma + \alpha) - W \cdot \sin\gamma + A \cdot \sin\left(\frac{\pi}{2} + \gamma\right) - m \cdot g \end{cases}$$



Separation into two independent sub-problems

- From balance of forces:
  - Too many unknowns for direct solution
  - No unique solution for configuration (e.g. Δ in lift caused by flap change can be compensated for by angle-of-attack)
- The problem is divided into two independent problems
  1. The configuration is estimated using machine learning
  2. $N1$ is estimated using an engineering approach
- Assumptions for independence of the two sub-problems:
  - Configuration changes occur mainly based on altitude / aircraft speed
  - $N1$ estimation assumes a mean configuration profile
- Restriction: requires training data

→ shown here: ① for approaches, ② for departures

Methods: the machine learning solution for the aerodynamic part

Configuration is a machine learning problem

- Configuration cannot be solved for uniquely, but for each point in time there is a most likely configuration
- Machine learning problem: classification task with supervised learning:

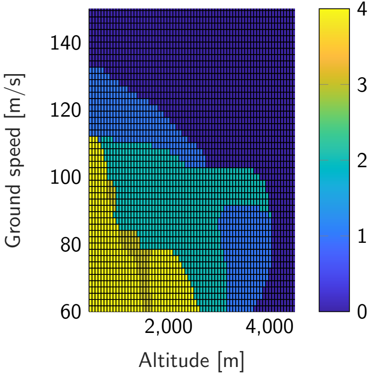
$$\{h, v, v_z\} \rightarrow \{\text{flap handle}, \text{landing gear}\}$$

- Possible to build for approaches and departures for all available aircraft types
- Example here: SVM classifier
  → hyperplane so that the distance from it to the nearest data point on each side is maximized

Example: classifiers for approaches A320

① Flap handle:

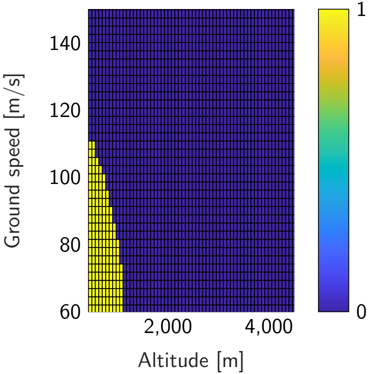
$$\{h, v\} \rightarrow \{\text{flap handle}\}$$



Estimated accuracy: 82%
(cross-validation)

② Landing gear:

$$\{h, v\} \rightarrow \{\text{landing gear}\}$$

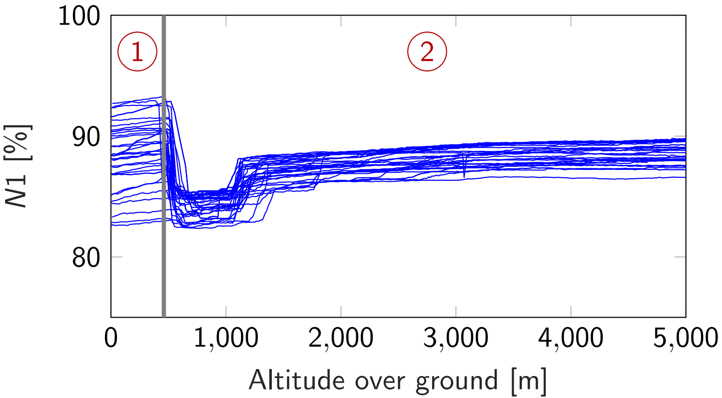


Estimated accuracy: 96%
(cross-validation)

Methods: the engineering solution for the engine part

Departures are modeled by segment-wise *N*1-profiles

*N*1-profiles A320



Segment-wise *N*1-profiles: ① flex take-off ② de-rated climb

Take-off profiles account for flex take-off

Ansatz: $\boxed{N1^2_{h=h_i} = a_0 + a_1 \cdot m \cdot \cos\bar{\gamma} + a_2 \cdot m \cdot \sin\bar{\gamma} + a_3 \cdot T_{h=h_i}}$

