AERODYNAMICALLY INDUCED SOURCES OF SOUND ON AIRCRAFT – AND ELSEWHERE–

Journée de la recherche du CRASH 26 Novembre 2025, Université de Sherbrooke, QC

Jan Delfs

DLR - Institut of Aerodynamics and Flow Technology

Braunschweig, Germany

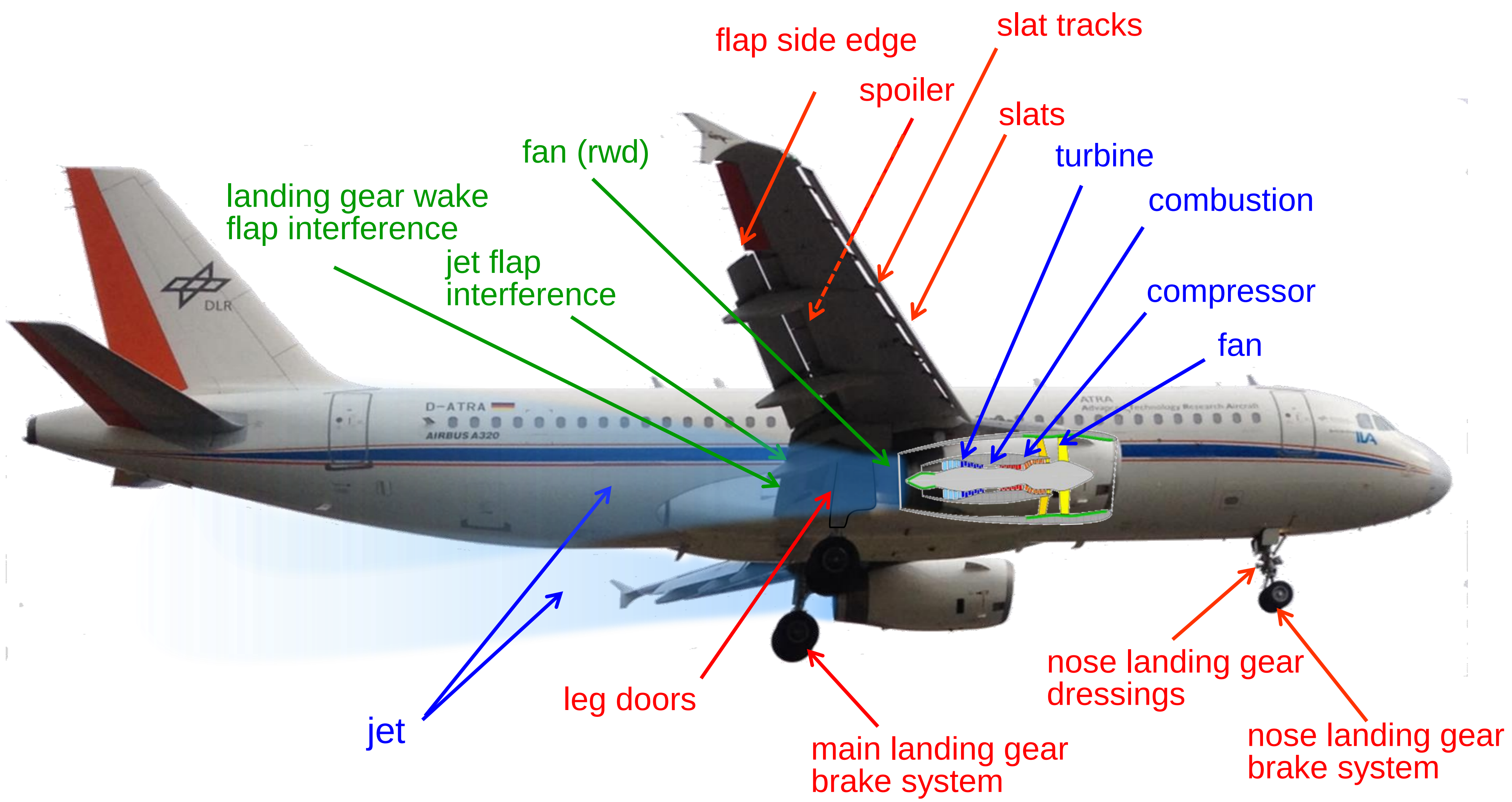
DLR

Outline

- Aircraft Noise
  - source of aerosound at transport aircraft
  - some noise reduction technologies

- Some more Aeroacoustics
  - a few surprising phenomena
  - cooperation work DLR/UdeS
    - alternative source localization
    - modeling sound generation a laminar separation bubble

Sources of sound at turbofan aircraft

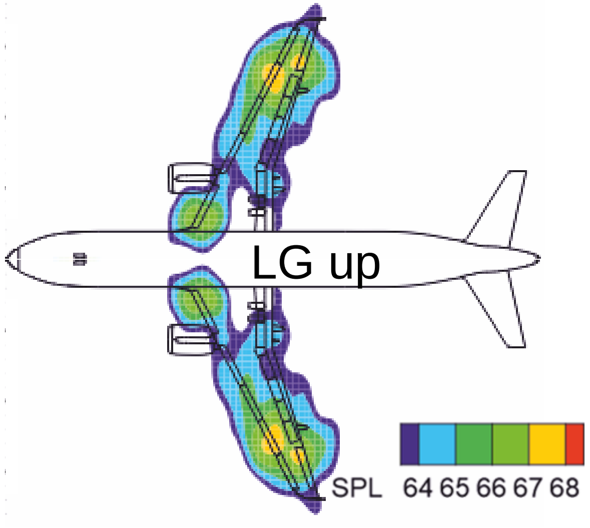


sources:

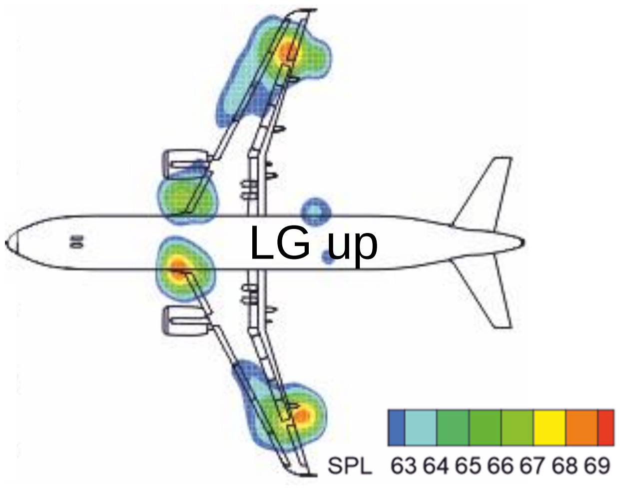
engine
airframe
installation

Photo: H. Siller

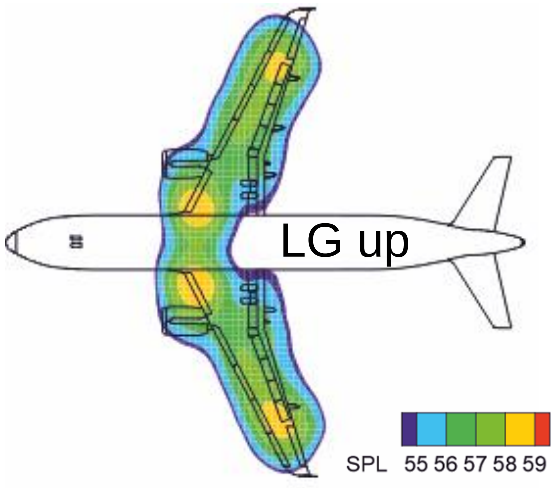
Sources of airframe noise – flyover array results



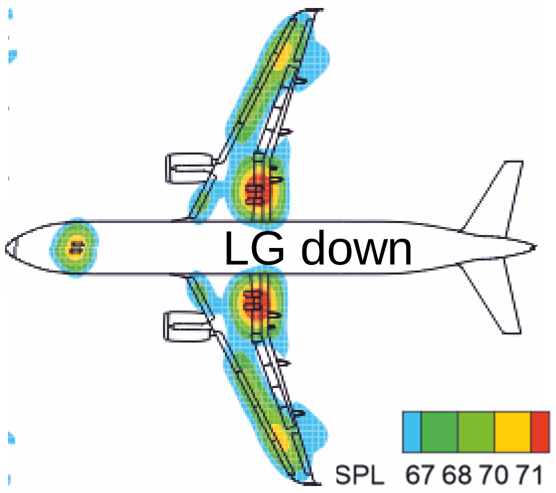
$f_m = 800\text{Hz}$



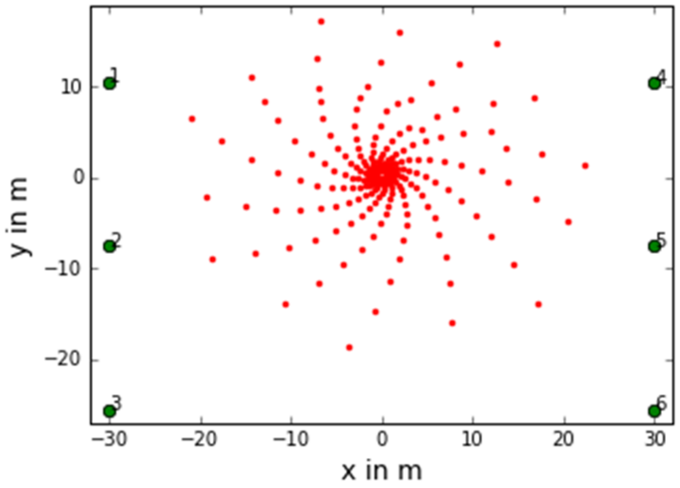
$f_m = 1250\text{Hz}$



$f_m = 3150\text{Hz}$



flaps full – 170kts overhead

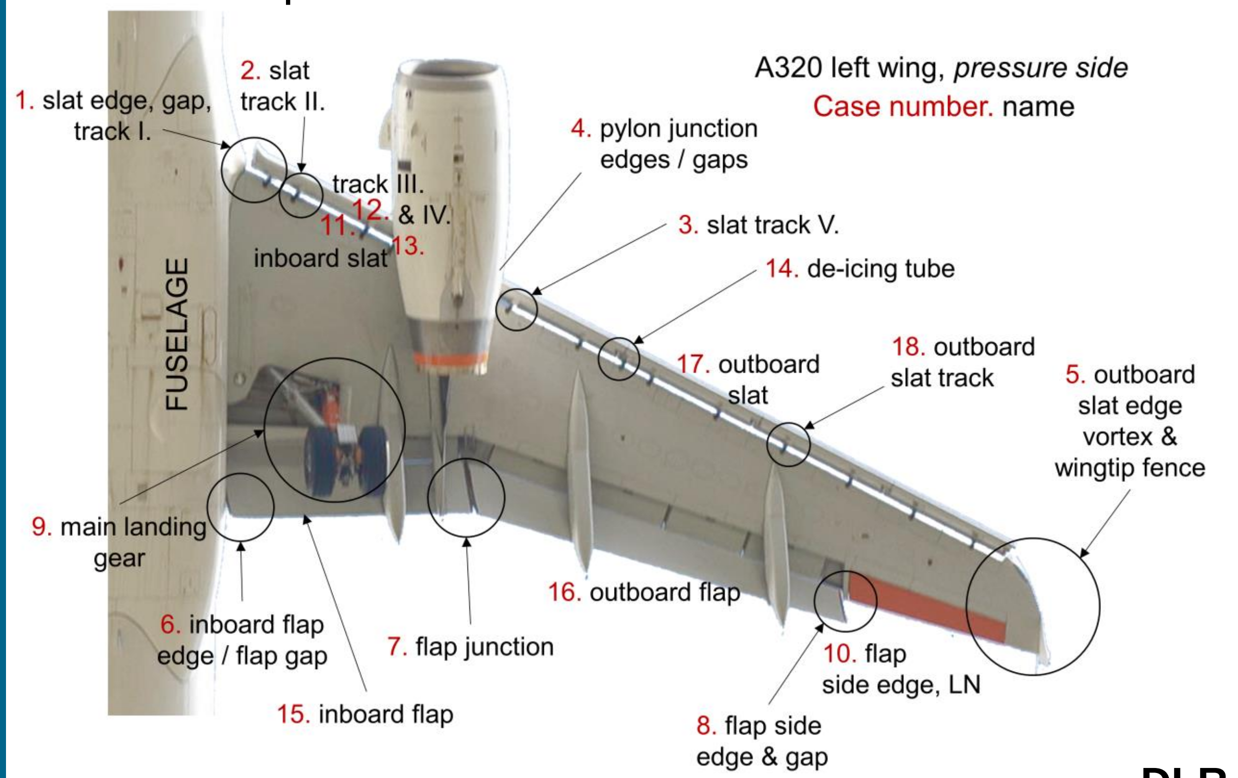


H. Siller, T. Schumacher W. Hage, AIAA 2021-2160

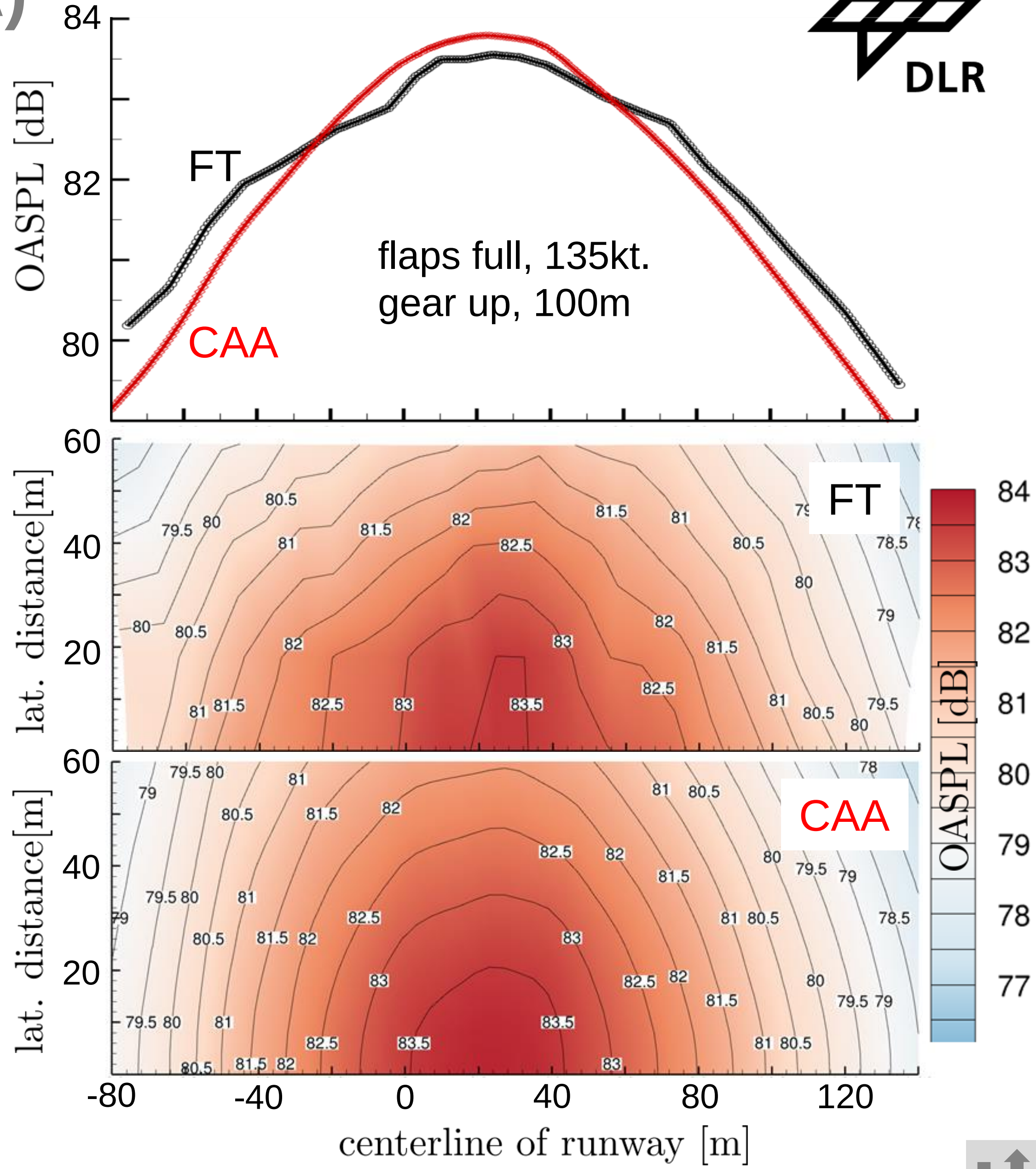
Full scale Flyover simulation (ATRA)

mean flow: **TAU**
sources: **FRPM**
acoustics: **DISCO++/FW-H**

component wise simulation



DLR SIAM



S. Proskurov et al., AIAA 2024-3242

LN-ATRA

→ A DLR project to **demonstrate** the potential of **noise reduction technologies** (NRT) for current transport aircraft
→ Implementation/test of known airframe+jet NRTs on real a/c

Flight test for noise reduction technologies

LNATRA

Concept:
Test of all measures simultaneously at DLR **A**dvanced **T**echnology **R**esearch **A**ircraft

Programme:
- Reference test 2016
- 1. part test 2017 (co-operation with EU AFLoNext)
- 2. part test 2018 (5 years preparation)
- main test, 1. part 2019
- ~~main test, 2. part 202x~~ –prepared, not flown–

Partners:

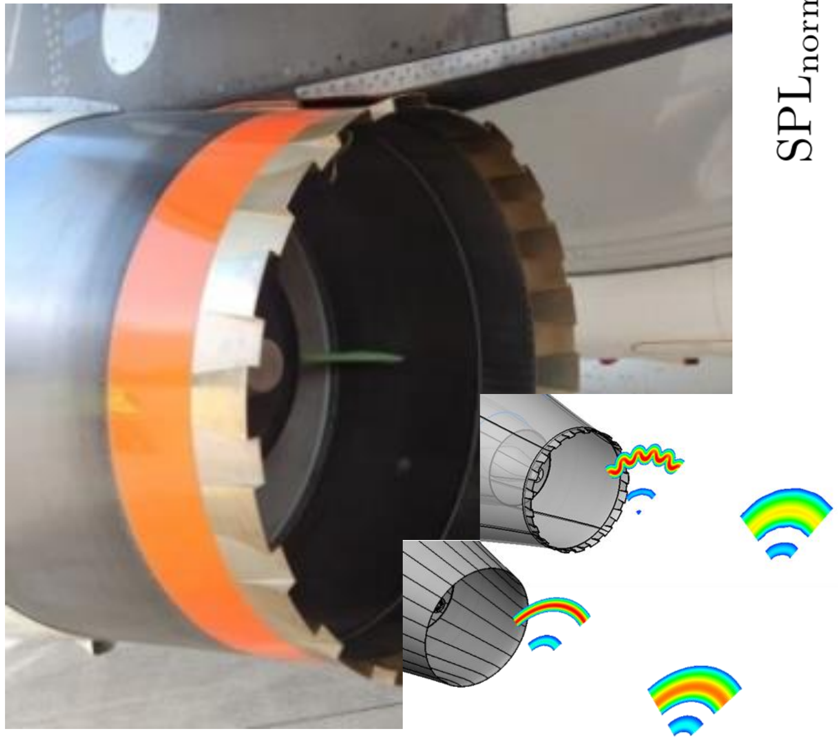
SAFRAN, SPÖRL, AMAS technology, Deharde, AIRBUS, Lufthansa Technik, asco, SONACA, Leichtwerk AG

