



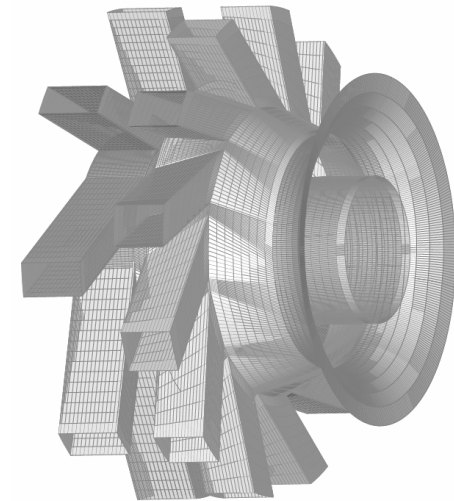
Technische
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Darmstadt

On the Importance of High Quality Flow Models in Energy Research

Prof. Dr.-Ing. Martin Oberlack

Fachgebiet Strömungsmechanik & Hydraulik

**New Links between Basic Research
and Applied Energy R&D -
The Computational Approach**



8th – 9th November 2004
Berlin WIAS



Fluid Mechanics and Hydraulics Group



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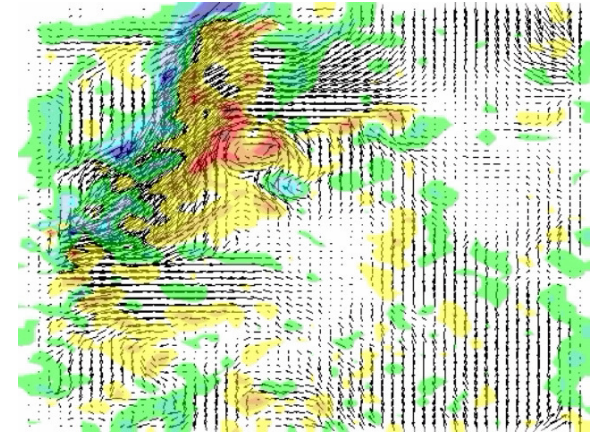
Results in collaboration

with

- RWTH Aachen: R. Niehuis, W. Schröder
- TU Darmstadt: J. Janicka, C. Tropea
- Uni Halle-Wittenberg: M. Sommerfeld
- TU München: T. Sattelmayer

