Transition Modeling Activities at AS-C²A²S²E (DLR)

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CFD Transition Modeling Discussion Group Meeting
7 June 2017, Denver (CO)
AIAA Aviation 2017

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Overview

- $C^2A^2S^2E$ – Numerical Methods Branch → CFD Code Development
  - **TAU code** – external aerodynamics, compressible
    → air vehicles
  - **THETA code** – internal/external flows, incompressible
    → combustion, wind turbines
  - ***Flucs* code** – external aerodynamics, compressible/incompressible
    → 2^{nd} order FV branch + HO-DG-branch
    → massive hybrid parallelization
    → development currently ongoing
    → 1^{st} release planned for 12/2019
- Main Customers
  - Internal: Transport Aircraft, Helicopters (incl. Wind Turbines), High-Speed Configurations, Spacecraft
  - External: Airbus Operations

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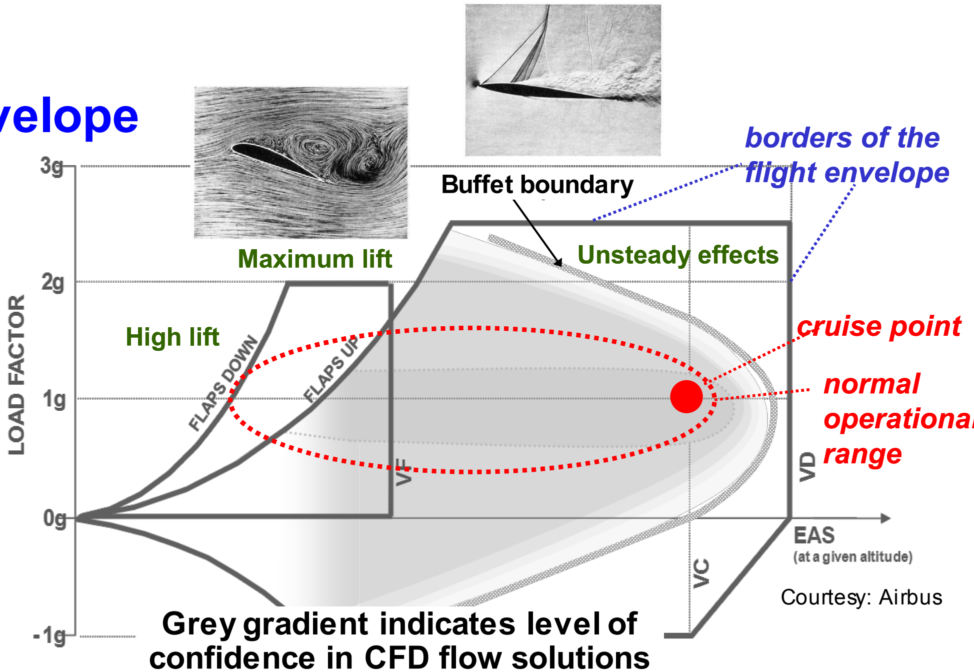
Vision: The Digital Aircraft

Numerical Analysis of Full Flight Envelope

- **Today**, very reliable results for **design point** applications.
- **Tomorrow**, same reliability needed for **complete flight envelope**.
  - Strong non-linearities
    - Separated flow regions
    - Strong shocks
    - Shock/boundary-layer interaction
  - Unsteady flows



- In general, all **major physical phenomena** must be captured with sufficient accuracy.
  - Flow separation, BL representation, shock/BL interaction, …
  - Vortices, wakes, free shear layers, engine jets, …
- CFD capabilities growing: discretization schemes, HPC capacities, grid generation, higher resolution, geometrical complexity and details, …
  - **Turbulence** and **transition models** are becoming weakest link in simulation chain.
  - Reliable **models are a key technology** in CFD.

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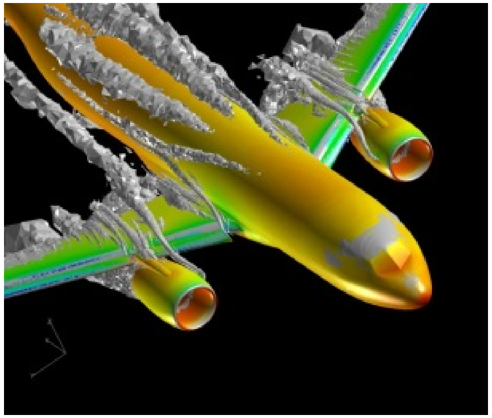
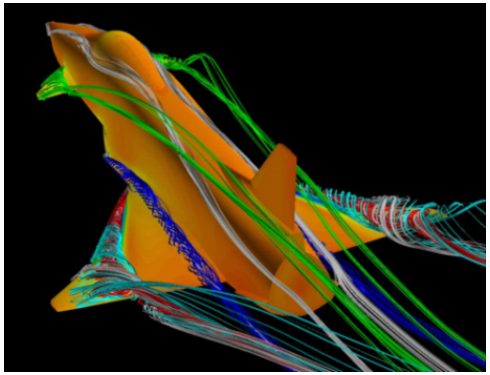
Fundamental Needs



Transition Prediction Capabilities in CFD Codes

- Applicable to **complex configurations**
- High level of **automation**, usable within simulation chains and multi-disciplinary simulation frameworks
  - No interference by code user
  - As little *a priori* knowledge as possible
  - Must be run in parallel on HPC clusters
- Transition mechanisms
  - **Crossflow, Tollmien-Schlichting, separation-induced, by-pass transition**
- **Accuracy** of simulation results
  - Point of transition onset, interaction with turbulence model
  - Impact on major flow quantities and properties: c_p, c_f, heat flux, separation/reattachment lines, size of separation, …



- **Stability** and **robustness** of implementation/procedure
- **User acceptance**
- **Large application range**
  - Steady RANS, unsteady RANS, rotating systems, SRS

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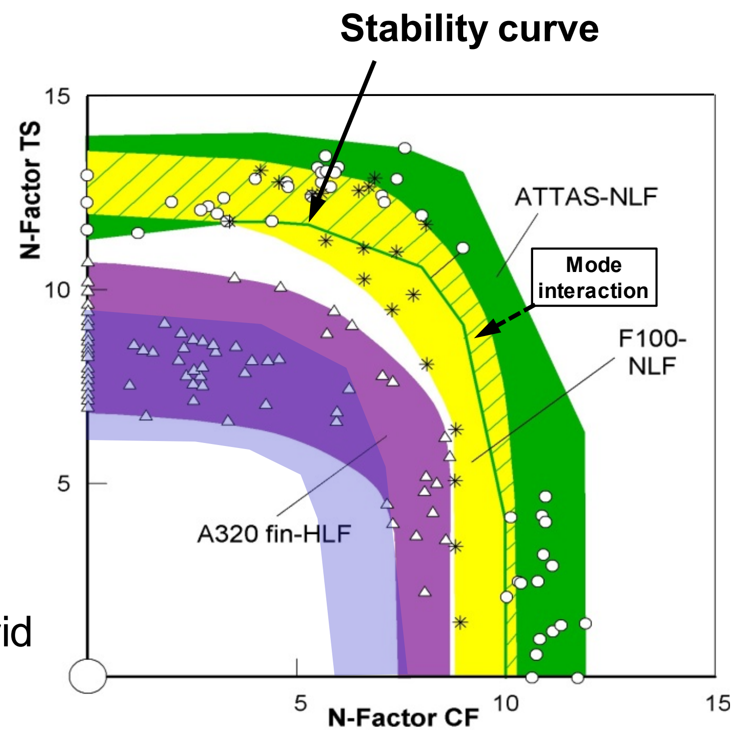
Fundamental Needs



