# IEA Wind TCP - Task 39
# Quiet Wind Turbine Technology
# Meeting #4, Lisbon, June 11th 2019
# Agenda, Minutes & Slides

## Agenda

10.00-10.10: Welcome

10.10-10.30: Status of the IEA Wind Task 39 – Report from the Last ExCo meeting

10:30-11:30: Presentation of the Serrated Trailing Edge Experimental Benchmark and Discussions

11:30-12:30: Presentation of the Wind Turbine Noise Code Benchmark and Discussions

12:30-13:30: Lunch break

13:30-14:00: Further on-going activities – Wind Turbine Noise Regulations catalogue, Fact sheets, etc…

14:00-16:00: Presentations by participants (Please send your presentation in advance to frba@dtu.dk)

Presenters: Florian Wenz, David Ecotière, Michaela Herr (see presentations attached).

16:00-16:30: Review of Task 39 Work Programme – Adding and/or activating new sub-tasks

16:30-17:30: Open discussion – Administrative issues (next meeting, etc)

### Present:

Esther Blumendeller, Roger Drobietz, Benoît Petitjean, Michaela Herr, Birger Luhman, Cordula Hornung, Florian Wenz, Wouter Van der Velden, Dick Bowlder, Jean Tourret, Andreas Fischer, Franck Bertagnolio, Bing Yang, Sylvia Broneske, David Ecotiére, Ronan Brieux Serré, Cristoph Scheit, Carlo Di Napoli, Brian Howe, Mark Bastasch, Luiz Cruz, Antonio Vieira

### Skype participants:

Daniele Ragni, Eugene McKeown, Koen Boorsma, Gerard Schepers, Ian Bonsma

# Meeting minutes

Welcome and round the table. Each participant presents him/herself.

Franck presents the IEA Wind TCP, Task 39 and its activities.

Objectives of the Task are reminded. No funding is available from the IEA Wind. Each country contributes on a voluntary basis.

<u>Serration benchmark:</u>

It is decided to go on with the planned geometries, i.e. the straight edge configuration, 1 simple serration geometry, and 1 more complex one.

More information and summary of this specific discussion will be distributed to the participants of this benchmark by Andreas.

<u>Wind turbine noise code benchmark:</u>

Dassault has not submitted data yet, because there was no time to convert to the required data for-mat. Results were presented at the AIAA aeroacoustics meeting and will be presented at the WTN 2019 (Wouter).

IAG sent their data but the email apparently did not go through. They will send their contribution soon and actual comparisons can start.

There is some confusion on the geometry at the tip. Differences between 3D geometry and 2D plan-form data (Michaela,Wouter)

3D geometry is more accurate (Koen)

Sensitivity analysis would be interesting to see if the inaccurate definition has an impact on noise/aerodynamic (Franck)

Wouter changed the blade geometry.

What is the correct deformed geometry? (Wouter)

Task 29: comparison of difference in deformation between codes is also performed (Koen)

Franck can send around a deformed geometry for test case 1.2 (flexible blades) for those who do not have a structural code in their setup.

Blade geometry needs to be clarified.

Stuttgart participated in Task 29 and has extracted geometrical data (Cordula)

It is decided to use the CAD data as it is so far, so that all high-fidelity models use the same input geometrical data.

Problems need to be put in the right framework (Roger)

So many uncertainties that it is not possible to make a real prediction (Roger)

It is noted that it is an idealized benchmark (Roger)

Industry is several years ahead (Roger)

Sensitivity analysis is important and makes sense in this Task (Roger)

Regulation overview:

Breakdown into subcategories (Sylvia)

Such breakdown sheet can create problems, because all the details cannot be covered in an overview sheet (Mark)

Details can make big differences (Mark), example was given

Keeping the sheet up to date is challenging... Use a more interactive format could be a solution.

General discussion on Task 39 activities:

IEA is expecting a broader aspect in Task 39 (Franck)

How do we activate people? (Franck)

Student who works with propagation... (Wouter)

Vibroacoustics should be included (Birger), try to activate people with a fact sheet as a starting point.

Birger will start a fact sheet (e.g. by only setting up the headers and it could be circulated so that participants can contribute on sub-topics they are confident with).

An epidemiologic study on the impact of wind turbine noise is in the application phase in France (David). It would improve the study if more countries can conduct a similar study. IEA could help to get in touch with people working on similar topics.

Basic understanding questions about how the IEA works without funding (Roger)

The task aims at helping bringing people together for exchange of knowledge and possible collaboration work, but there are no clear guidelines from IEA on how to conduct the collaborations. It is up to the participants to define the task activities. IEA Wind only requires reporting from these activities and provides the general framework (Franck)

Write down common research goals and communicate them to the national funding bodies could be one useful sub-task (Michaela)

Happy to define research agenda from point of view of the industry (Roger)

More exchange between engineering and social science would be welcome (Michaela, Franck)

Perdigao experiments include noise data and may be used for propagation benchmark (Michaela)

Same holds from a previous French study on an existing noise propagation measurement campaign (David)

DLR active in noise propagation (Thomas Gertz is the main investigator/contact if needed)

Task 39 administration:

Administrative issues are discussed. Budget for the Task 39 is proposed, using other tasks as model and considering the fact that Task 39 is relatively small still.

200 hours / year + 4 travels for a total of 18000 Euros/year (it would be 6000/participants if 3 countries, 4500 if 4 countries which is realistic for year 2020... it goes quite fast down in view of the few number of participants)

Next meeting date and venue:

The next meeting is planned sometime around October-November-December 2019.

WindEurope Offshore conference in Copenhagen in November could have been an option, but any of the current participants is going to the conference anyway.

Germany is suggested. Option #1: DLR (Braunschweig), Option #2: GE (München, more easily accessible by public transport)

## ACTIONS TO BE TAKEN:

- Fact sheet on structural vibration and mechanical noise: To be initiated by Birger

- International Wind Turbine Noise Regulation Catalogue: To be continued by Franck and Eugene (Gavin?)

- Wind Turbine Noise Research Agenda: To be initiated by Roger (Michaela?)

- Wind turbine noise code & Serration benchmarks: To be continued by Franck, Andreas


# IEA Wind TCP Task 39

## Quiet Wind Turbine Technology

***Meeting #4 - Lisbon***

June 11, 2019

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# IEA & IEA TCPs

- *International Energy Agency:*

The International Energy Agency (IEA) was formed in 1974 as an autonomous body within the Organization for Economic Co-operation and Development (OECD). The IEA works to ensure reliable, affordable and clean energy for both its member countries and nations around the world. Currently, there are 29 member countries.

The IEA focuses their R&D, demonstration, and information exchange on four main areas: Energy security, Economic development, Environmental awareness, Worldwide engagement

TCPs on various energy technologies: fossil fuels, renewable energy, nuclear fusion research, and efficient energy end-use

- *IEA Wind TCP:*

The International Energy Agency Wind Technology Collaboration Programme (IEA Wind TCP) is an international co-operation that shares information and research activities to advance wind energy research, development and deployment in member countries.

# News from IEA Wind TCP ExCo 83

- *New chairman:* John Mc Cann (SEAI, Ireland)
- *Secretariat:* Ignacio Marty + 4 members team (DTU)
- *Presentation of Task 39 (see later)*
- *New subtasks:*

  - Task 40: Downwind turbine technology – Accepted

    (*OA: Shigeo Yoshida – Possible collaboration with Task 39?*)

  - New task proposals:
    - Life extension (DTU, Anand Natarajan)
    - Digitalization (NREL, Jason Fields)
    - Grand vision for wind energy (DTU/NREL, Katherine Dykes)

# Task 39 – A Short History

- Initiated by Trinity College Dublin, 2016
- But TCD faced funding/resources problems
- Sustainable Energy Authority of Ireland (SEAI, John McCann) takes over as OA
- Task 39 kick-off in Oct. 2017
- John McCann steps down as OA in Sept. 2018
- DTU takes over, Jan. 2019.

# Task 39 - Objectives

- Project Objectives and Outcomes:
  - **Coordinate international research on quiet wind turbine technology and in related technology fields**

**“*Technology*” not only wind turbine technology but also related technologies and *practices,* that may facilitate deployment, in related fields including *acoustics and noise regulations***

# Expected Results

- **Review report of international wind turbine noise regulations**

  → **Goal: Improving regulation &**
  **Recommended framework for *wind turbine noise regulations***

  → **Should not overlap with IEC efforts**

- **State-of-the-Art reports**

  → **Goal: Improving practices through peer comparisons (Modelling/Software/Codes, Test facilities, Field experiments, Quiet wind turbine technologies for manuf.)**

- **Benchmarks...**

# Milestones & Deliverables – Not yet defined

## Work programme drafted
## Revised in Sept. 2018
## at last Task meeting (Hbg)

- 3 WPs dedicated to specific area of WTN research
- A number of topics identified as possible sub-tasks with which participants may engage

| No | WP | Sub-WP | Remark | Milestone |
|---|---|---|---|---|
| **WP0** | **Management and coordination** | Technical management<br>Administrative management | Change of operating agent | |
| **WP1** | **Interdisciplinary Education and Guidance** | Table of contents for state of the art report on quiet wind turbine technology | | |
| | | Template for catalogue/database of national wind turbine noise regulations<br>Associated explanatory graphic(s)<br>Considerations when developing WTN guidance | To be provided as online resource | |
| | | Fact sheets - Key topics explained in as simple as possible language for regulators<br>• Amplitude Modulation<br>• Low Frequency noise<br>• Infrasound<br>• Tonal Noise<br>• Measurement technology<br>• Noise indices and measurement<br>Public Engagement on Noise<br>• Communicating noise concepts to the lay person<br>• Auralisation | (Task 28 collaboration) | |
| **WP2** | **Physics of Noise** | Noise modelling<br>• Benchmarking of noise models<br>• Propagation studies<br>• Farm level and wakes | (Collaboration with MEXNEXT)<br>(Collaboration with WAKEBENCH?) | |
| | | Quiet Wind Turbine Technologies<br>• Categories and classification – sources and pathways addressed<br>• Noise emission mitigation<br>• ?Optimisation? compromises e.g. soundscape manipulation/ customization, aerodynamic v.s tonal noise | | |
| | | Quantification/Qualification<br>• Consideration of physical effects & pathways - High Frequency Noise, Low Frequency Noise, Infrasound, Tonal Noise, vibration (& Vibration induced noise?)<br>• Field experiments (TREMAC, WEA Akzeptanz etc.<br>• Physical metrics<br>• Field measurements<br>• Data and findings from compliance monitoring<br>• Field experiments by practicing acousticians<br>• Results from field testing of Quiet Wind Turbine Technologies | | |
| **WP3** | **Psychology of Noise** – Psychoacoustics *(To be developed upon recruitment of participants)* | Field-based psychoacoustic surveys<br>• Quantifying annoyance – survey instrument design | (Collaboration with Task 28) | |
| | | Laboratory based psychoacoustics | (subject to participant) | |

# Technical Results

## 2 on-going benchmarks:

1. Wind turbine noise simulation codes
   - Joined with Task 29 Phase IV
   - Identify shortcomings & difficulties
   - Improve knowledge & accuracy

   (conference paper at WTN 2019, June, Lisbon)

2. Serration noise database and benchmarking of serration models
   - Use of new DTU acoustic Wind Tunnel
   - Goals: validating serration noise models + aerodynamics
   - Improve knowledge & accuracy

   (in discussion between participants)

# Technical Results

## State of the art reports & Fact sheets:

1. Fact sheet on Amplitude Modulation
    - Physics & Current regulations

    (published on IEA Wind Task website)

2. Fact sheet on Low Frequency Noise (as a future deliverable…)

3. International Wind Turbine Noise regulations
    - Database providing an overview of current regulations ww
    - For regulators, law-makers and persons new to the field

    (in progress, ION Acoustics, Gavin Irvine)

# Country Participation

- ***Confirmed:*** **China, Denmark, Germany, Ireland(?)**

- ***In progress:*** **The Netherlands**

- ***Potentials (i.e. have been participating to some meetings so far)***

**Finland, Switzerland, Norway, USA, Canada, UK,...**

# Annual Task 39 Report

- ***Delivered at ExCo 83 meeting***
- ***To be done – ExCo comments:***
  - ***Need to re-define the Task thoroughly***
  - ***Draft a new Task proposal***
  - ***To be discussed in the afternoon…***


# IEA Wind TCP Task 39

Quiet Wind Turbine Technology

***Meeting #4 - Lisbon***

June 11, 2019

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# Preliminary Task 39 Report

- ***Delivered at ExCo 83 meeting***
- ***To be done – ExCo suggestions:***
  - ***Need to re-define the Task thoroughly***
  - ***Draft a new Task proposal***

# Milestones & Deliverables – Not yet defined

## Work programme drafted
## Revised in Sept. 2018
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| | | Laboratory based psychoacoustics | (subject to participant) | |

# Financing

- Year 2018: Ireland (OA) cover all expenses
- Year 2019: Denmark (OA) covers all expenses
- Task 29 (Aerodynamics)
  & Task 36 (Forecasting) OAs: 350 hours
  + 4 travels: 2 ExCo meetings + 2 Task meetings
- Proposed budget frame:

| | | |
|---|---|---|
| » 200 hours x 75Euros/hour | = 15000 | Euros |
| » 4 travels x 750Euros | = 3000 | Euros |
| Total | = 18000 | Euros |
| / 3 countries = | = 6000 | Euros |
| / 4 countries = | = 4500 | Euros |
| / 5 countries = | = 3600 | Euros |

DTU

## IEA Wind Task 39 – Quiet Wind Turbine Technology

# Serration benchmark

# Participants

# Agenda

- Wind Tunnel Tests (DTU, Delft, VT)
- Simple serration geometry
- Complex serration geometry
- Who will participate with computations?
- Test matrix
- Coordination with BANC
- Conclusions and actions

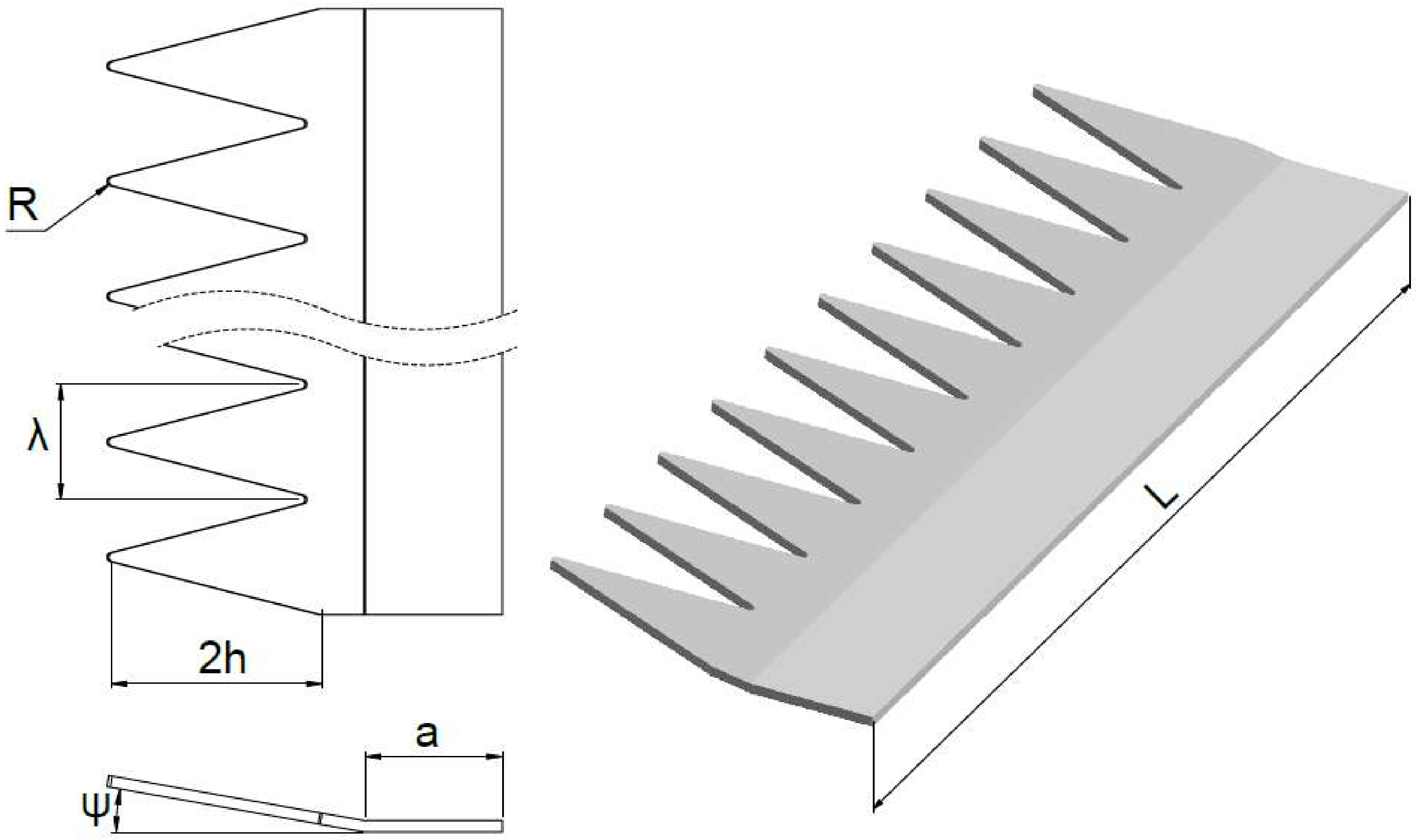
# NACA63018 reference aerofoil


- Aerodynamic and acoustic measurements in VT stability Tunnel (only baseline), Poul la Cour Tunnel (DTU) and Delft Wind Tunnel
- Scale model tested in a smaller wind tunnel of TU Delft (?)

# Time line for wind tunnel tests

- VT Stability Tunnel : May 2019
- Poul la Cour Tunnel (DTU) : October 2019
- Delft Wind Tunnel : before September 2019 or after December 2019 (if possible?)
- Small scale test at Delft :

# Simple serration geometry

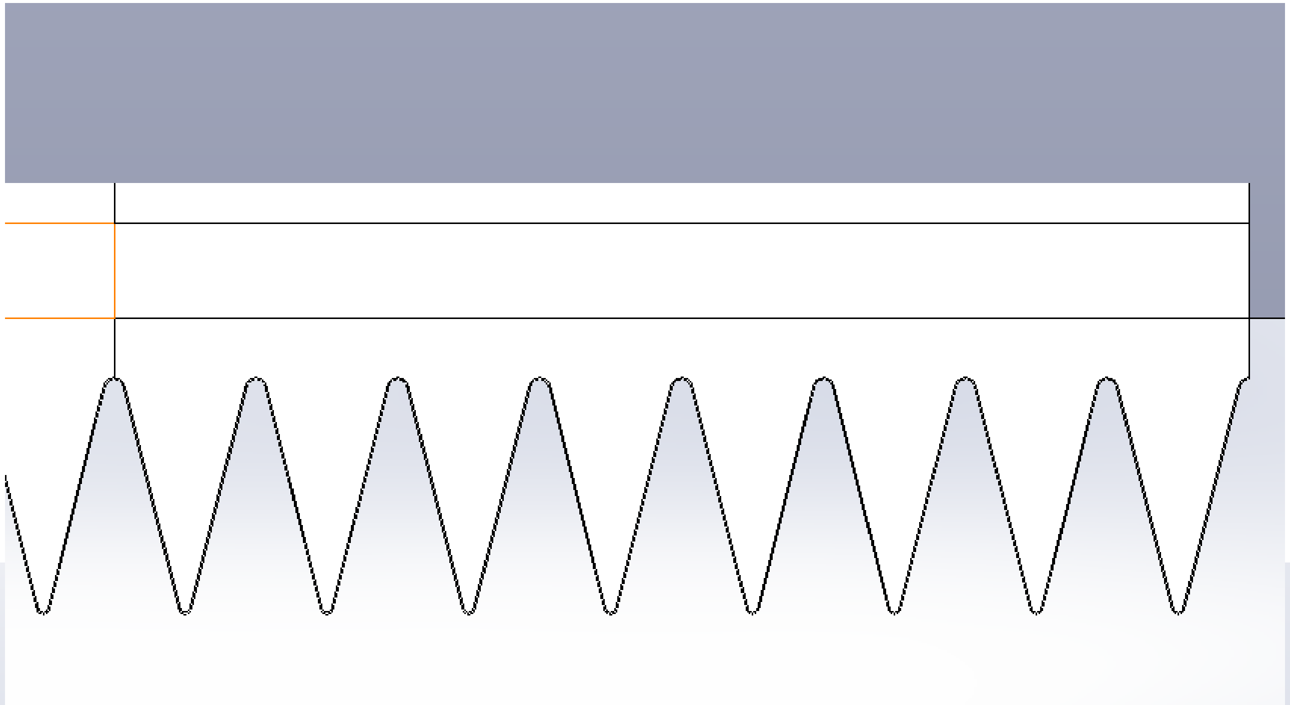


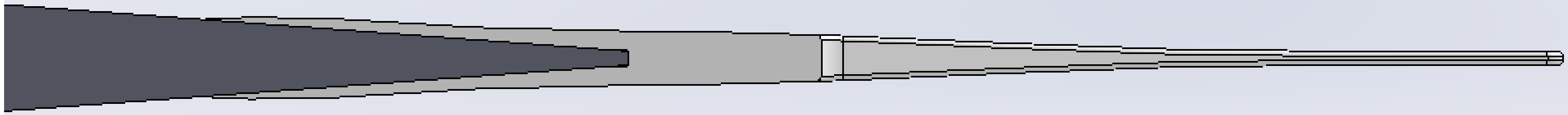
# Simple serration geometry

- The serrations will be manufactured with 3D printing
- There was an interested to test different serration angles
- It was agreed to have 2 different sets of serrations with different angle $\psi$ (Baseline serrations aligned with the chord ($\psi = 0$) and one angle $\psi > 0$)
- Design guidelines
  – $0.1c < 2h < 0.2c$ (Wouter)
  – $R = 3$ mm (Daniele)

# Symmetric simple serration geometry

- 2h = 0.1c (90 mm)
- Lambda = h
- Rr = 3 mm (root)
- Rt = 2 mm (tip)
- Symmetric attachment (keep symmetry)
- Soft edges r = 0.5 mm
- Thickness tip 1.35 mm
- Max thickness 4 mm
- Root length 17 mm





# Asymmetric simple serration geometry

- Identical to symmetric setup, but with a serration angle of 4 degrees

# Complex serration geometry

- It was pointed out that there will not be many participants that can contribute with predictions for the complex geometry
- Therefore it was decided to design a complex geometry that has similarities to the simple geometry, such as sawtooth with combs in between or iron shaped serrations
- DTU can contribute with predictions for iron shaped serrations, but not sawtooth with combs

# Who will participate with computations?

# Test Matrix

- Reynolds number
- Angle of attack
- Configurations

# Coordination with BANC

# Conclusions and actions

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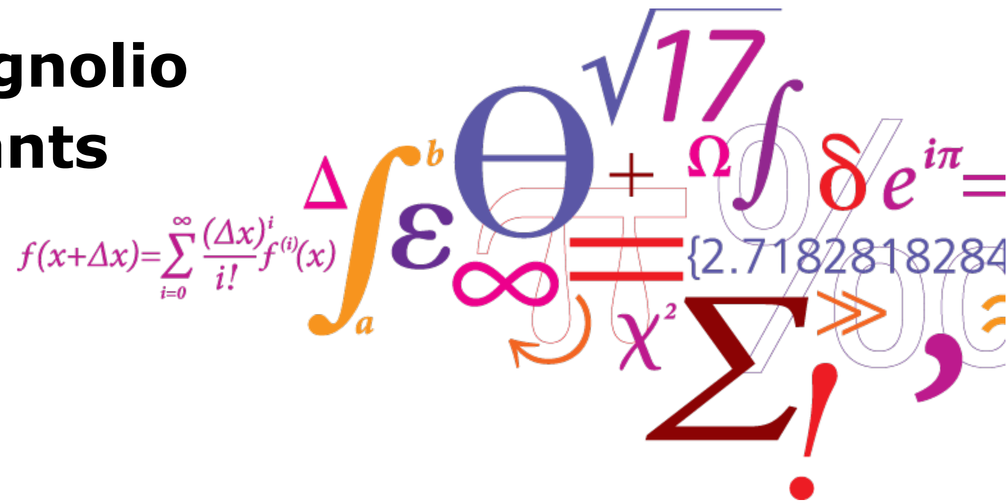
DTU

# Wind Turbine Noise Code Benchmark – Round 1

**Franck Bertagnolio**
**And Participants**




DTU Wind Energy
Department of Wind Energy

# IEA WIND TCP - Task 39

- **IEA Wind** ***Technology Collaboration Programme***

  **An international co-operation that shares information and research activities to advance wind energy research, development and deployment in member countries**

- **Task 39** ***Quiet Wind Turbine Technology*** **– Scope**

  **Coordinate international research on quiet wind turbine technology and in related technology fields**

→ **”technology”: not only wind turbine technology but also related technologies and *practices*, that may facilitate deployment, in related fields including *acoustics* and *noise regulations***

# Expected Outputs

- Review <u>report</u> of international wind turbine noise regulations
  - Goal: Improving regulations & Recommended framework for *wind turbine noise regulations*
  - Should not overlap with IEC efforts

- State-of-the-Art <u>report</u>
  - Goal: Improving practices through peer comparisons
    - Modelling/Software/Codes
    - Test facilities
    - Field experiments
    - Quiet wind turbine technologies (manufacturers)

- Benchmarks...

# Participating Countries

- *Confirmed:* China, Denmark, Germany, Ireland
- *In progress:* The Netherlands
- *Potentials?* Finland, Switzerland, Norway, USA, Canada, UK...

**Participating? Informations?**

- *Contact:* Franck Bertagnolio

frba@dtu.dk

# Wind Turbine Noise Code Benchmark

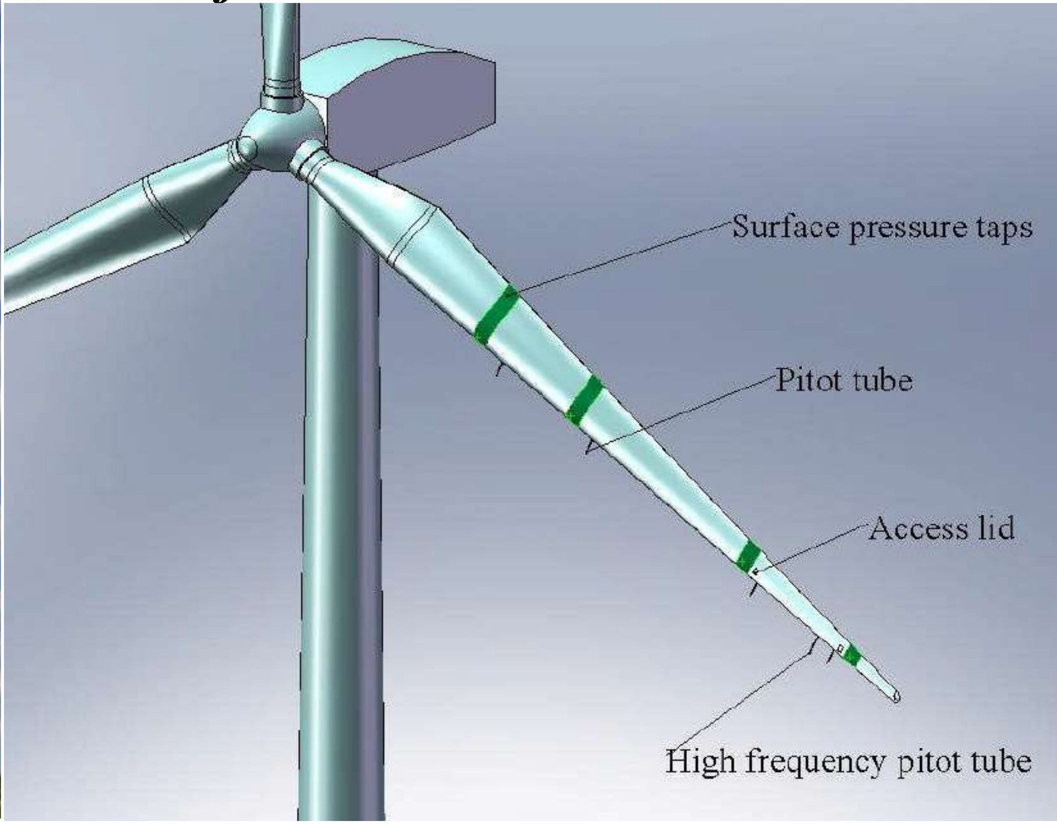
- **WHY?**
  - WT rotor noise as a source mostly available from standard IEC measurements in order to evaluate immission noise
  - Academia & Industry develop simulations codes encompassing all aerodynamic noise source mechanisms at the blade/rotor level with various levels of fidelity
  - Difficult to evaluate accuracy with more advanced models (as opposed to industry models tuned for years with -mostly- empirical formula)

# Wind Turbine Noise Code Benchmark

- **Joined with Task 29 comparison benchmark (DANAERO experiment)**
- **Comparing codes for wind turbine aerodynamic noise as <u>sources</u> (*no propagation!*)**
- **Looking at Aerodynamics + Surface Pressure + Acoustic Noise**
- **Objectives:**
  - **Identify <u>shortcomings</u> & <u>difficulties</u>**
  - **<u>Improve</u> knowledge and models' accuracy**

# DANAERO – NM80 Wind Turbine

- **Campaigns July-Sept. 2009** ***with 1 instrumented blade***
- **Including wind tunnel** ***airfoil tests***



# 4 Means of Comparisons

- **Aerodynamics**
  **Validation of the basic aerodynamics (AOA, Vrel,...)**
  **Similar analysis to Task 29**

- **Boundary layer data near TE**
  **Useful for TE noise prediction and validation**
  **Similar analysis to BANC**

- **Surface pressure near TE / TI?**
  **As measured in DANAERO experiment with HF mics. flush-mounted in blade at $r = 37$m**
  **Similar analysis to BANC**

- **Far-field noise (IEC position)**
  **Immission noise (excluding propagation effects)**

# WTN Codes Benchmark = 3 Rounds

- **Round #1**

  **Validation of the codes for four idealized cases**

  **Symmetrical cases - Rigid & Flexible rotors**

  **Two operational parameters analyzed:**
  - **Rotor rotational speed**
  - **Wind shear**

- **Round #2**

  **Realistic cases from DANAERO experiment**

  **Comparison with measurement data**

- **Round #3 (*tentative*)**

  **SPL as a function of wind speed**

  **(incl. rpm/pitch control)**

# Round #1 – 4 Test-Cases

## (Based on Task 29 aeroelastic benchmarking)

- Case 1.1 - Wind Speed = 6.1m/s - RPM = 12.3
  - Rigid rotor
  - Axi-symmetric (no tilt/yaw/shear/tower/turbulence)
  - Pre-bend included

- Case 1.2 = Case 1.1
  - BUT Flexible rotor

- Case 1.3 = Case 1.1
  - BUT RPM = 16.2

- Case 1.4 = Case 1.1
  - BUT Wind shear – $U(z)=U_{hub}*(z/H_{hub})^{0.3}$

# 4 Means of Comparisons

- **Aerodynamics**

  **Validation of the basic aerodynamics (AOA, Vrel,...)**

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- **Surface pressure near TE / TI?**

