Deutsche Gesellschaft für Luft- und Raumfahrt Lilienthal-Oberth e.V. Bezirksgruppe Hamburg

ROYAL AERONAUTICAL SOCIETY HAMBURG BRANCH e.V.

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HAW HAMBURG

Hamburg Aerospace Lecture Series
Hamburger Luft- und Raumfahrtvorträge

Das ZAL lädt ein zum Vortrag in Kooperation mit DGLR, RAeS, VDI und HAW Hamburg

ZAL Diskurs

Leise Reise – Reduzierung von Fluglärm im Fokus

Vortrag

Voranmeldung:
https://diskurs-leise-reise.eventbrite.de

Eintritt frei !

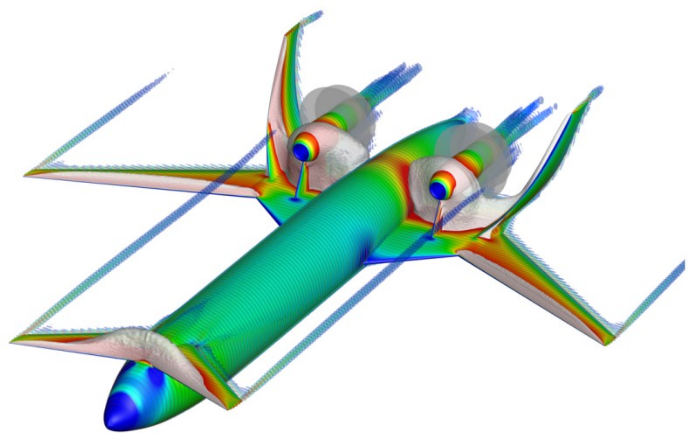
Datum: Dienstag, 07. Mai 2019, 16:00 Uhr
Ort: ZAL TechCenter
Hein-Saß-Weg 22, D-21129 Hamburg
Auditorium

Luftfahrt verbindet Mensch und Wirtschaft weltweit und ermöglicht die Überwindung ungeahnter Entfernungen in kürzester Zeit. Diese Form der Mobilität muss jedoch mit dem Bedürfnis nach Lärmschutz in Einklang gebracht werden. Luftfahrt und Politik haben sich ehrgeizige Ziele gesetzt. Bis 2050 soll Flugzeuglärm stark verringert werden. Bereits bis 2020 dürfen neue Maschinen nur noch halb so laut sein wie zur Jahrtausendwende. In unserem Diskurs zeigen wir den Stand der Forschung sowie neue Flugzeugentwürfe mit dem Fokus auf Lärmemission.

- Dr. **Lothar Bertsch**, DLR Göttingen:
  Vorhersage des Außenlärms von existierenden sowie neuen Flugzeugmustern bei Start und Landung

- **Jan Eike Hardegen**, stellv. Leiter Zentralbereich Umwelt, Flughafen Hamburg:
  Die Relevanz lärmarmer Flugzeugbaumuster –
  Historie, Steuerungsmöglichkeiten und Perspektiven aus Flughafensicht

- **Podiumsdiskussion**



Local flow velocity, turbulence and supersonic regions around the DLR - Low Noise Aircraft (LNA) during cruise flight.

Credit: DLR (CC-BY 3.0)

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RAeS Hamburg Branch http://www.raes-hamburg.de
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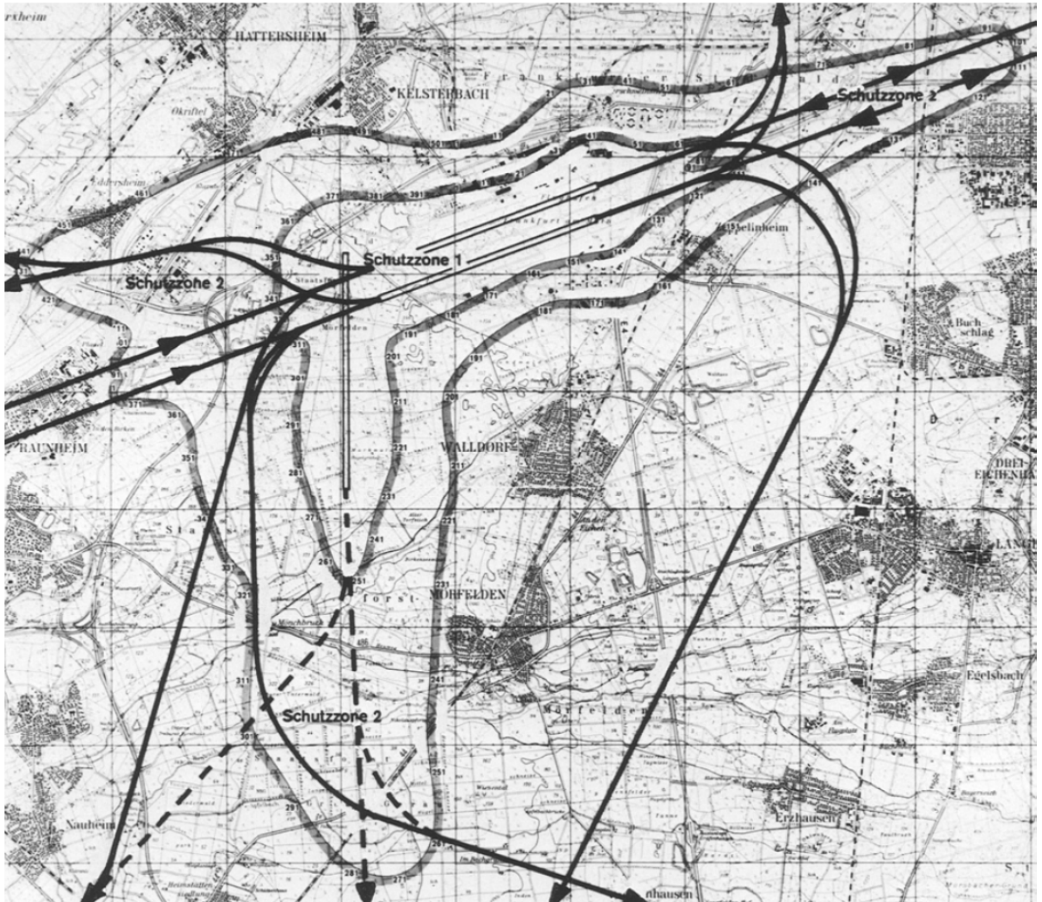
ZAL Diskurs Leise Reise, 07. May 2019, Hamburg

Exterior noise prediction of existing and novel tube-and-wing aircraft during departure and approach



Lothar Bertsch

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https://doi.org/10.5281/zenodo.5589238

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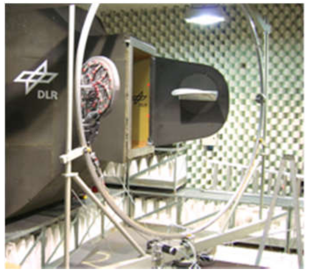
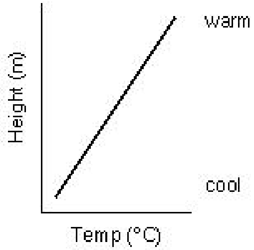
presentation outline

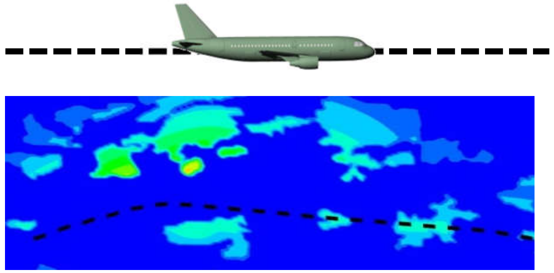
- introduction & motivation
- tools and methods
- application
- future work
- summary

introduction: DLR research of aircraft noise

emission → propagation effects → immission → noise effects / perception







emission

- theory,measurement and simulation of noise sources
- reduction concepts
- measurement techniques
- tools: windtunnels & Hi-Fi simulation

propagation effects

- propagation through turbulent atmosphere & weather
- ground attenuation

immission

- overall a/c assessment (simulated & measured)
- technologies: retrofit and new design, operation, …
- traffic routing / vehicle integration / airport planing
- measurement techniques
- tools: DLR a/c fleet & simulation

noise effects / perception

- exposure-response relationsship (e.g. effects on sleep)
- tools: laboratory & large field studies

DLR institutes:

emission:

- Aerodyn. and Flow Technology
- Propulsion Techn.

propagation effects:

- Atmospheric Physics

immission:

- Aerodyn. and Flow Technology
- Propulsion Techn.
- Flight Guidance
- Flight Systems
- Air Transport and Airport Research

noise effects / perception:

- Aerospace Medicine

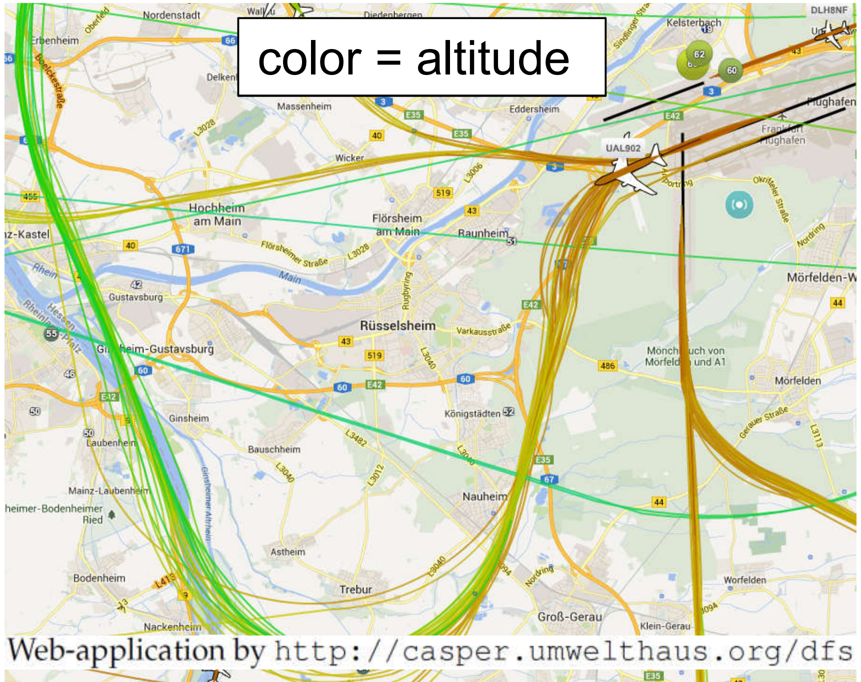
introduction: aircraft noise

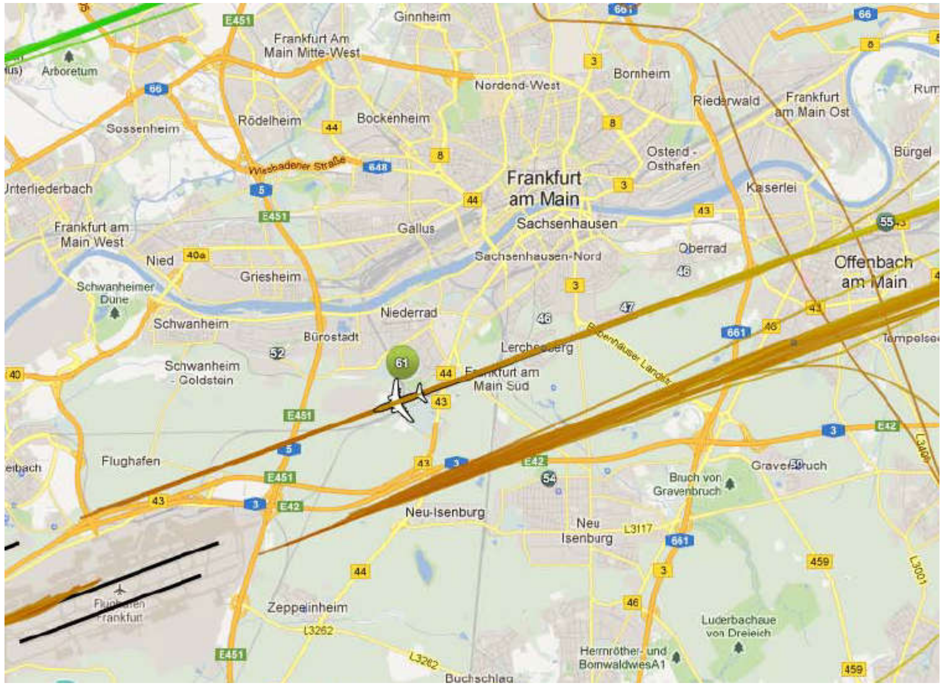
take-off situation

- max. payload/fuel → high engine setting → high noise emission
- fast altitude gain → increasing source distance (+)
- individual routing → possible noise distribution (+)

landing situation

- complex orchestra of noise sources (-)
- glide slope → slow descent → large areas subject to low/slow flights (-)
- traffic routes and separation → “hotspots” with large number of flights (-)





