Improvement of physical modeling for vortex-dominated flows

Project Proposal

Window on Science Seminar

24 September 2018

US Air Force Research Laboratory (AFRL)
Wright-Patterson Air Force Base, OH, USA

$C^2A^2S^2E$
DLR, Institute for Aerodynamic and Flow Technology

German Initiative – DLR, AFRL, AFOSR, Germany, NATO
Project Proposal: *Improvement of physical modeling for vortex-dominated flows*

Background

Requirements from the German MoD and Procurement Agency (BMVg/BAAINBw) with respect to DLR's military research funding:

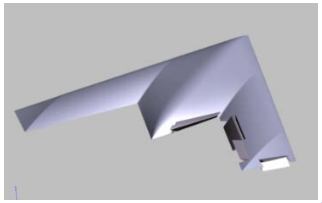
- ***Sustainment and improvement of capabilities to design, layout and assess the performance of military areal vehicles***

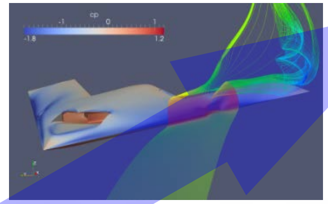
Mephisto (2014-2018)

- Multi-Fidelity overall design

FaUSST (2011-2013)

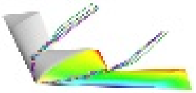
- Preliminary overall design
- Generic UCAV configuration, round leading edges & control devices

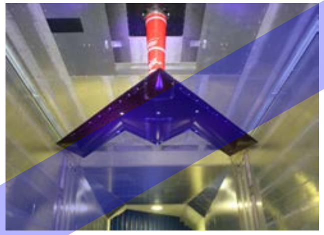


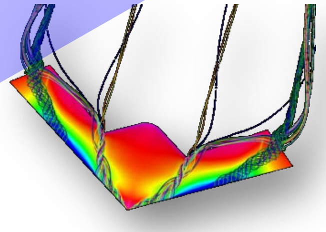


UCAV-2010 (2007-2010)

- Maneuver simulation
- UCAV configuration, round leading edges
- Flight trajectory simulation

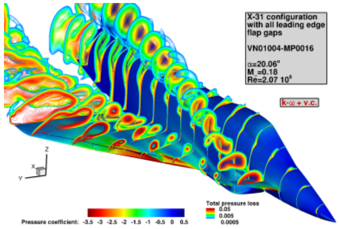






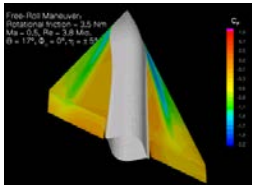
SikMa (2003-2006)

- Maneuver simulation
- Real configuration, round leading edges



AeroSUM (1998-2003)

- Maneuver simulation
- Delta wing, sharp leading edge



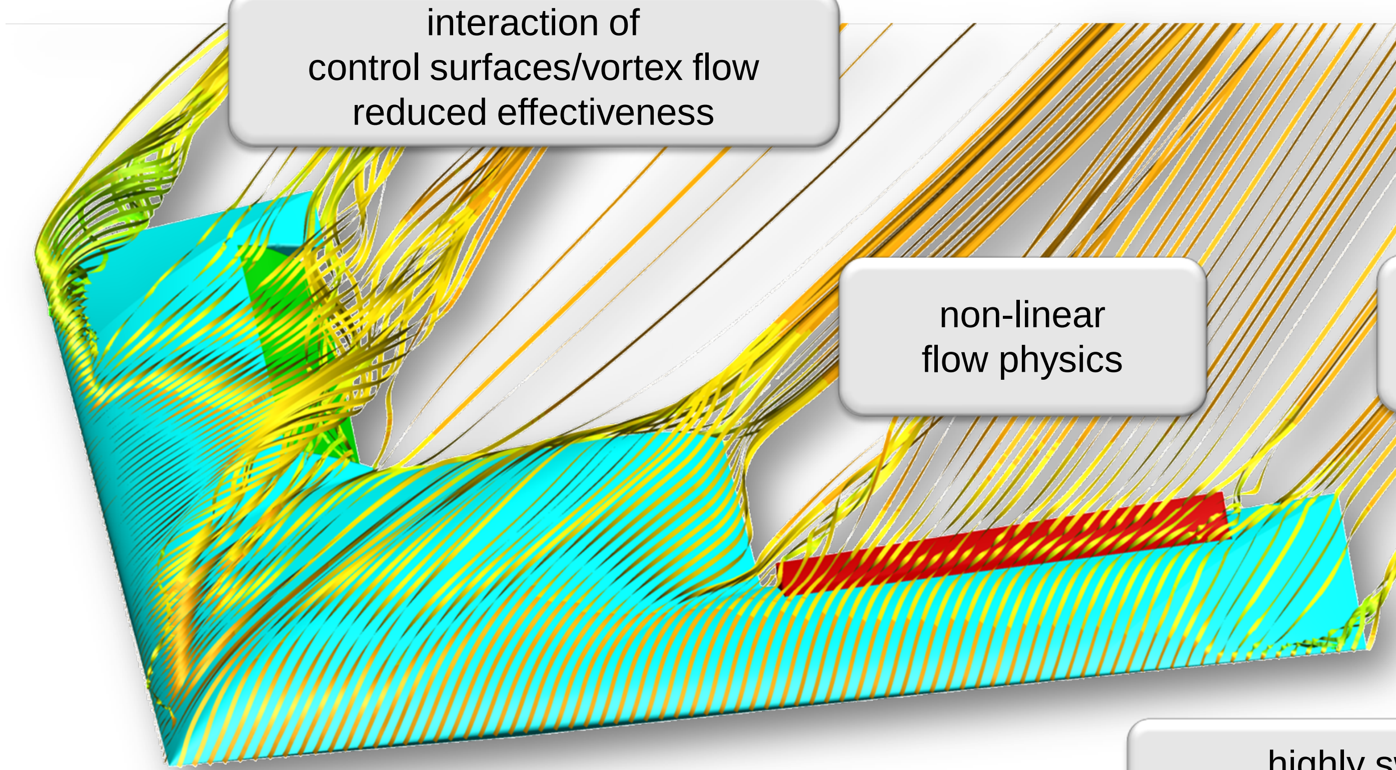
- Continuous activities over 20 years
- Funding strongly limited

Chart: A. Schütte

DLR

Motivation/Challenges for our institute

Consolidation of design capabilities for agile, low observable military configurations with vortex-dominated flow physics



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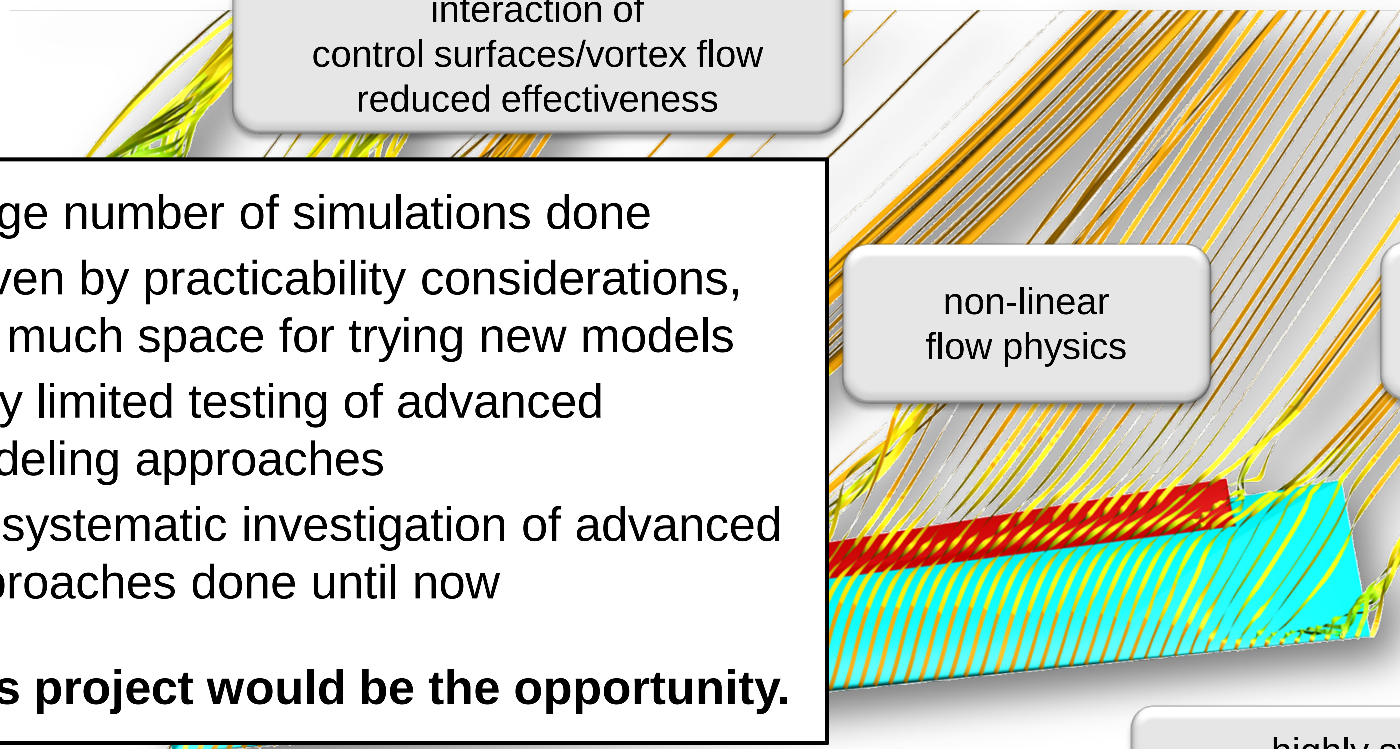
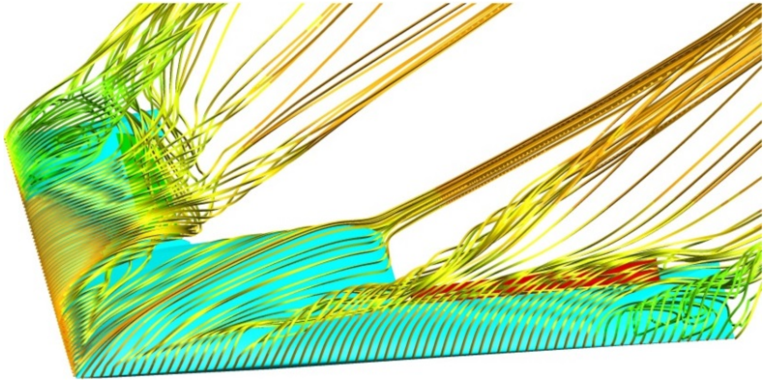


- Large number of simulations done
- Driven by practicability considerations, not much space for trying new models
- Very limited testing of advanced modeling approaches
- No systematic investigation of advanced approaches done until now

This project would be the opportunity.