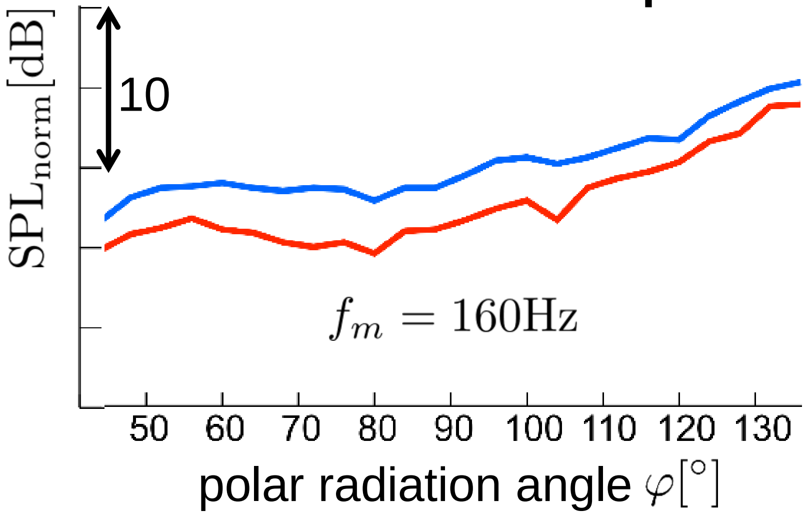
photo: M. Lindner 2018

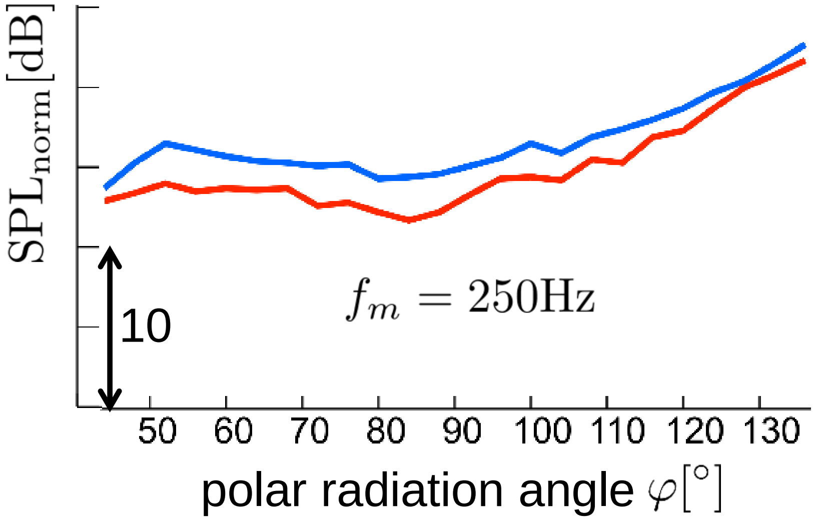
Jet noise

take-off – flaps 2: 22°/20° - gear up

Nozzle modification







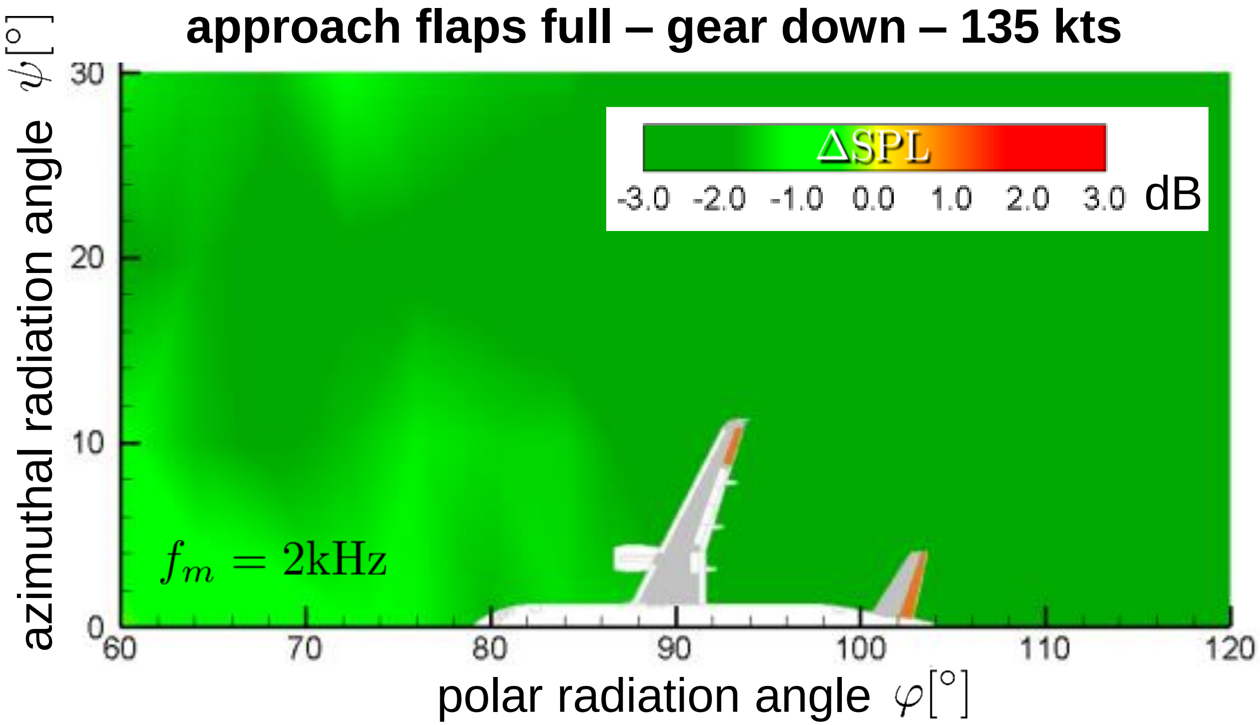
standard nozzle (2016)
modified nozzle (2019)

$$\mathrm{SPL_{norm}} = \mathrm{SPL_{meas}} - 80\,\mathrm{lg}\left(\frac{v_{\mathrm{jet}} - v_{\mathrm{tas}}}{c_{\mathrm{ref}}}\right)[\mathrm{dB}]$$

- significant reduction at low frequencies, slight increase (~1dB) at high frequencies

Landing gear noise reduction

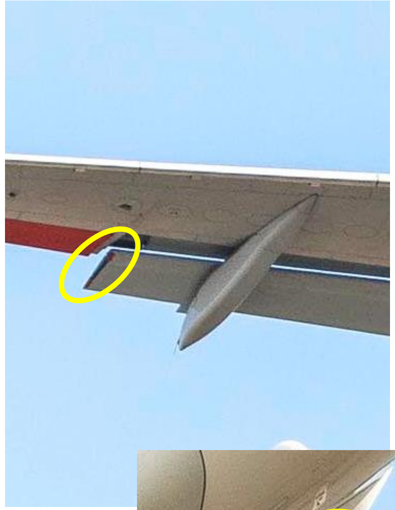
Nose/Main LG modification



- wide area broadband noise reduction ~ 2-3dB (single mics!)

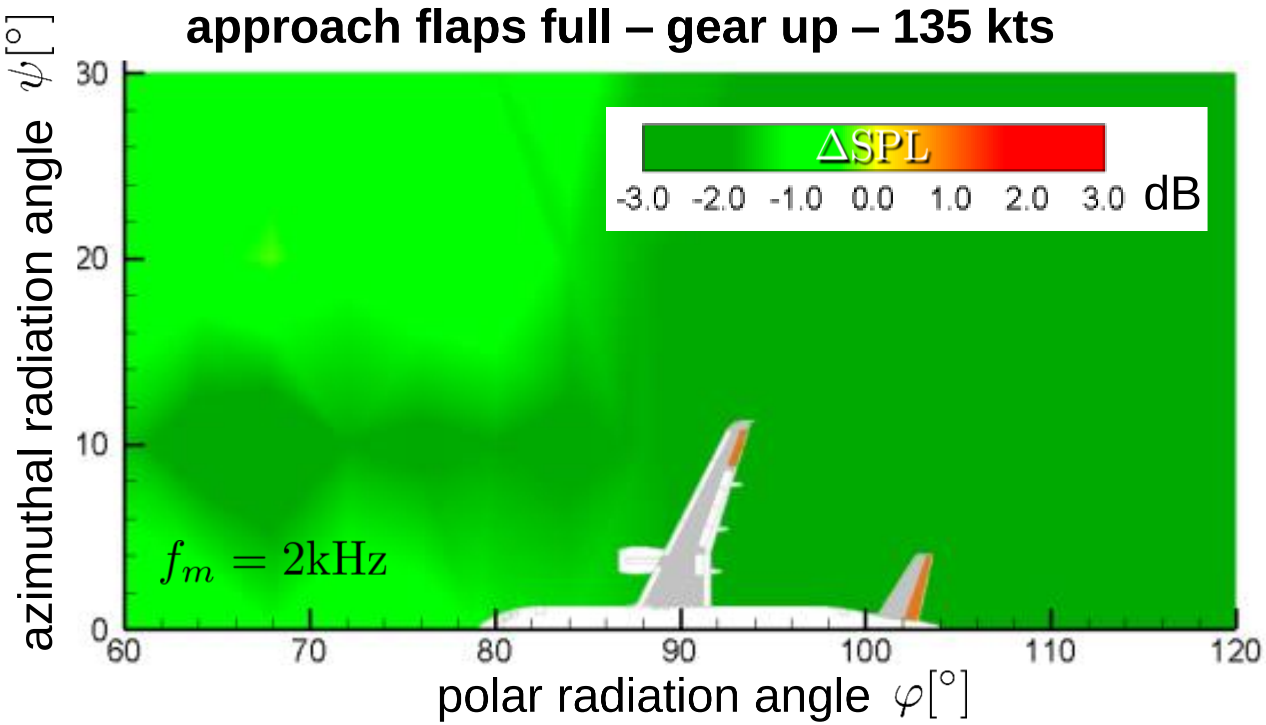
High Lift noise reduction

HLD side edge modification



aluminum foam

open cell urethane foam



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High Lift noise reduction

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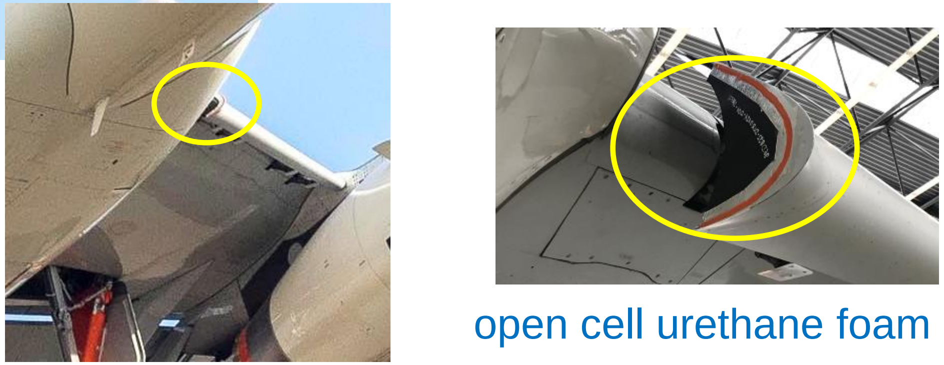
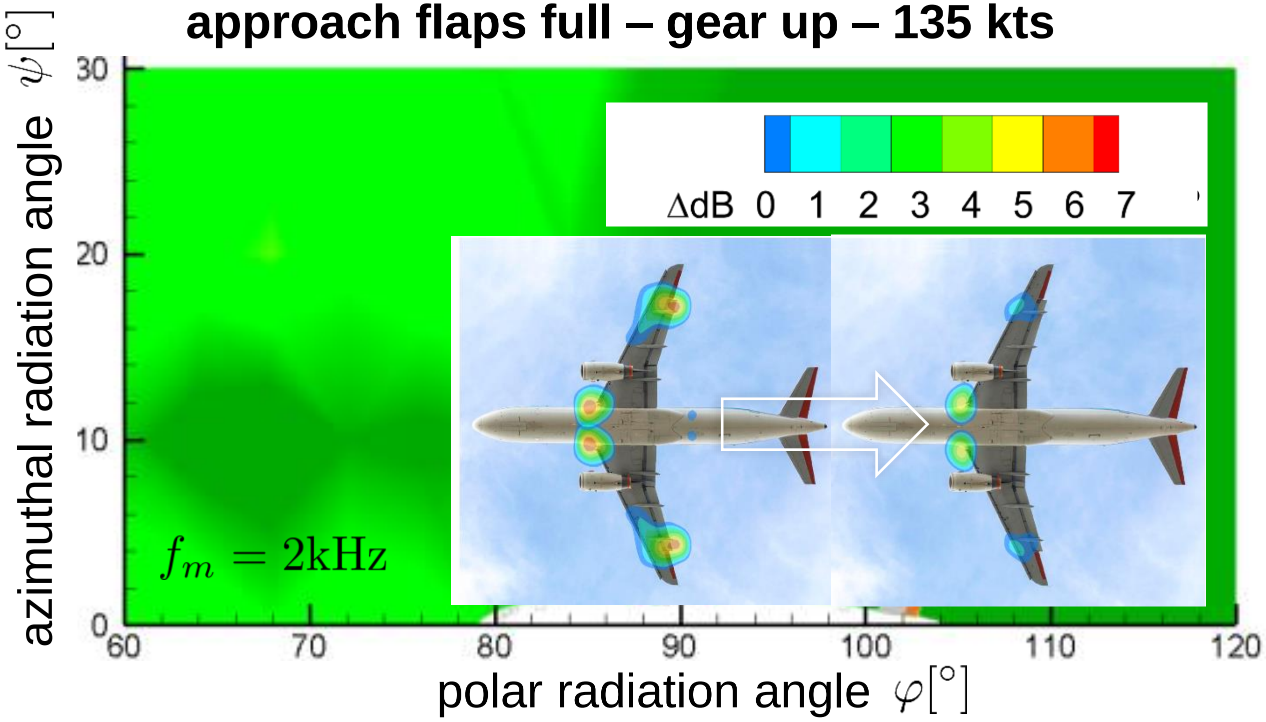
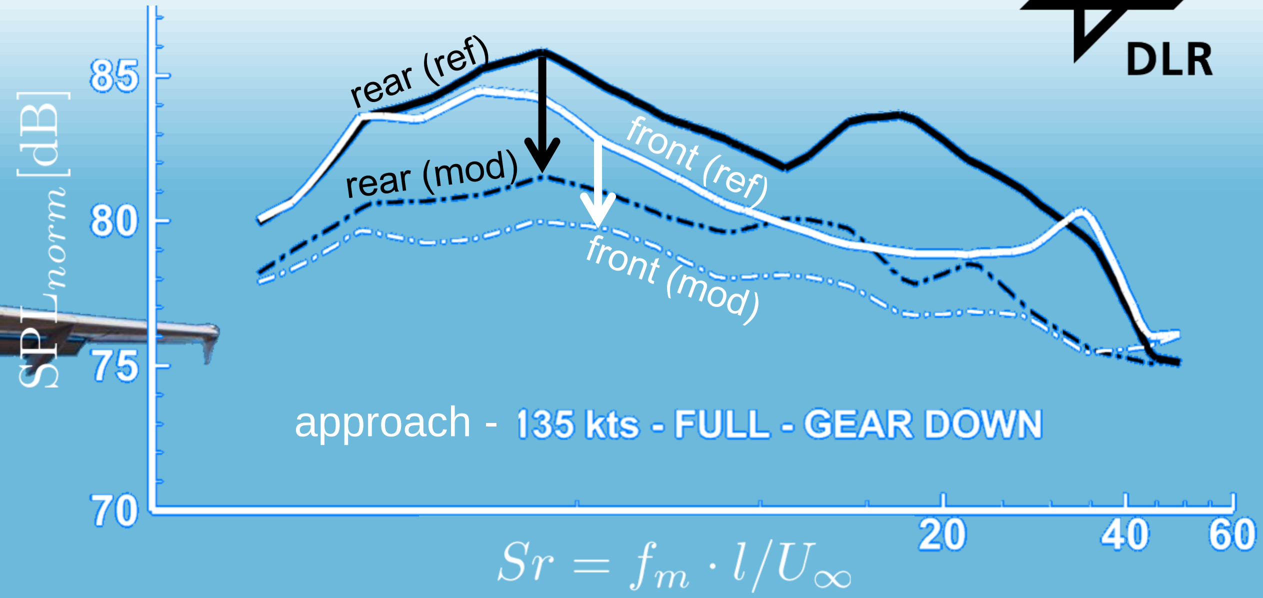


open cell urethane foam



- wide area broadband noise reduction ~ 2-3dB (single mics!)

Low noise ATRA - synopsis



Much more subsequent work on NRTs:

- Jet-flap noise reduction by porous flap inserts
- MLG-flap interaction noise reduction
- Slat noise reduction by slat cove liner
- Slat track noise reduction by shaping
- HLD noise reduction Slat→Kruger
- …

✓ broadband reduction 3 – 4 dB for standard approaches
✓ spoiler noise eliminated
✓ 1 – 2 dB reduction at departure

- up to **5dB reduction** at approach (if including slat modification)

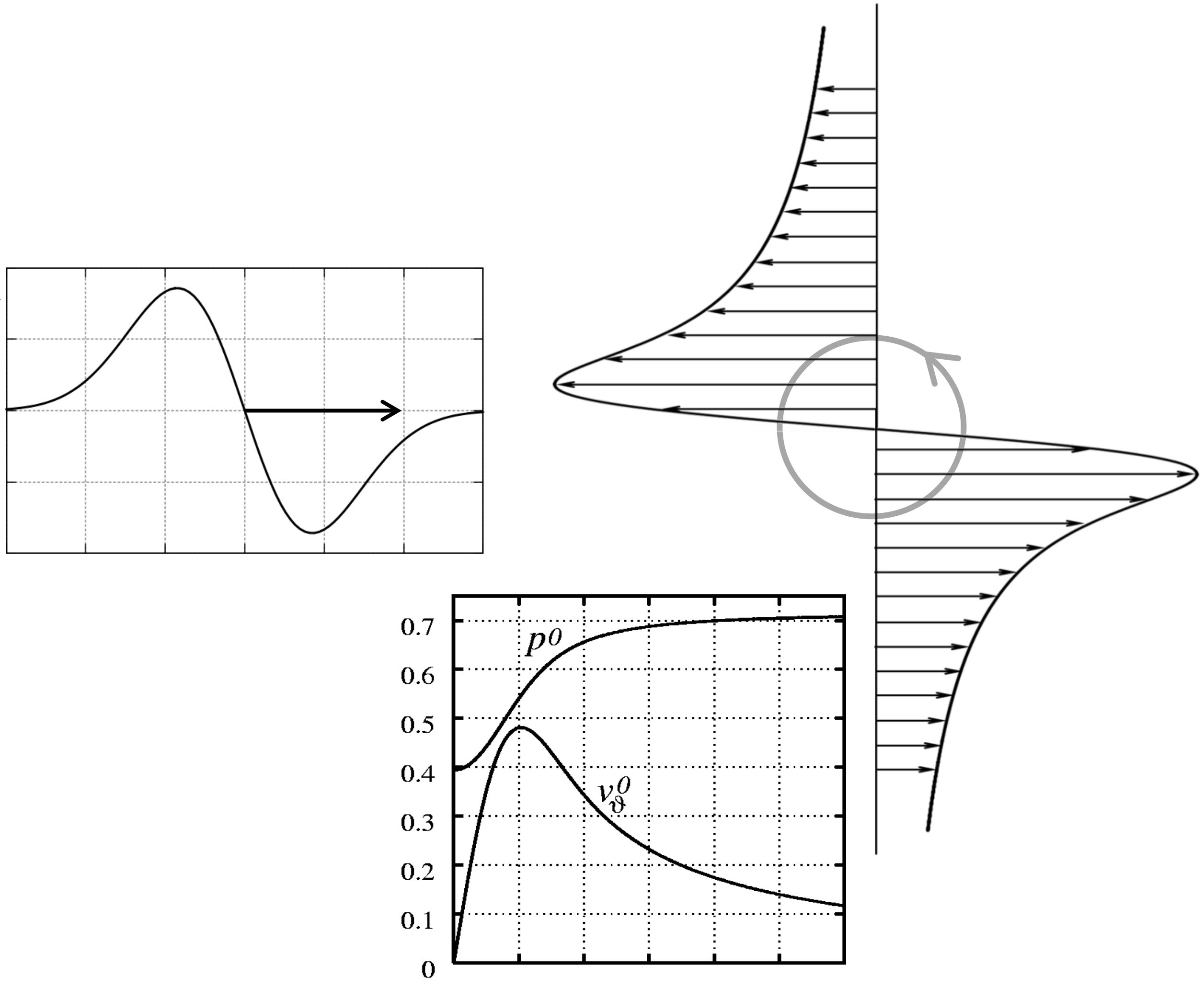
- **a few surprising phenomena**
  - Sound where it is not supposed to go: „aeroacoustic tunnel effect“ !!
  - Vortex as „pressure trap“ ??
  - Level increase with distance ??
  - Doppler effect: „without relative motion“ ??
  - Convective amplification: „upstream or downstream“ ??
  - (Installed) propellers: „where is the source“ ??
  - Acoustic windtunnels: „aerodynamic lenses“ ??
- **cooperation work DLR/UdeS** (work in progress)
  - alternative source localization ●
  - modeling sound generation of a laminar separation bubble ●