  **As measured in DANAERO experiment with HF mics. flush-mounted in blade at $r = 37$m**

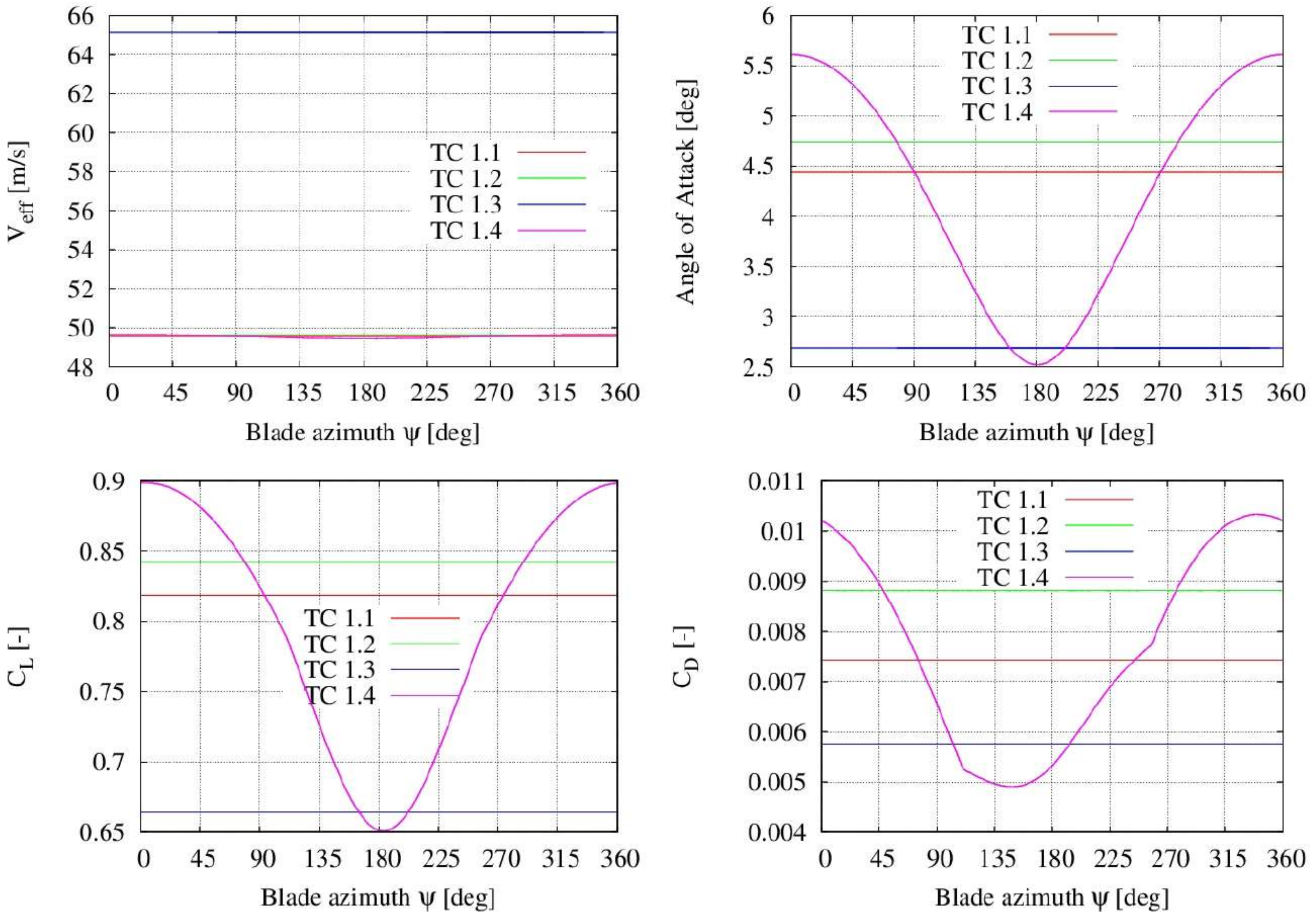
  **Similar analysis to BANC**

- **Far-field noise (IEC position)**

  **Immission noise (excluding propagation effects)**

# Aerodynamic data comparison

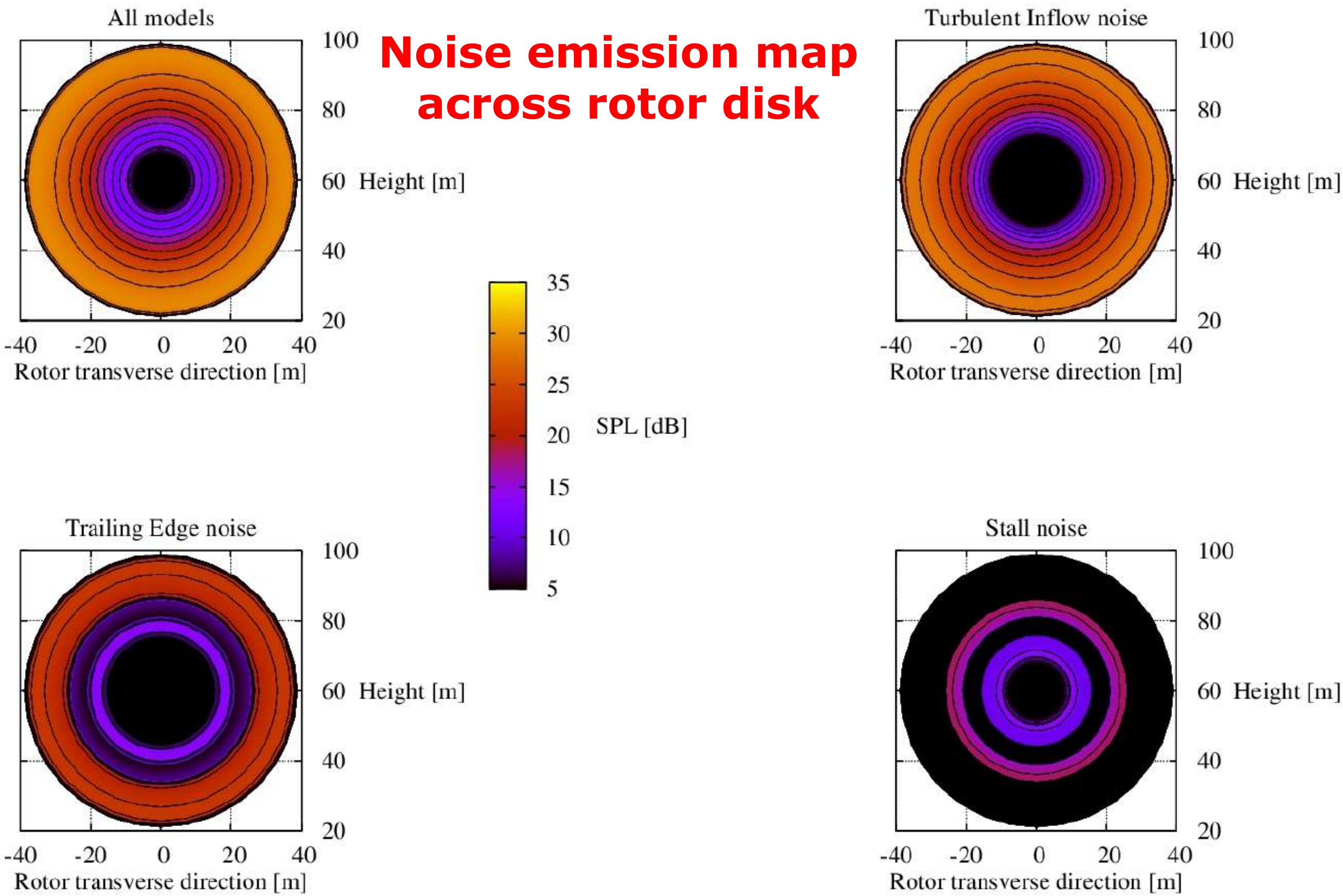
## Radius = 37 m = 92% span



# Noise emission comparison

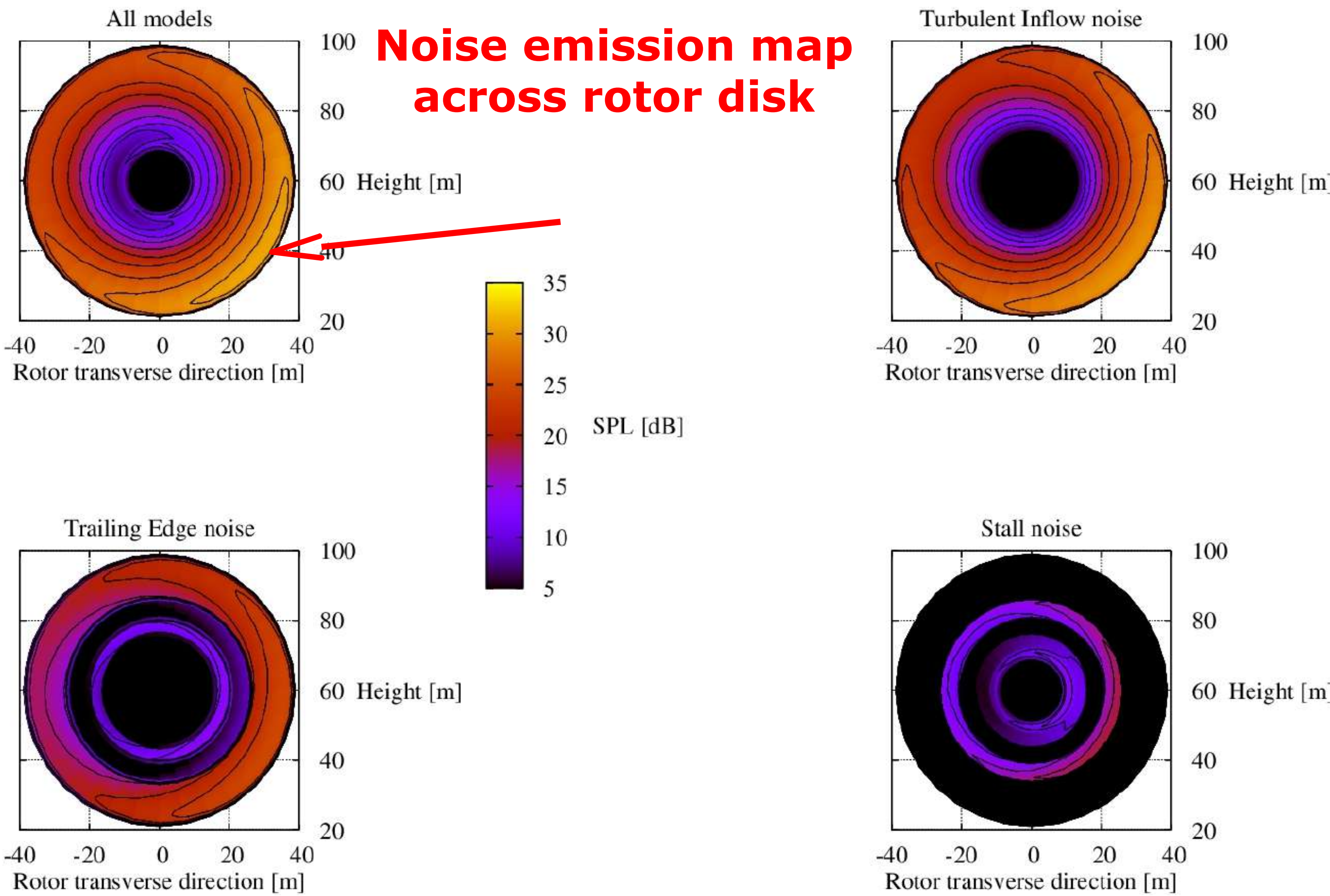
## Test Case 1.1 – View from Observer at Hub Height

**Noise emission map across rotor disk**



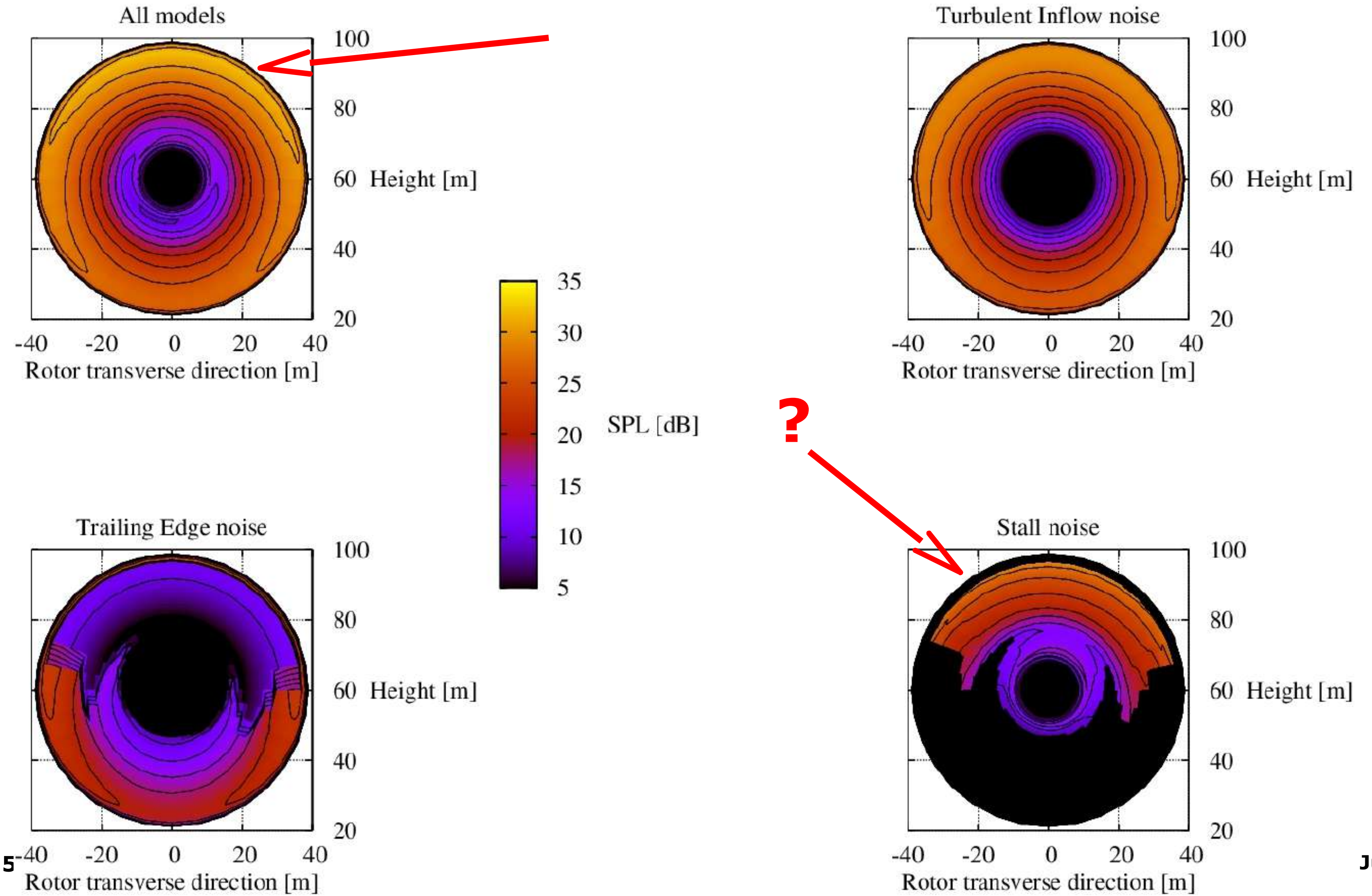
# Noise emission comparison

## Test Case 1.1 – View from Observer on the Ground



# Noise emission comparison

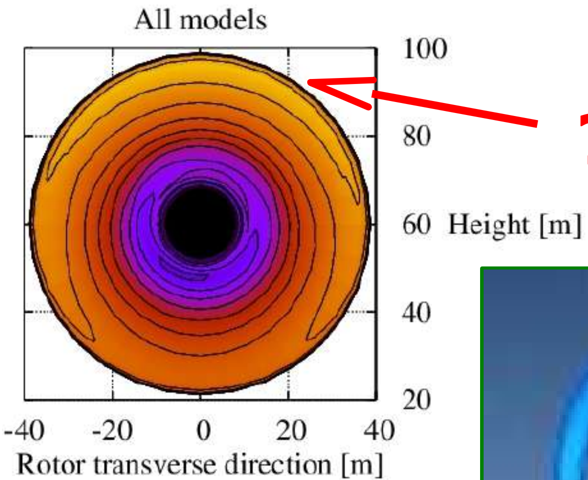
## Test Case 1.4 – View from Observer on the Ground
*with wind shear!*



# Noise emission comparison

## Test Case 1.4 – View from Observer on the Ground

*with wind shear!*

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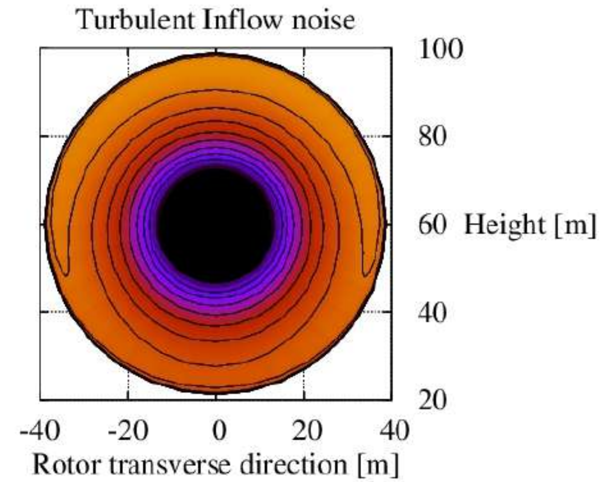
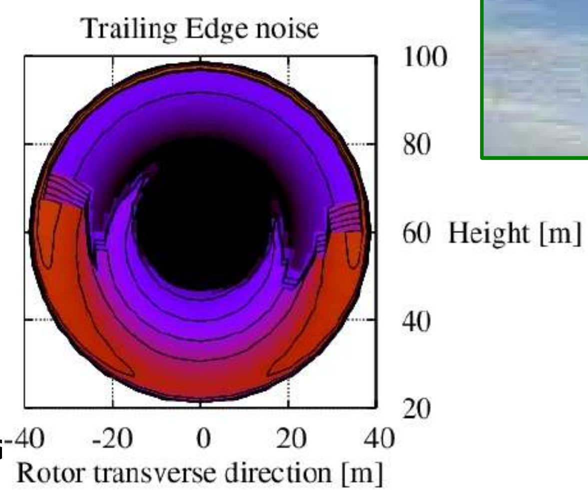
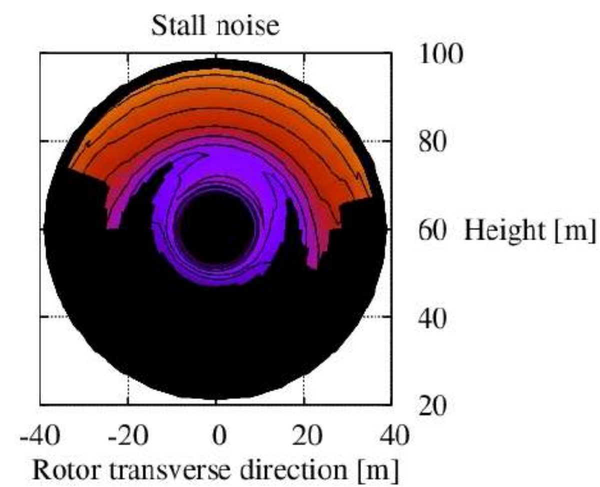


# Conclusions

- **Benchmark – Joined IEA Wind Task 29 & 39 effort**
- **Definition of test-cases completed**
  **May be too challenging in term of required efforts?**
- **Waiting for contributions/results from participants**
- **Here, looked mostly at qualitative features**
  **BUT benchmark will focus on quantitative details**
  **and comparisons with experimental data (DANAERO)**
  **+ analysis of discrepancies between models**

University of Stuttgart
Germany

# Current work at IAG

Florian Wenz, Cordula Hornung, Thorsten Lutz

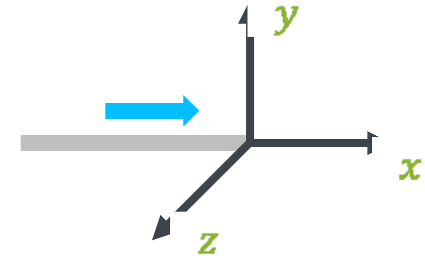
IEA Task 39 Lisbon 2019

IAG

WindForS
Windenergie Forschungscluster
Wind Energy Research Cluster

# Noise prediction with IAGNoise+

## Inflow Noise (based on Amiet Model)




**Flow around turbine**

- Geometry
- Karman spectrum: Lenght scales and turbulence intensity of inflow

**Effective lift**

- Depends on ratio of lenght scales in inflow spectrum to chord (Amiet)

**Far field noise**

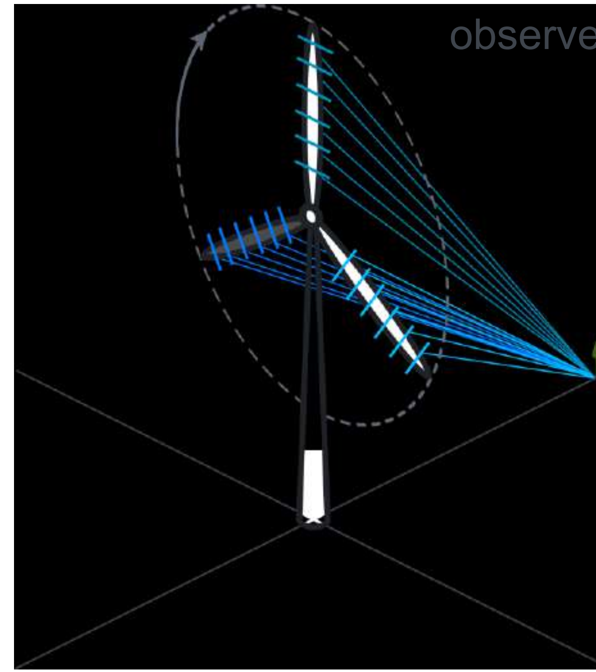
- Thickness correction
- Radiation to far field under consideration of directivity

$$G_{pp}(\vec{r},\omega) = 2\left(\frac{\omega\rho_0 cz}{2c_0\sigma^2}\right)^2 \pi U \frac{L}{2} \left|\mathcal{L}(\vec{r},\mathrm{K_x},\mathrm{K_y})\right|^2 \Phi_{ww}(K_x,K_y)$$

# Noise prediction with IAGNoise+

## 3D Rotors

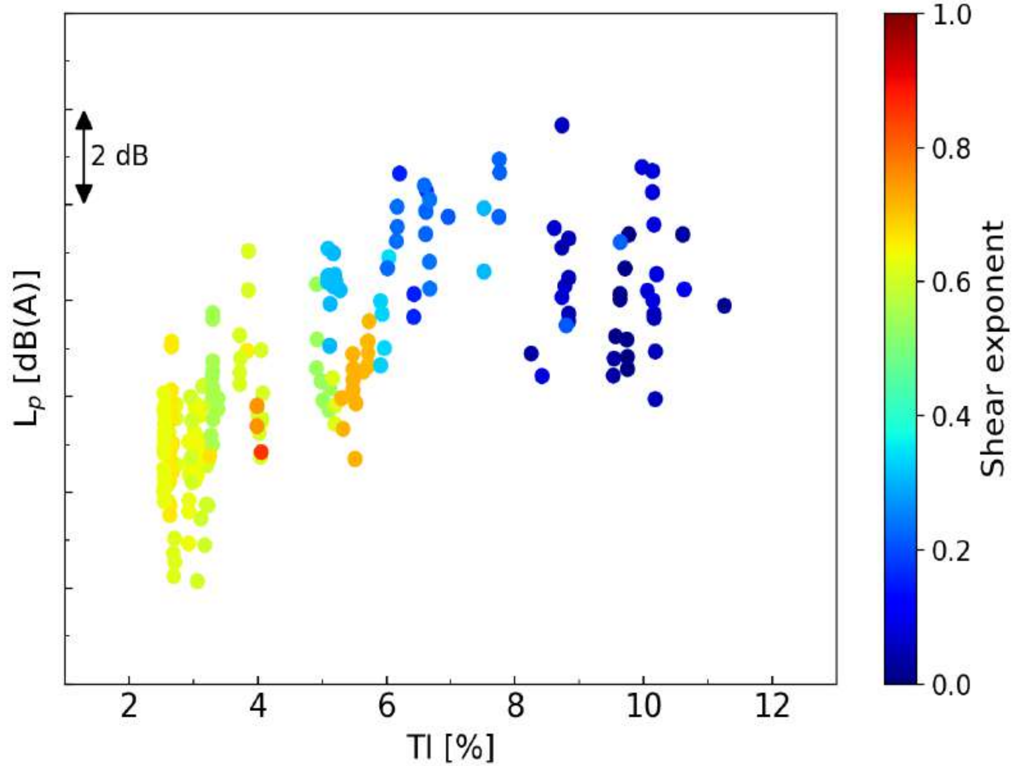
Addition of noise from all sections at observer position



- Noise from sections is determined separately
- Based on angles between section and observer noise is propagated to observer
- Different directivity functions for inflow noise and trailing edge noise
- Doppler effect considered

## Measurement Campaign

Sound pressure level at 50 Hz vs. Turbulence Intensity (15.2 rpm)




Shear expontent determined between 98 m and 63 m

# Measurement Campaign

## Length scales

- According to Kelly 2018 the length scale $\Lambda$ can be determined form measurements via:

$$\Lambda \approx \frac{\sigma_u}{dU/dz} \quad \text{or} \quad \Lambda \approx \frac{z\,\sigma_u}{U\,\alpha}$$

$\alpha$: shear coefficient
$z$: distance above ground
$\sigma_u$: variance of measured fluctuations
$U$: Wind speed

With a third order regression:

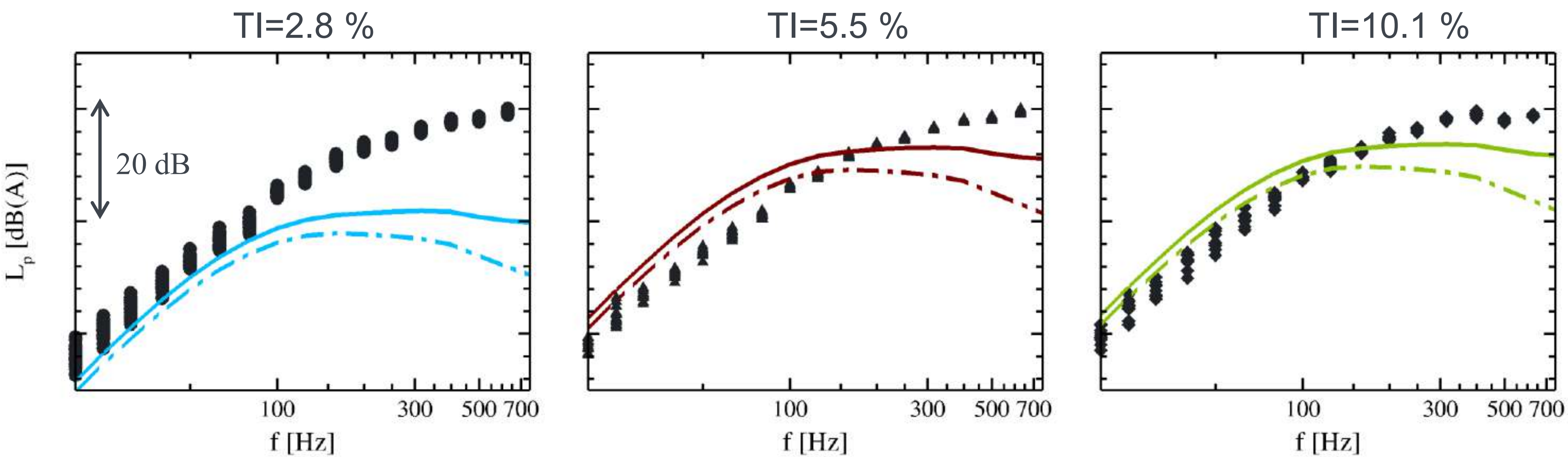
→

| | 15.2 rpm | | |
|---|---|---|---|
| TI [%] | 2.8 | 5.5 | 10.1 |
| $\Lambda$ [m] | 6.23 | 6.05 | 39.08 |

# Comparison Prediction - Experiments

## Inflow noise

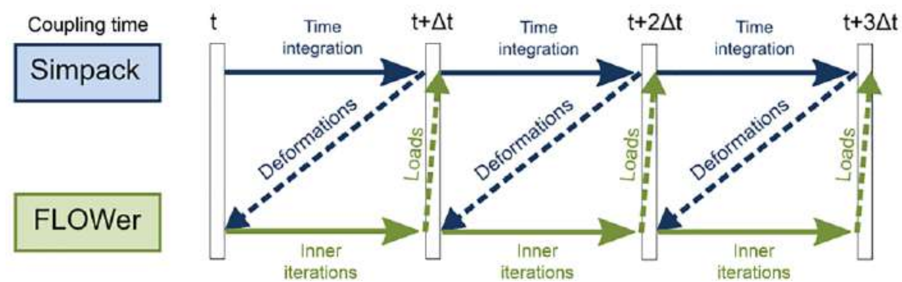
▲ ● ◆ Measurements
Prediction w/o correction
Prediction with Moriarty corr.

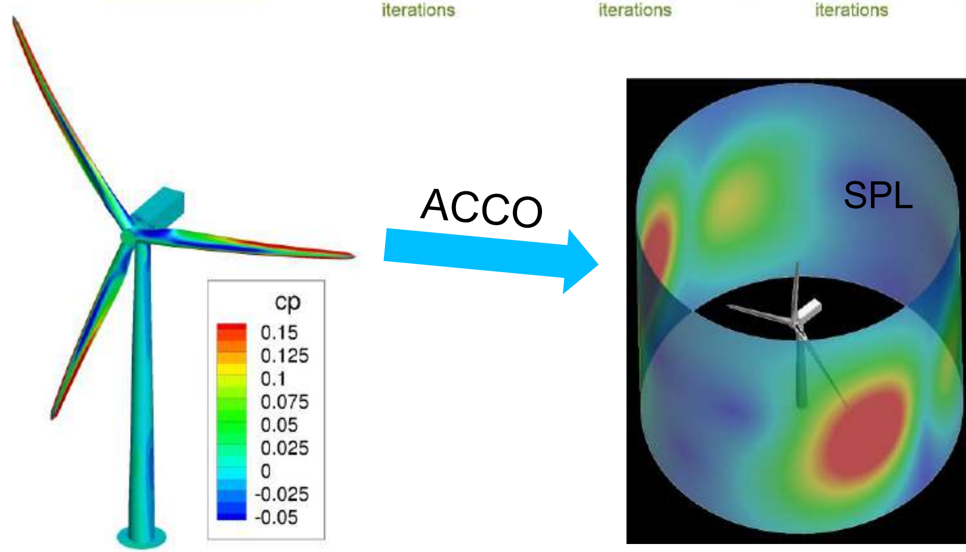


# Simulation of low-frequency sound emissions

## CFD – CSD – FW-H

- Flow solver (CFD)
  - FLOWer: in-house, compressible
- Structural solver (CSD)
  - SIMPACK: Beam model and controller
  - KRATOS: Shell/beam model
- Flexible turbine components
  - blades, tower, drive train
- Controller
  - Pitch, rotation speed, flaps
- Acoustic propagation
  - Ffowcs-Williams Hawkings

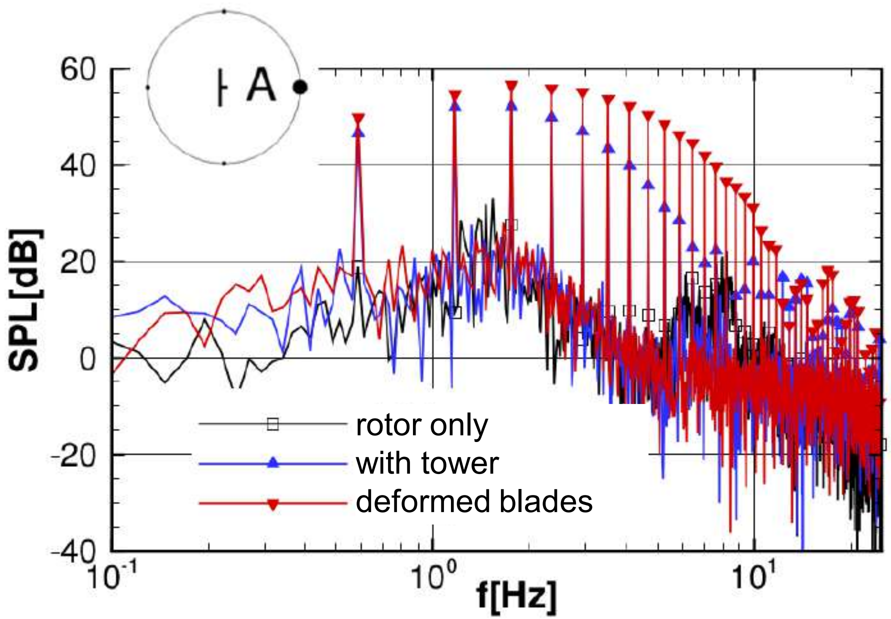


# Noise types: Low-frequency noise

## Mechanisms

Spectrum of the NREL 5MW turbine

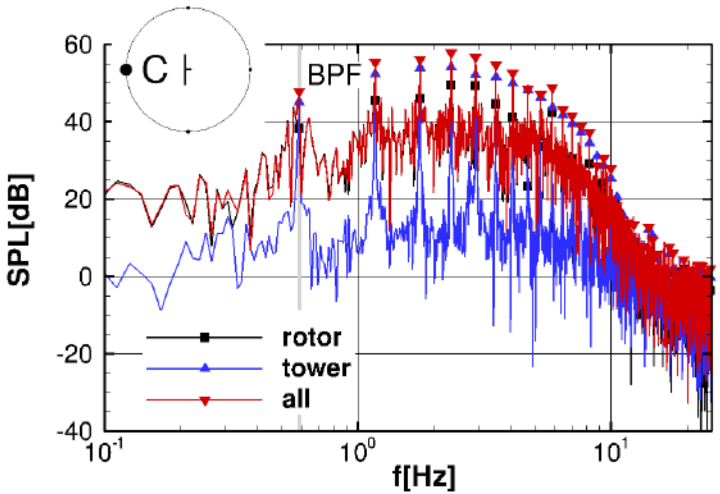


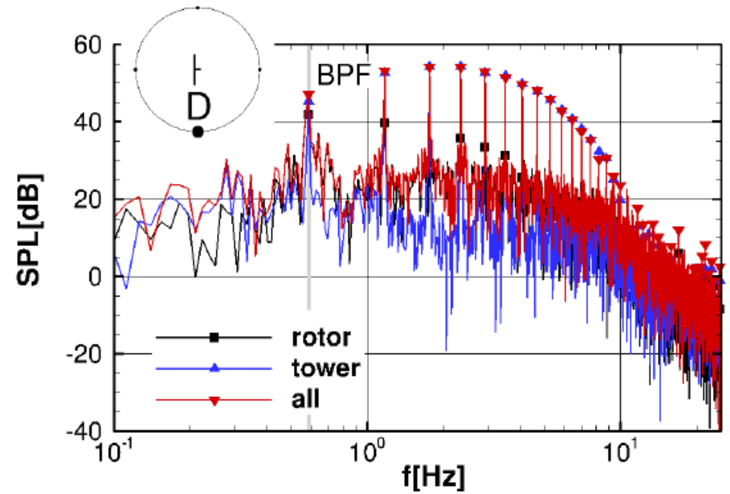

- Dominated by blade passage in front of the tower and higher harmonics
- Passing blade induces pressure fluctuation on tower surface
- Blade-tower distance has strong influence on intensity (deformation must be taken into account)

L. Klein et al.: Advanced CFD-MBS coupling to assess low-frequency emissions from wind turbines; Wind Energy Science

# Noise types: Low-frequency noise

## Acoustic emission of tower and rotor



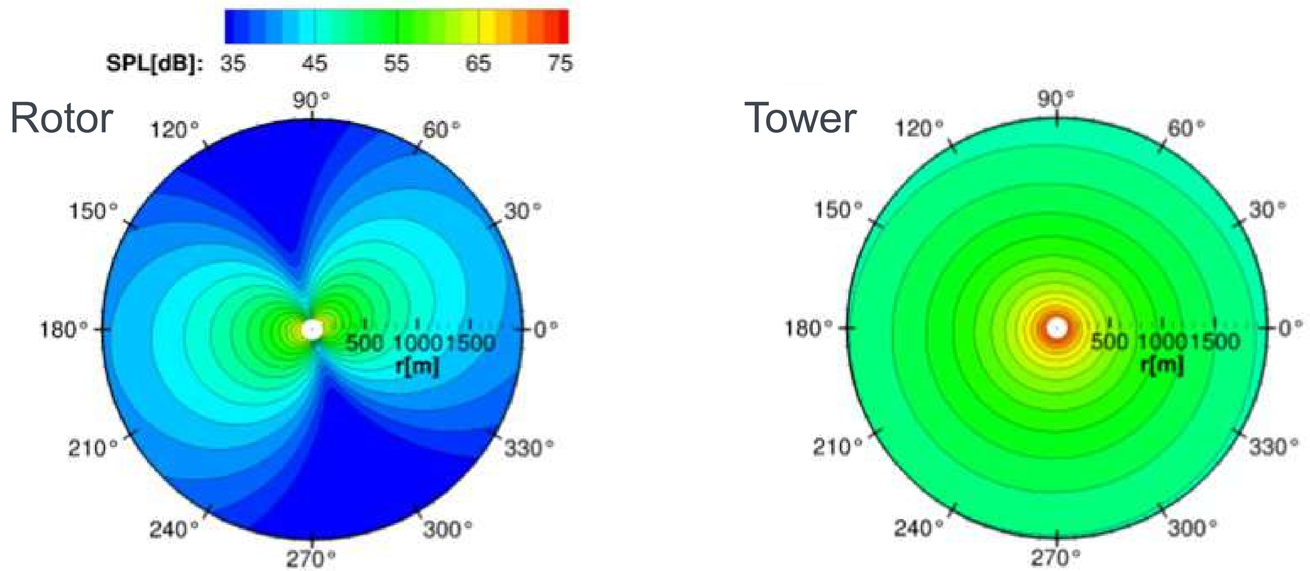




- Rotor emits more broadband noise to the front and causes only small peaks at BPF harmonics
- Tower emits less broadband noise, especially in the direction of flow, but peaks at BPF harmonics have much higher amplitudes and are more prominent
- The tower radiates a large part of the low frequency tonal noise

L. Klein et al.: Advanced CFD-MBS coupling to assess low-frequency emissions from wind turbines; Wind Energy Science

# Noise types: Low-frequency noise

Directivity of tower and rotor at third BPF harmonic (~1.7Hz)




- Tower emits more sound for this turbine than the rotor
- Tower emission has no directional characteristic while rotor has upstream/downstream directivity

L. Klein et al.: Advanced CFD-MBS coupling to assess low-frequency emissions from wind turbines; Wind Energy Science

University of Stuttgart
Institute of Aerodynamics and Gas Dynamics

Thanks goes to Levin Klein for conducting the evaluated CFD simulations and C. Scheit, N. Noffke and A. Altmikus from WRD GmbH.

