FROM EMISSION TO IMMISSION - AIRCRAFT NOISE RESEARCH AT DLR GÖTTINGEN

01.12.2022
i-LUM Doktoranden-Kolloquium
HAW Hamburg

Lothar Bertsch, DLR Göttingen

previous contact with HAW

- contact to Prof. Scholz (some years ago)
  - Diplomarbeit with TU Braunschweig and DLR
- work featured in Mobiles (2015)

new low-noise aircraft – **forschung und entwicklung**

aircraft design

conceptual design of new low-noise aircraft

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- PhD candidate from HAW at DLR Göttingen (until 2021)
- Prof. Akkermans: joint M.S. thesis (2022)

DLR

content of talk

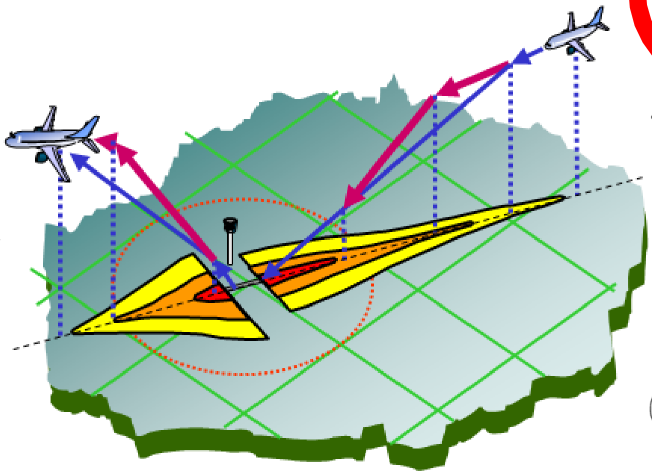
- research teams & tasks
- introduction ➡
- (mixed fidelity) low-noise aircraft design ➡
- challenges ➡
- summary/conclusion ➡

research teams & tasks

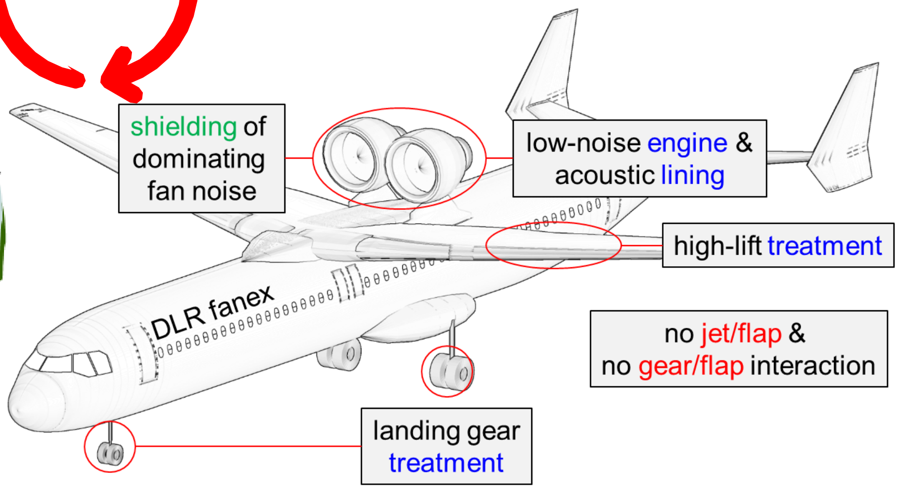
- 3 dedicated teams (each with staff of 3-4): scenario noise (since 1994), **low-noise a/c design** (since 2014), and **small aircraft noise and local pollutants** (since 2022)

- main tasks:
  - **software development**, e.g., noise prediction, design, flight simulation, multi-fidelity simulation …
  - **research / applications**, e.g., assessment of mitigation measures
  - **consulting**, e.g. ICAO, EASA …
  - **teaching**, e.g. lecturing, Master/PhD thesis work …

technology retrofit



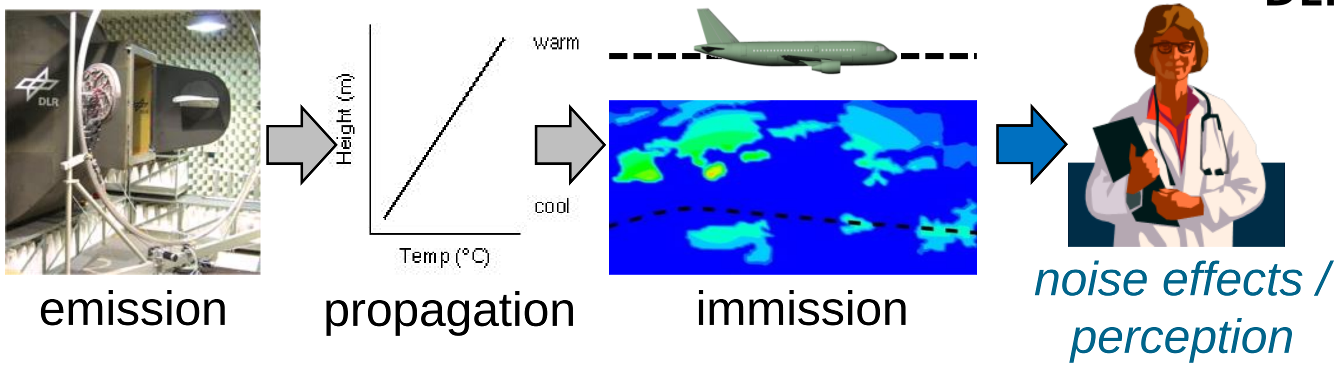
flight operation



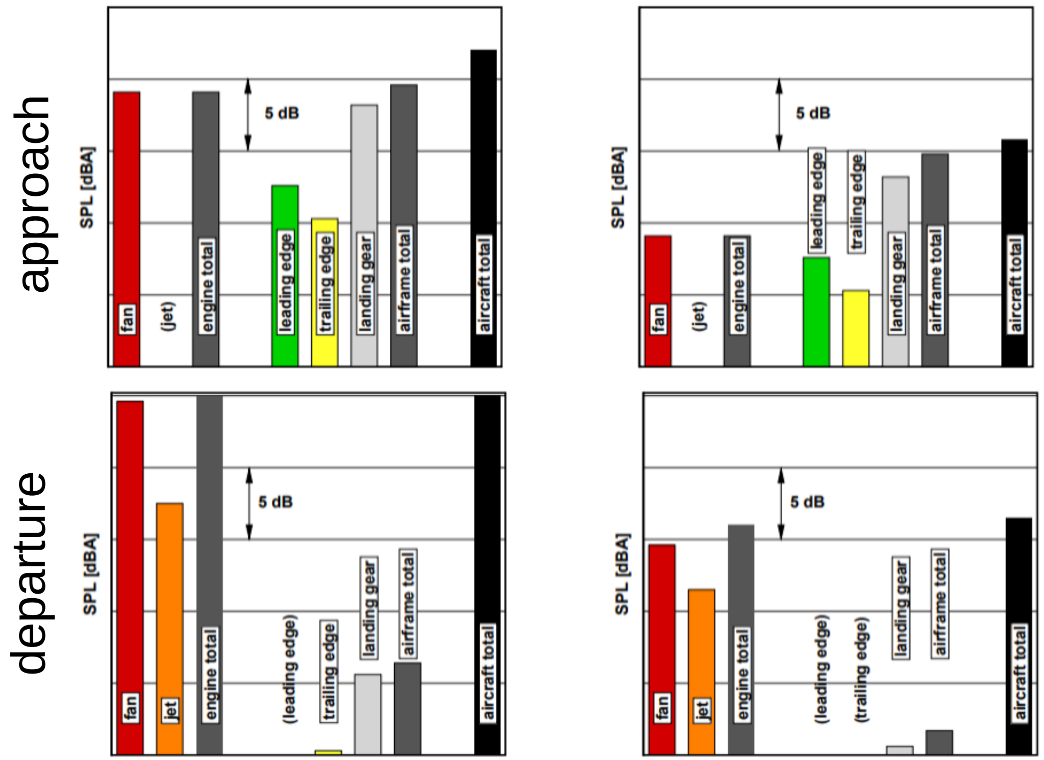
novel a/c design

research teams & tasks

- **prediction**
  - from emission to immission along entire flight trajectory
  - strongly multi-disciplinary
    → account for relevant disciplines



- **reduction**
  - radical noise goals, e.g., ACARE, not achievable with technology retrofit
    → required measures: combination of **retrofit**, **operation**, and **design**
  - main acoustic properties defined by design
    → noise as early **design objective**