within the

BMBF Research Collaboration: Turbulent Flows with Strong Streamline Curvature

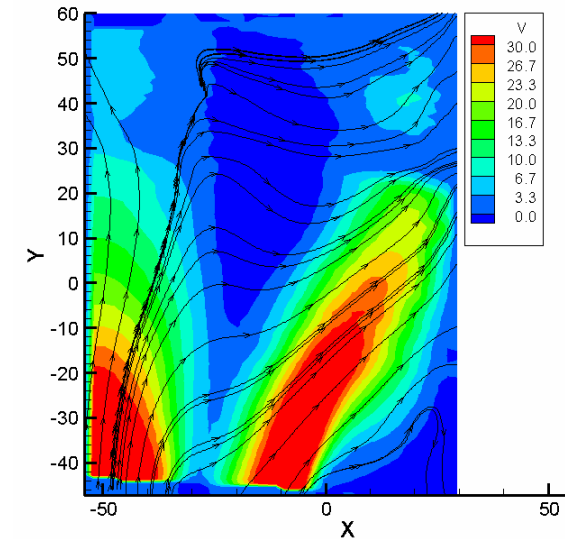


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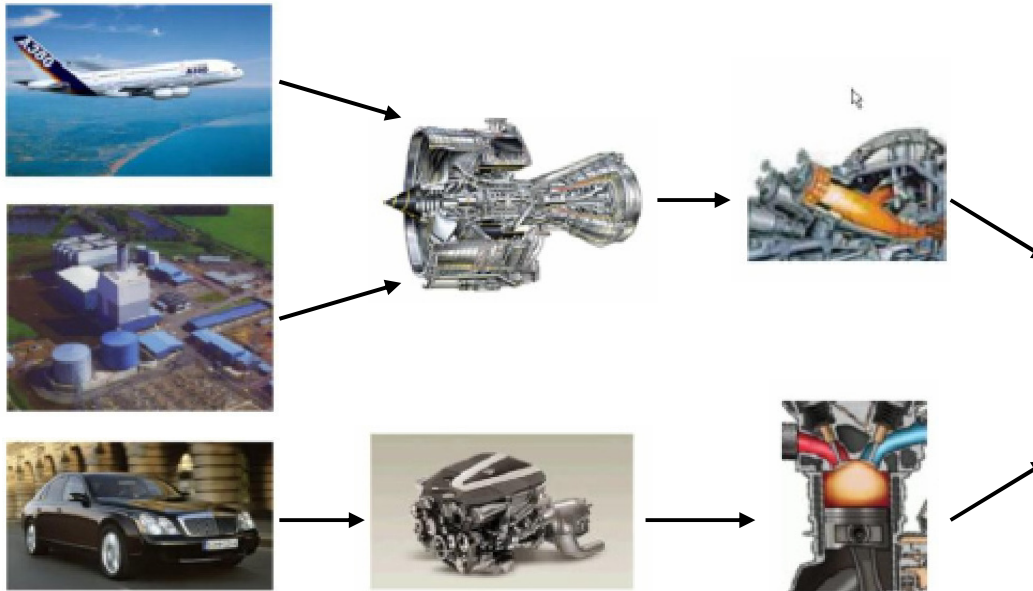
- Motivation
- Scientific technical relevance
- Basic flow examples
- Problems and solution approach
- Primary aim
- Different levels of turbulence modelling
- Modelling tools for LES and RANS
- Flow examples close to energy applications
- Summary and conclusions





Motivation of the collaboration

Ability of Modelling and Simulation →



Zur Anzeige wird der QuickTime™
Dekompressor „YUV420 codec“
benötigt.

← Complexity and Application

Characteristic feature: Strong streamline curvature





Scientific technical relevance



- Turbulent flows with strong rotation/ streamline curvature possess high technical relevance for energy technology
 - Swirling flows (e.g. burners)
 - Stagnation point flows (e.g. sprays in diesel engines)
 - Separation/recirculation/secondary flow

but

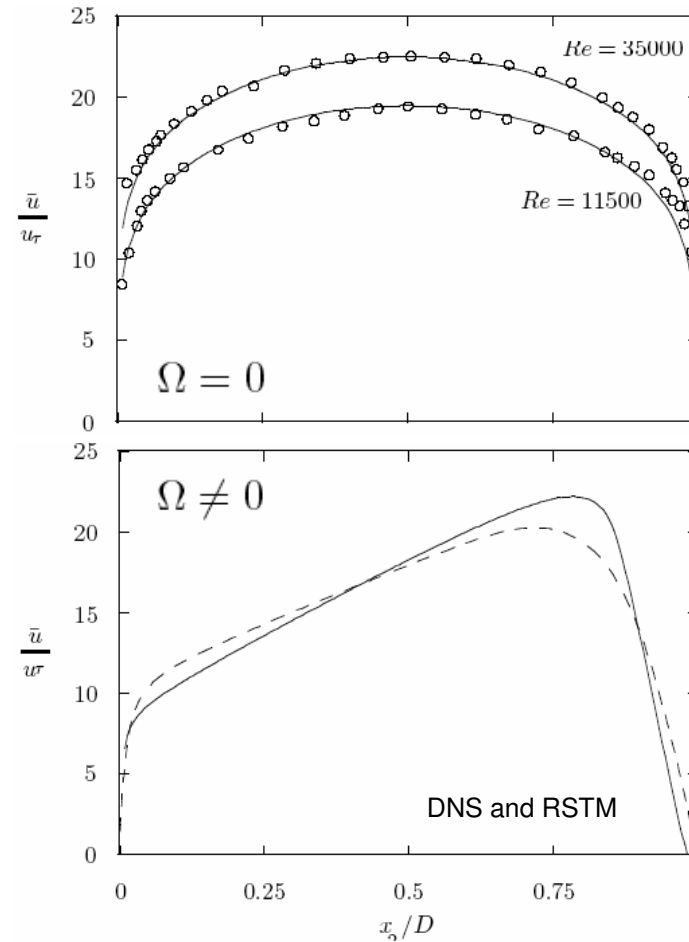
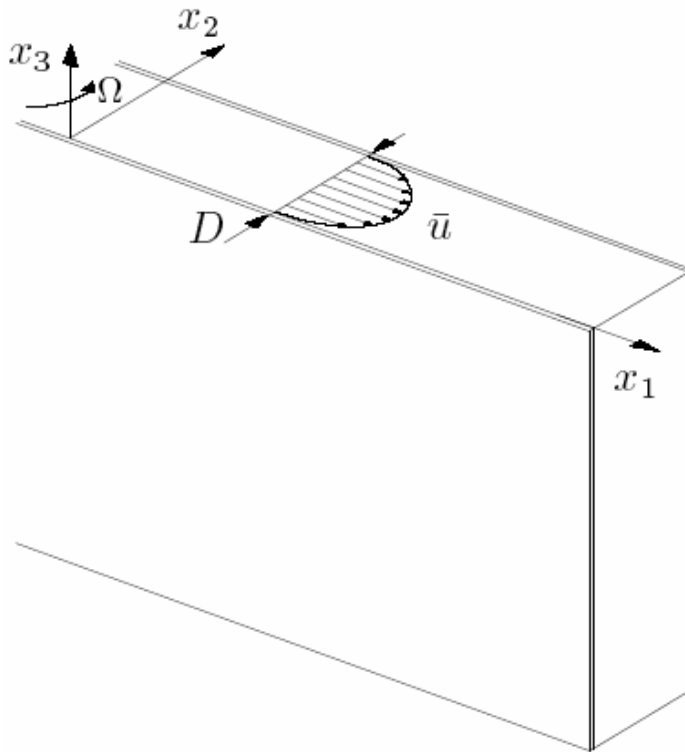
- Classical two-equation turbulence model, e.g. k - ϵ model, (still the main „*working horse*“ in industrial application) give **physically incorrect results**