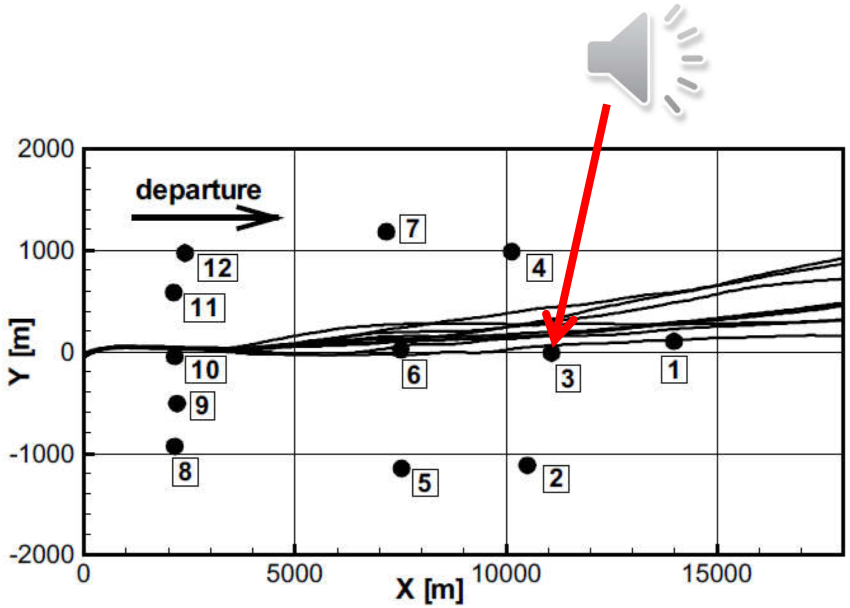
introduction: aircraft noise

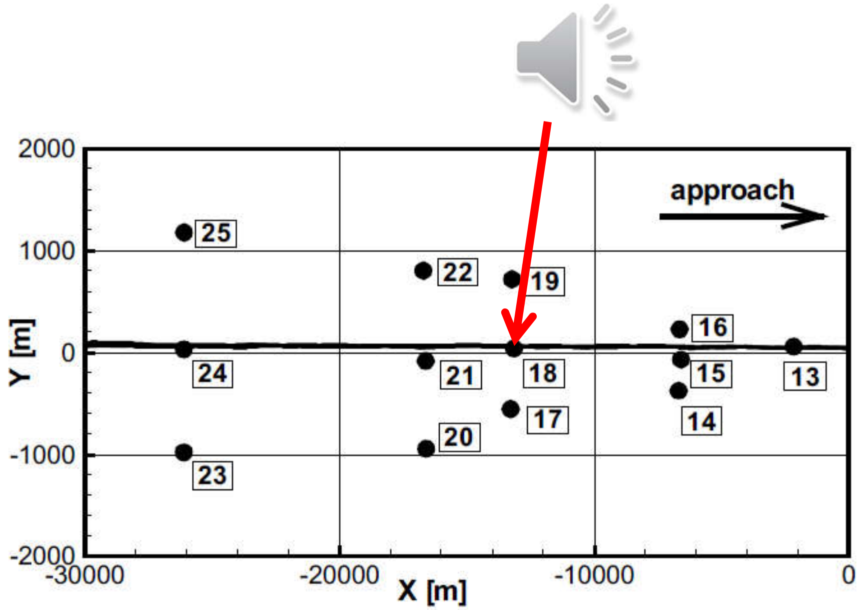
take-off situation

- observer at 11 km after rwy threshold
- flight altitude: 1300 m
- clean configuration
- $L_{A,max}$ approx. 70 dB

landing situation

- observer at 12 km prior rwy threshold
- flight altitude: 1000 m
- high-lift elements deployment: middle
- $L_{A,max}$ approx. 70 dB



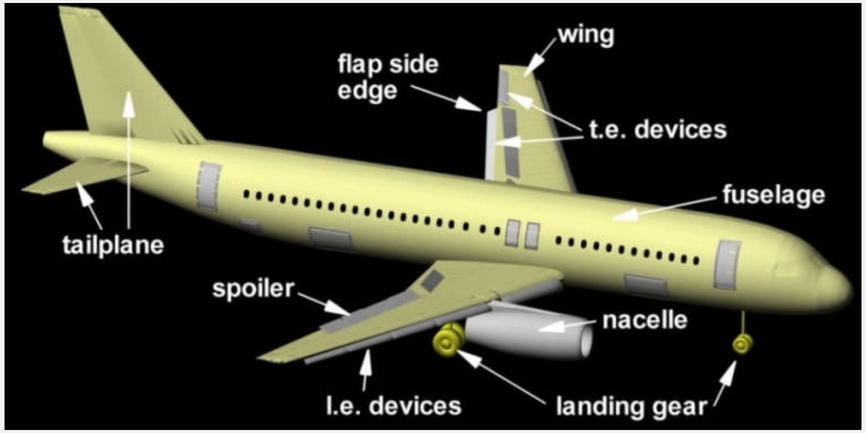


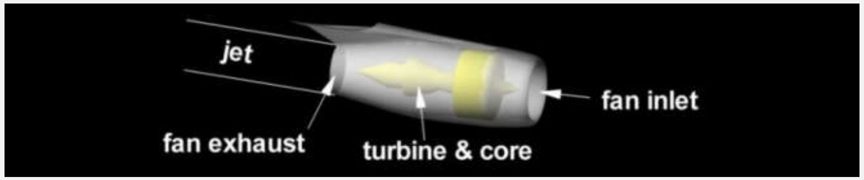
- inherently different:	operating conditions & noise source dominance
- in common:	high noise levels @ close distances / transient signals / mix of broadband and tones

introduction: noise generation on board

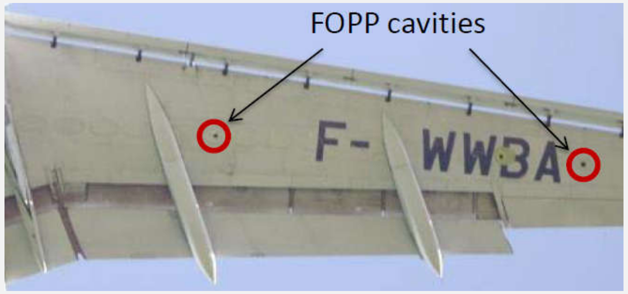
conventional tube-and-wing aircraft (w. turbofan engines)

overall vehicle noise

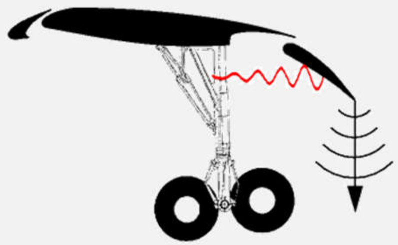




„classical“ noise sources (airframe & engine)



parasitic noise sources



interaction noise sources

ranking and relevance of individual effect is strongly dependent on specific vehicle and operating condition !!!

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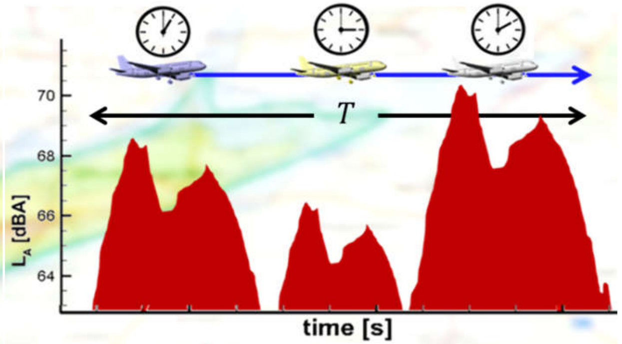
motivation: aircraft noise reduction

time-weighted, equivalent continous sound pressure level L_{Aeq} (noise protection zones: e.g. 65 dB isocontour = Tagschutzzone 1)



$$L_{Aeq} = 10 \cdot log10\left(\frac{1}{T}\sum_{i=1}^{N} g_i \cdot 10^{SEL_i/10}\right)$$

exemplary ground location/observer

- reduce number of flyover events
- traffic routing (distribution) / land development
- avoid/reduce flights during „sensitive“ times
- night flight curfew
- modify noise source (retrofit or new design)
- tailor and adapt flight procedures

non-technical

ICAO Balanced Approach

defined measures to reduce aircraft noise

technical

motivation: aircraft noise reduction

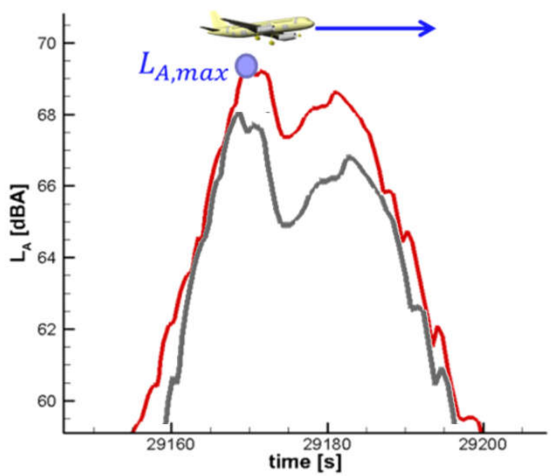
technical ICAO measures

reduction of sound exposure level SEL

$$SEL_i = 10 \cdot log_{10}\left(\frac{1}{t_{ref}}\int 10^{L_A(t)/10}\,dt\right)$$

1. reduction at the source
   - according to noise source dominance
   - retrofit (modifications to existing vehicle) versus design of novel aircraft

2. modification to flight procedure
   - timing of high-lift and gear deployment
   - avoid air-brakes
   - optimize velocity and altitude profile
   - avoid corrections via engine thrust



most effective: simulatenous application of both measures
→ combined assessment only possible via simulation !!!

essential prerequisite: adequate simulation capabilities to capture modifications simultaneously

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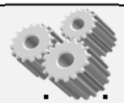
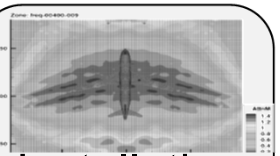
tools and methods