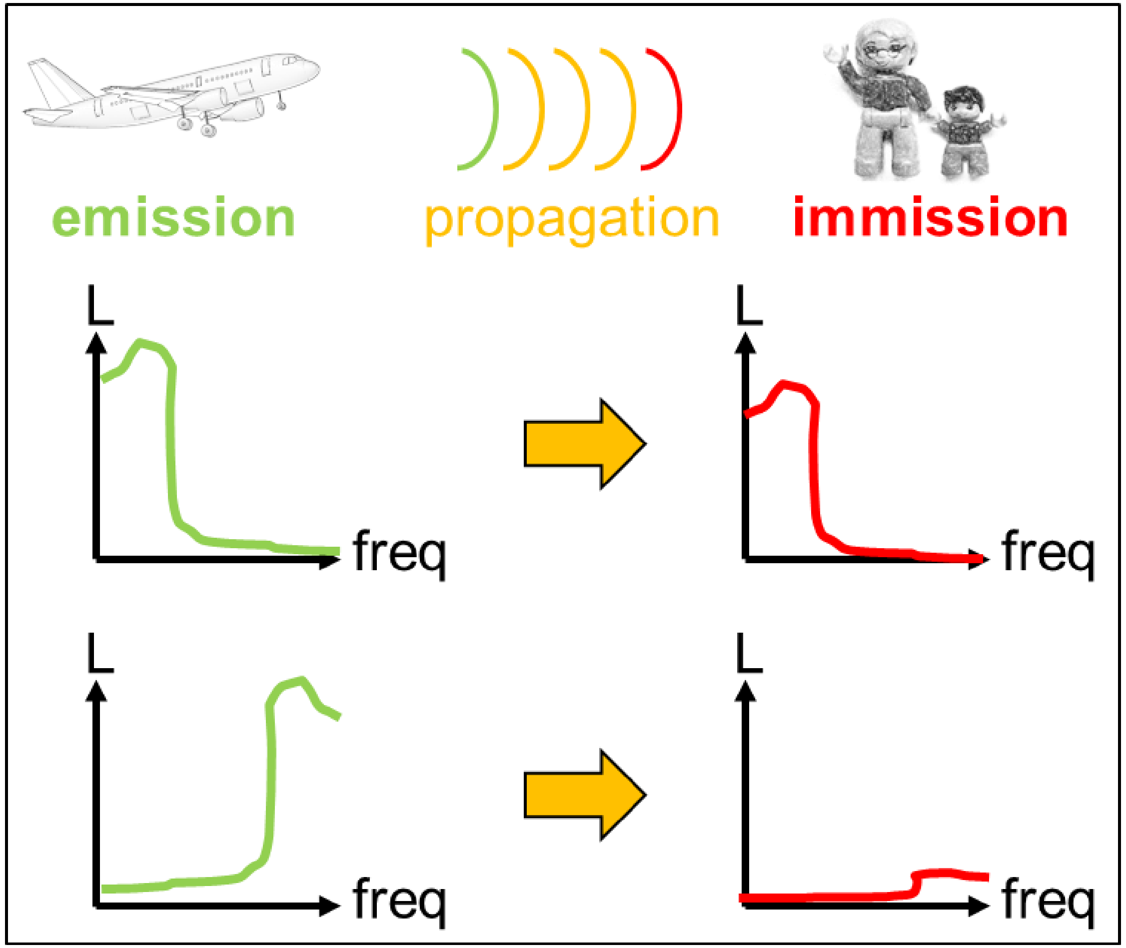
reference

advanced techn. retrofit

https://doi.org/10.34912/ac-n0is3

introduction: terminology

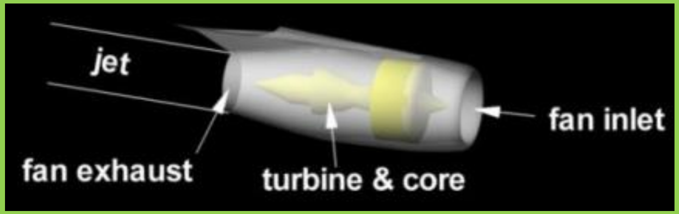
- **emission** = source
- **propagation** (through turbulent atmosphere)
  - **dependent** on freq / noise source
    here: atmospheric attenuation
  - **independent** of freq / noise source
    - distance (geometric spreading)
    - moving source effects:
      for example: Doppler shift
- **immission** = receiver situation



$$\frac{f_{moving}}{f_{stationary}} = \frac{1}{1 - Ma \cdot \cos(\theta)}$$

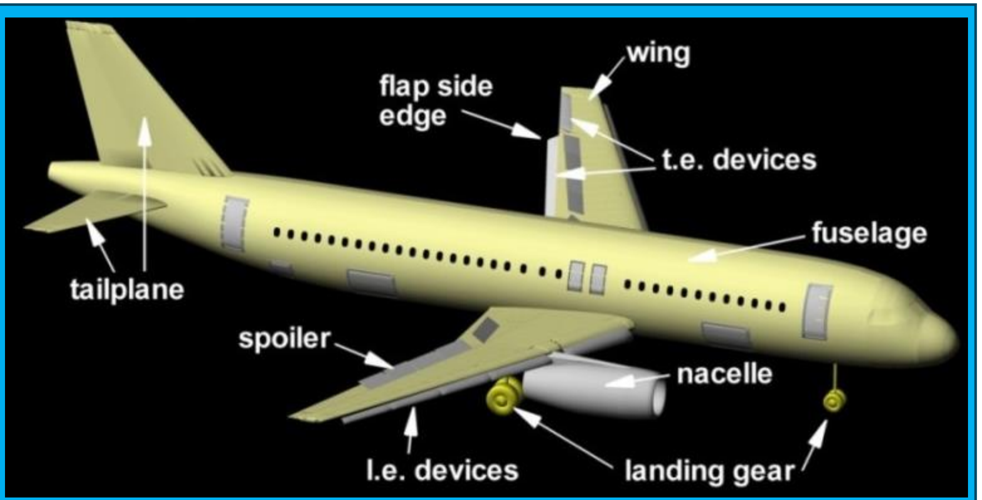
introduction: noise source categories
(here: tube-and-wing a/c w. turbofan)

propulsion noise sources



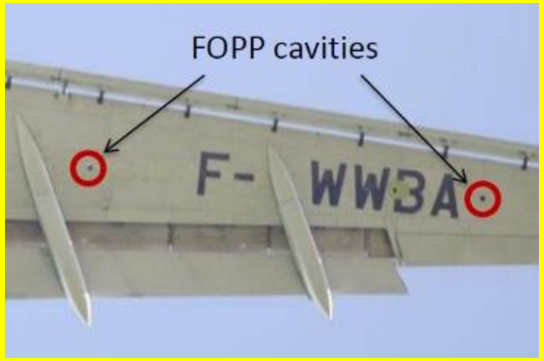
aerodynamic noise sources

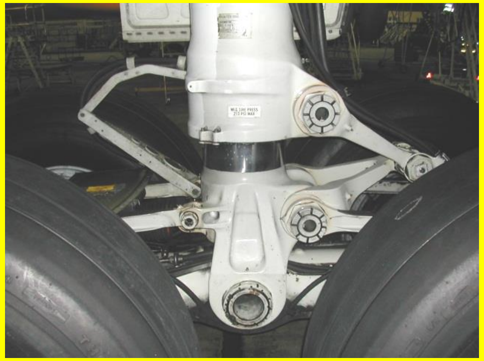
- airflow around vehicle / components



interaction noise sources

- additional contribution; avoidable by separation of components





parasitic noise sources

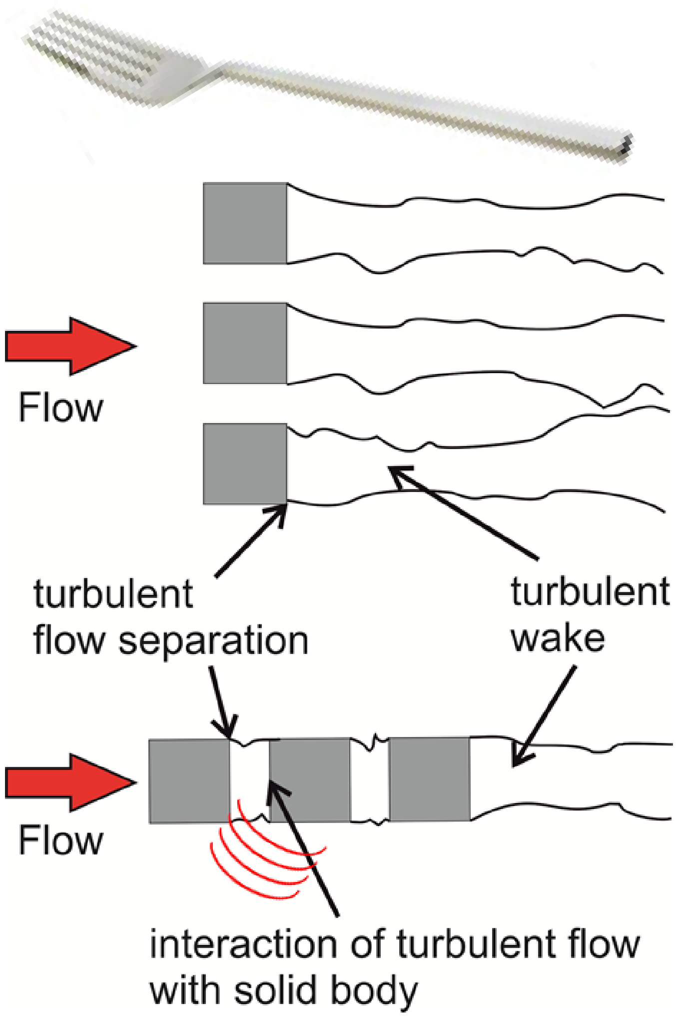
- „unnecessary“ contribution: avoidable by design choices

