



Automatische Transitionsvorhersage im DLR *TAU* Code Status der Entwicklung und Validierung

Automatic Transition Prediction in the DLR *TAU* Code - Current Status of Development and Validation

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Airbus

Outline

- Introduction
- Different Coupling Approaches
- Transition Prediction Coupling Structure
- Computational Results
 - 2D two-element configuration
 - 2D three-element configuration
 - 3D generic aircraft configuration (very brief)
- Conclusion & Outlook

Introduction

- **Background of considering transition in RANS-based CFD tools**
 - **Better numerical simulation results**
 - Capturing of physical phenomena, which were discounted otherwise
 - Quantitatively, sometimes even qualitatively the results can differ significantly w/o transition
 - Influence on lift and drag, pressure and skin friction distribution
- **Long term requirement from research organisations and industry**
 - Possibility of general transition prescription
 - Some kind of transitional flow modelling
 - Transition prediction
 - Automatically: no intervention by the code user
 - Autonomously: as little additional information as possible
 - Multi-element wing configurations

Introduction

- Main objectives of the functionality today
 - Improved simulation of interaction between transition and separation
 - Exploitation of the full potential of advanced turbulence models
- Applications areas today
 - EU- and DLR-Projects
 - INROS (Design of helicopter airfoils)
 - SIMCOS (Dynamic Stall)
 - iGREEN (Shock buffet of laminar wings)
 - TELFONA (N factors of ETW)
 - Design of high lift systems with long laminar boundary layers (EL II)
 - Cruise configurations (Lufo IV-Aeronext, Wing stall investigation)
 - Performance of sailplanes (laminar length on fuselage up to 20%)
 - Future laminar wing of a transport aircraft

➤ Different coupling approaches:

- RANS solver + stability code + e^N method
- RANS solver + boundary layer code
+ stability code + e^N method
- RANS solver + boundary layer code
+ e^N database method(s)
- RANS solver + transition closure model or
transition/turbulence model

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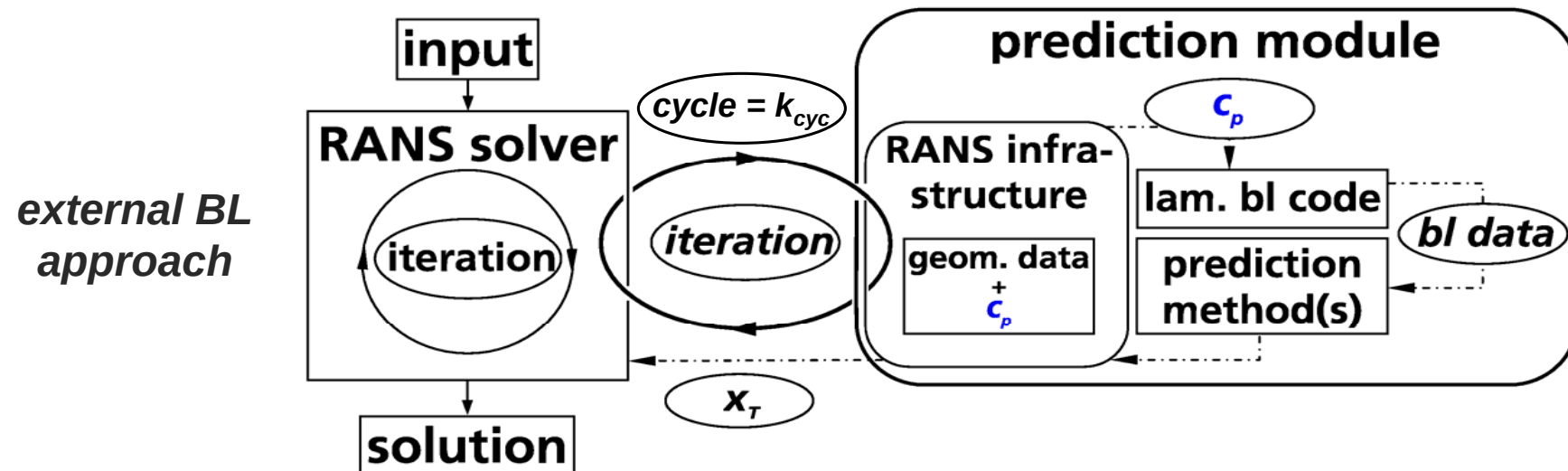
- Different coupling approaches:
 - RANS solver + stability code + e^N method
 - RANS solver + boundary layer code
+ fully automated stability code
+ e^N method
 - RANS solver + boundary layer code
+ e^N database method(s)
 - RANS solver + transition closure model or
transition/turbulence model



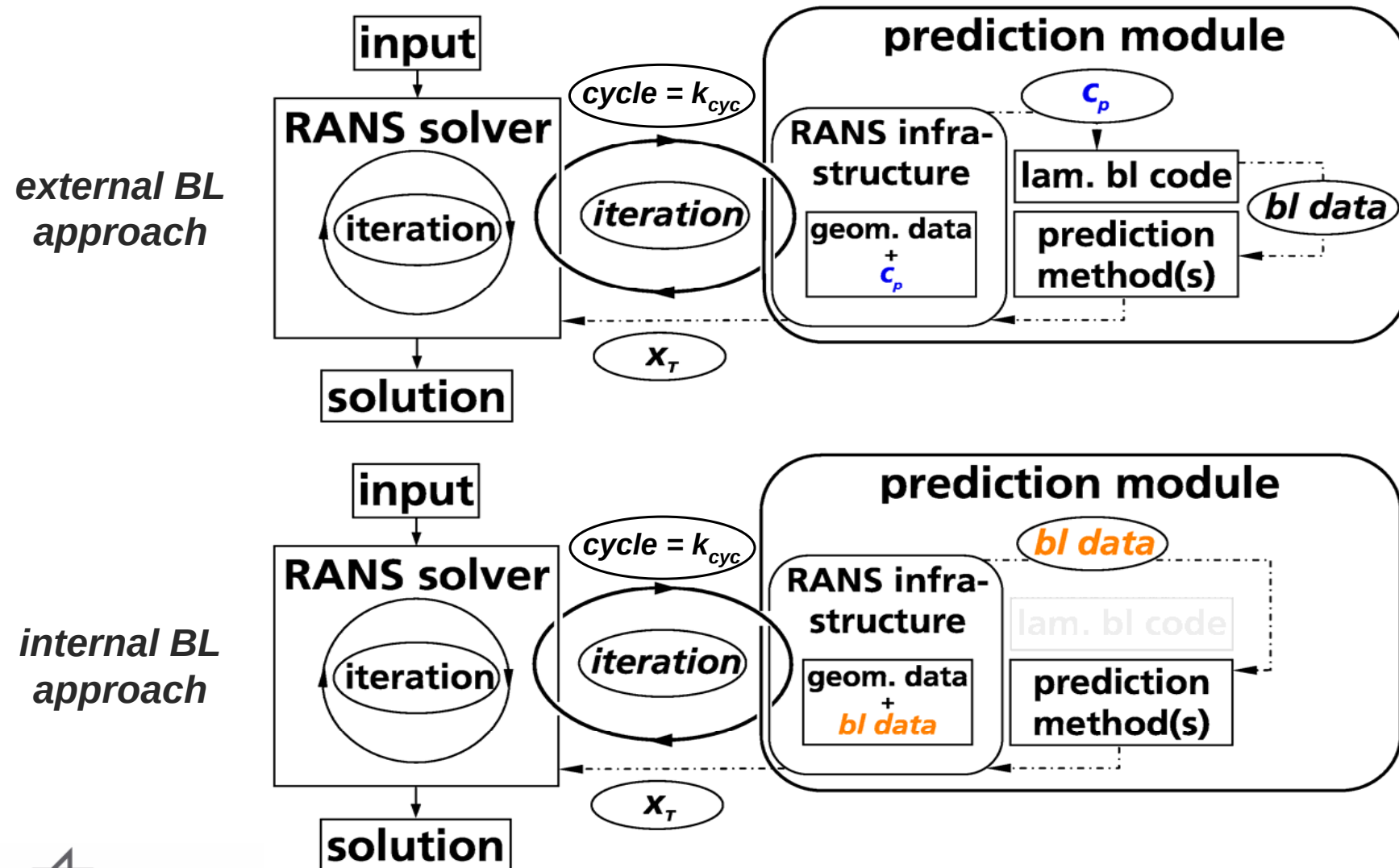
➤ Different coupling approaches:

- **RANS solver + fully automated stability code + e^N method** ← 2
- **RANS solver + boundary layer code + fully automated stability code + e^N method** ← 1
- **RANS solver + boundary layer code + e^N database method(s)** ← 3
- **RANS solver + transition closure model or transition/turbulence model** ← future