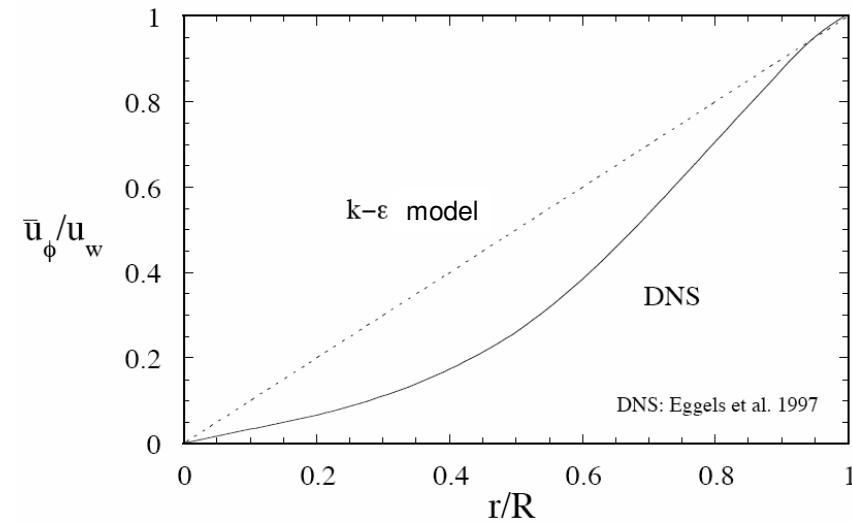
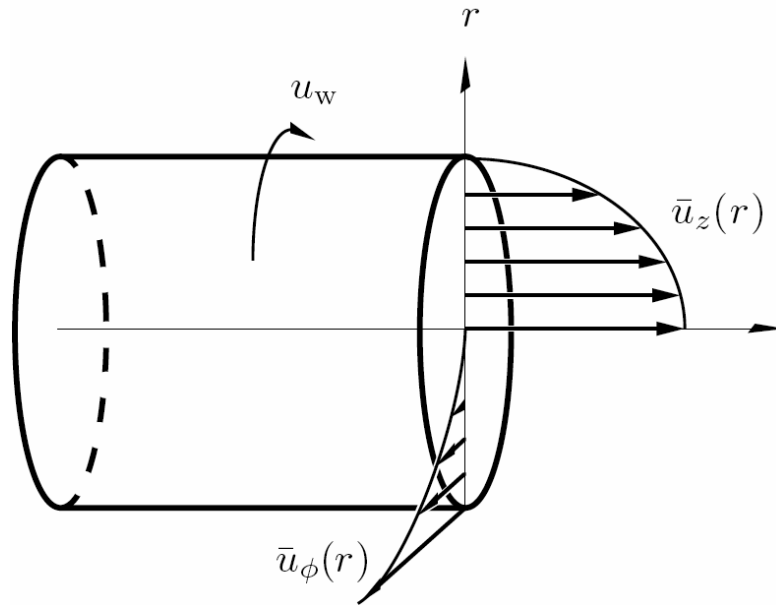
Basic example I: Rotating channel flow