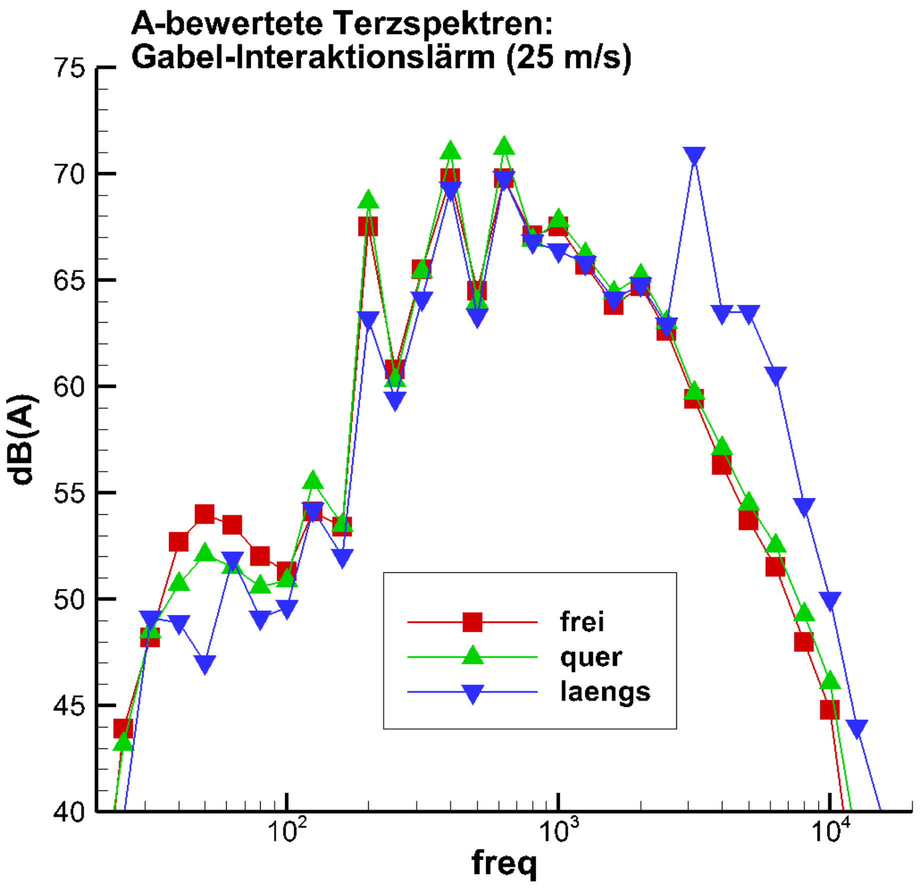
ranking and relevance of individual effect **not constant**
→ strongly dependent on specific geometry/vehicle and operating condition

introduction

interaction noise source

- simple example

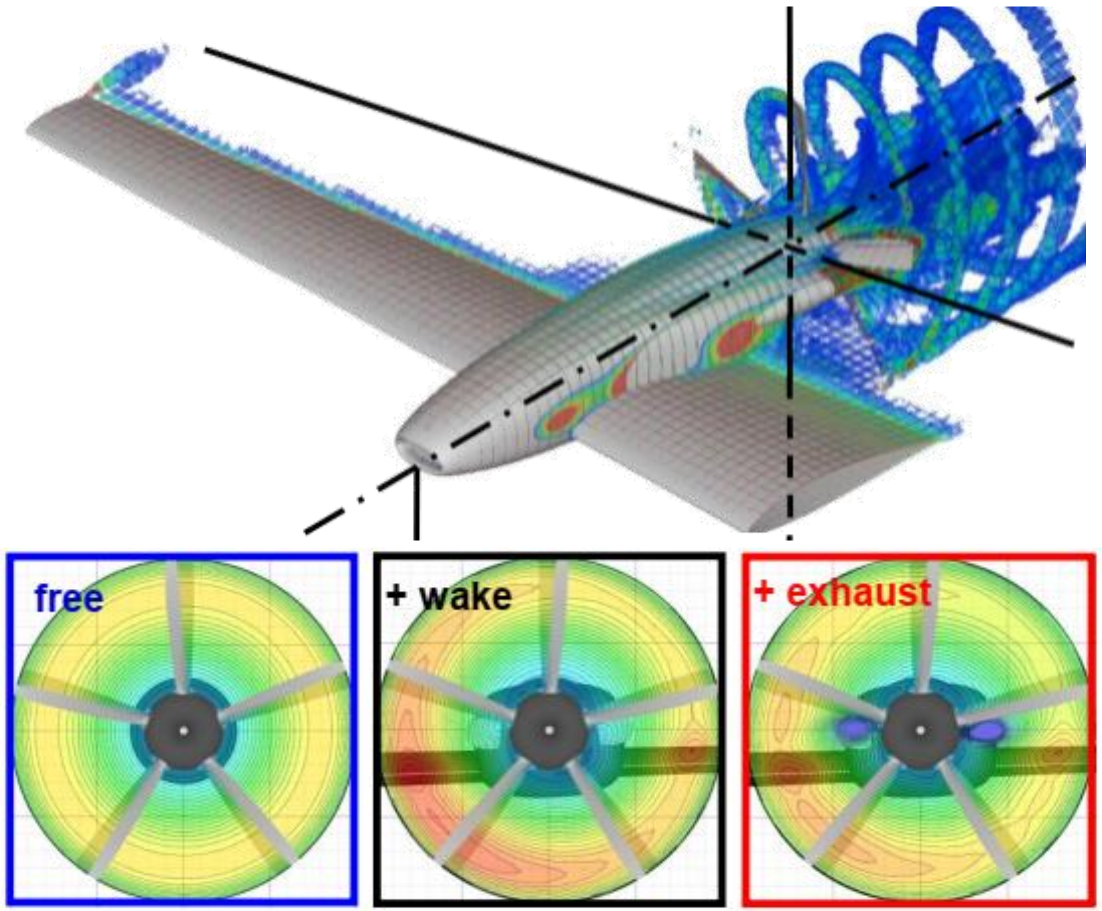


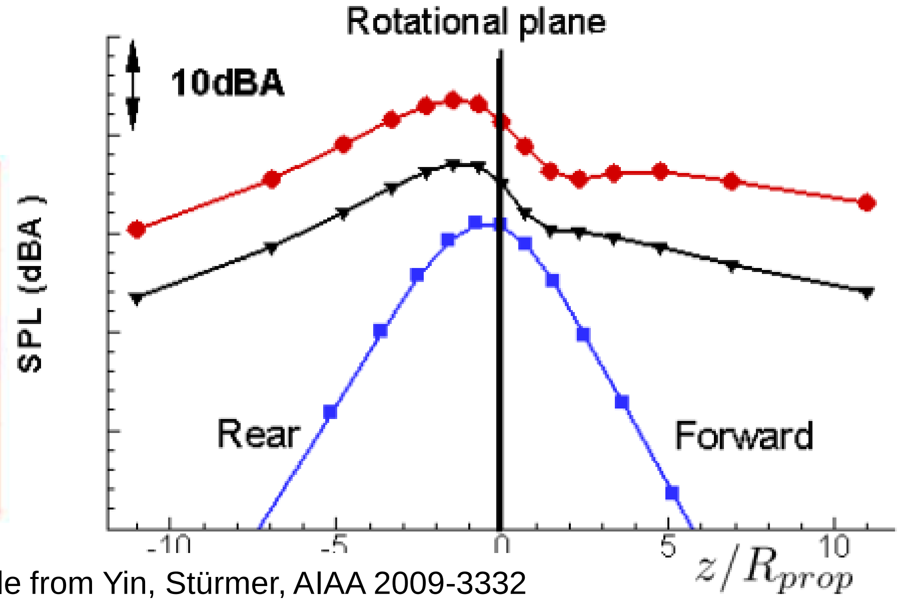


- audio file:
  frei / - / quer / - / längs

introduction
interaction noise source

- real life example:





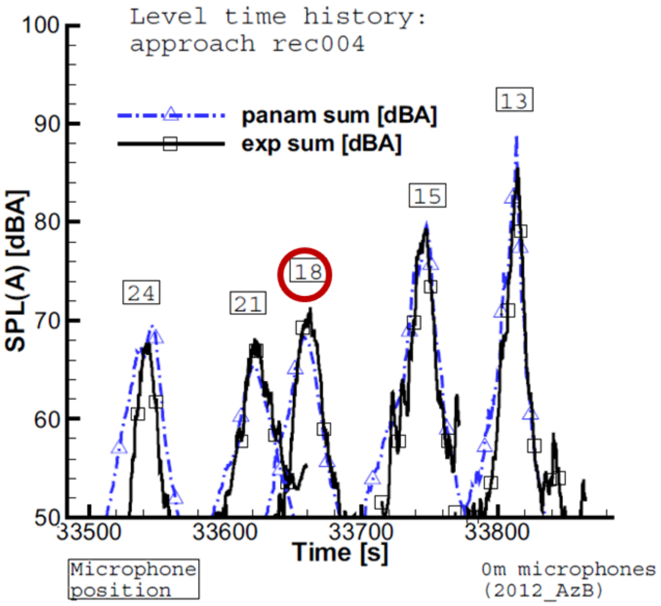
towards a flying

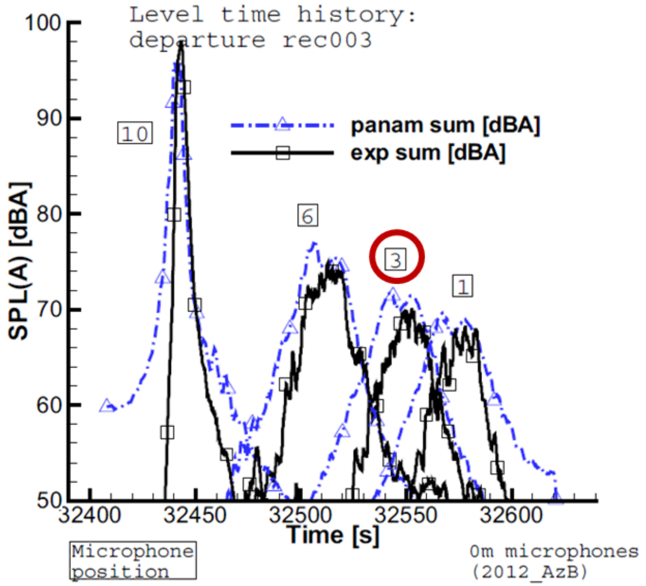
???