Transition Prediction Coupling Structure



Transition Prediction Coupling Structure

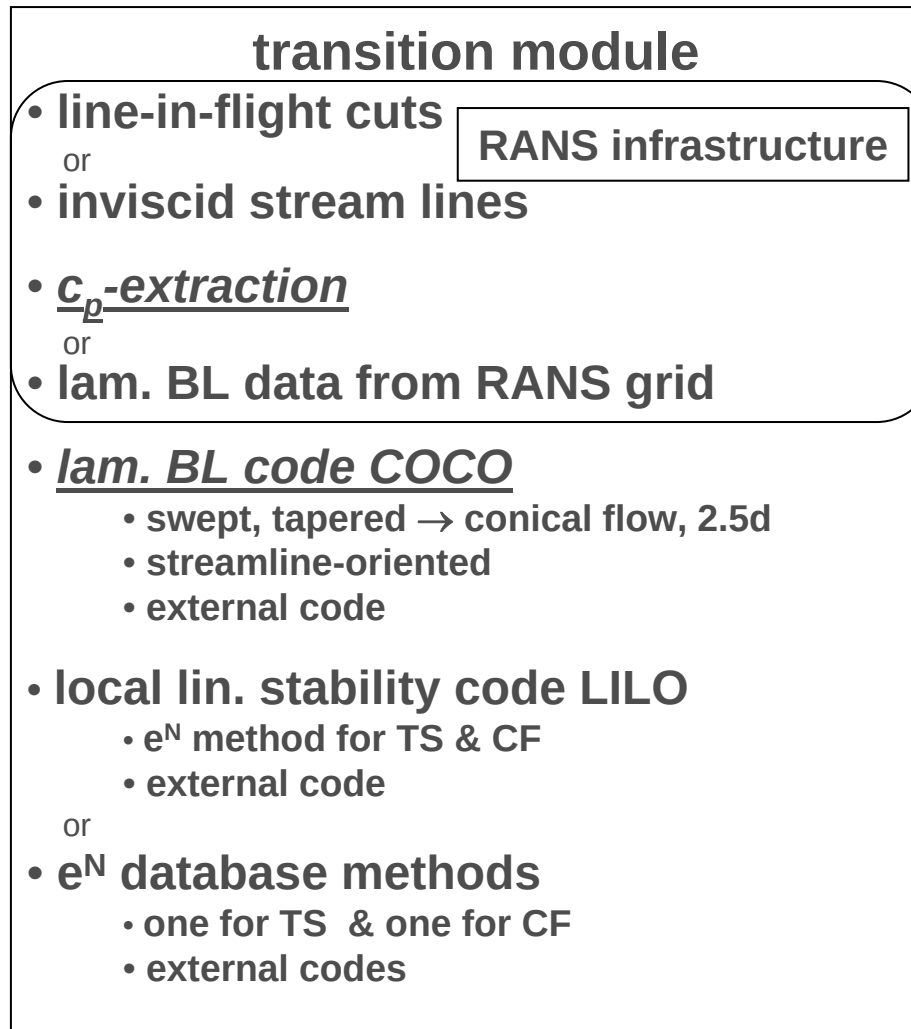


➤ Transition prediction module

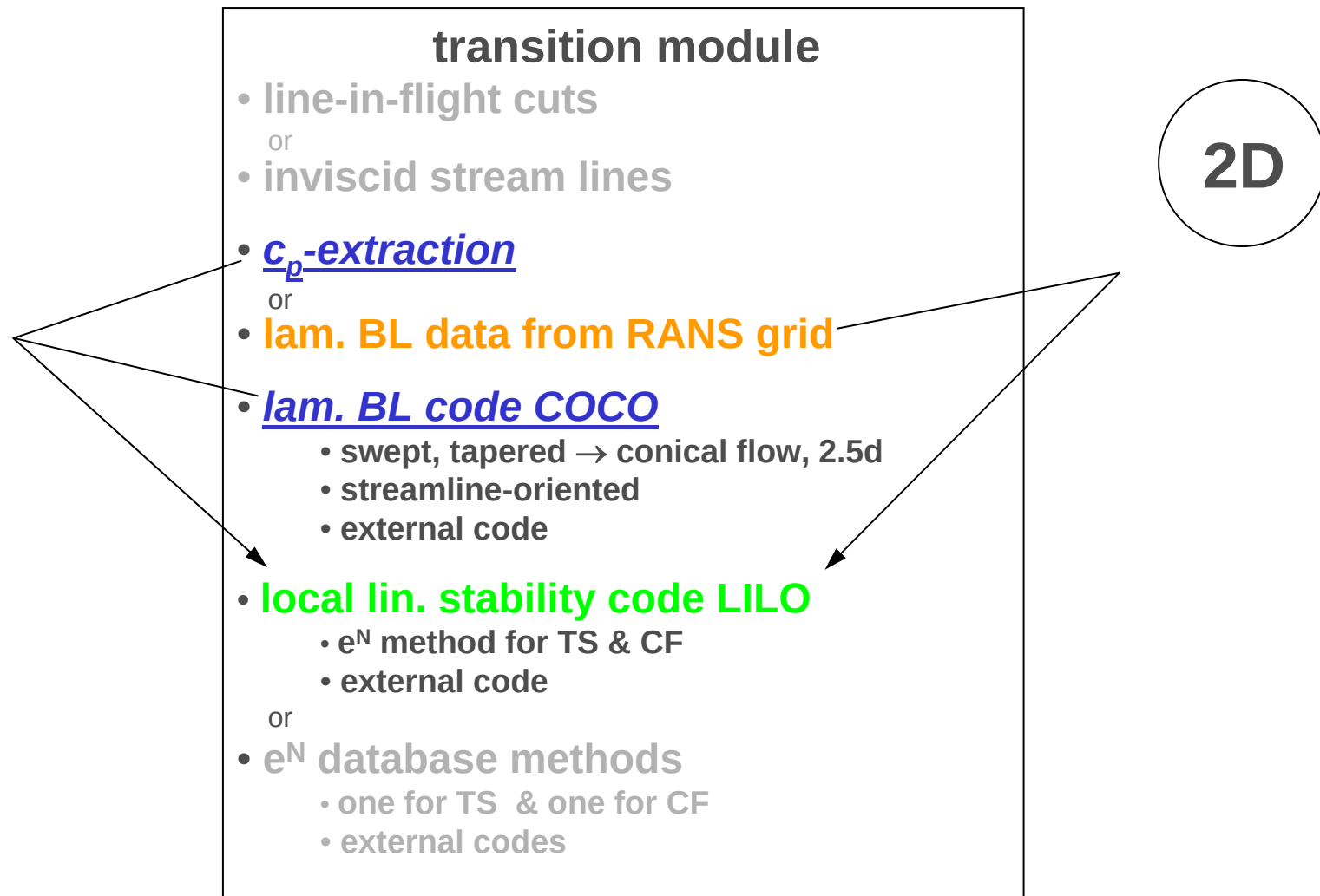
transition module

- line-in-flight cuts
- or
- inviscid stream lines
- c_p -extraction
- or
- lam. BL data from RANS grid
- lam. BL code COCO
 - swept, tapered → conical flow, 2.5d
 - streamline-oriented
 - external code
- local lin. stability code LILO
 - e^N method for TS & CF
 - external code
- or
- e^N database methods
 - one for TS & one for CF
 - external codes

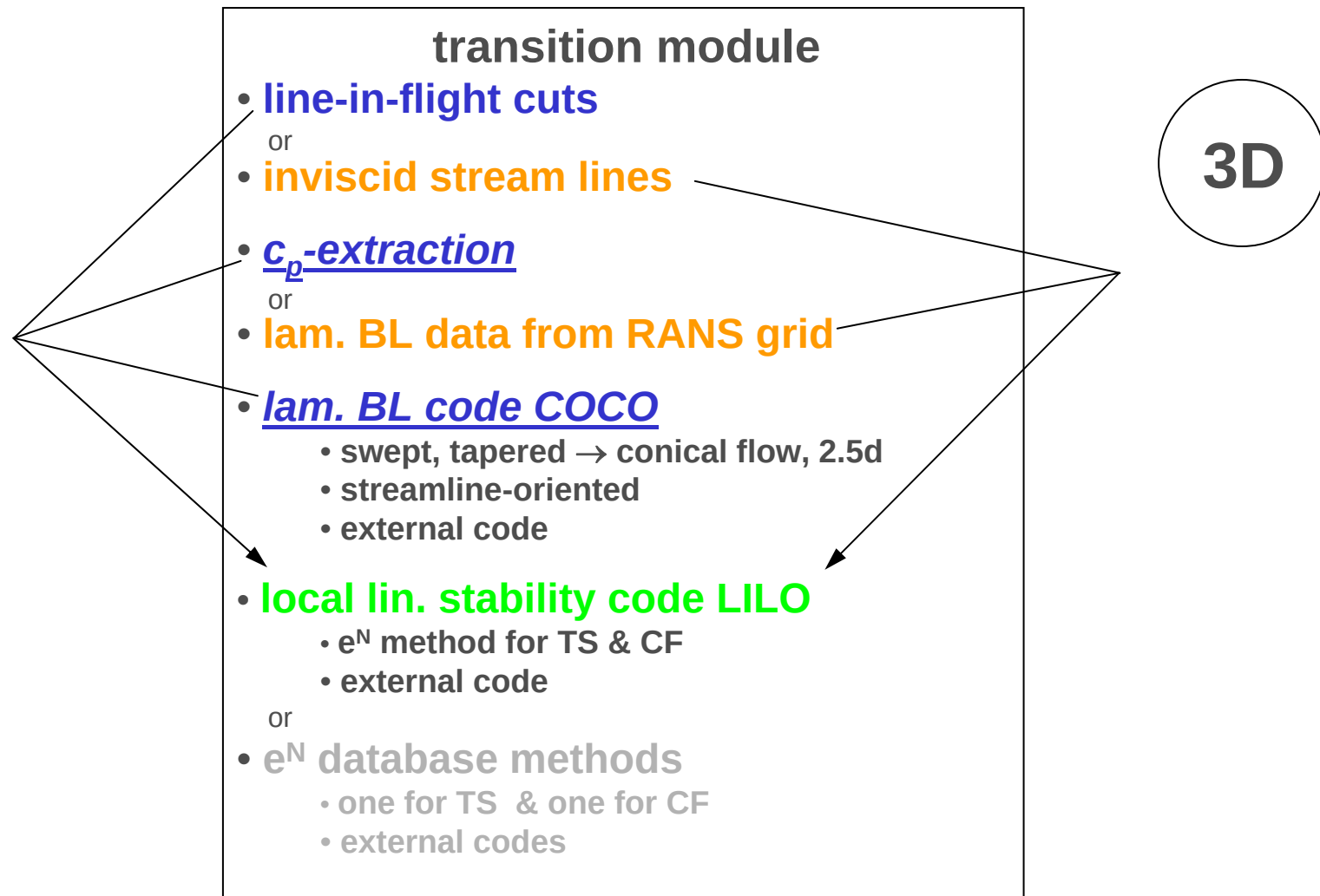
➤ Transition prediction module



➤ Possible combinations currently available



➤ Possible combinations currently available





➤ Application areas

- 2d airfoil configurations
- 2.5d wing configurations: inf. swept
- 3d wing configurations
- 3d fuselages
- 3d nacelles

- Single-element configurations
- Multit-element configurations

- Flow topologies
 - attached
 - with lam. separation:
 - LS point as transition point
 - real stability analysis with stability code inside bubble
 - + many points in prismatic layer

➤ Application areas

- 2d airfoil configurations
 - 2.5d wing configurations: inf. swept
 - 3d wing configurations
 - 3d fuselages
 - 3d nacelles
- streamlines
necessary!
- Single-element configurations
 - Multit-element configurations
 - Flow topologies
 - attached
 - with lam. separation:
 - LS point as transition point
 - real stability analysis with stability code inside bubble
 - + many points in prismatic layer

lam. BL data from RANS grid needed!
for 3d case: for CF
→ 128 points in wall normal direction necessary!!!