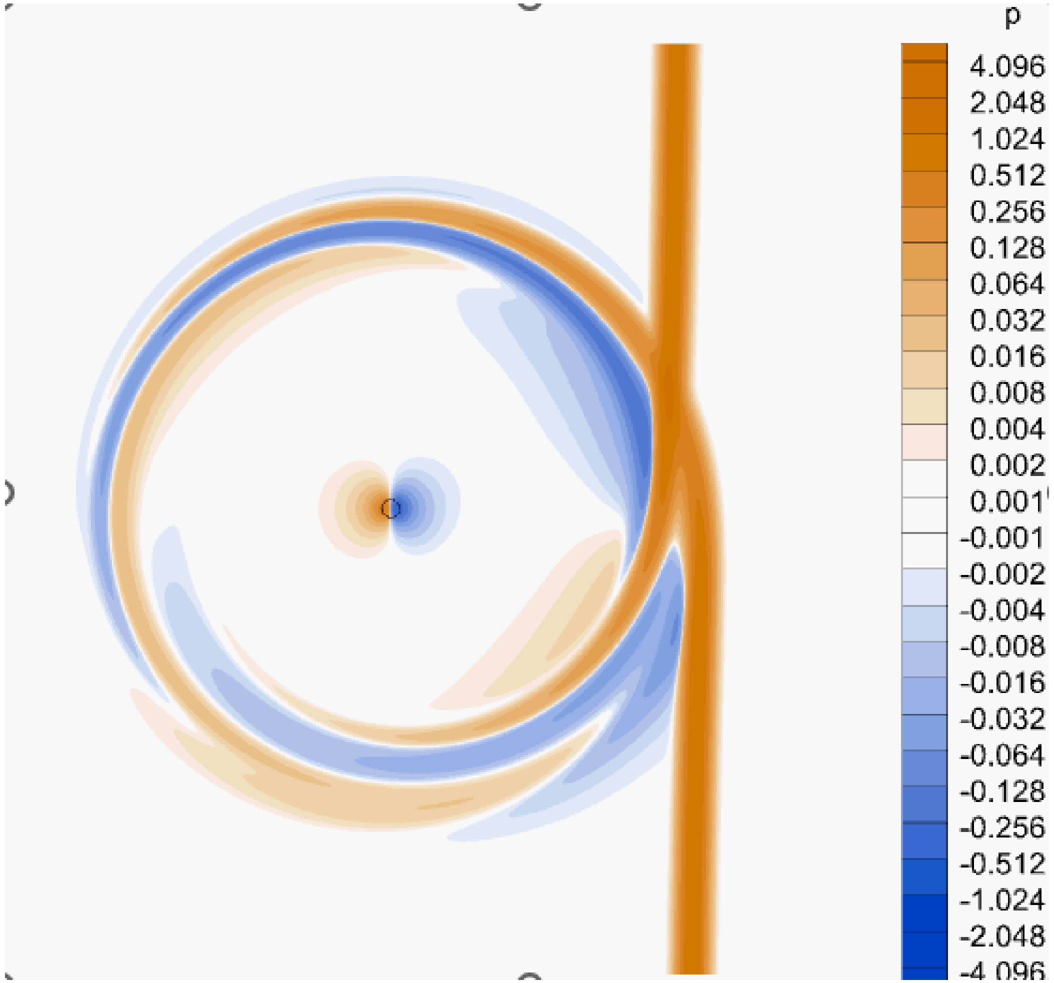
SOME MORE AEROACOUSTICS

Thank you!

Vortex as „pressure trap“ ??

Scattering of sound at a single (Lamb-Oseen) vortex





Vortex as „pressure trap“ ??

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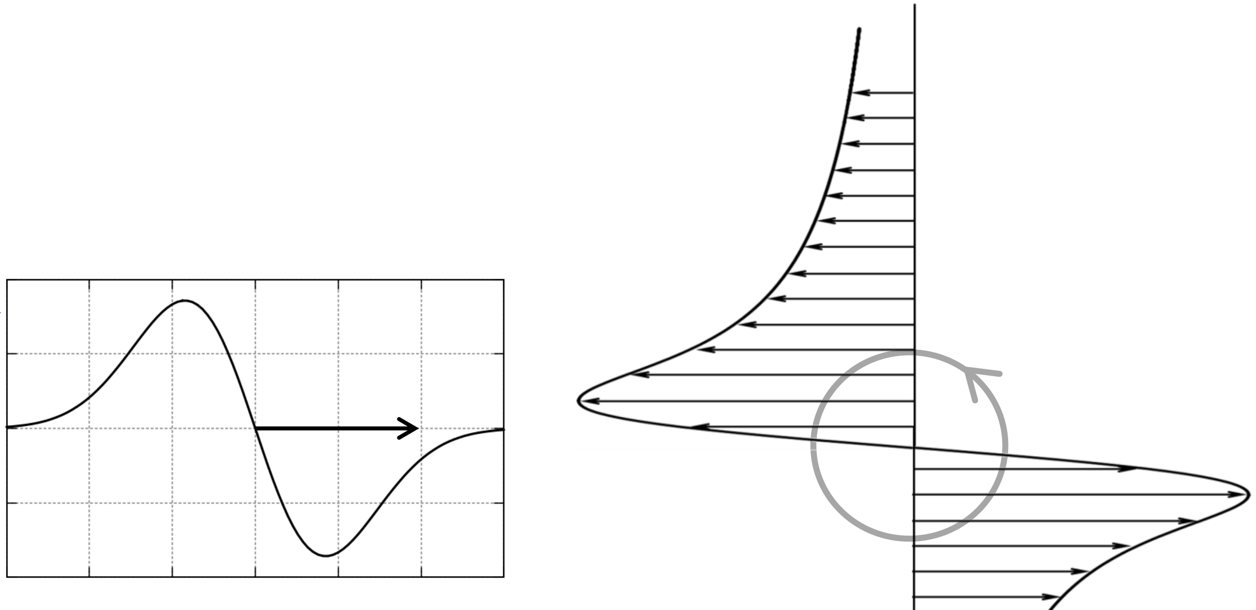
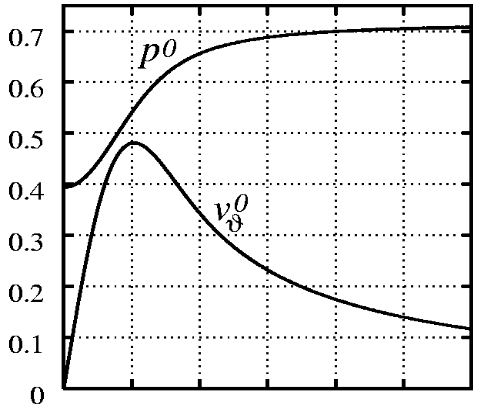
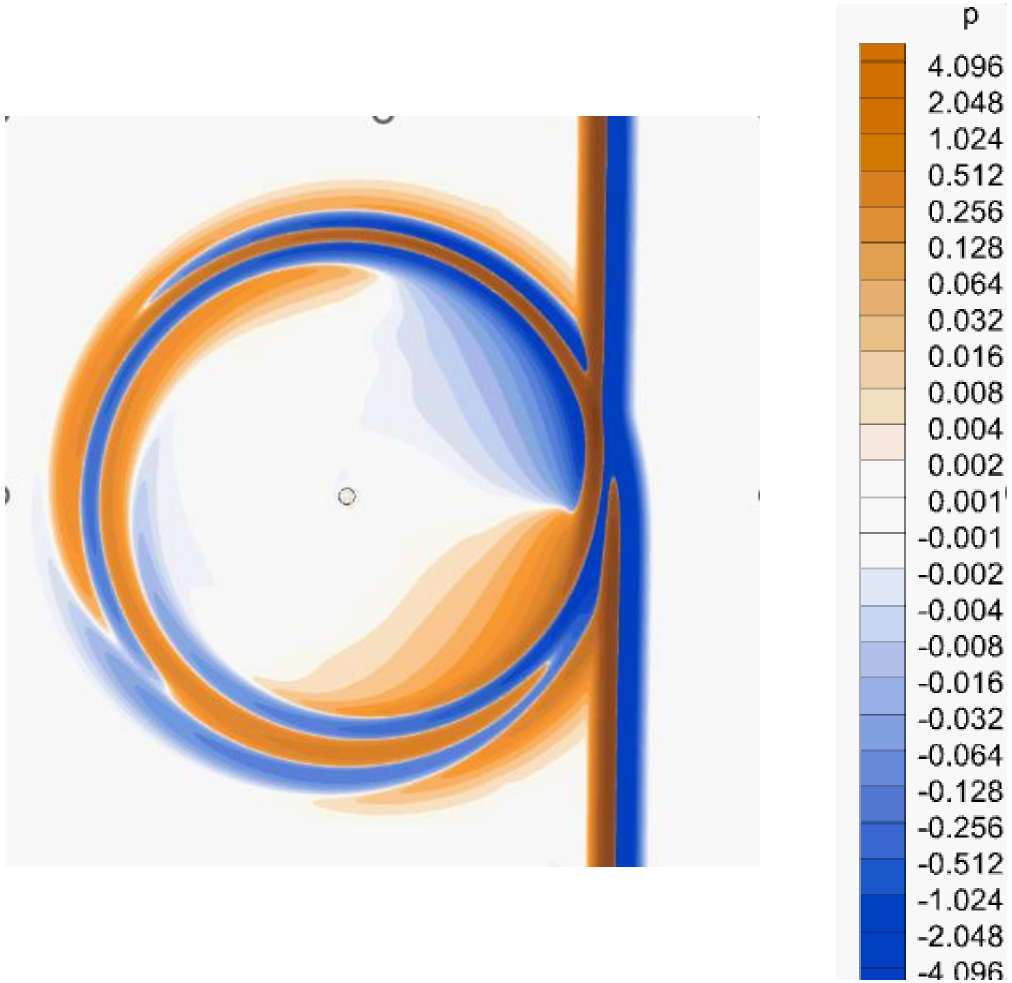
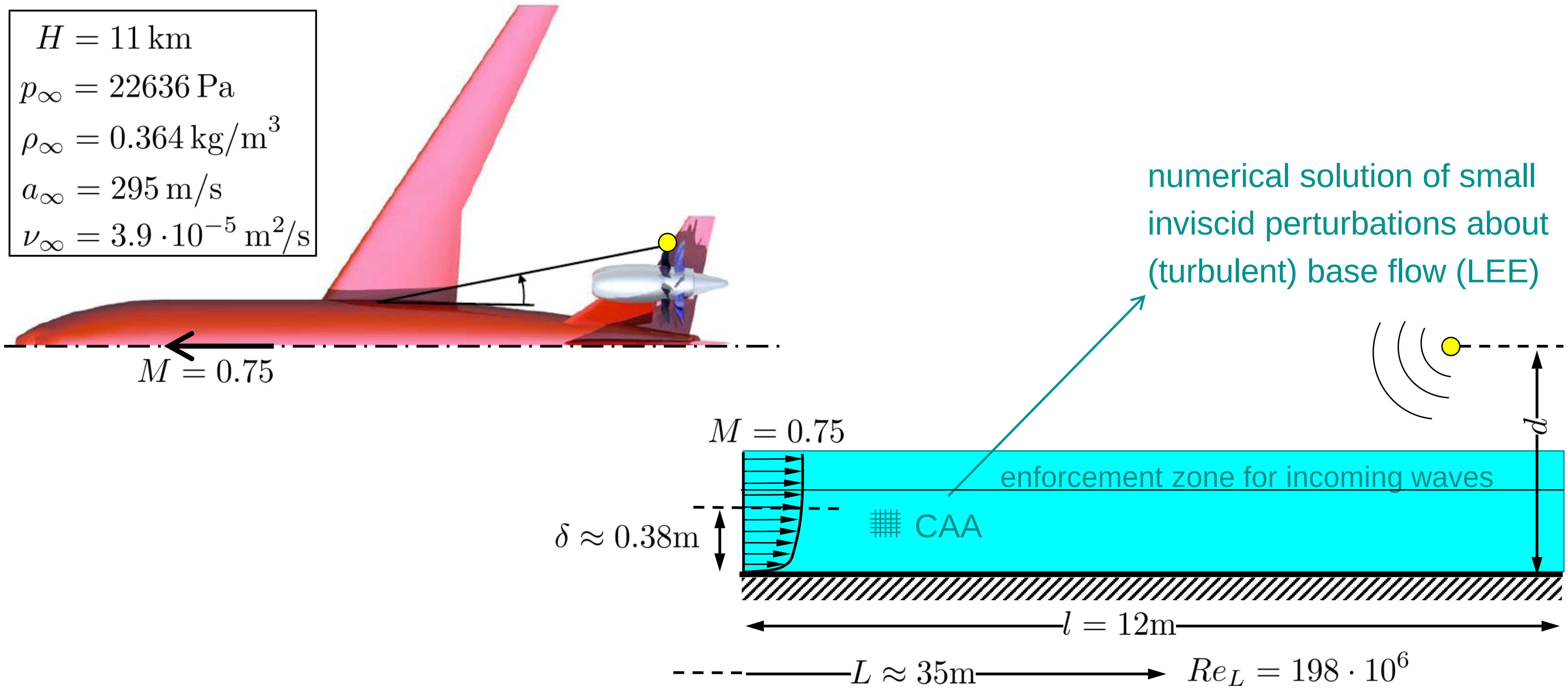




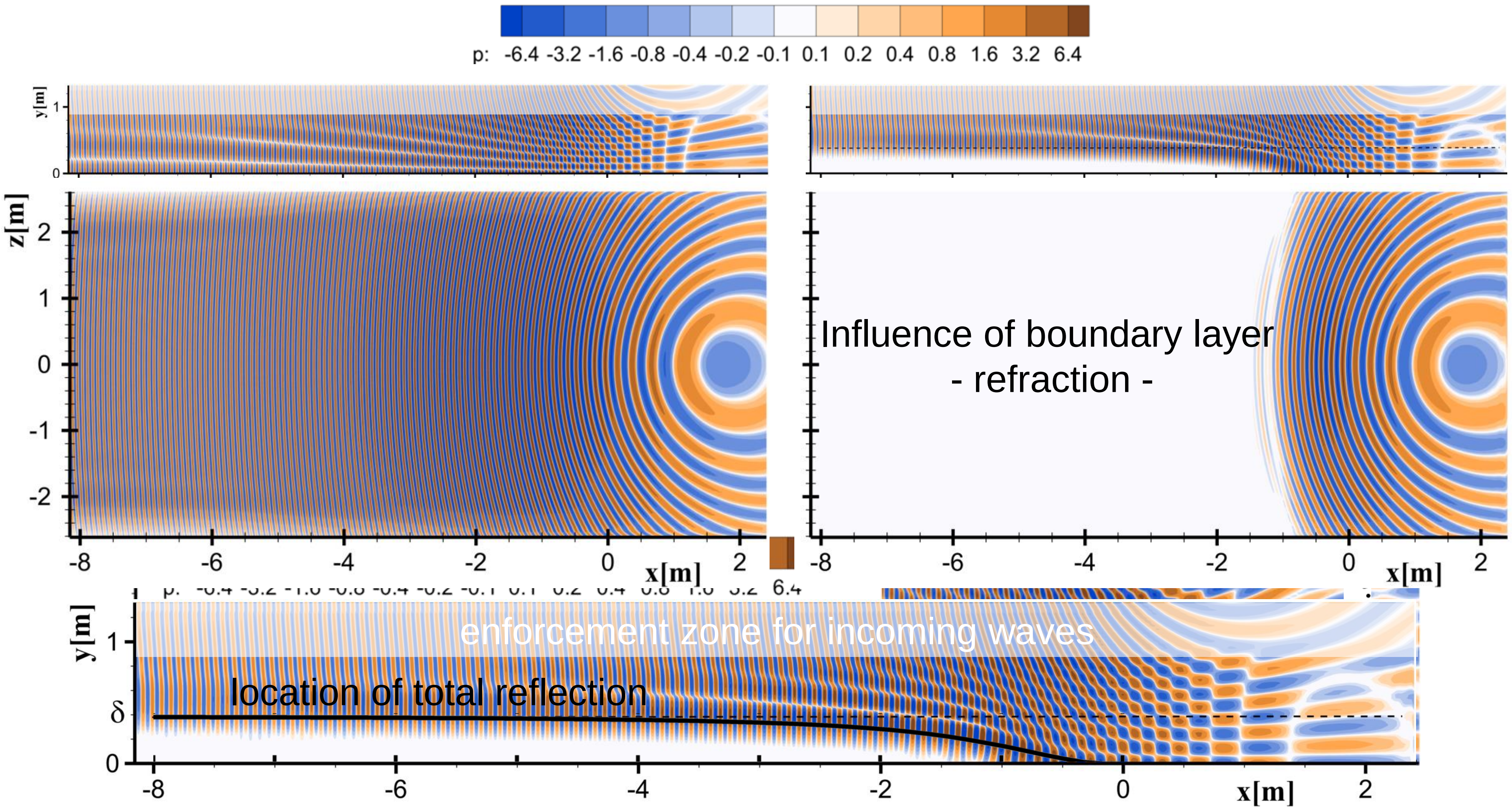


Level increase with distance ??

Acoustic pressure on skin of fuselage

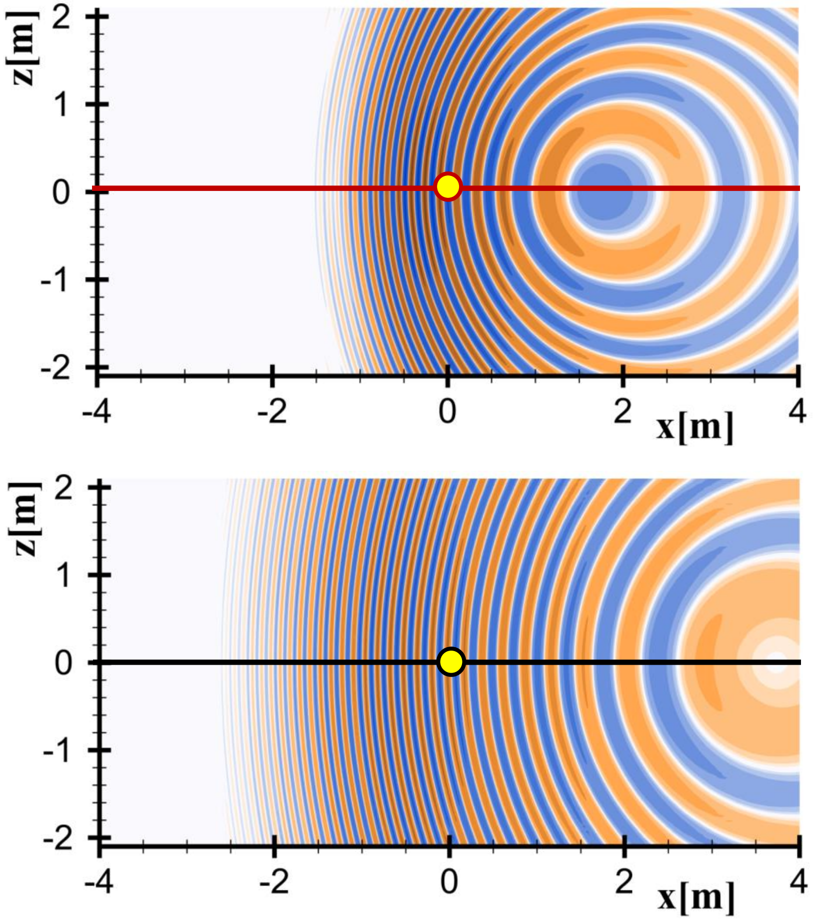


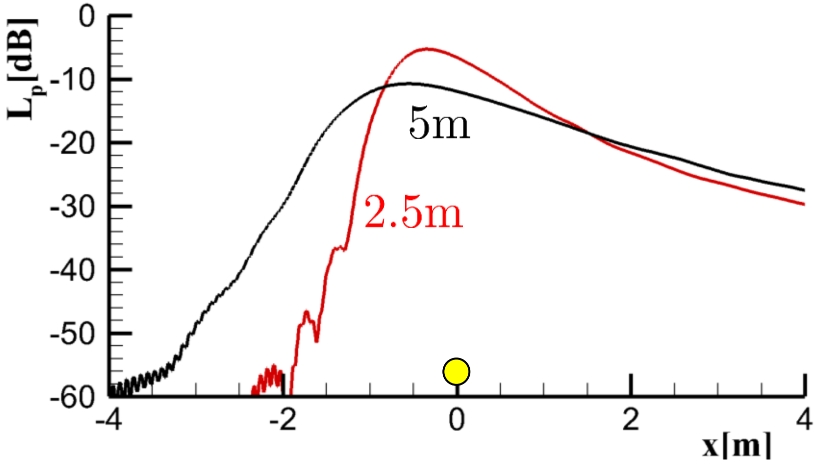
Level increase with distance ??