Parametric Aircraft Noise Analysis Module (PANAM)

simulation | **input data**



emission (source) description



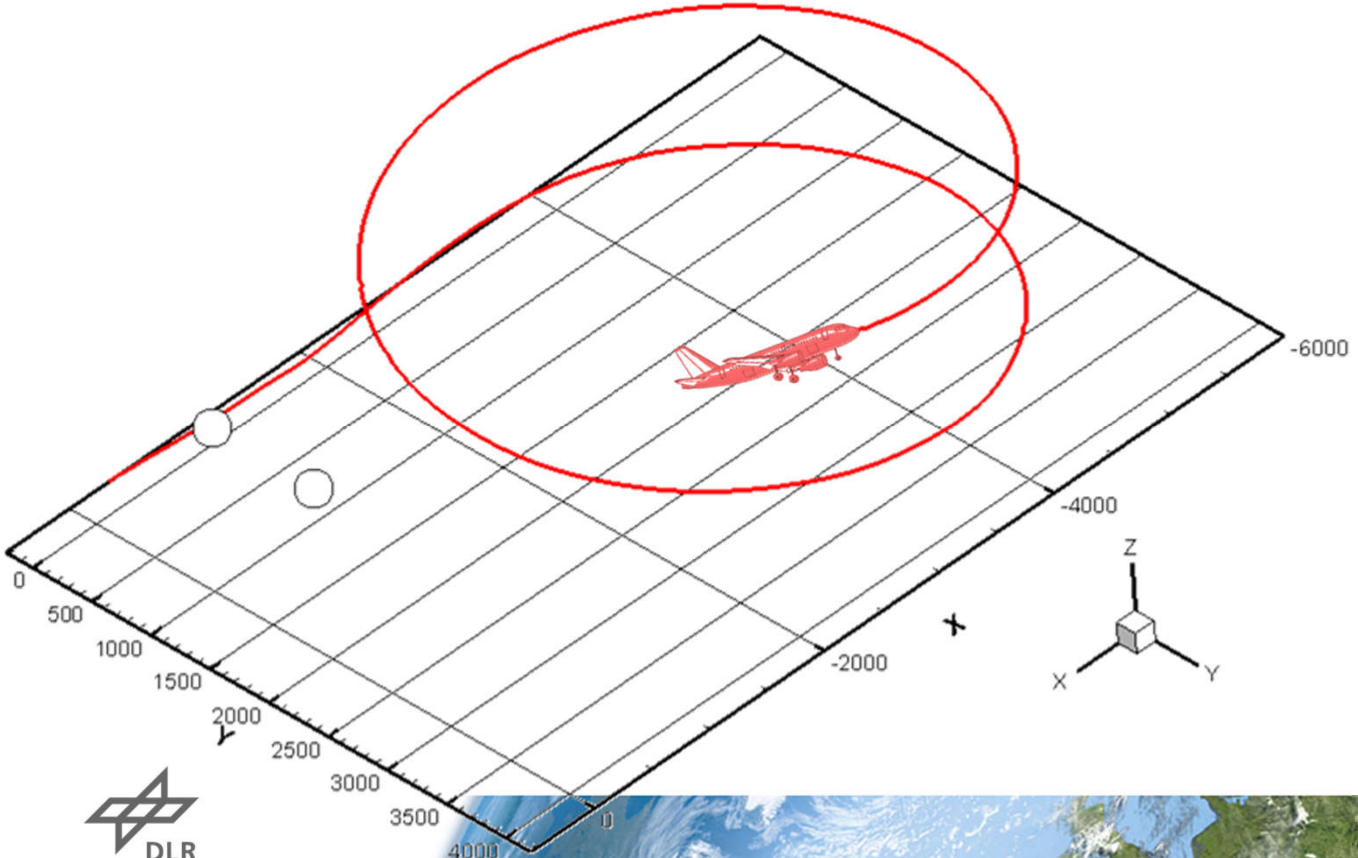
installation effects

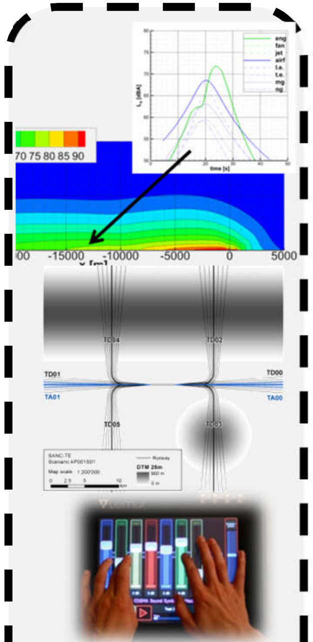
prop. & ground effects

geometry & aerodynamics

geometry & performance

flight operation





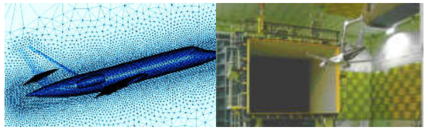
scenario definition

tools and methods

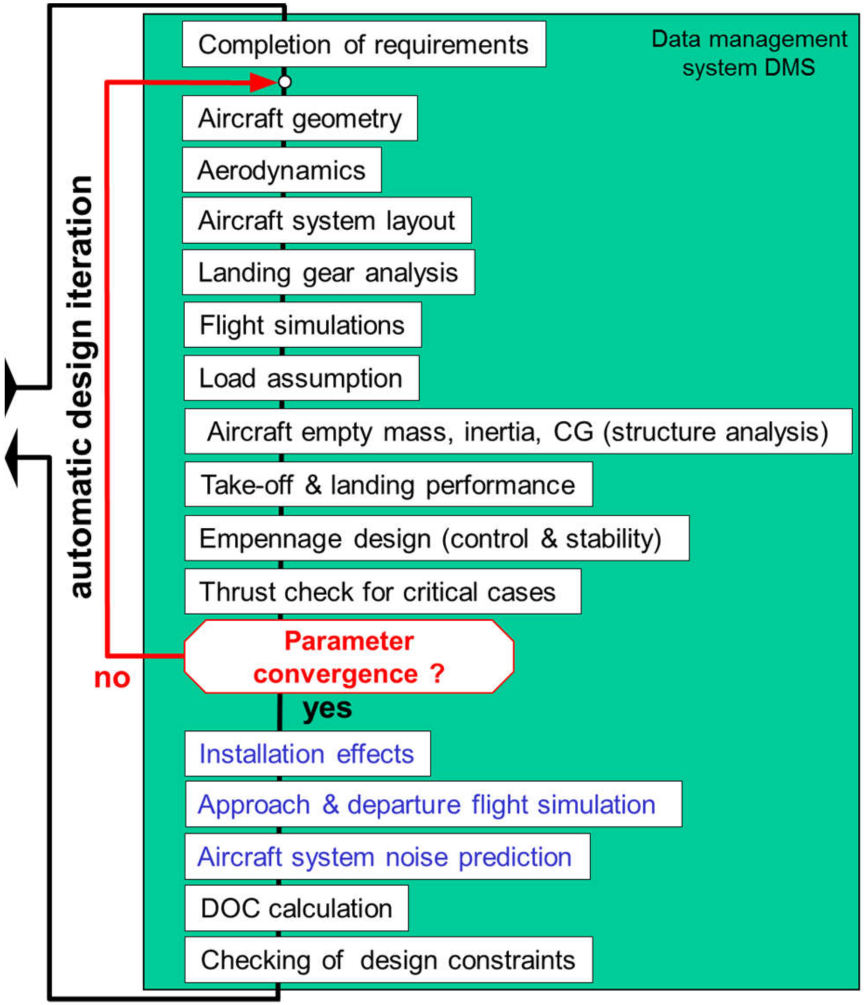
simulation process

Preliminary Aircraft Design and Optimisation* (PrADO)

- aircraft design synthesis
- iterative & multidisciplinary
- common data base
- individual modules for defined tasks
- modules can be **replaced**



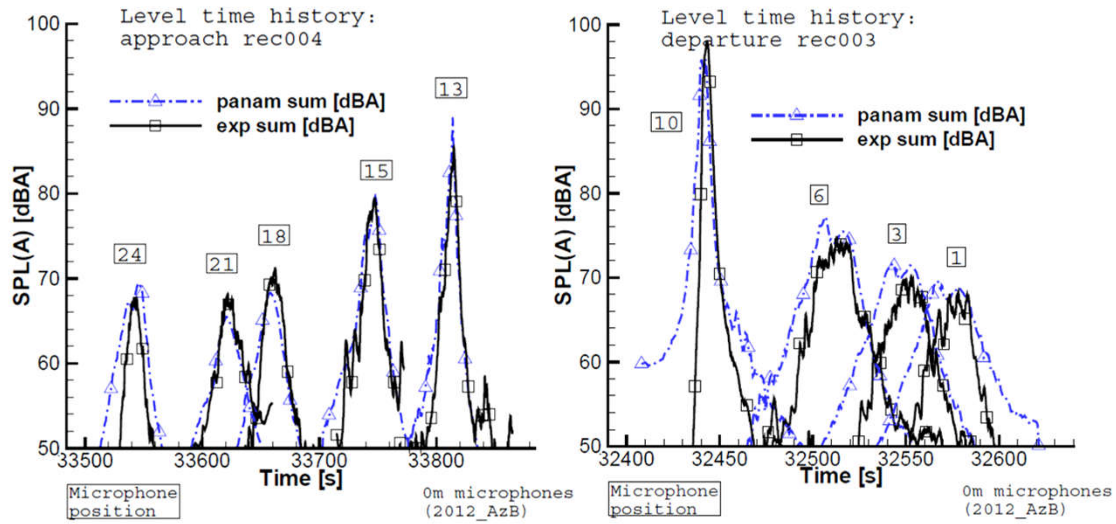
- output: required input for **noise simulation** **
  - shielding effects
  - flight procedure
  - source description



*) Wolfgang Heinze, ZLR-Forschungsbericht, 1994
**) Bertsch, AIAA Aeroacoustics, 2014

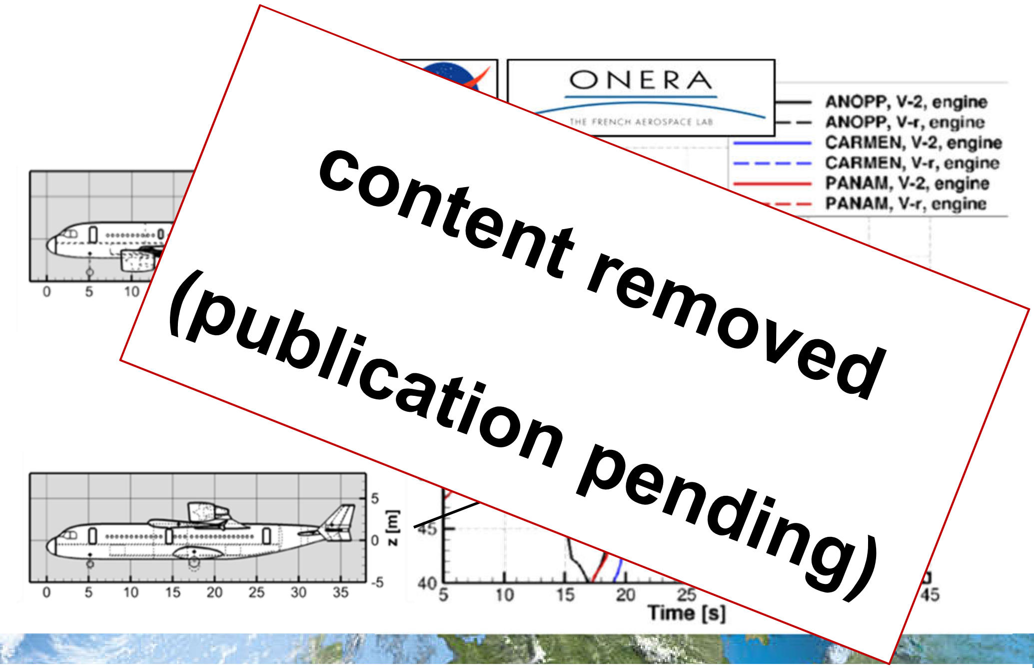
tools & methods
validation

- comparison with <u>experimental</u> data
    - components: windtunnel data / engine testbed
    - overall aircraft: measured fly-over data: **A319***, A320, B747, and VFW 614



- comparison with <u>numerical</u> data
    - components: Hi-Fi aeroacoustic simulation
    - overall aircraft: **tool-to-tool**** comparison

- (plausibility/feasibility check: textbook, existing knowledge …)