➤ Application areas

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- 3d wing configurations
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➤ Application areas

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- **2.5d wing configurations: inf. swept**
- **3d wing configurations**
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- **3d nacelles**
- **Single-element configurations**
- **Multielement configurations**
- **Flow topologies**
 - **attached**
 - **with lam. separation:**
 - LS point as transition point
 - **real stability analysis with stability code inside bubble**
 - + **many points in prismatic layer**

➤ Algorithm

- **set s_{tr}^u and s_{tr}^l far downstream** (→ start mit quasi fully-laminar conditions)
- **compute flow field**
- **check for lam. separation in RANS grid**
 - **set laminar separation points as new $s_{tr}^{u,l}$**
 - ⇒ stabilization of the computation in the transient phase
- **$c_l \approx const.$ in cycles**
 - **call transition module**
 - **use** **a.) new transition point directly**
 or
 b.) lam. separation point of BL code as approximation
- **see new $s_{tr}^{u,l}$ underrelaxed** → $s_{tr}^{u,l} = s_{tr}^{u,l} \delta, \quad 1.0 < \delta < 1.5$
 ⇒ damping of oscillations in transition point iteration

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⇒ damping of oscillations in transition point iteration
- **check convergence** → $\Delta s_{tr}^{u,l} < \varepsilon$

no

yes

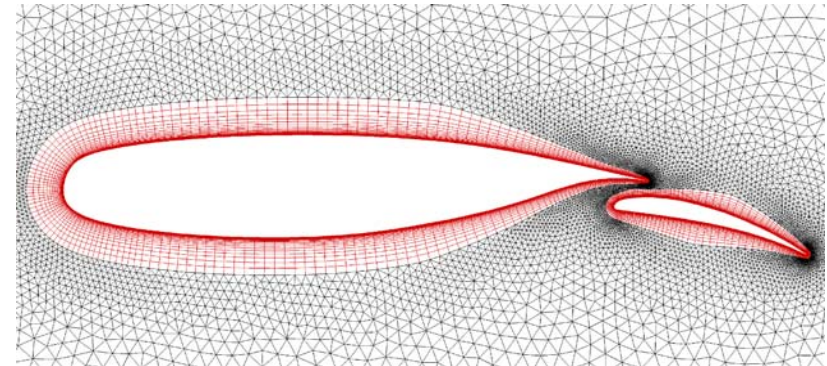
STOP



Computational Results

➤ 2d two-element configuration:

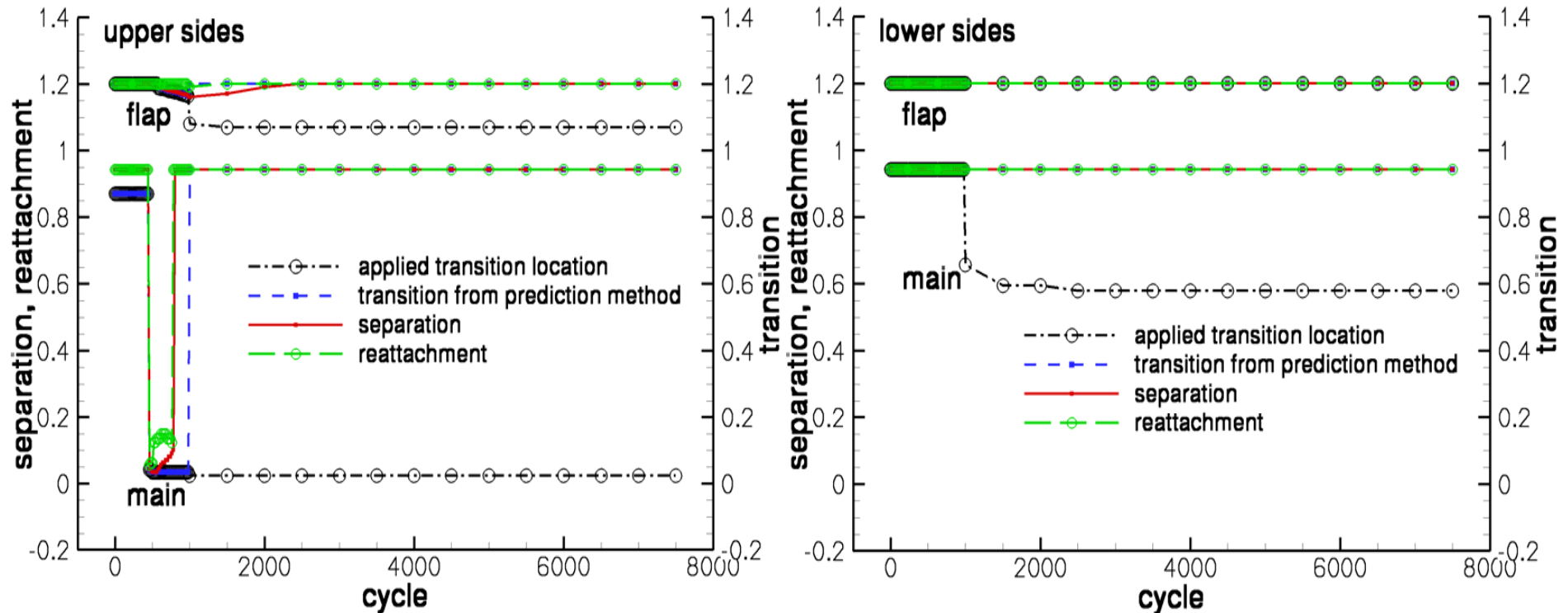
- NLR 7301 with flap
- gap: 2.6% c_{main} , $c_{flap}/c_{main} = 0.34$
- $M = 0.185$, $Re = 1.35 \times 10^6$, $\alpha = 6.0^\circ$
- grid: 23,000 triangles + 15,000 quadrilaterals
on contour: main → 250, flap → 180, 36 in both prismatic layers
- SAE
- $N_{TS} = 9.0$ (arbitrary setting)
- exp. transition locations: upper → main: 3.5% & flap: 66.5%
 lower → main: 62.5% & flap: fully laminar
- different mode combinations:
 - a) laminar BL code & stability code → BL mode 1
 - b) laminar BL inside RANS & stability code → BL mode 2



grid: Airbus



Transition iteration convergence history: BL mode 1

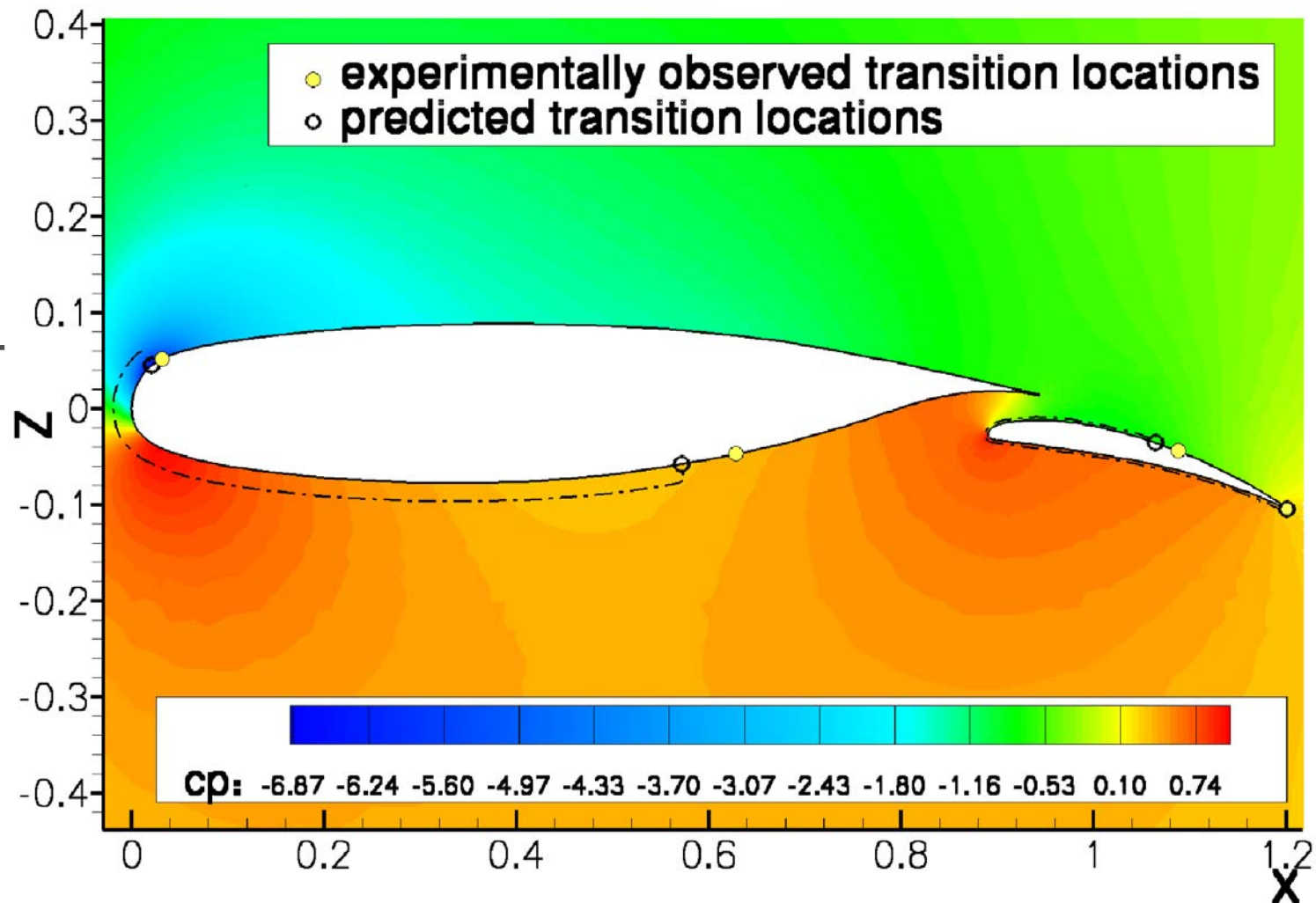


- pre-prediction phase → 1,000 cycles
every 20 cycles
- prediction phase → starts at cycle = 1,000
every 500 cycles