© interaction noise example from Yin, Stürmer, AIAA 2009-3332

introduction
noise source ranking in reality

- complex orchestra of noise sources → varying rank-order of sources, esp. approach
- approach situation:
  - observer location ~ 12 km prior runway threshold
  - aircraft at ~ 1000 m altitude
  - configuration: mid high-lift / no gear
  - engine setting: low
  - maximum noise level (A-weighted) ~ 70 dBA
- departure situation:
  - observer location ~ 11 km after runway threshold
  - aircraft at ~ 1300 m altitude
  - configuration: clean
  - engine setting: high
  - maximum noise level (A-weighted) ~ 70 dBA



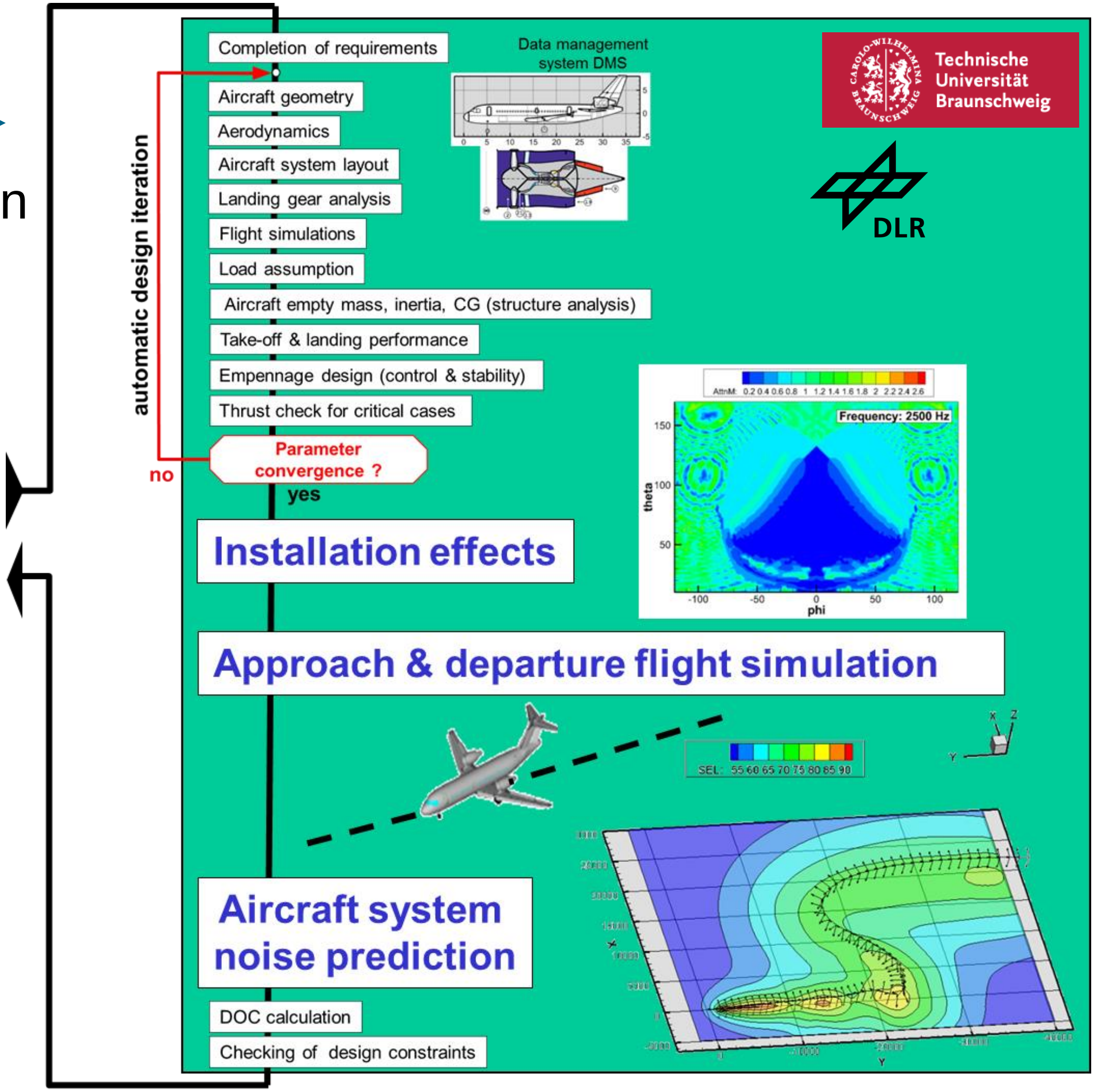


(mixed-fidelity) low-noise aircraft design
simulation process

- in-house a/c design process w. fully embedded noise assessment
  - **componential** & **parametric** noise simulation
  - interfaces to process external data

- external a/c: noise evaluation (incl. flight simulation)
  - common simulation plattform **RCE**
  - common data language **cpacs**

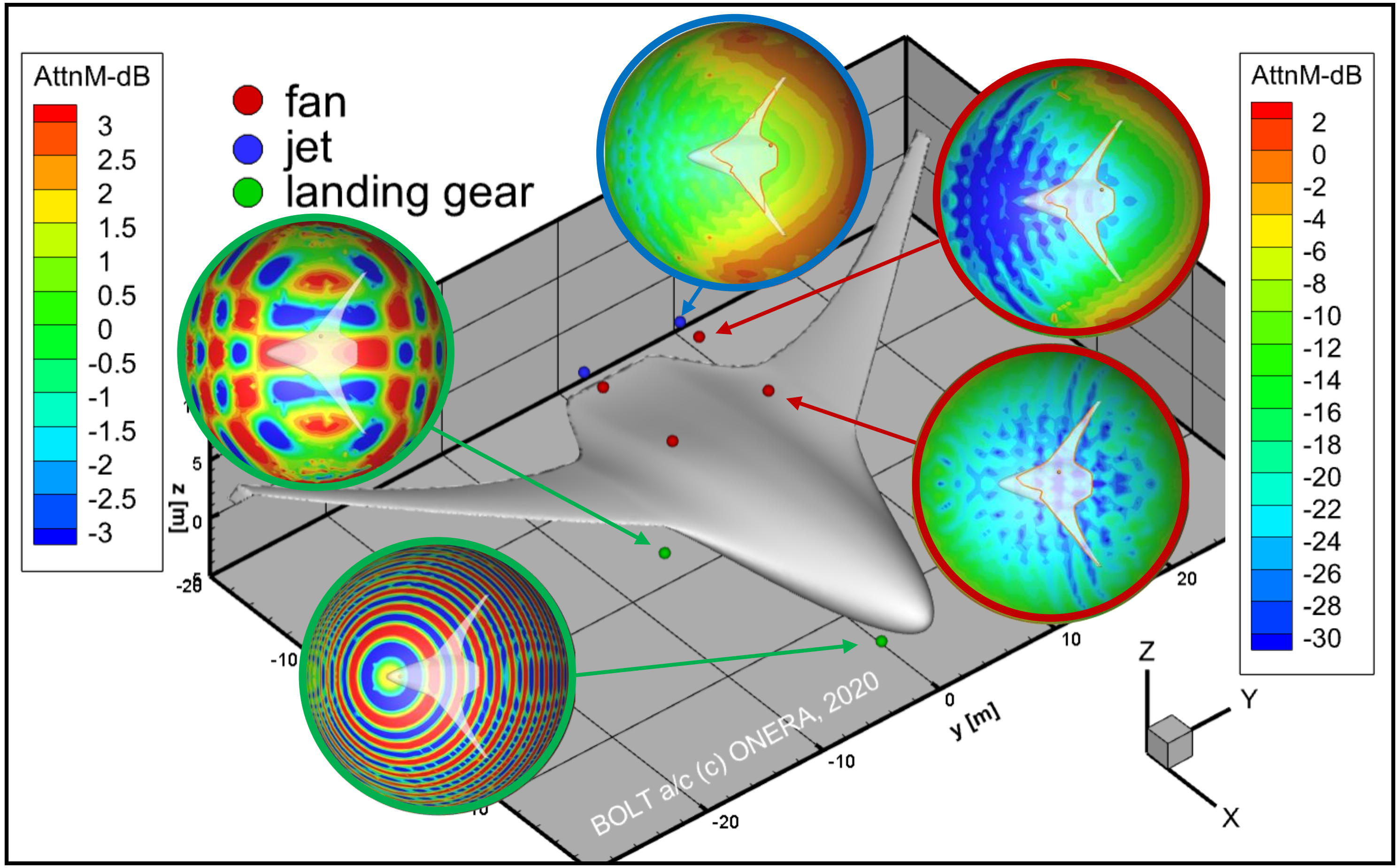
- assessment of arbitrary noise descriptors at arbitrary receivers



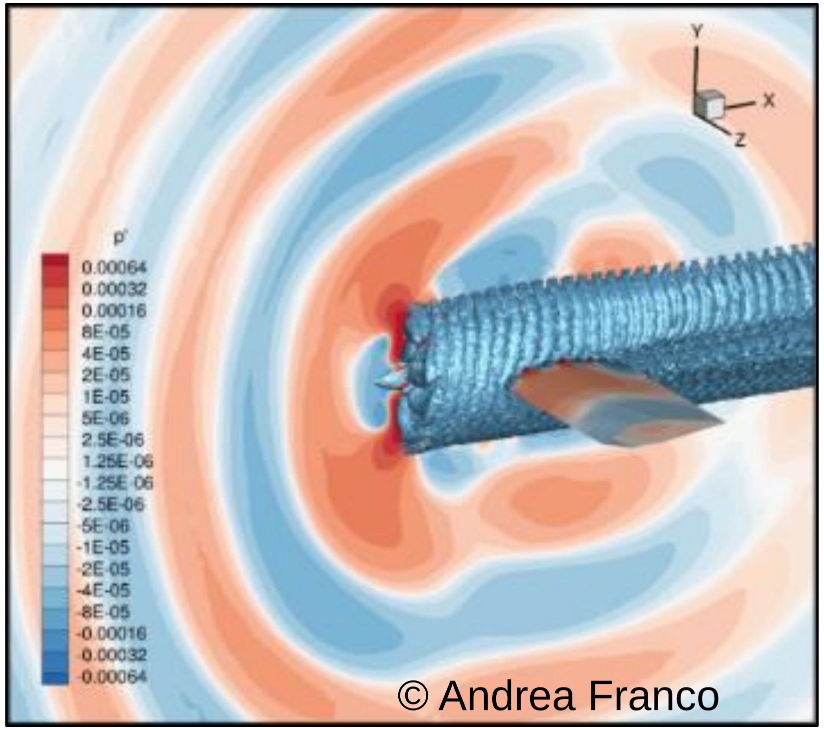
(mixed-fidelity) low-noise aircraft design

external input data

- numerical or experimental data (typically source information: emission)
- absolute or delta values