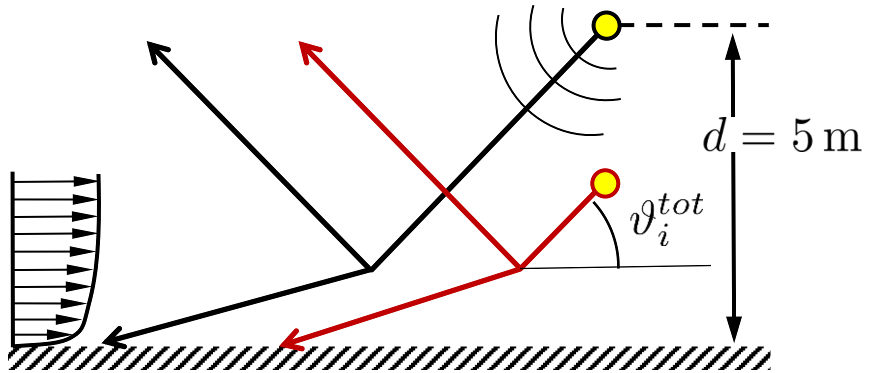


Level increase with distance ??

Influence of boundary layer - refraction

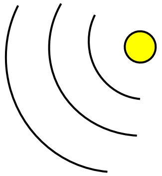


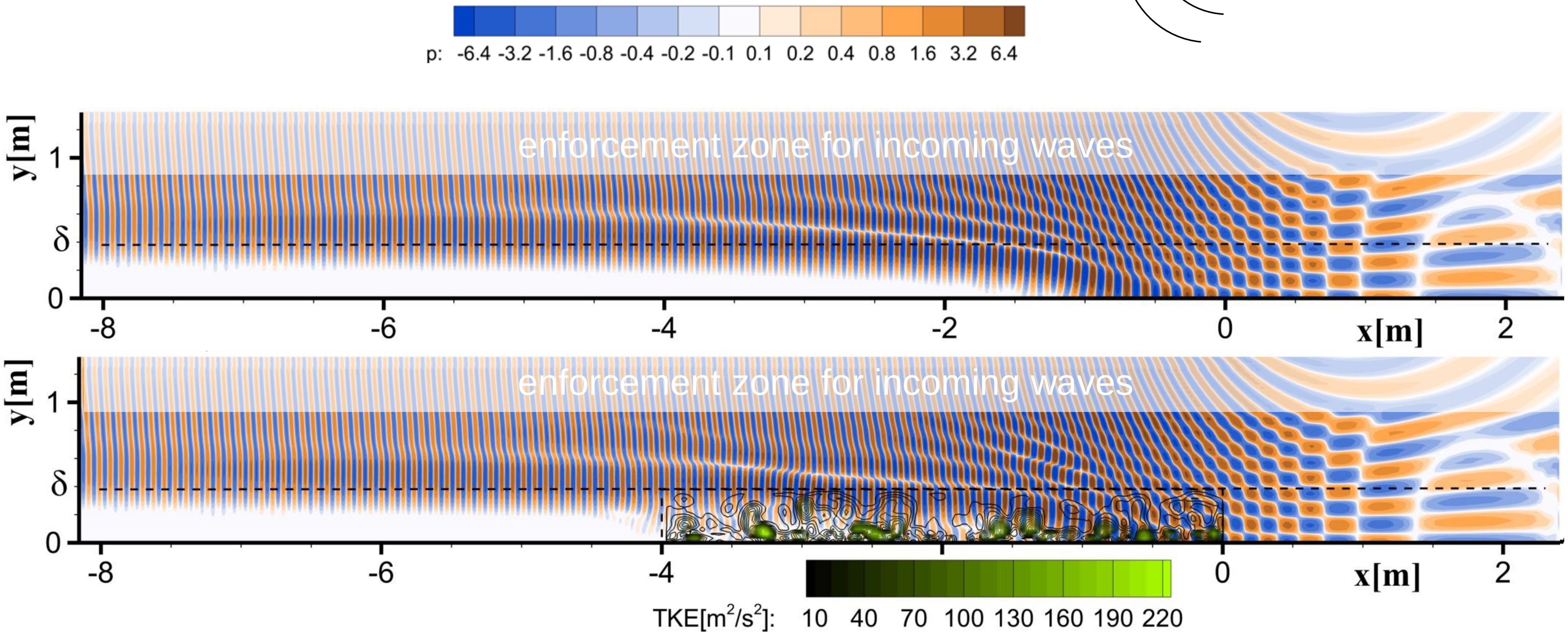




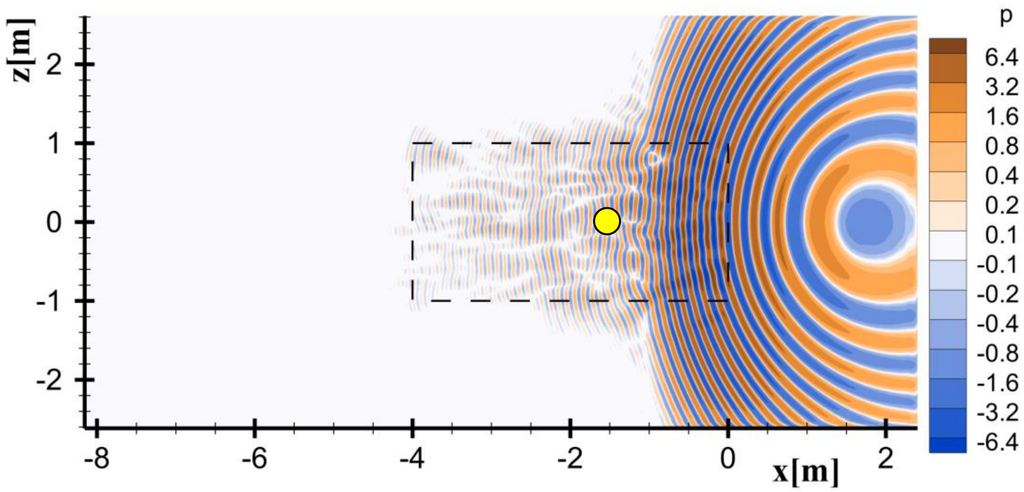
Doppler effect - „without relative motion“ ??

Influence of boundary layer – refraction and scattering

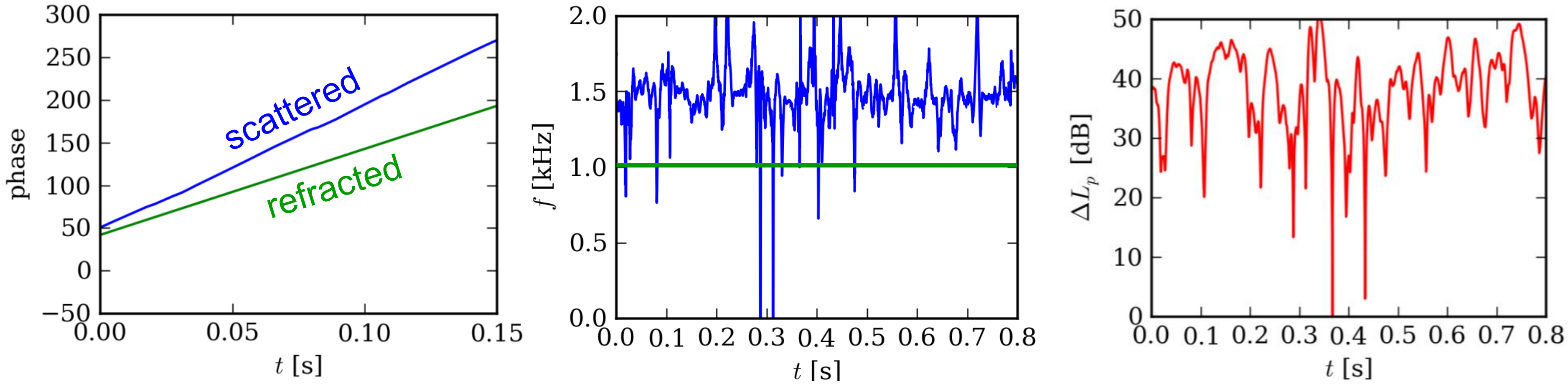




Doppler effect - „without relative motion“ ??



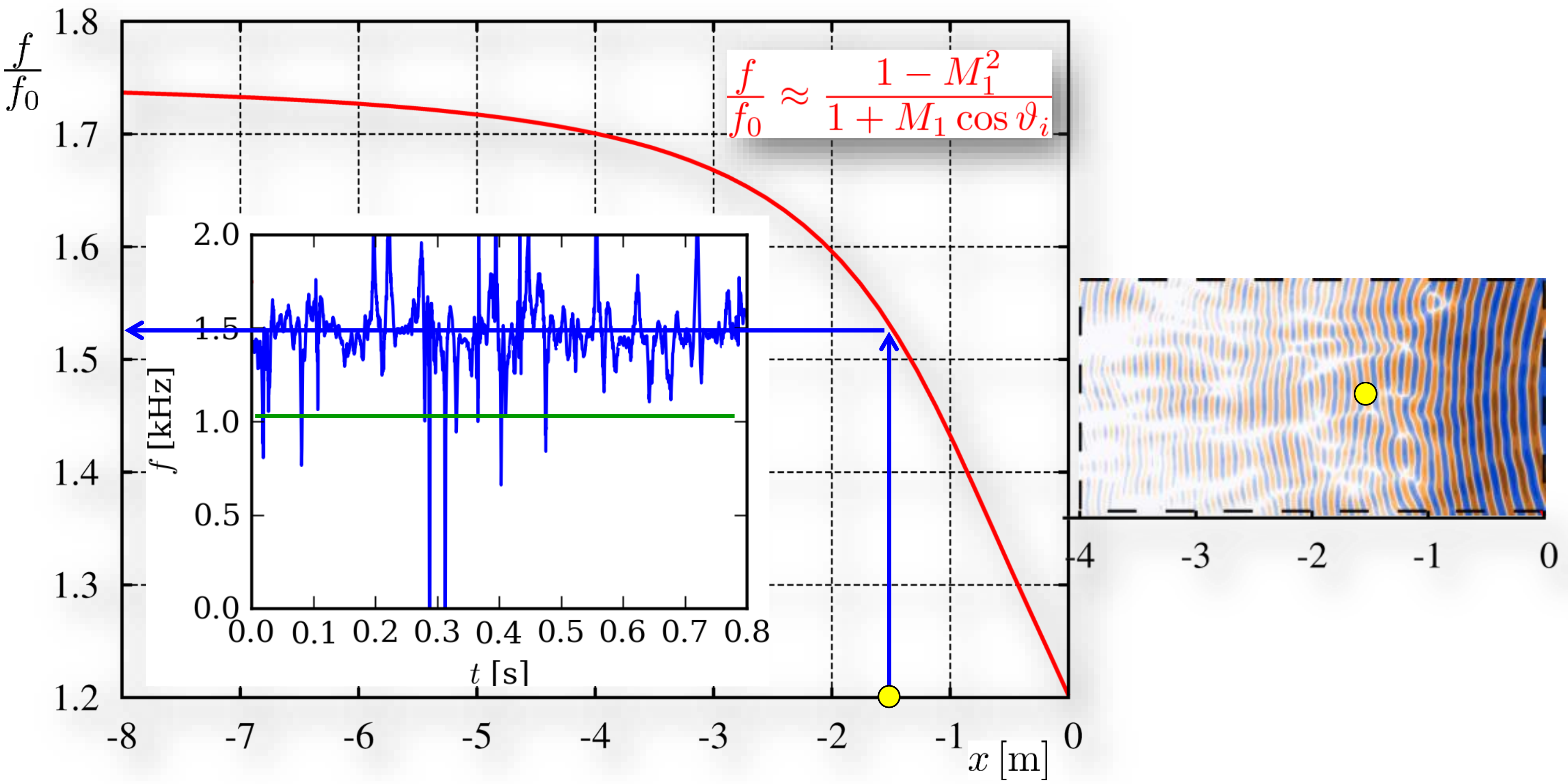
Hilbert transformation of pressure signal at $x = -1.5\,\mathrm{m}$:



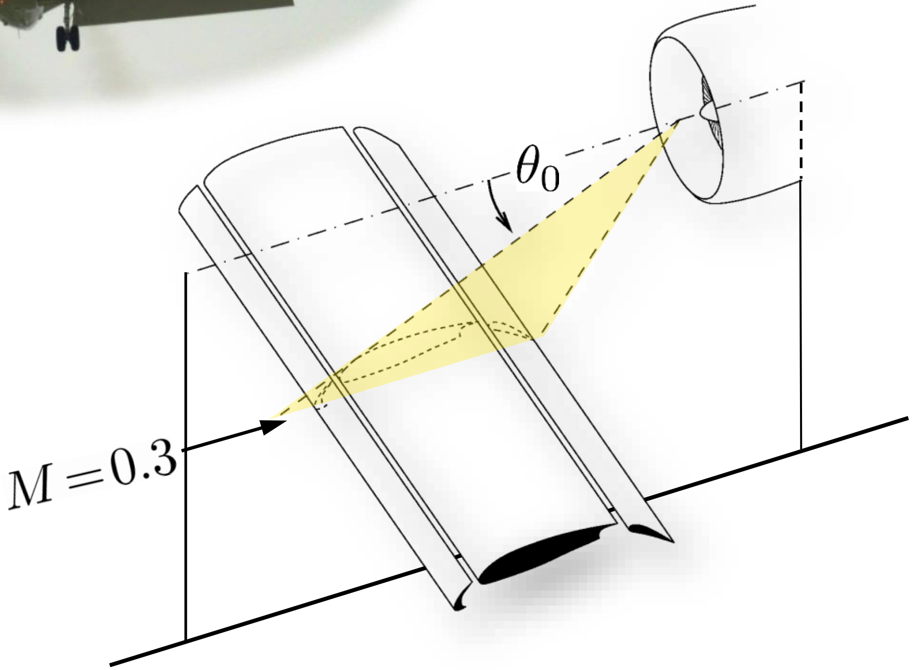
pressure appears „Doppler-shifted“!

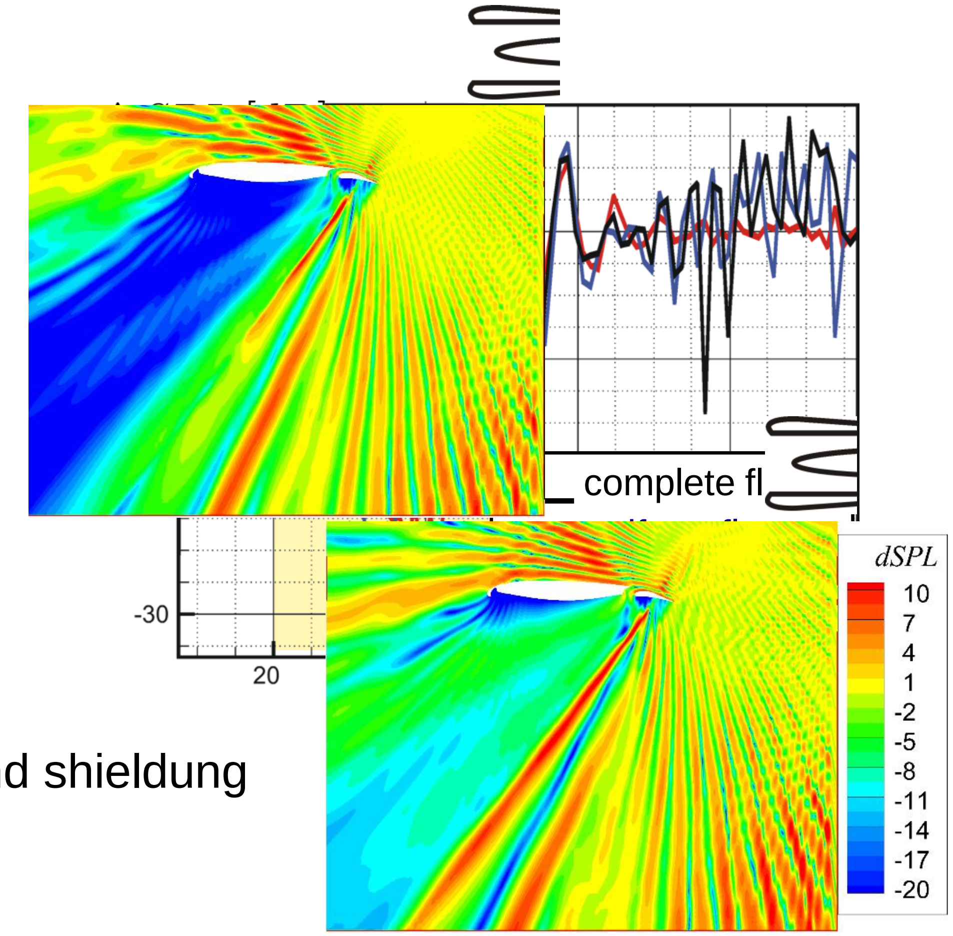
Doppler effect - „without relative motion“ ??

Influence of boundary layer – refraction and scattering



Sound where it is not supposed to go: „aeroacoustic tunnel effect“



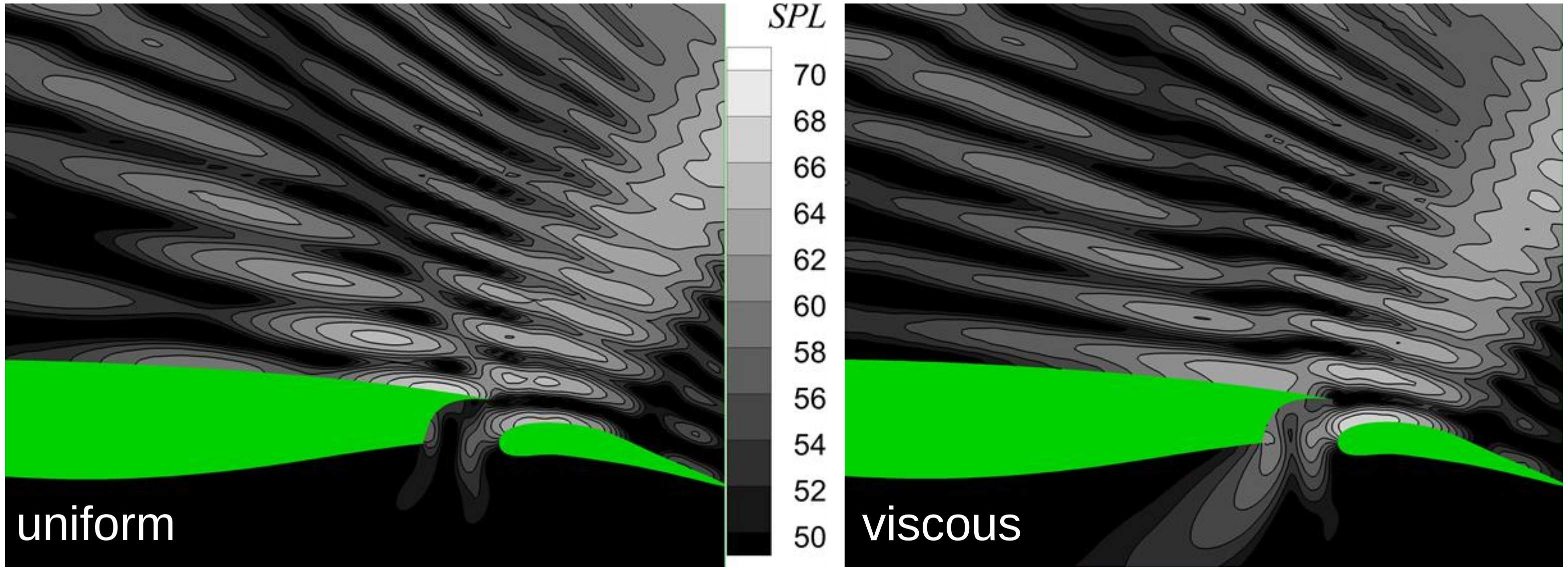


Why would viscous flow influence sound shieldung so dramatically?