# Thank you!

**Florian Wenz**

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phone +49 (0) 711 685-63434
fax +49 (0) 711 685-63438

University of Stuttgart
Institut für Aerodynamik und Gasdynamik
Pfaffenwaldring 21

# PIBE project

## (Predicting the noise impact of wind turbine noise)

D. Ecotière

Joint Research unit on Environmental Acoutics (UMRAE)

# The project

Prévoir l'Impact
du **Bruit des Éoliennes**

www.anr-pibe.com

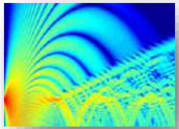
- **Title**: Predicting the noise impact of wind turbine noise
- **Funding:** French Research National Agency (ANR)
- **Partners**: <u>UMRAE</u> (Cerema/Ifsttar), IMSIA (ENSTA-ParisTech), LMFA (ECL), EDF Renouvelables, EDF DTG (+ Cerema CE, Cerema NC)
- **Project start**: 01/01/2019 (durée 4ans)
- **Cost**: 1 360 k€ (ANR=702 k€)
- **Support** : Pôle Mer Bretagne Atlantique

# The project

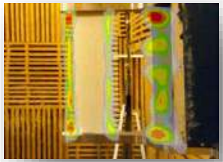
Prévoir l'Impact du **Bruit des Éoliennes**

**WP 1**: **Characterizing the amplitude modulation phenomena**

**WP 2**: **Estimating the variability of sound levels and the associated uncertainties**



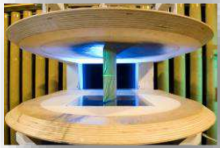
**WP 3**: **Reducing noise at source**



# WP1

Prévoir l'Impact du Bruit des Éoliennes

**WP 1**: **Noise source modeling: amplitude modulations**



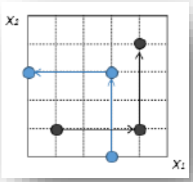
- Characterization of dynamic stall noise (anechoic wind tunnel)
- AM modeling
- Long term *in situ* measurements (occurrences of AM estimation)

# WP2

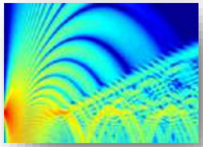
Pibe) Prévoir l'Impact du **Bruit des Éoliennes**

## **WP 2**: **Sound levels variability and uncertainties**

- Uncertainties estimation due to sound emission and to sound propagation, sensitivity analysis



- Estimation of global/coupled uncertainties on noise predictions (propagation of uncertainties)



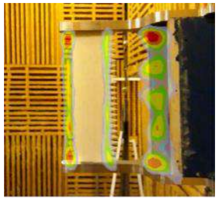
- Experimental validation of the uncertainty model: 1 year in situ measurements (sound levels, meteo, ground absorption …)

# WP3

## WP 3: Reducing noise at source

- Comparison of several noise reducing devices: anechoic wind tunnel measurements, aerodynamic and acoustic

- Design and test of new solutions (in anechoic wind tunnel)



# Outcomes

Prévoir l'Impact du **Bruit des Éoliennes**

**Main outcomes**

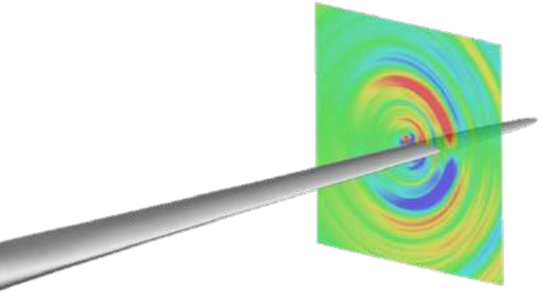
- Development of a model for predicting amplitude modulation
- A database of experimental data on the wind tunnel characterization of noise due to dynamic stall at wind turbine blades.
- A database of experimental data on wind turbine noise propagation
- A database and a model for estimating the uncertainties of wind turbine noise predictions
- The evaluation and the development of new solutions for reducing wind turbine noise at source.

# Thank you for your attention

- Contact :
  - david.ecotiere@cerema.fr


www.anr-pibe.com

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR
ANR



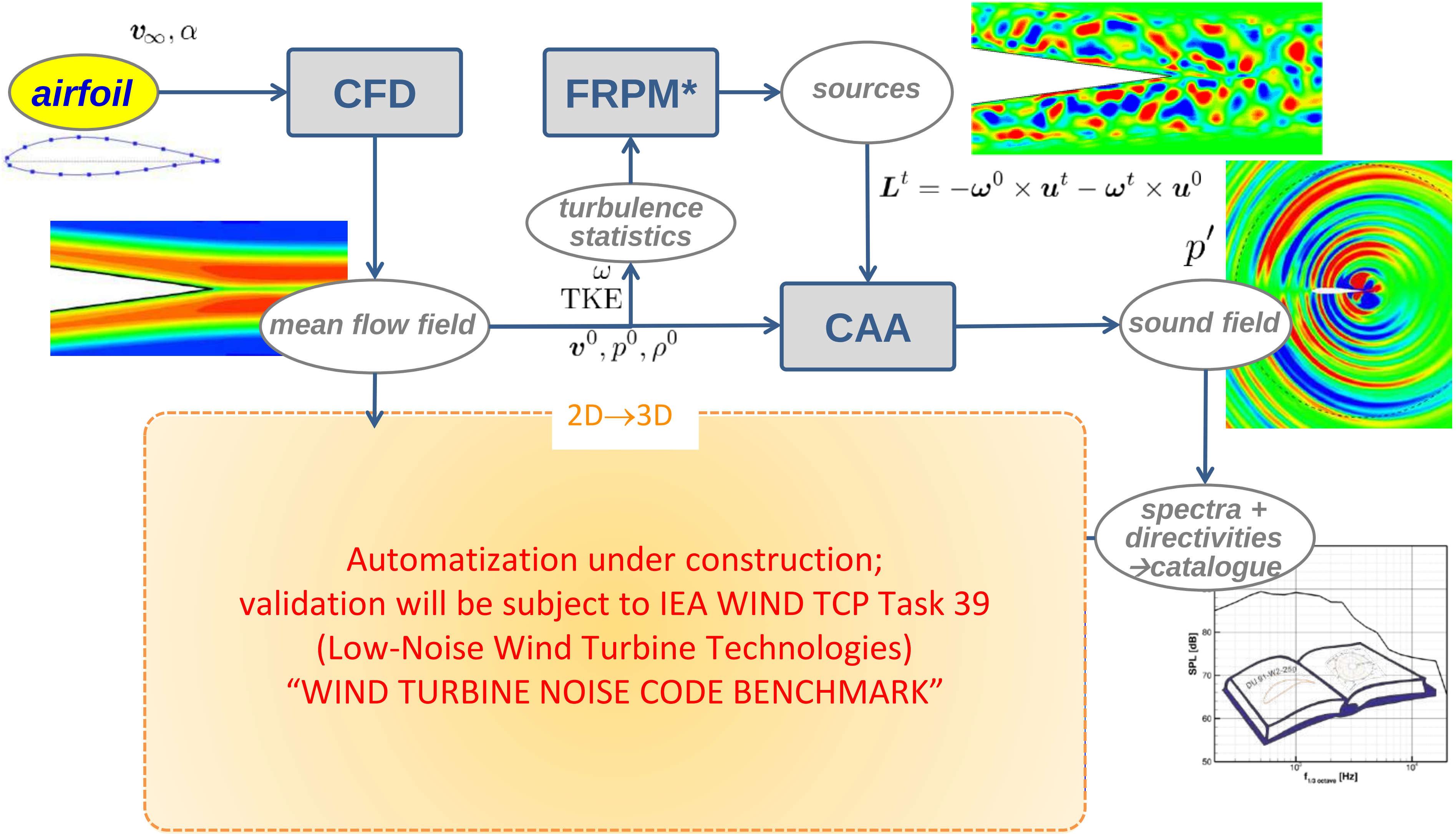
# WT aeroacoustic research at DLR

## Status on activities since September 2018

Michaela Herr on behalf of DLR colleagues
Institute of Aerodynamics and Flow Technology, Technical Acoustics
German Aerospace Center (DLR), Braunschweig, Germany

IEA Wind TCP Task 39 - Quiet Wind Turbine Technology
Lisbon, 11 June 2019

# Numerical approach
# 2D-based non-empirical hybrid CFD/CAA TEN prediction method




*Ewert, Comp. & Fluids (Vol. 37)

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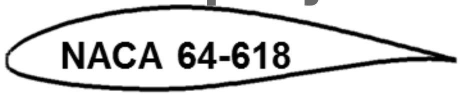
aufgrund eines Beschlusses des Deutschen Bundestages

# Application example from project BELARWEA → Friday's presentation

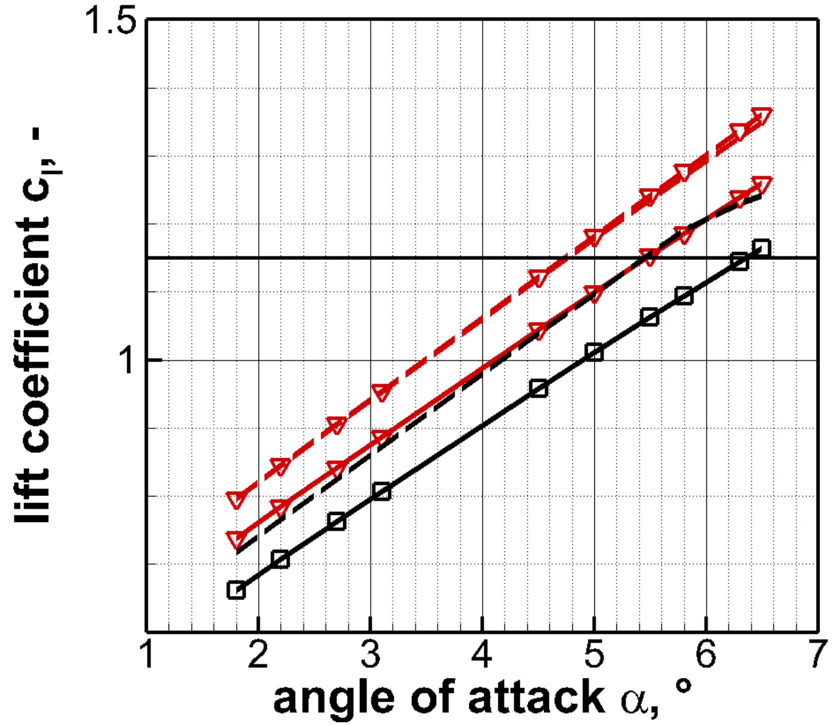

vs.

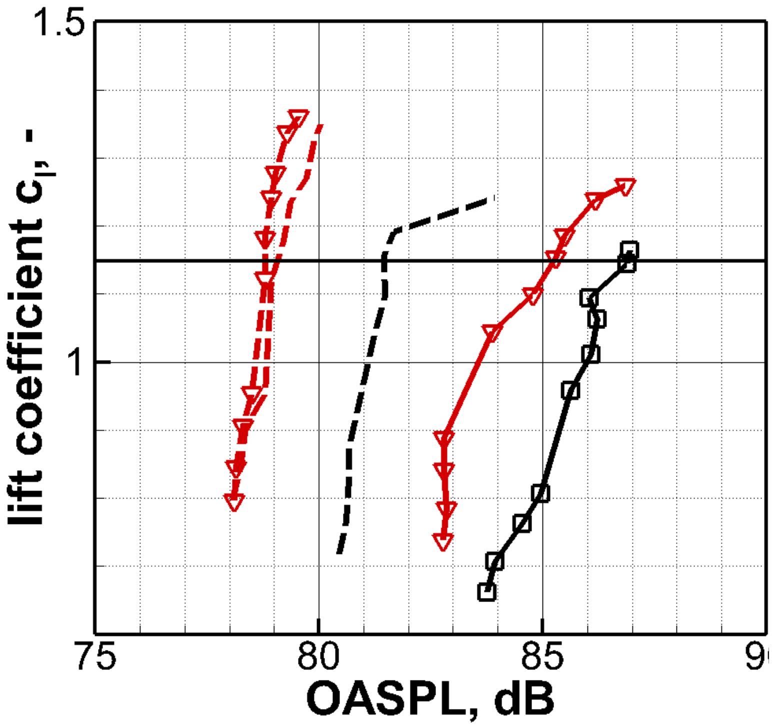


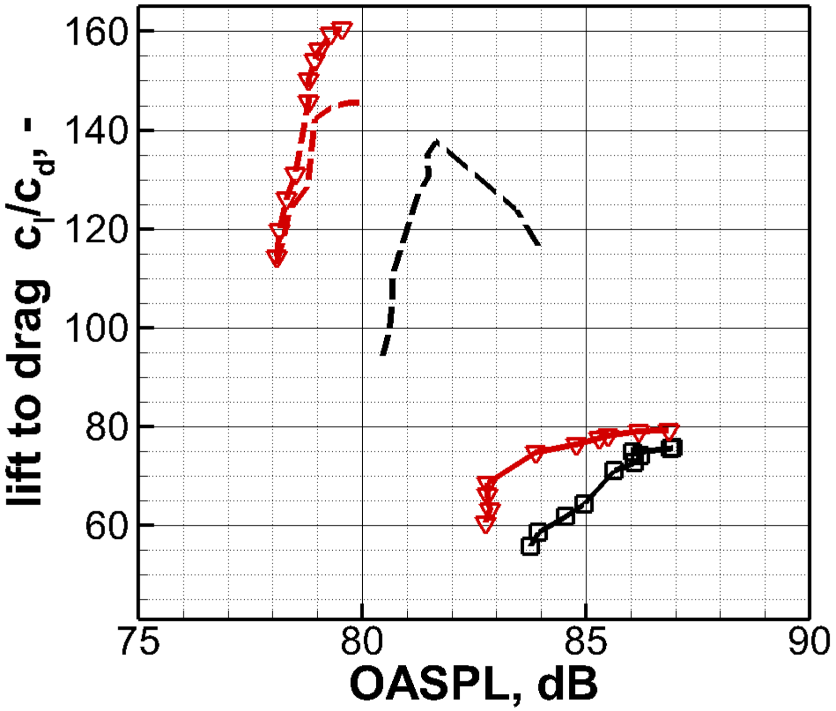

reference at WT (NWB)-conditions

**$u_\infty$= 80 m/s**

**solid lines with symbols:** FUL = tripping (SS/PS) @ 5%/10%
**dashed lines with symbols:** NATFIX = tripping (SS/PS) @ 42%/60%
**dashed lines:** NAT = untripped airfoils




→ Expectation for WTT: 2–2.5 dB reduction in terms of OASPL

# 1st evaluation step: spectral shape & parametric dependences 2D blade sections in the Acoustic Wind Tunnel Braunschweig (AWB)

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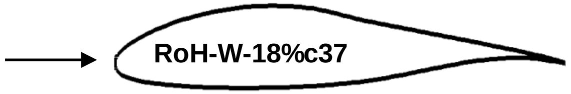
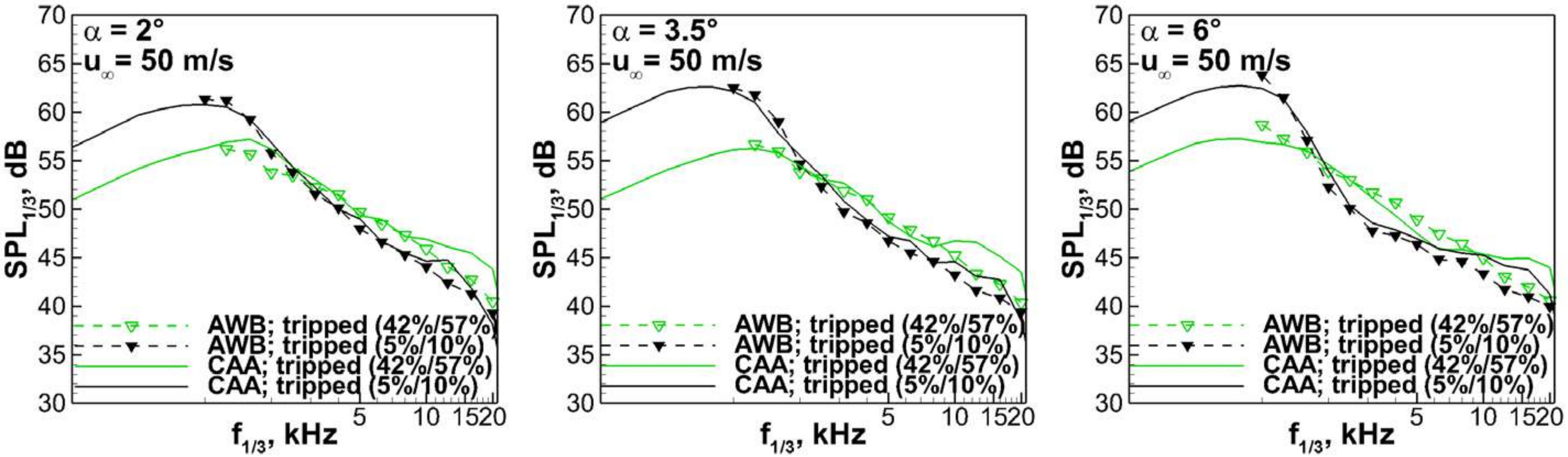
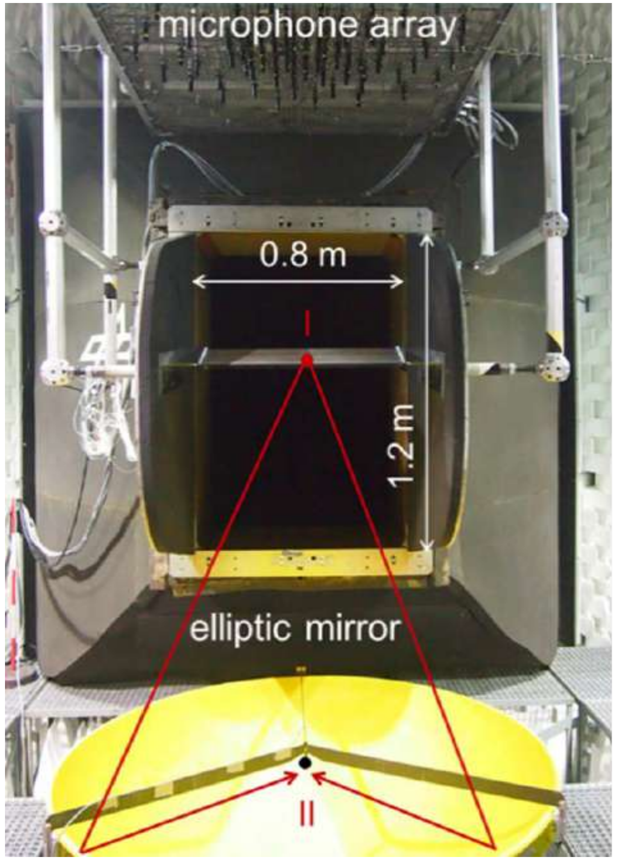
aufgrund eines Beschlusses des Deutschen Bundestages

## AWB measurements vs. simulation results RoH-W-18%c37 with varying tripping position




- → for complete AWB results cf. e.g. AIAA 2017-3534
- → preselection of best add-on solutions to be tested at the wing tip config.
- → but: predicted noise reduction vs. NACA 64-618 reference could not be evaluated because TEN maximum for NACA 64-618 is located below the low-frequency limit of the measurement!

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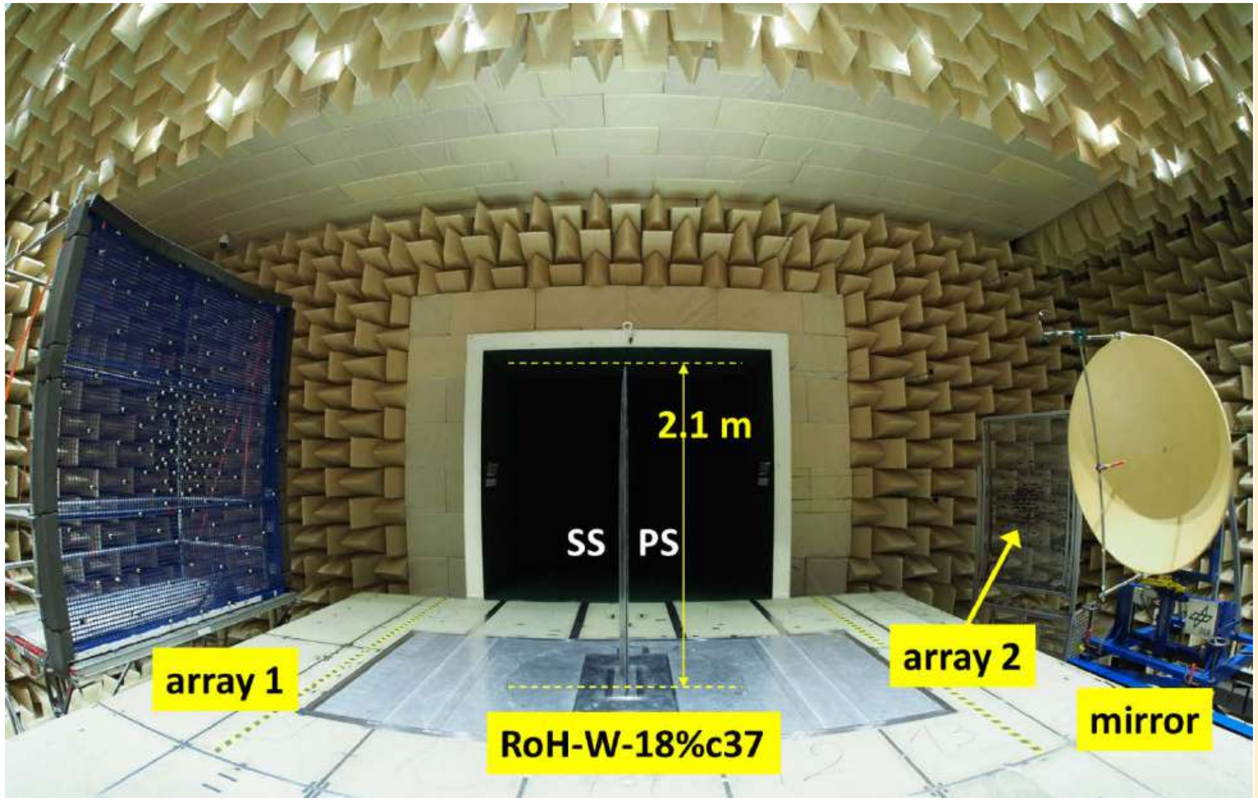
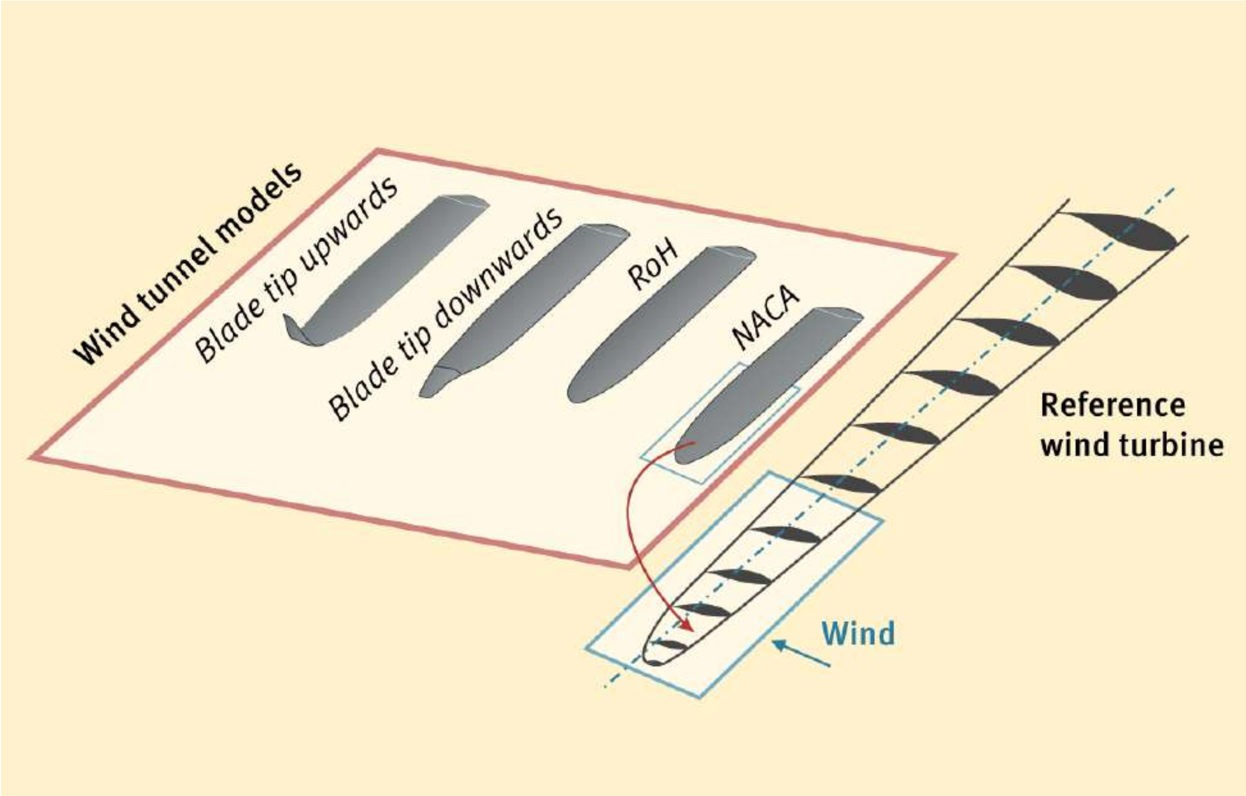
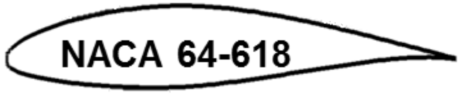
aufgrund eines Beschlusses des Deutschen Bundestages

# 2nd evaluation step
# 3D blade tips in low-speed wind-tunnel DNW-NWB

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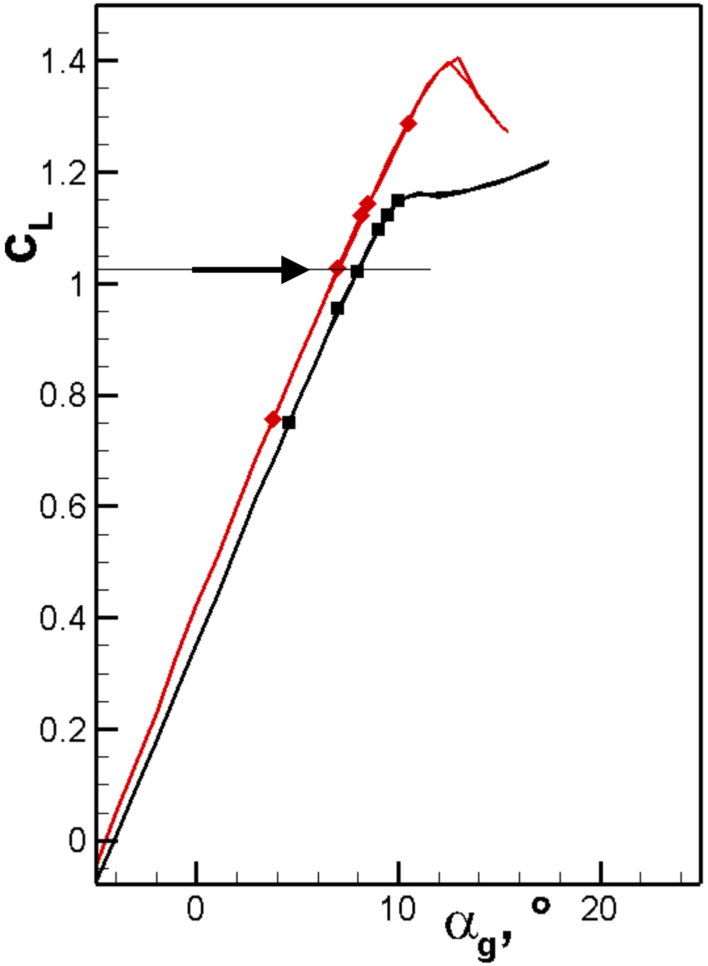
aufgrund eines Beschlusses des Deutschen Bundestages