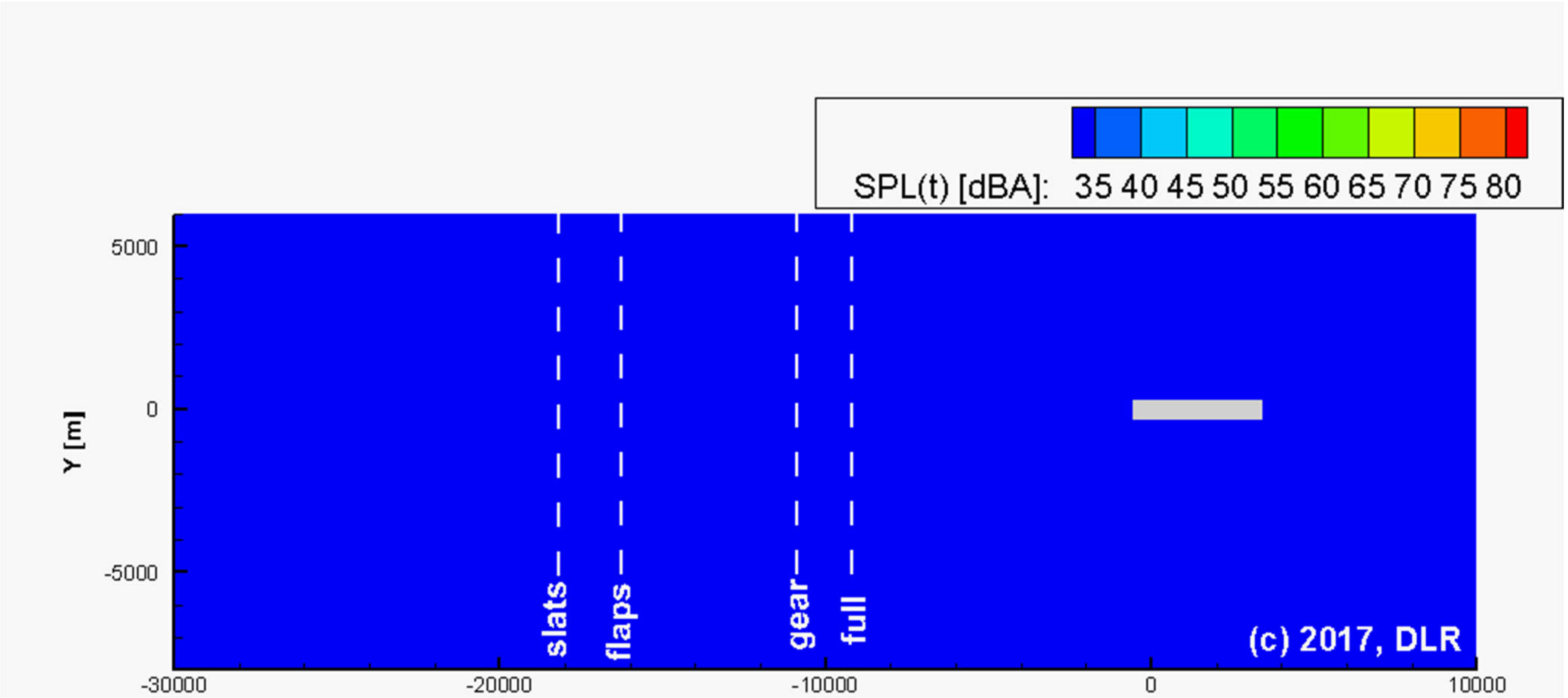
DLR

*) Bertsch, AIAA Aeroacoustics 2014 **) ANSWr results, AIAA Aeroacoustics 2019

tools & methods

simulation capabilities

emission → propagation effects → immission



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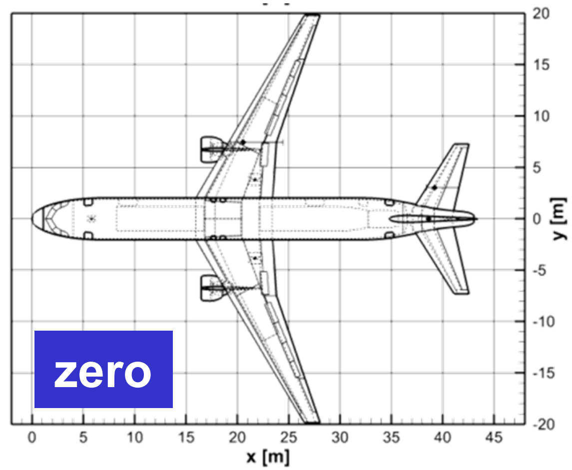
application 1: low-noise aircraft design



tube-and-wing a/c design:

- top level aircraft requirements (TLAR)
  - 4000 km range
  - 180 Pax
  - 1890 kg payload
  - cruise Mach 0.8
- reference w. **BPR 6** engines ("zero")

low-noise design modifications:

- engine: replacement with geared turbofan (**BPR 12**)
- architecture: engine noise shielding concept*
- airframe: low-noise high-lift and gear concept

application example here:

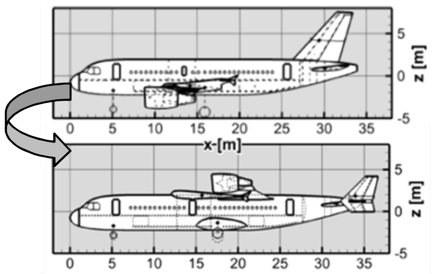
effect of engine replacement (on conventional and on low-noise a/c)

Bertsch et al., AIAA SciTech 2018 *) TLAR: cruise Mach of 0.7

application 1

	conventional		low-noise	
	zero	**neodapt**	**V-2 (af)**	**fanex**
engine	ref	GTF	ref	GTF
architecture	ref	ref	fan shielding	fan shielding
airframe	ref	ref	low-noise	low-noise

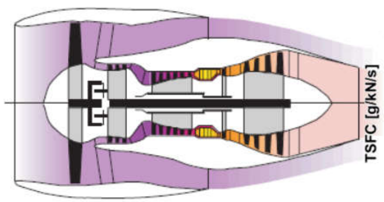
fan shielding



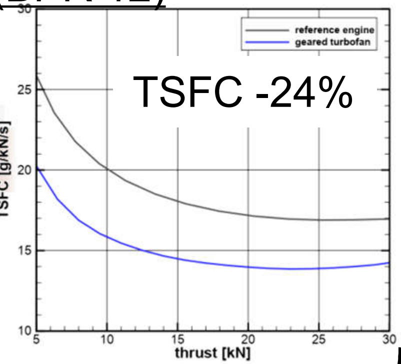
selected fan shielding

based on large design study (~ **500** variants)

GTF (BPR 12)



GTF (left fig. © GasTurb)



external high-fidelity simulation → design, weight, performance

low-noise airframe:

high-lift system

external exp. / simulation → weight, aerodynamics, ΔdB

gear mesh fairing (fig. © Dobrzynski)

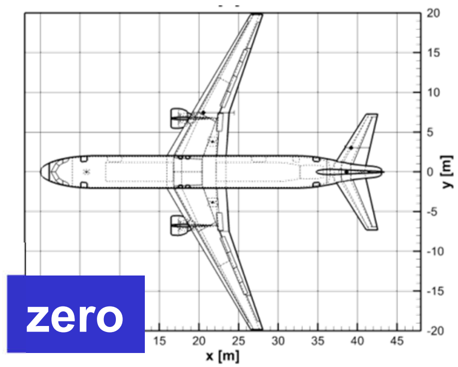
previous findings → ΔdB

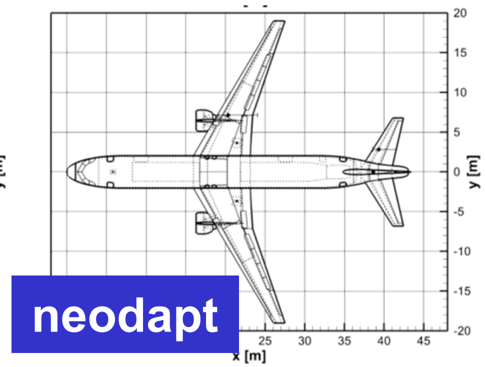
low-noise airframe: gear –*3dB*, slats –*6dB*, flaps –*5dB*

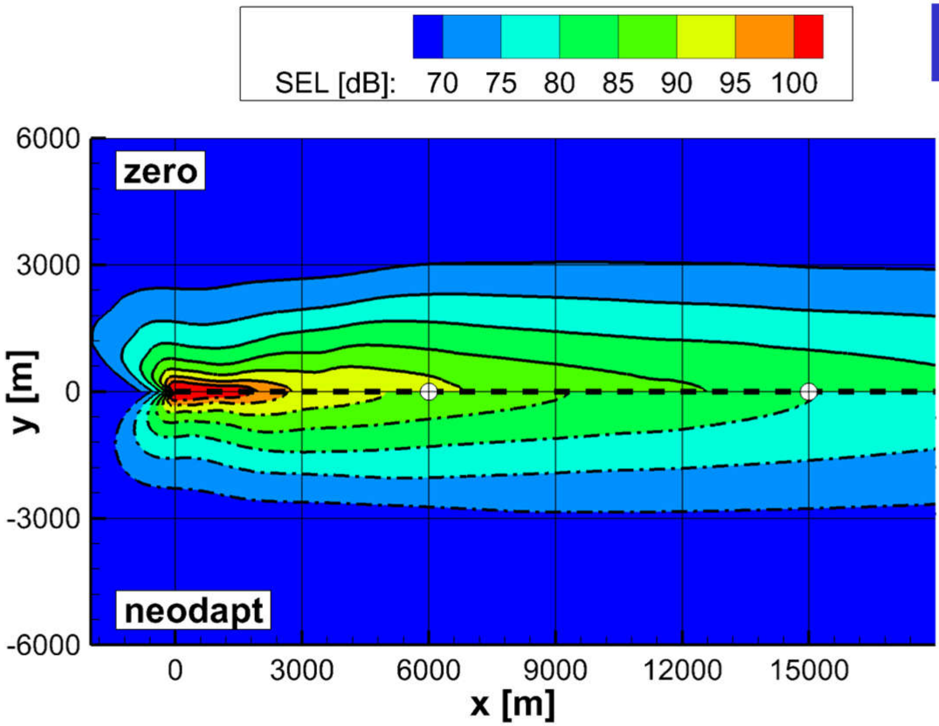
DLR

application 1

engine replacement on reference architecture (BPR 6 vs. BPR12)





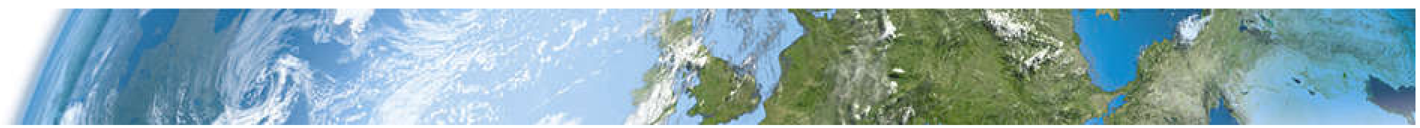


metric	Δ (neodapt-zero)	
	6 000 m	15 000 m
$L_{A,max}$ [dB]	**-3.5**	**-4.9**
$EPNL$ [dB]	**-6.2**	**-5.8**
SEL [dB]	**-3.1**	**-3.1**

DOC [€/flight]	**-1452** (-7.75%)

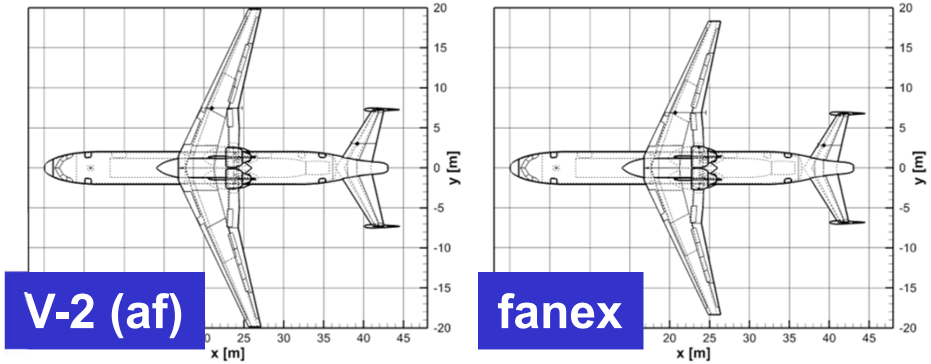
- gtf reduces noise levels (jet → $L_{A,max}$ & SEL, fan → $EPNL$)
- significantly reduced Direct Operating Costs (per flight)

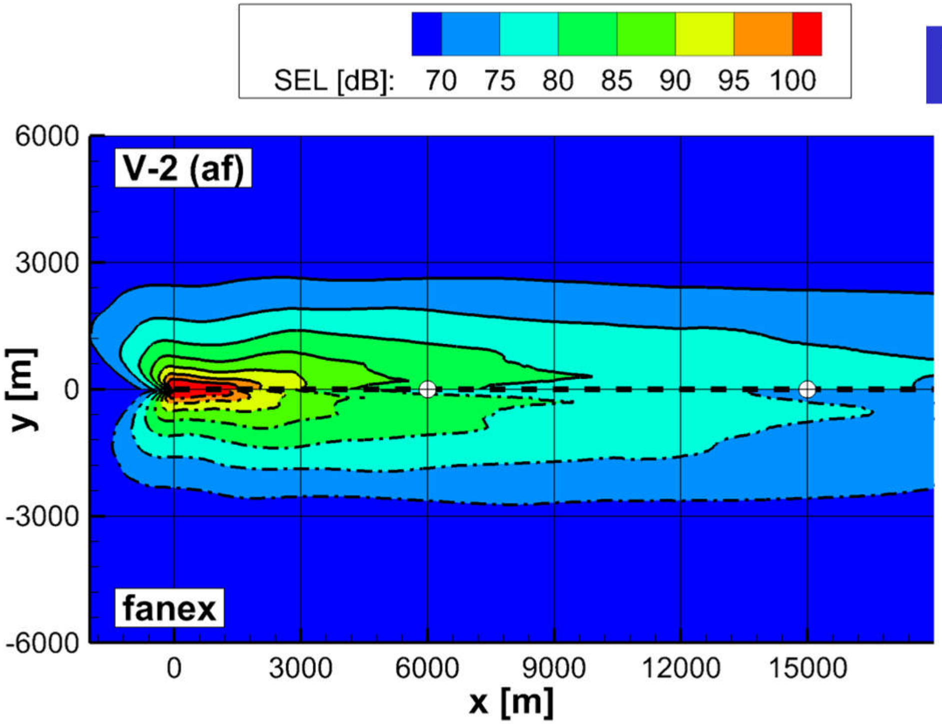
DLR



application 1

engine replacement on shielding architecture (BPR 6 vs. BPR12)