- Thrust is a function of mass and climb behavior (balance of forces under assumptions $a \approx 0$, $\gamma \approx \text{const.} = \bar{\gamma}$):

$$F = f\left(m \cdot \cos\bar{\gamma}, m \cdot \sin\bar{\gamma}\right)$$

- Thrust is a quadratic function of $N1$:

$$F_{h=h_i} \propto N1^2_{h=h_i}$$

- $N1^2$ is approximately linearly dependent on temperature:

$$N1^2_{h=h_i} \propto T_{h=h_i}$$

- [Proxy for aircraft mass: $m \propto v^2_{IC}$]

Climb profiles account for de-rated climb

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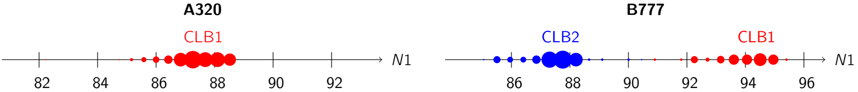
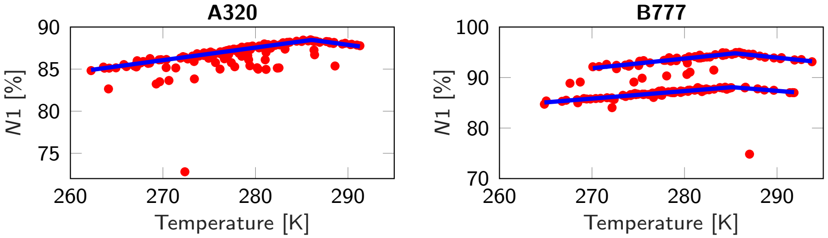
Ansatz: ① per de-rate ② $\boxed{N1_{h=h_i} = a \cdot |T_{h=h_i} - b| + c}$

- One or two de-rated climb settings, e.g. $N1$ at $h = 2\,000$ m over ground



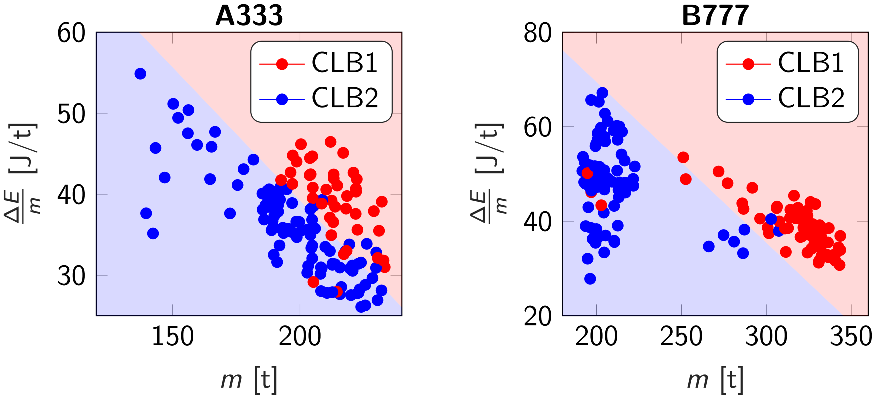
- Variance inside climb setting is due to temperature variations



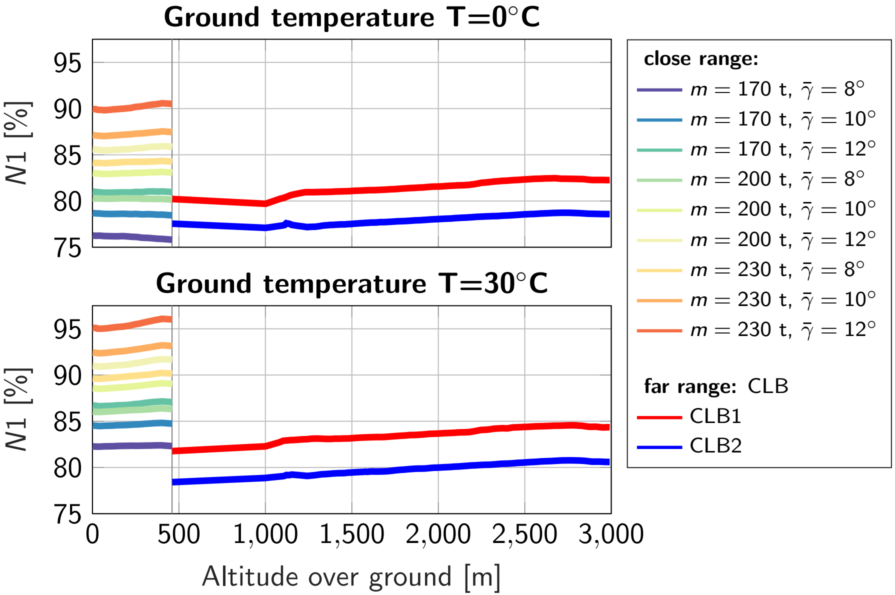
How to distinguish climb settings?