- Model flow for radial compressor



Basic example II: Rotating pipe flow

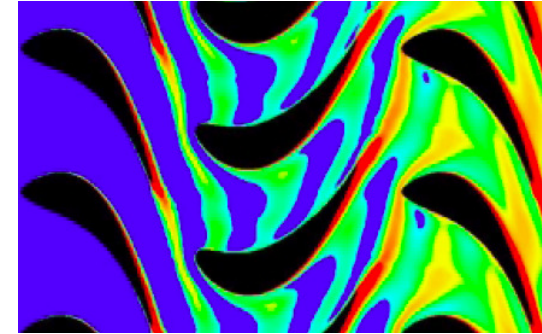
- Model for swirling flow in pipes and jets



Two-equation models such as classical k- ϵ model are insensitive to rotation/streamline curvature



Problems & solution approach



- Flow and turbulence models are the basis for all simulations

„bottleneck“ for further progress

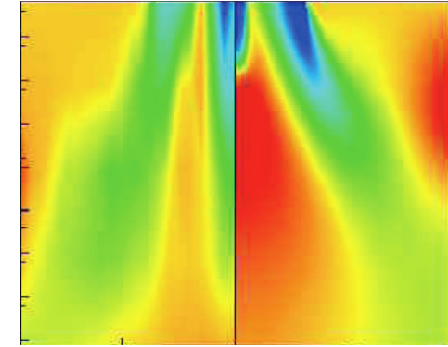
- Innovative RANS- and LES models allow for a fundamental improvement
- New analytical methods such as **symmetries (Lie groups)** allow for an essential progress for technical turbulence models





Primary aim

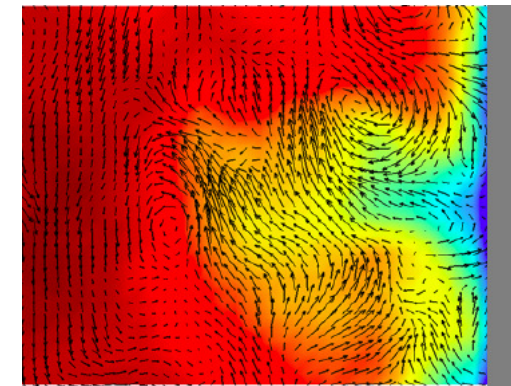
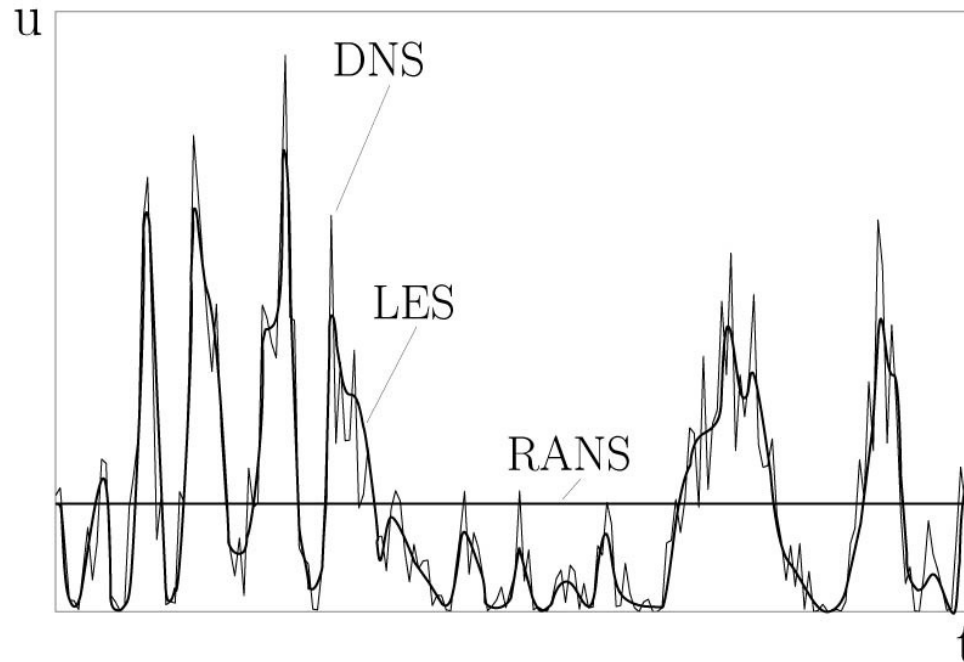
- **Model development for strong stream line curvature**
- Detailed aims
 - Improved prediction capabilities
 - Implementable in established (commercial) codes
 - Moderate numerical cost
 - Elaborate validation experiments
 - Exemplary application