• very fast convergence

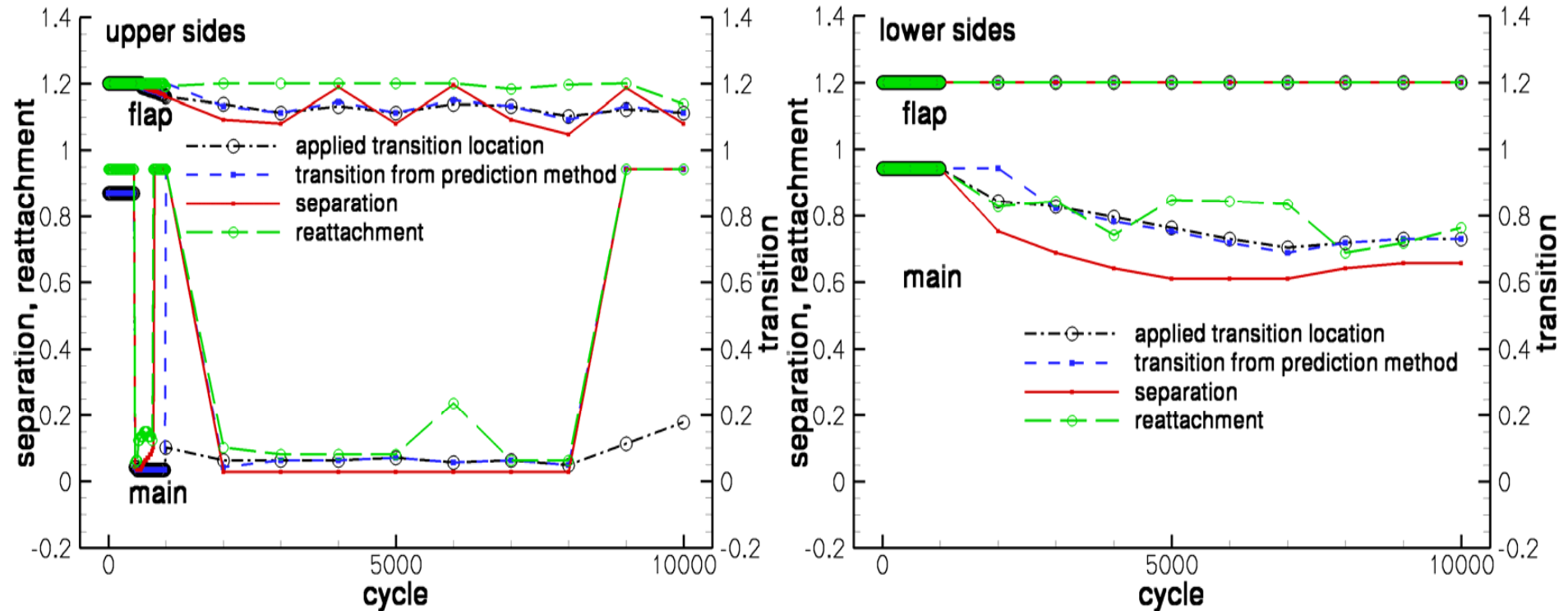
c_p -field and transition points: BL mode 1

- all transition points *up-stream* of experimental values
- *no* separation in final RANS solution
- good approximation of the measured transition points





Transition iteration convergence history: BL mode 2, run a

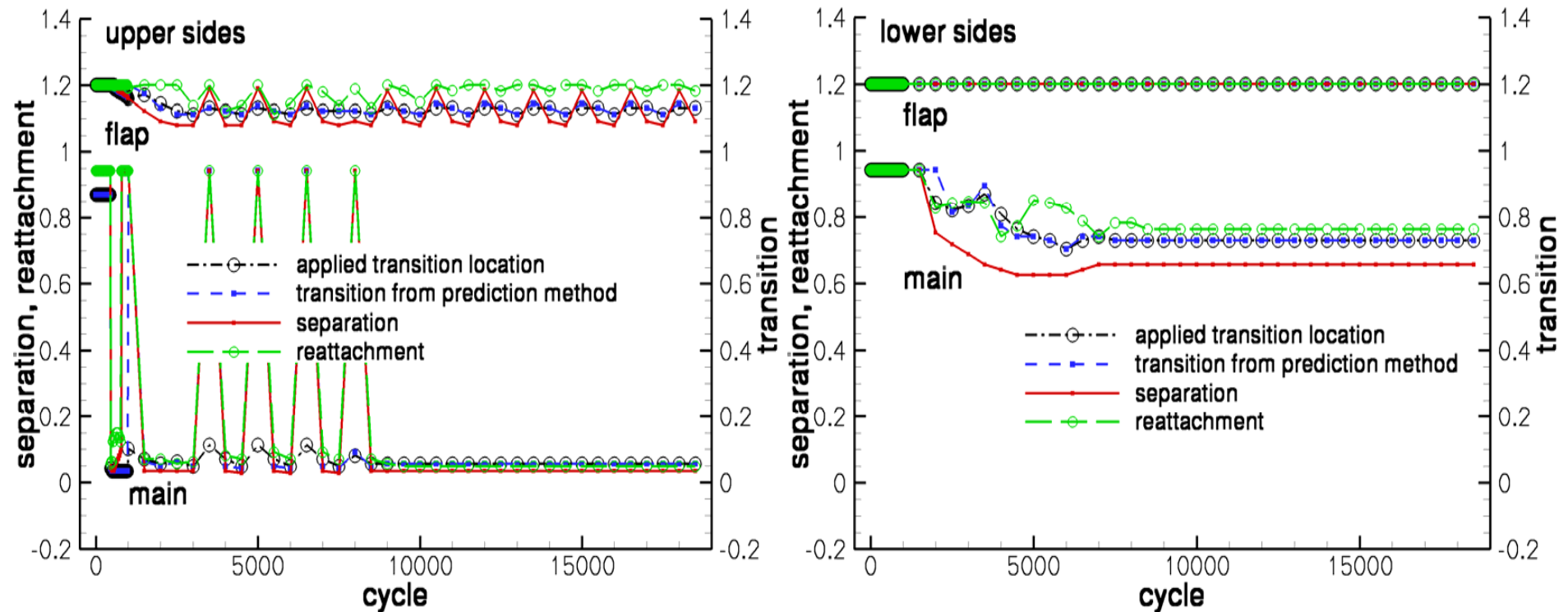


- pre-prediction phase → 1,000 cycles
every 20 cycles
- prediction phase → starts at cycle = 1,000
every 1,000 cycles
stops at cycle = 10,000

- no convergence
- 1st numerical instability on flap
→ induced by transition iteration
- 2nd numerical instability on main
→ induced by RANS procedure



Transition iteration convergence history: BL mode 2, run b



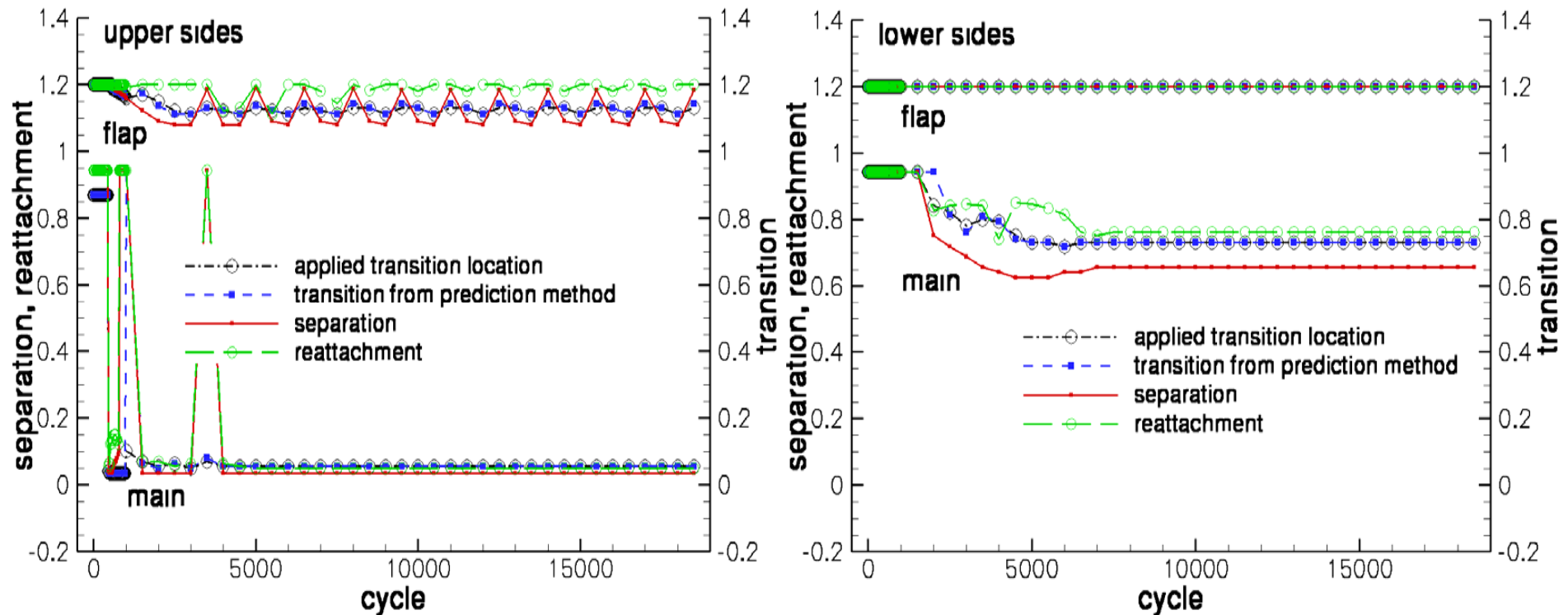
- pre-prediction phase → 1,000 cycles every 20 cycles
- prediction phase → starts at cycle = 1,000 every 500 cycles

- limited convergence
- 1st numerical instability on flap → remains
- 2nd numerical instability on main → damped by the procedure