Chart: A. Schütte

Proposal of a research project over 3 years

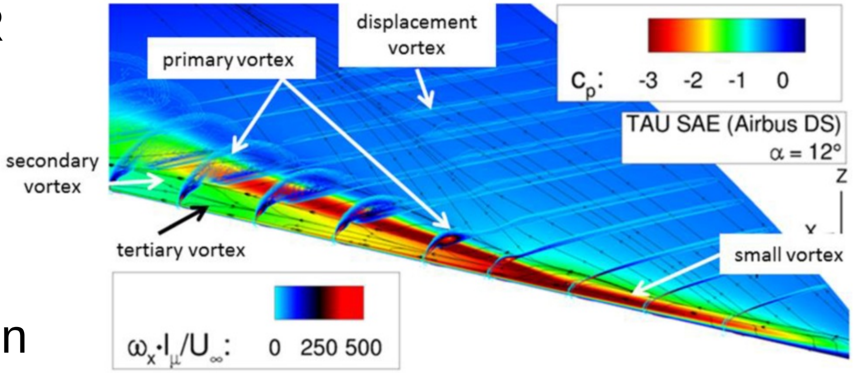


Current situation:

State-of-the-art CFD methods lack the ability to predict onset and progression of separated vortex-dominated flows, ***especially from smooth surfaces***

Approach:

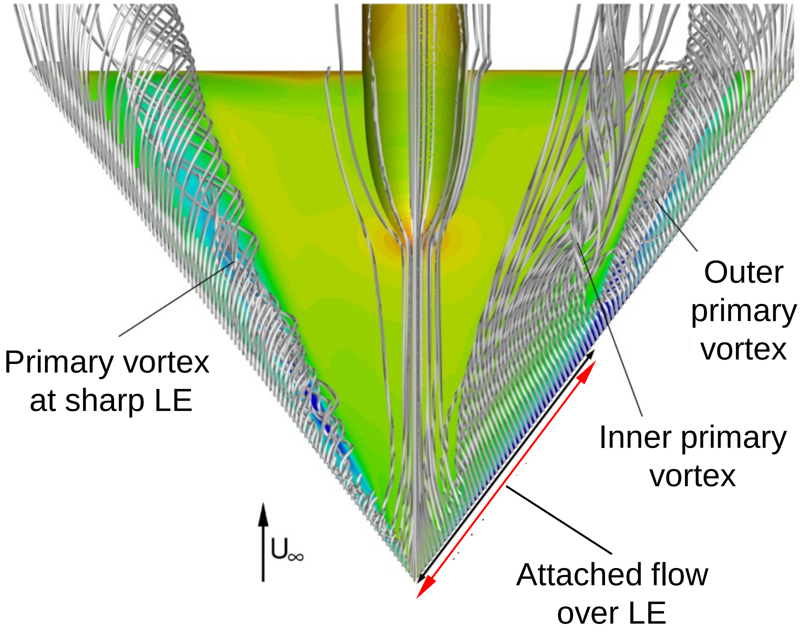
- Evaluation and enhancement of innovative turbulence modeling approaches including both advanced RSM and SRS approaches recently developed at DLR
- Investigations will be carried out using the DLR TAU code
- Test cases to be carefully selected by DLR and AFRL
- Information exchange intended between DLR, AFRL and Airbus Defense and Space



Proposal of a research project over 3 years

Not yet solved:

- Correct prediction of complex vortex structures
  - Secondary vortex separation
  - Multiple vortex structures



Proposal of a research project over 3 years

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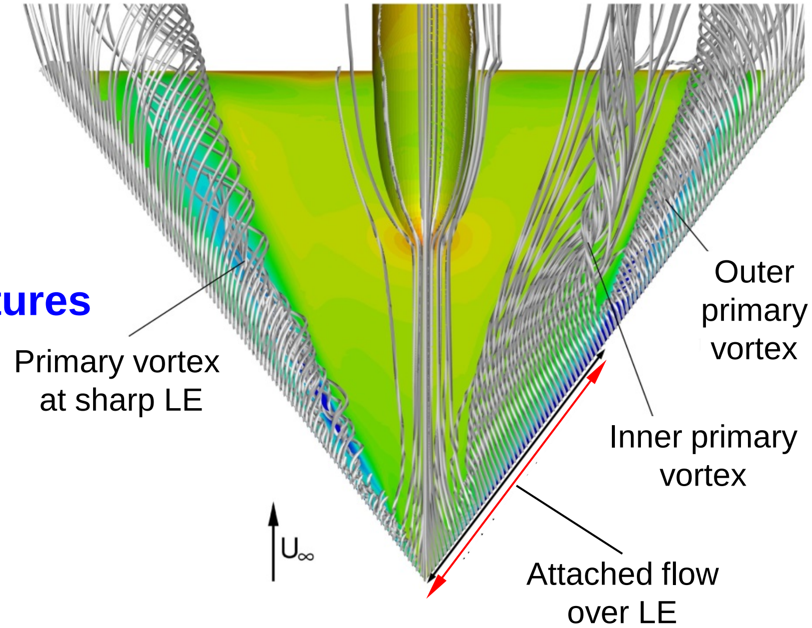
  - Multiple vortex structures

  → **good representation of rotational flow features**

  → **existence and location of vortices**



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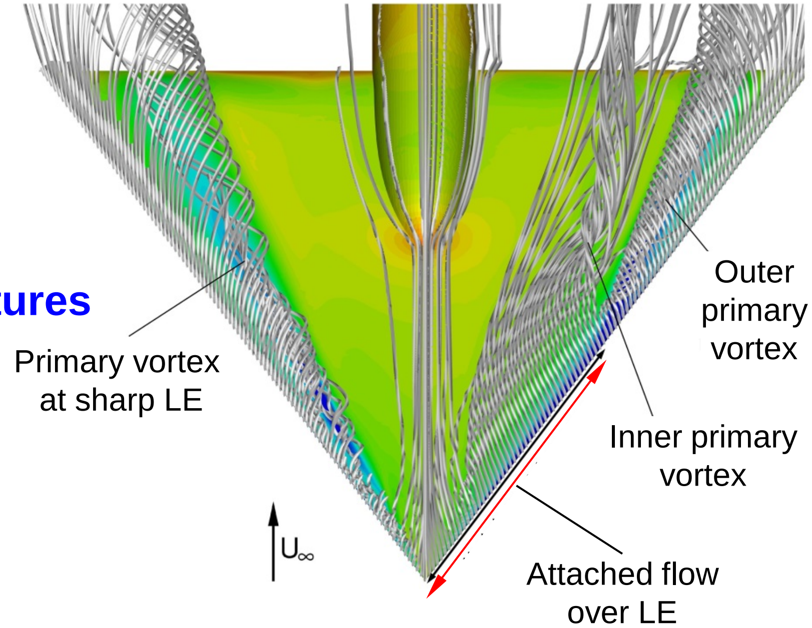
- Correct prediction of the vortex strength



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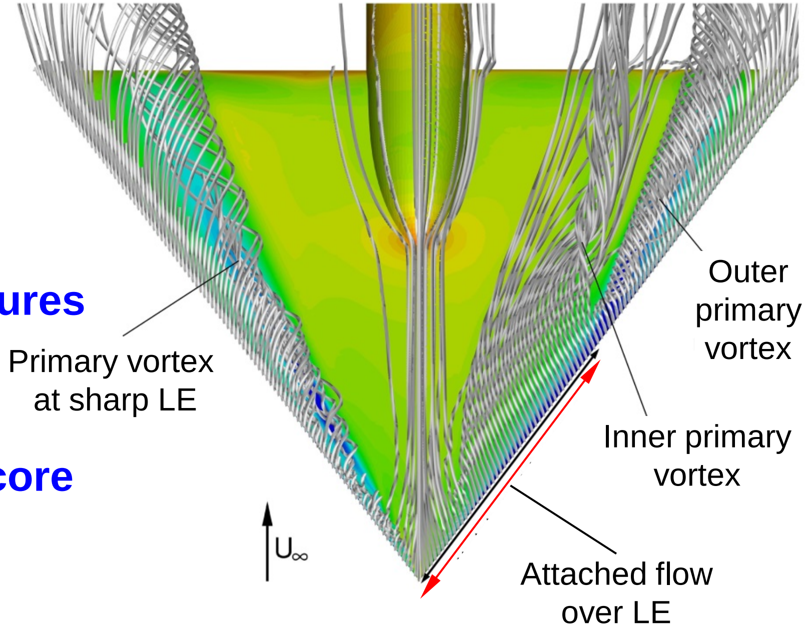
  → **RSM: better prediction of wing-tip vortex core**