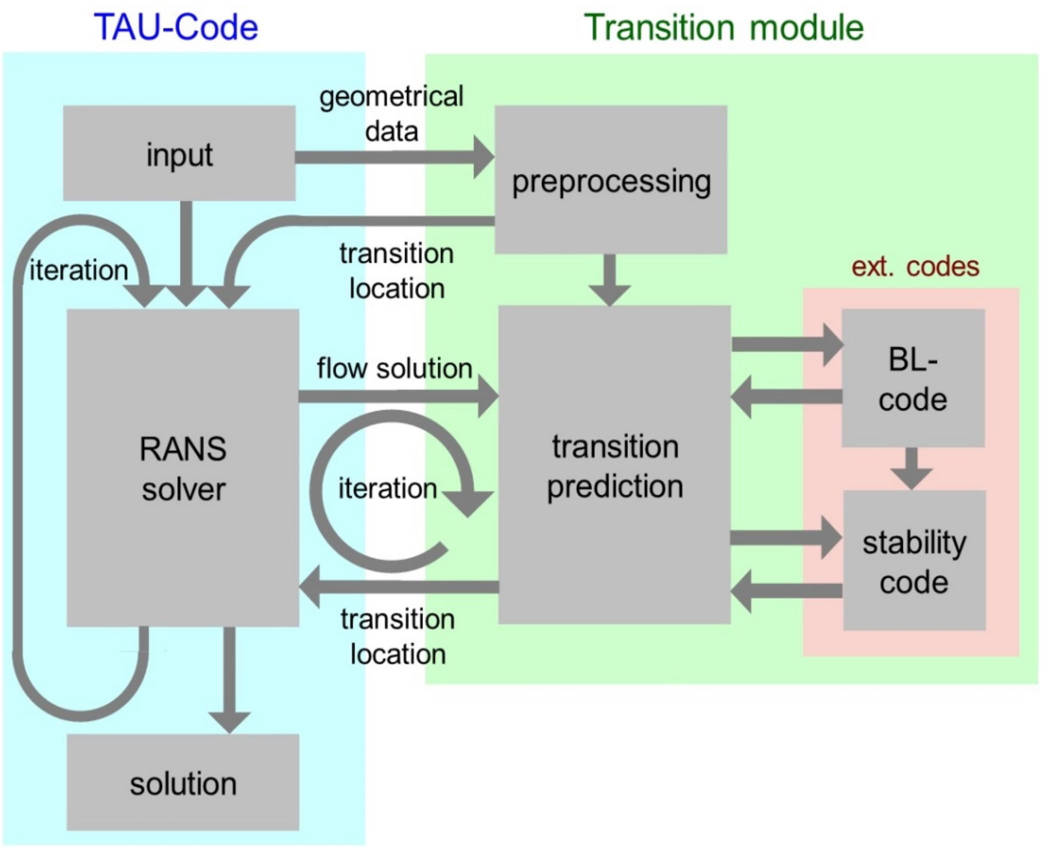
Transition Prediction Capabilities in CFD Codes

- **More than one method necessary** to satisfy the wide range of requirements.
  - **Streamline-based** approaches using a simplified ***two-N-factor* strategy** + by-pass criterion
    - Different ways of BL computation
      - Based on RANS solution and RANS grid
      - Laminar BL code
  - **γ-Re$_\theta$** transport equation model **+** DLR **crossflow (CF) extension**
- **Complementary use** of the different approaches for different applications, e.g.
  - Laminar flow design and analysis using *two-N-factor* strategy
  - Massively unsteady flows (e.g. with rotation) using γ-Re$_\theta$-CF model

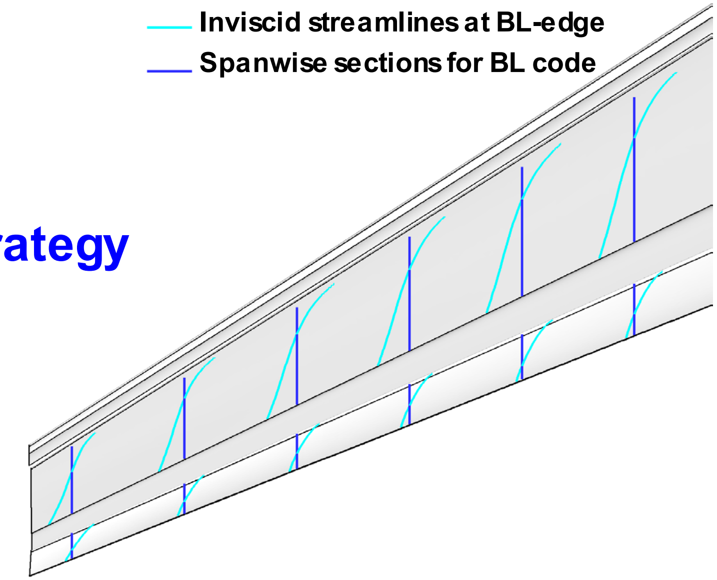
TAU Transition Prediction Module

Streamline-based approaches & *two-N-factor* strategy

- Coupling of TAU code with transition prediction module

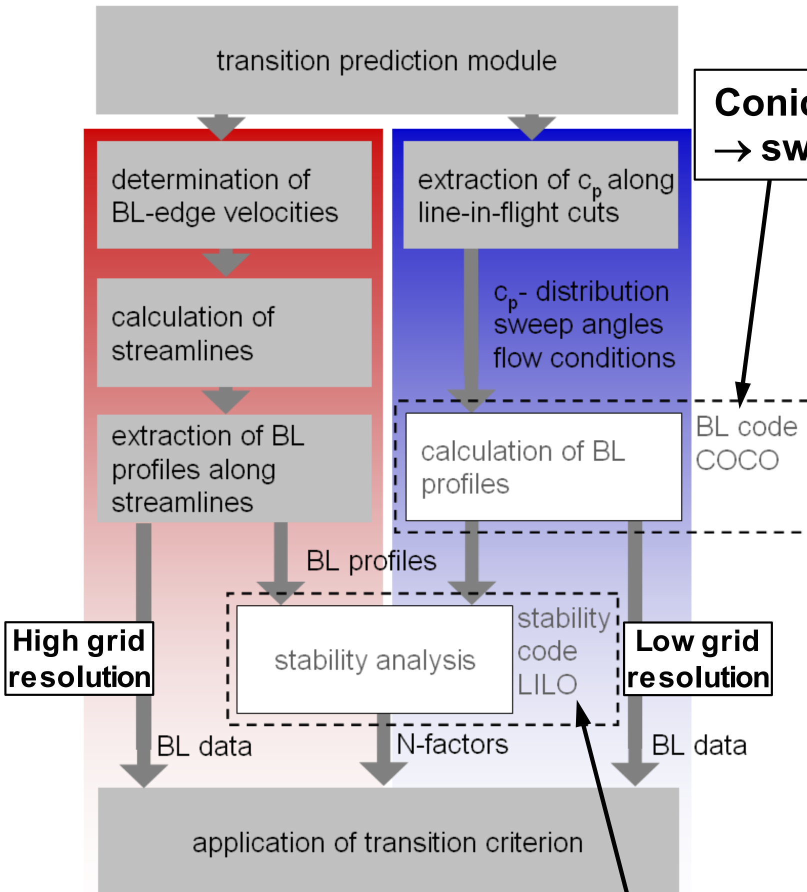


TAU Transition Prediction Module



Streamline-based approaches & *two-N-factor* strategy

- Internal structure of transition prediction module



Conical laminar BL code
→ swept, tapered wings

Fully automated local, linear stability code
→ frequency + wave length estimators for automation