Transition iteration convergence history: BL mode 2, run b

new

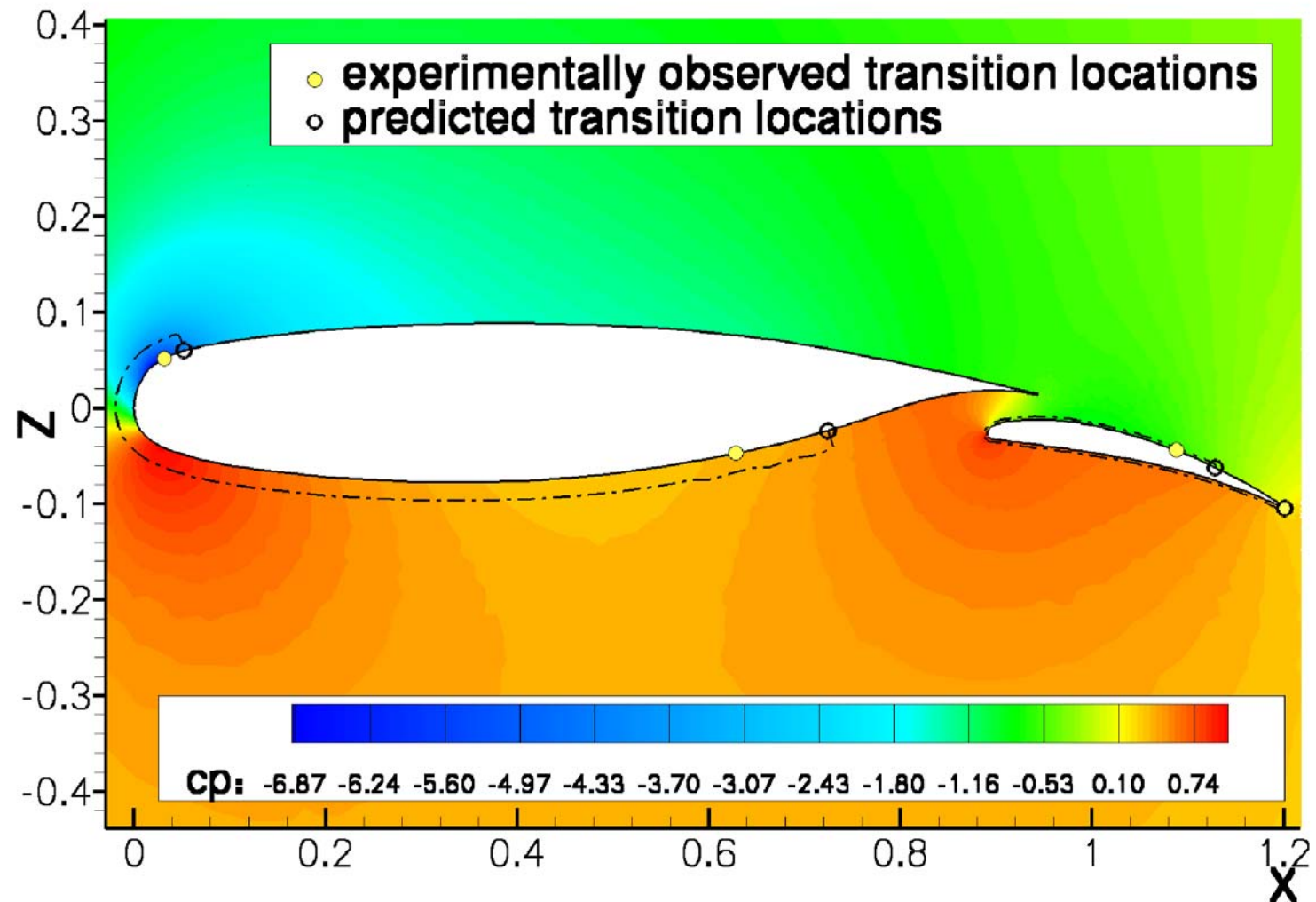


- pre-prediction phase → 1,000 cycles
every 20 cycles
- prediction phase → starts at cycle = 1,000
every 500 cycles

- limited convergence
- 1st numerical instability on flap
→ remains
- 2nd numerical instability on main
→ damped *faster* by the procedure

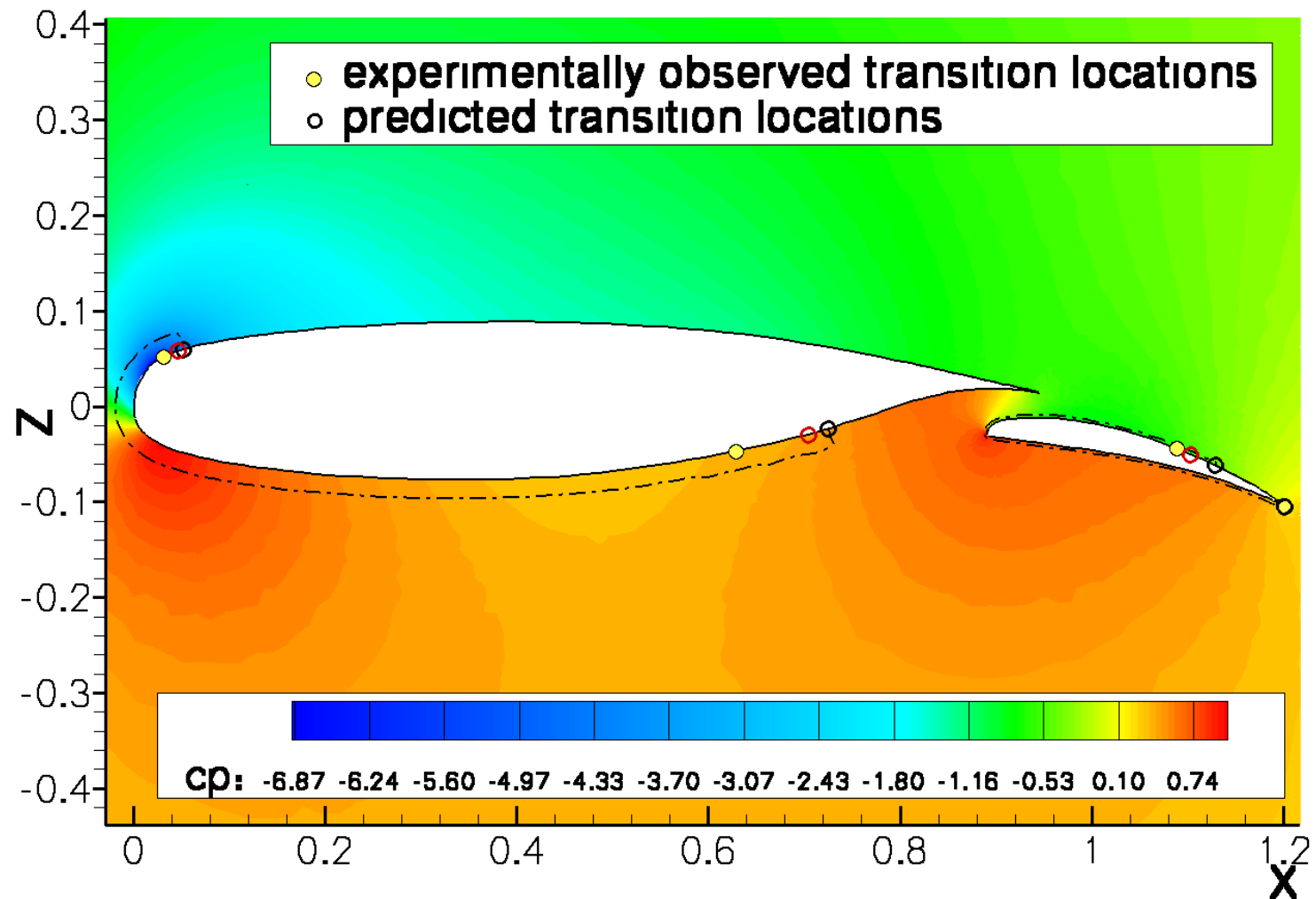
c_p -field and transition points: BL mode 2

- all transition points *downstream* of experimental values
- *two* separations in final RANS solution
- flap separation oscillation remains
- improved transition locations using calibrated N factor
- *individual, automatic shut-down of transition module necessary*



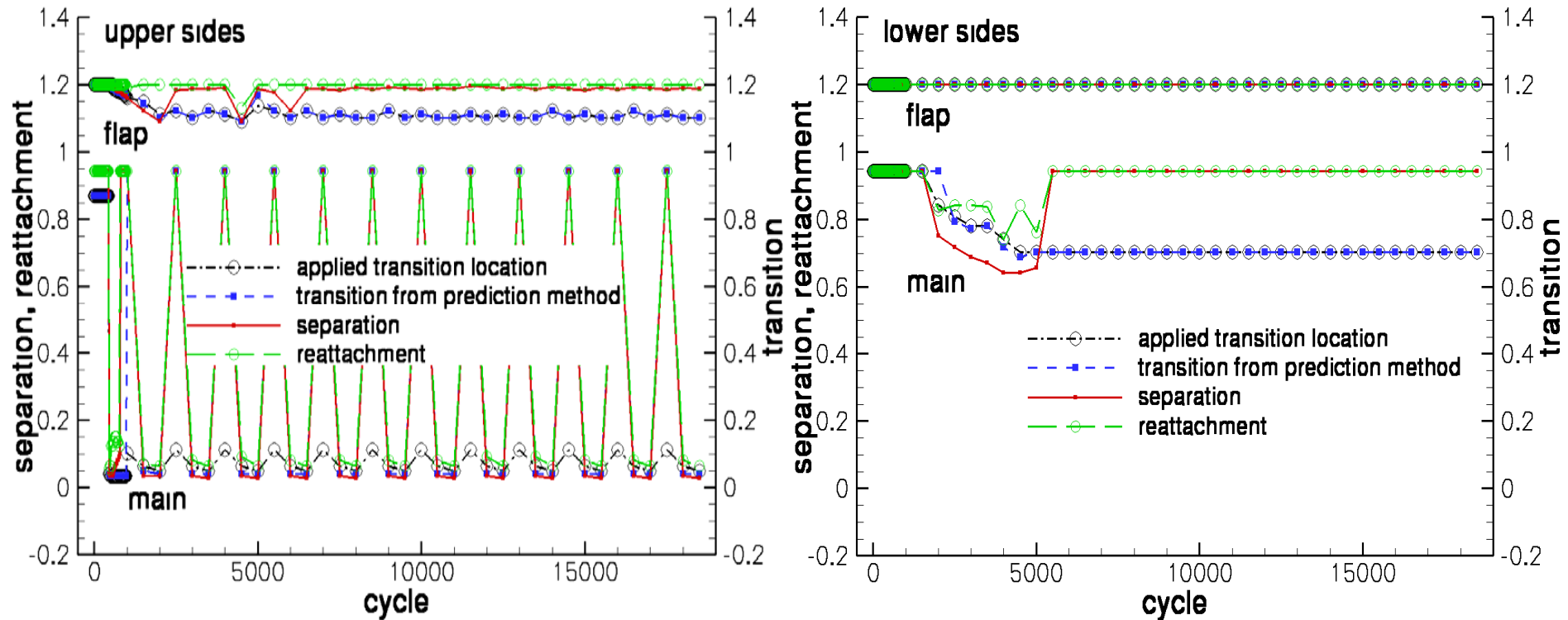
c_p -field and transition points: BL mode 2