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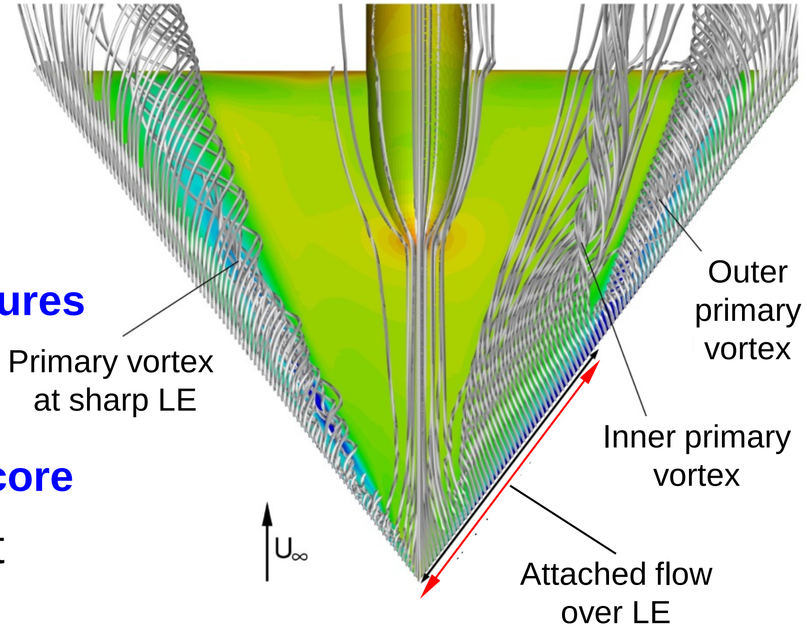

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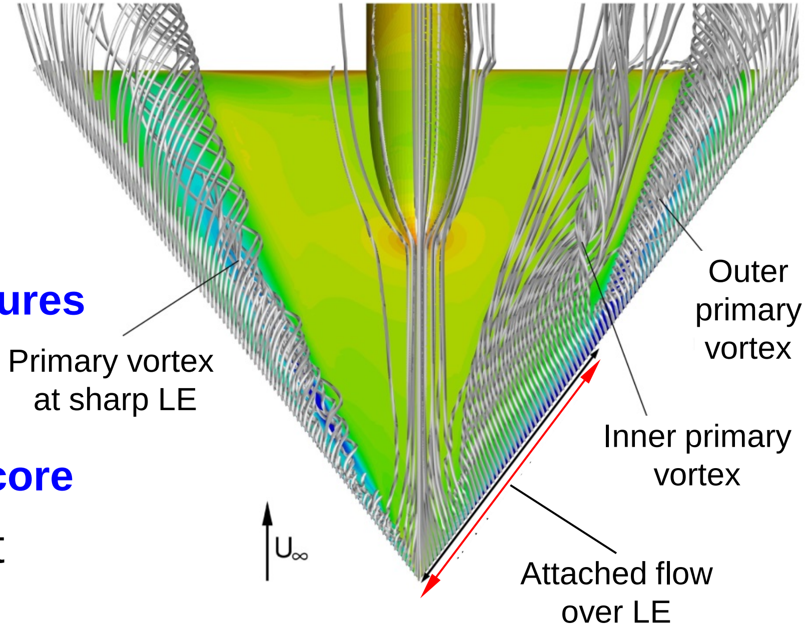
  → **RSM: better separation onset locations in APG TBL possible**



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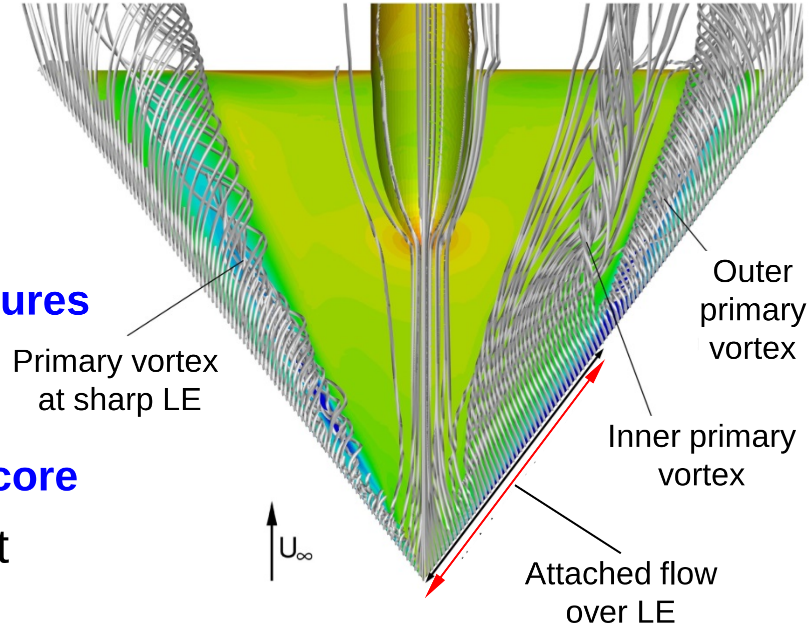
  → RSM: better separation onset locations in APG TBL possible
  → SRS: might be necessary



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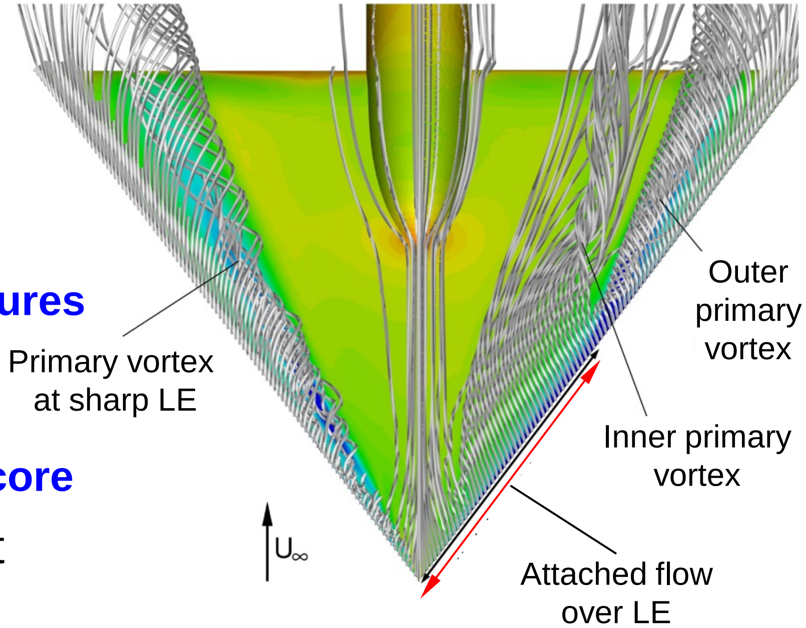

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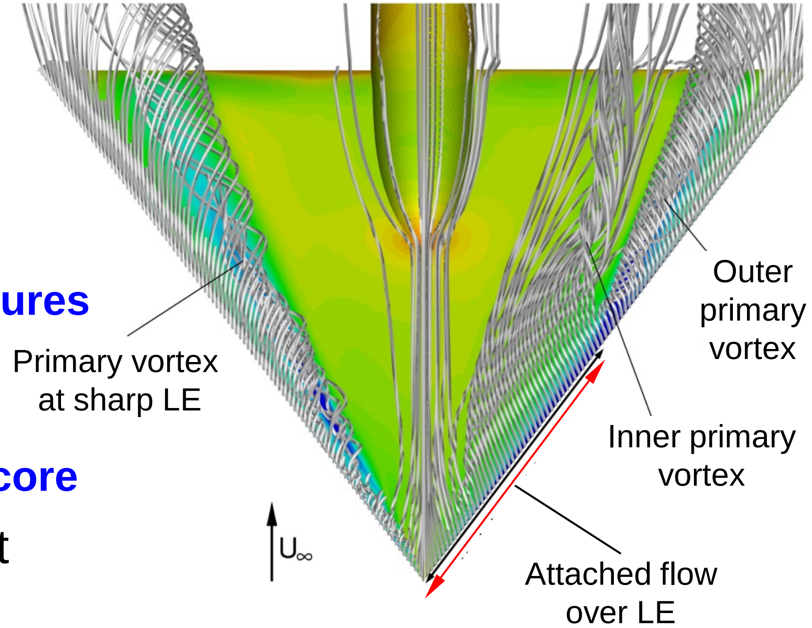

Still work to be done:

- Reliable prediction of vortex burst point

Proposal of a research project over 3 years

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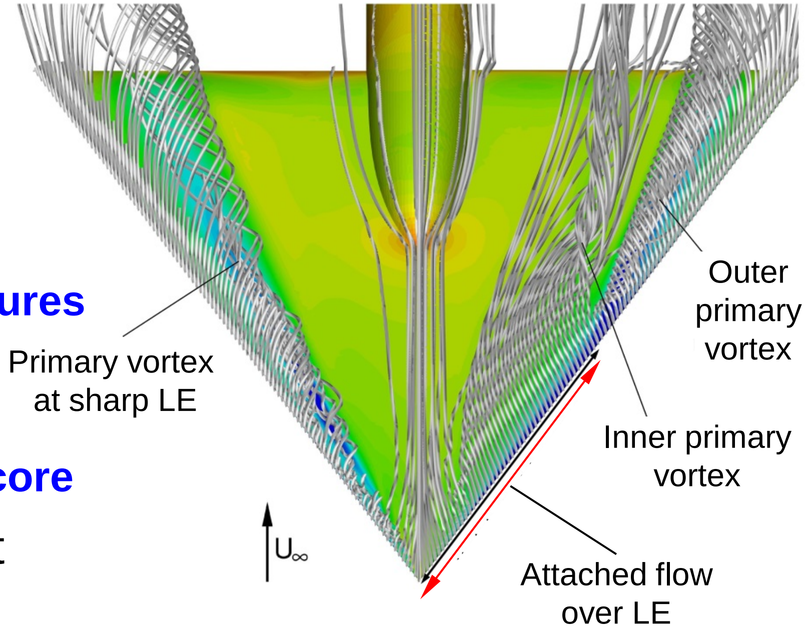


Still work to be done:

- Reliable prediction of vortex burst point
  → **SRS probably necessary: highly unsteady!**