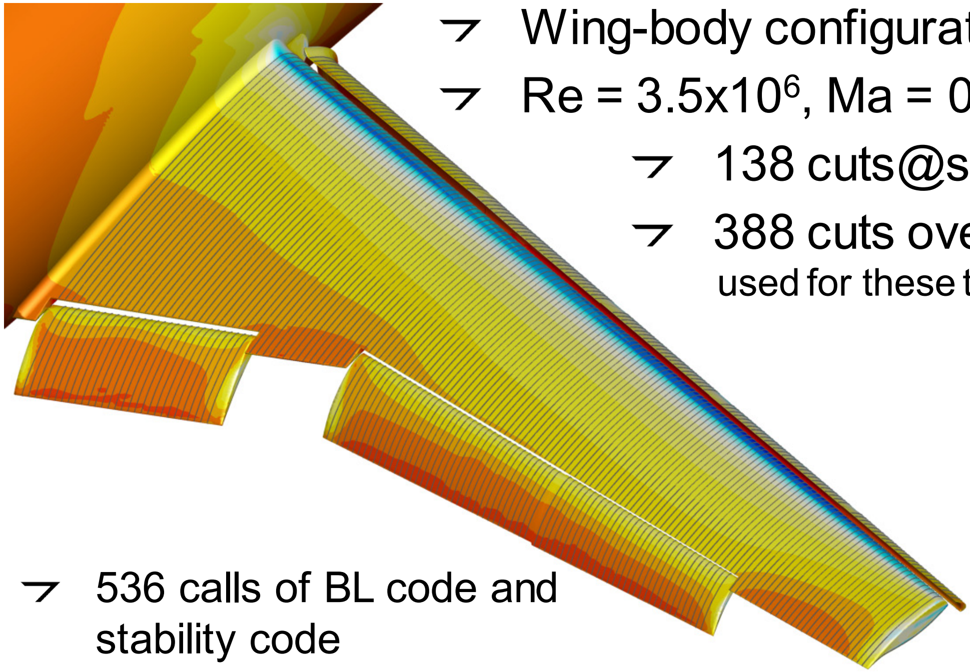
- ***Line-in-flight* cuts** (strip theory)
  - Accurate results for swept tapered wings.
  - Two sides (upper/lower) per cut, divided by stagnation/ attachment line point
- **Inviscid streamlines**
  - Necessary for fuselages, nacelles etc.
  - Start at attachment line
    → Attachment line must be determined too.
  - Suggests separate treatment of upper and lower sides
- **Execution of the stability code along these lines**
  - One single transition point per cutside/line.
  - Transition line is a polygonal line on the surface.

- external BL approach
- BL data from BL code
- line-in-flight cuts

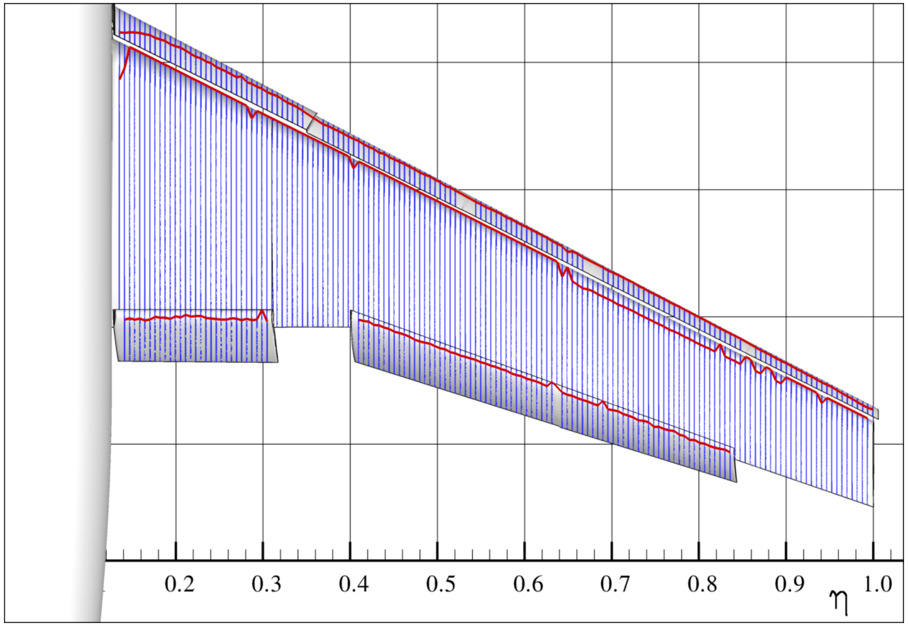
TAU Transition Prediction Module

Streamline-based approaches & *two-N-factor* strategy

- **Technical feasibility**



- Wing-body configuration with 4-element high-lift wing
- Re = 3.5x10^6, Ma = 0.17, α = 14.0°, only T-S considered
  - 138 cuts@slat 148 cuts@wing, 29/73 cuts@flap
  - 388 cuts overall, 536 transition points (≈ 50 cuts usually used for these type of configuration)



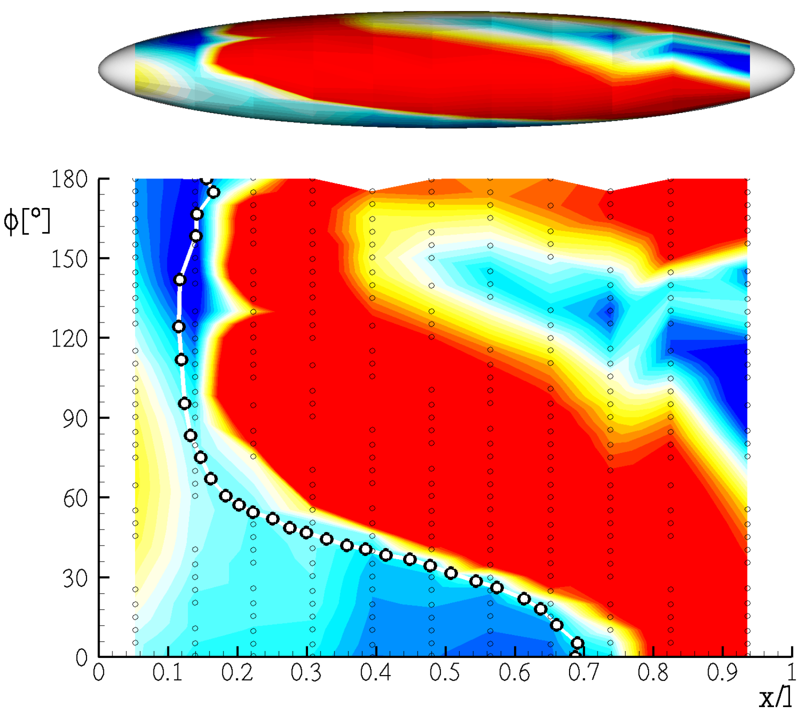
- 536 calls of BL code and stability code
- **96 processes**
- **Computations stable and reliable on HPC clusters**