- all transition points *downstream* of experimental values
- two separations in final RANS solution
- flap separation oscillation remains
- improved transition locations using calibrated N factor $N = 5.8$
- individual, automatic shut-down of transition module necessary





Transition iteration convergence history: BL mode 2, $N = 5.8$

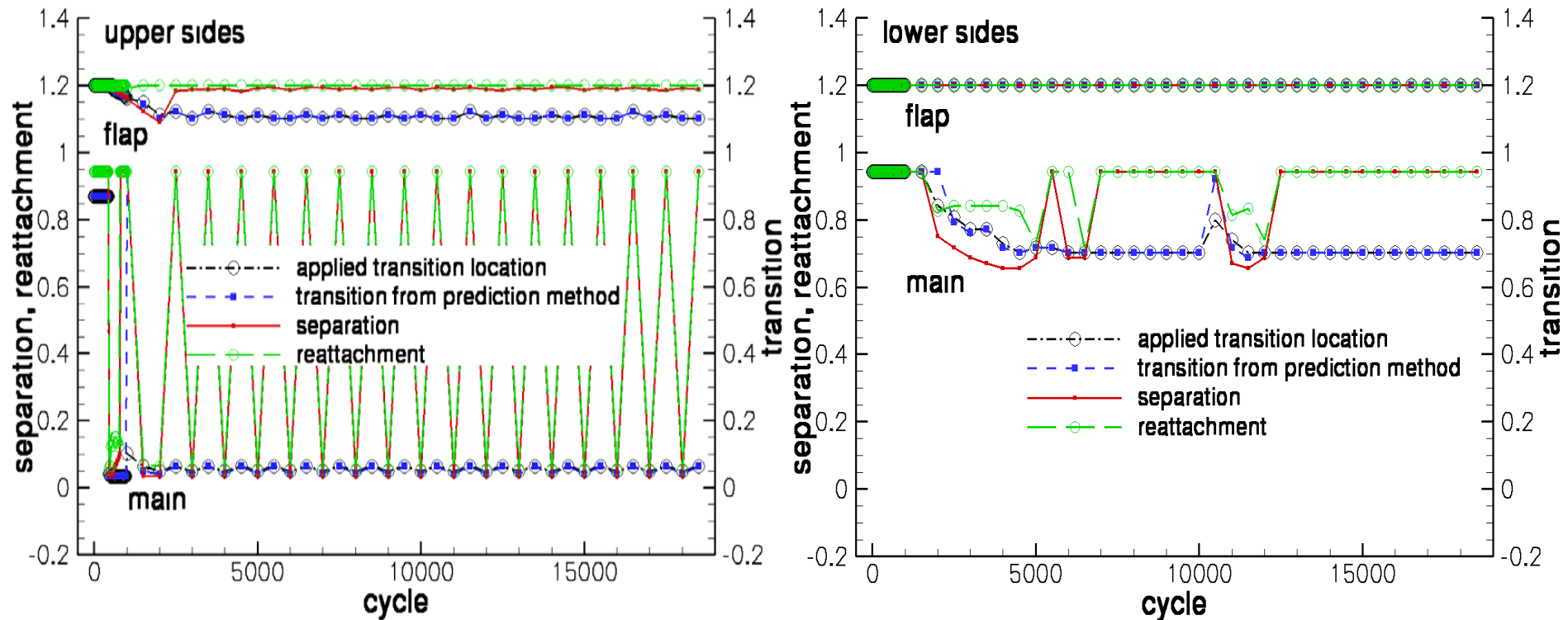


- pre-prediction phase → 1,000 cycles
every 20 cycles
- prediction phase → starts at cycle = 1,000
every 500 cycles

- limited convergence
- 1st numerical instability on flap
→ small and acceptable
- 2nd numerical instability on main
→ NOT damped



Transition iteration convergence history: BL mode 2, $N = 5.8$ *new*

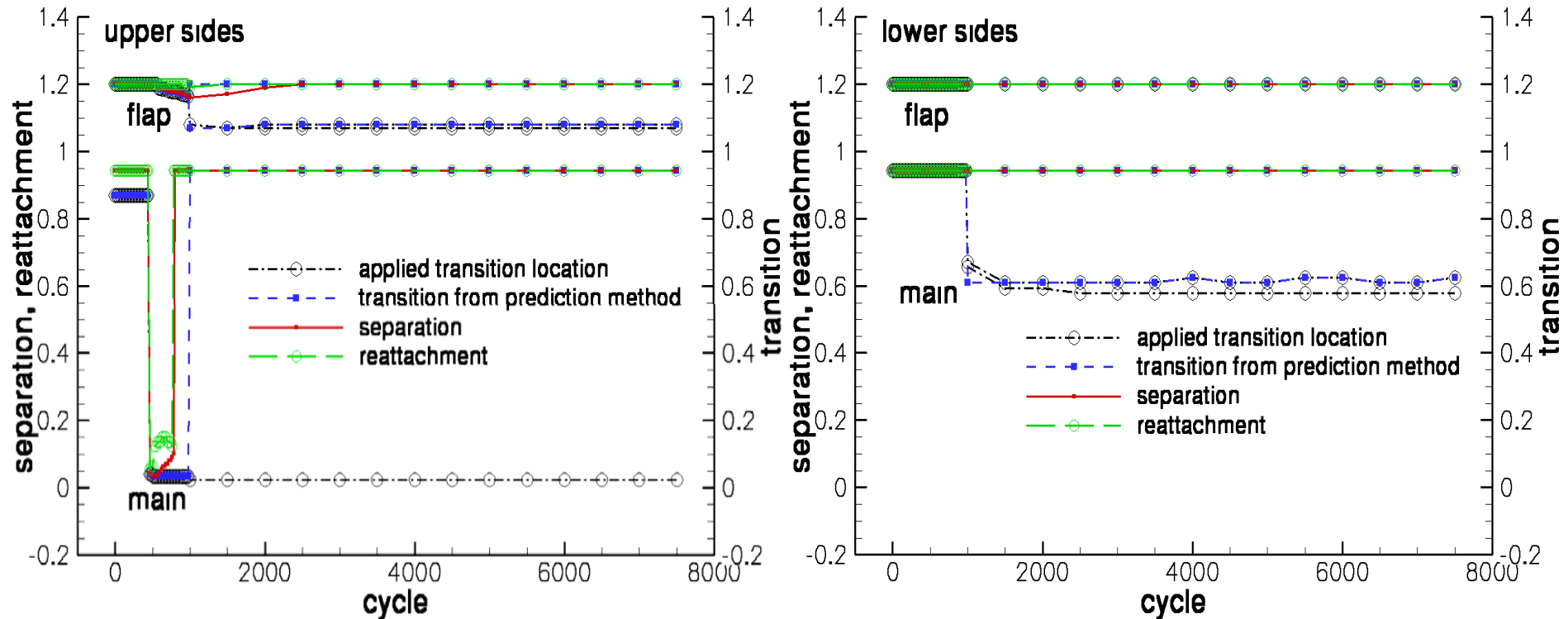


- pre-prediction phase → 1,000 cycles
every 20 cycles
- prediction phase → starts at cycle = 1,000
every 500 cycles

- limited convergence
- 1st numerical instability on flap
→ small and acceptable
- 2nd numerical instability on main
→ smaller, but still NOT damped



Transition iteration convergence history: BL mode 1, $N = 5.8$ *new*



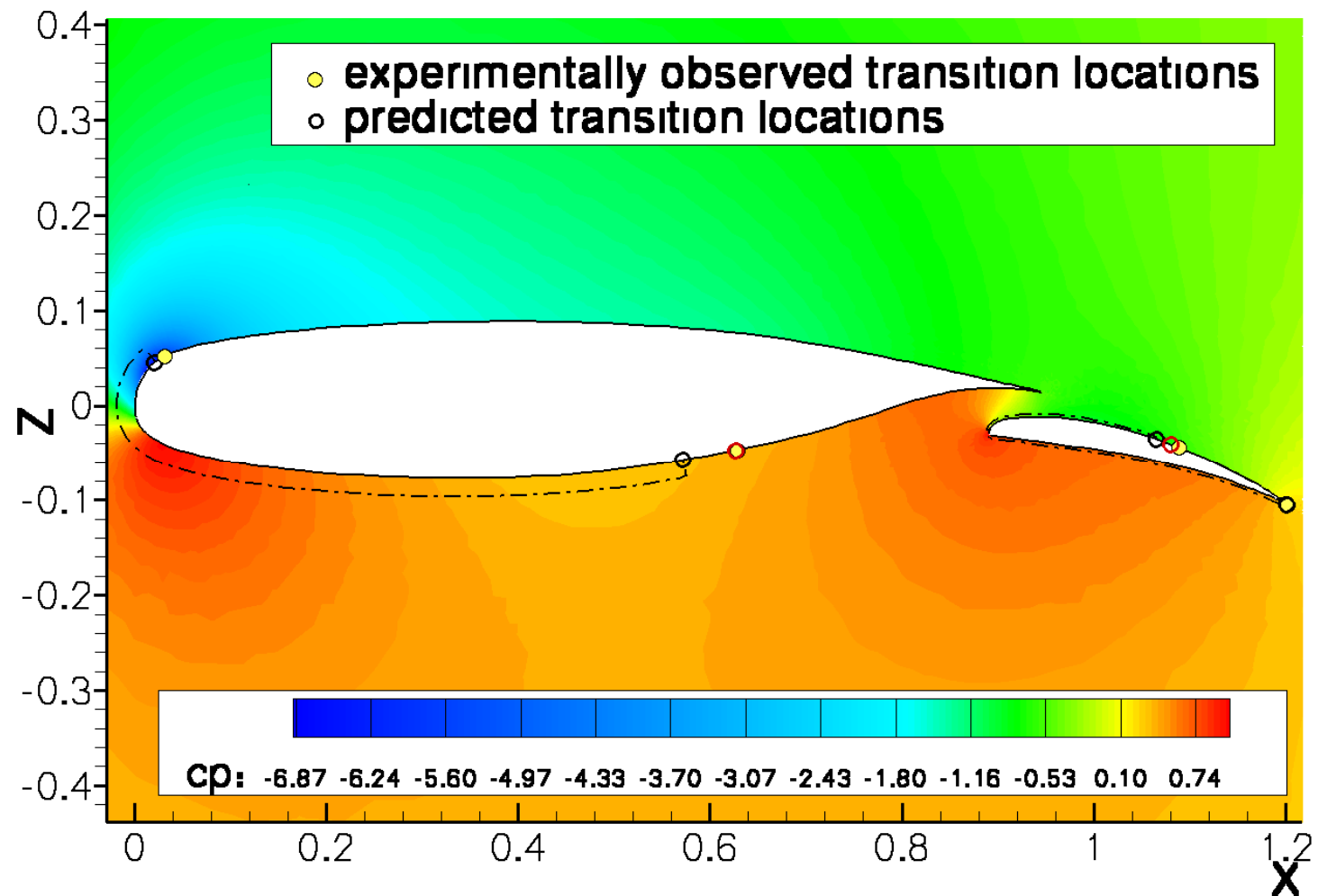
- pre-prediction phase → 1,000 cycles every 20 cycles
- prediction phase → starts at cycle = 1,000 every 500 cycles