WP 1: Computation of selected test cases using SSG/LRR-RSM

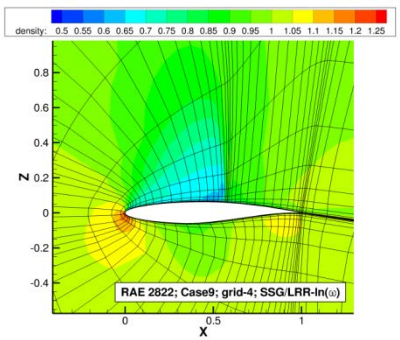
- Selection of test cases: DLR + AFRL $\rightarrow$ Cases with round leading edges
- Generation of appropriate computational grids
- Simulations using SSG/LRR Reynolds stress model
  - Model variant of the standard RSM in TAU: SSG/LRR-ω
  - Alternatively, use of g or $ln(\omega)$ formulation of model $\rightarrow$ Higher numerical stability
- Grid study: refinement, cell types (hexahedral?), …
- Investigation of Reynolds number effects
- Comparison with experimental data
- Additional computations with a eddy-viscosity model $\rightarrow$ Which? Decision at project runtime

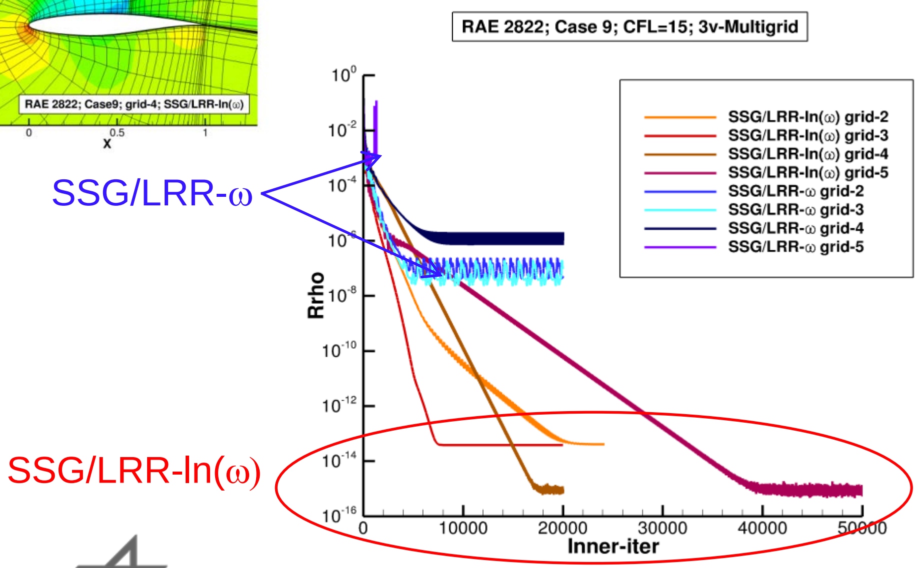
Goals:
- Assessment of predictive capability of SSG/LRR-RSM for separated vortex-dominated flows $\rightarrow$ Is RSM sufficient?
- Application recommendations, Best Practice

SSG/LRR-RSM with different length-scale formulations

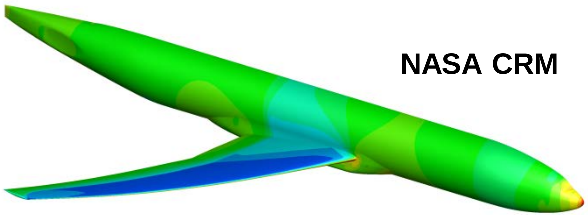
- The model is identical with all formulations of the length-scale equation
- Results (almost) identical if grids are fine enough (identical, if grid convergece achieved)
- Numerical stability of $\omega < g < ln(\omega)$
- With $ln(\omega)$ results towards machine-accuracy possible

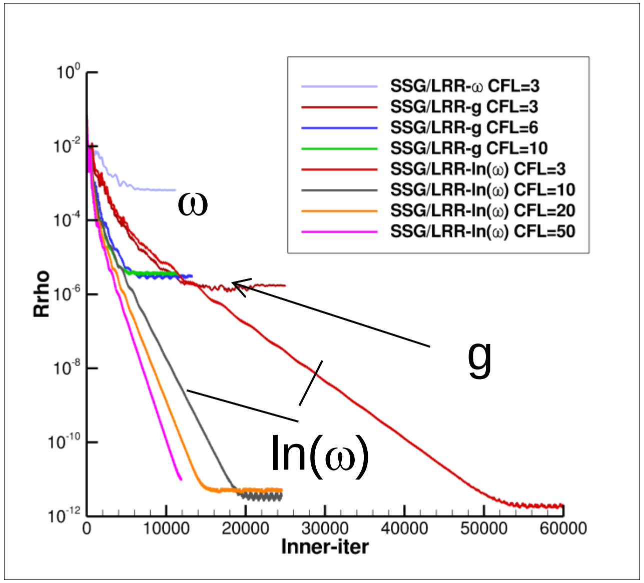
RAE 2822 airfoil





NASA CRM

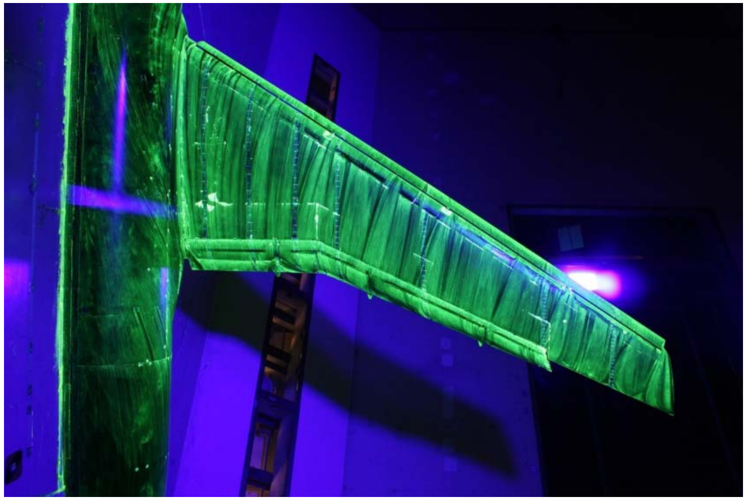


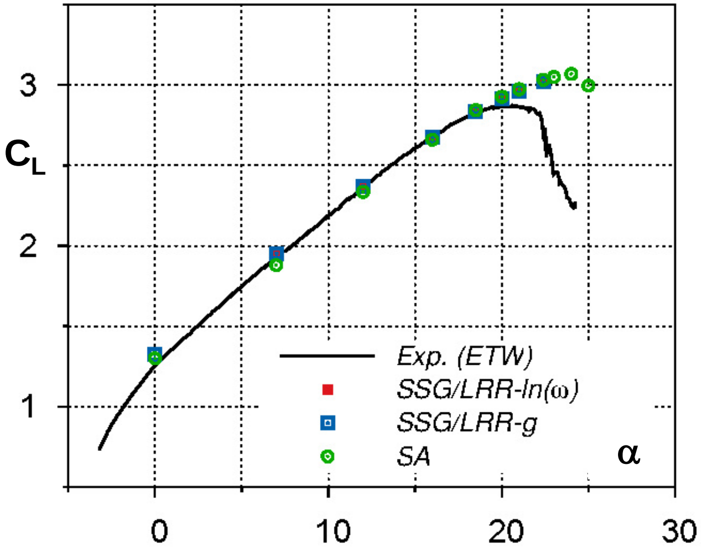


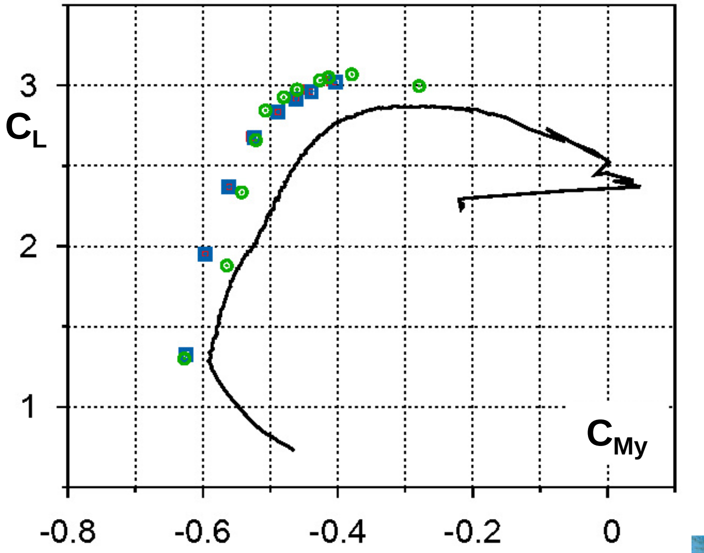
SSG/LRR-RSM with different length-scale formulations

- For DLR-F11: $Re_{MAC} = 15 \times 10^6$, Ma =0.175
  - *SSG/LRR-ω* fully unstable $\rightarrow$ no results
  - *SSG/LRR-g*/$ln(\omega)$ $\rightarrow$ similar residual levels, with $ln(\omega)$ higher convergence rates