Sound where it is not supposed to go: „aeroacoustic tunnel effect“

Observations

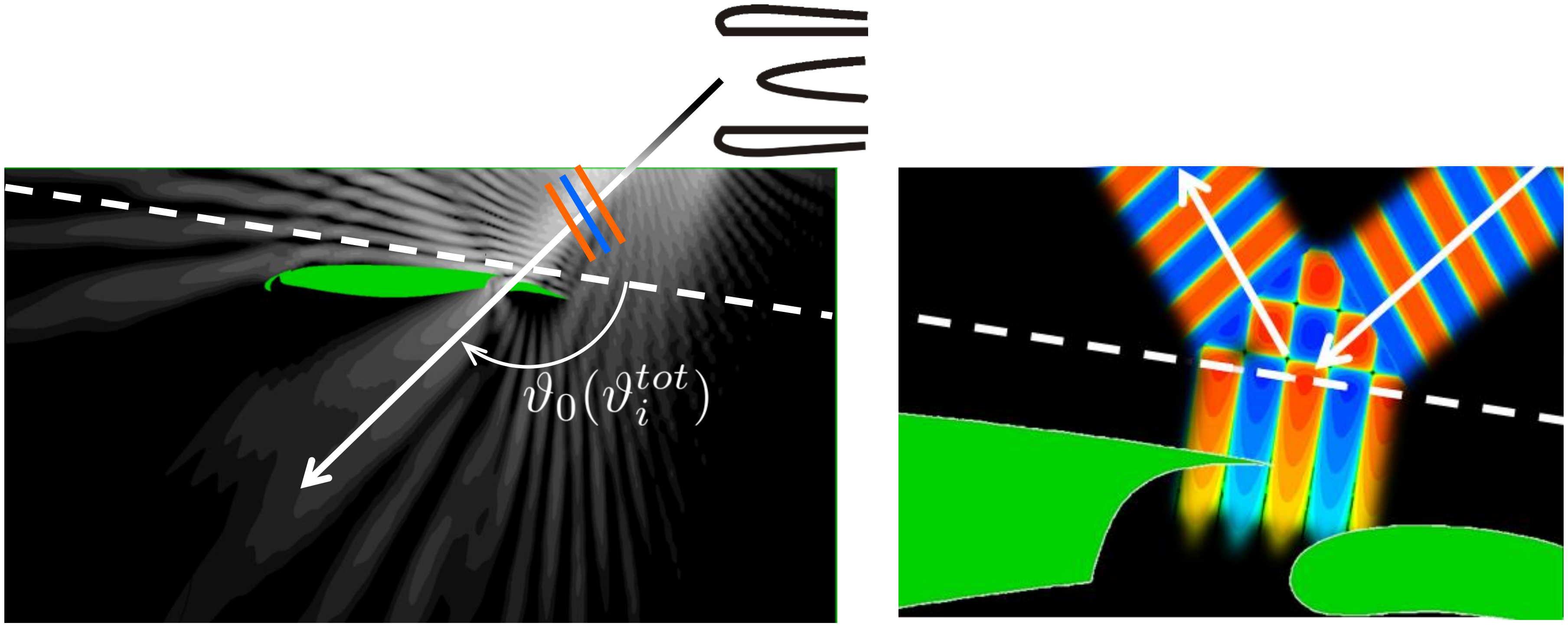
$$c = 0.453 \text{ m}$$
$$f = 11.733 \text{ kHz}$$
$$\lambda = 0.029 \text{ m}$$



distinct differences in near wall distribution of p_{rms}

Sound where it is not supposed to go: „aeroacoustic tunnel effect“

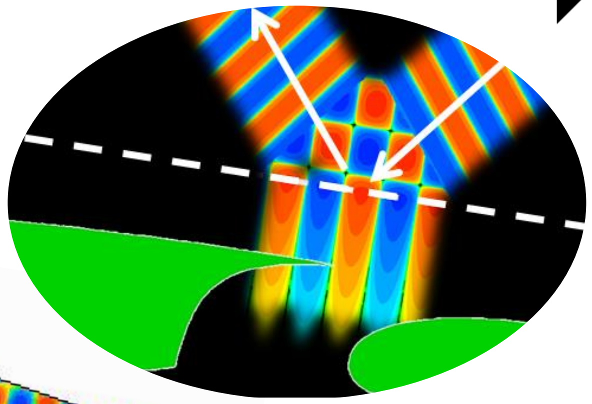
Observations



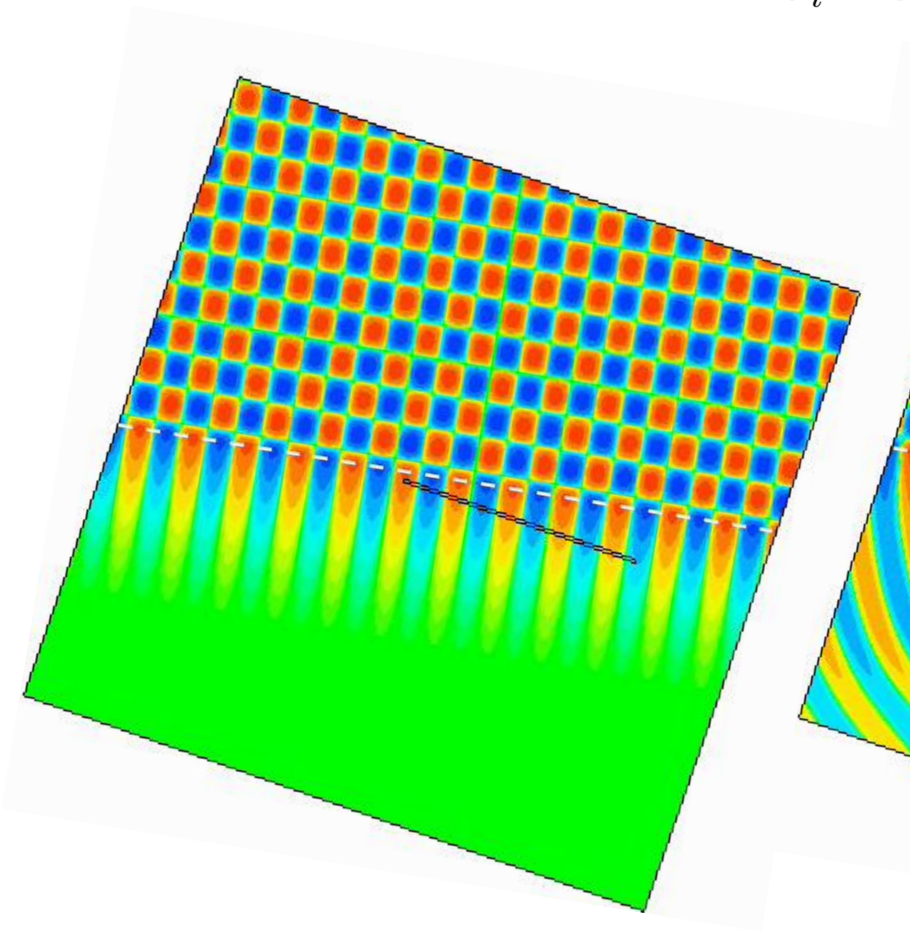
Conditions for total reflection satisfied

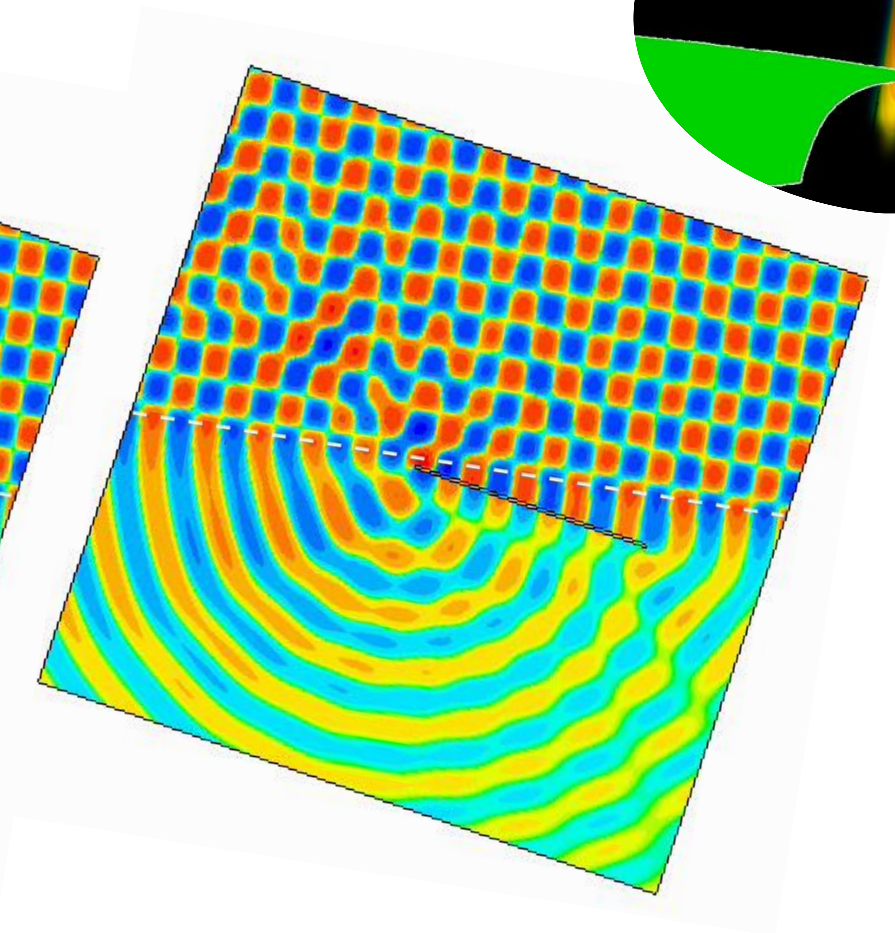
Sound where it is not supposed to go: „aeroacoustic tunnel effect“

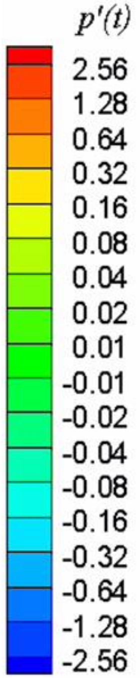
Edge in plane evanescent pressure field



$$\vartheta_i = \vartheta_i^{tot} + 2^\circ$$





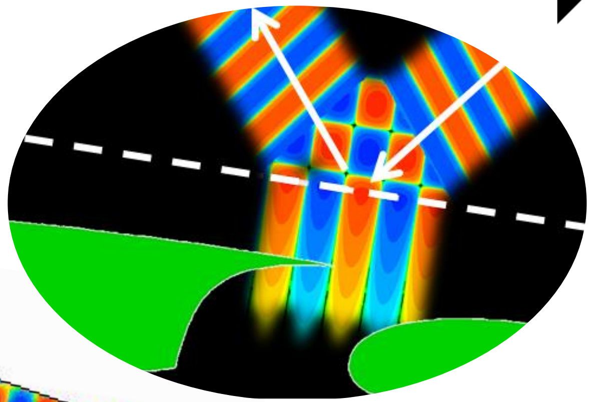


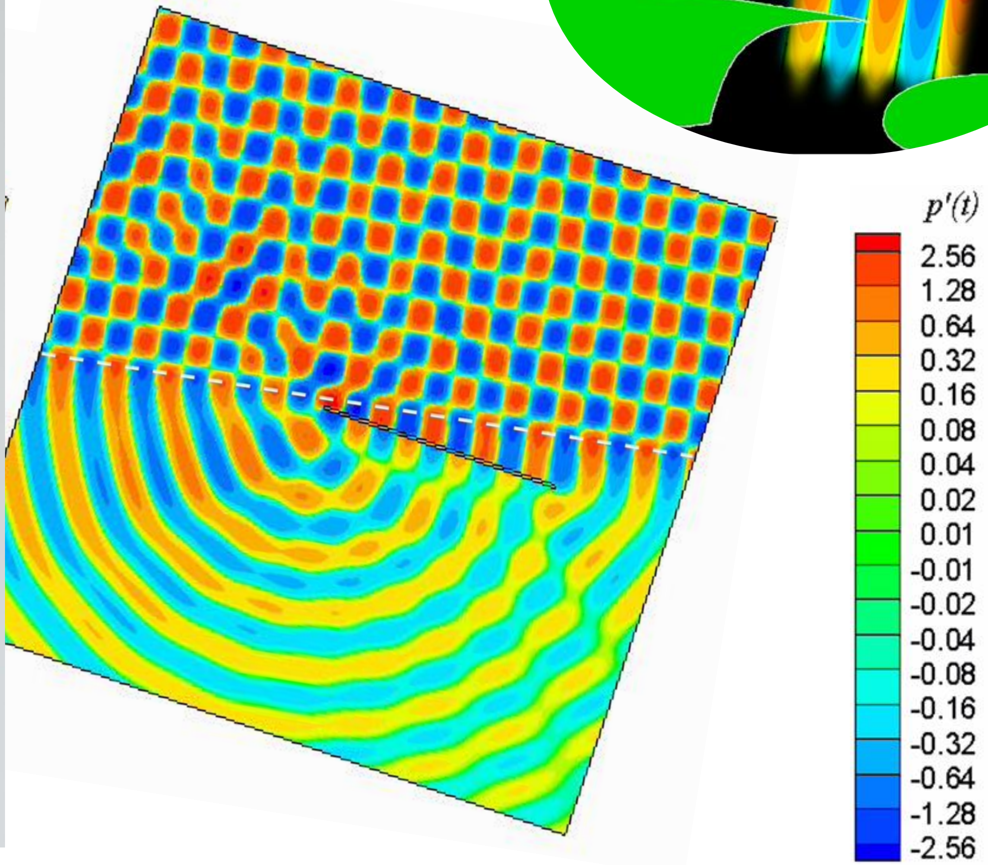
„frustrated total reflection“ = „tunnel effect“ = sound generation at edge! ?

Sound where it is not supposed to go: „aeroacoustic tunnel effect“

Edge in plane evanescent pressure field

$$\vartheta_i = \vartheta_i^{tot} + 2^\circ$$



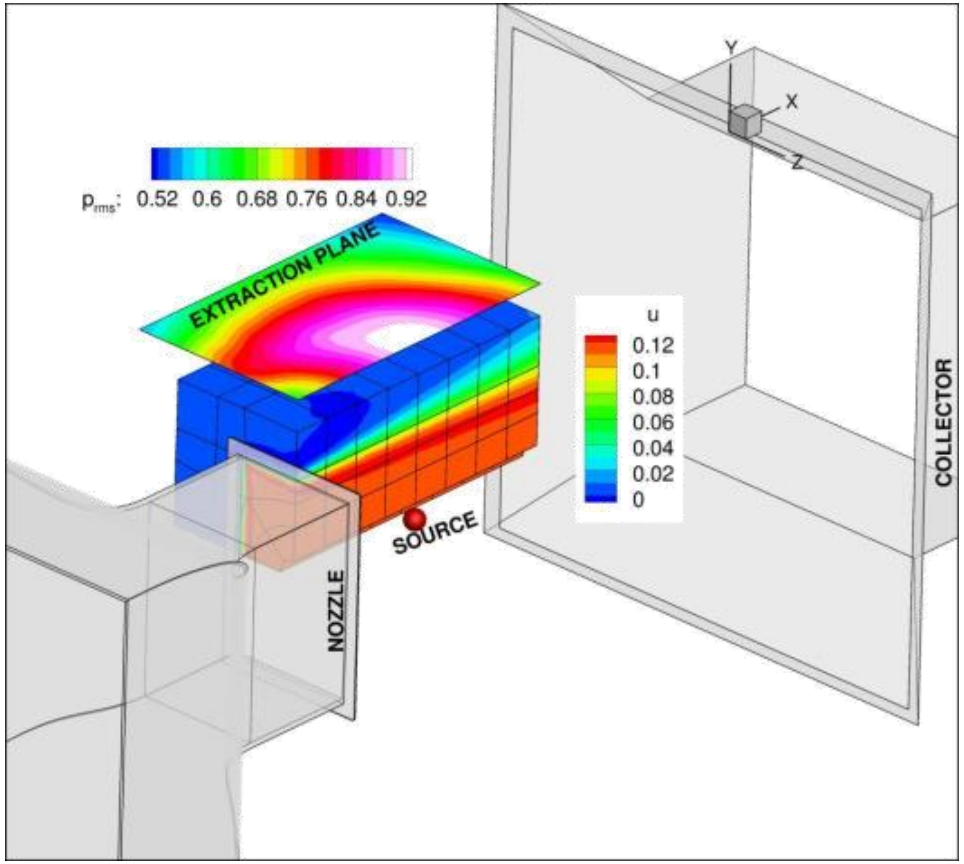


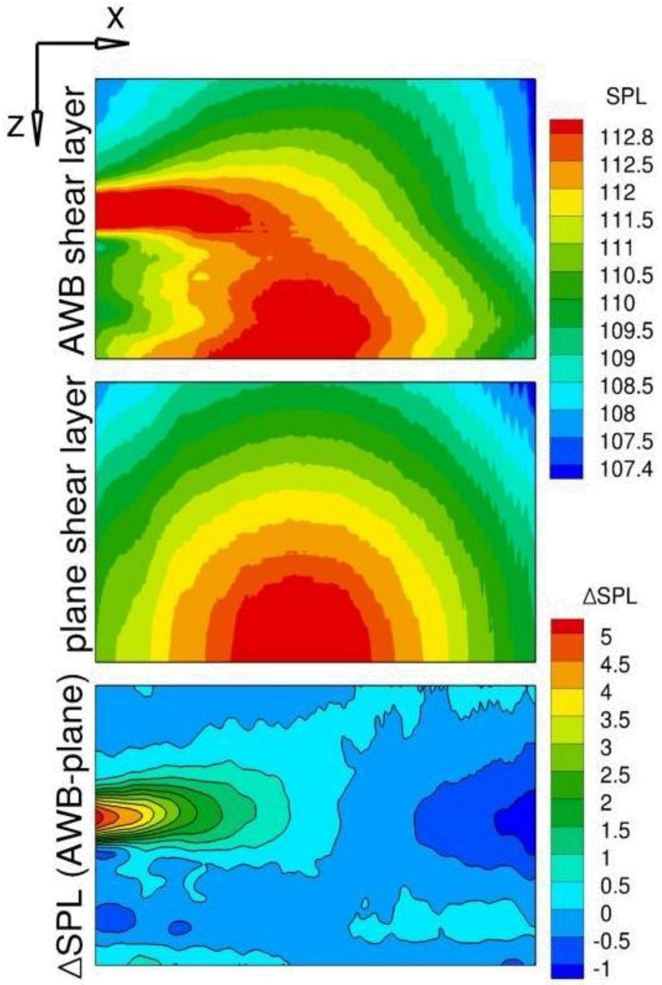
source: Olli Niemitalo / Wikipedia

„frustrated total reflection“ = „tunnel effect“ = sound generation at edge! ?

Acoustic windtunnels: „aerodynamic lenses“ ??