# 2nd evaluation step
# 3D evaluation of RoH-W-18%c37 vs. NACA 64-618 wing tips in NWB

**$u_\infty$ = 80 m/s**

**NAT = untripped airfoils**


**Force balance:**
**$c_L$ = 1.02…1.03**

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# 2nd evaluation step
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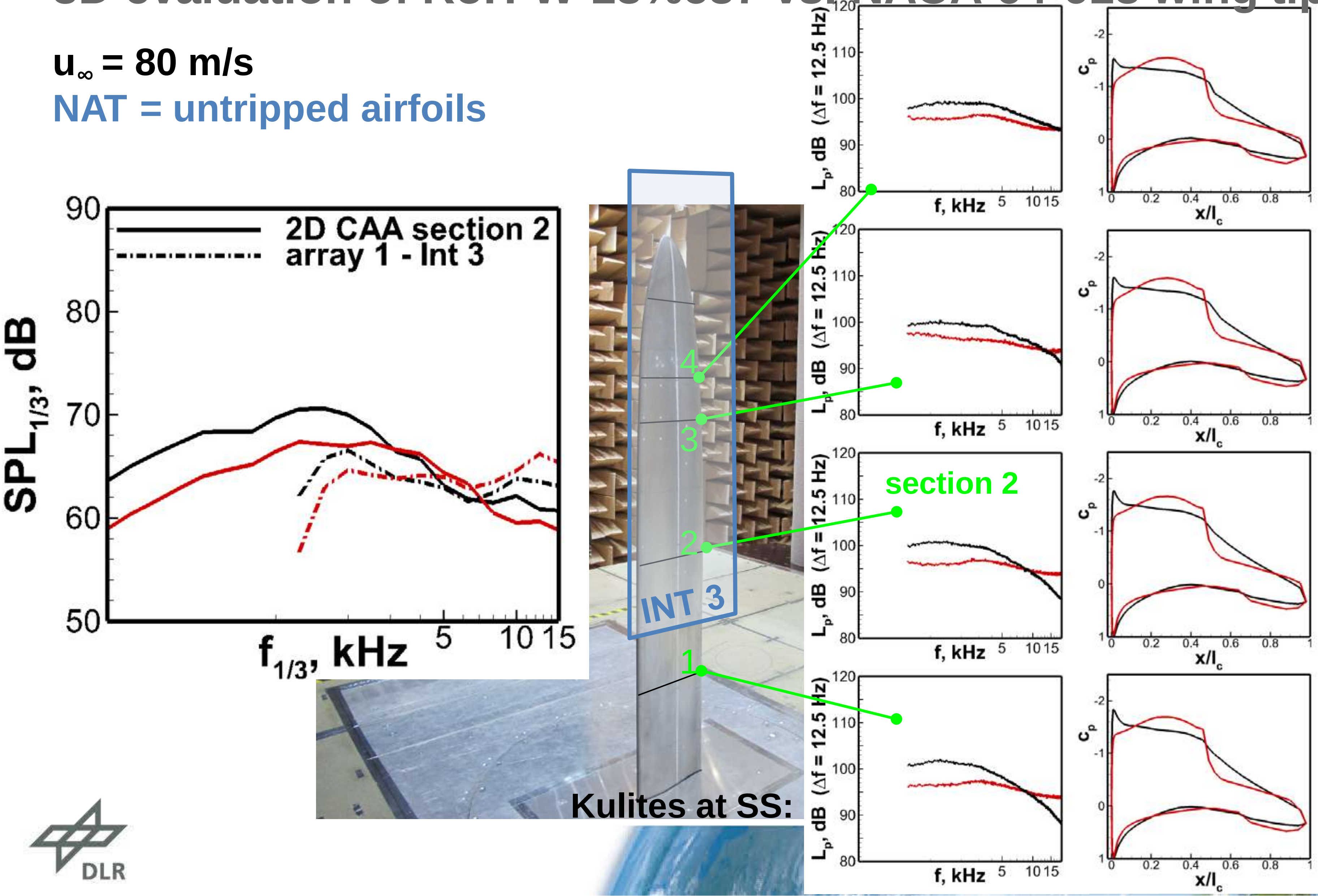
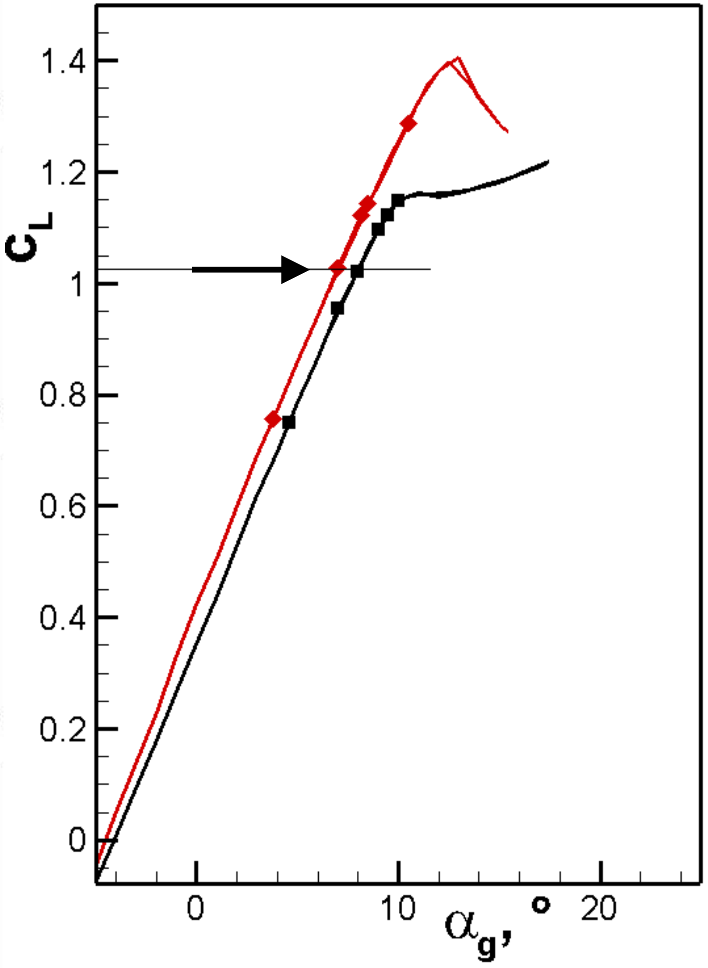



**Force balance:**

**$c_L$ = 1.02…1.03**



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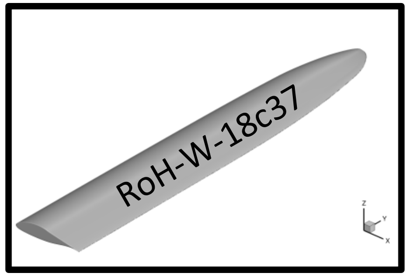
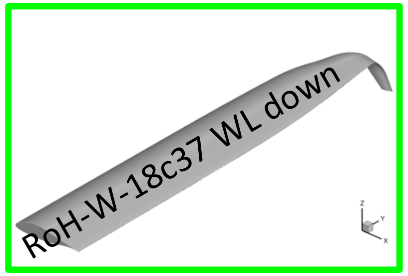
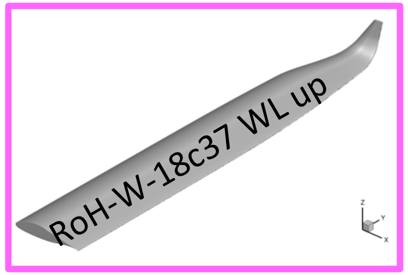
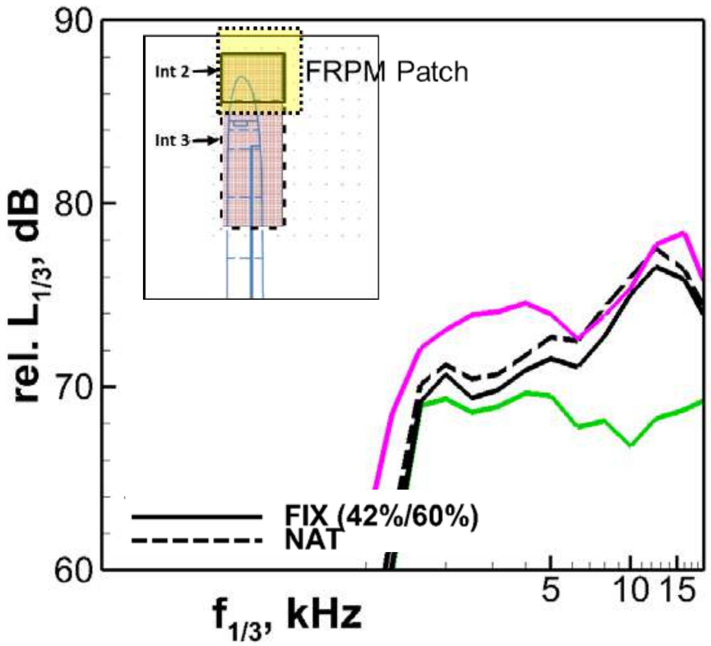
# Full 3D assessment of tip noise or of complex add-ons
## $u_\infty$= 80 m/s, $\alpha$ = 7°

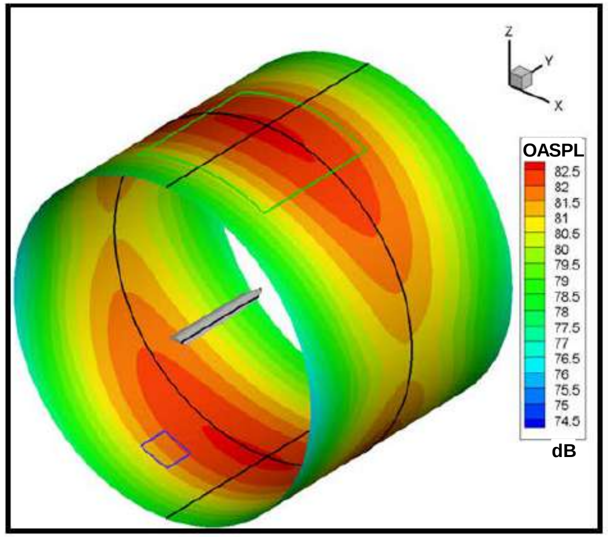


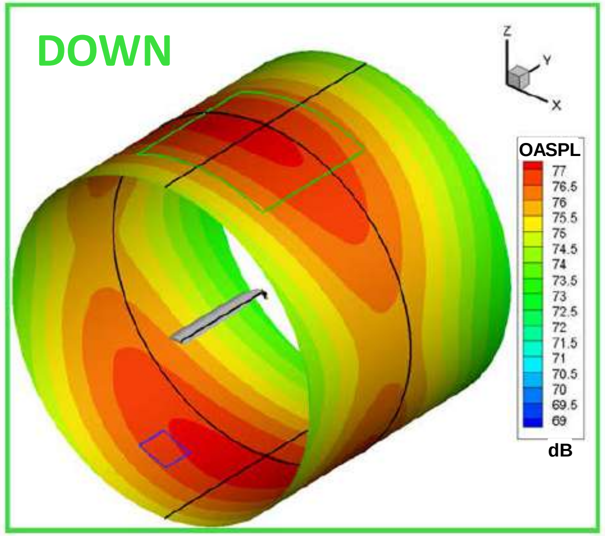



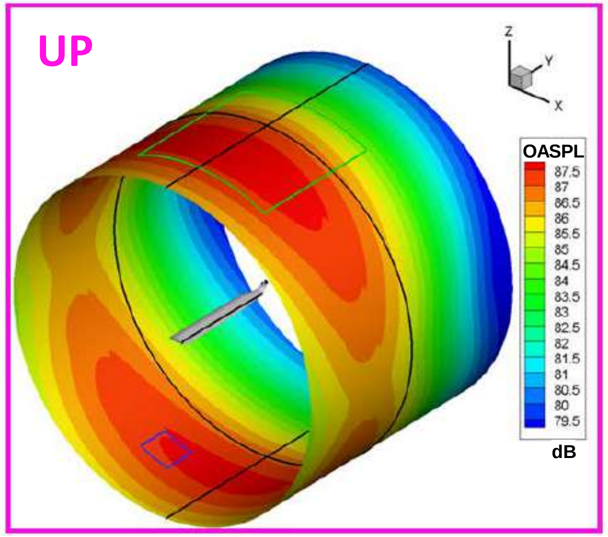

RoH-W-18%c37
+ Winglet DOWN
+ Winglet UP

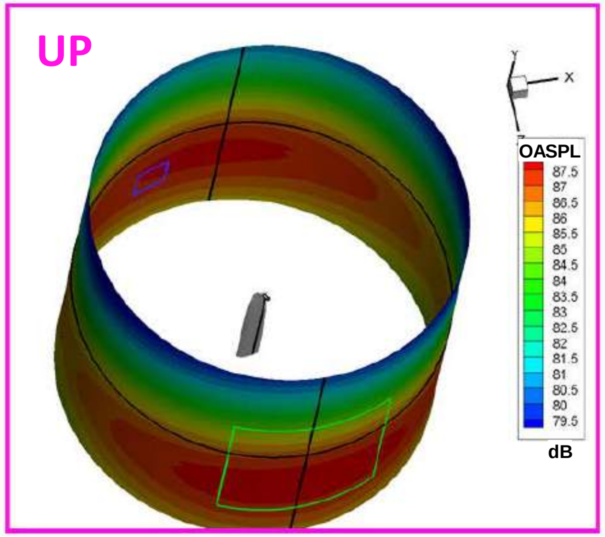


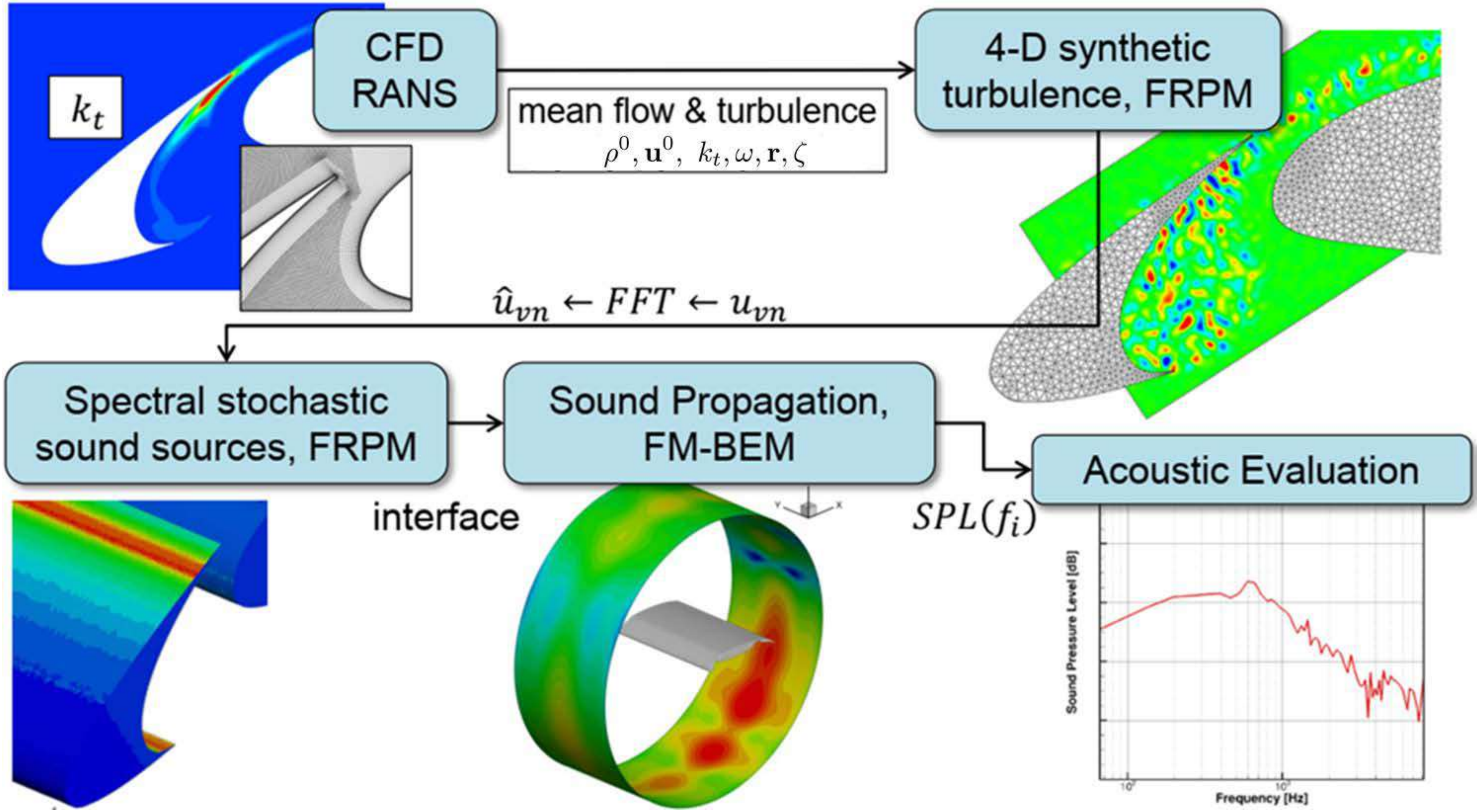




DLR

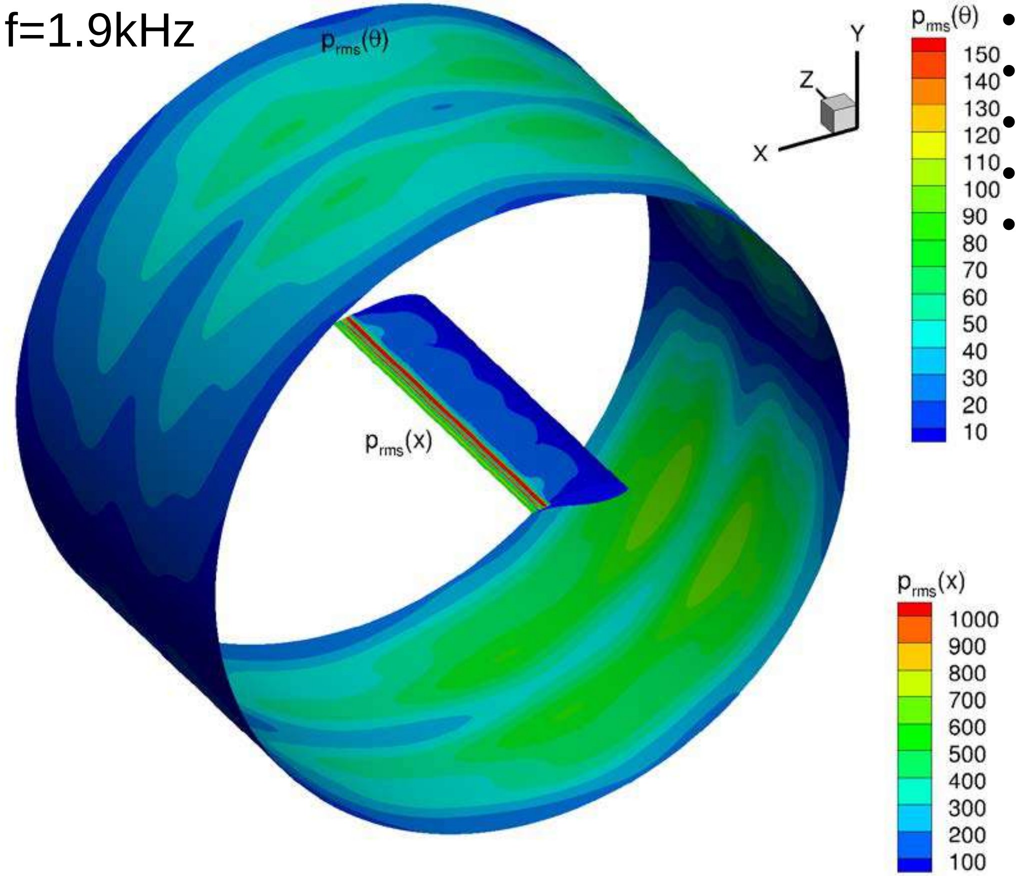
# RANS-FRPM/FM-BEM coupling for aeroacoustic simulation in wind energy
## Numerical scheme



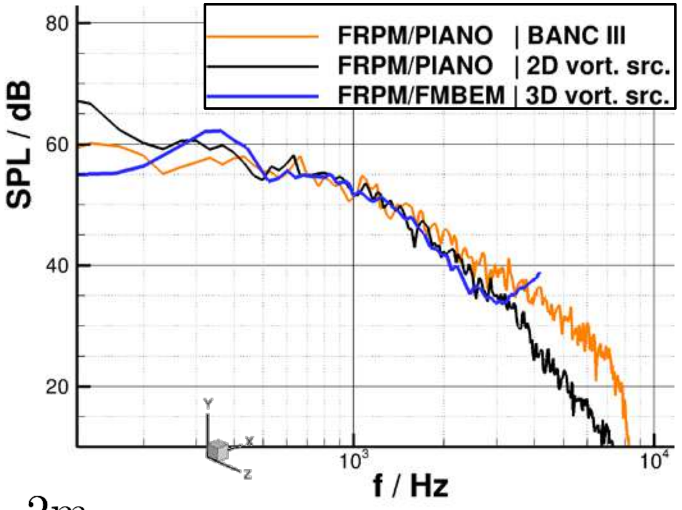

DLR FM-BEM code: FMCAS

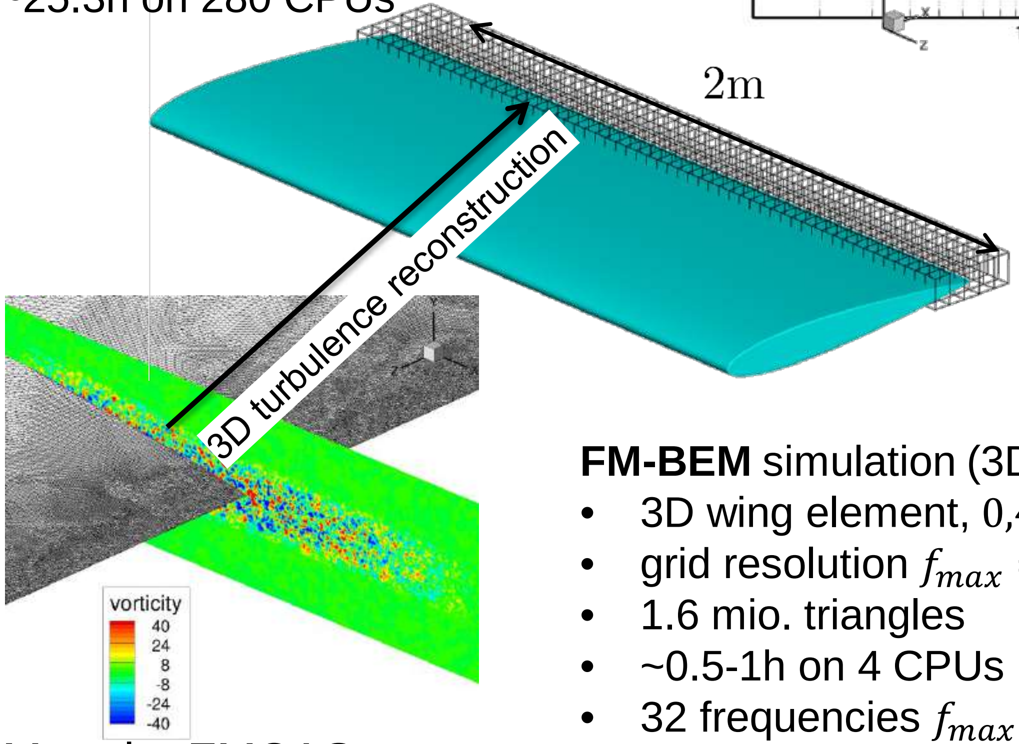
# RANS/FRPM/FM-BEM | verification & validation
# 2D TEN problem

f=1.9kHz




**Parallel FRPM** simulation (3D):
- domain extent $0.4l_c \times 0.1l_c \times 5.0l_c$
- 300x100x5040 grid points
- 300 mio. particles
- 280 subdomains
- ~25.3h on 280 CPUs

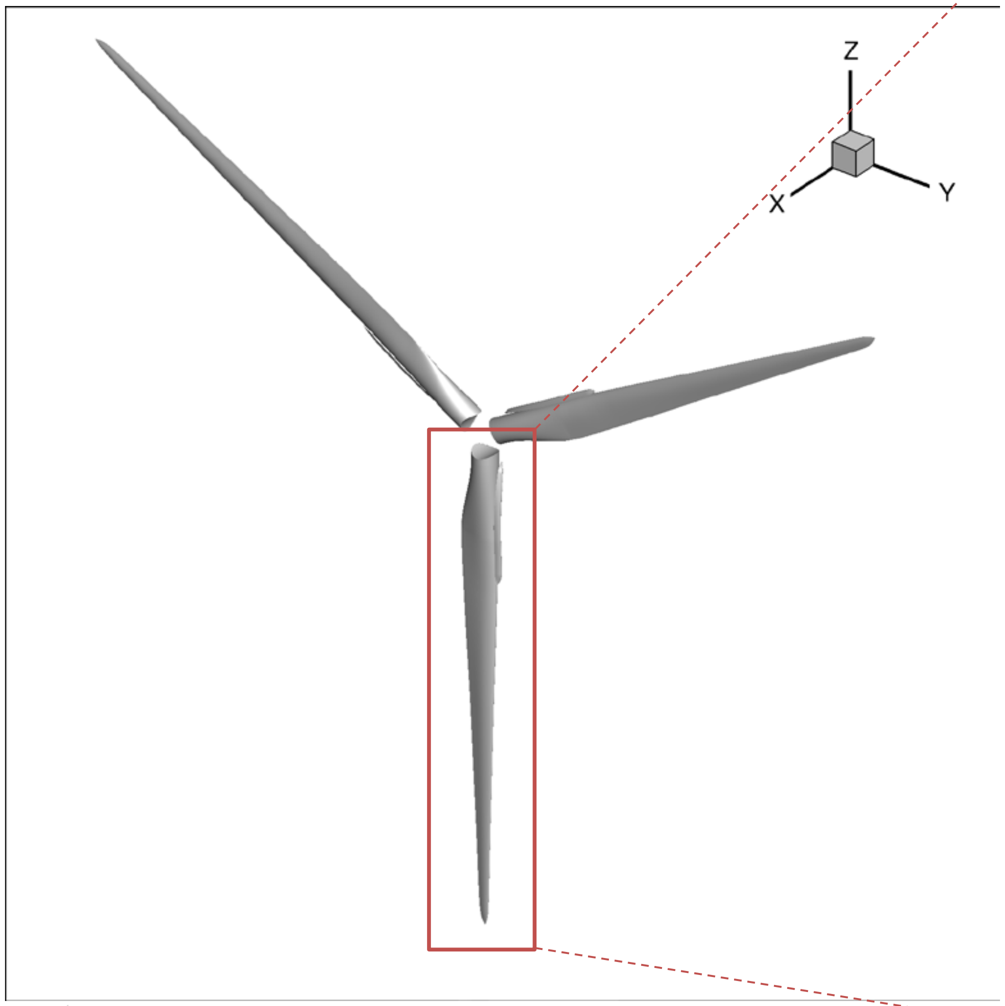


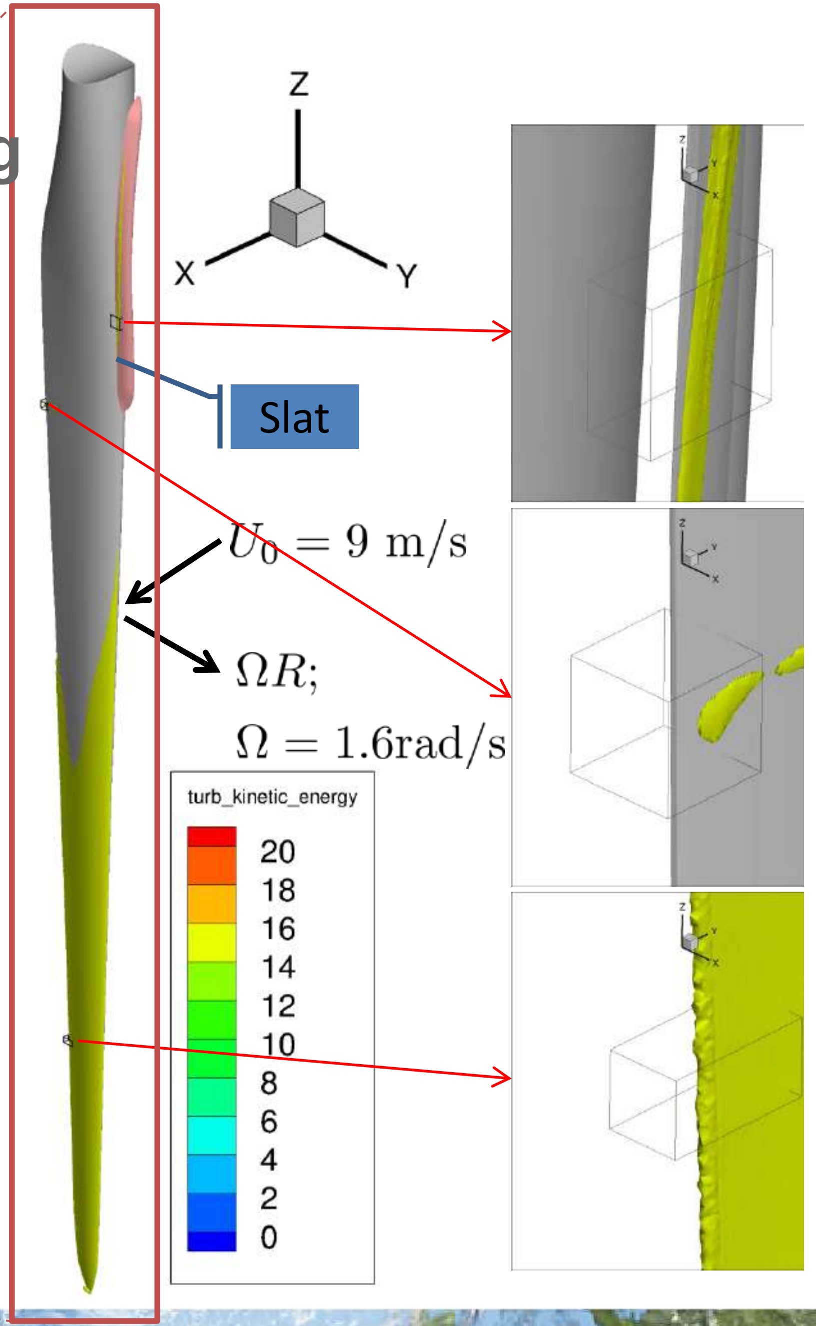




**FM-BEM** simulation (3D):
- 3D wing element, $0{,}4m \cdot 2m$
- grid resolution $f_{max} = 14.2Hz$, 6.5 ppw
- 1.6 mio. triangles
- ~0.5-1h on 4 CPUs ( for 1 frequency)
- 32 frequencies $f_{max} = 4kHz$

DLR FM-BEM code: FMCAS

# 3D problem 1: slat
# project SmartBlades 2.0: source ranking

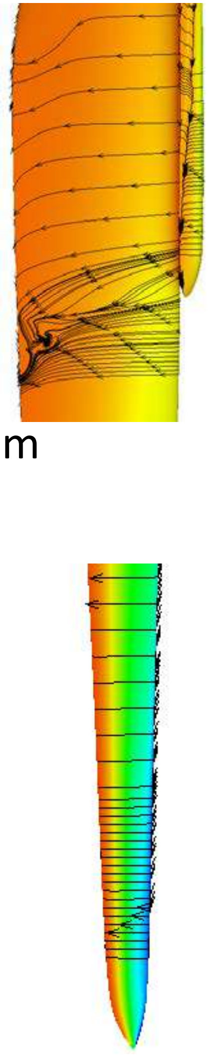



R=10m

R=14.15m

R=36m



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DLR

# 3D problem 2: flap side-edge project SmartBlades 2.0: source ranking

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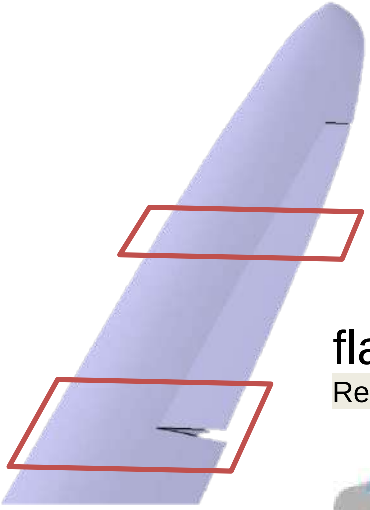
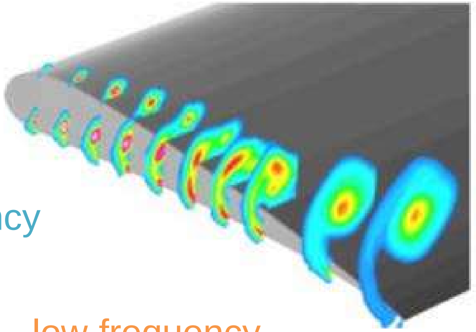
IWES Wind Turbine IWT-7.5-164 + plain flap



trailing-edge noise

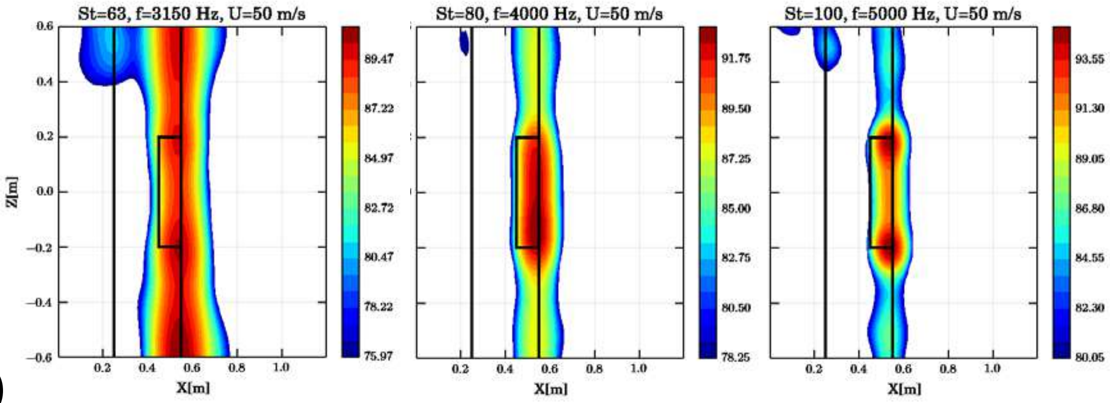
flap-side edge noise

Ref: C.L Street, AIAA-98-2226



high frequency contribution

low frequency contribution


- Validation of CAA tool chain with measurements (AWB)