EU ARTEM: BWB noise shielding delta levels

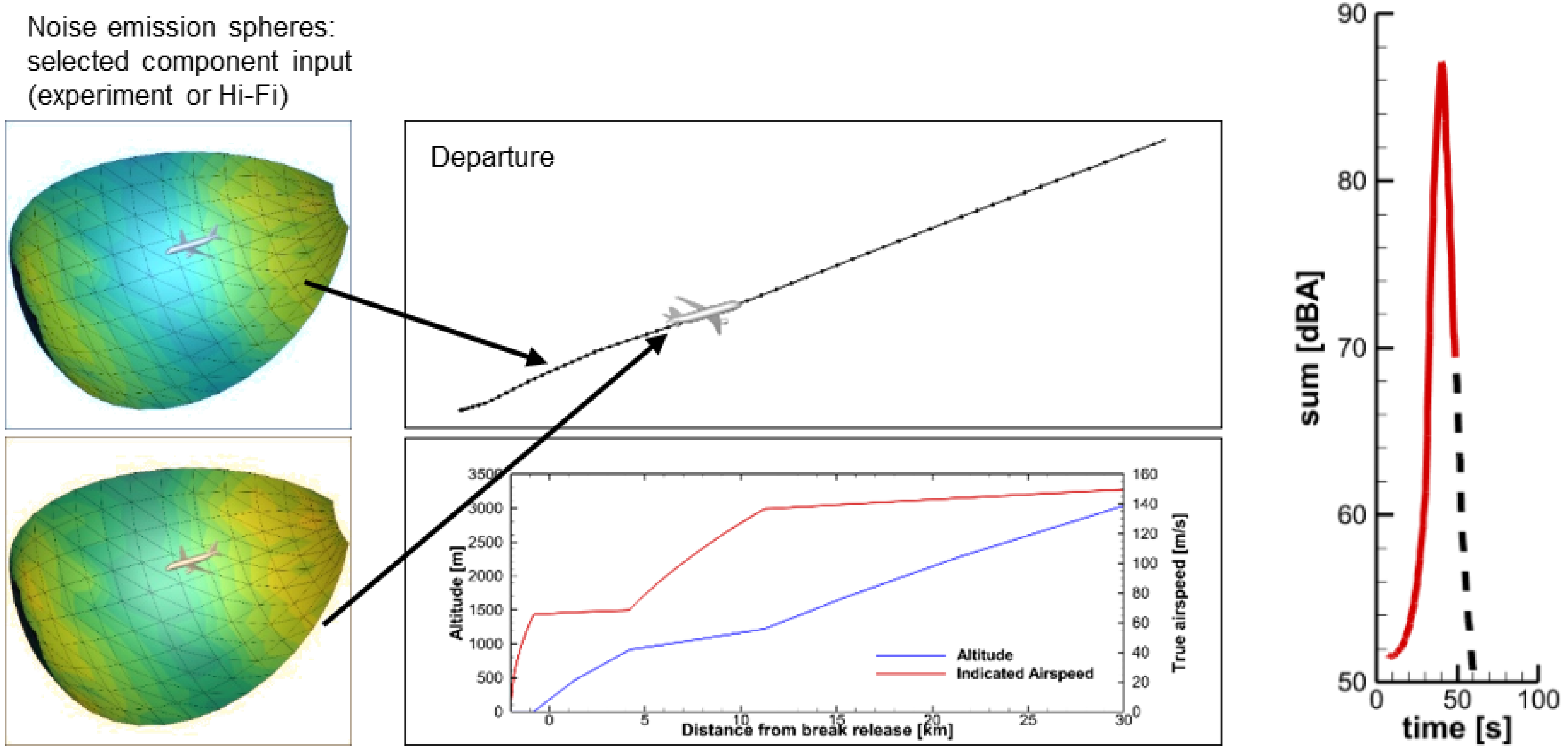


SE2A: propeller installation absolute noise levels

(mixed-fidelity) low-noise aircraft design

external input data

- example: processing absolute levels (noise emission spheres)

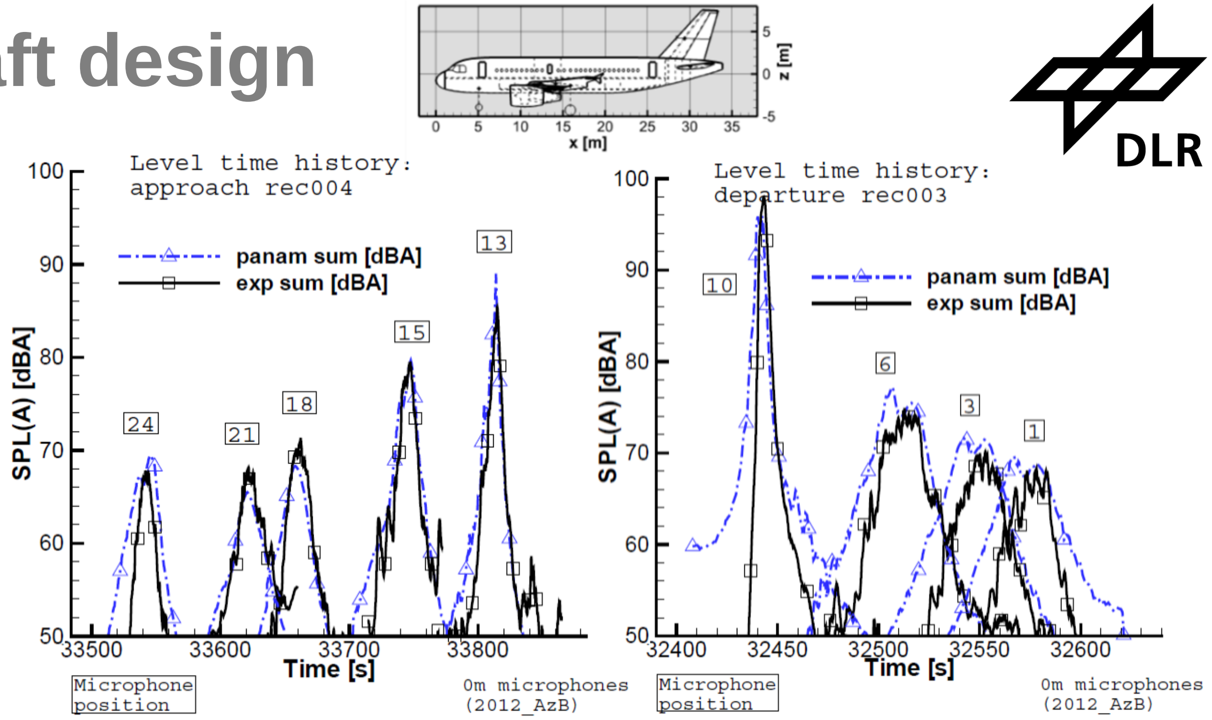


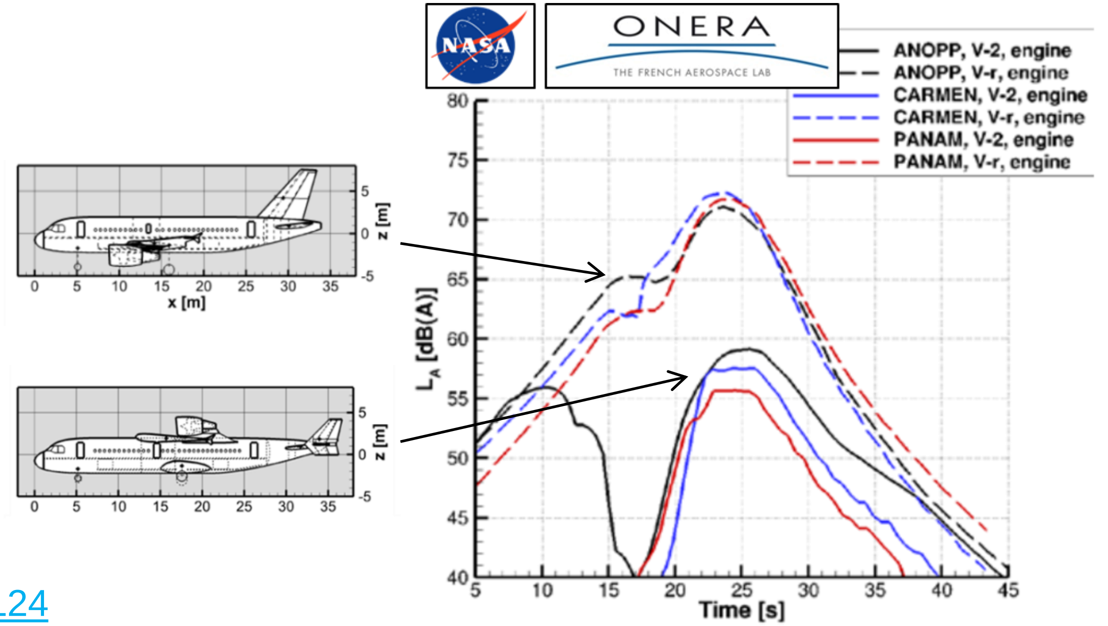
(mixed-fidelity) low-noise aircraft design

tube-and-wing aircraft: result validation

- comparison with experimental data
  - components: windtunnel data / engine testbed
  - overall aircraft: measured fly-over data, e.g., A319*, A320, B747, Dornier 228, and VFW 614
  - available data bases (cert. levels, NPD)