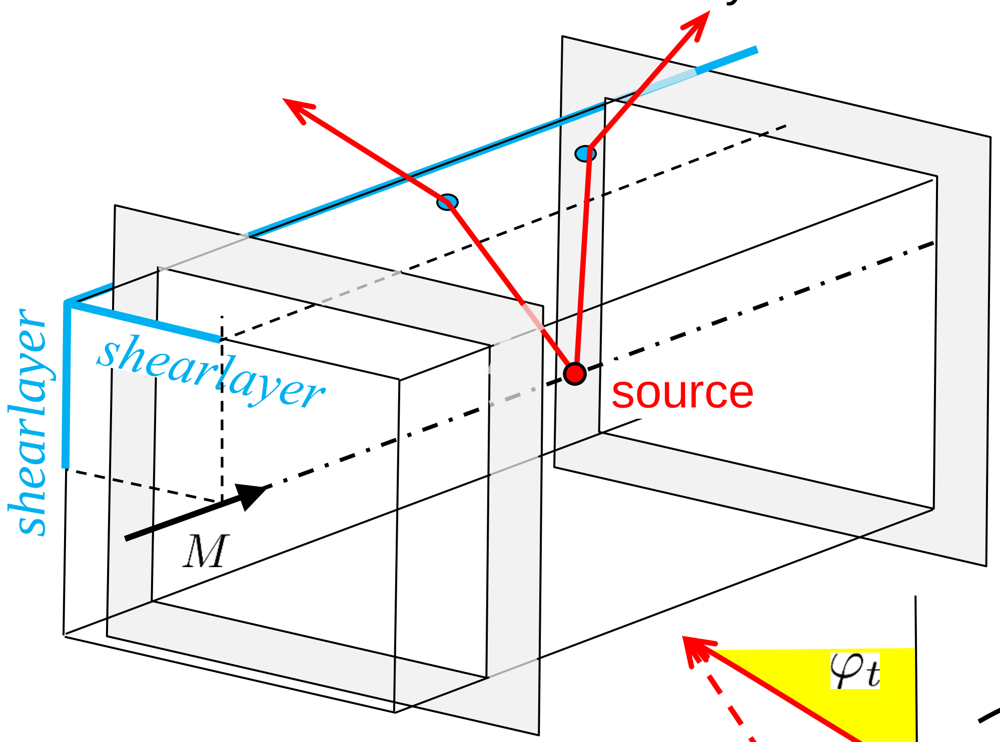
Acoustic wind tunnel correction – 3D effects

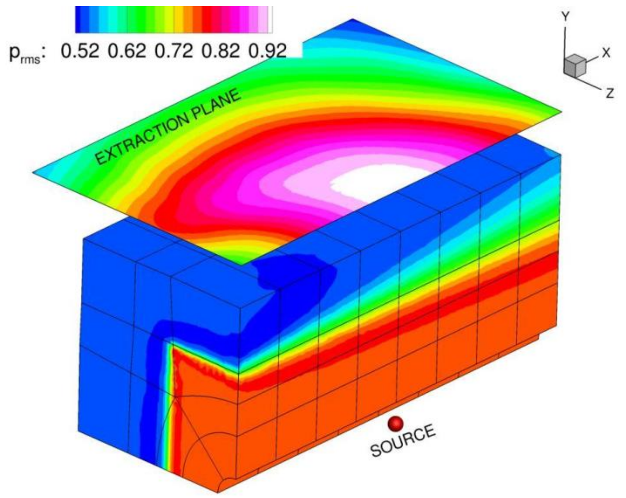


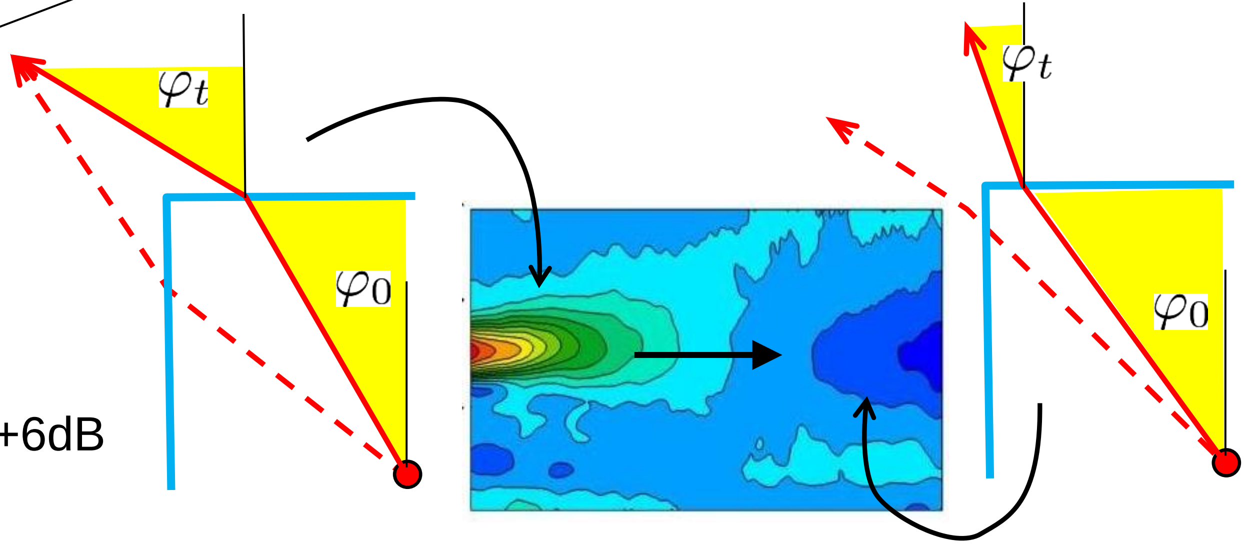


Acoustic windtunnels: „aerodynamic lenses“ ??

Acoustic wind tunnel correction – 3D theory

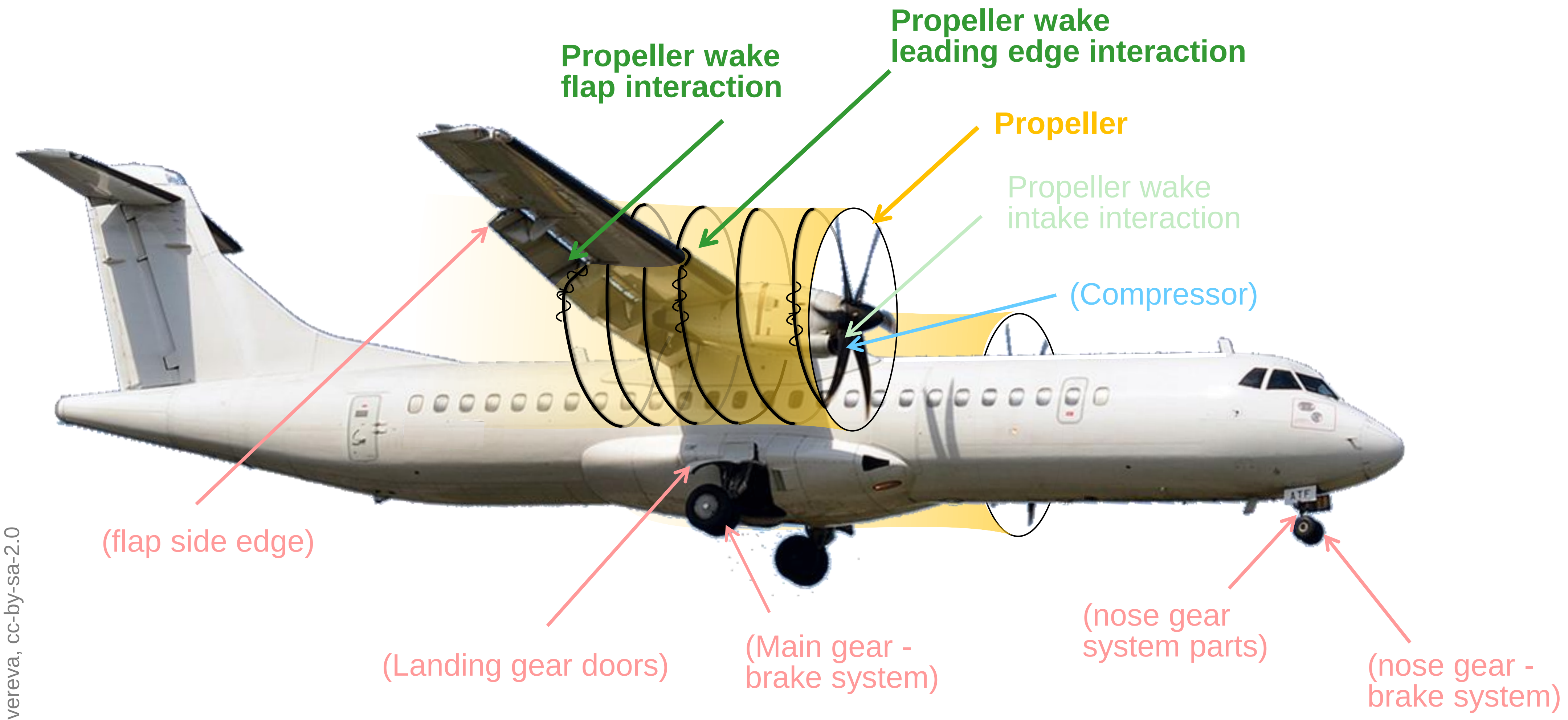






- „converging lens“ upstream: +6dB
- „diverging lens“ downstream

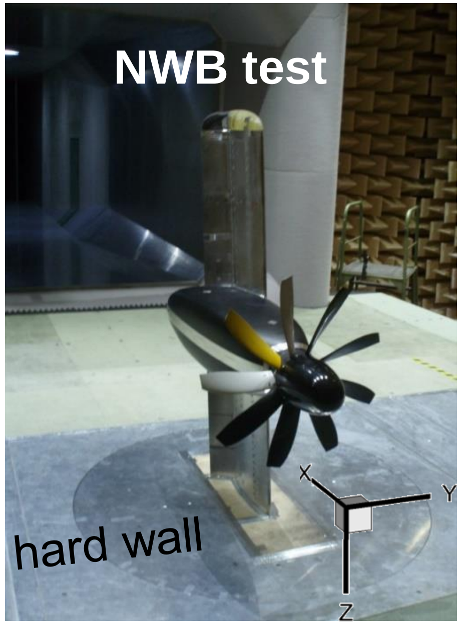
(installed) Propellers - „where is the source“ ??



sources:

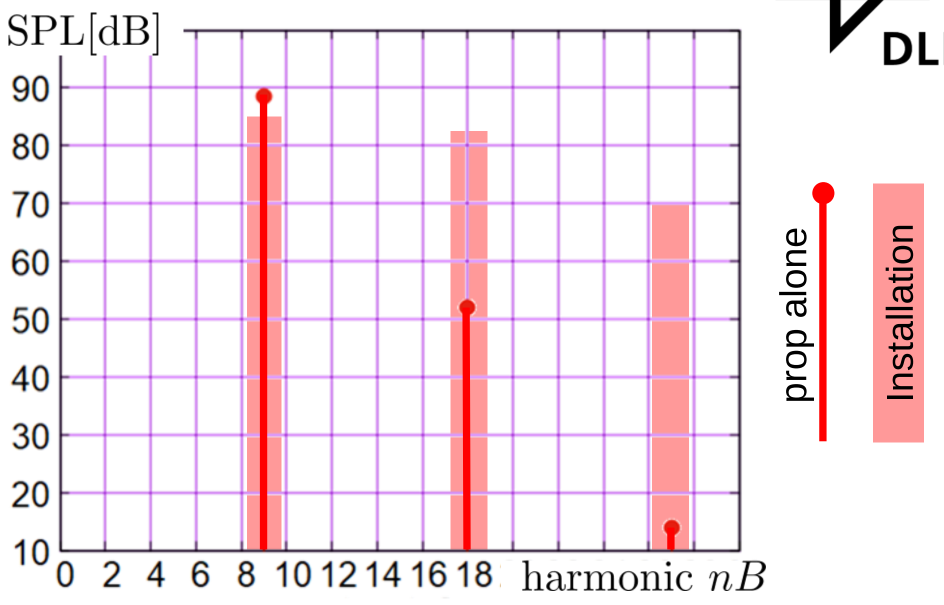
(engine)
propeller
airframe
installation

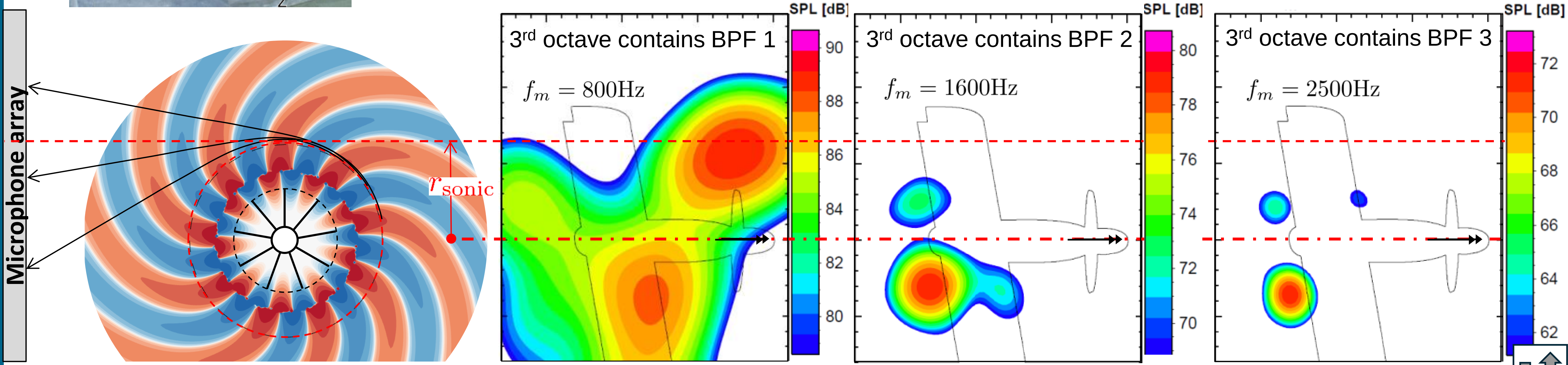
(installed) Propellers - „where is the source“ ??



$$V_\infty = 51 \text{ m/s}$$
$$N_P = 5105 \text{ rpm}$$
$$\beta = 28^o$$
$$M_{tip} = 0.52$$

! only tonal contribution !

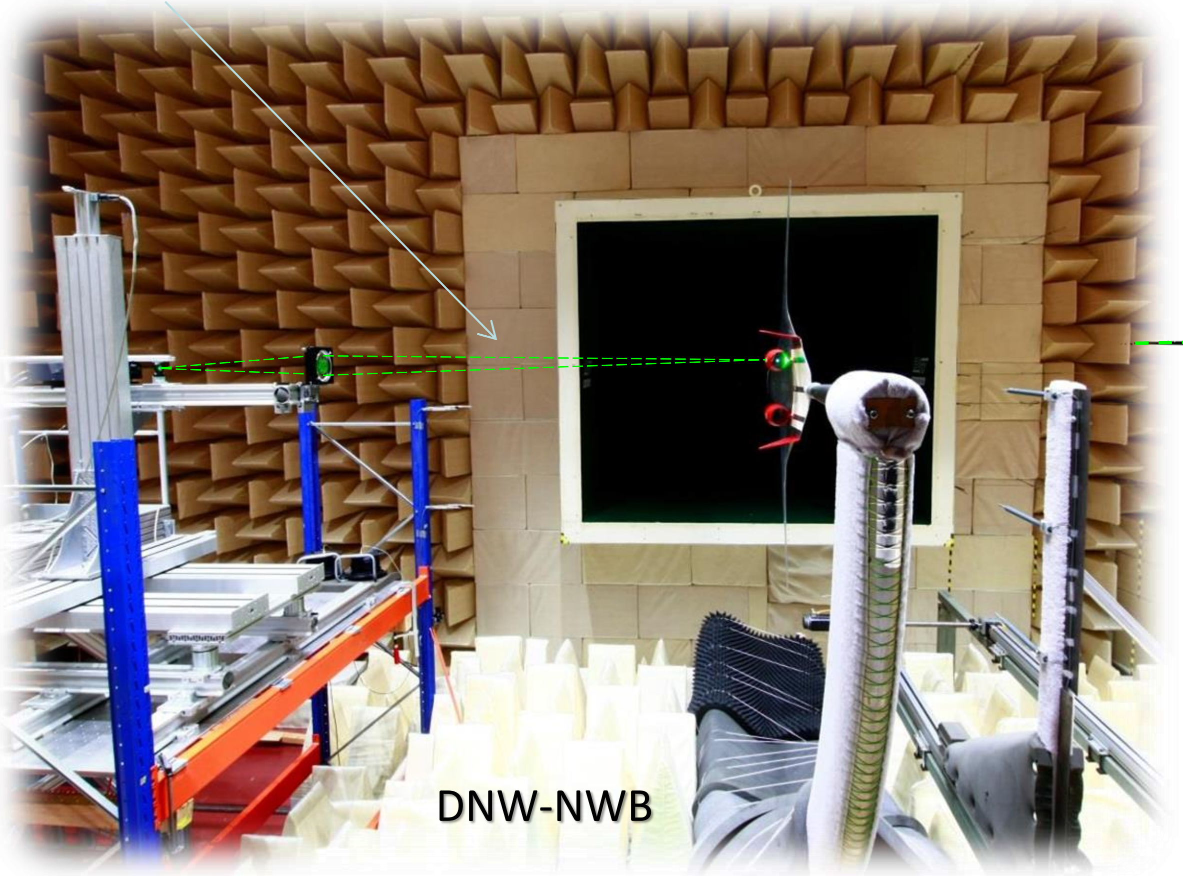


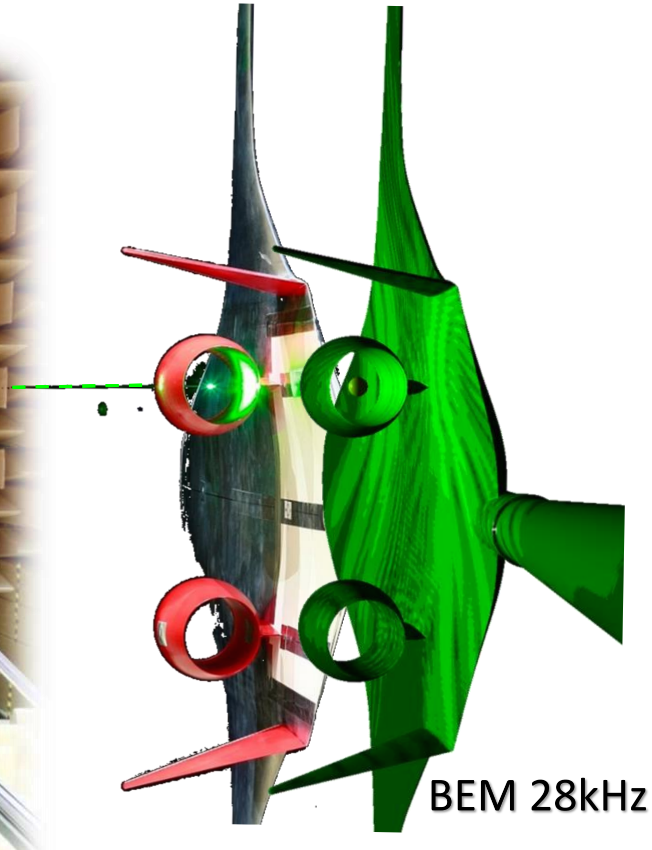


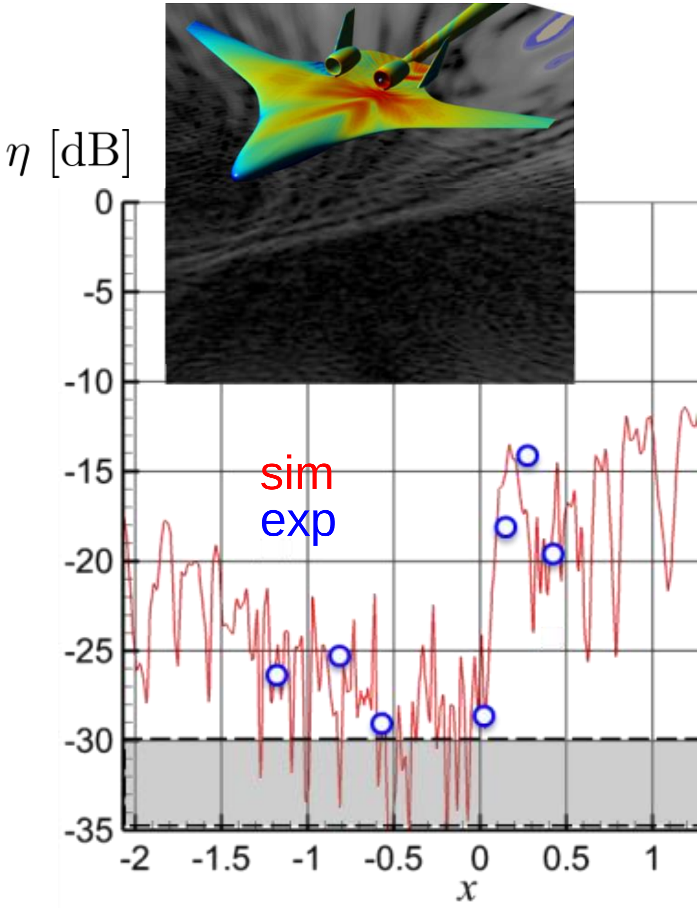
Convective amplification: „upstream or downstream“ ??