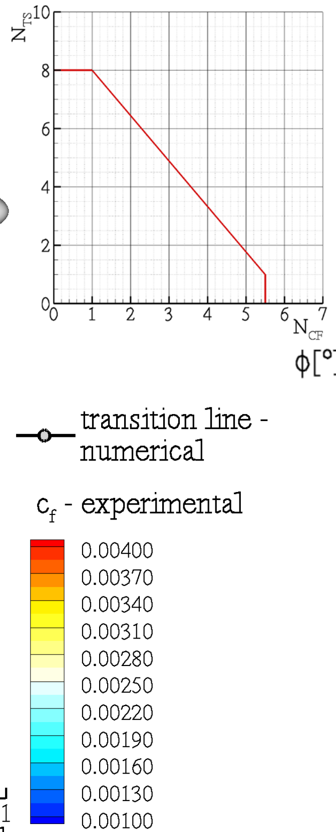
TAU Transition Prediction Module

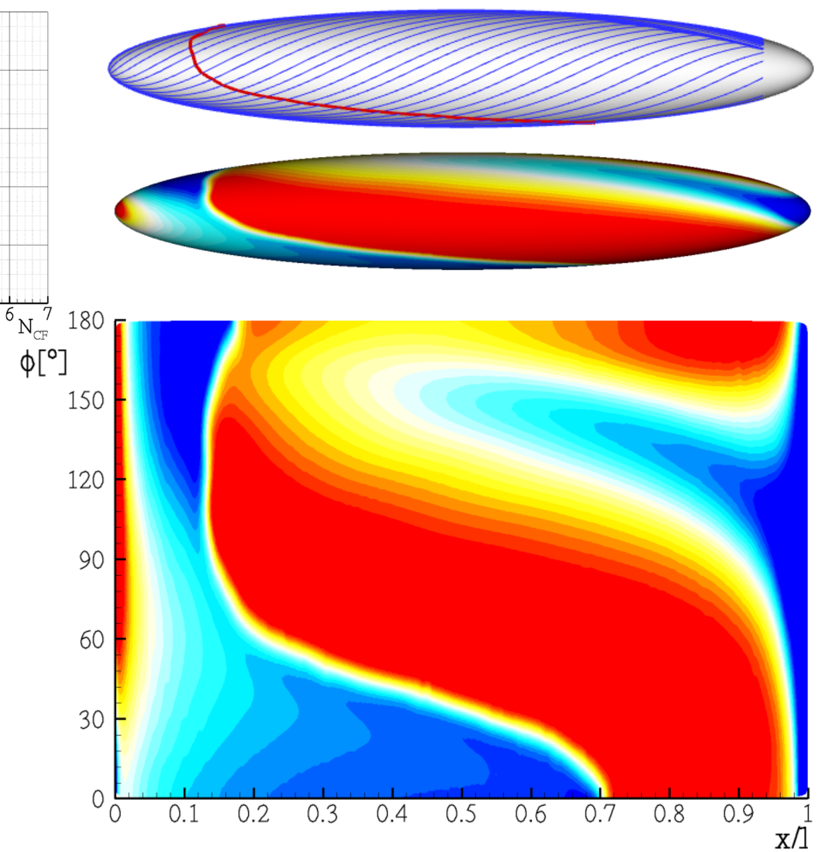
- internal BL approach
- BL data from RANS
- inviscid streamlines

Streamline-based approaches & *two-N-factor* strategy

- **Validation**
  - Inclined prolate 6:1 spheroid: Re = 6.5x10^6, Ma = 0.13, α = 15.0°
  - CF-dominated

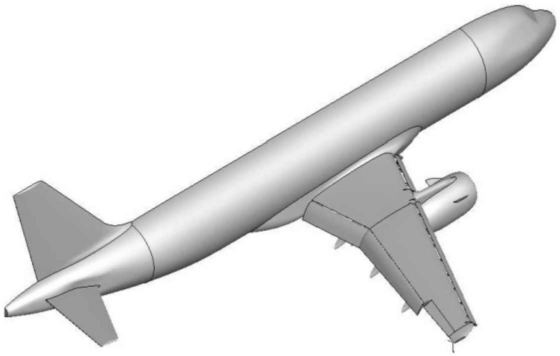






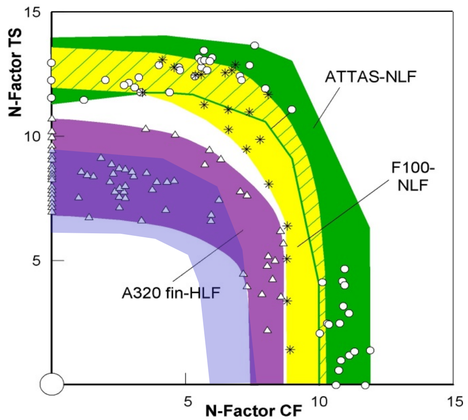
- external BL approach
- BL data from BL code
- line-in-flight cuts

TAU Transition Prediction Module

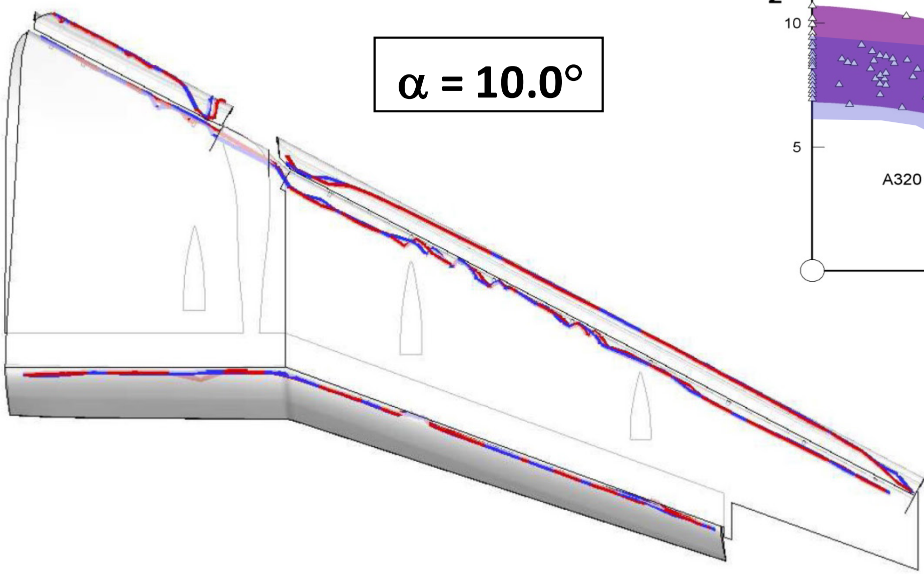


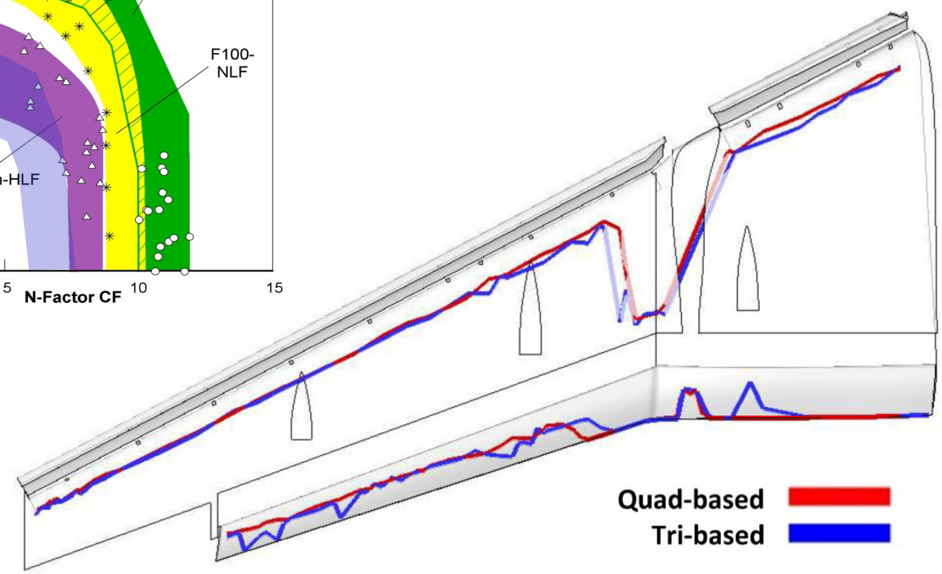
Streamline-based approaches & *two-N-factor* strategy

- **Impact on CFD results**
  - DLR A320 D-ATRA high-lift landing configuration
  - Re = 17×10^6, Ma = 0.2
  - Two different grids