- comparison with numerical data
  - components: Hi-Fi aeroacoustic simulation
  - overall aircraft: tool-to-tool** comparison
- *(plausibility/feasibility check: textbook, existing knowledge …)*



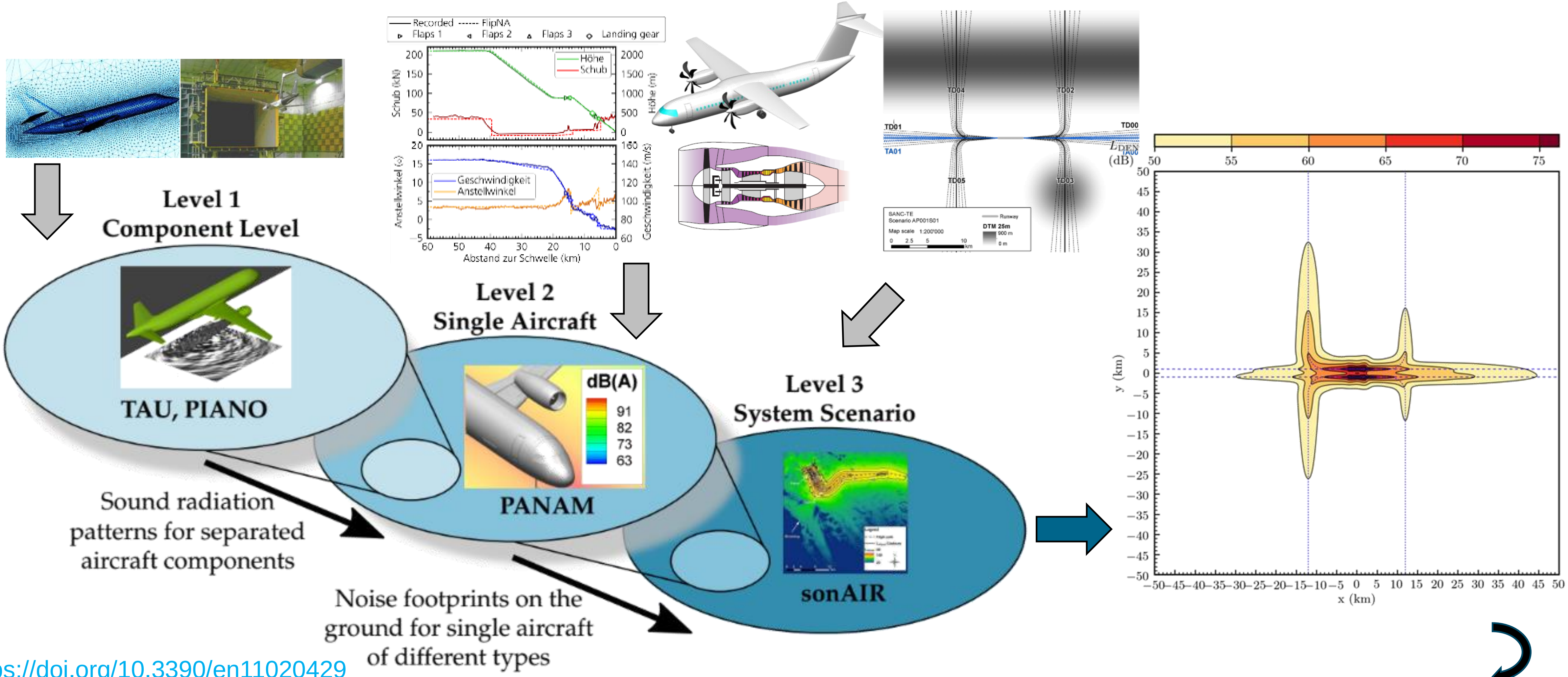


*) https://doi.org/10.34912/n0is3-d3sign **) https://doi.org/10.2514/1.C036124

(mixed-fidelity) low-noise aircraft design

multi-level simulation

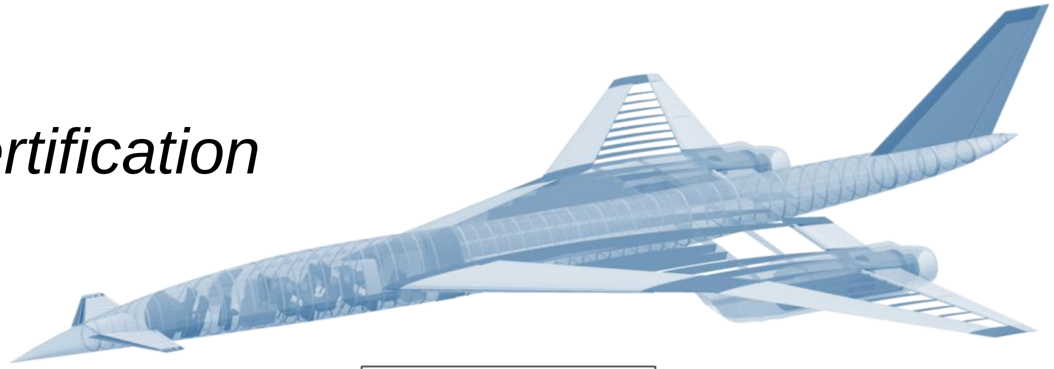
- three-level approach: component, single aircraft, and scenario
  - scenario simulations according to Doc 29, AzB, DIN or physics-based sonAIR



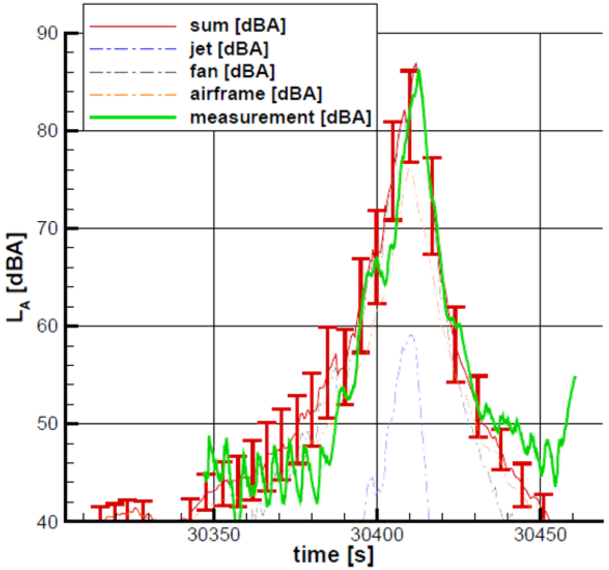
https://doi.org/10.3390/en11020429

challenges

- *super sonic transport noise certification*
  (not further discussed today)



- *simulation uncertainties*
  (not further discussed today)



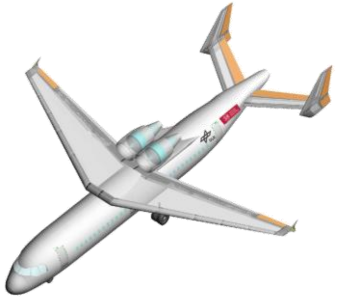
- perception influenced design
- advance air mobility noise assessment (single flight & scenario)

challenges

perception influenced design ™

- reference: A319 *(-ish)*
- low-noise a/c: „game changer“
- approach situation
- receiver: 4 km prior touch-down