DLR-F11 high-lift configuration







SA results from *AIAA-2014-0915* by Rudnik and Melber-Wilkending

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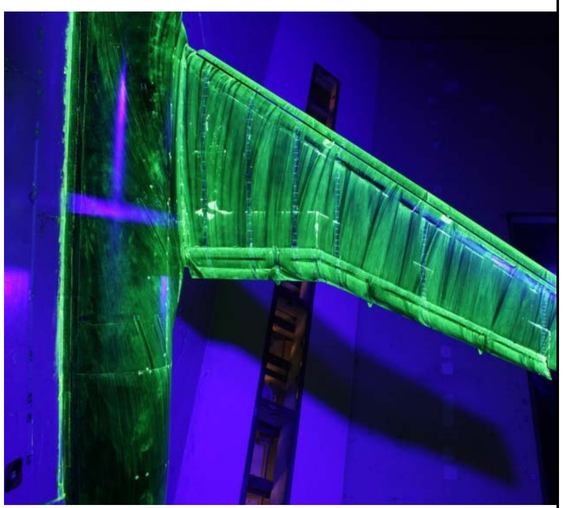
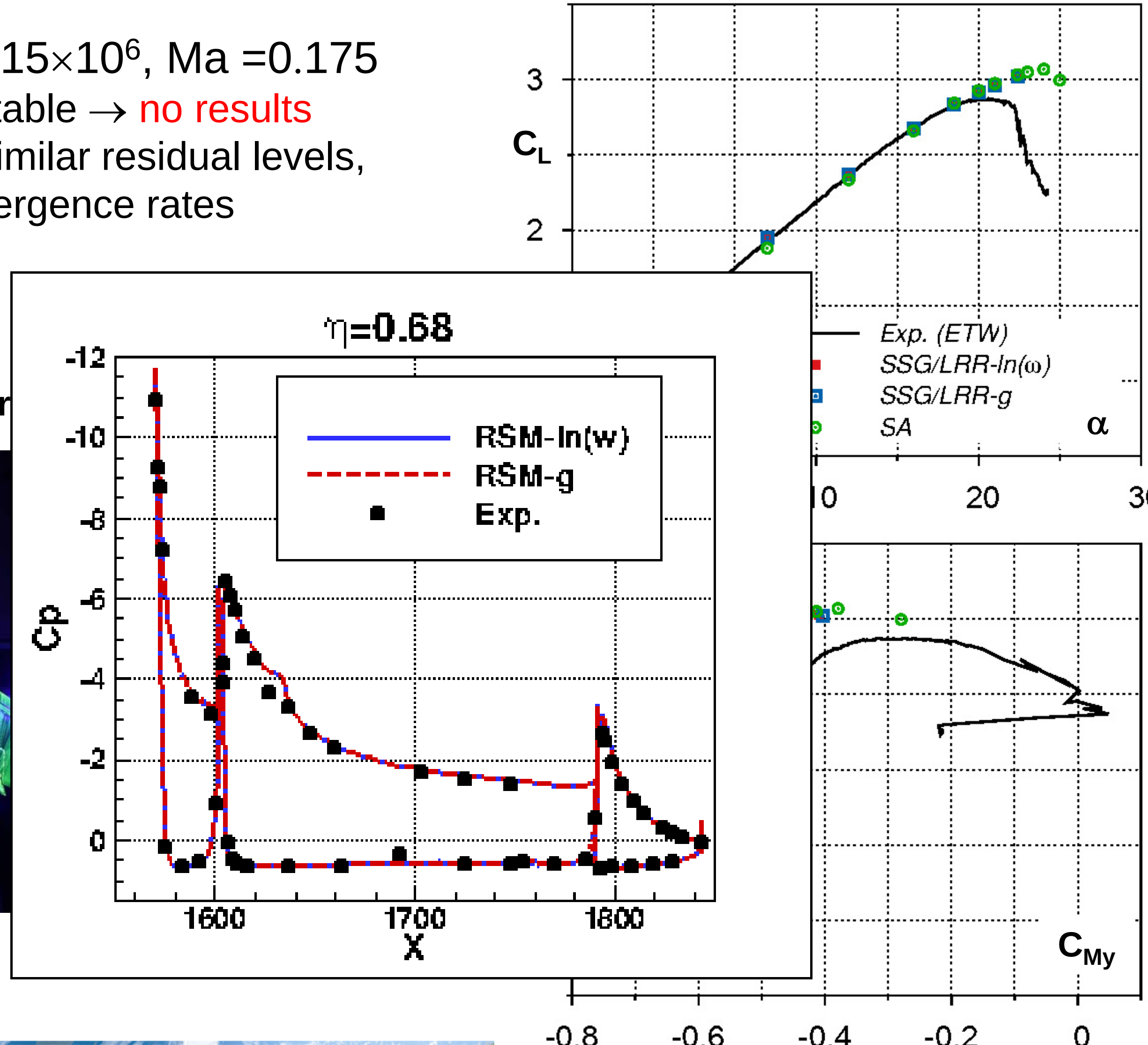
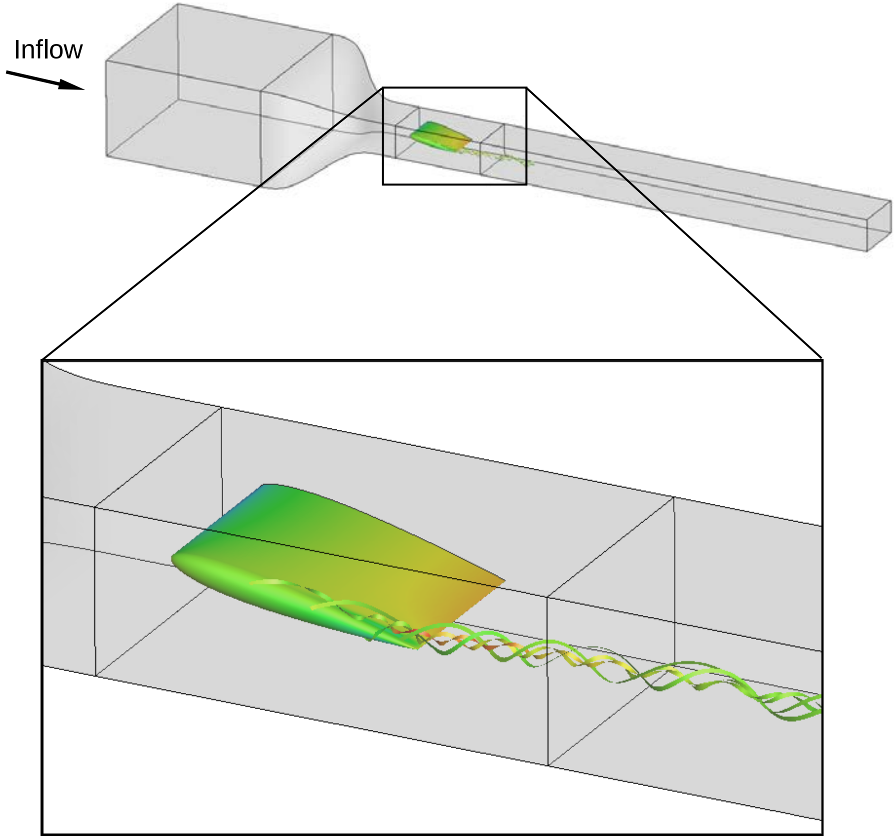


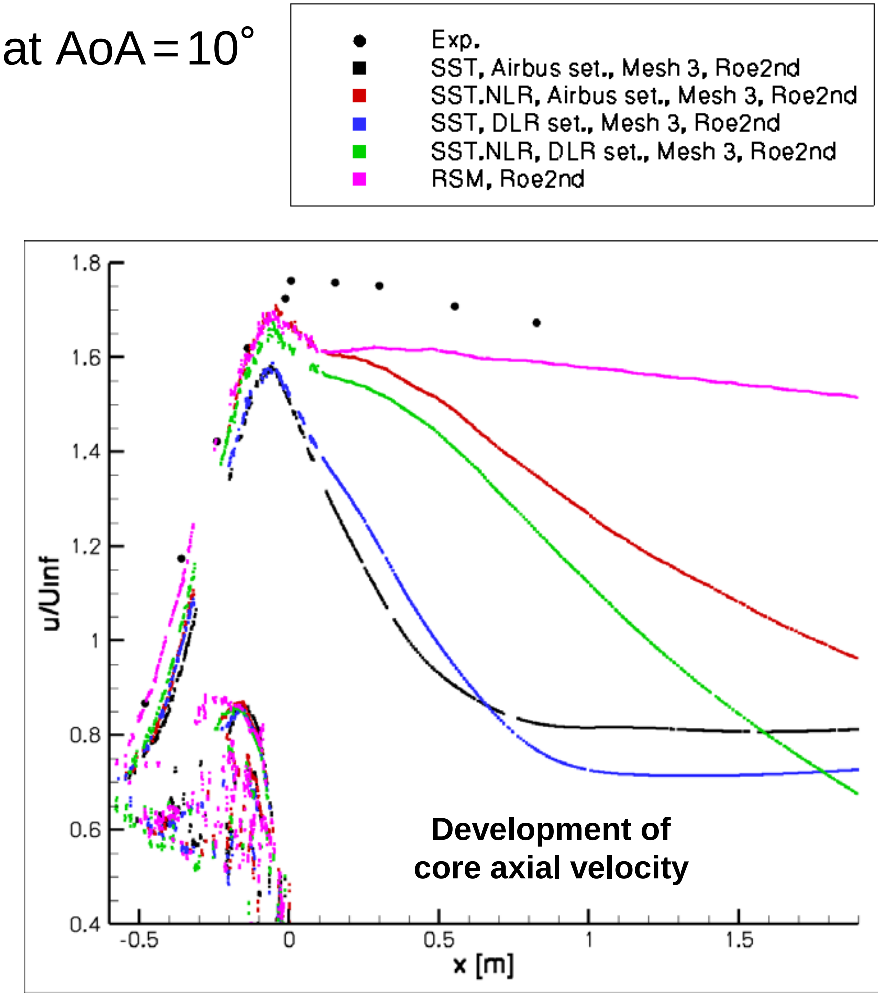


SA results from *AIAA-2014-0915* by Rudnik and Melber-Wilkending

Simulation of vortices after separation from smooth surfaces

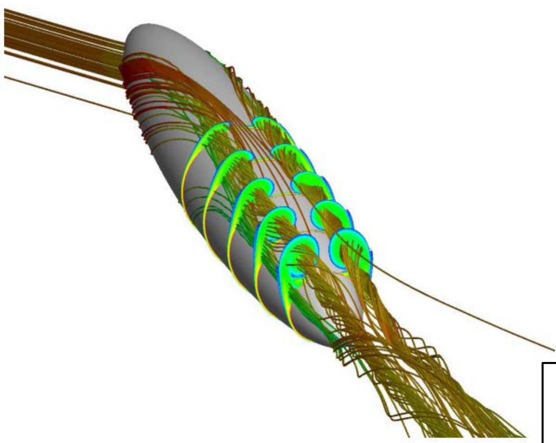
- ***Test case:*** NACA0012 Wing Tip Vortex at AoA = 10°
  - Measured in 32x48 inch low speed WT at NASA Ames Research Center