α = 10.0°





Suction side

Pressure side

- external BL approach
- BL data from BL code
- line-in-flight cuts

TAU Transition Prediction Module

Streamline-based approaches & *two-N-factor* strategy

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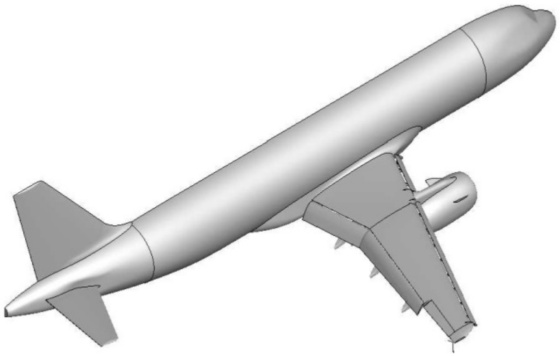
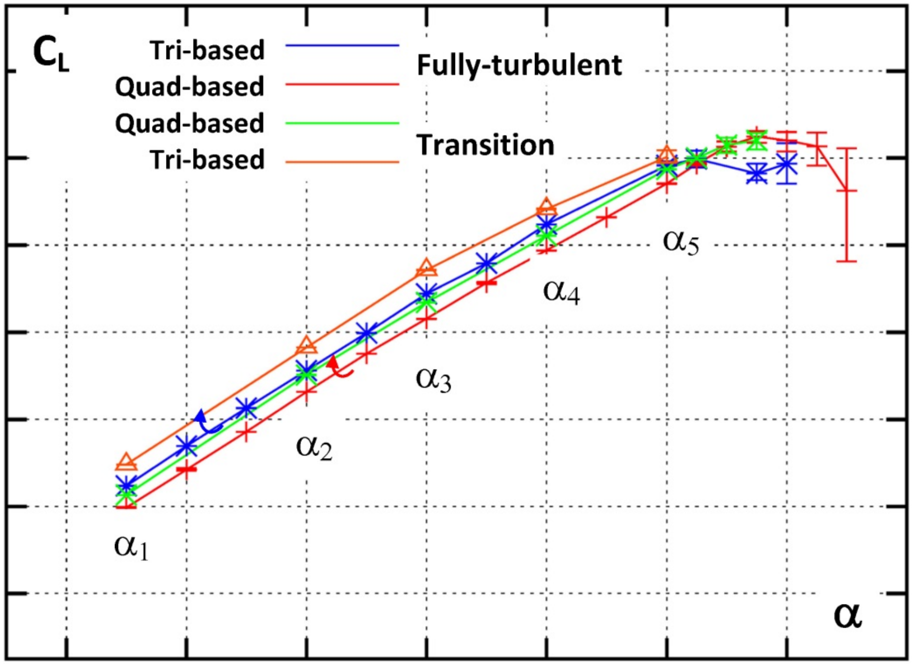
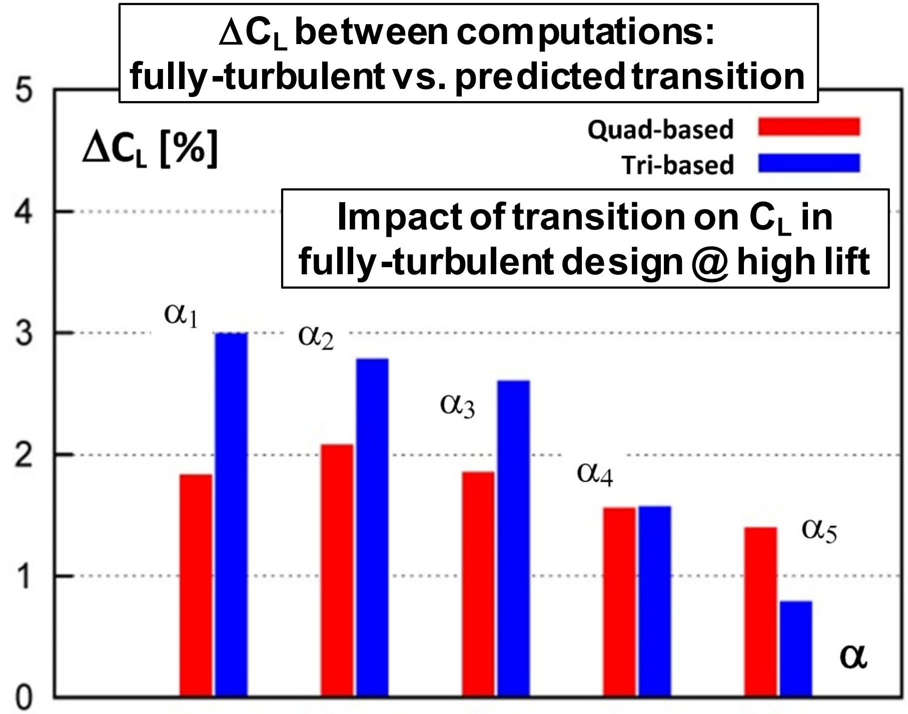
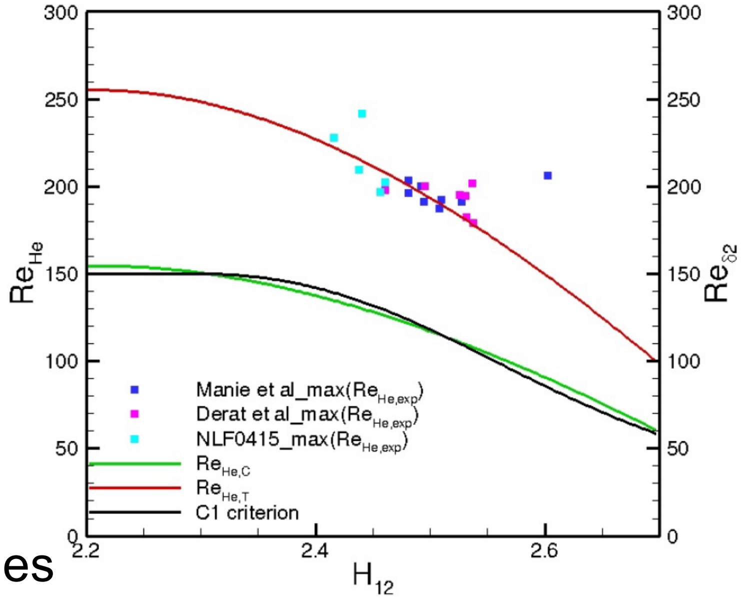