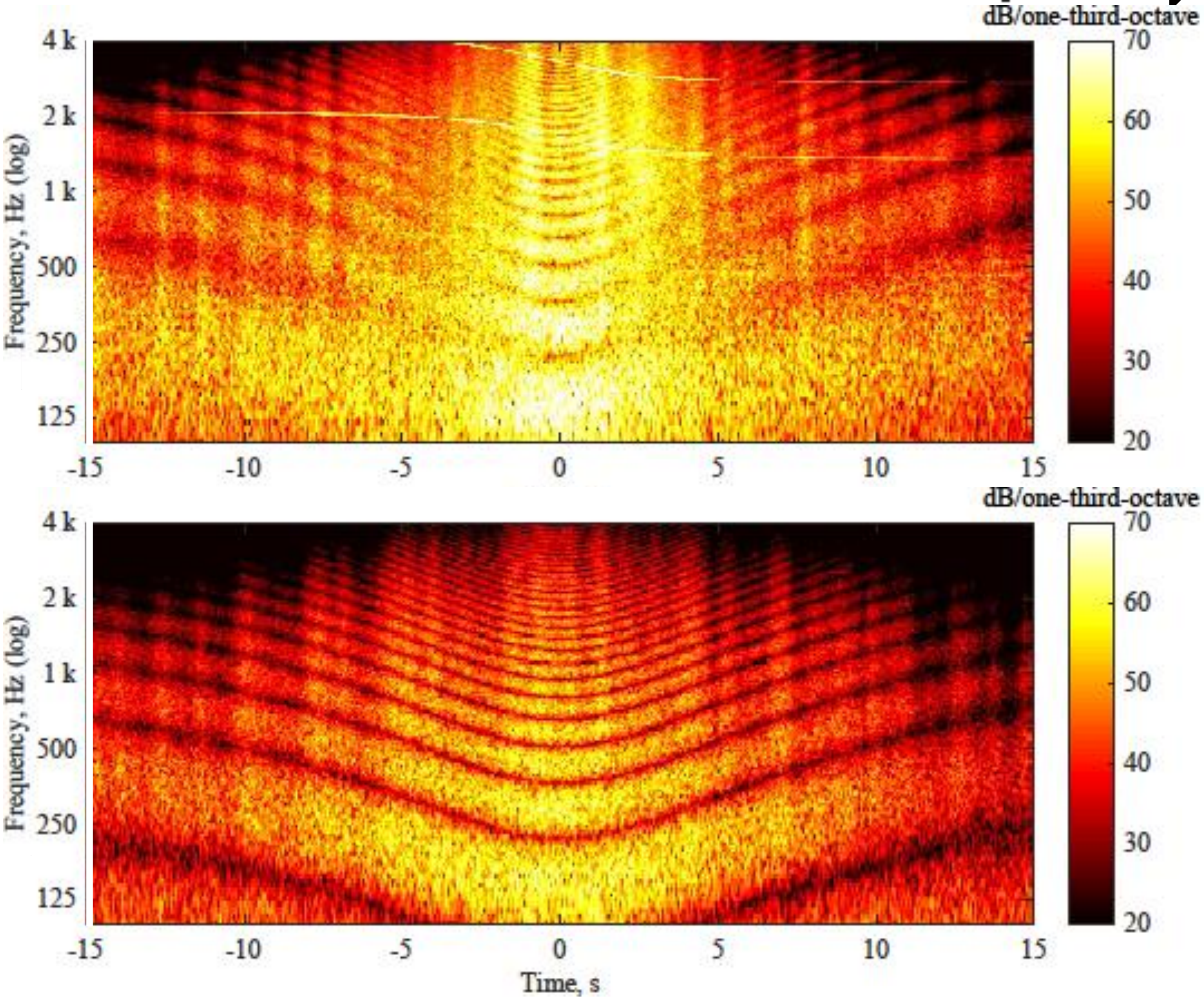
reference



game changer

Freitag, 17. Januar 2020 Neue Zürcher Zeitung FORSCHUNG UND TECHNIK 55

Die Flugzeugflüsterer



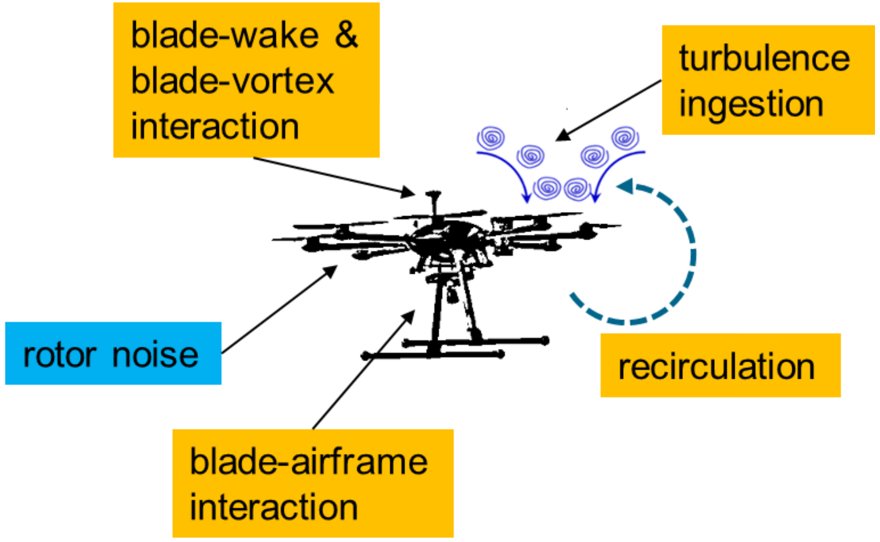
https://doi.org/10.1016/j.scitotenv.2019.07.253

~~propulsion~~ aerodynamic ~~parasitic~~ interaction

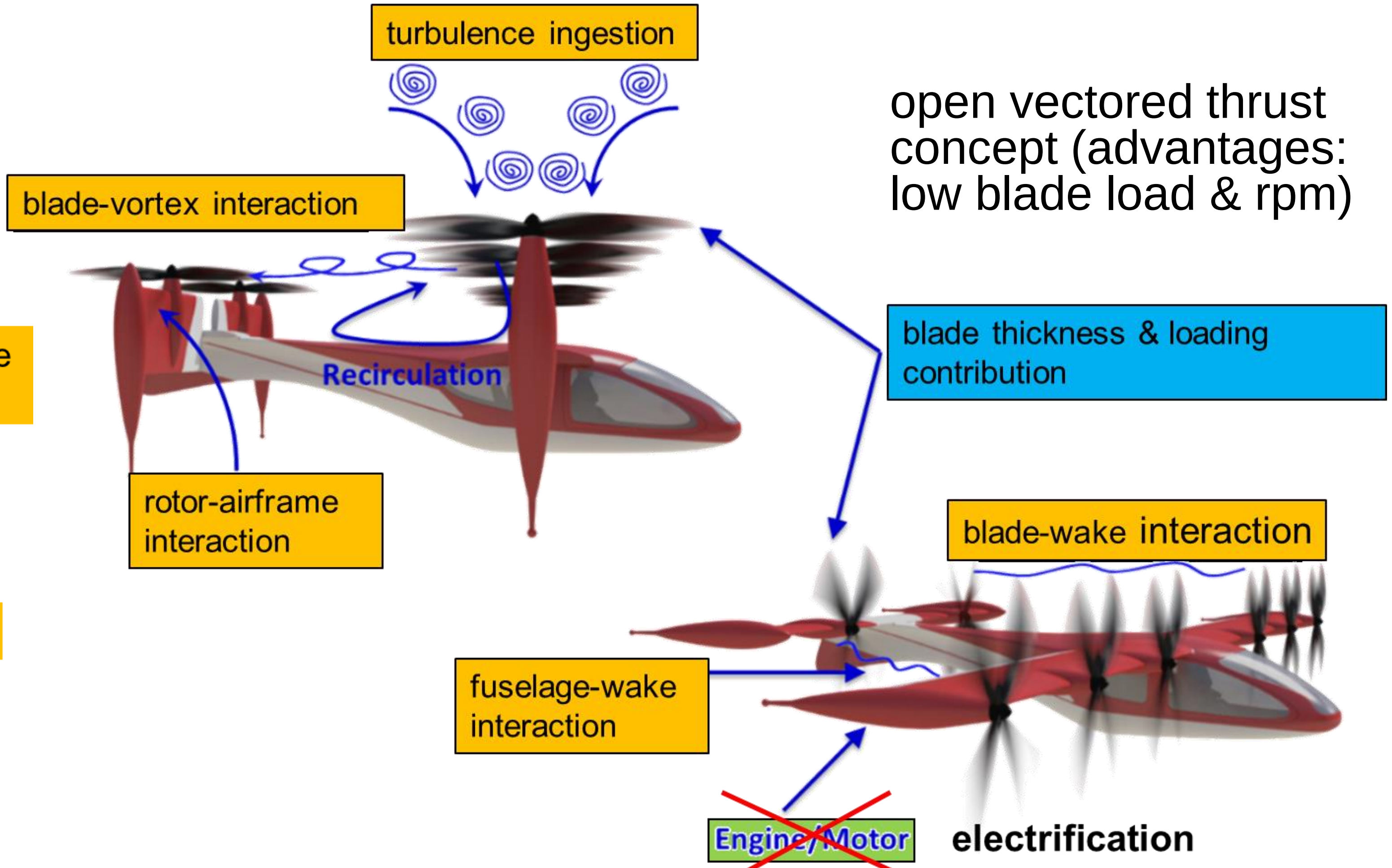
challenges
advanced air mobility (and drones)

- dominating interaction noise → highly dependent on **operating condition**
- examplary vehicles:

octocopter



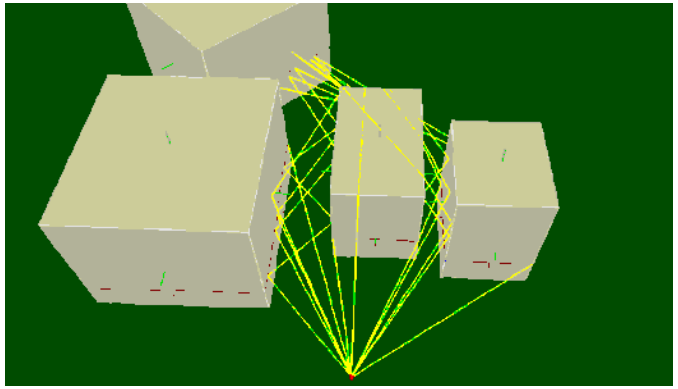
open vectored thrust concept (advantages: low blade load & rpm)