a non-intrusive sound source in flow

laser pulse

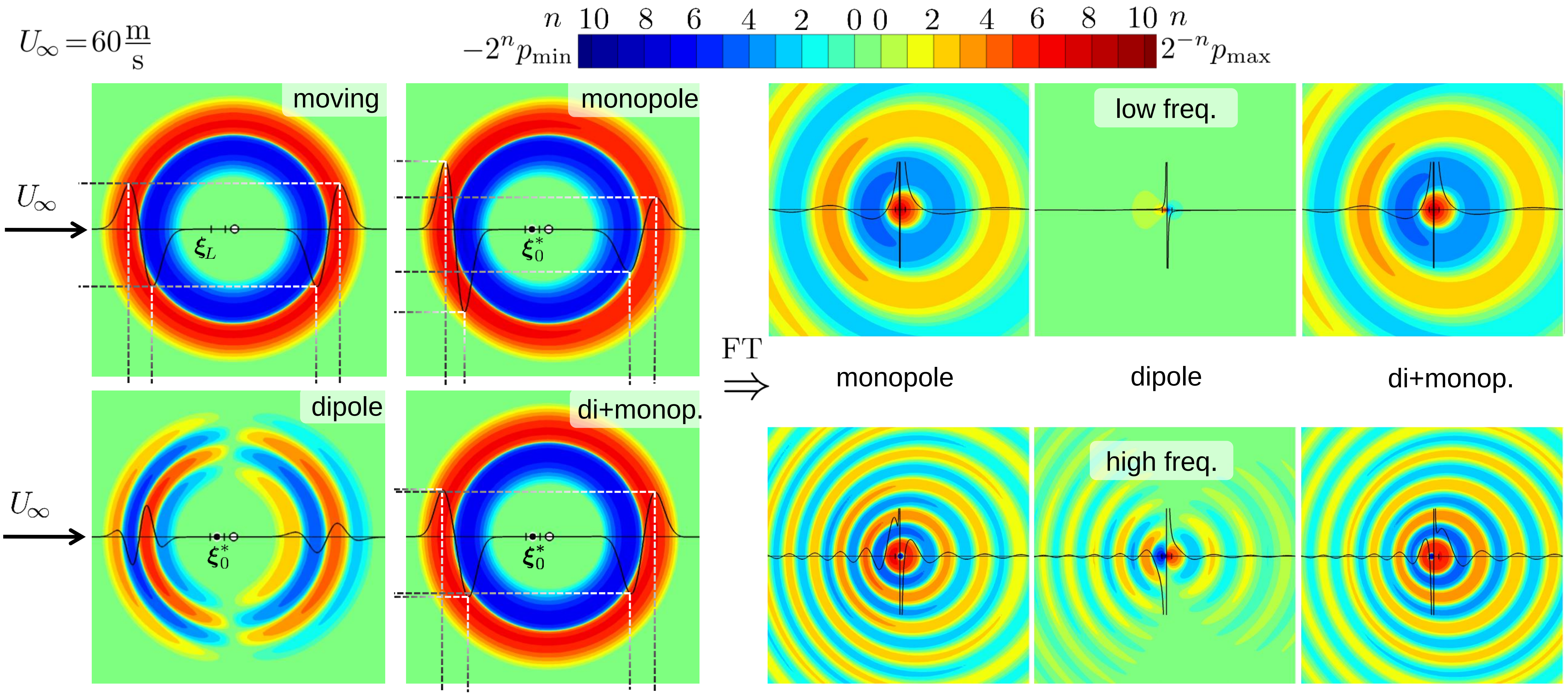




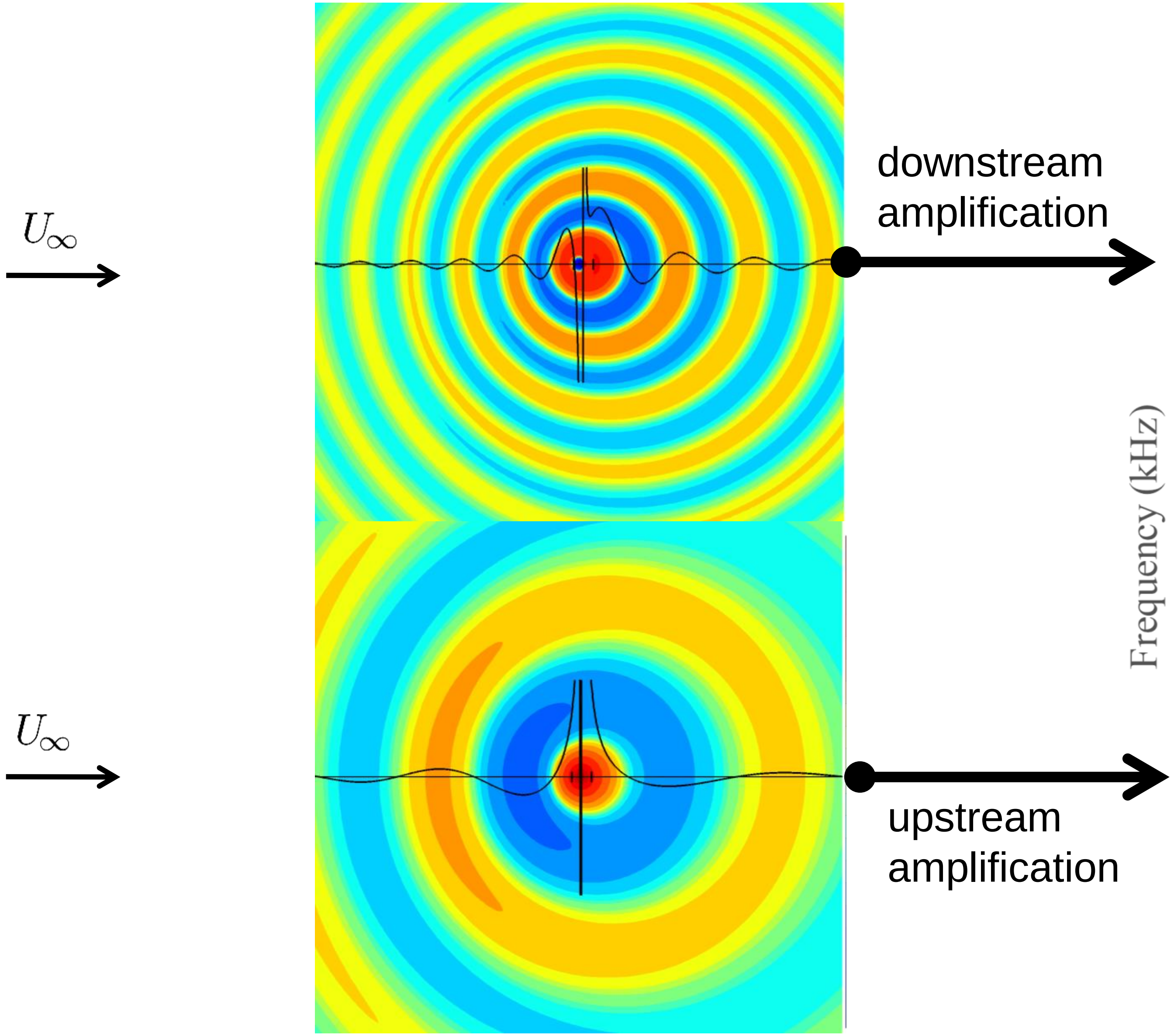


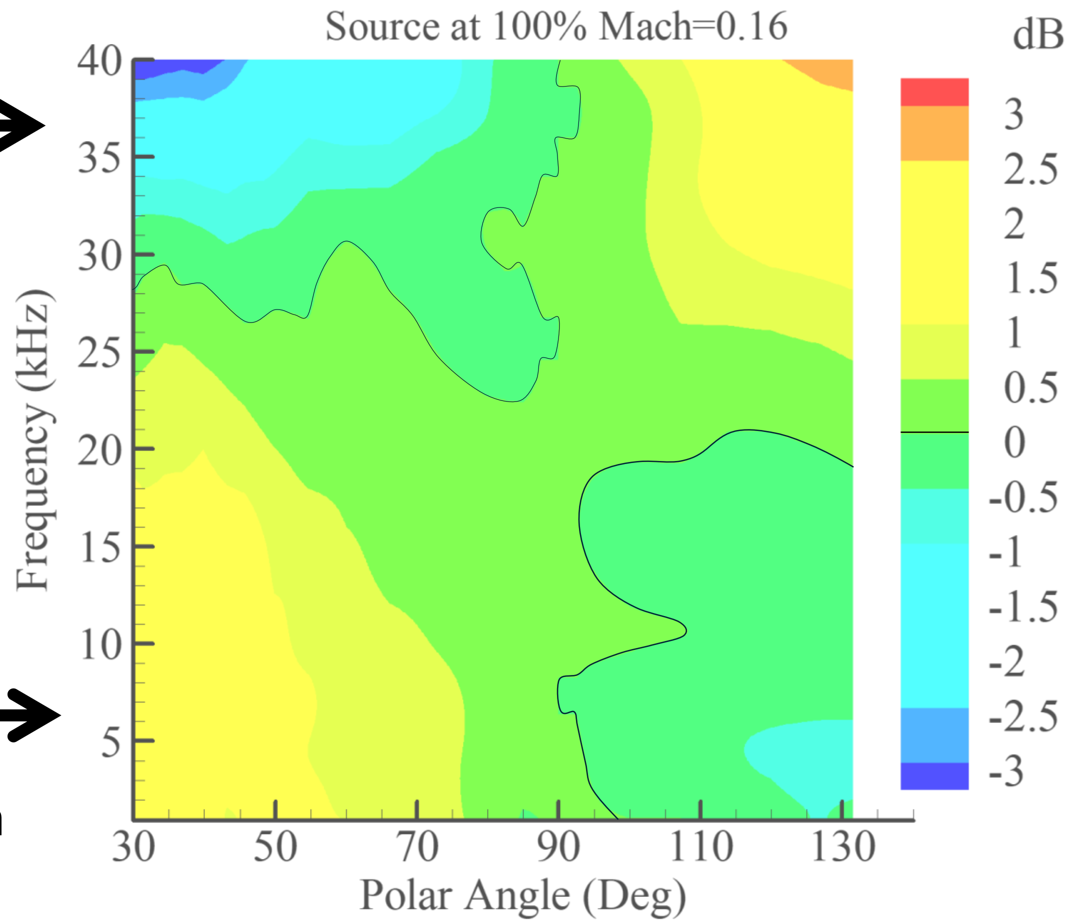
Convective amplification: „upstream or downstream“ ??

Convert moving laser point source into fixed point source: Taylor-exp. about ξ_0^*



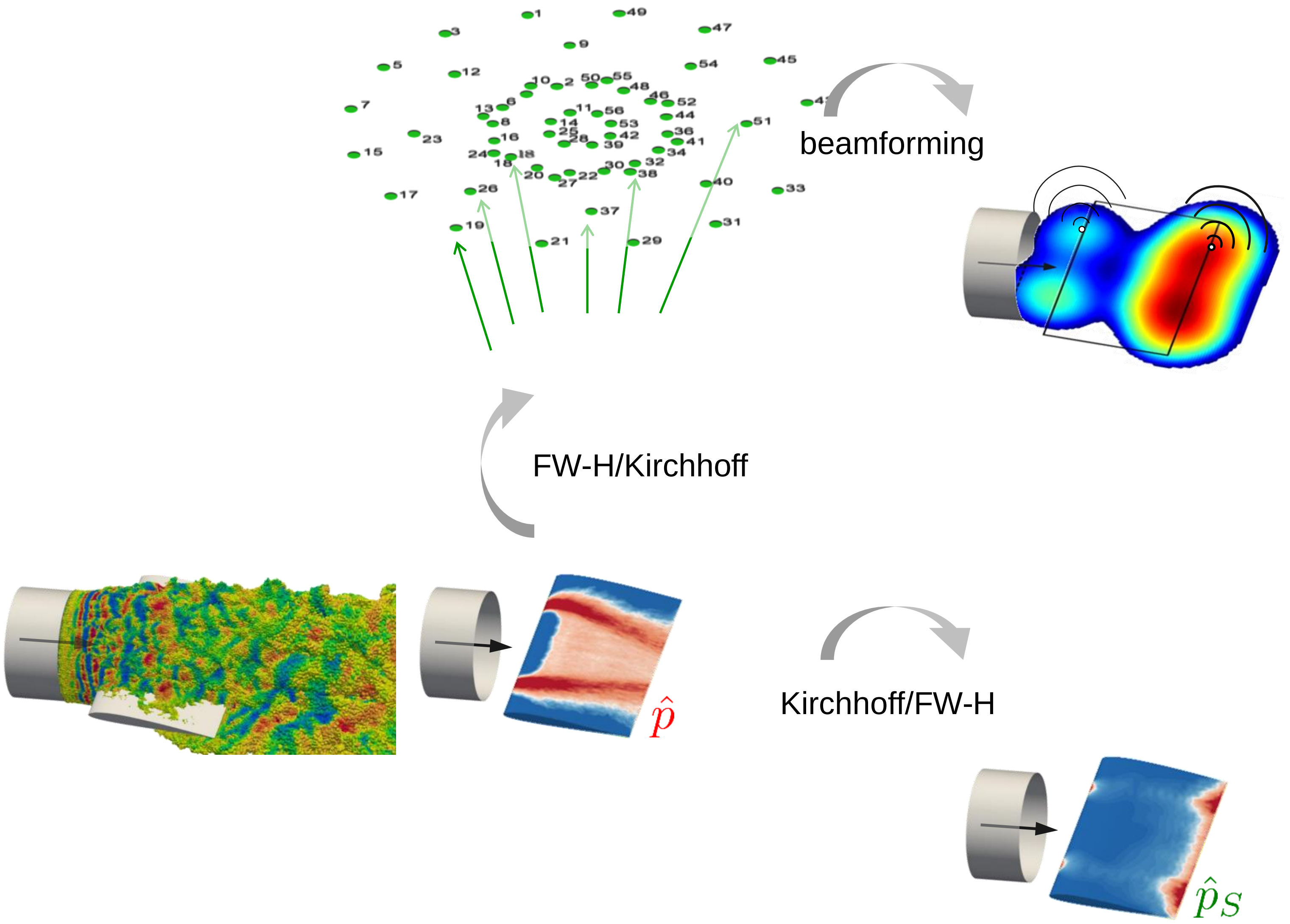
Convective amplification: „upstream or downstream“ ??



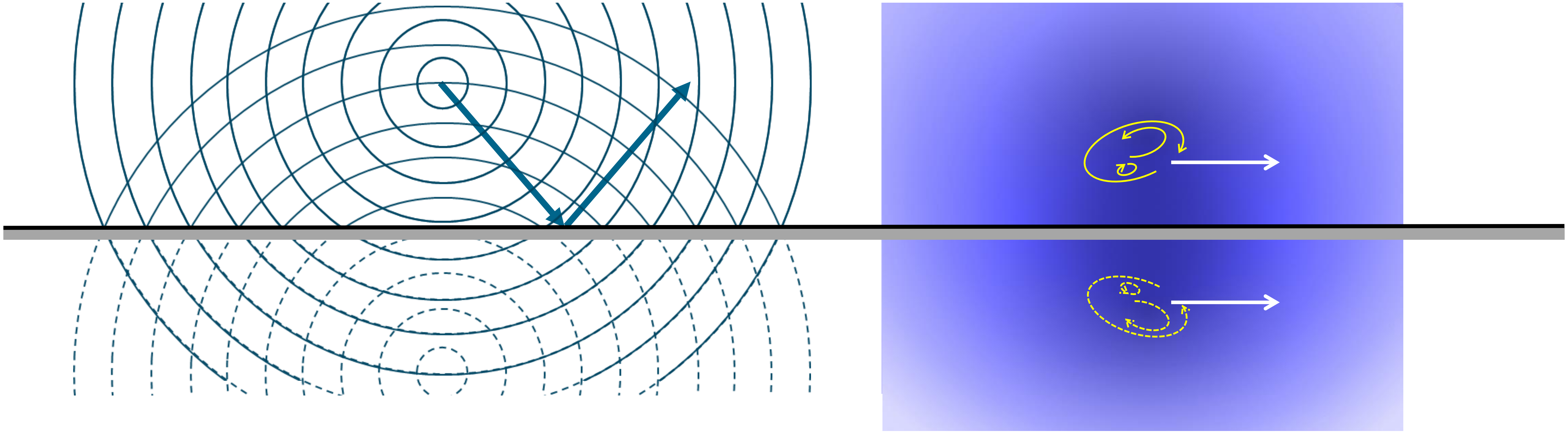


Exp. laser pulse NASA QFF

Alternative source localization (on surfaces subject to turbulence)



Alternative source localization (on surfaces subject to turbulence)

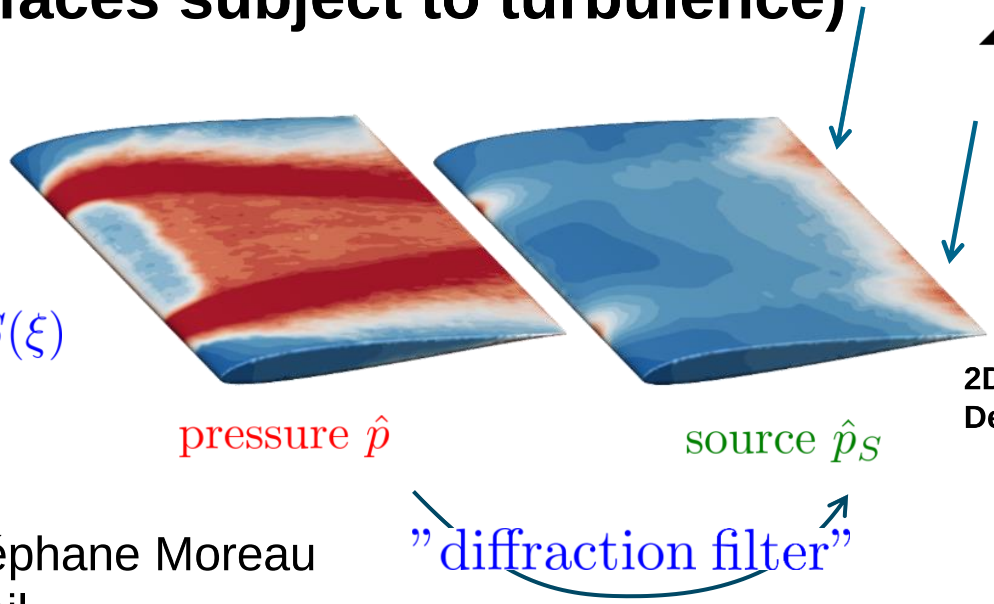


no sound **generation** by pure **reflection** of incident pressure field $\hat{p}_f$

$\Rightarrow$ source of sound on surfaces is **pure diffraction** of pressure field