# 3D problem 2: flap side-edge project SmartBlades 2.0: source ranking

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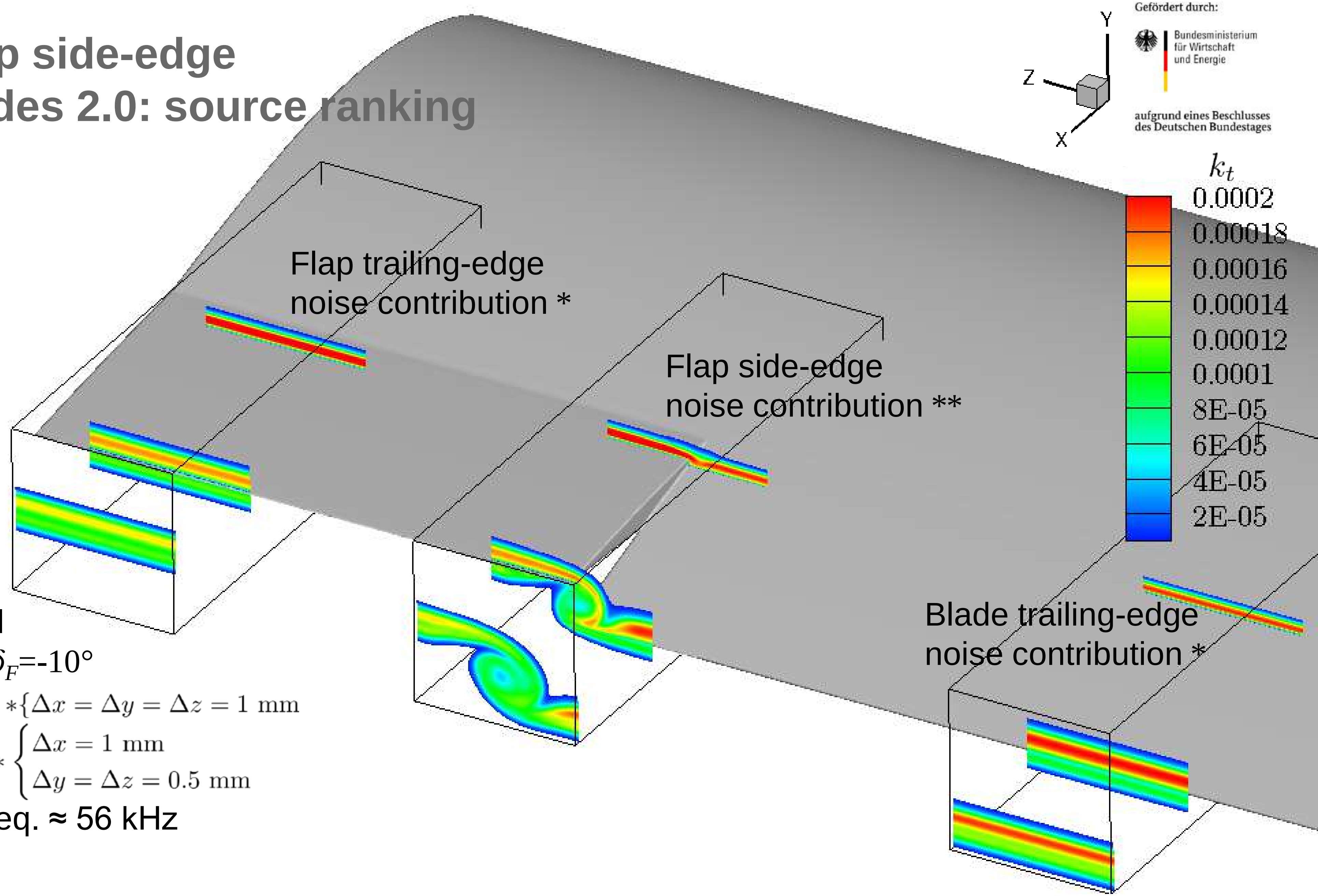
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

## Numerical setup




CFD: k-ω SST model

DU08-W-180, $\alpha$=3°, $\delta_F$=-10°

Volumetric patches: $*\{\Delta x = \Delta y = \Delta z = 1\ \mathrm{mm}$

$$** \begin{cases} \Delta x = 1\ \mathrm{mm} \\ \Delta y = \Delta z = 0.5\ \mathrm{mm} \end{cases}$$

Resolved acoustic freq. ≈ 56 kHz

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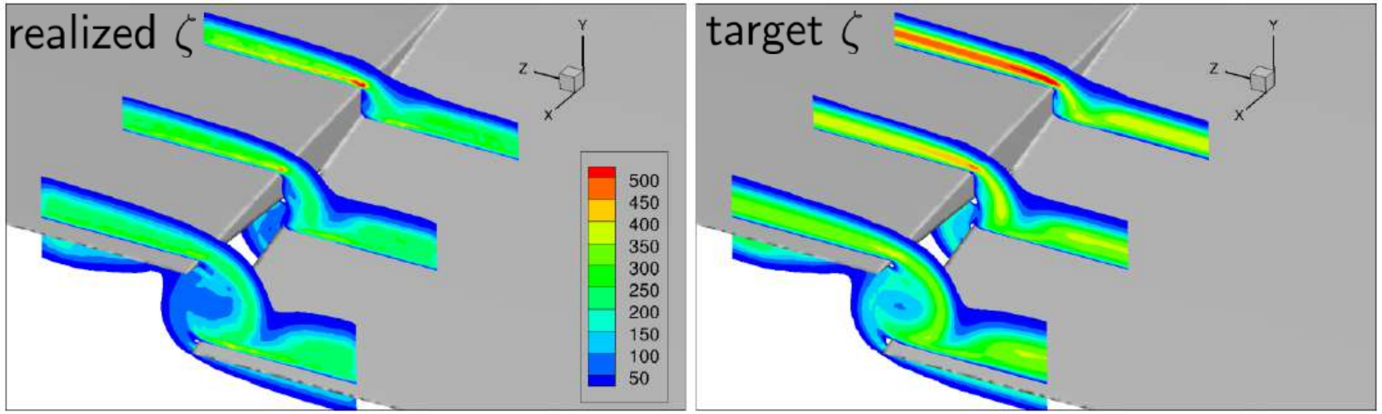
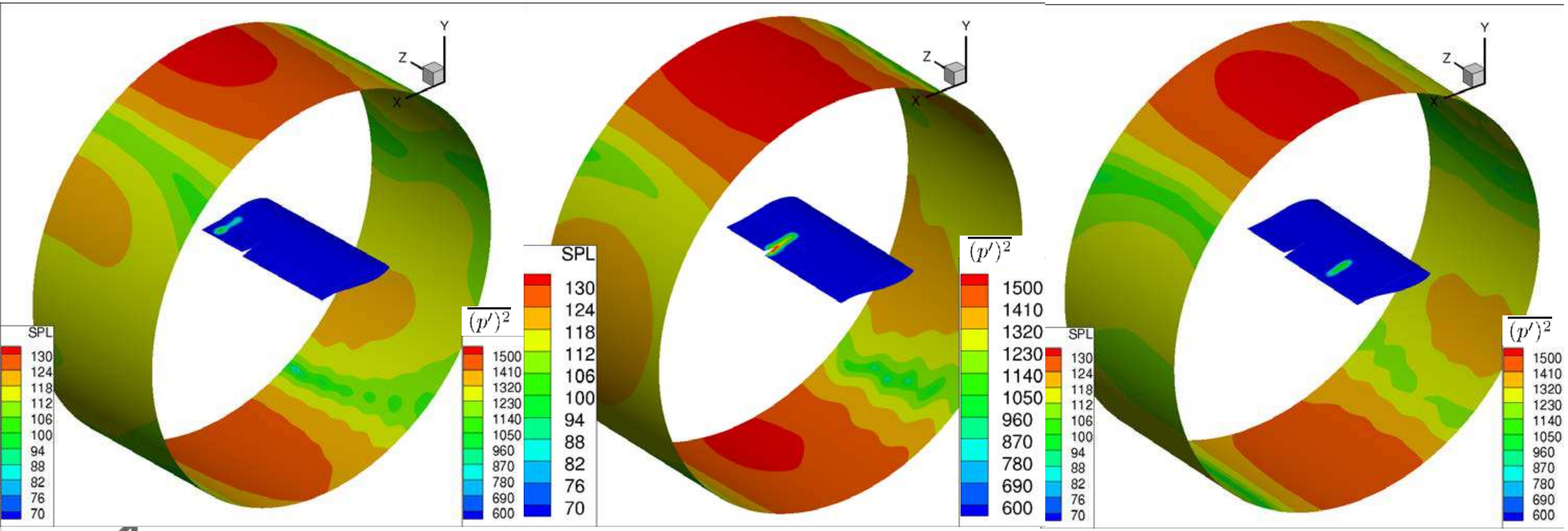
# 3D problem 2: flap side-edge project SmartBlades 2.0: source ranking

Preliminary results $f \approx 4 \text{ kHz}$




DLR

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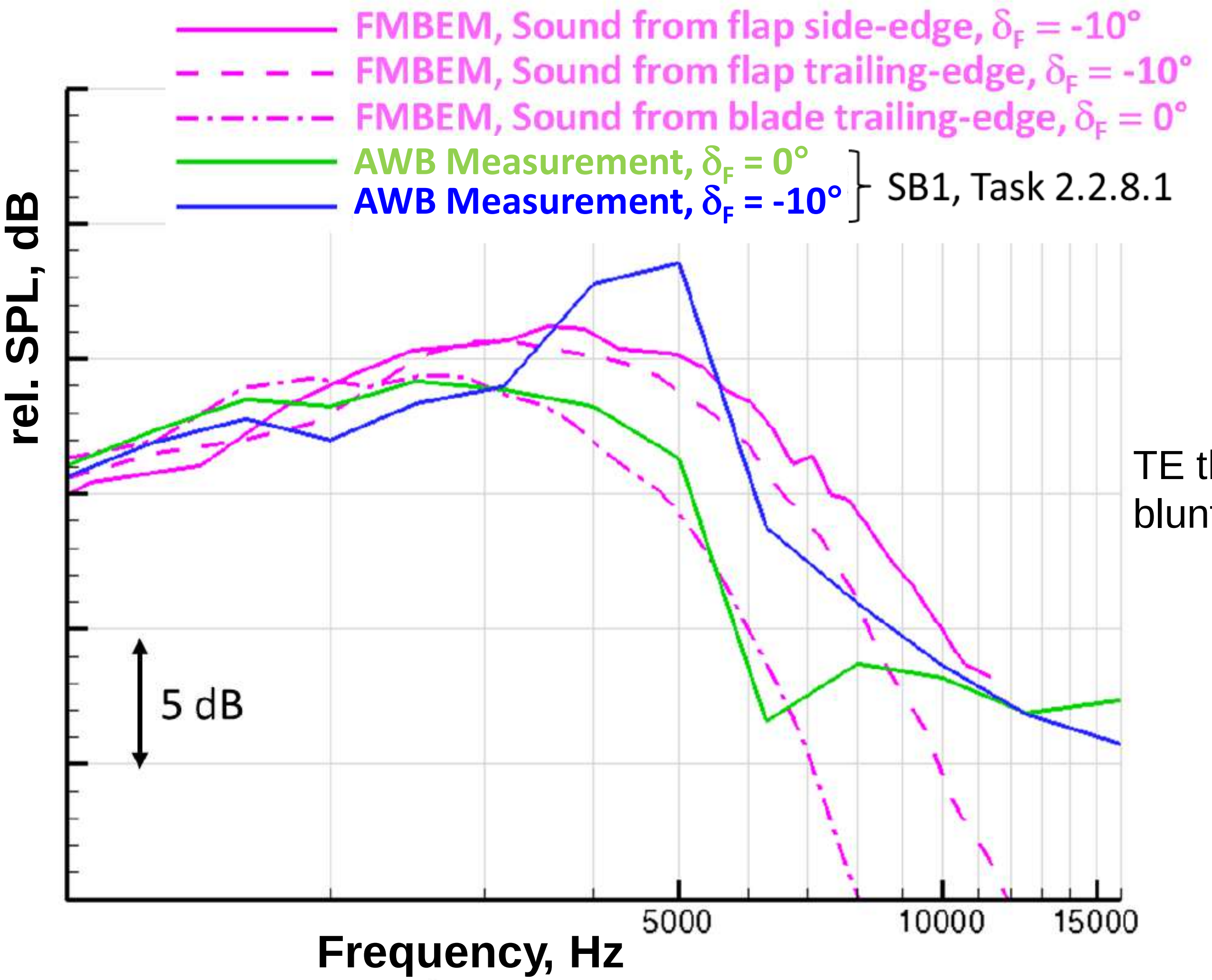
aufgrund eines Beschlusses des Deutschen Bundestages

# 3D problem 2: flap side-edge project SmartBlades 2.0: source ranking

Preliminary results

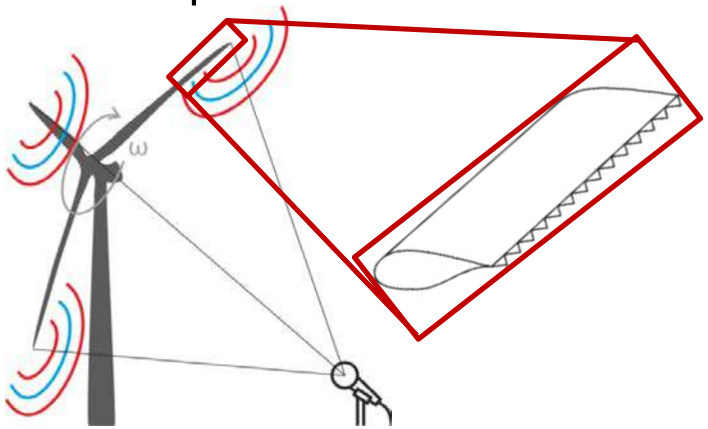



TE thickness: 2 mm
blunt TE vortex-shedding noise?

DLR

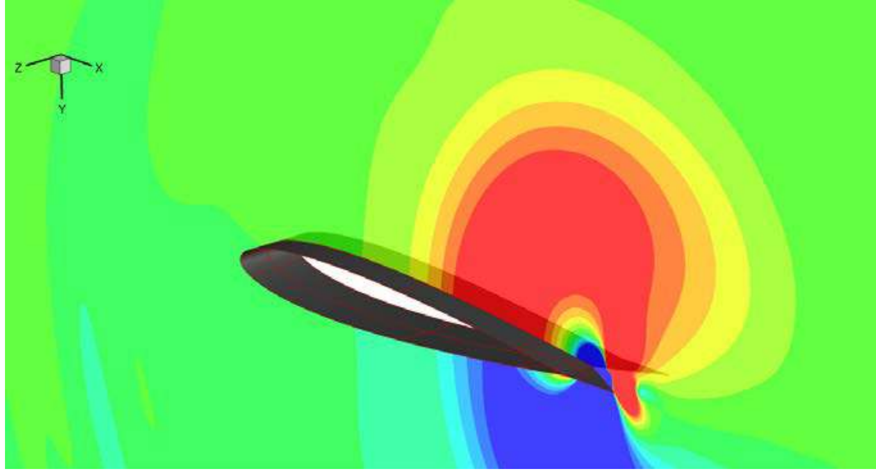
# Future topics | near- to mid term

- Verification/validation of 2D-based simulation of overall WT noise within IEA Wind TCP Task 39
- Simulation of noise reduction effects by 3D noise reduction technos; i.e. further development and validation of the presented initiated 3D CAA simulation capabilities with applications to
  - blade tips
  - TE serrations & derivatives
  - porous materials

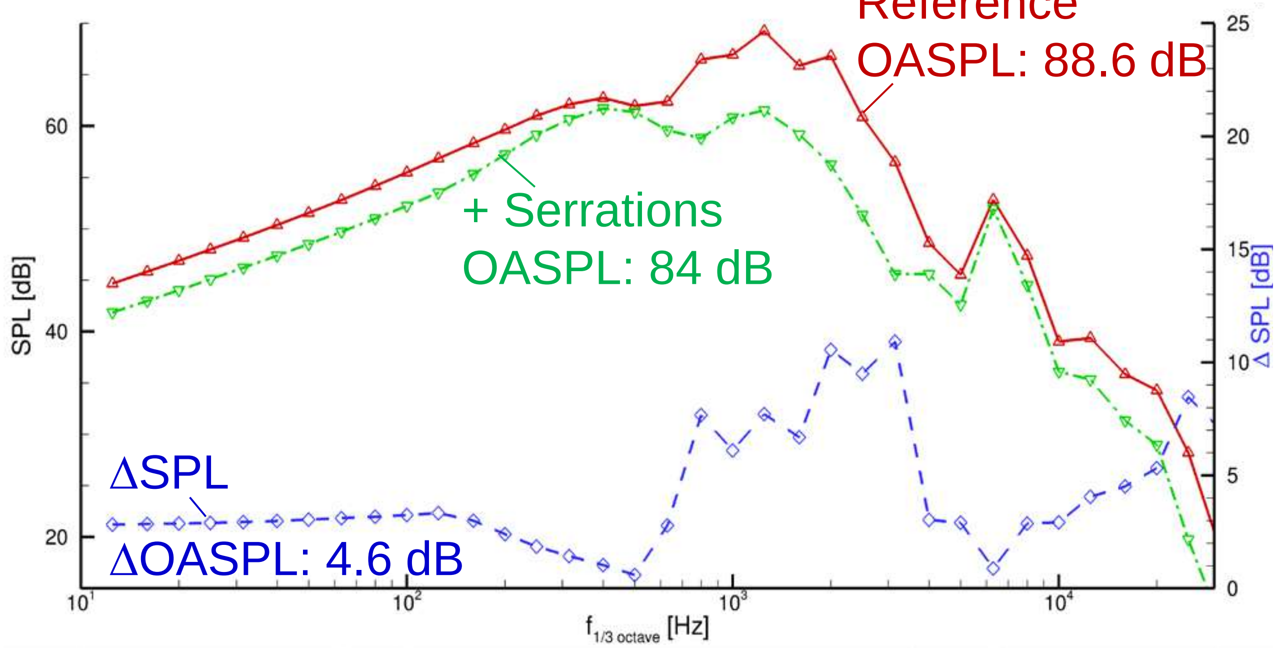


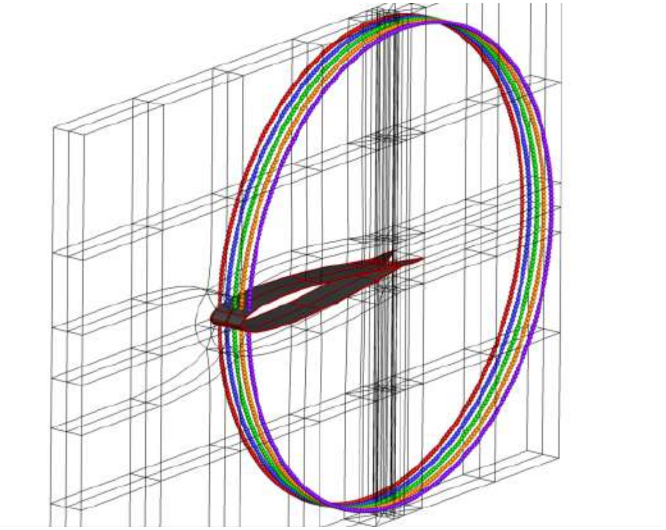
- Provide acoustic design support for such arbitrary geometries
- Simulation of blunt TE vortex shedding noise (flatback profiles) / AFC self noise

# Future topics | near- to mid term



- Supportive activity to IEA Wind TCP Task 39 “Serrations Benchmark”
- First FRPM + PIANO forced eddy simulation results: NACA0012 with serrated TE



Mic. @ 90° below TE

# Future topics | mid- to long term

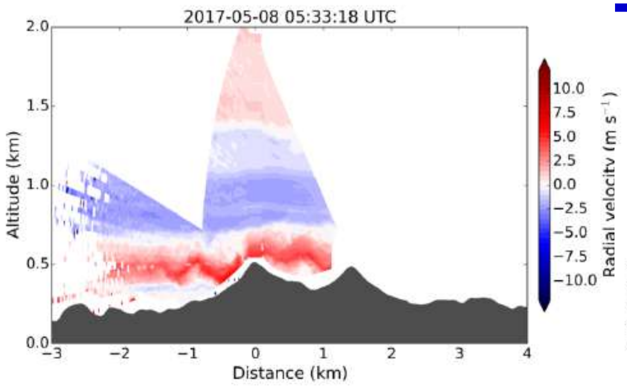
## Potential topic candidates related to IEA Wind TCP tasks 39 / 28 / 31*

***IEA Wind TCP Task 31** „Wakebench – International Wind Farm Flow Modelling and Evaluation Framework“

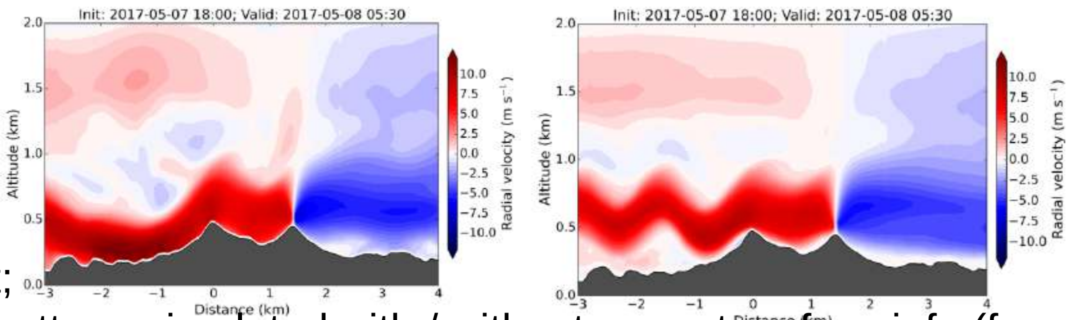
- Link to subjective human perception assessments & diagnostics → Task 28
- Link of noise source prediction tools to advanced noise propagation simulations (DLR Institute of Atmospheric Physics, …) → Task 31
- …


**Source noise research at**

**DLR Institute of Aerodynamics and Flow Technology**




wind velocity: top: measurement;




bottom: simulated with / without correct surface info (forest)

**Noise propagation research at**

**DLR Institute of Atmospheric Physics**

DLR

# IEA WIND TCP Task 39 – Low-Noise Wind Turbine Technologies
# Status on WIND TURBINE NOISE CODE BENCHMARK

Christina Appel, Michaela Herr
Institute of Aerodynamics and Flow Technology, Technical Acoustics
German Aerospace Center (DLR), Braunschweig, Germany

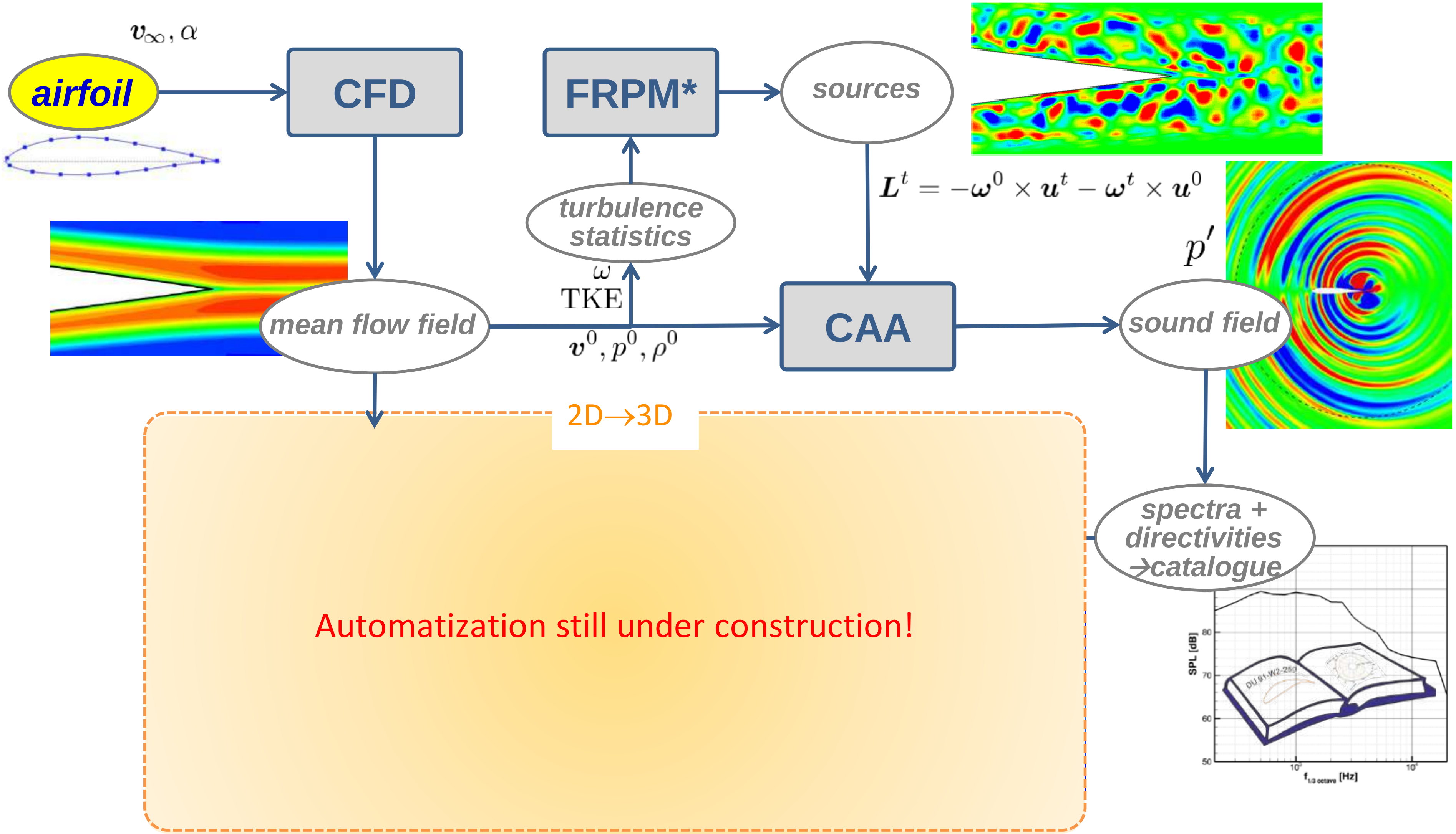
IEA Wind TCP Task 39 - Quiet Wind Turbine Technology
Lisbon, 11 June 2019


DLR iea wind

# Outline

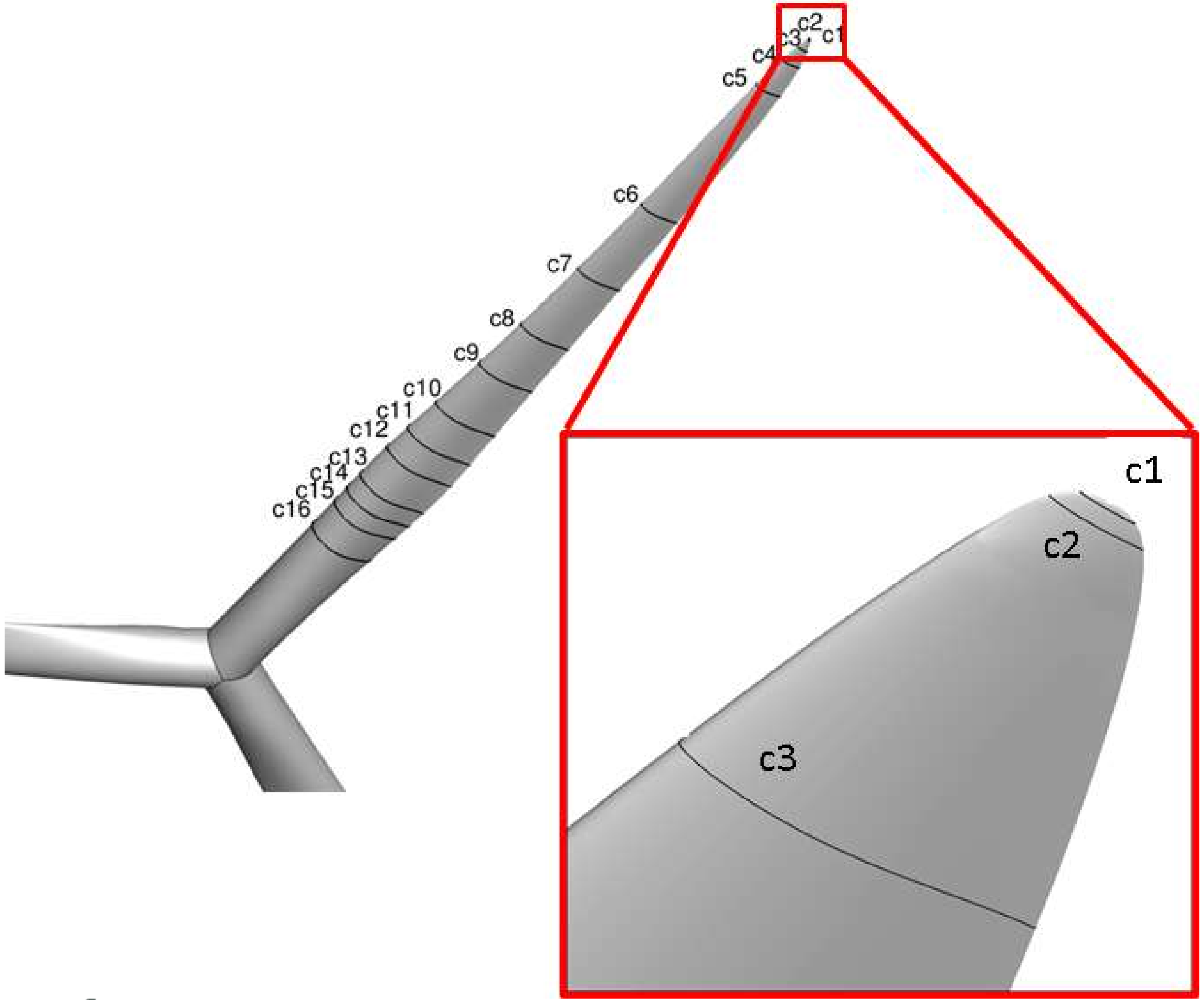
- Hybrid CAA prediction method
- Overview on geometrical input data
- 2D RANS results and comparison to 3D data
    - kinetic energy of turbulence
    - pressure distributions
    - mean velocity
- CAA setup and first 2D results
- Summary

# Numerical approach
# 2D-based non-empirical hybrid CFD/CAA TEN prediction method




*Ewert, Comp. & Fluids (Vol. 37)

# Geometrical input data and benchmark conditions




- Rigid construction
- No tilt, no tower shadow
- Pre-bending is included
- Air density rho = 1.231 kg/m$^3$
- Temperature T = 19°C
- Wind speed: VH = 6.1 m/s
- No wind shear
- Rotor speed: 12.3 rpm (constant)
- Transition: $x_{tr,s}/C=0.065$ - $x_{tr,p}/C=0.20$
- Airfoil positions as given in sketch