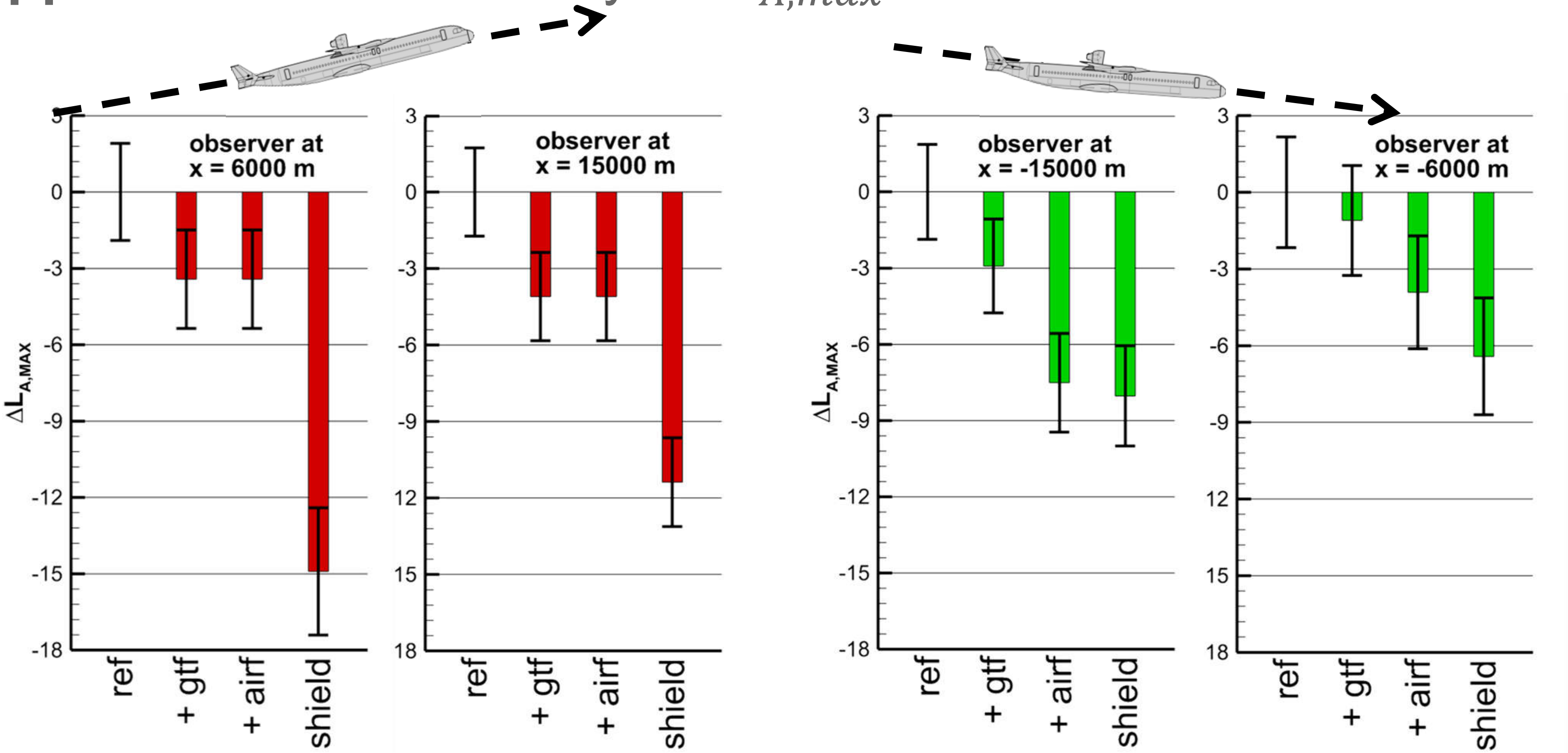
metric	Δ (fanex – V-2(af))	
	6 000 m	15 000 m
$L_{A,max}$ [dB]	**-4.1**	**-3.0**
$EPNL$ [dB]	**-4.1**	**-2.8**
SEL [dB]	**-3.5**	**-2.3**

DOC [€/flight]	**-1482** (-7.34%)

- (less) fan noise reduction for fanex (already significant fan noise shielding)
- combination of shielding and gtf is most promising (all metrics: 2-4 dB reduction)
- low-noise airframe measures become very efficient (approach not shown here)
- significant DOC reduction

DLR

application 1: uncertainty* of $L_{A,max}$ for low-noise measures



- level differences & uncert. vary along simulated flight and per observer
- different conclusions for app. and depart.

assumed modeling uncert.:

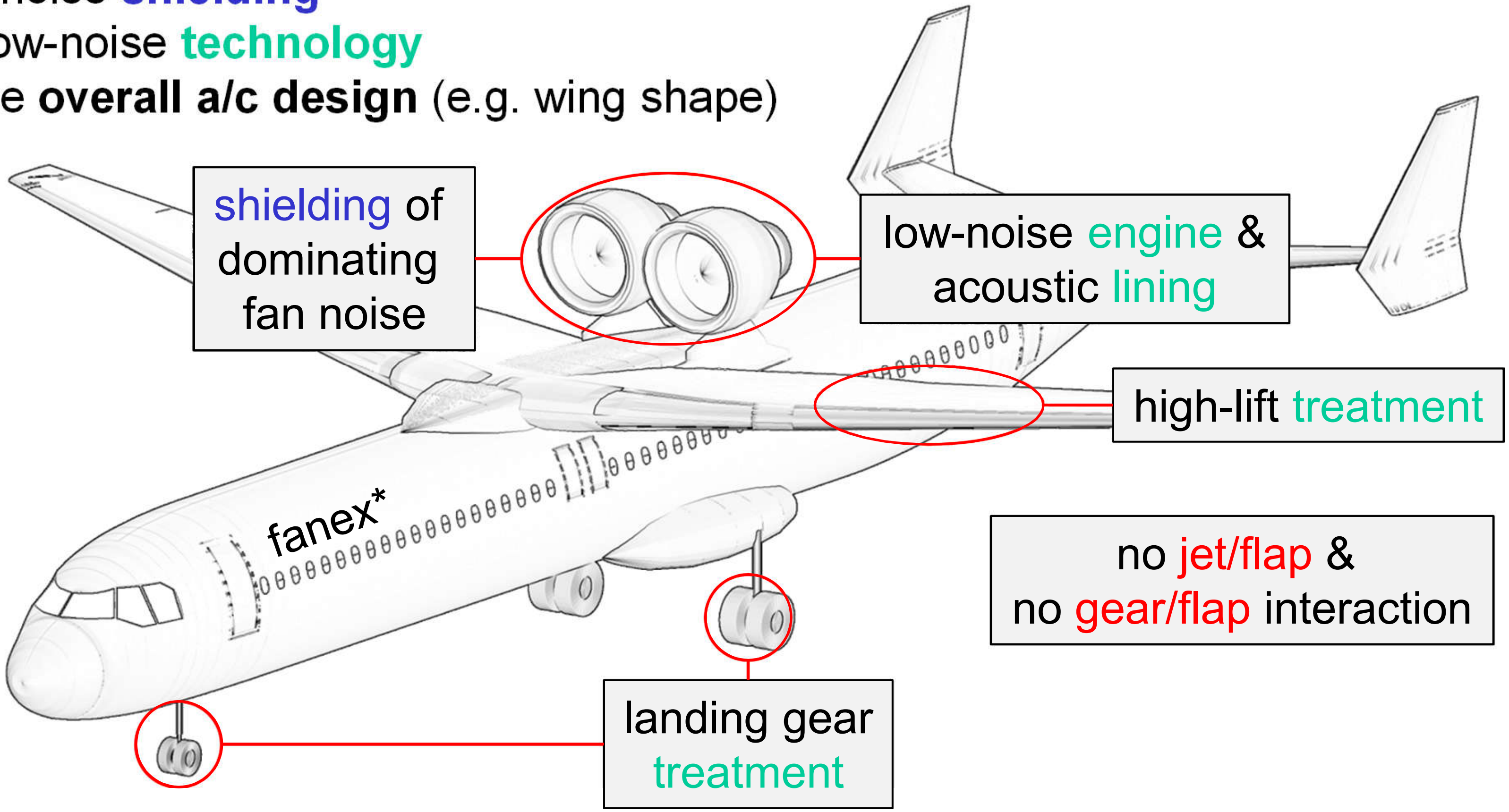
airfr.: gear & high-lift($\pm 1.4dB$), other($\pm 1dB$)   eng.: fan**(ref $\pm 3.6dB$; gtf $\pm 4.2dB$), jet($\pm 1.5dB$)

*) including covariances to account for correlated terms   **) shielding algorithm applied to all fan predictions ($\pm 3dB$)

application 1: most promising low-noise concept

according to low-noise recipee:

1. avoid **interaction noise** sources
2. exploit noise **shielding**
3. apply low-noise **technology**
4. optimize **overall a/c design** (e.g. wing shape)