γ-Re$_\theta$-CF Model

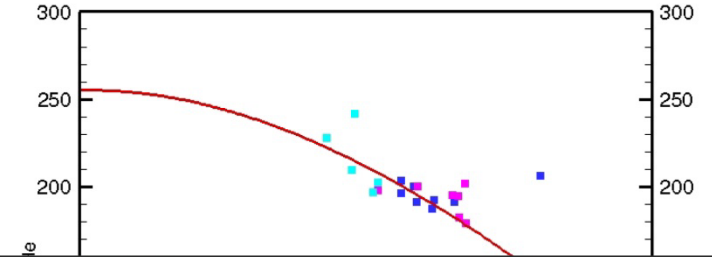


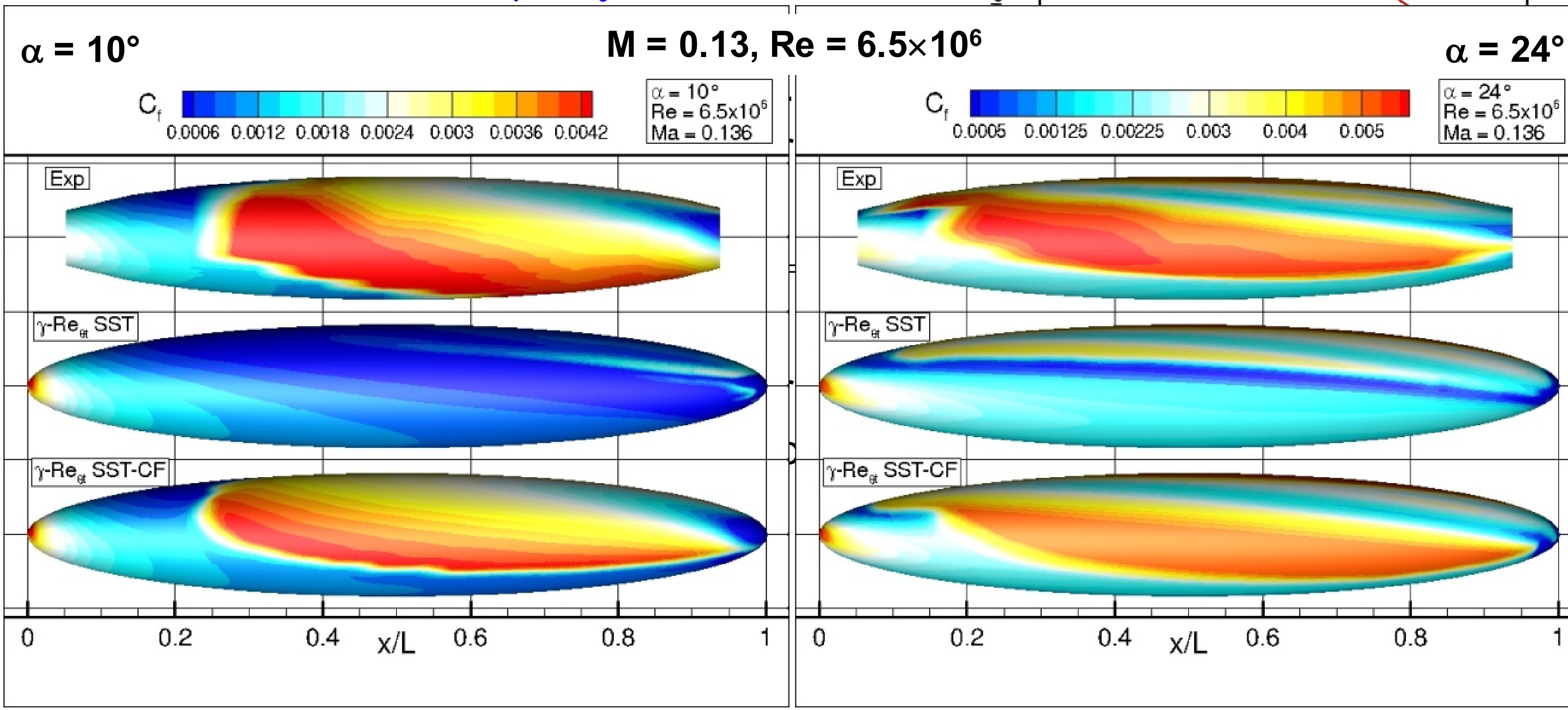
Crossflow extension of γ-Re$_\theta$ model

- Published 06/2016 in conjunction with Menter SST k-ω
- Based on helicity Re number $Re_{He} = y^2/\nu\, He/||\boldsymbol{u}||$
- $Re_{\delta 2c}(H)$ and $Re_{He}(H)$ qualitatively very similar
- Calibration of $Re_{He,tr}(H)$ using ISW standard cases
- Find empirical fully-local correlation function for shape factor H

γ-Re_θ-CF Model

Crossflow extension of γ-Re_θ model





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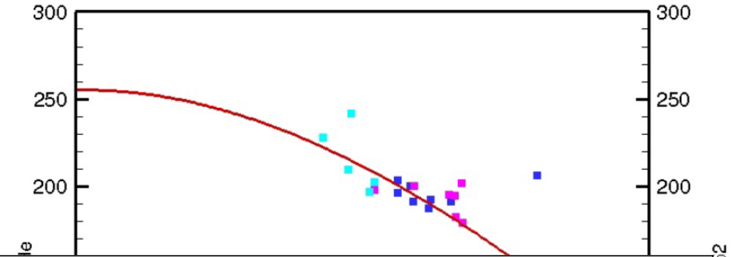
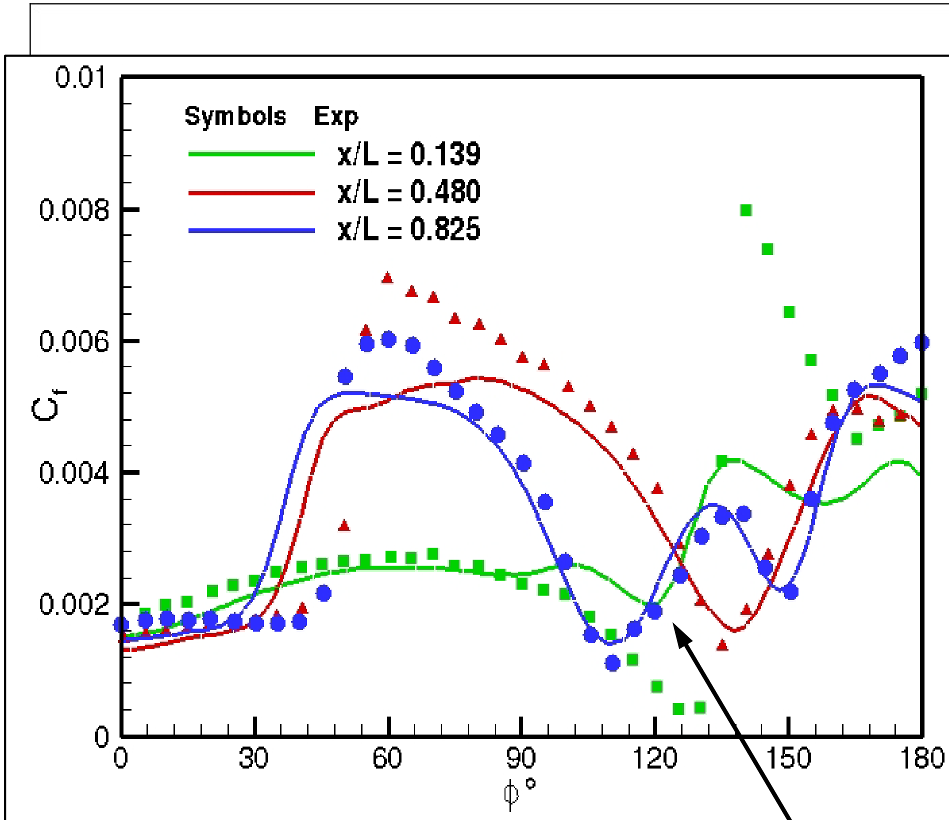
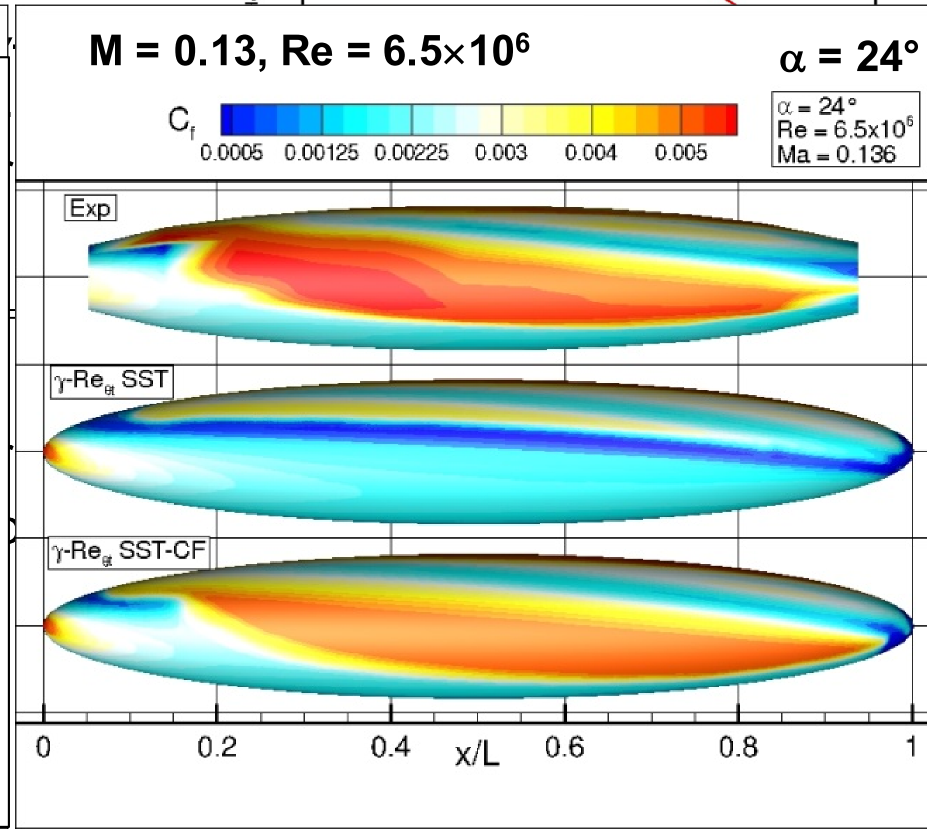
γ-Re_θ-CF Model