# 2D settings according to 3D computation

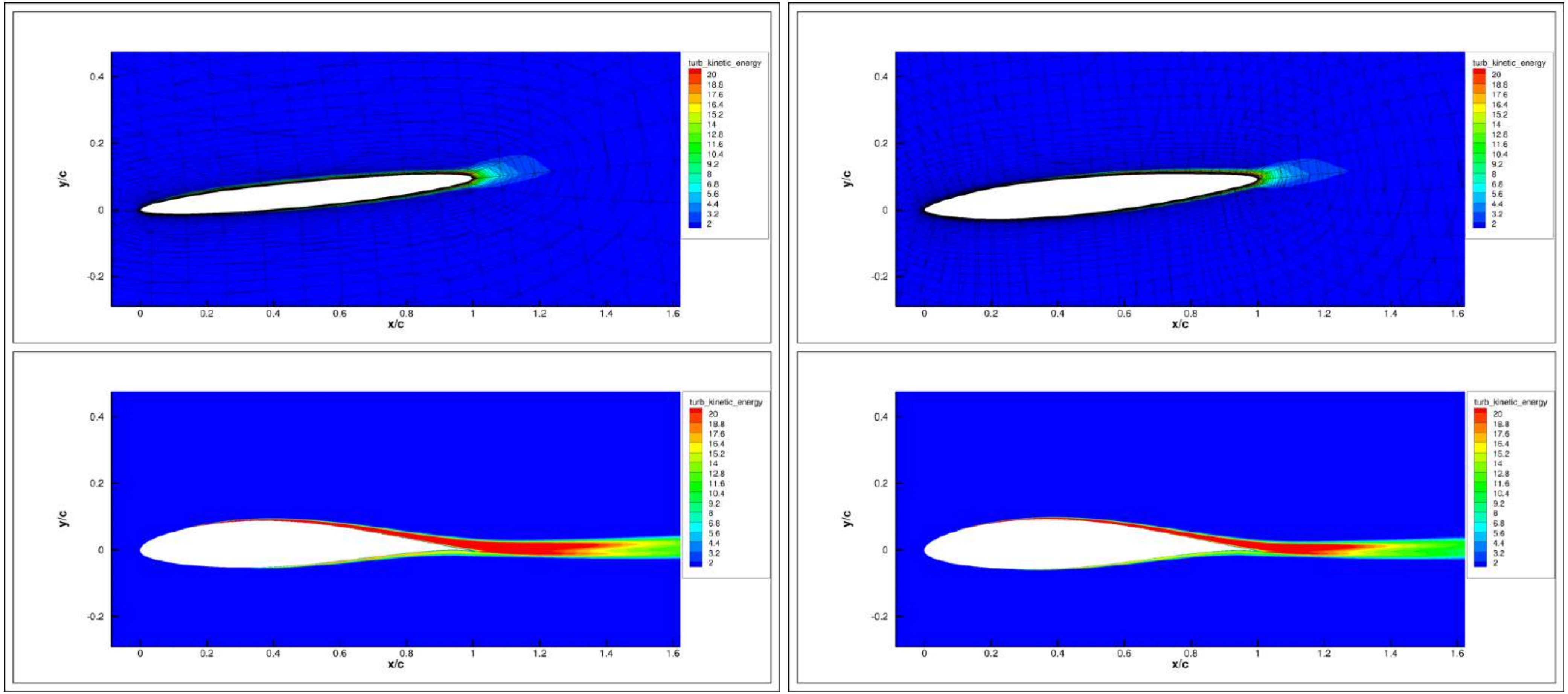
| Slice | Airfoil | AoA $_{local}$ | Chord [m] | Mach $_{local}$ | V $_{local}$ [m/s] | Re $_{local}$ |
|---|---|---|---|---|---|---|
| c1 | NACA-63414 | 4,3° | 0,07 | 0,157 | 53,09 | 247753 |
| c2 | NACA-63415 | 4,3° | 0,146 | 0,155 | 52,13 | 507398 |
| c3 | NACA-63416 | 4,3° | 0,546 | 0,150 | 50,46 | 1836744 |
| c4 | NACA-63417 | 4,3° | 0,847 | 0,146 | 49,15 | 2775336 |
| c5 | NACA-63418 | 4,2° | 1,206 | 0,139 | 46,99 | 3777996 |
| c6 | NACA-63419 | 4,5° | 1,785 | 0,111 | 37,6 | 4474400 |
| c7 | NACA-63420 | 4,5° | 2,053 | 0,096 | 32,45 | 4441323 |
| c8 | NACA-63422 | 4,5° | 2,346 | 0,083 | 27,89 | 4361996 |
| c9 | NACA-63424 | 4,5° | 2,606 | 0,073 | 24,65 | 4282526 |
| c10 | NACA-63427 | 4,3° | 2,889 | 0,063 | 21,3 | 4102380 |
| c11 | NACA-63430 | 4,0° | 3,058 | 0,057 | 19,12 | 3899205 |
| c12 | NACA-63433 | 4,5° | 3,168 | 0,052 | 17,5 | 3696000 |
| c13 | Prof40 | na | 3,141 | 0,045 | 15,32 | 3208008 |
| c14 | Prof45 | na | 3,073 | 0,042 | 14.28 | 2925496 |
| c15 | Prof50 | na | 3,003 | 0,039 | 13,29 | 2660658 |
| c16 | Prof60 | na | 2,874 | 0,035 | 11,69 | 2239804 |

- local AoA estimated via comparison with full 3D rotating RANS data to yield similar $c_p$ distributions
- 3D RANS mesh provided by DTU
- 3D computation by M. Imiela (DLR AS-HEL, IEA Wind TCP Task 29) with DLR TAU code
- fully turbulent flow
- for use as CAA input: transition settings as prescribed
- 2D computations with sharp trailing edges (TE), 3D with blunt TE
- inner airfoils (slice c13-c16) not yet processed

# Turbulent kinetic energy (TKE) distribution slice c1 and c2

3D

2D

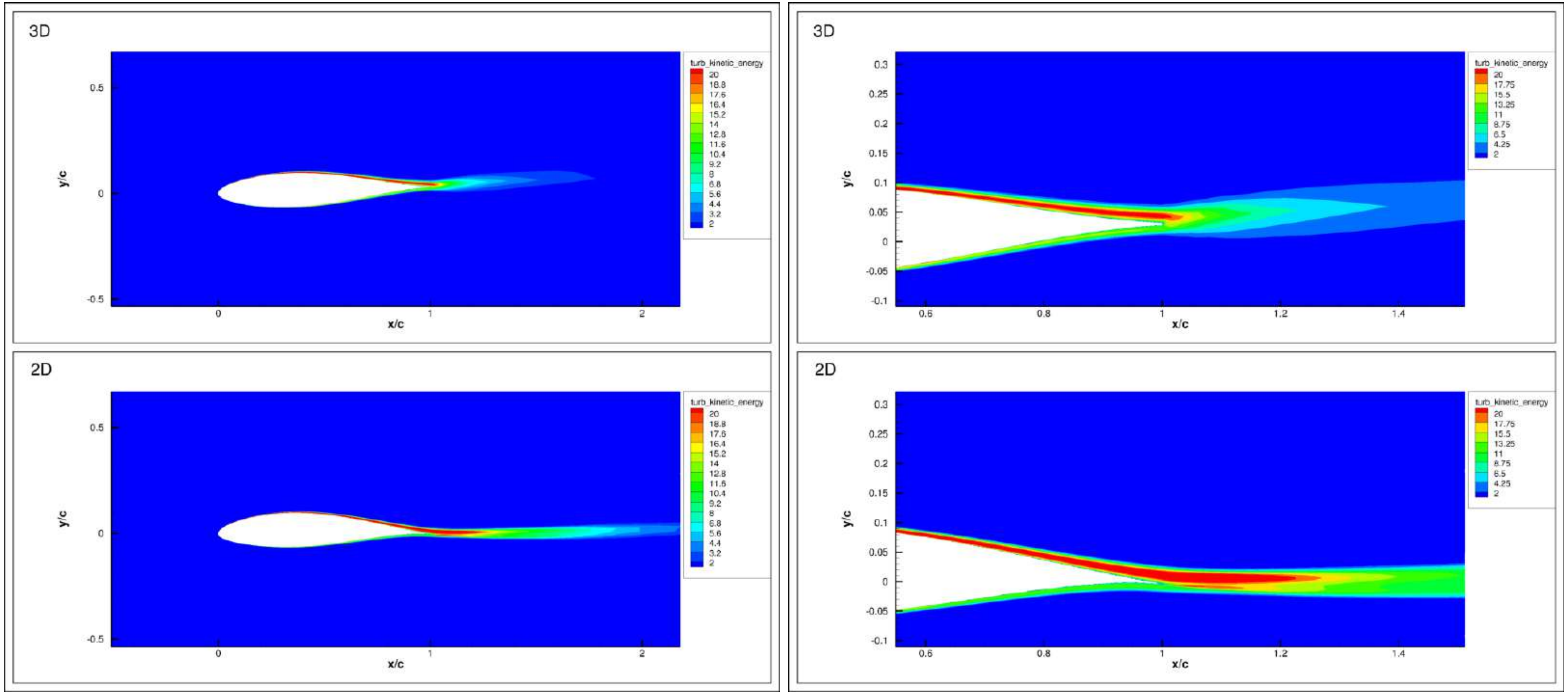



- 3D cap design of the blade obviously does not match with airfoil shape
- Improved 3D CAD data is needed!
- O-grid topology of 3D grid is too coarse to resolve boundary layer at blade tip

# TKE distribution slice c3

3D

2D

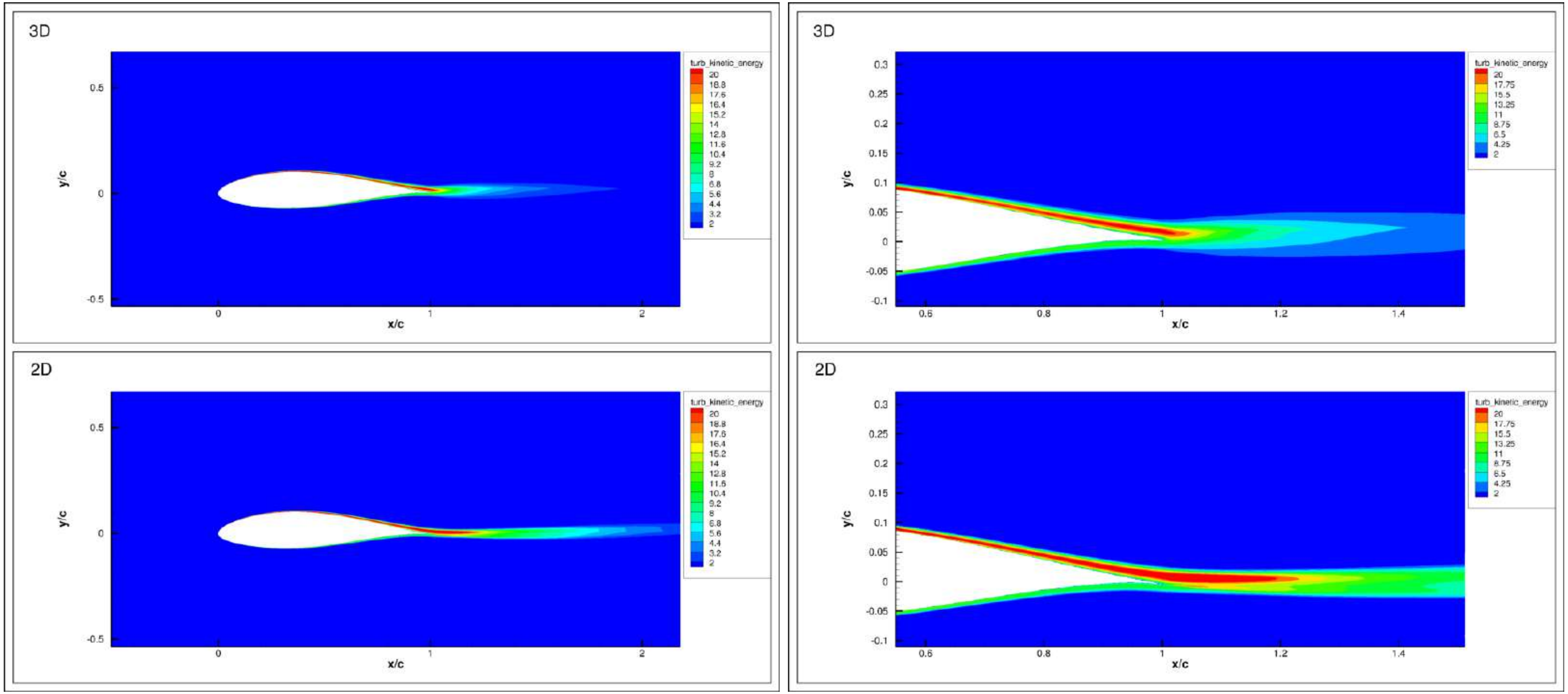



- TKE levels in the BL match
- 2D wake is much finer resolved

# TKE distribution slice c4

3D

2D

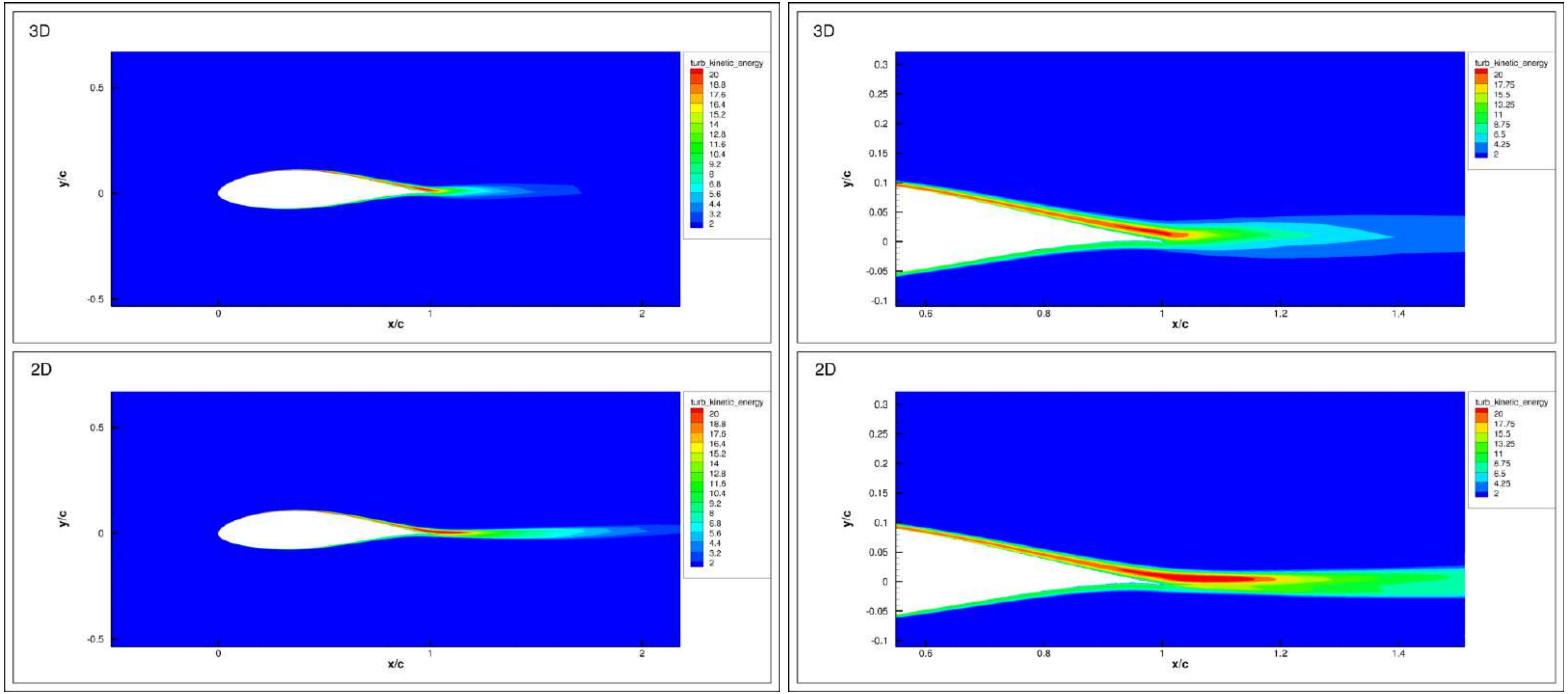



- TKE levels in the BL match
- 2D wake is much finer resolved

# TKE distribution slice c5

3D

2D

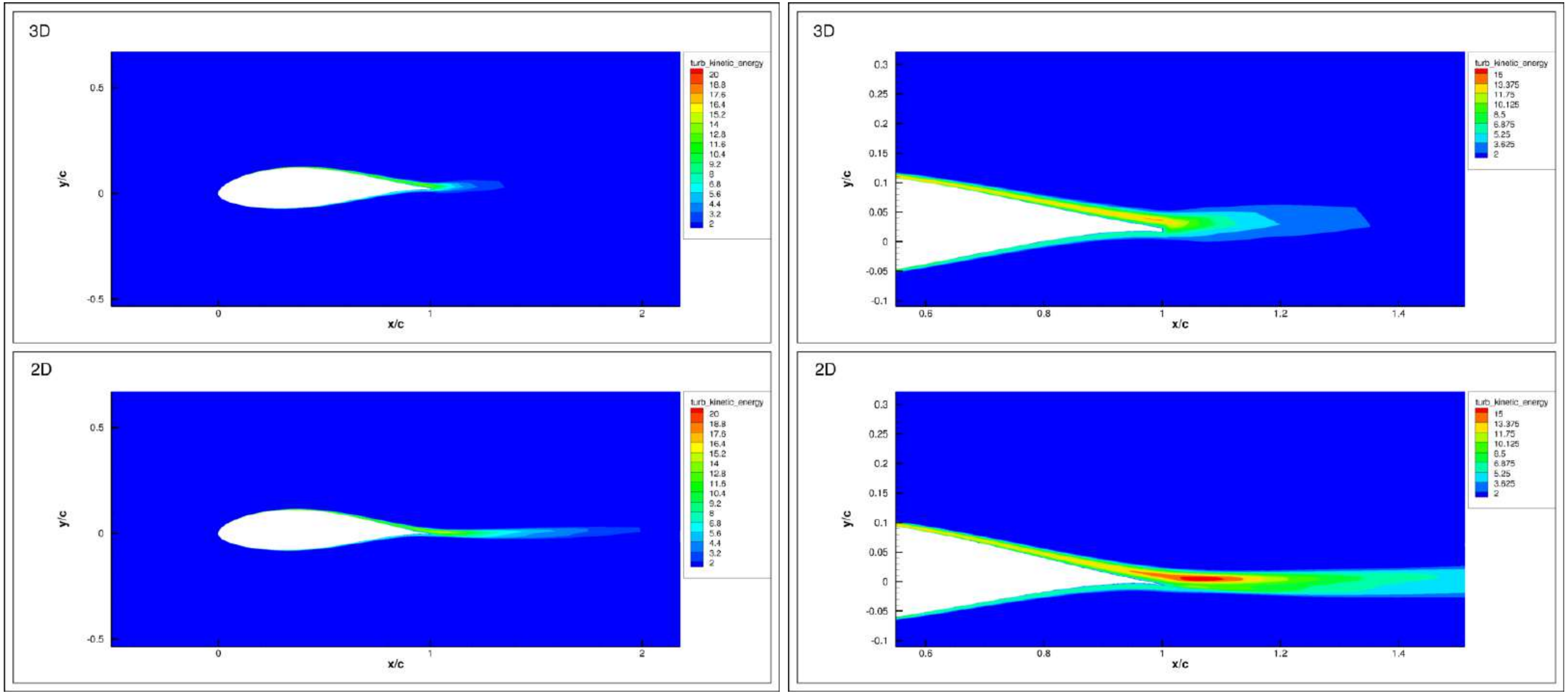



- TKE levels in the BL match
- 2D wake is much finer resolved

# TKE distribution slice c6

3D

2D

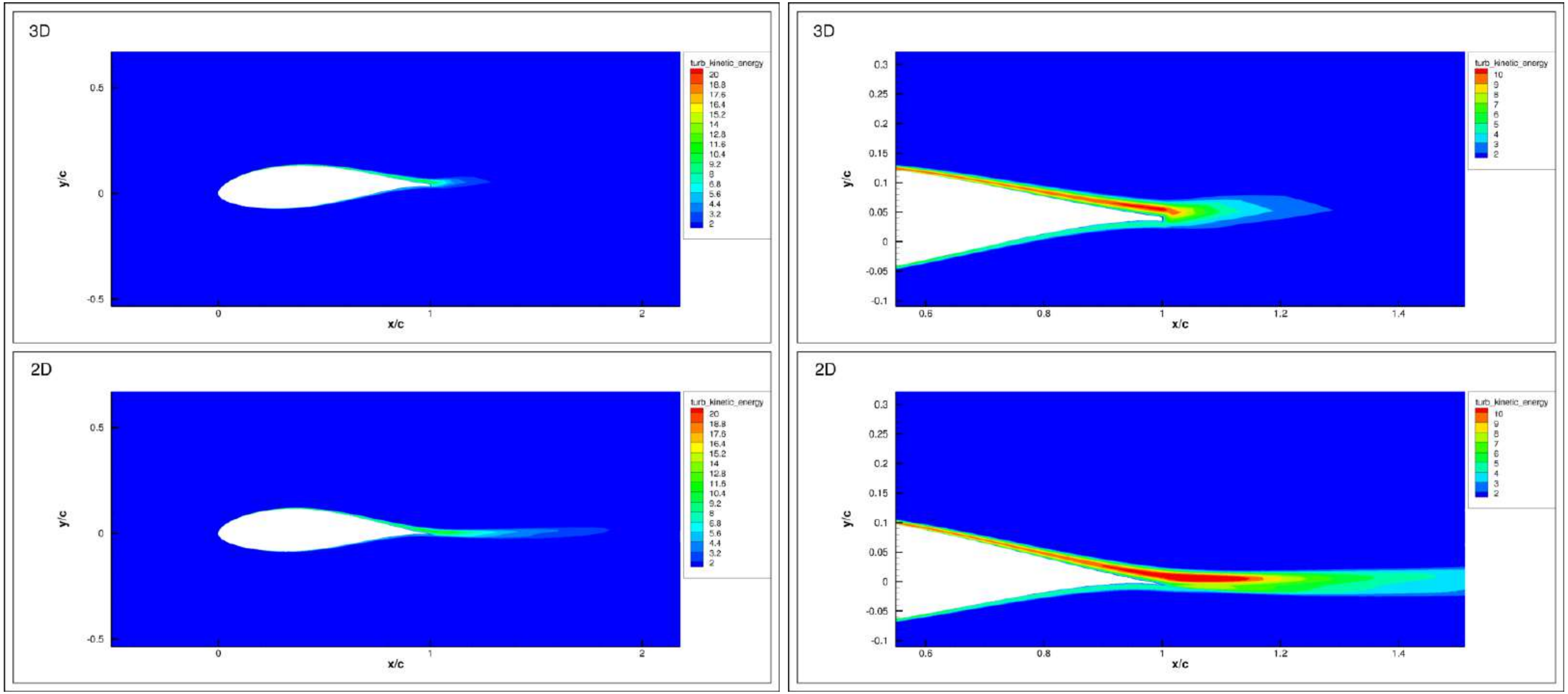



- 2D provides higher kinetic energy of turbulence, maxima in BL roughly match
- 2D wake is much finer resolved

# TKE distribution slice c7

3D

2D

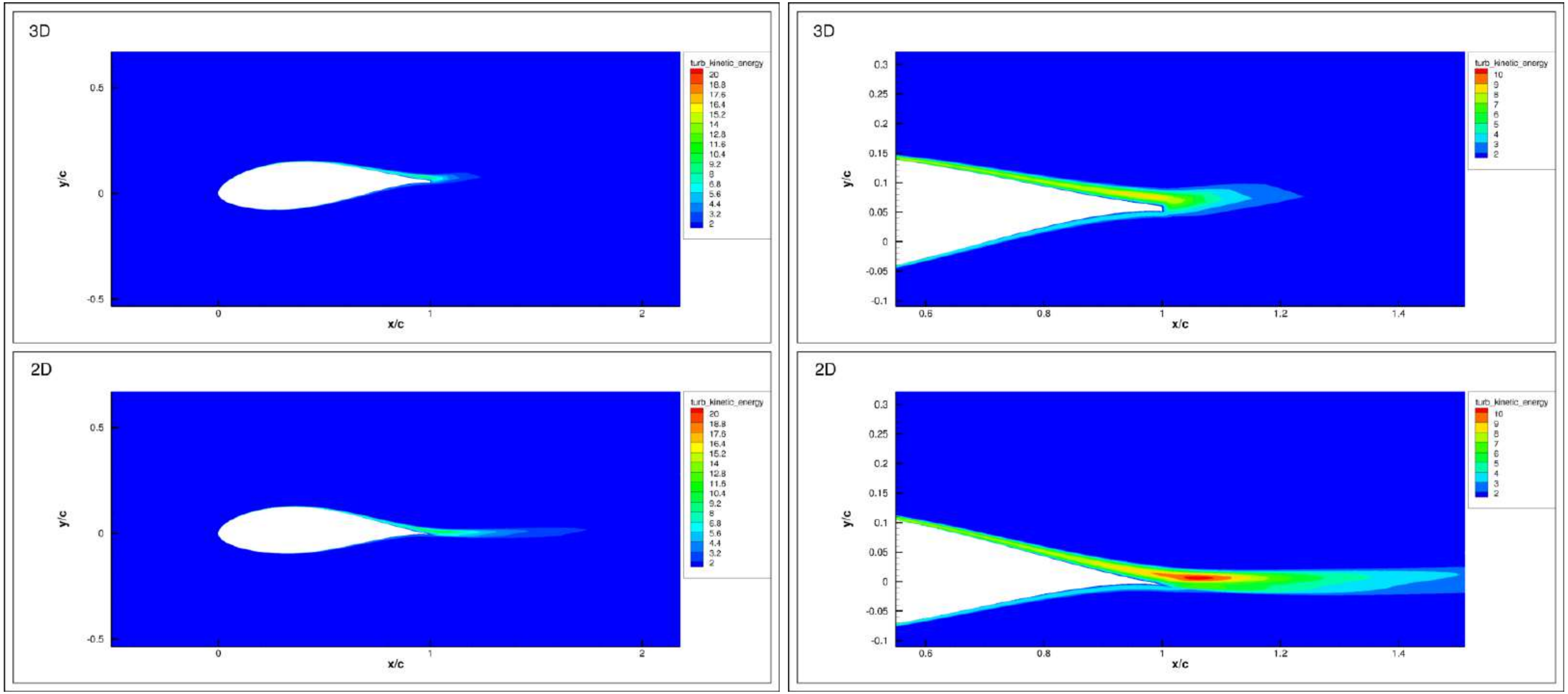



- TKE levels in the BL match
- 2D wake is much finer resolved

# TKE distribution slice c8

3D

2D



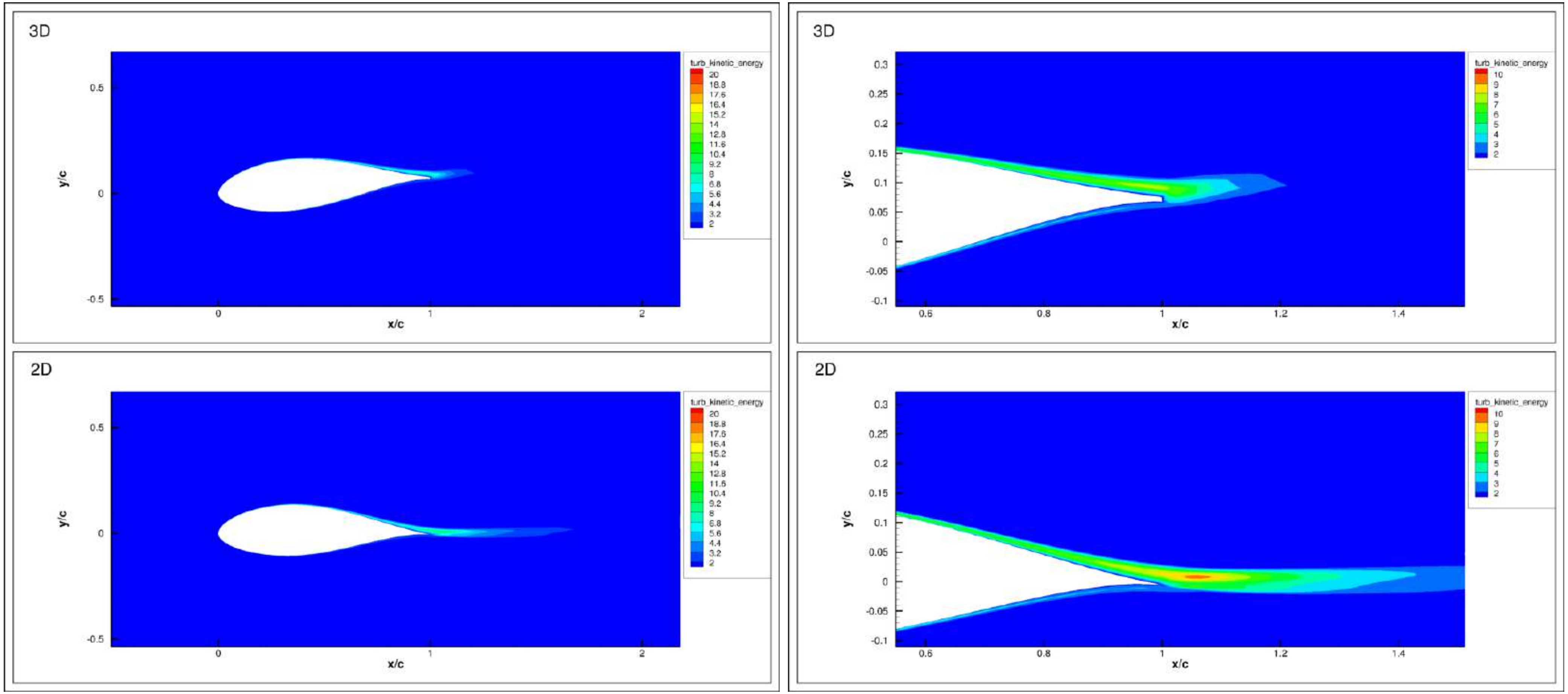

- 2D provides higher kinetic energy of turbulence
- 2D wake is much finer resolved

DLR

# TKE distribution slice c9

3D

2D

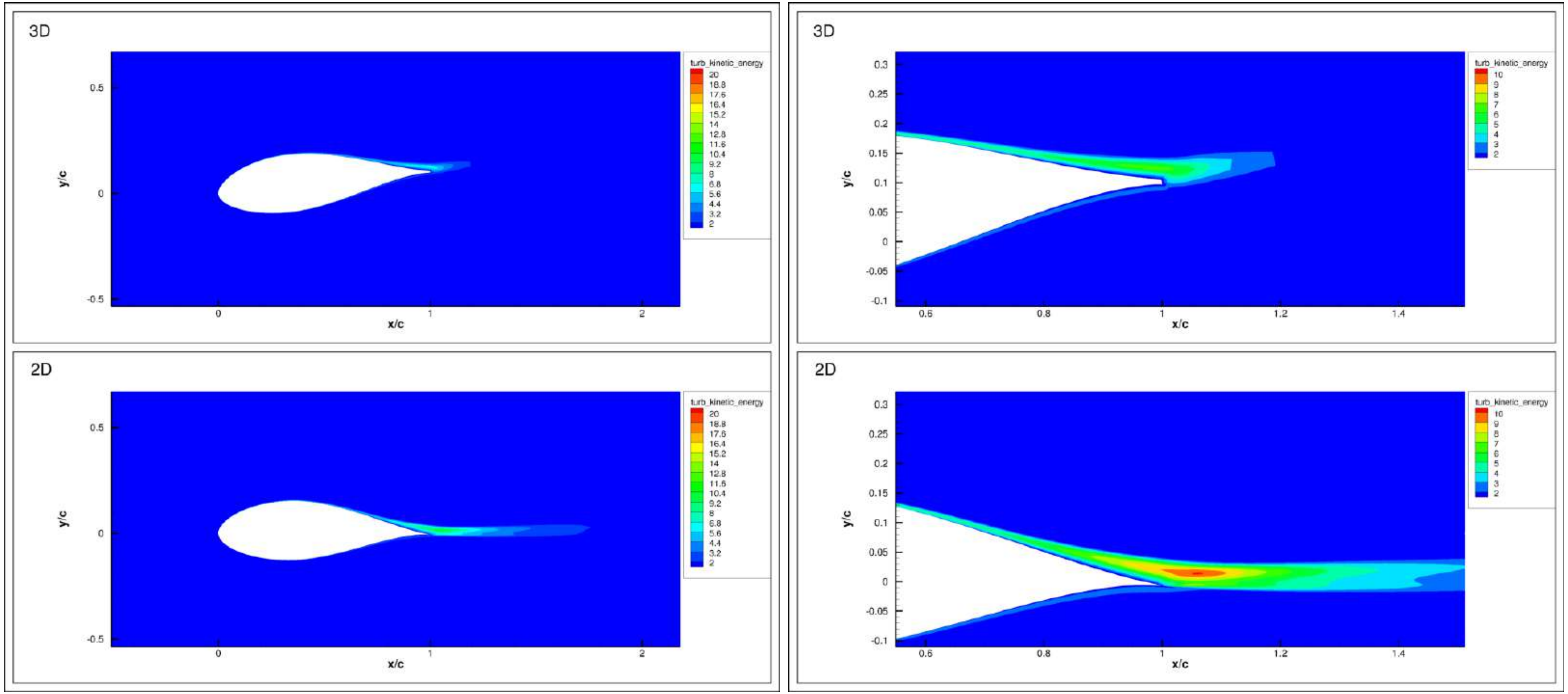



- 2D provides higher kinetic energy of turbulence
- 2D wake is much finer resolved