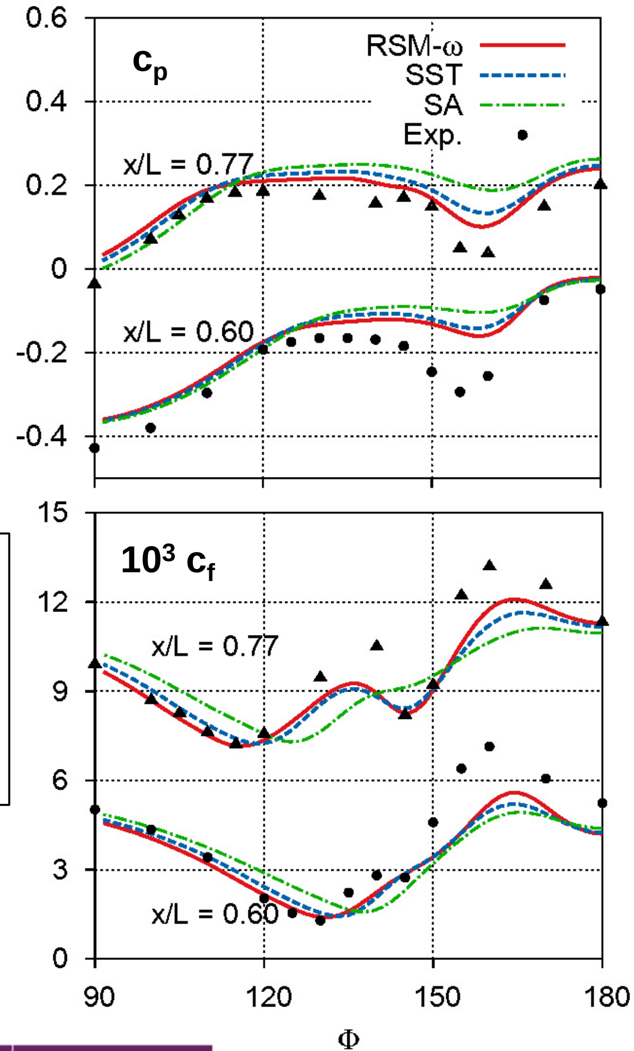




Simulation of vortices after separation from smooth surfaces

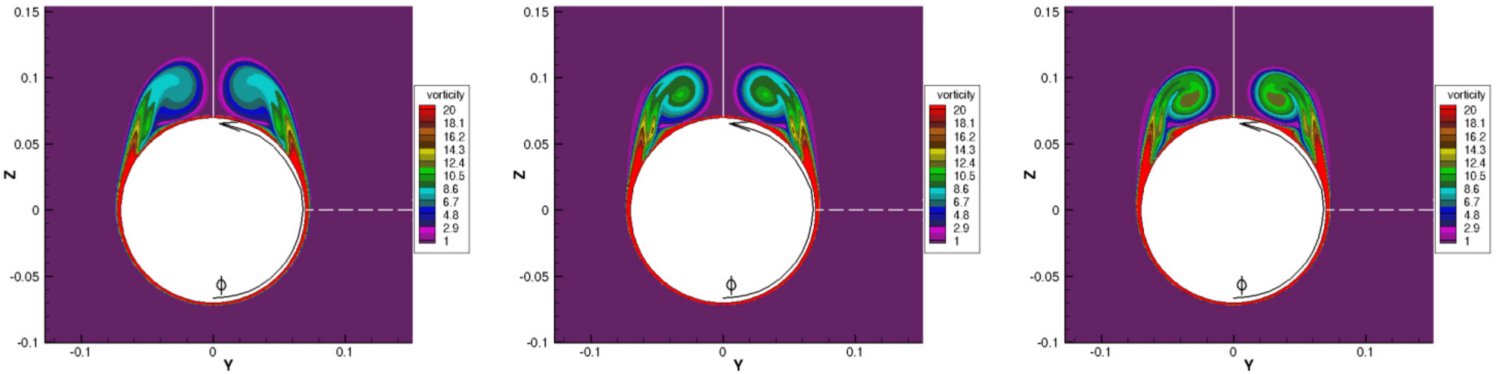
- ***Test case:*** Prolate Spheroid
  - Re = 4.2×10^6, Ma =0.2, AoA = 20°
    at NASA Ames Research Center
  - 61×10^6 grid points (mostly hexahedral)





Too weak interaction of vortex and BL lead to incorrect local c_p peak at Φ ~ 155°
- Finer grid in boundary layer
- For EVMs application of vortex corrections

Vorticity contours at x/L = 0.77
- weaker with EVM



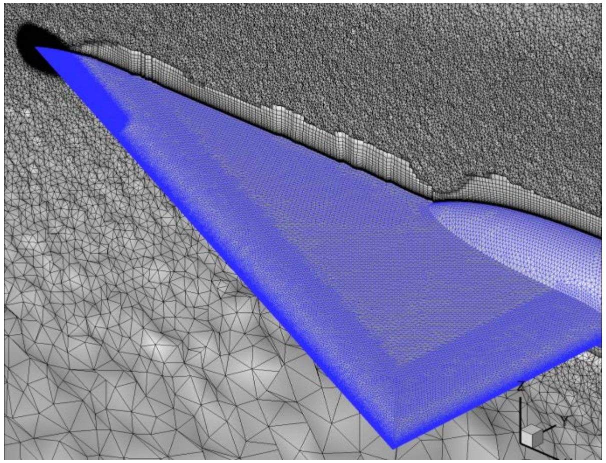
WP 2: Computations using selected SRS approaches

- Computations of some (selected) cases of WP1
- Selection of appropriate SRS approaches
  - Based on the results and findings from WP1
  - Taking into account latest achievements and results of other ongoing activities at DLR
  - Hybrid RANS/LES, e.g. DDES, IDDES, ADDES → Decision at project runtime
    - SGS: SA, SST → Decision at project runtime
- Generation of appropriate computational grids (preferably derived from WP1)
- Comparison with experimental data and results from WP1

Goals:
- Clarification in which flow situations RSM is sufficient or if SRS is necessary to predict the flow over a specified configuration
- Clarification which SRS approach is the appropriate (most appropriate) one
- Application recommendations, Best Practice

Hybrid RANS/LES results for VFE-2 Delta Wing at α = 23°

Sharp Leading Edge



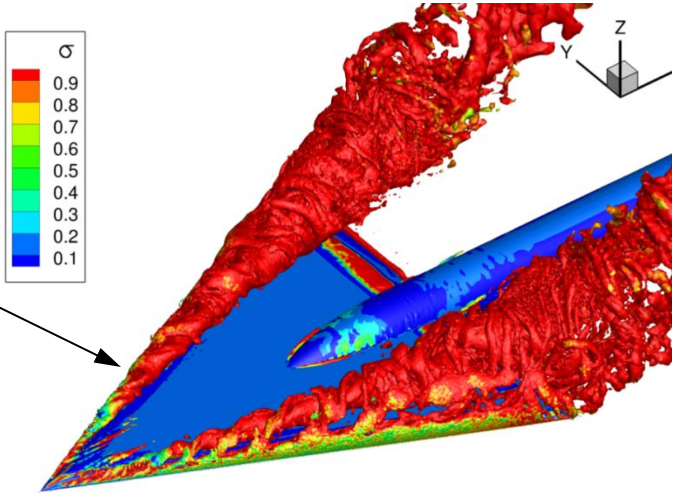
Unstructured grid from Airbus-DS:
- „industrial“ prism/tetra grid
- 17.5 million points

Numerics:
- DLR-TAU code
- assessment of hybrid LD2 (HLD2) scheme → active only in LES regions