Crossflow extension of γ-Re_θ model

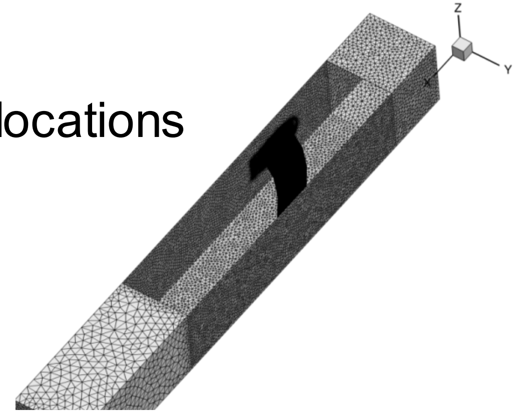






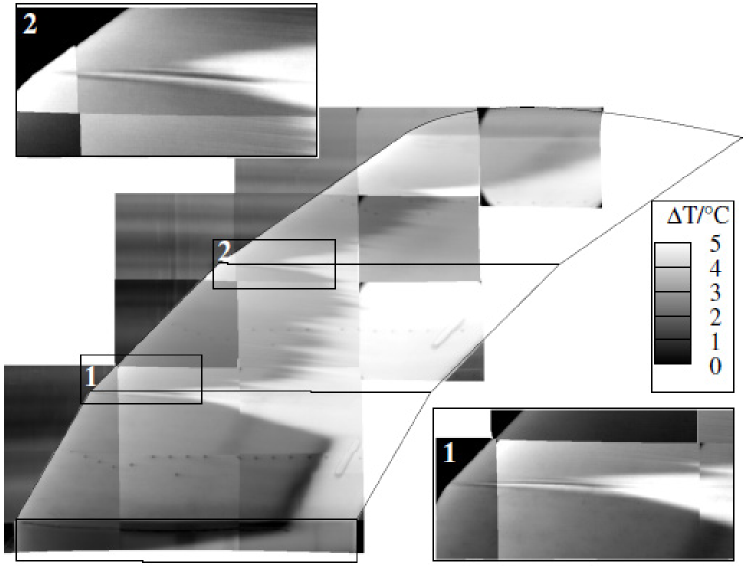
Still room for improvement.

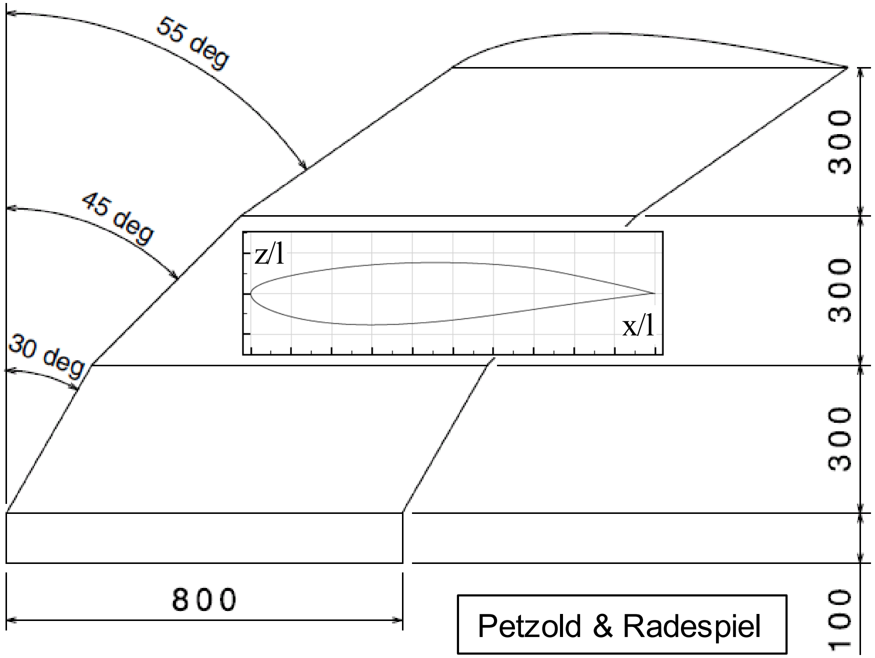
γ-Re_θ-CF Model



Sickle-shaped wing (Petzold and Radespiel, 2015)

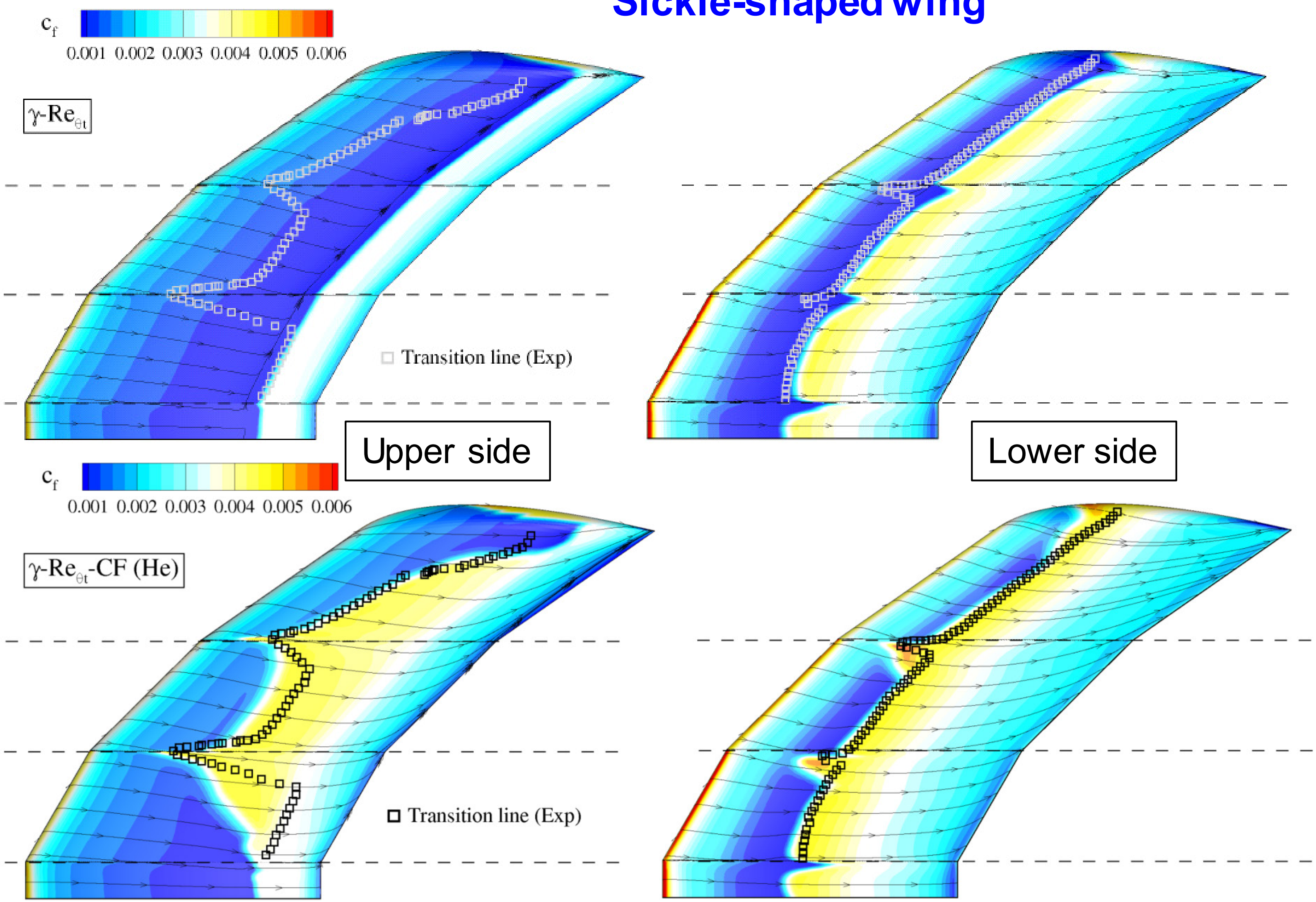
- Well documented, pressure distributions & transition locations
- Surface roughness and turbulence intensity given
- $Re_c = 2.75 \times 10^6$, $\alpha = -2.6$, $M = 0.16$