# TKE distribution slice c10

3D

2D

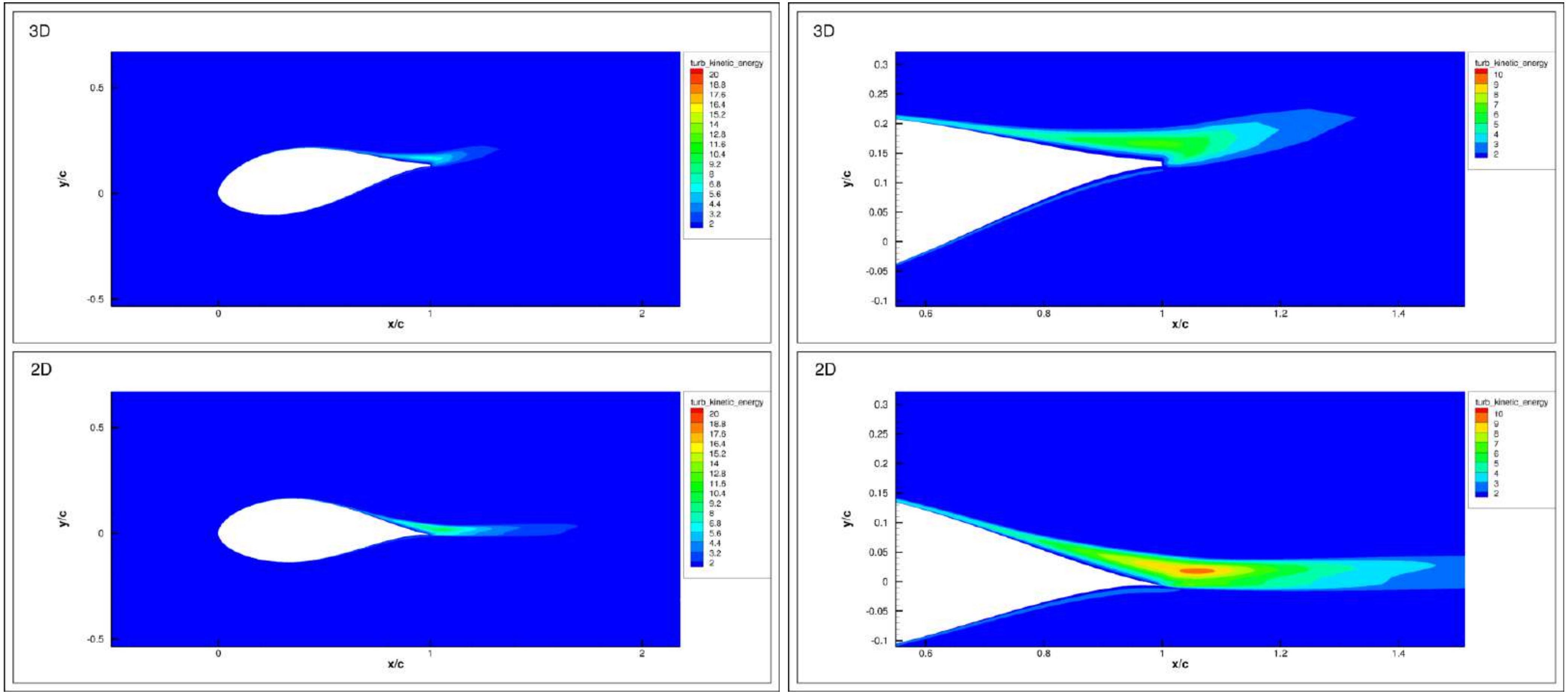



- 2D provides higher kinetic energy of turbulence
- 2D wake is much finer resolved

# TKE distribution slice c11

3D

2D

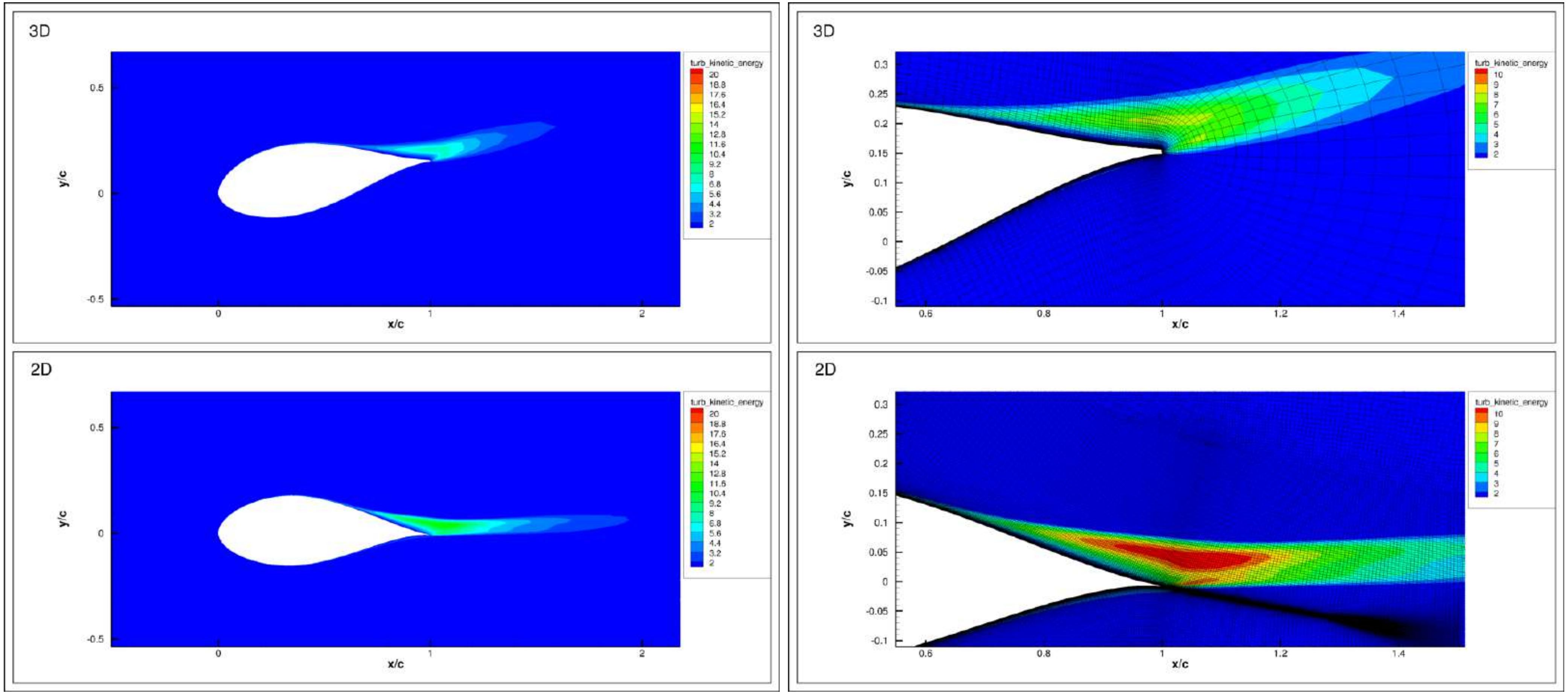



- 2D provides higher kinetic energy of turbulence
- 2D wake is much finer resolved

# TKE distribution slice c12

3D

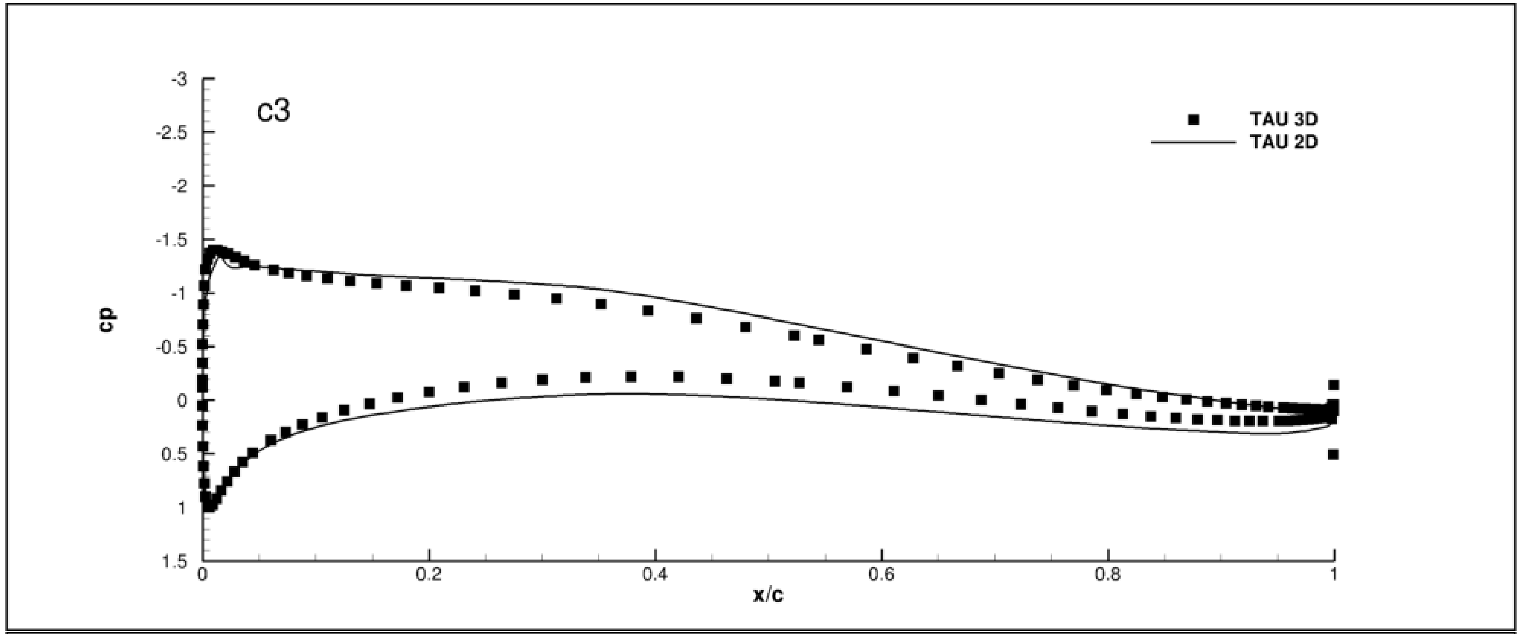
2D

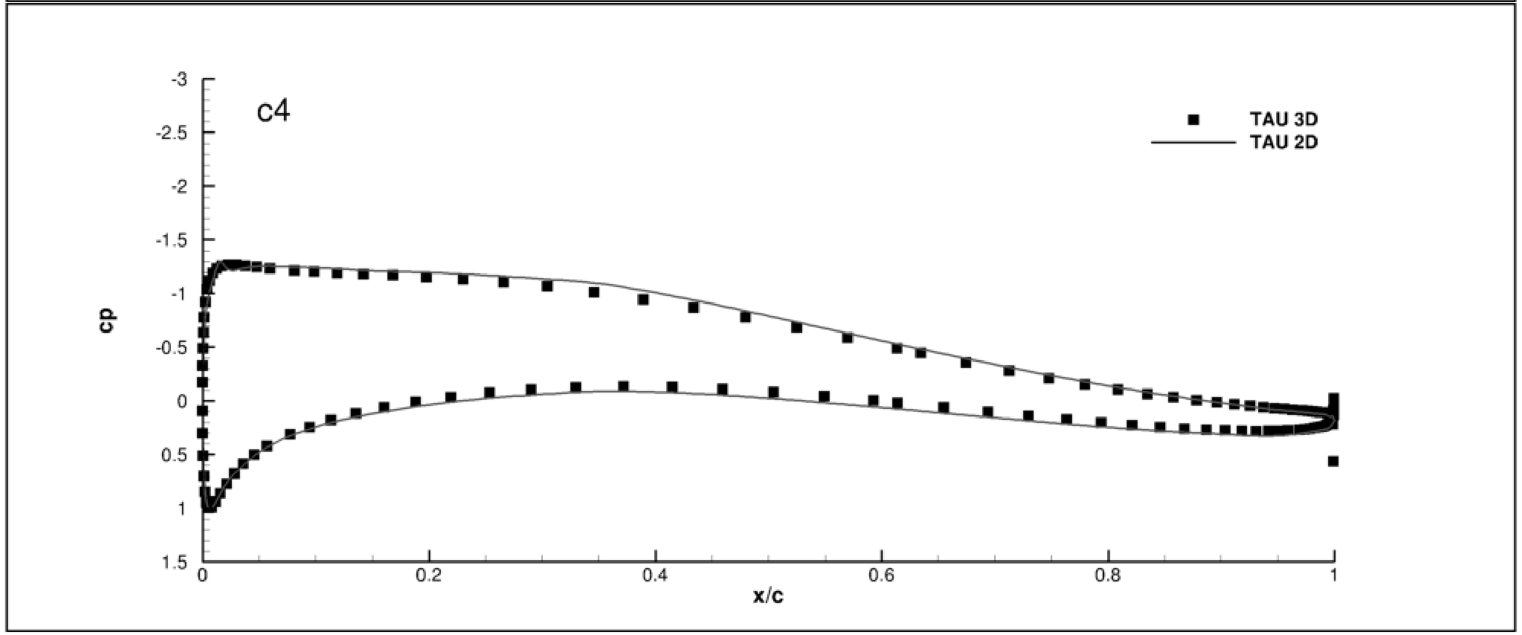



- 2D provides higher kinetic energy of turbulence
- 2D wake and TE are much finer resolved than in 3D

# $C_p$ distribution slice c3 –c4

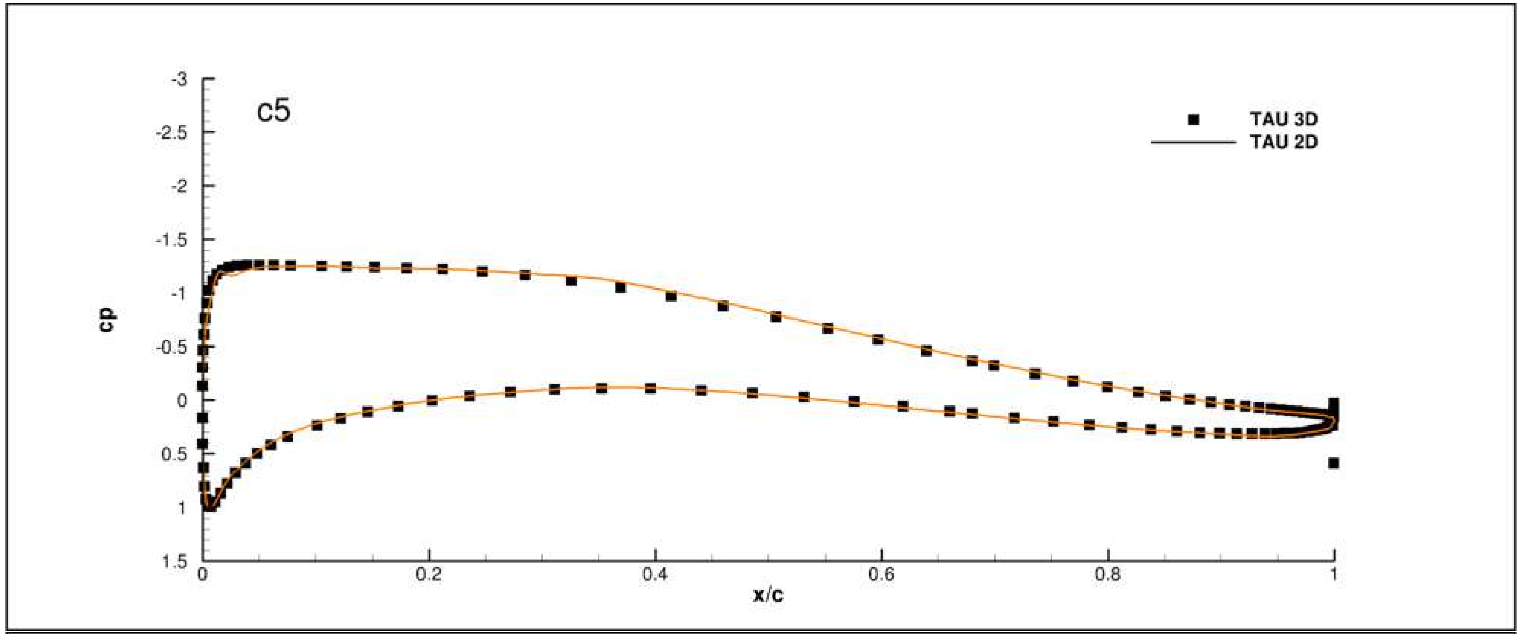
- 2D $c_p$ distributions are fitted with extracted $c_p$ data from 3D computation via adapting the AoA
- since blade element method data are not available, this procedure provides comparable 2D conditions
- for the slices c1 and c2 a comparison is useless due to the diverging airfoil shapes
- in the cases c10- c12 the $c_p$ distributions are not well matching due to the strong bluntness of the 3D TE

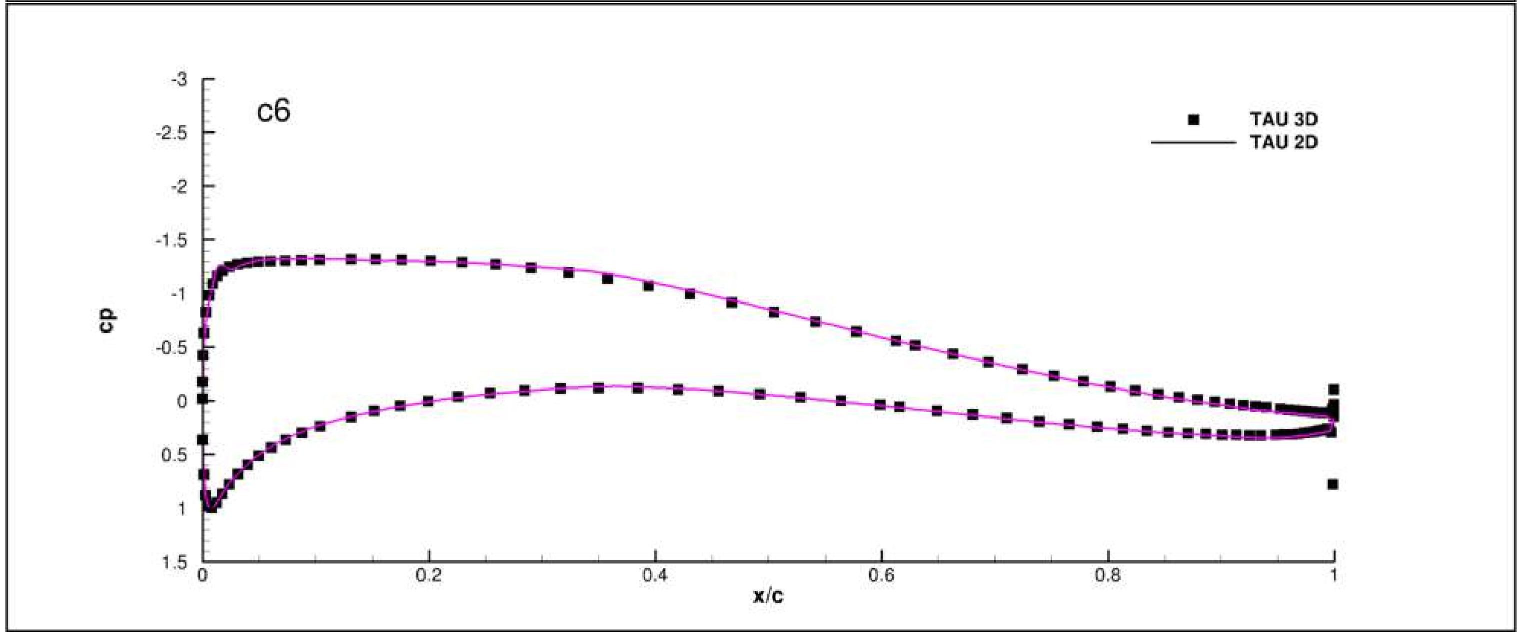


# $C_p$ distribution slice c5 –c6

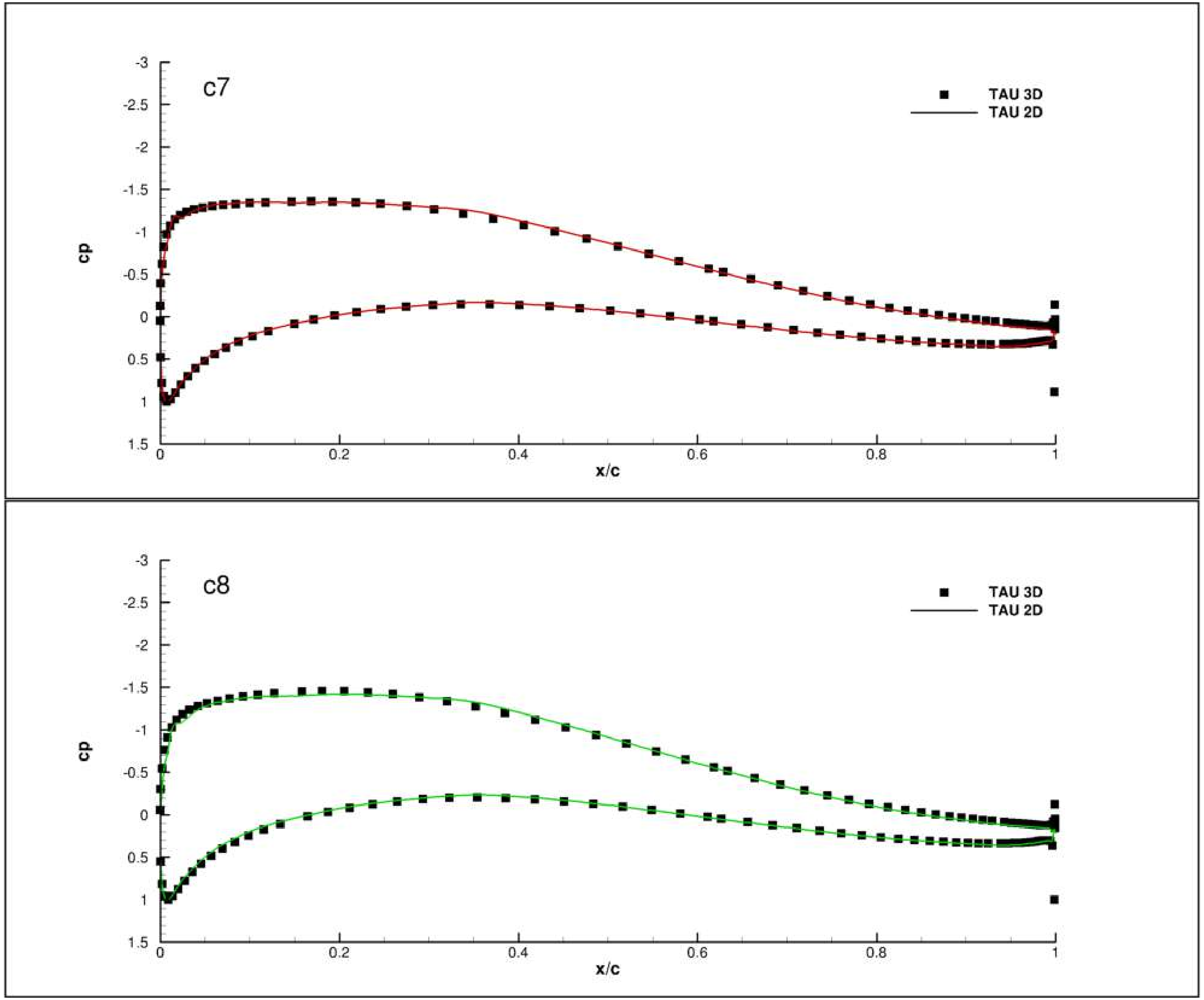
- 2D $c_p$ distributions are fitted with extracted $c_p$ data from 3D computation via adapting the AoA
- since blade element method data are not available, this procedure provides comparable 2D conditions
- for the slices c1 and c2 a comparison is useless due to the diverging airfoil shapes
- in the cases c10- c12 the $c_p$ distributions are not well matching due to the strong bluntness of the 3D TE



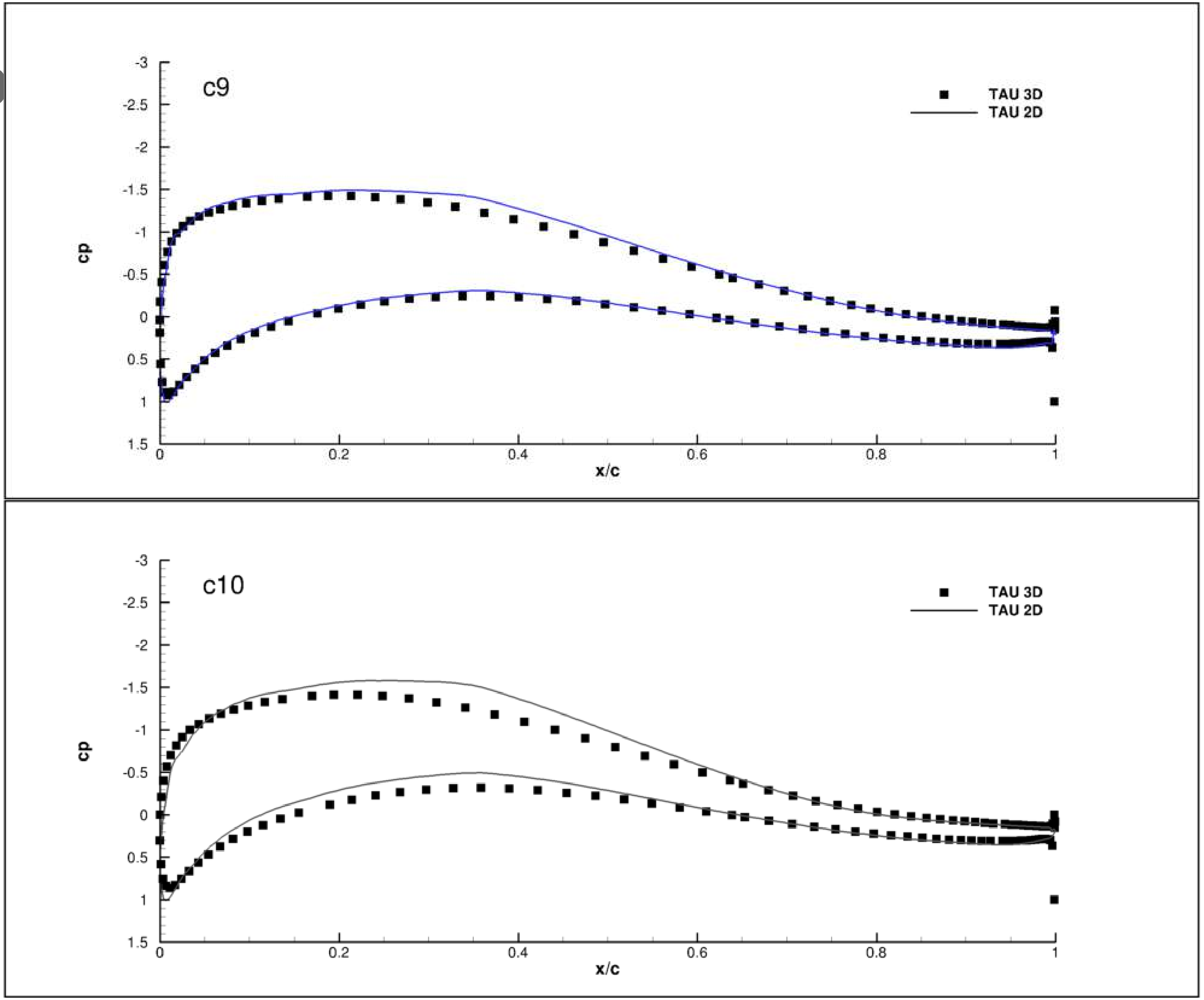
# $C_p$ distribution slice c7 –c8

- 2D $c_p$ distributions are fitted with extracted $c_p$ data from 3D computation via adapting the AoA
- since blade element method data are not available, this procedure provides comparable 2D conditions
- for the slices c1 and c2 a comparison is useless due to the diverging airfoil shapes
- in the cases c10- c12 the $c_p$ distributions are not well matching due to the strong bluntness of the 3D TE



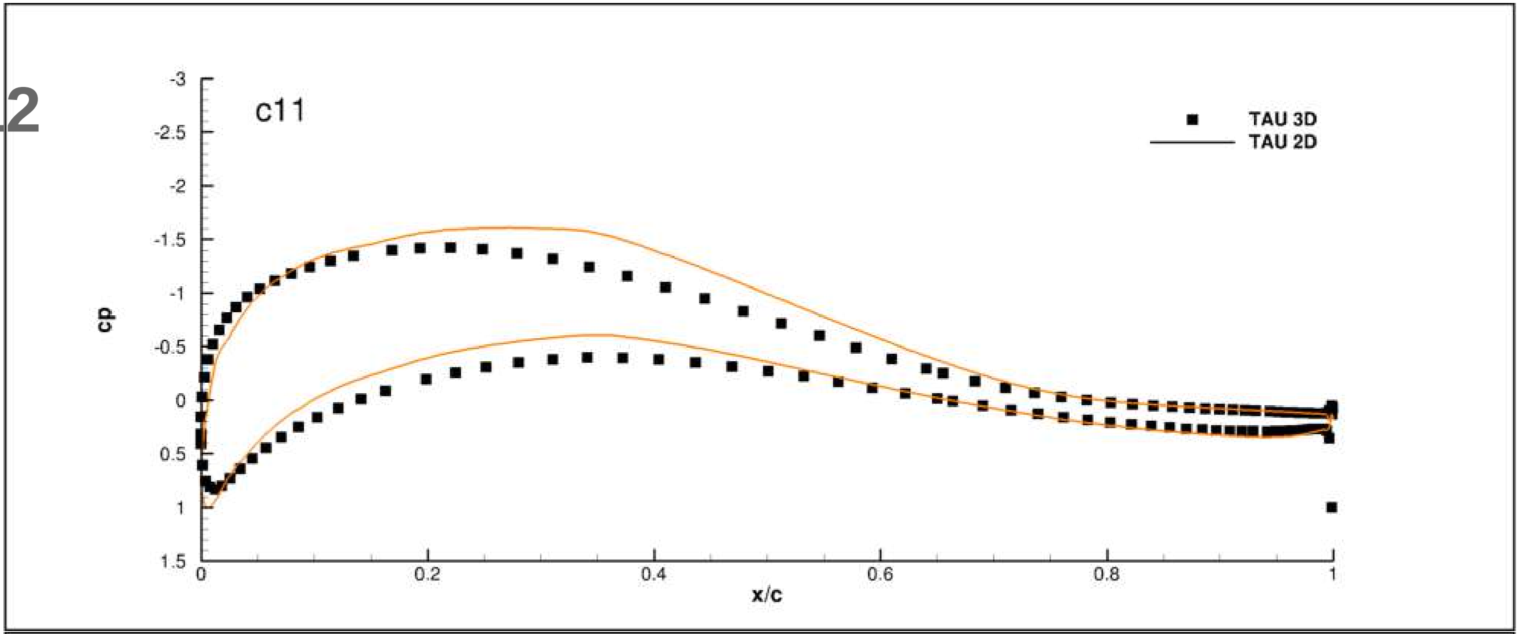
# $C_p$ distribution slice c9 –c10

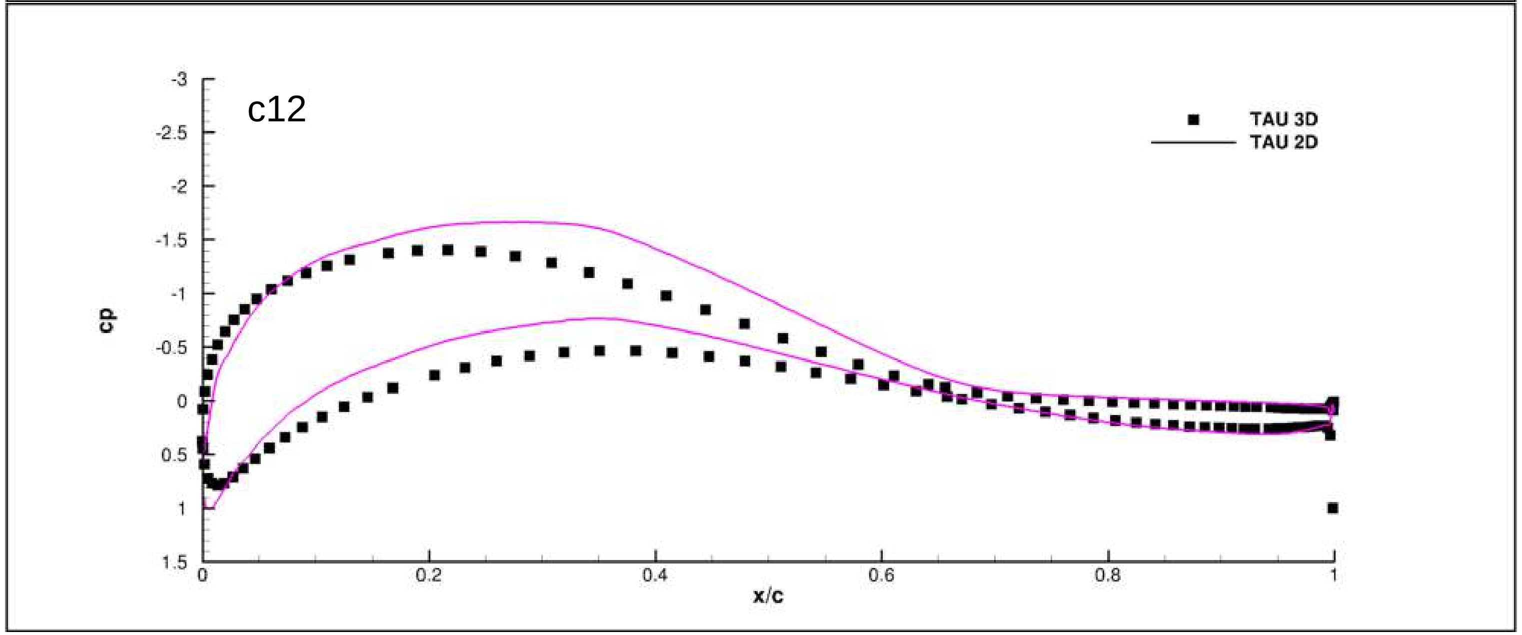
- 2D $c_p$ distributions are fitted with extracted $c_p$ data from 3D computation via adapting the AoA
- since blade element method data are not available, this procedure provides comparable 2D conditions
- for the slices c1 and c2 a comparison is useless due to the diverging airfoil shapes
- in the cases c10- c12 the $c_p$ distributions are not well matching due to the strong bluntness of the 3D TE