Different levels of turbulence modelling

- Direct numerical simulation (DNS)
- Large-eddy simulation (LES)
- Reynolds averaged Navier-Stokes equations (RANS)





Different RANS models

- Two-equation models e.g. k - ϵ : *insensitive to rotation*
- Non-linear two-equation models: *weakly sensitive*
- Explicit algebraic Reynolds stress models: *weakly sensitive to rotation with improved prediction capabilities*
- Reynolds stress transport models: *sensitive to rotation (with some exceptions)*





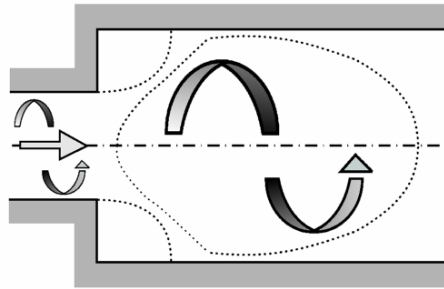
Modelling tools for LES and RANS

- Calibration against classical benchmarks
 - Homogeneous and isotropic turbulent flows
 - Shear flows
 - Channel/pipe flow
 - ...
- Data from experiments and DNS
- Realizability
- ***Symmetry methods***
 - *Axiomatic properties of any physical model*
 - *Unifies classical solutions and gives many new ones*



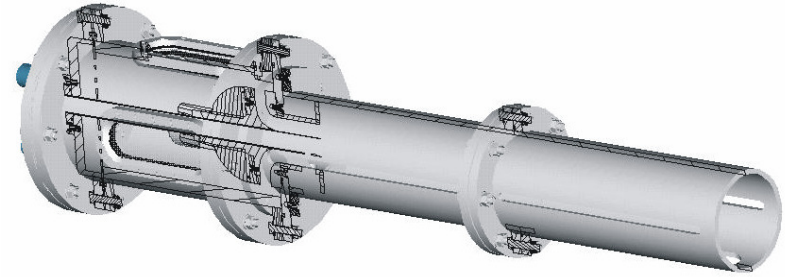
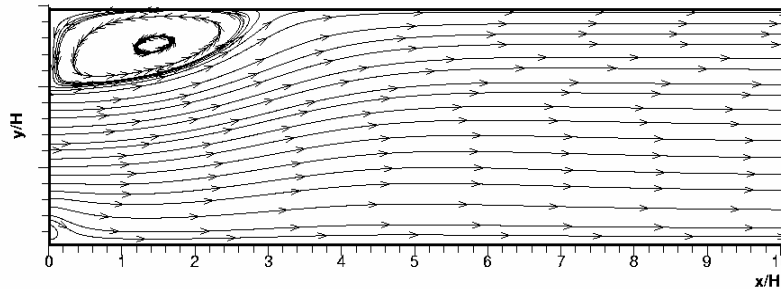