Model: SST-DDES

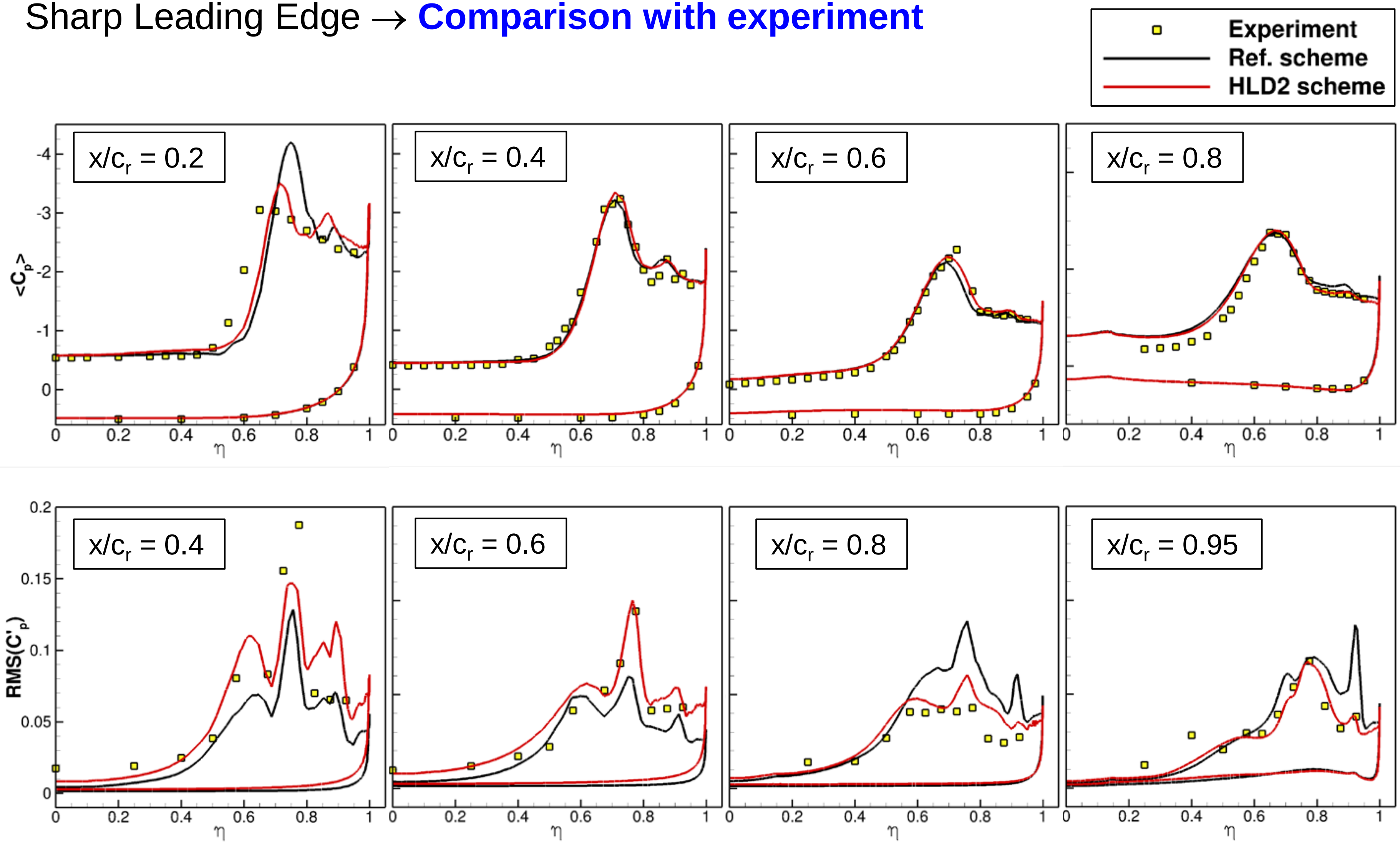
Temporal settings:
- time step: $3.75 \cdot 10^{-4}$ CTU
- total time: 11 CTU

HLD2 sensor:



Hybrid RANS/LES results for VFE-2 Delta Wing at α = 23°

Sharp Leading Edge → **Comparison with experiment**



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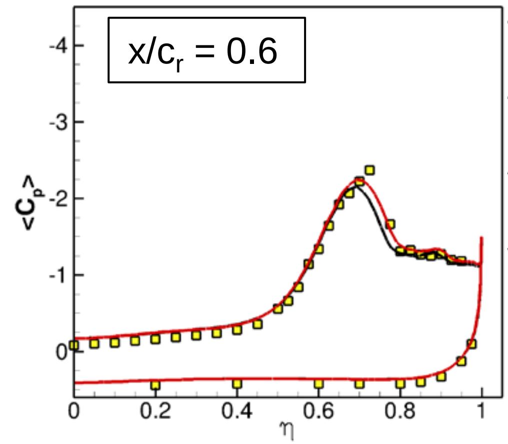
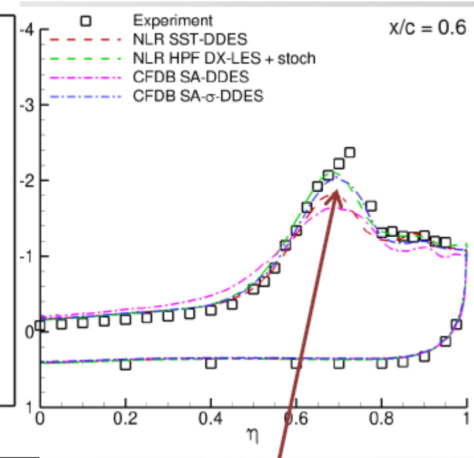
Hybrid RANS/LES results for VFE-2 Delta Wing at α = 23°

Sharp Leading Edge → **Comparison with experiment**

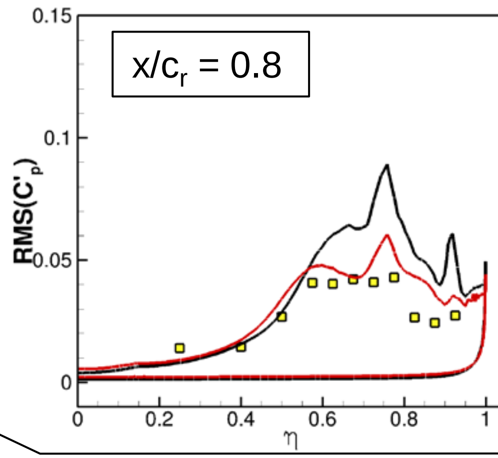
Go4Hybrid (EU project) **partner results:**

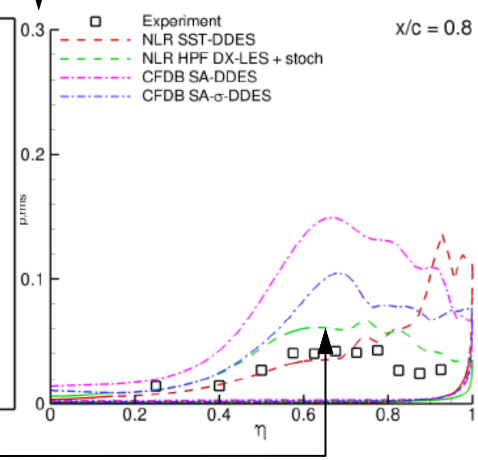
▪	**Experiment**
—	**Ref. scheme**
— (red)	**HLD2 scheme**





Note different scale!





Best match (green) **from a 4th order, structured code**

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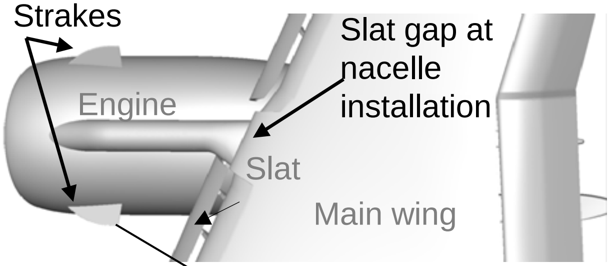
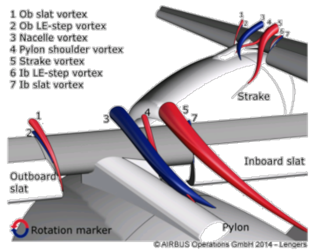
Hybrid RANS/LES results for a vortex-boundary-layer interaction

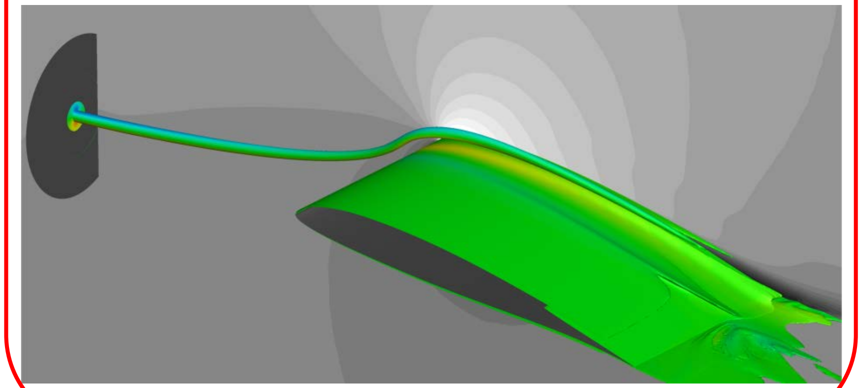
Reality:
Wing with engine nacelle





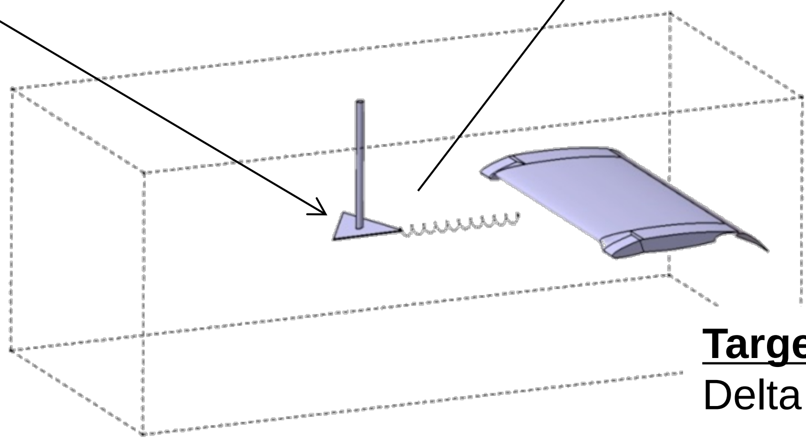
Picture from: M. Lengers; Industrial Assessment of Overall Aircraft Driven Local Active Flow Control

Principal study:
Actuator disc + HGR01 single-element



Reduction of computational effort
→ enable systematic investigations

Reduction of Complexity
→ Concentrate on relevant flow features



Target configuration:
Delta wing + DLR-F15 two-element

Hybrid RANS/LES results for a vortex-boundary-layer interaction

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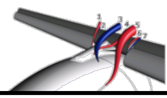

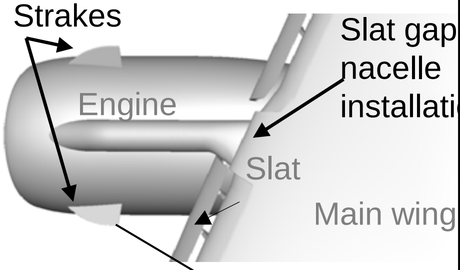

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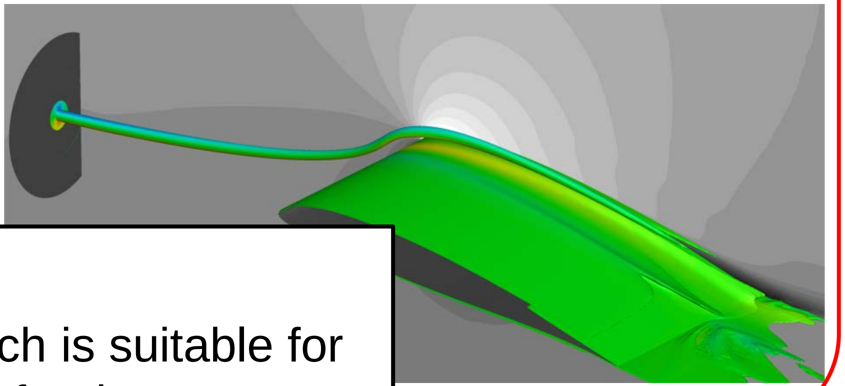
→ Concentrate on relevant flow features