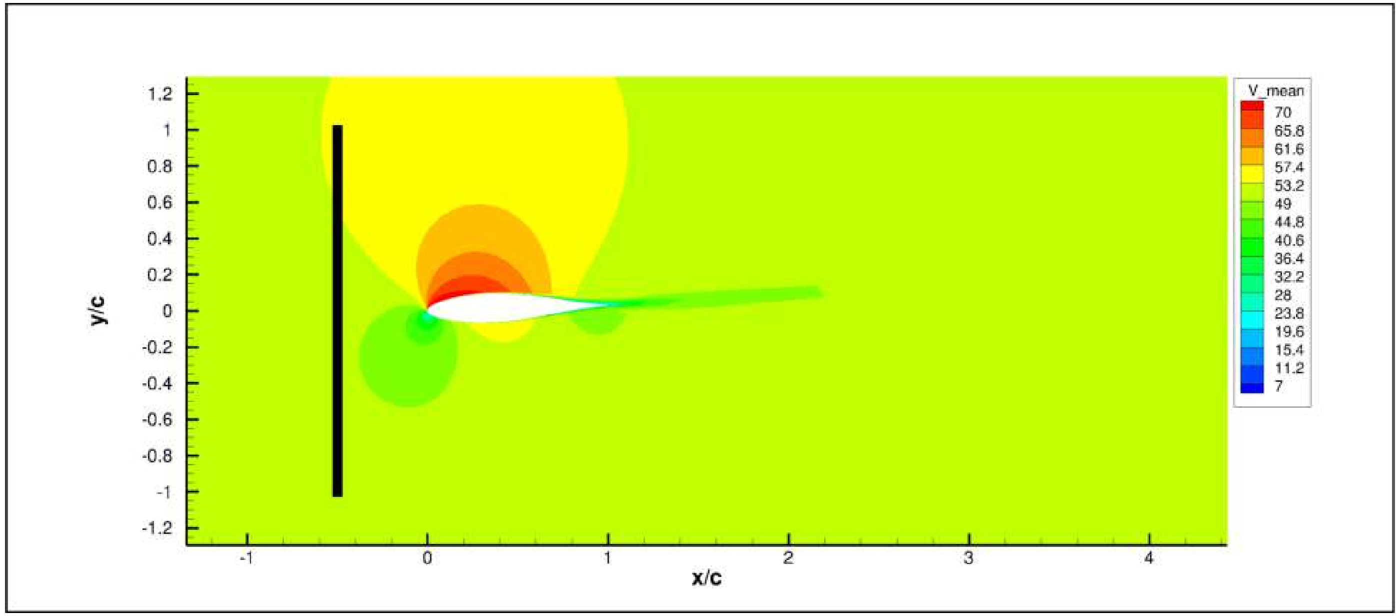
# $C_p$ distribution slice c11 –c12

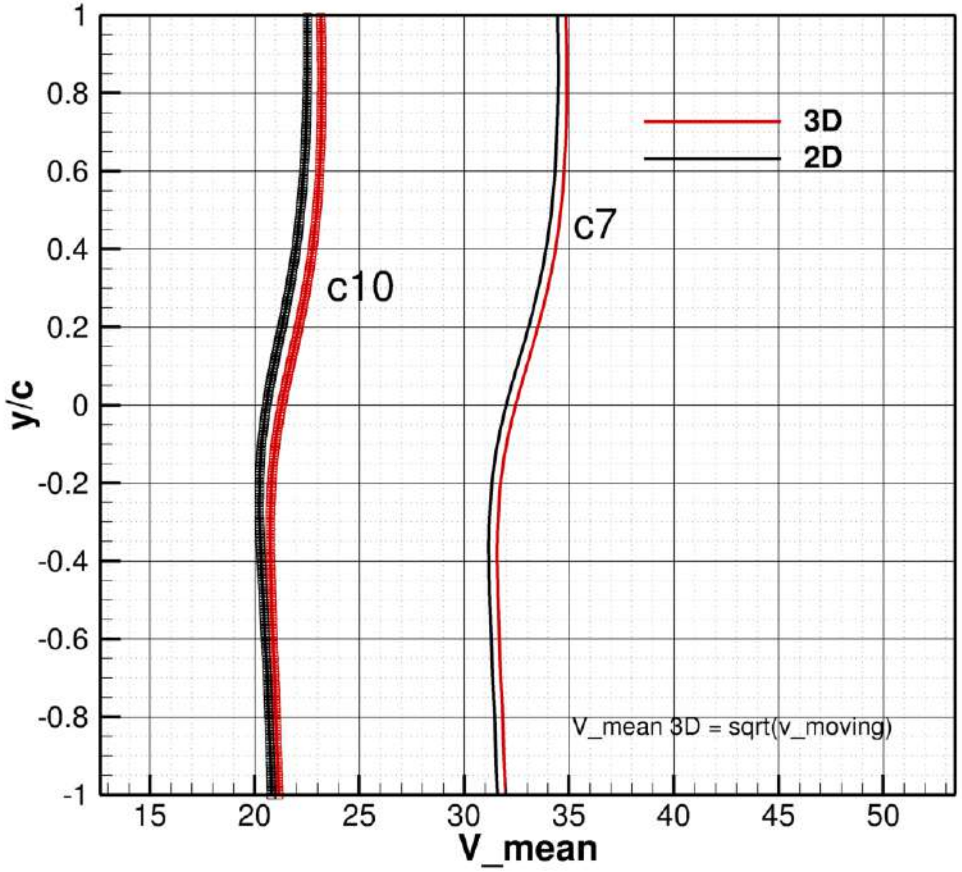
- 2D $c_p$ distributions are fitted with extracted $c_p$ data from 3D computation via adapting the AoA
- since blade element method data are not available, this procedure provides comparable 2D conditions
- for the slices c1 and c2 a comparison is useless due to the diverging airfoil shapes
- in the cases c10- c12 the $c_p$ distributions are not well matching due to the strong bluntness of the 3D TE



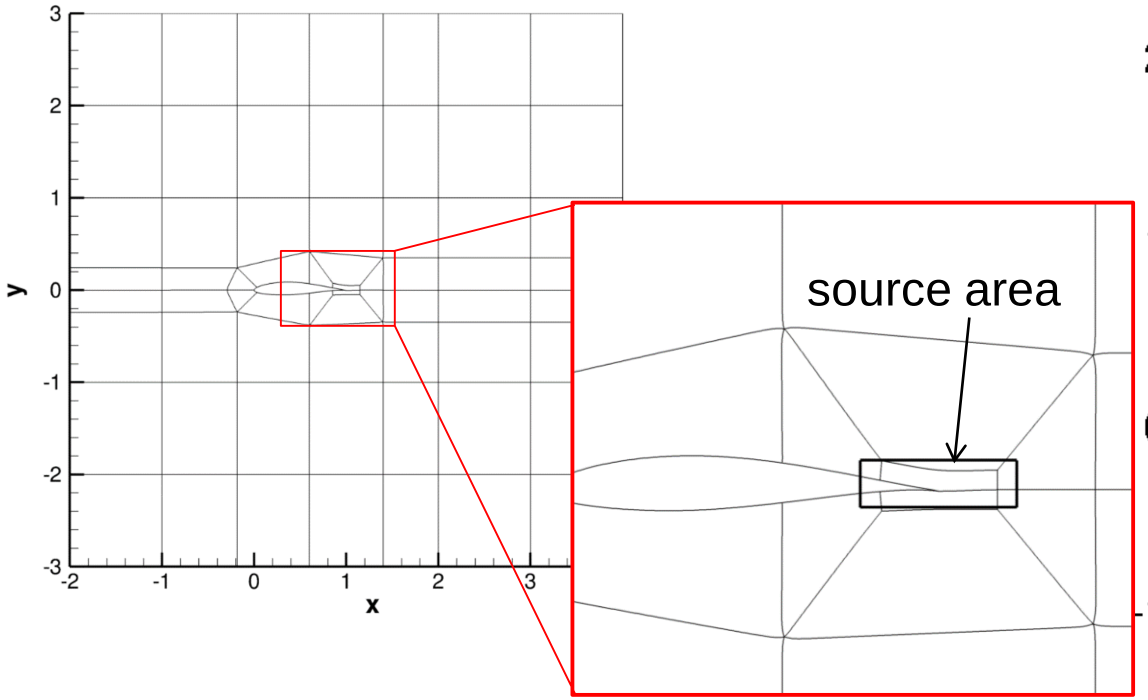
# Mean Velocities

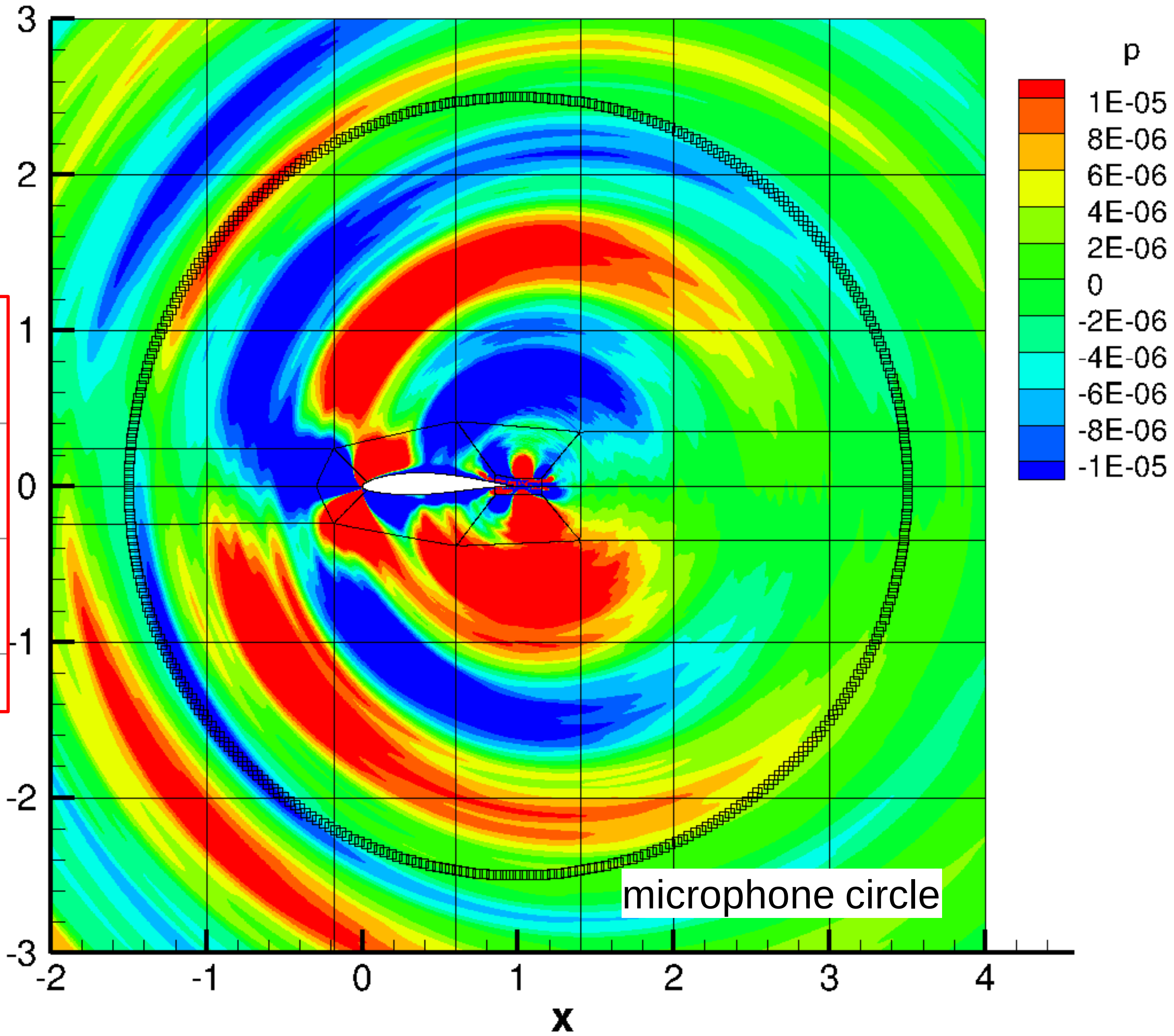



- Mean velocities depend on the wind speed, the rpm of the rotor and the induced velocity
- Wind and rotor speed are considered directly, while the induced speed is estimated by extracting point data in the undisturbed flow field and compare this with the 3D flow field at the same position.

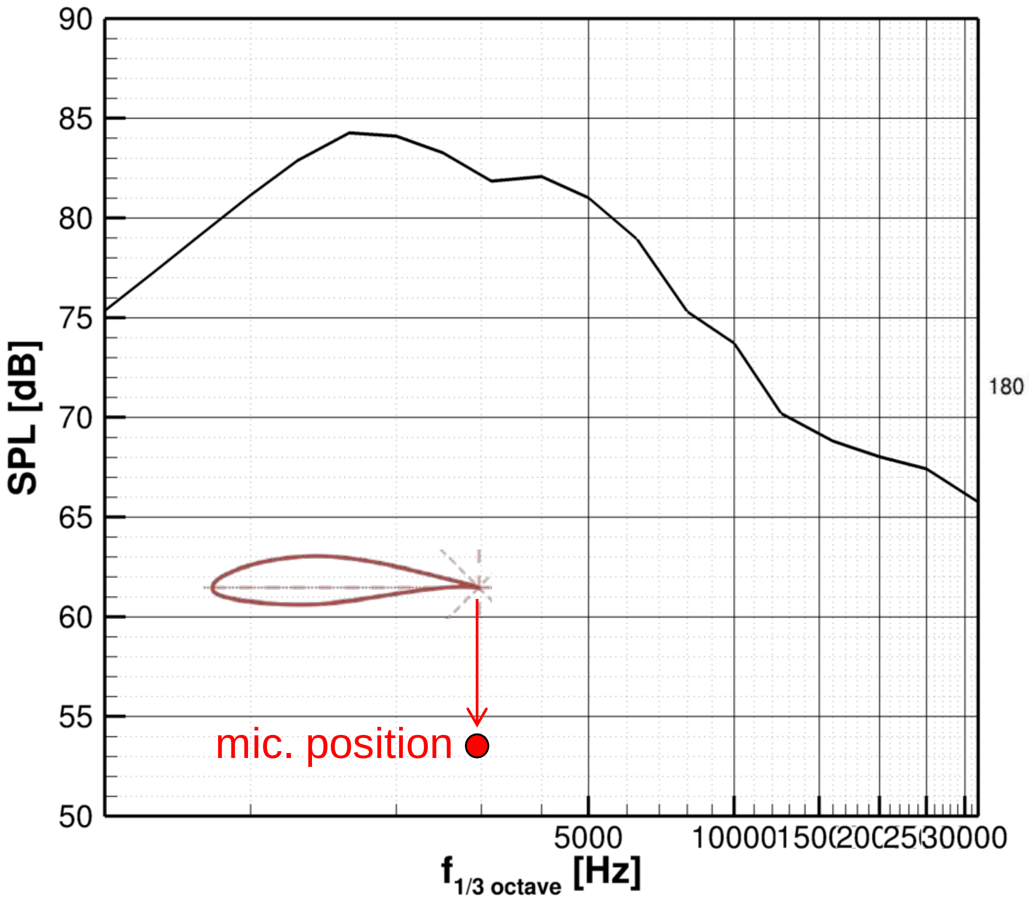
# CAA Simulation setup

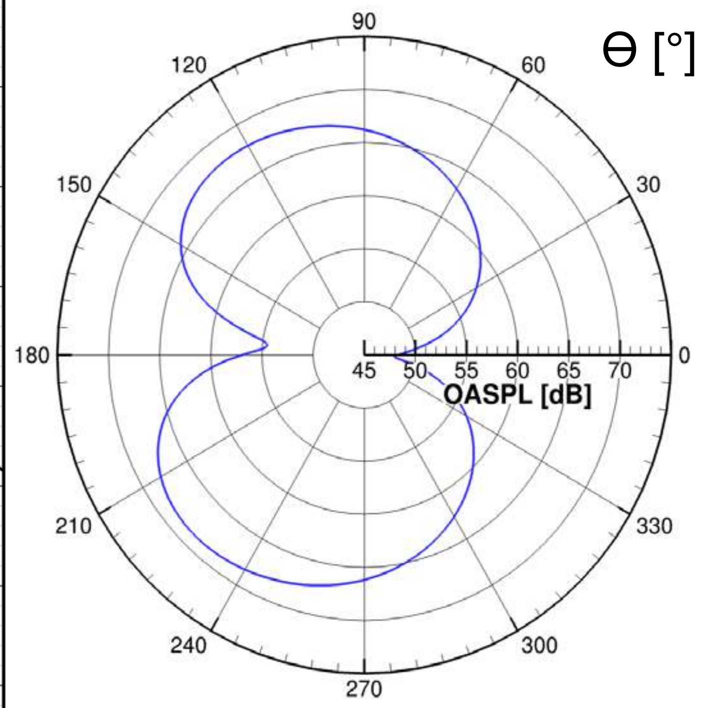


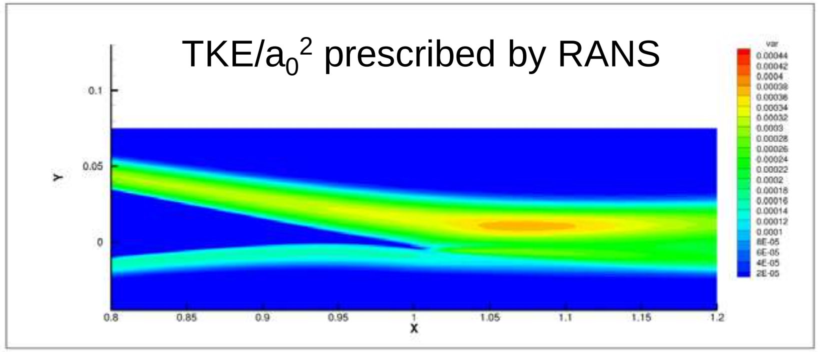



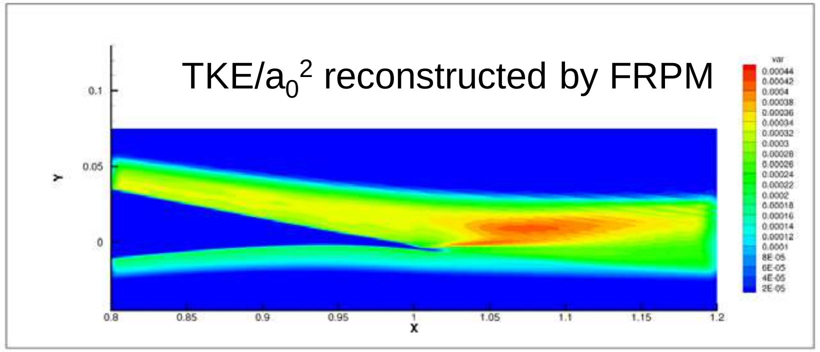

- 2D CAA computation with PIANO/FRPM
- Best practice (BANC workshop)
- dimensionless grid
- frequency resolution according to chord length
- here : c1 → l=0.07m → fmax=80kHz

# CAA results – c1



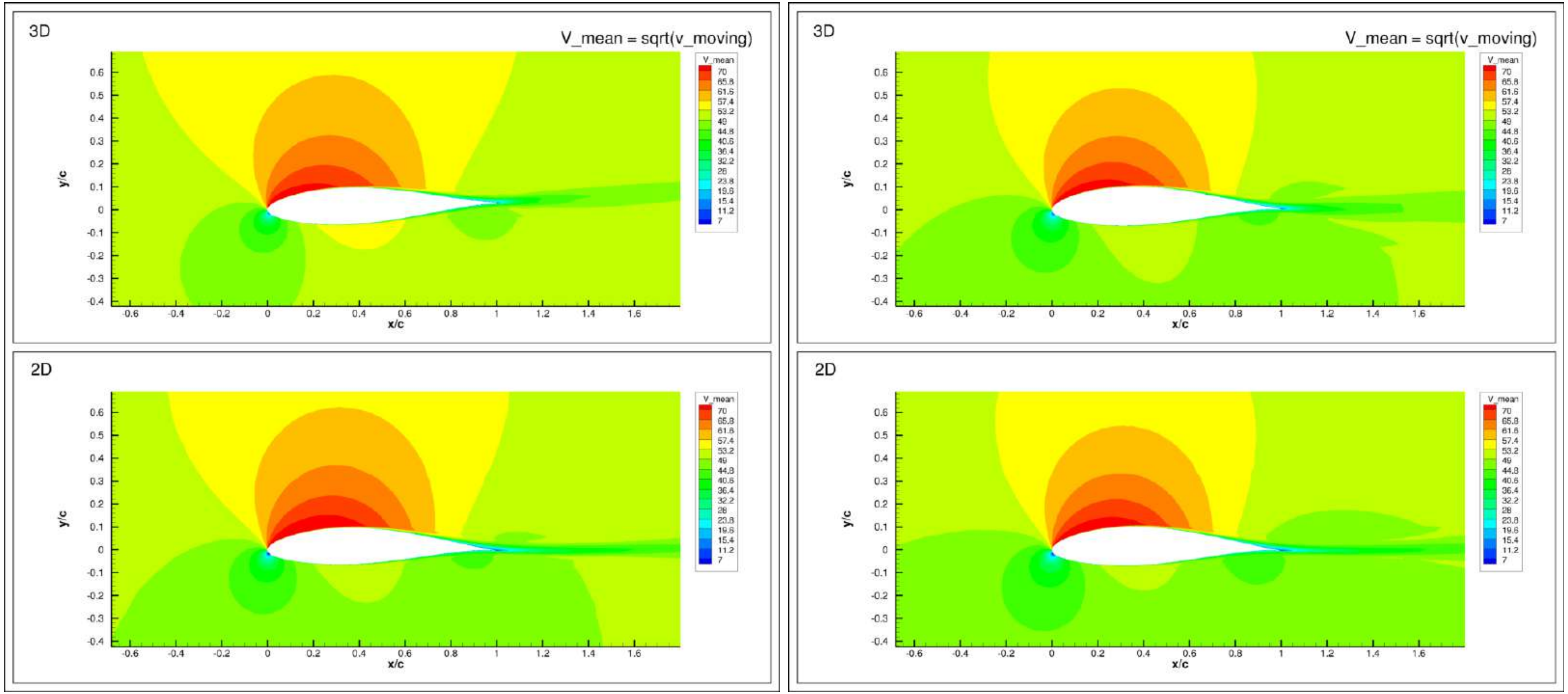
# Summary

- 2D RANS computations have been conducted and compared with 3D results
- 3D RANS data was used to yield the local flow condition for each slice
- TKE, mean velocity and pressure distributions are verified between both computations
- CFD calculations for the 4 inner slice positions are still pending, because the mesh topology has to be adapted
- CAA computation for the most outer slice c1 is already finished
- The CAA simulations for the other slices and the summation over the whole blade are in process
- There is a need to improve the CAD description of the blade tip. In the current state it is not suitable to be used for 3D CFD or CAA simulations

# Appendix: Velocity distributions c3 – c4

3D

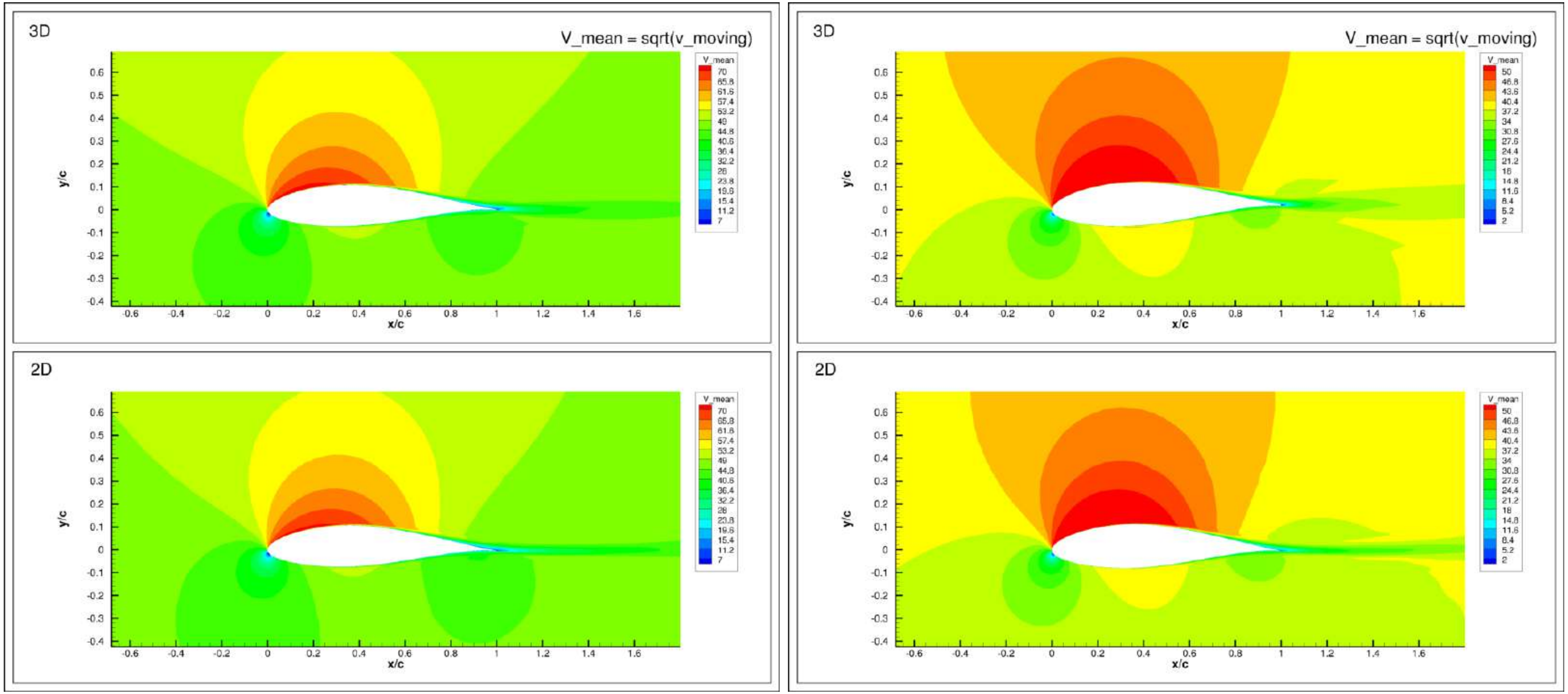
2D



# Appendix: Velocity distributions c5 – c6

3D

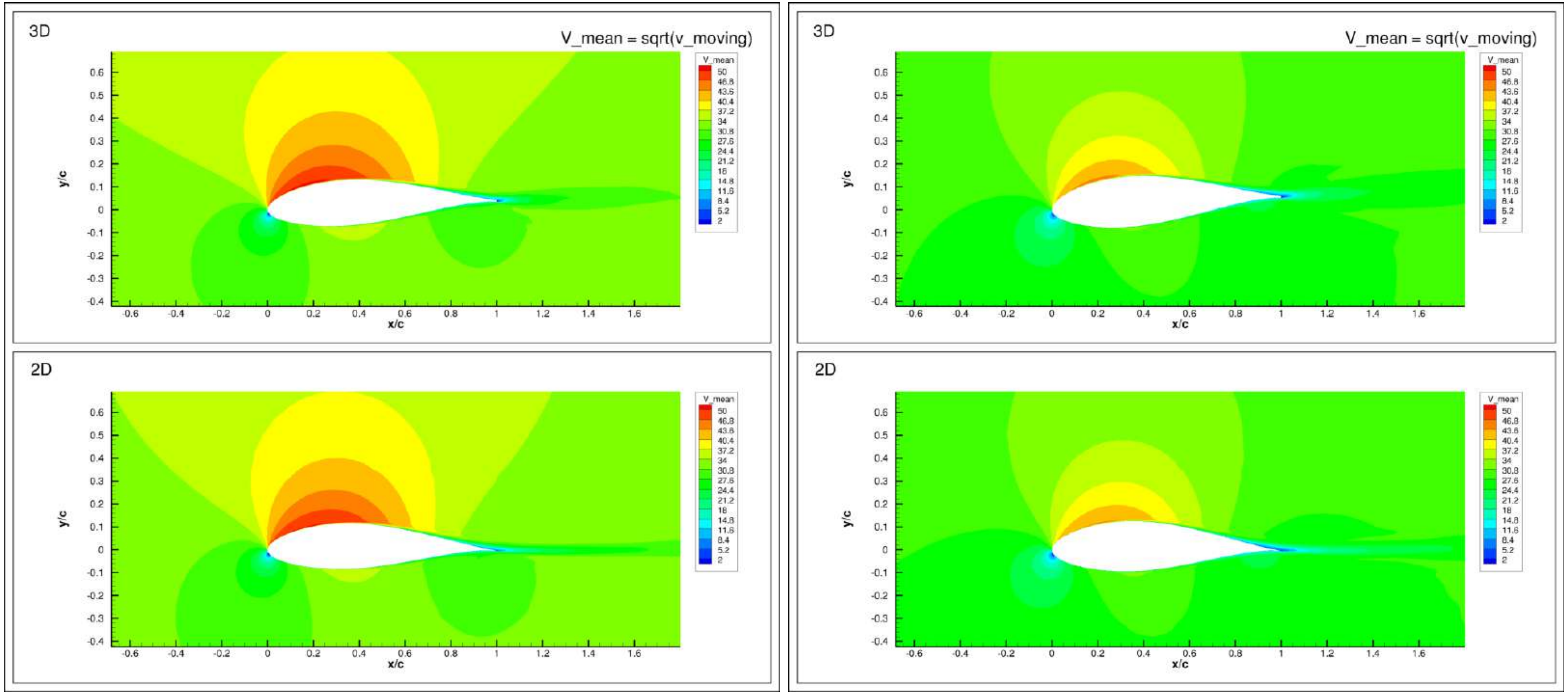
2D



# Appendix: Velocity distributions c7 – c8

3D

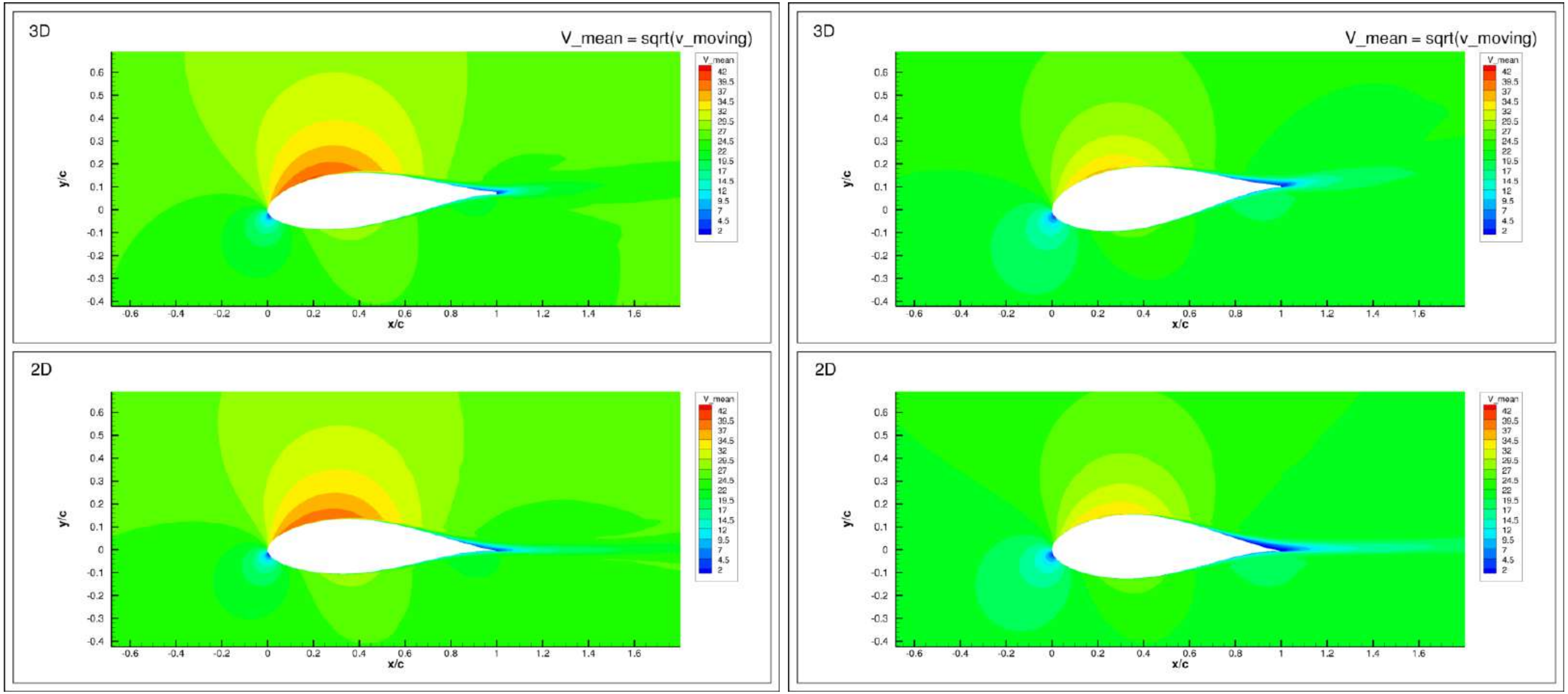
2D



# Appendix: Velocity distributions c9 – c10

3D

2D



# Appendix: Velocity distributions c11 – c12

3D

2D