Combustion chamber

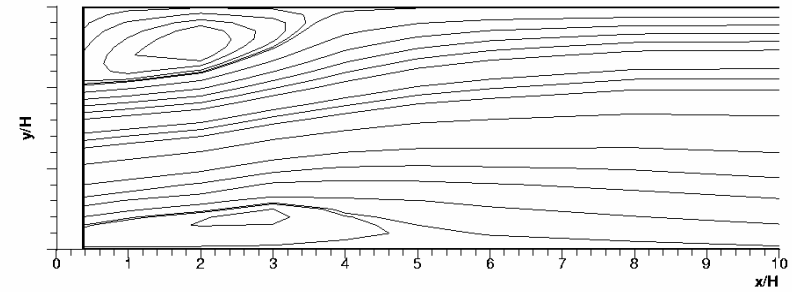


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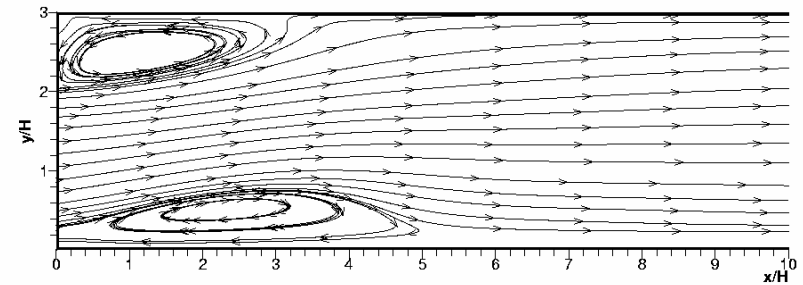
- Standard k-ε



- Experiment



- High-Re RANS model

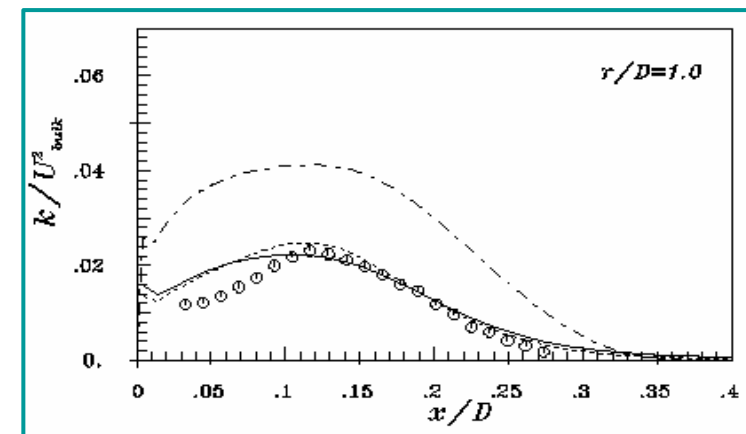
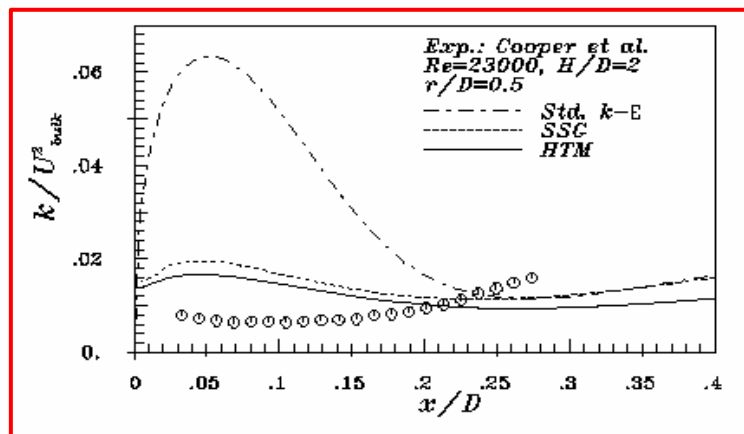
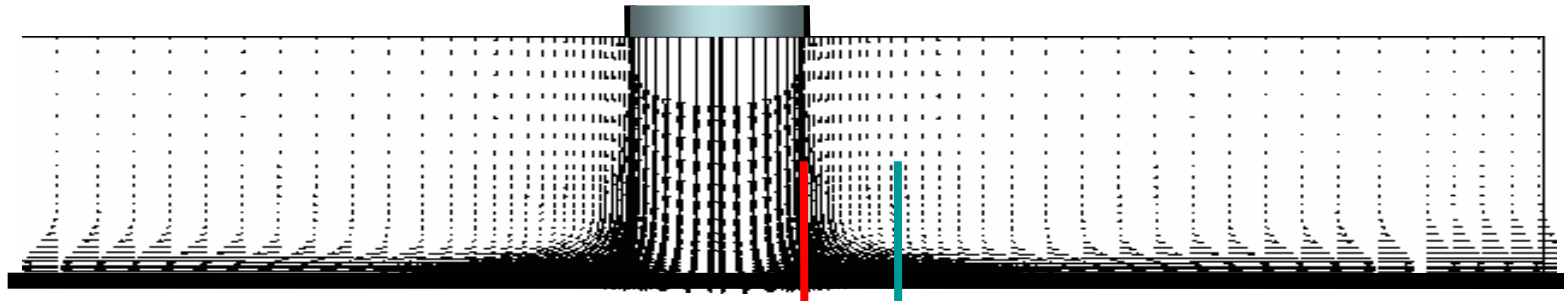