Two factors to consider: aircraft mass m and increase in energy ΔE between two points in time t_1 and t_2, e.g. $h_1 = h(t_1) = 1\,000$ m over ground and $h_2 = h(t_2) = h(t_1 + 300 \text{ s})$.

$$① \; m \qquad ② \; \frac{\Delta E}{m} = 0.5 \cdot \left(v_2^2 - v_1^2\right) + g \cdot (h_2 - h_1)$$



Example *N*1-profiles for A333



Summary: increased accuracy

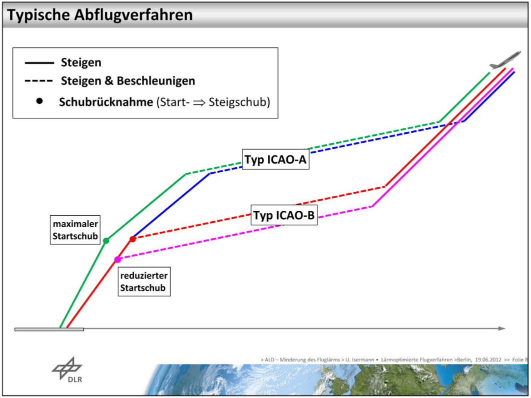
Roundup and conclusions

- sonAIR is able to provide increased accuracy for existing aircraft noise applications as well as the application to new kinds of investigations using single flights
- The parameter estimation is crucial for the application of sonAIR
- The solution consists in
  - Using machine learning for the configuration problem
  - Using an engineering approach for the $N1$ estimation problem
- Validation shows good agreement, resulting in receiver L_{AE} errors of less than 1 dB for both close and far range
- Solution works for non-SWISS aircraft and other airports

Challenges and next steps: towards generalization

Improvements for further generalization

- Addition of new aircraft types, e.g. Bombardier C-Series
- Improve training database for non-SWISS aircraft
  - In-house $N1$ determination from acoustics
- Investigation into procedures for a variation of airlines and airports
  - ICAO Noise Abatement Departure Procedures NADP 1&2:



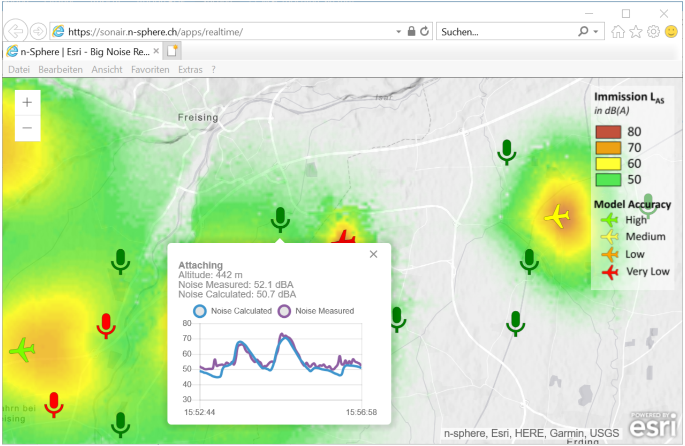
Typische Abflugverfahren

> ALD – Minderung des Fluglärms > U. Isermann • Lärmoptimierte Flugverfahren >Berlin, 19.06.2012 >> Folie 8

Outlook: live aircraft noise calculations with sonAIR

Live aircraft noise calculations with sonAIR

Pilot project for Airbus: Empa in cooperation with partner n-Sphere



Attaching
Altitude: 442 m
Noise Measured: 52.1 dBA
Noise Calculated: 50.7 dBA

Thank you for your attention. Questions?