• very fast convergence



c_p -field and transition points: BL mode 1, $N = 5.8$, *new*

- *no* separation in final RANS solution
- *very good* approximation of the measured transition points



➤ 2d three-element configuration:

➤ $M = 0.221$, $Re = 6.11 \times 10^6$, $\alpha = 21.4^\circ$

➤ grid 1: 22.000 points
grid 2: 122.000 points, noses highly resolved

➤ SAE

➤ $N_{TS} = 9$

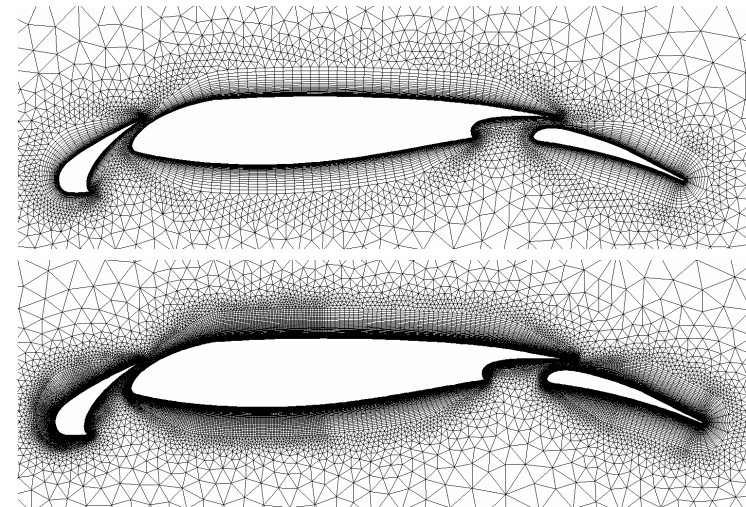
➤ prediction only on upper sides, lower sides fully laminar

➤ exp. transition locations → slat: 15% & flap: 34.5%
‘kink’ on main upper side → 19%

➤ different mode combinations:

a) laminar BL code & stability code → BL mode 1

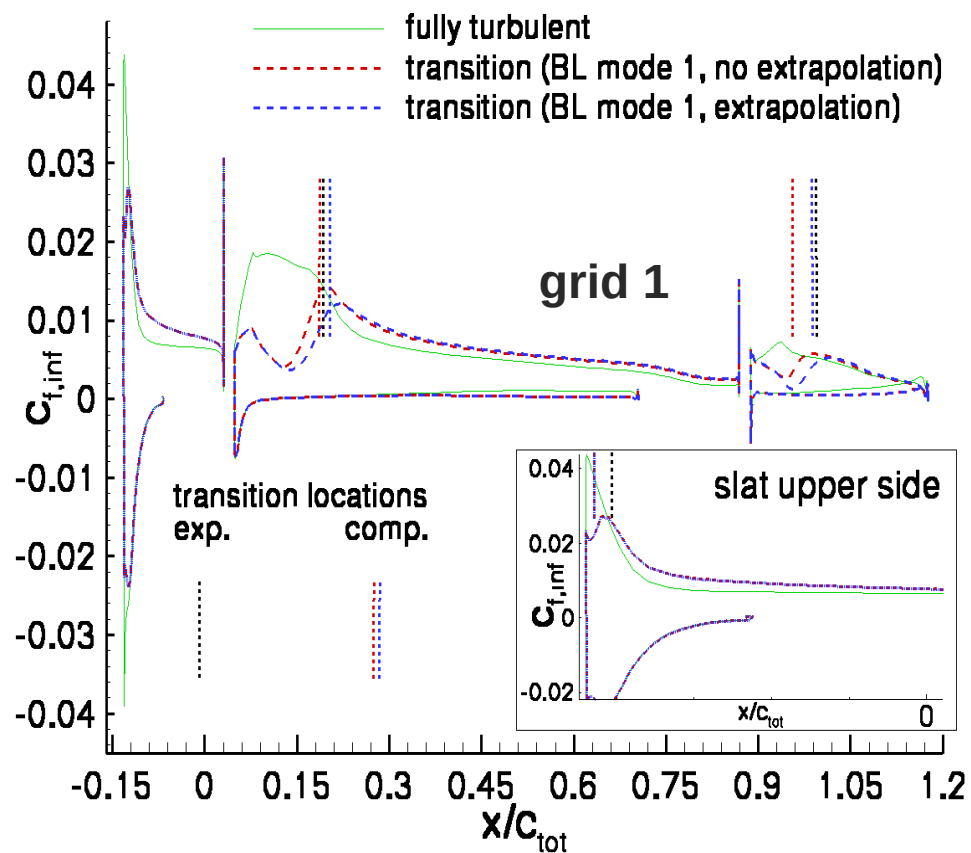
b) laminar BL inside RANS & stability code → BL mode 2