Tropea, Jacirlic, Palm, Jester-Zürker (TU Darmstadt)





Impinging jet (Cooling)

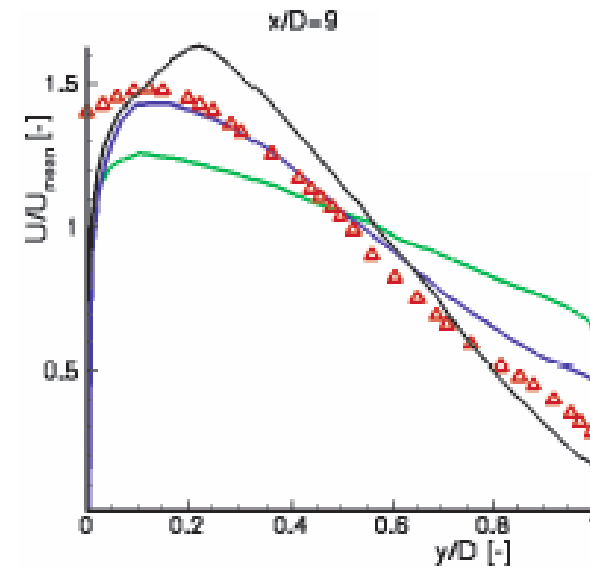
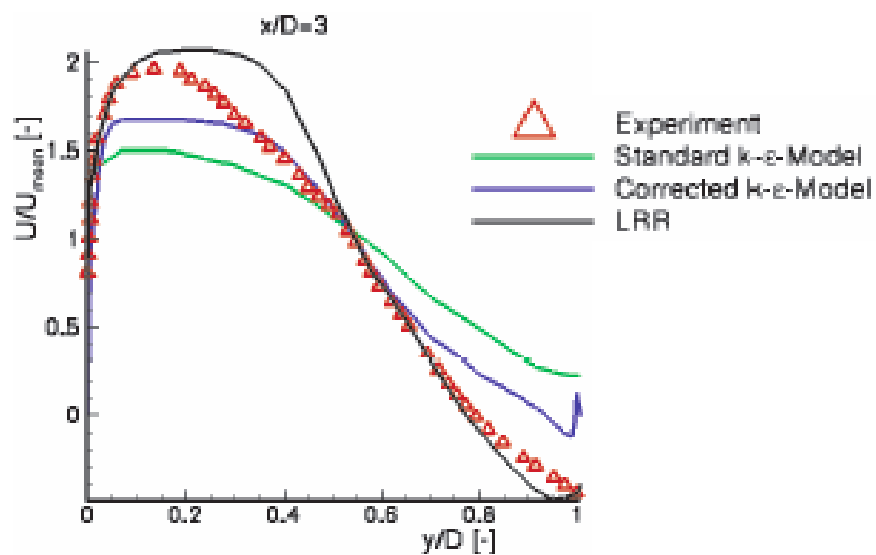
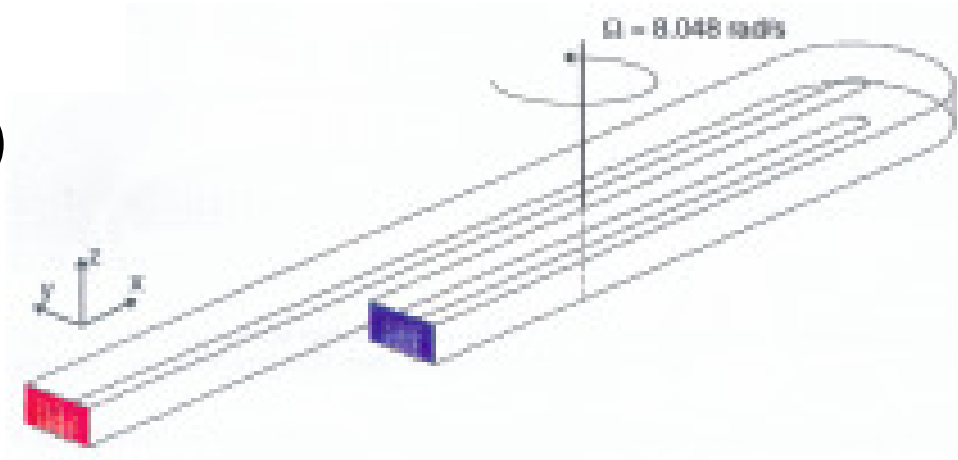