5. define **tailored** low-noise flight **trajectory**

*) DLR SLD17-400 „fanex“

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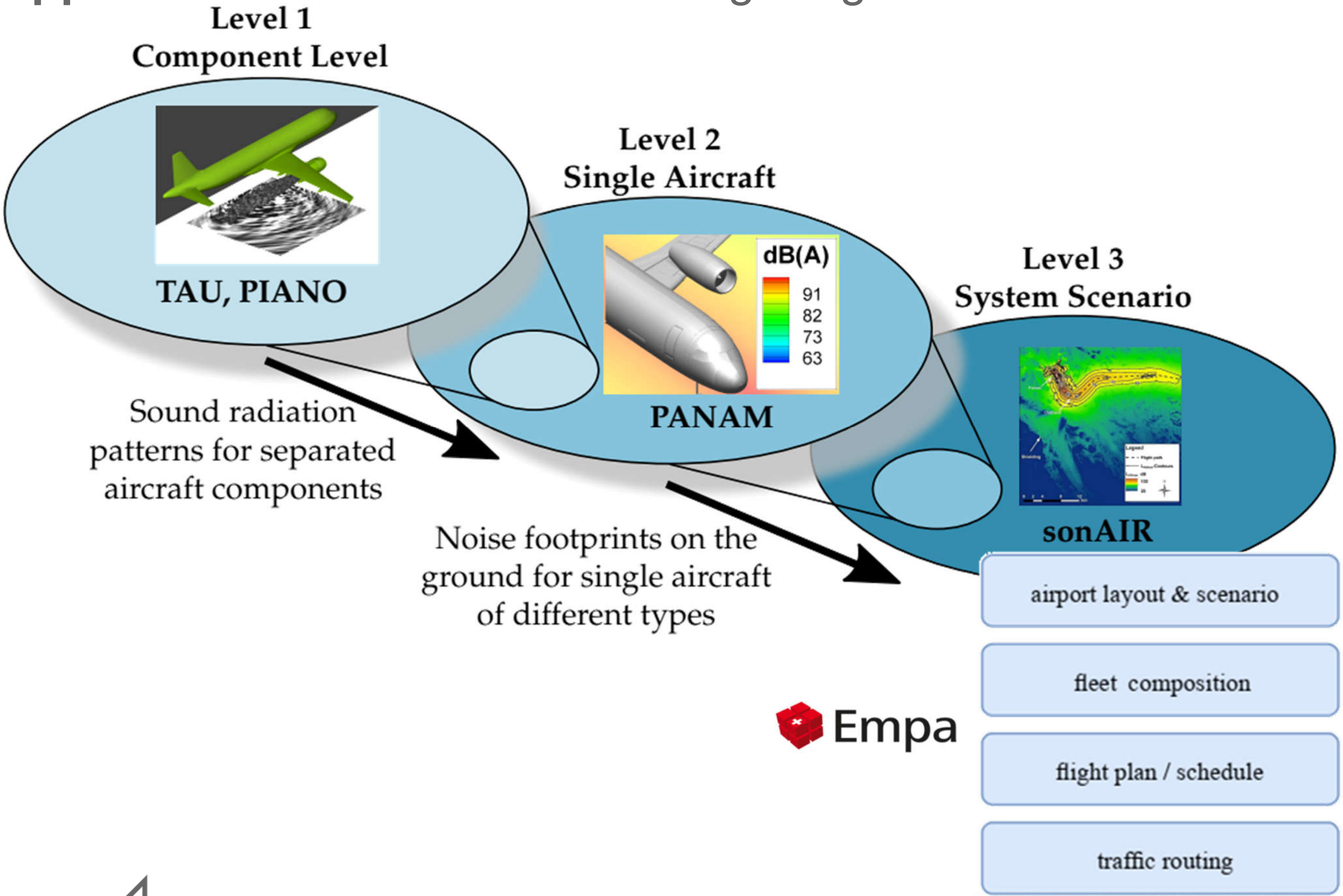
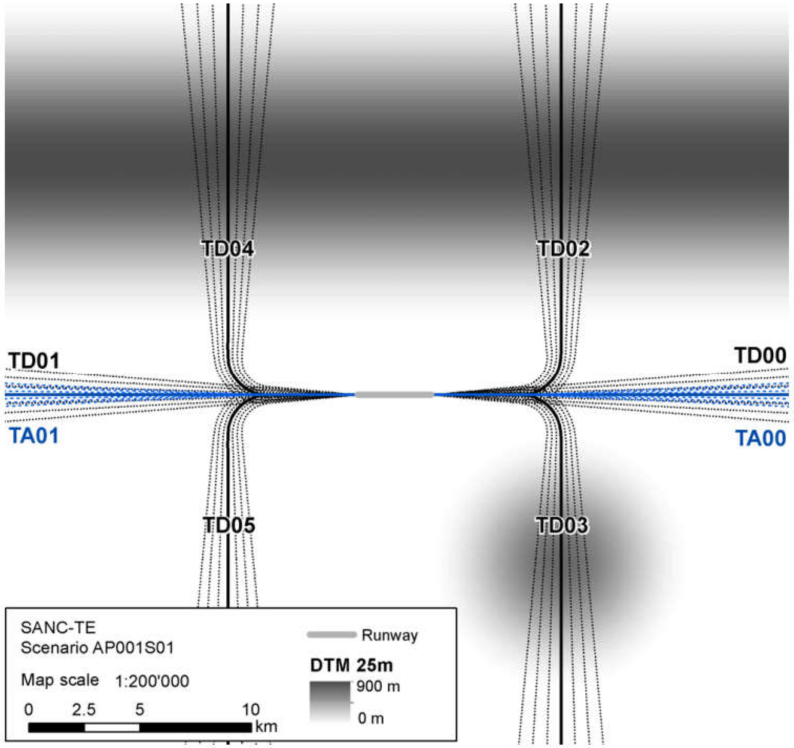
application 2: translation from single flight to scenario



Christoph Zellmann et al., InterNoise 2019

application 2: translation from single flight to scenario



Aircraft types	2015	2025	2035	20XX-1	20XX-2
Business jets	10%	10%	10%	10%	10%
ceo	58%	36%	18%		
B737 NG	6%	4%	2%		
Turboprops	7%	4%	3%		
E190	[illegible]	5%			
F100		[illegible]			
A333					
RJ1H					
neo				[illegible]	10%
B37M*					[illegible]
B788					
BCS1					
BCS3					
neo (af)					
neodapt					
neodapt (af)					
fanex					[illegible]%
Technology:	CT	→	NT-1	→	[illegible]T-2

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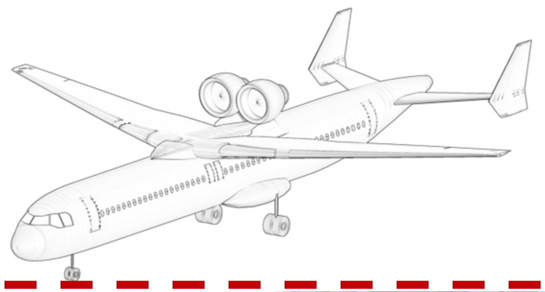

Christoph Zellmann et al., InterNoise 2019

application 2: translation from single flight to scenario

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Christoph Zellmann et al., InterNoise 2019

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- summary

application 3: low-annoyance aircraft design

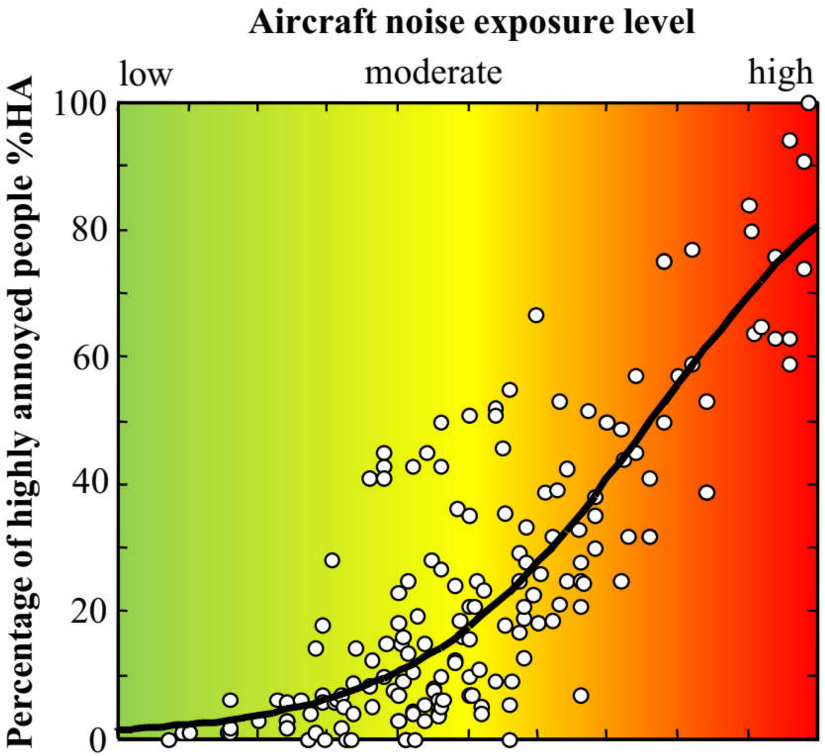
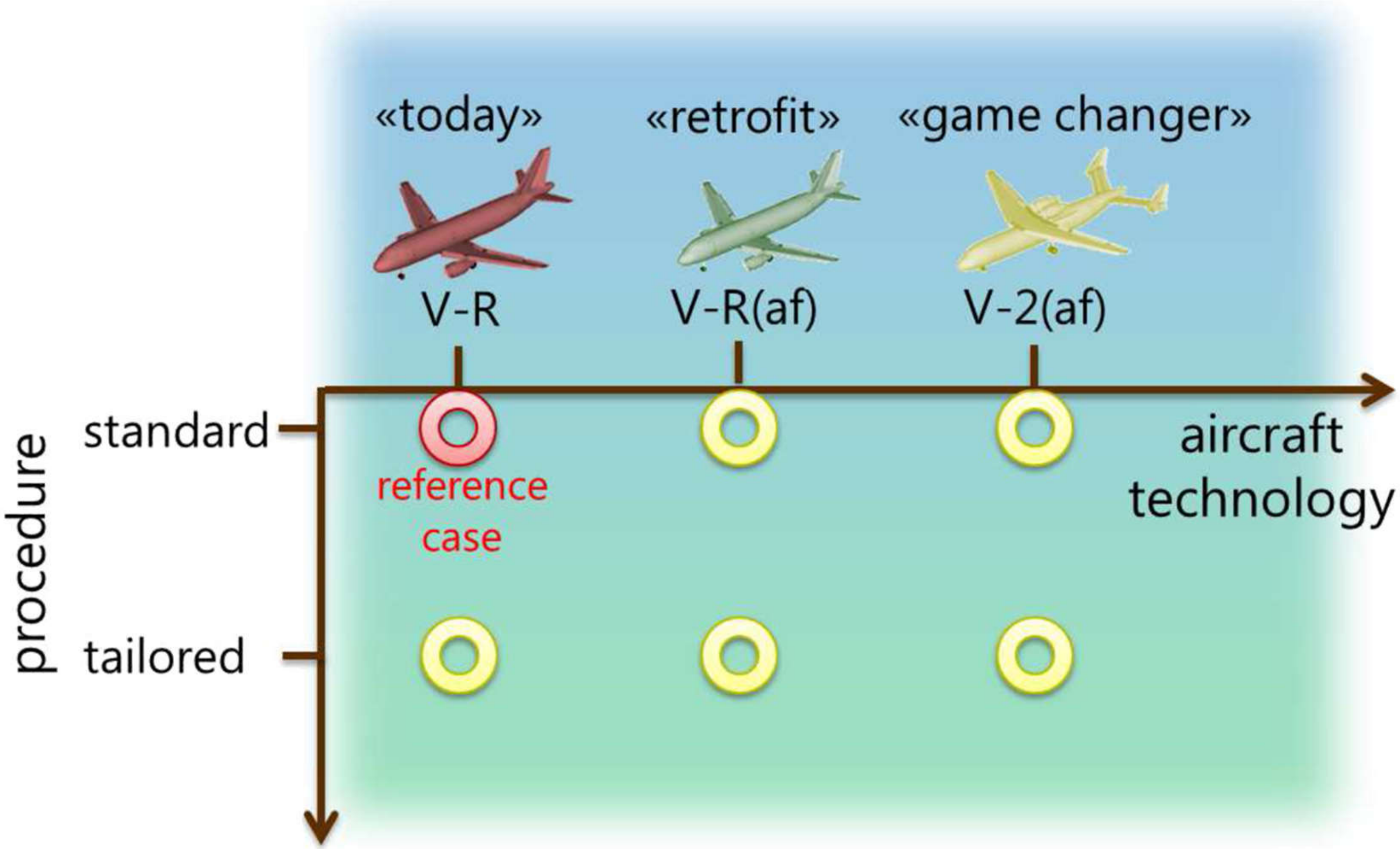


Fig.: exemplary exposure-response relationship
(ECAC Doc. 29, 2006; each point = 1 study!)

open questions
- low-noise = low-annoyance?
- conventional metrics applicable?
- can some noise sources be louder?
- do low-annoyance vehicles look different?