γ-Re_θ-CF Model

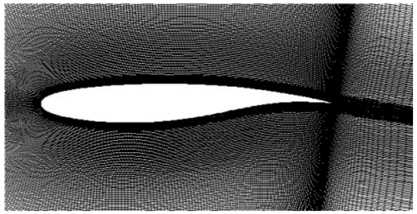
Sickle-shaped wing

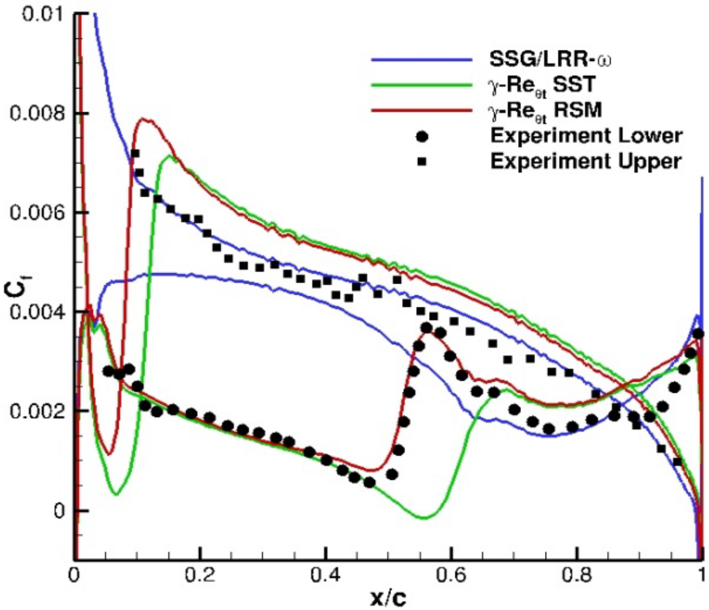


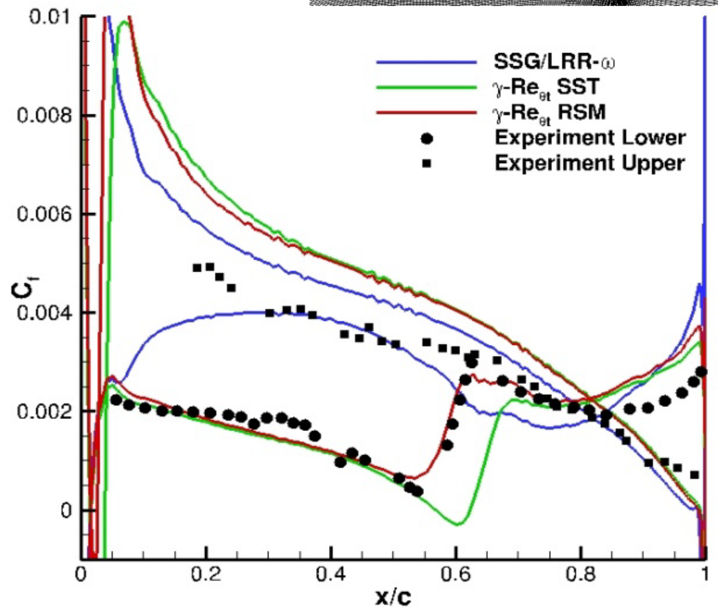
γ-Re$_\theta$-CF Model

Coupling to SSG/LRR-ω DRSM → PhD thesis just finalized

- γ-Re$_\theta$ + γ-Re$_\theta$-CF models: model functions newly calibrated
- 2 publications underway
- **MBB VA-2 airfoil:** M = 0.2, Re = 2.0×10^6, α = 3.5° and 7.5°







- **Improvement:** Good results for the two angles of attack for γ-Re$_\theta$-RSM using consistent setting of FSTI (identical values) in contrast to γ-Re$_\theta$-SST (different values necessary)

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Open Issues & Future Plans

Streamline-based approaches & *two-N-factor* strategy

- Intermittency function to be implemented
  - Currently only ‘point-transition‘ at point of transition onset
  - Probably, for every turbulence model an individual calibration necessary
- Linear PSE + compressible analysis + curvature: ???
  - Instead of, currently, incompressible analysis using LST
  - Is it possible/reasonable/reliable for more than infinite swept wing?
  - Currently under discussion
- Programming of a ‘new’ python-based version of the transition module
  - Currently available for TAU and THETA, via library
  - Coupling of the new module the multi-disciplinary simulation environment **FlowSimulator**
    - Couples new transition module to TAU, THETA, *Flucs* (and potentially other CFD codes)
    - Couples CFD to CSM and Flight Mechanics
  - This will be a major effort!

Open Issues & Future Plans

γ-Re_θ-CF Model

- Improvement of CF extension
- Rotor applications → modifications for rotating systems
- Galilei invariance → focus on helicity-based CF extension
- Improvement of the stream-wise criterion for high Reynolds numbers

both approaches

- Extension for Hybrid-laminar Flow Control (HLFC)
  - Started for streamline-based approaches → validation of suction BCs
  - For γ-Re_θ-CF: fully open!
- Incorporation of surface roughness, steps and gaps, waviness
- Coupling, verification, validation, application with scale-resolving simulation methods (HRLM, SAS)
- …

CFD Transition Modeling Discussion Group Meeting

Some thoughts

- Verification of implemented models/approaches necessary

  - Along the lines of Turbulence Modeling Resource (TMR) Website (NASA-LaRC): https://turbmodels.larc.nasa.gov

  - For transport equation approaches: concept could be adopted as is
    - γ-Re_θ(-CF), AFT, γ(-CF), laminar kinetic energy, …
    - Documentation of approaches would be necessary.

  - For approaches using a point of transition onset:
    - Numerical treatment of laminar and transitional points in the computational grid must be verified
    - Fixed/prescribed transition
    - e^N methods, empirical criteria, …
    - Point transition vs. intermittency functions
    - …

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CFD Transition Modeling Discussion Group Meeting

Some thoughts

- **Before** all this: Verification of the turbulence model used in conjunction with any transition model MUST be verified!
- Test Cases
  - Need for cases with sufficient and reliable measurement data relevant for transition
    - Point of transition, transition region, end of transition region
    - c_f-distribution
    - Wind tunnel turbulence intensities including variations in test section
    - Measurement uncertainties, error bars
    - Definition of the ‘transition point’
    - …
  - More 3D cases
    - JAXA JSM
    - HL-CRM
    - NLF-CRM
    - …