Tropea, Jacirlic, Basara (TU Darmstadt)





U-Bend flow (Turbine cooling)



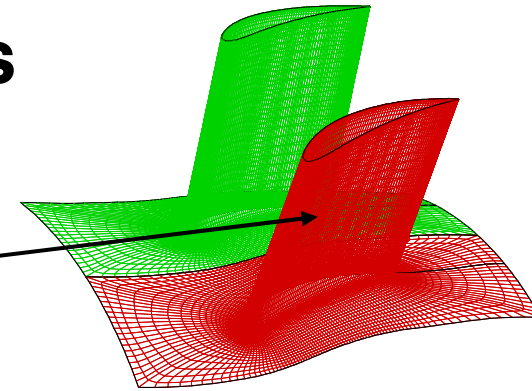
Grottko, Hirsch, Sattelmayer (TU München)



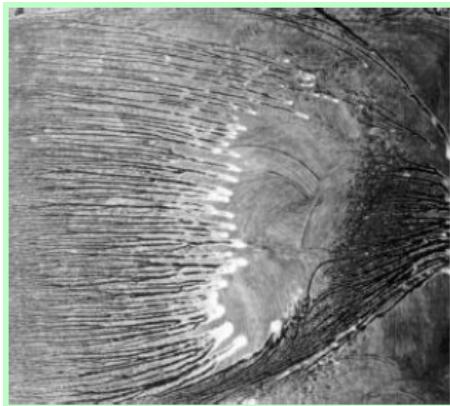


Flow separation on turbines

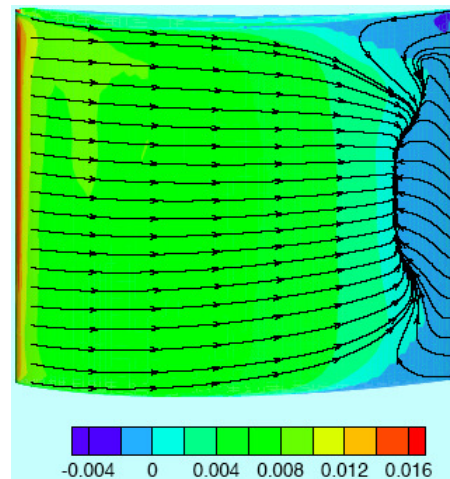
Oilfilm experiment



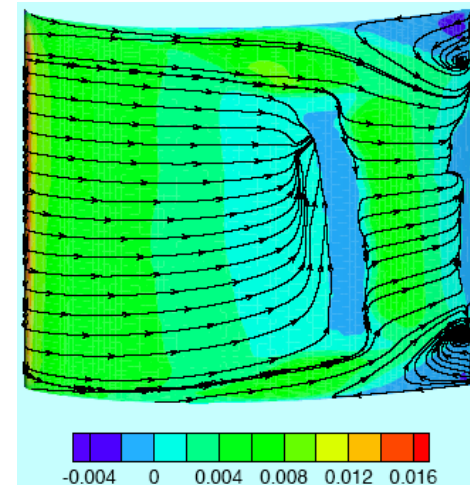
Experiment



Chien model



Chien model
with transition

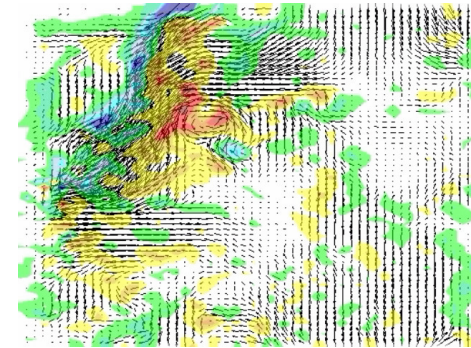


Niehuis, Wickerath (RWTH Aachen)





Summary and conclusions



- Turbulence modelling is still the „**bottleneck**“ for complex flows with rotation/streamline curvature
- Different level of turbulence models give improved prediction capabilities (RANS -> LES -> DNS)

but

- Numerical cost for LES and DNS is still too demanding
- **Still great need for simple models with good prediction capabilities especially for complex flows**





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Thank you for your attention!



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