- DLR and Empa cooperation: **short-time noise annoyance**

application 3: low-annoyance aircraft design



furthermore: 4 different observer locations

1. capture different flight phases
2. account for varying noise source ranking and distance / orientation

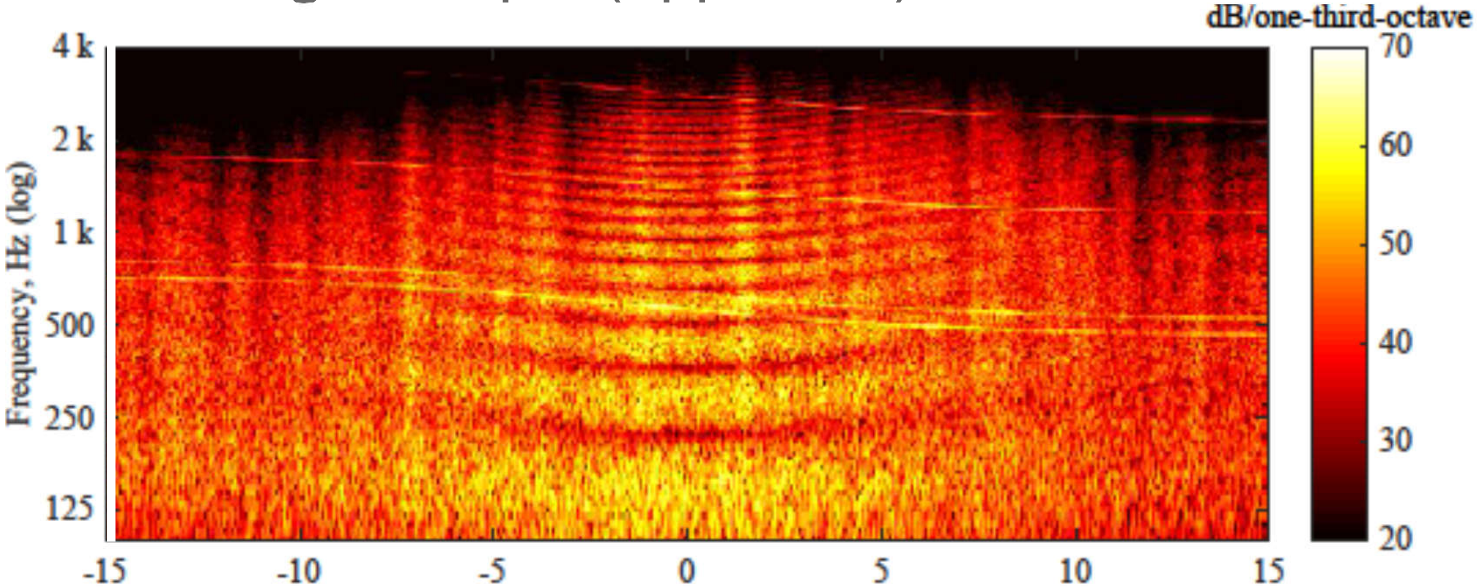
→ total of 24 stimuli for listening tests

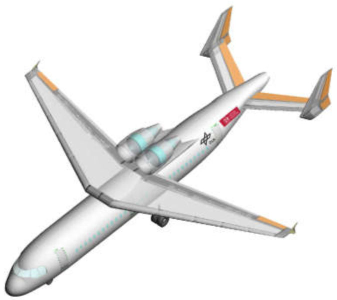
Reto Pieren et al., AIAA SciTech 2018

application 3: listening example (approach)

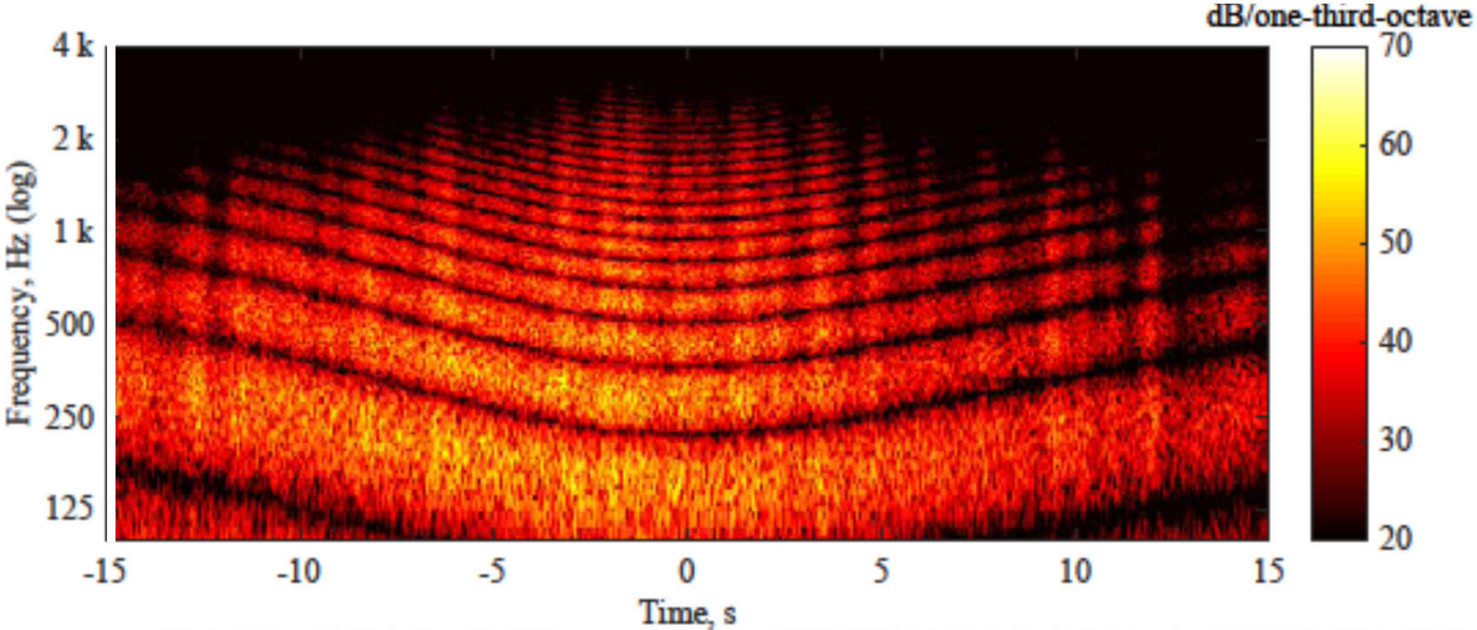
observer @ 15 km

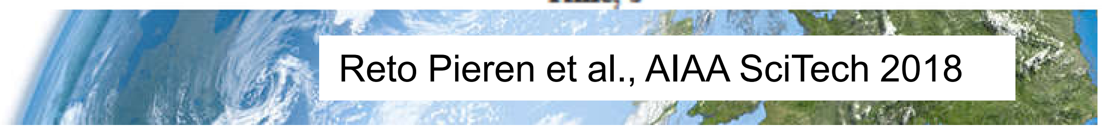
reference





game changer





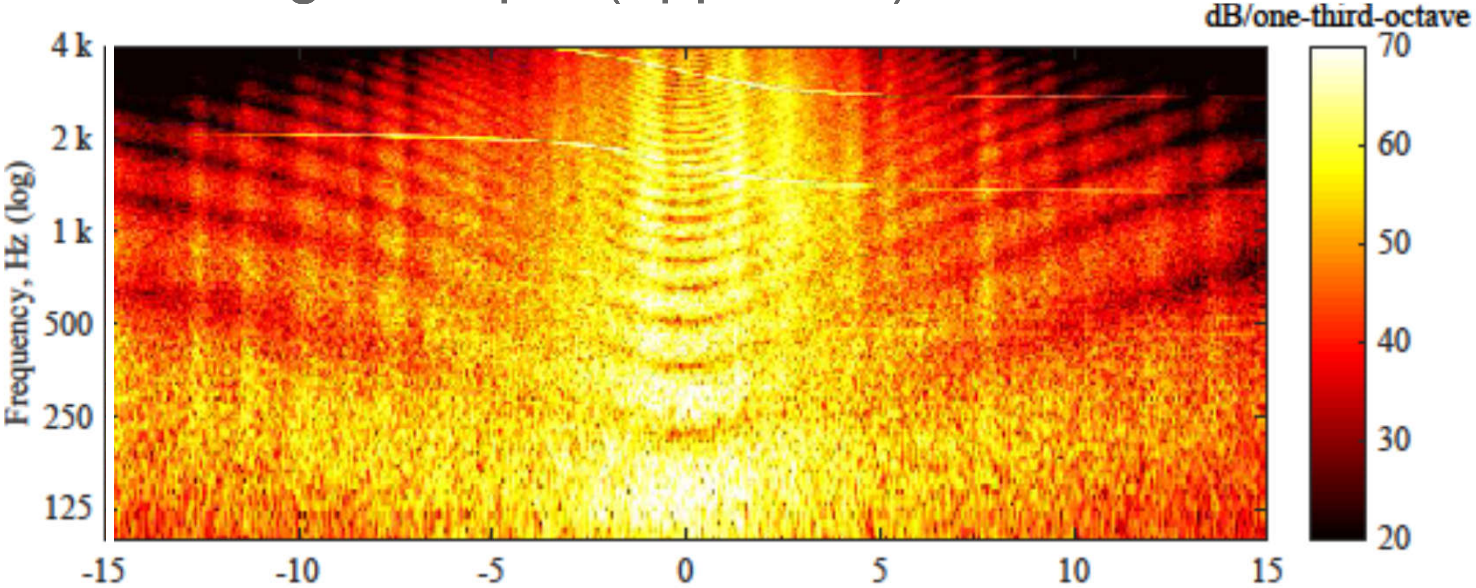
DLR

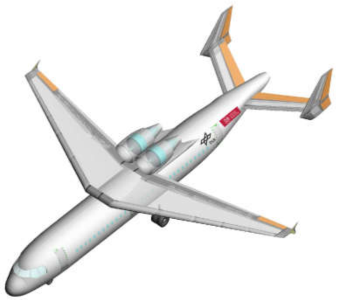
Empa

application 3: listening example (approach)