Principal study:
Actuator disc + HGR01 single-element



… of
…onal effort
… systematic
…ons

…**ation**:
…R-F15 two-element

Motivation:

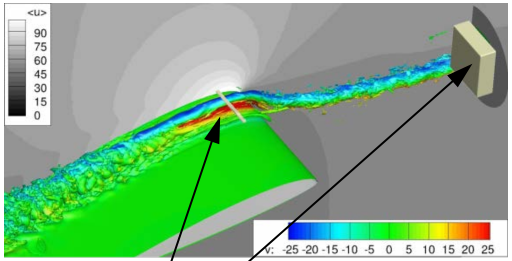
- Which modeling approach is suitable for a correct representation for the vortex-boundary-layer interaction?
- Is RANS with RSM sufficient?
- Is SRS necessary?
- How must the different approaches be applied? → grid properties, time steps, CTUs, …
- Will there be vortex burst?
- …

Experiences in vortex simulations are currently being made

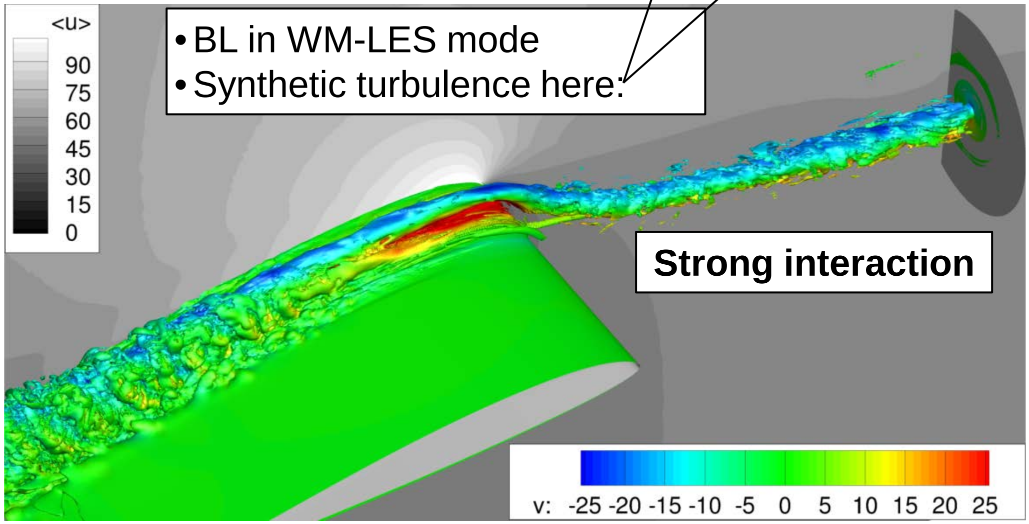
DLR

Chart: S. Probst

Hybrid RANS/LES results for a vortex-boundary-layer interaction

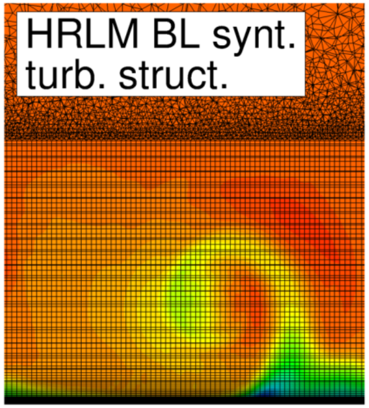


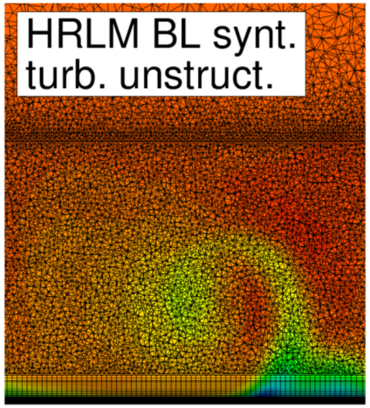
- **Resolved structures →**

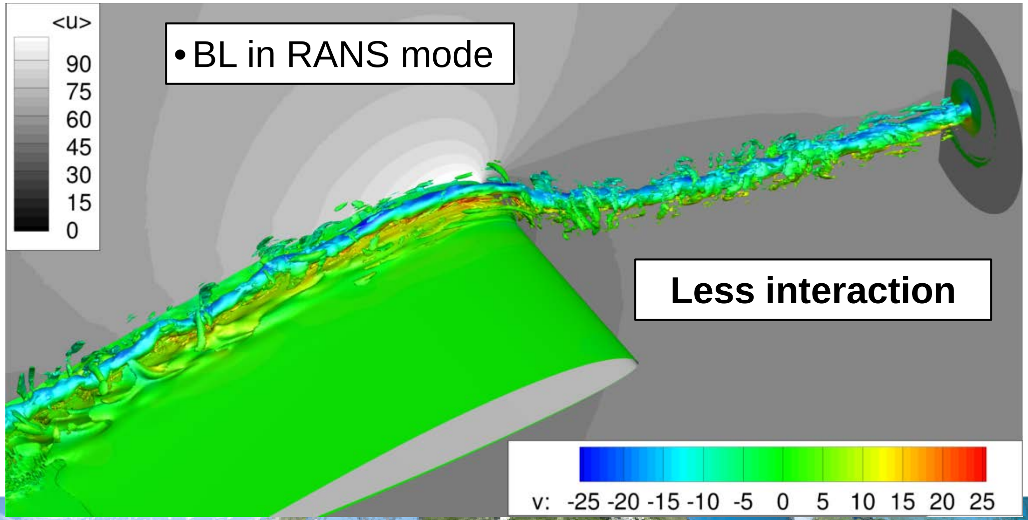


- **Effect of the vortex on the boundary layer at $x/c = 0.67$**

↓







- **Grid influence low**

Chart: S. Probst

WP 3: Extension a SRS approach through coupling to RSM

- Coupling of SSG/LRR to the SRS infrastructure in the TAU code
- Test computations using the most promising SRS + RSM
  - Demonstrate basic usability/functioning (from technical point of view)
  - Verification and simple validation test cases

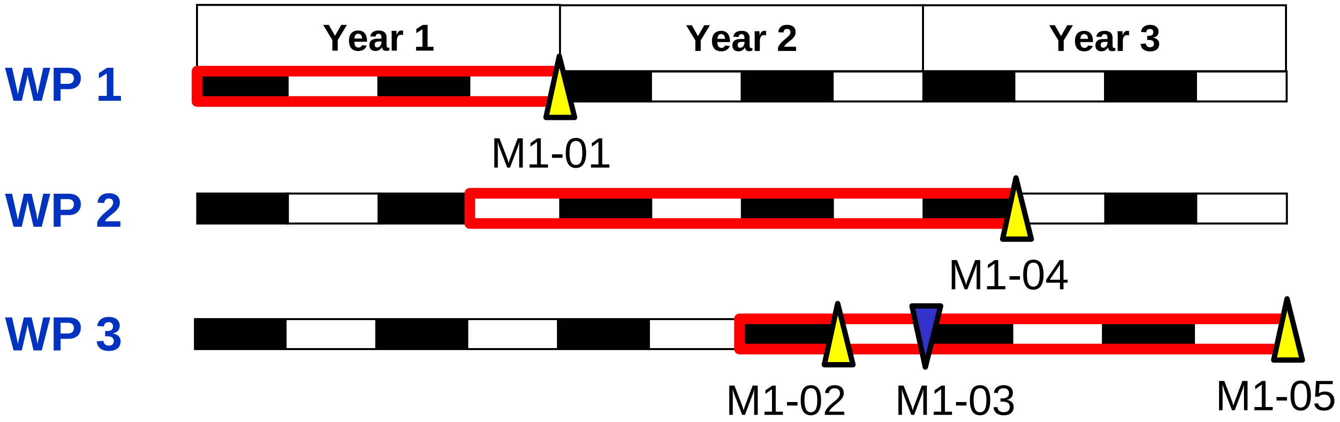
    $\Rightarrow$ ***Decision Milestone:*** if this fails suggestion(DLR)/discussion how to proceed
  - Decision if ω or *g or* $ln(\omega)$
- Selection of one SRS approach based on the results and findings from WP2
- Computation of selected test cases from WP2
- Comparison with experimental data and results from WP2

Goals:
- Clarification if RSM-based SRS beneficial and preferable compared to EVM-based SRS
- Determination and classification of the advantages
- Application recommendations, Best Practice

Timeline & Configurations

Milestones:

M1-01	Assessment of RSM capabilities for separated vortex-dominated flows available	QIV/Y1
M1-02	Basis SRS-RSM coupling implemented	QIII/Y2
M1-03	Verification of SRS-RSM coupling and simple validation test cases finalized	QIV/Y2 **!!!**
M1-04	Clarification which SRS approach is appropriate available	QI/Y3
M1-05	Determination and classification of advantages of SRS-RSM	QIV/Y3



Possible configurations:

- VFE-2
- Diamond wing (NATO/STO AVT-183)
- SACCON/DLR-F17
- …

DLR

References

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[2] Visonneau, M., Guilmineau, E., Toxopeus, S., ‚Incompressible ow calculations of blunt leading edge separation for a 53 degree swept diamond wing, AIAA 2015-0065

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