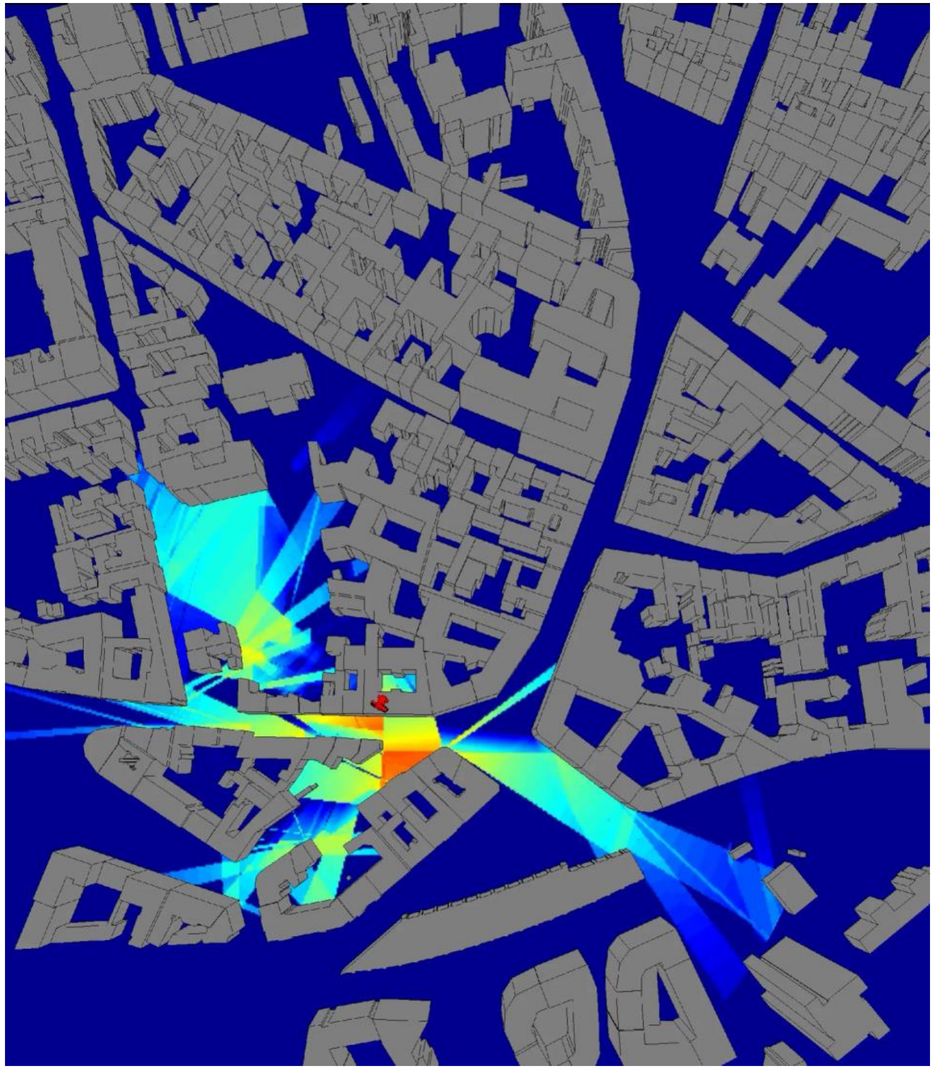


challenges

advanced air mobility (and drones)

- inherent unique challenges
  - high number of flight movements (much more than helicopters)
  - operation in close proximity to densely populated areas
  - short propagation distances (no advantageous atmospheric attenuation)
    → higher frequencies are not attenuated
  - street canyons → reflections
  - unprecedented and/or additional noise exposure for large parts of the population





challenges
advanced air mobility (and drones)

- **acceptance of AAM ??**
  - community disturbance: increase in perceived levels due to certain factors
  - for example equivalences from old ISVR study *:
    - negative reaction to leisure flying + 5 dB(A)
    - poor community/airfield relations + 10 dB(A)
    - fear of crashes + 10 dB(A)
    - nobody acts on complaints + 20 dB(A)
    - aircraft are flying too low + 20 dB(A)

    (equivalences are not reversible)

*) Ollerhead, J. et al.: “A Study of Community Disturbance Caused by General and Business Aviation Operations”, ISVR, University of Southampton, U.K. Department of Transport, July **1988**

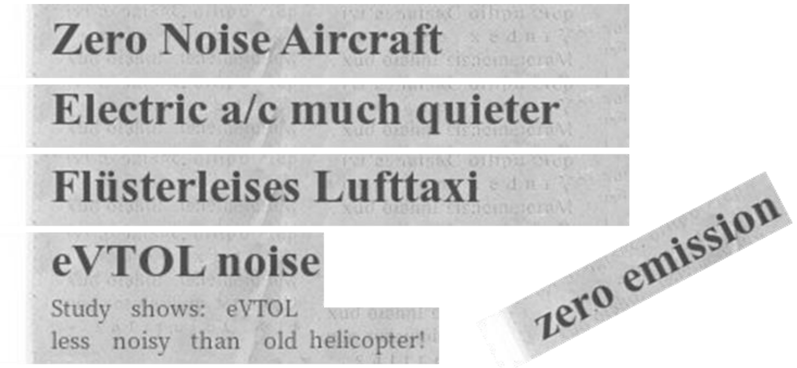
  - example: comparison of drone to car drive-by (video © Prof. Shane Ross, Virginia Tech, 2021)
    - significantly different perception of video
    - magnitude of level does not reflect the problem (selection of metric?)

summary & conclusion

- main reserach activities in Göttingen: prediction & reduction of a/c noise
- challenges: SST, AAM & drones, perception influenced design, and simulation uncertainties
- most important lessons learned for noise assessment
  - caution with “representative” or “typical” situation: magnitude of contributions and rank-order/dominance of sources NOT constant
  - avoid overly simplified assessment (no meaningful results)
    - don‘t focus on fixed operating conditions
    - don‘t focus on few observer locations
    - apply multiple noise descriptors (evaluation biased by noise descriptor!)
- AAM & drones
  - acceptance issue
  - interaction noise source are dominant
  - short distances → frequency content (emission!)
  - carefull with differential engine control → annoyance
  - **too simplified assessment can be completely off!**

2 pure tones at 800 Hz

pure tone at 780 and 800 Hz



Questions?

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- H2020 project ARTEM: BWB

Aircraft Auralization

Current Long-Range Aircraft - Tube & Wing

vs.

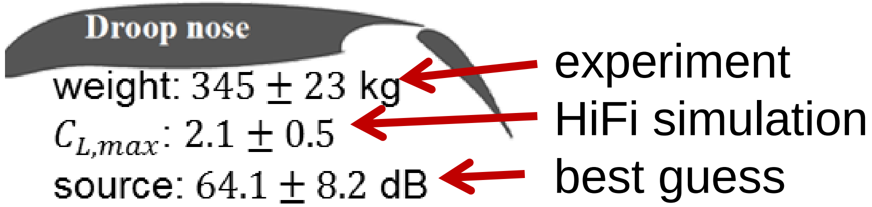
Future Concept (2050) - Blended Wing Body

contributing to the Horizon 2020 project ARTEM

[Internoise 2022 paper](); https://www.youtube.com/watch?v=5cuORVT-Wt8

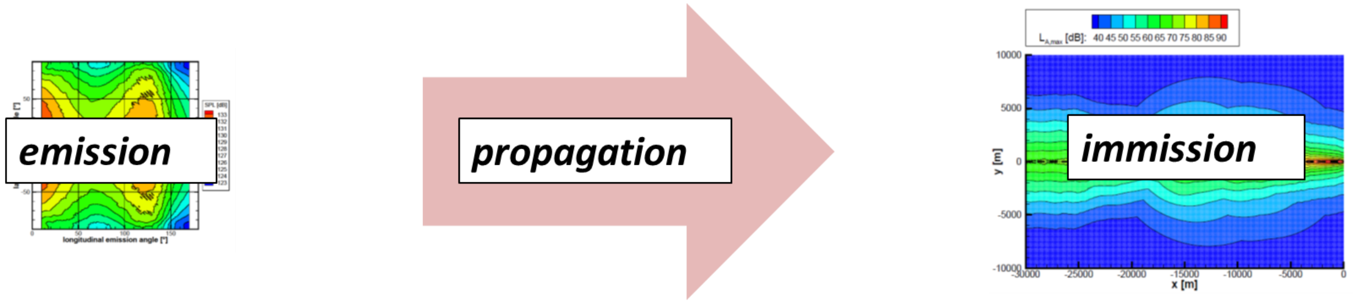
challenges
uncertainty quantification

- quantification of simulation uncertainties:
  - essential for mixed-fidelity methods
  - essential for dose-response studies

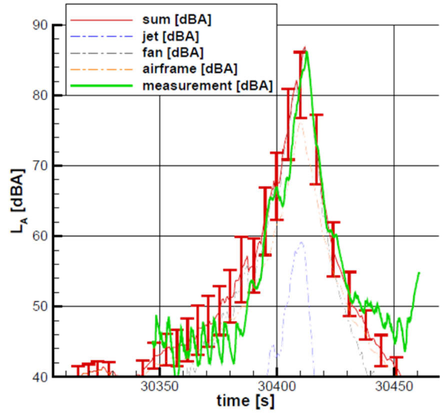


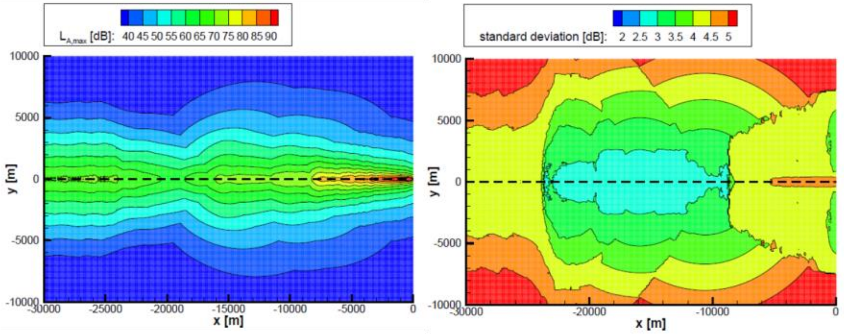
$$P_{\mathrm{AWR}} = 1.894 \cdot 10^{-3} \cdot L^2_{A,\max} + 4.008 \cdot 10^{-2} \cdot L_{A,\max} - 3.3243$$

- overall UQ:
  - input uncertainty
  - model uncertainty
  - propagation uncertainty



- approach: first-order second-moment (FOSM)
  - linearization / Taylor approximation
  - valid for small uncertainties: good agreement with Monte Carlo / Polynomial Chaos
  - fully embedded assessment (1 run): spacial and temporal distribution





max. level distribution

corresponding uncertainty distribution

https://doi.org/10.2514/1.J061143; https://doi.org/10.2514/1.C034809