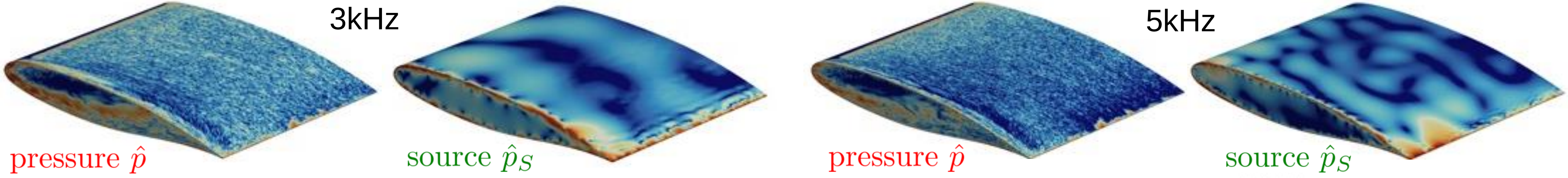
Alternative source localization (on surfaces subject to turbulence)

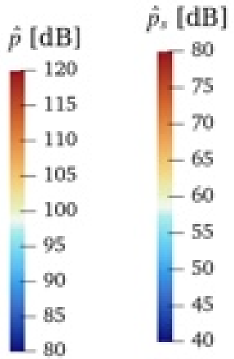
$$\hat{p}_S := \hat{p}(\boldsymbol{x}) - 2\hat{p}_f(\boldsymbol{x}) = \frac{1}{2\pi}\fint_{\partial V_B} \exp(-ikr)(ikr+1)\frac{\boldsymbol{e}_r \cdot \boldsymbol{n}}{r^2}\hat{p}\; dS(\xi)$$



2D airfoil
Delfs, Ruck 2024

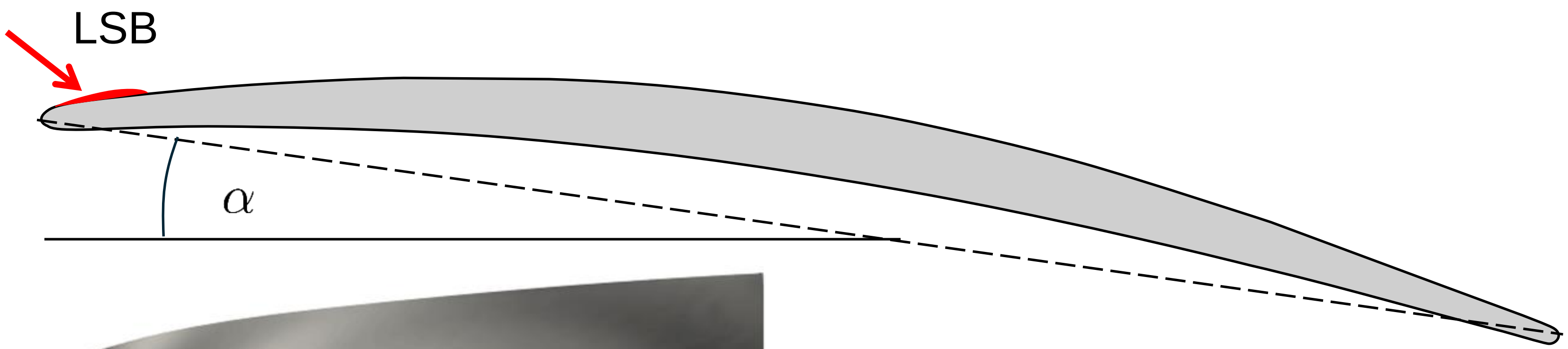
Co-operation DLR, UdeS : Patrick Deng, Jan Delfs, Stéphane Moreau
→ Test source localization on side edge noise of an airfoil

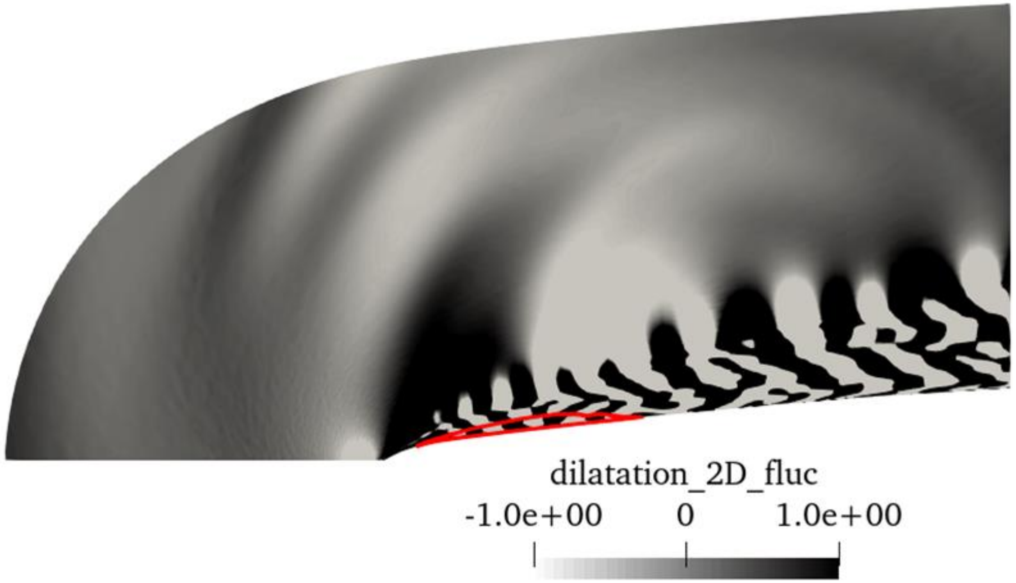




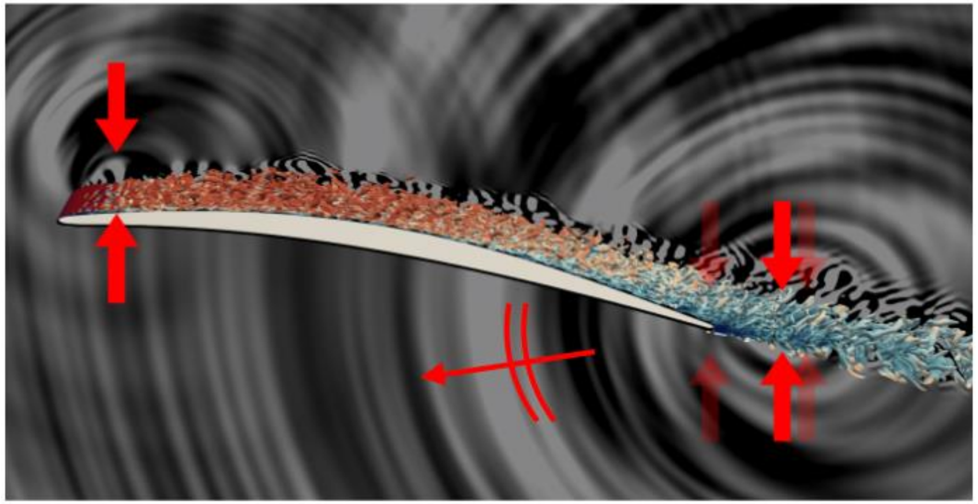
AIAA Abstract submitted (Nov. 2025):
Source Localization of Airfoil Tip Noise on the Basis of Surface Pressure

Modeling sound generation of a laminar separation bubble





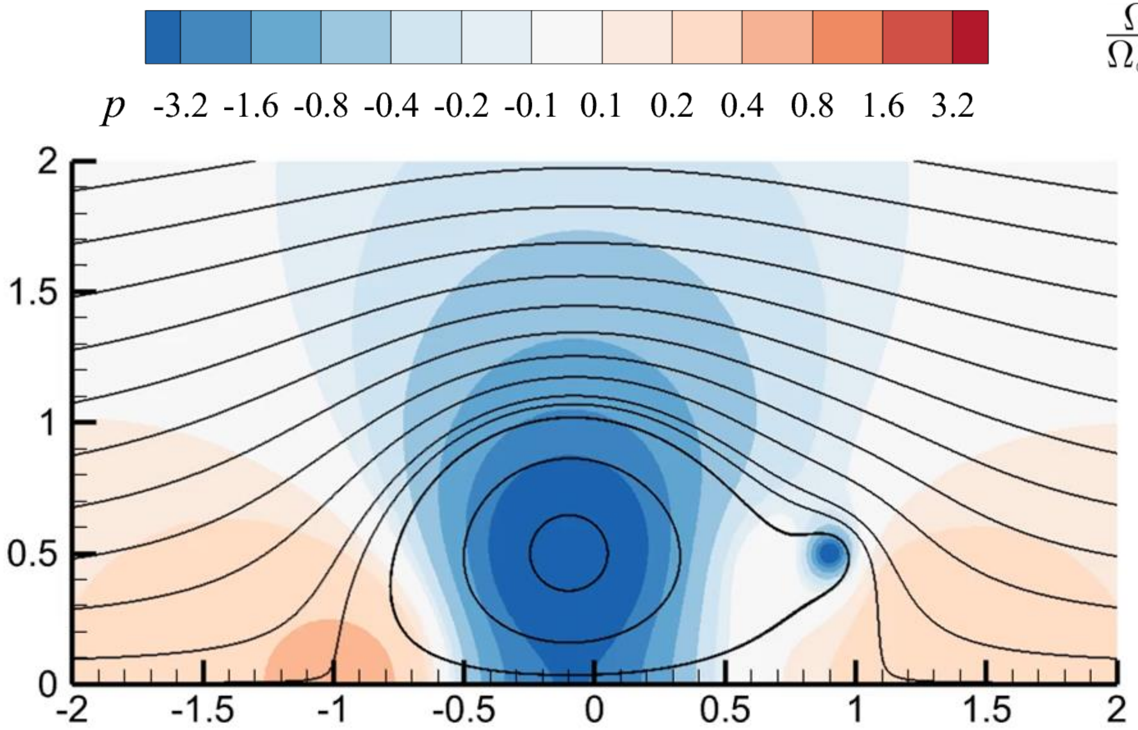
DNS of LSB

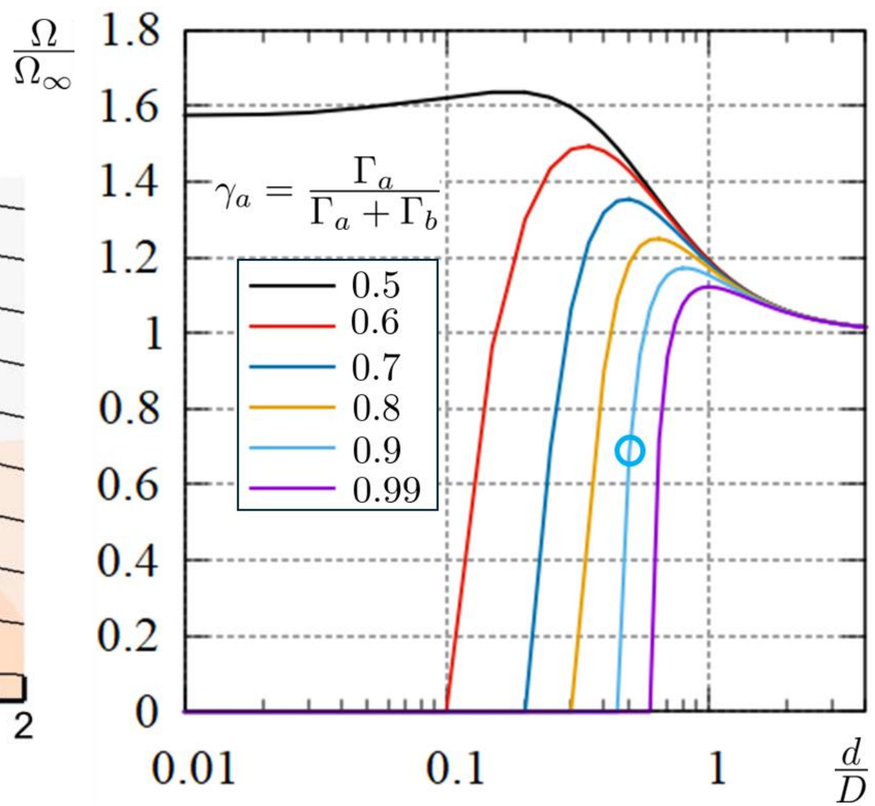


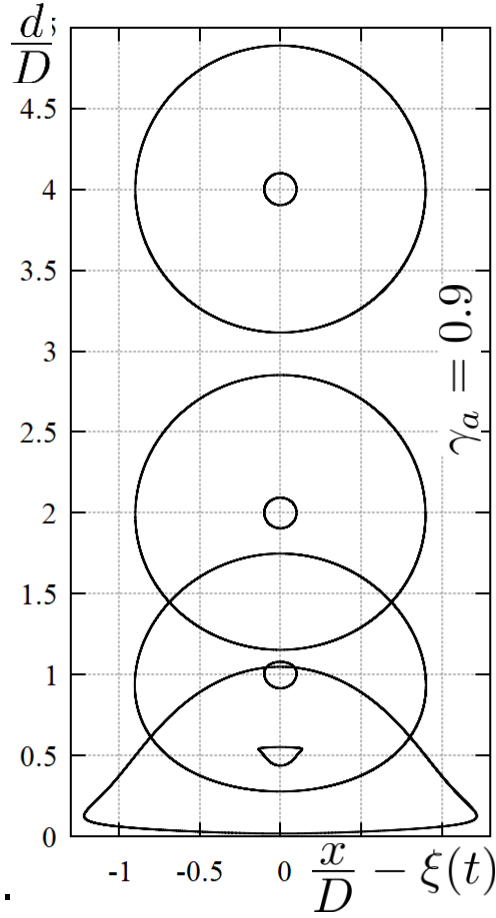
Co-operation DLR, UdeS : Jan Delfs, Yann Gentil, Stéphane Moreau
→ explain mechanism of oscillation by simple analytical model

Modeling sound generation of a laminar separation bubble

Approach co-rotating (potential) vortex pair near wall







First result: model finds relevant oscillation frequencies based on LSB circulation and height.

AIAA Abstract submitted (Nov. 2025):
Towards a simple model for the unsteady dynamics of a laminar separation bubble as basis for its sound radiation

Modeling sound generation of a laminar separation bubble

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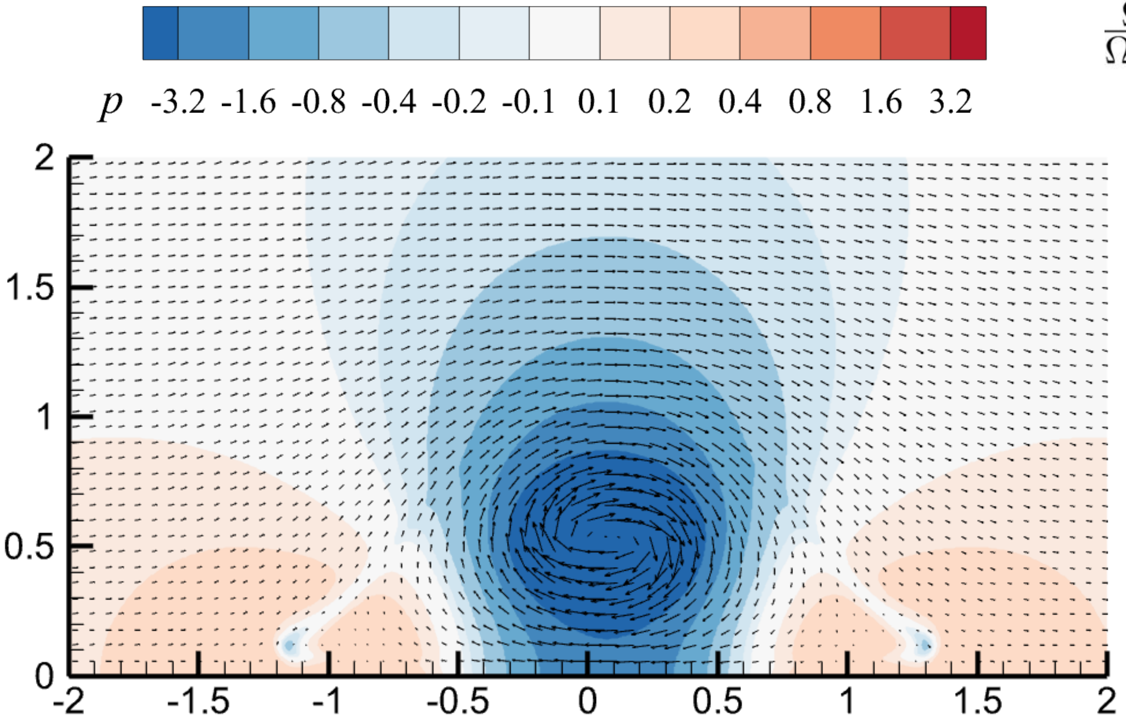

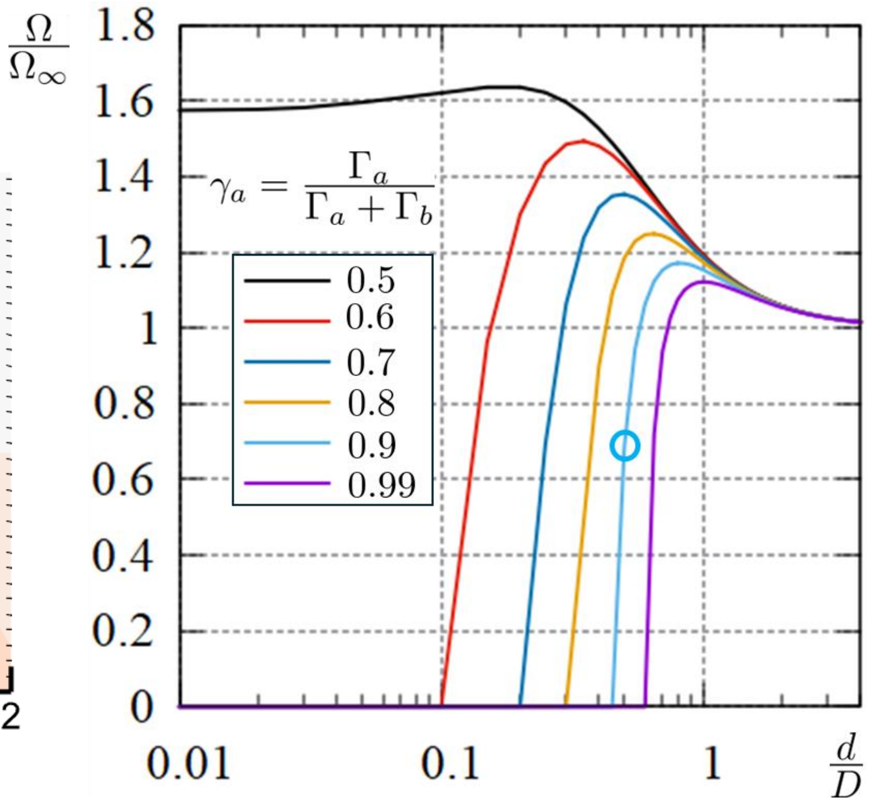

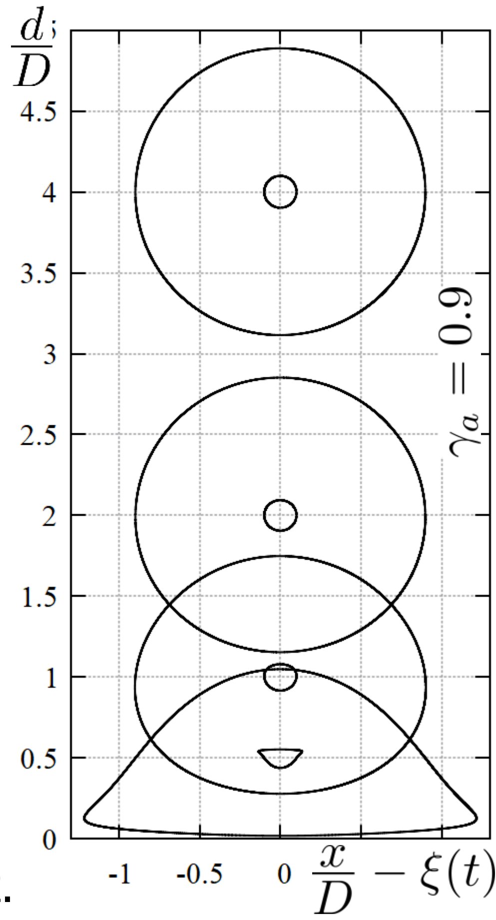

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