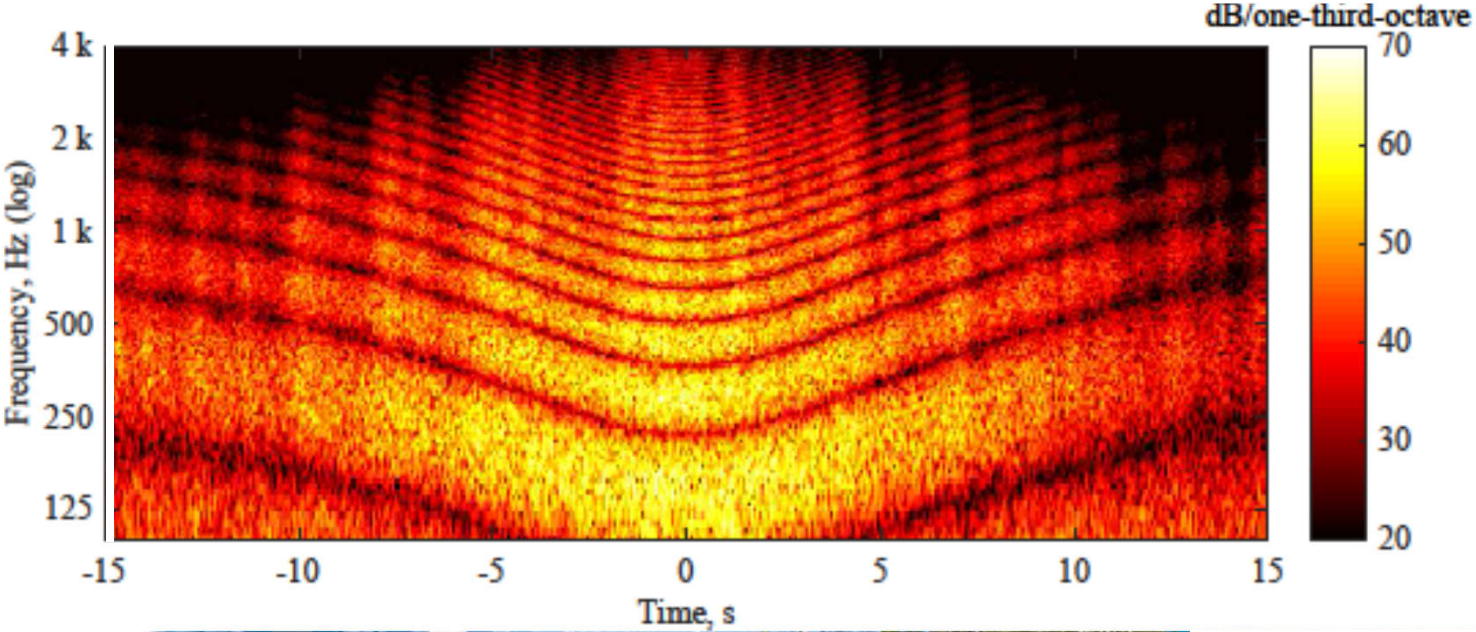
observer @ 4 km

reference





game changer



Reto Pieren et al., AIAA SciTech 2018

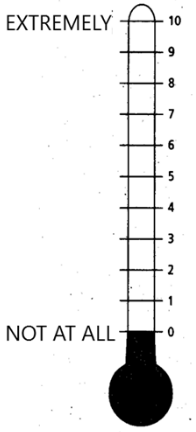
DLR

Empa

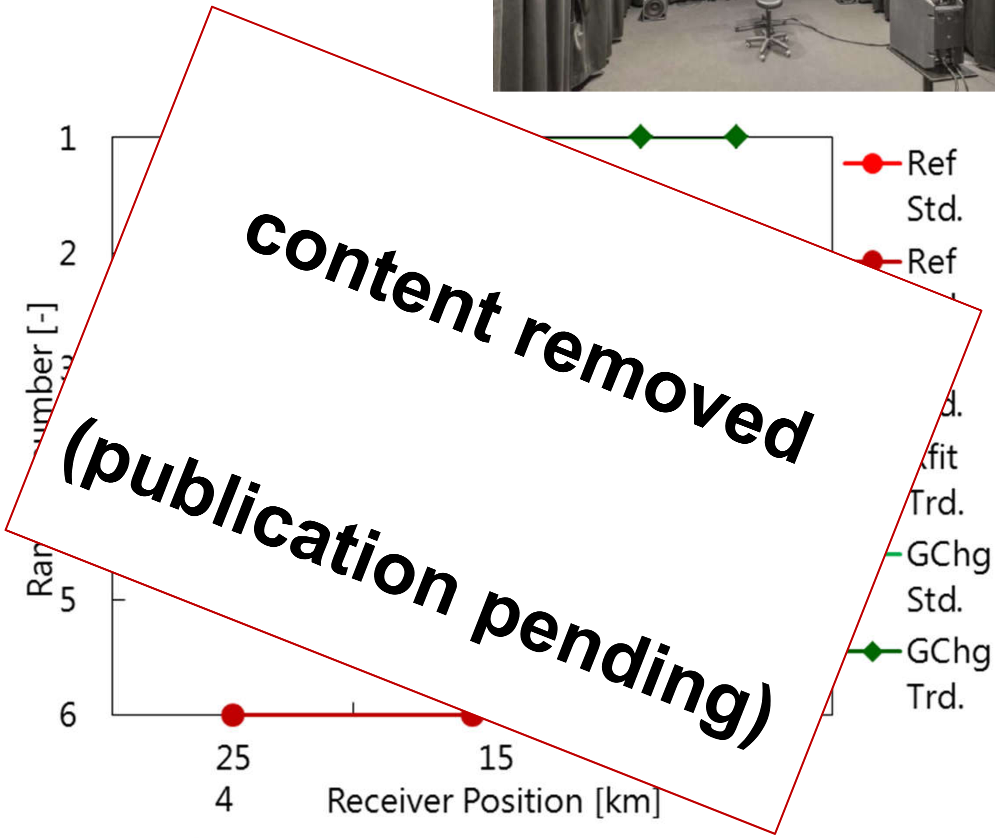
application 3: low-annoyance aircraft design

inspired by S. Rizzi, NASA

- **listening tests → short term noise annoyance** of novel vehicles along individual flight procedures
- multiple observer locations



“Wenn Sie sich vorstellen, dass dies die Geräuschkulisse in ihrem Garten ist, welche Zahl zwischen 0 und 10 gibt am besten an, wie stark Sie sich dadurch insgesamt gestört oder belästigt fühlen würden?”



Ranking:
1 = best (least annoying)
6 = worst (most annoying)

DLR

Reto Pieren et al., Science of the Total Environment 2019

Empa

presentation outline

- introduction & motivation
- tools and methods
- application
- future work
- summary

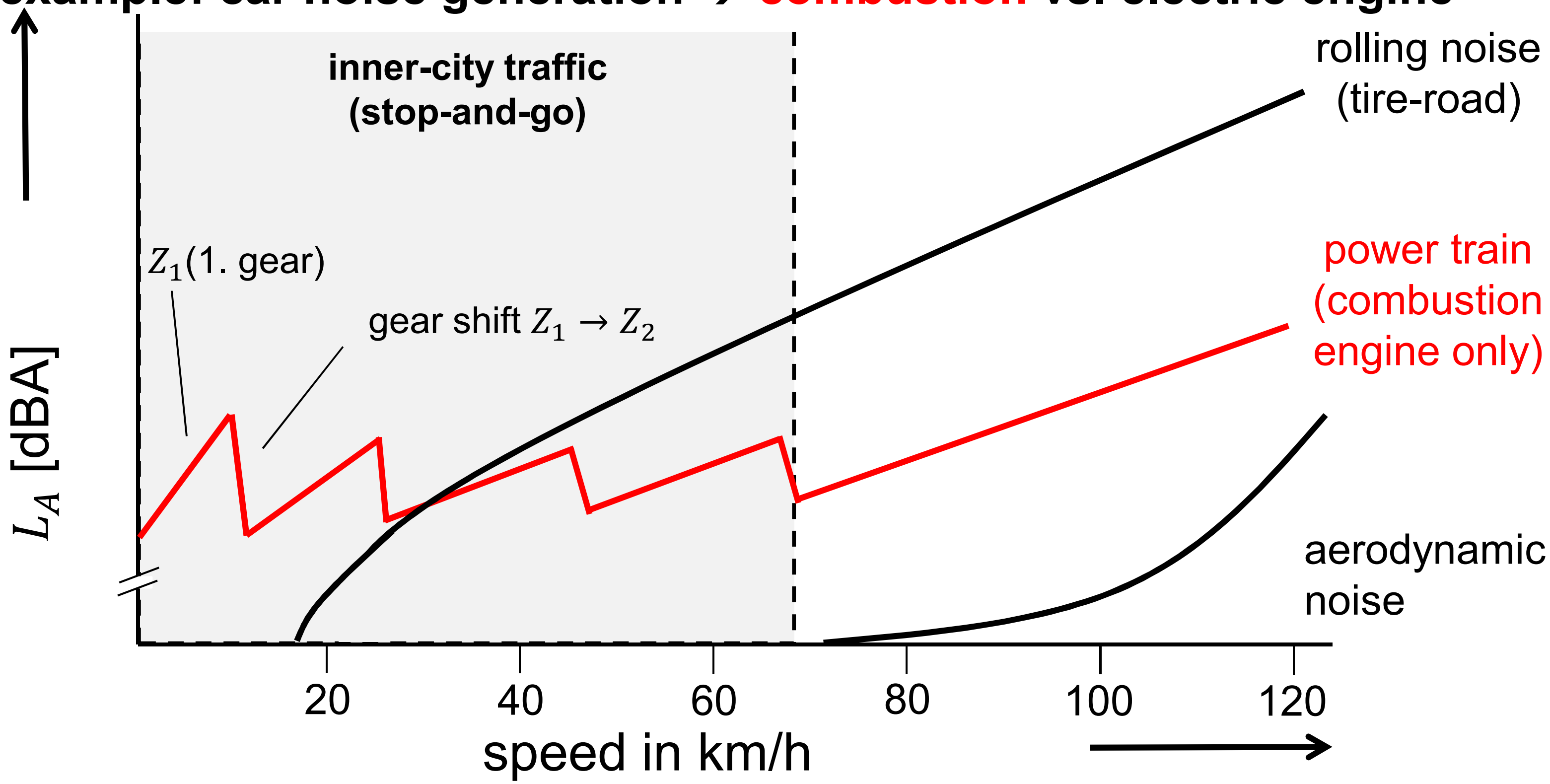
DLR

future work: fully and more electric aircraft

? electrification = noise reduction ?

→ up to this day: **no overall assessment** published
(June 2019: PhD topic at DLR Göttingen)

example: car noise generation → combustion vs. electric engine

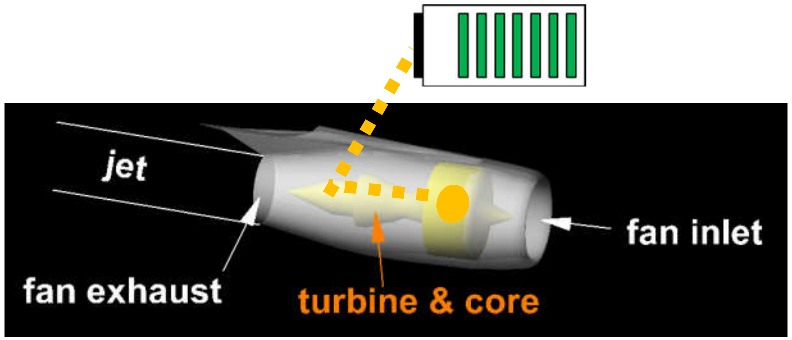


relevant noise sources (above 30 km/h) are **not affected** by propulsion concept!

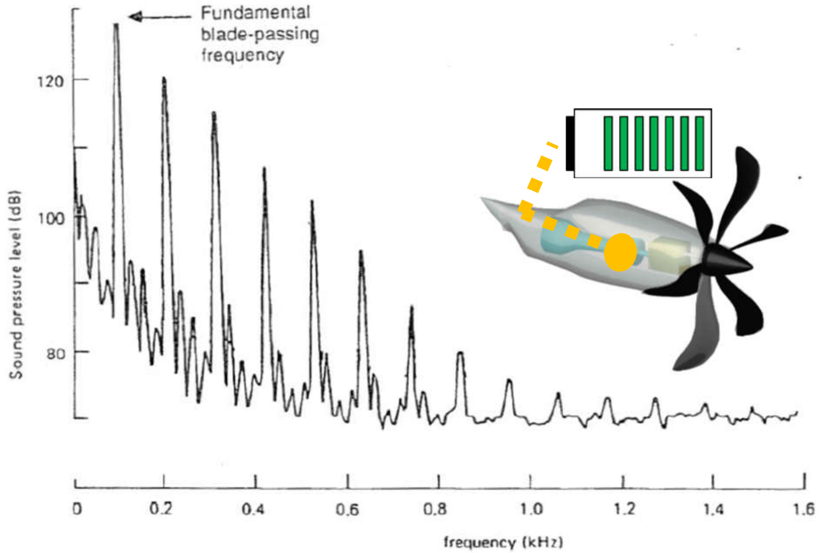
adapted from Roland Schuster et al, InterNoise, 2017

future work: fully and more electric aircraft

retrofit of turbofan aircraft:
- avoidance of turbine & core noise
- reduction of jet noise
- no impact on airframe noise
- increase in fan noise?



retrofit of turboprob aircraft:
- no impact at all → **dominating** propeller noise unchanged
  (avoidance of piston engine: significant noise reduction)



© Groeneweg, NASA TM-101361, 1988

future work: fully and more electric aircraft

- new aircraft design (distributed propulsion):
    - smart engine integration concepts **promising**
    - crucial: **avoid interaction** noise sources
    - avoid **differential** engine control (annoyance)

2 pure tones
at 800 Hz

pure tone at
780 and 800 Hz

- exploit installed electric power
    - active high-lift concepts & noise control (e.g. noise cancellation)

possible advantage for retrofit and new design:
engines off / windmilling to enable low-noise flights, e.g., steep approach

presentation outline

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summary

<u>methodology to avoid typical shortcommings</u>

1. a/c noise & design = **separate** disciplines
   (acoustics not available within design: subsequent assessment of predefined concept)
2. incomplete consideration of relevant disciplines/interactions
   (e.g. not including flight performance aspects)
3. insufficient problem assessment
   (e.g. focus limited to emission or few components, limitation to specific noise metric and/or fixed operating conditions)

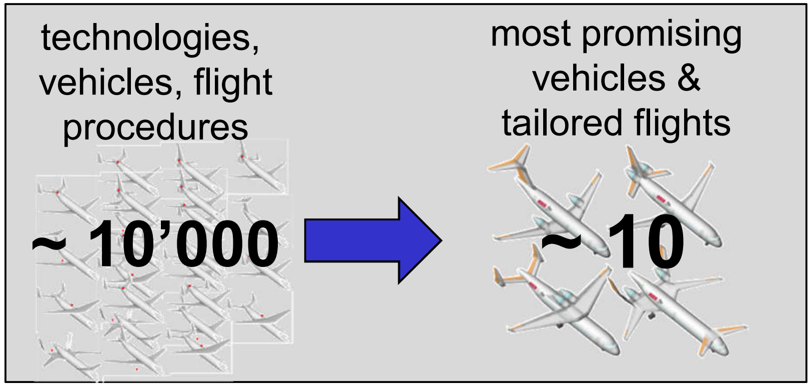
<u>simulation process for a/c noise prediction within conceptual design</u>

- engine installation effects (no embedded engines or BLI at the moment)
- interfaces to external input data (aircraft design, flight performance, and noise)
- tailored flight procedures
- (initial) assessment of uncertainties
- comparison with experiment and other simulation codes: satisfying agreement

summary

enabling a decision making support

- extract promising concepts from large solution space
- no “black-box” → **comprehensible results**
- complete assessment → **resilient results**
    → a/c impact on performance AND noise generation
    → multiple metrics & distributed observers



- next step: final evaluation & “fine tuning” → **final solution(s)**
    - specialized departments: high-fidelity computation & windtunnel experiments

Thank you for your attention. Questions?

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