Grids: J. Wild, DLR

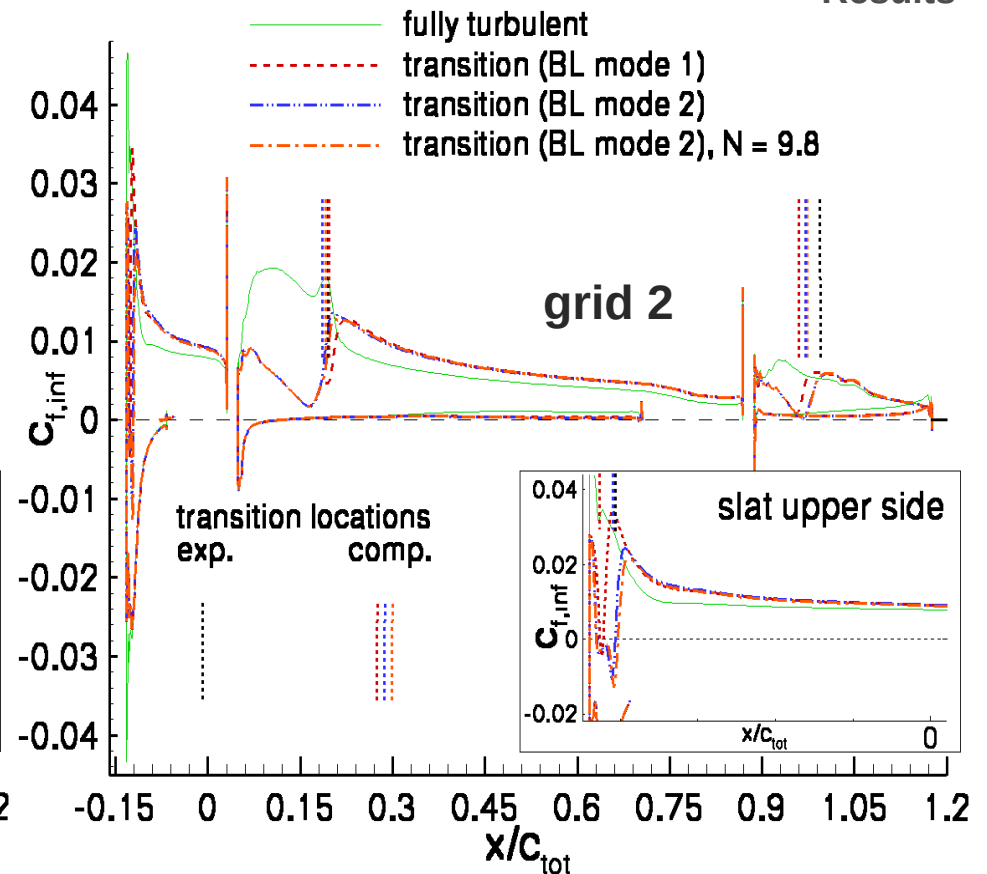


Results



NO separation bubbles

transition locations: very good → flap



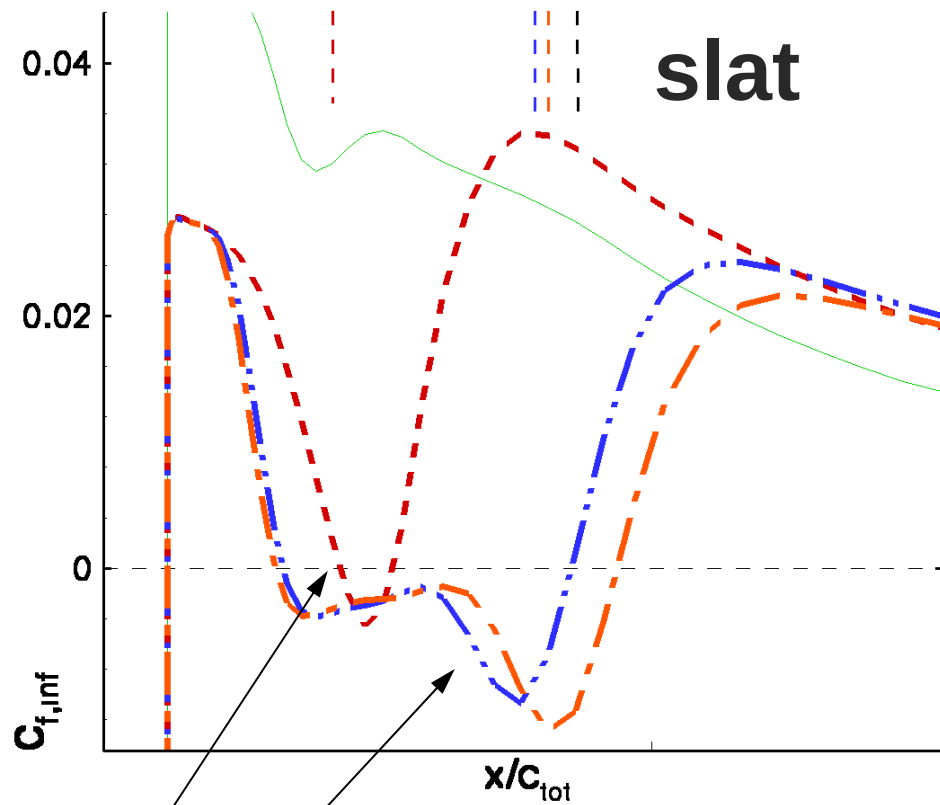
slat separation bubble

transition locations: very good → slat
good → flap

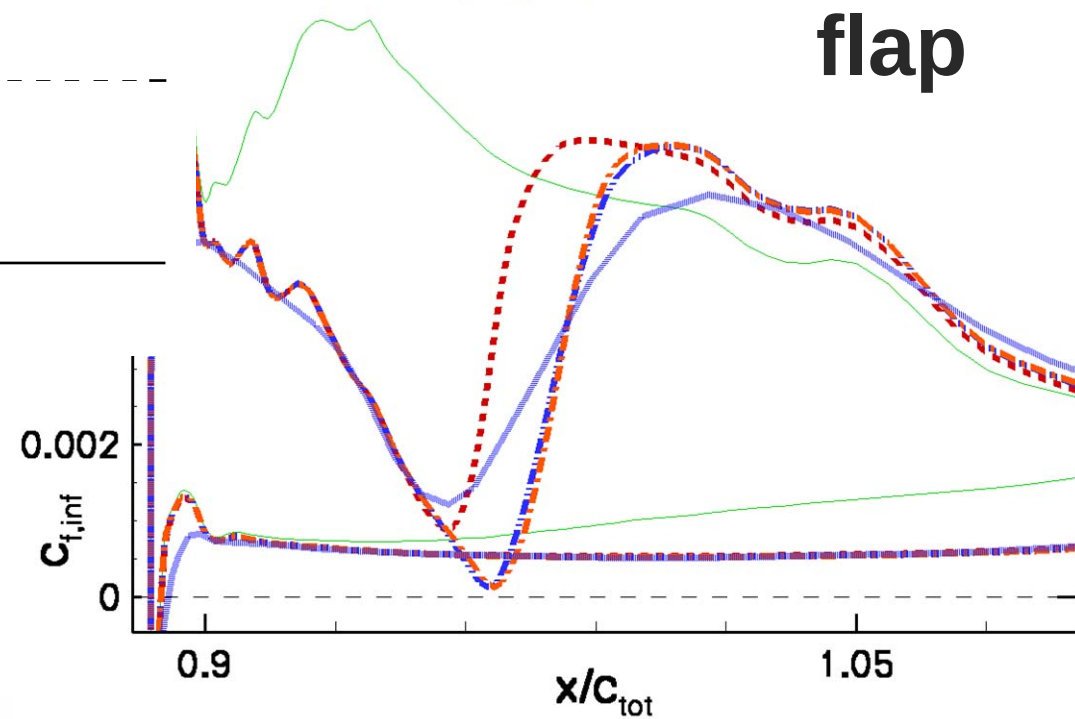
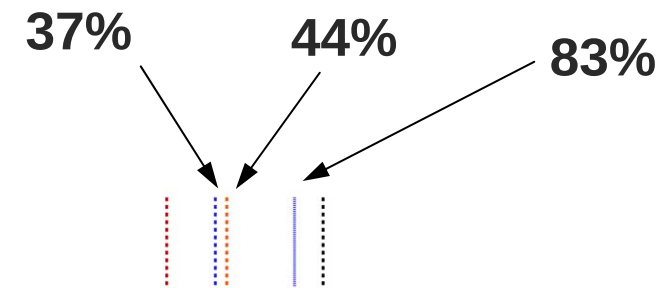
the higher N, the larger the bubble



Results



transition locations error reduction



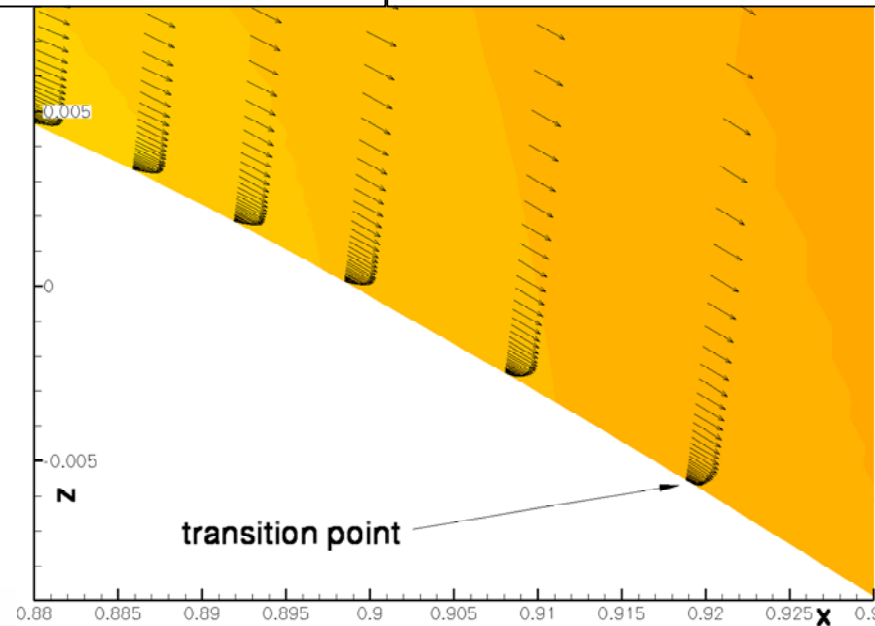
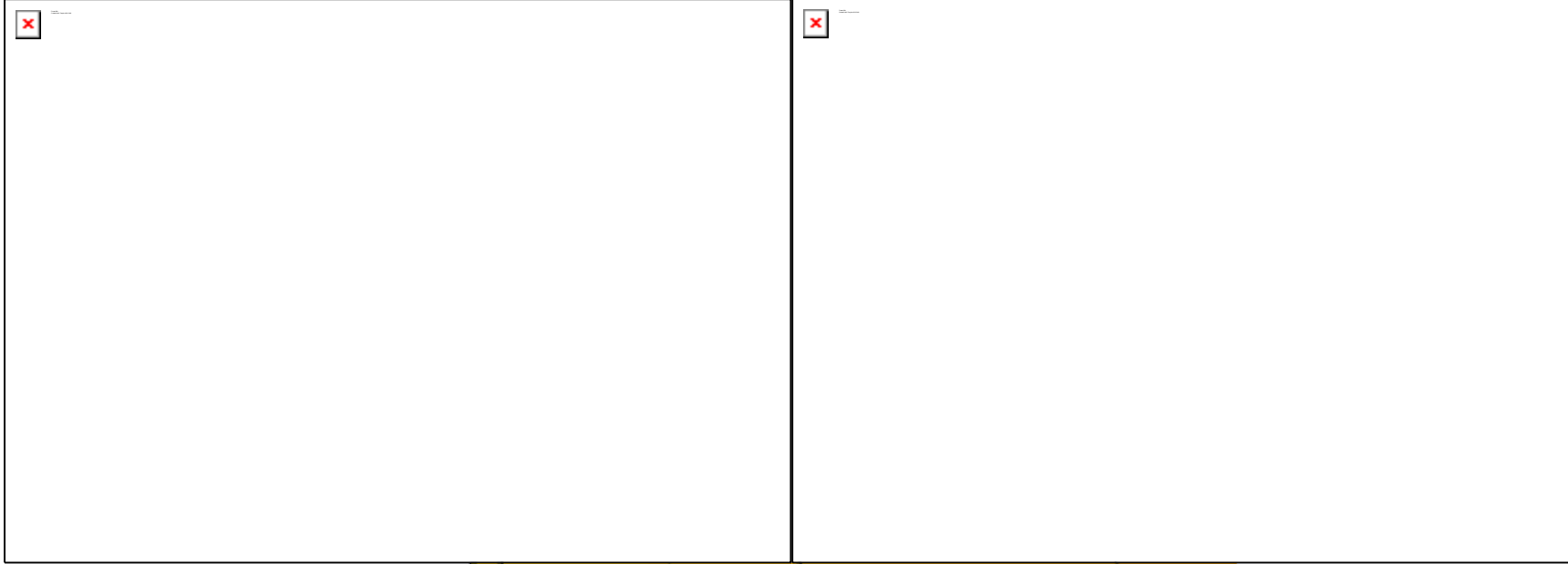
grid 2



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Results

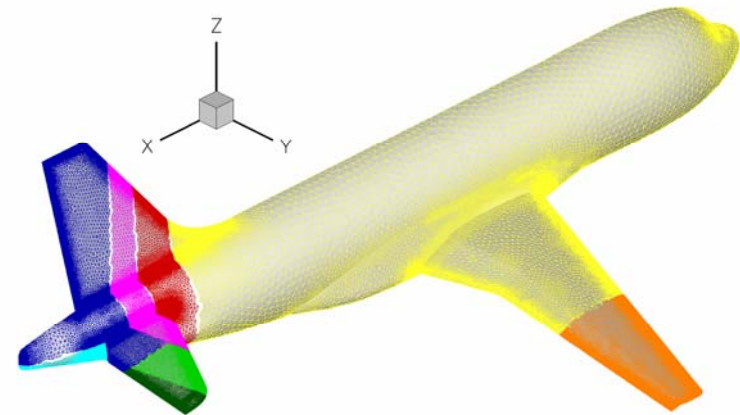




Results

➤ 3D generic aircraft configuration:

- $M = 0.2$, $Re = 2.3 \times 10^6$, $\alpha = -4^\circ$, $i_{HTP} = 4^\circ$
- grid:
 - 12 mio. points
 - 32 cells in prismatic layers
 - at HTP: 48 cells in prismatic layers



geometry: Airbus, grid: TU Braunschweig

- SAE
- $N_{TS} = N_{CF} = 7.0$ (arbitrary setting)
- transition prediction on HTP only, upper and lower sides
- different mode combinations:
 - a) laminar BL code & stability code & *line-in flight cuts*
→ BL mode 1
 - b) laminar BL inside RANS & stability code & *inviscid streamlines*
→ BL mode 2
- parallel computation: either 32, 48, or 64 processes
- 2.2 GHz Opteron Linux cluster with 328 CPUs





Results

BL mode 2

- c_f -distribution
- wing sections
(thick white)
- skin friction
lines (thin black)

BL mode 1

upper side

lower side

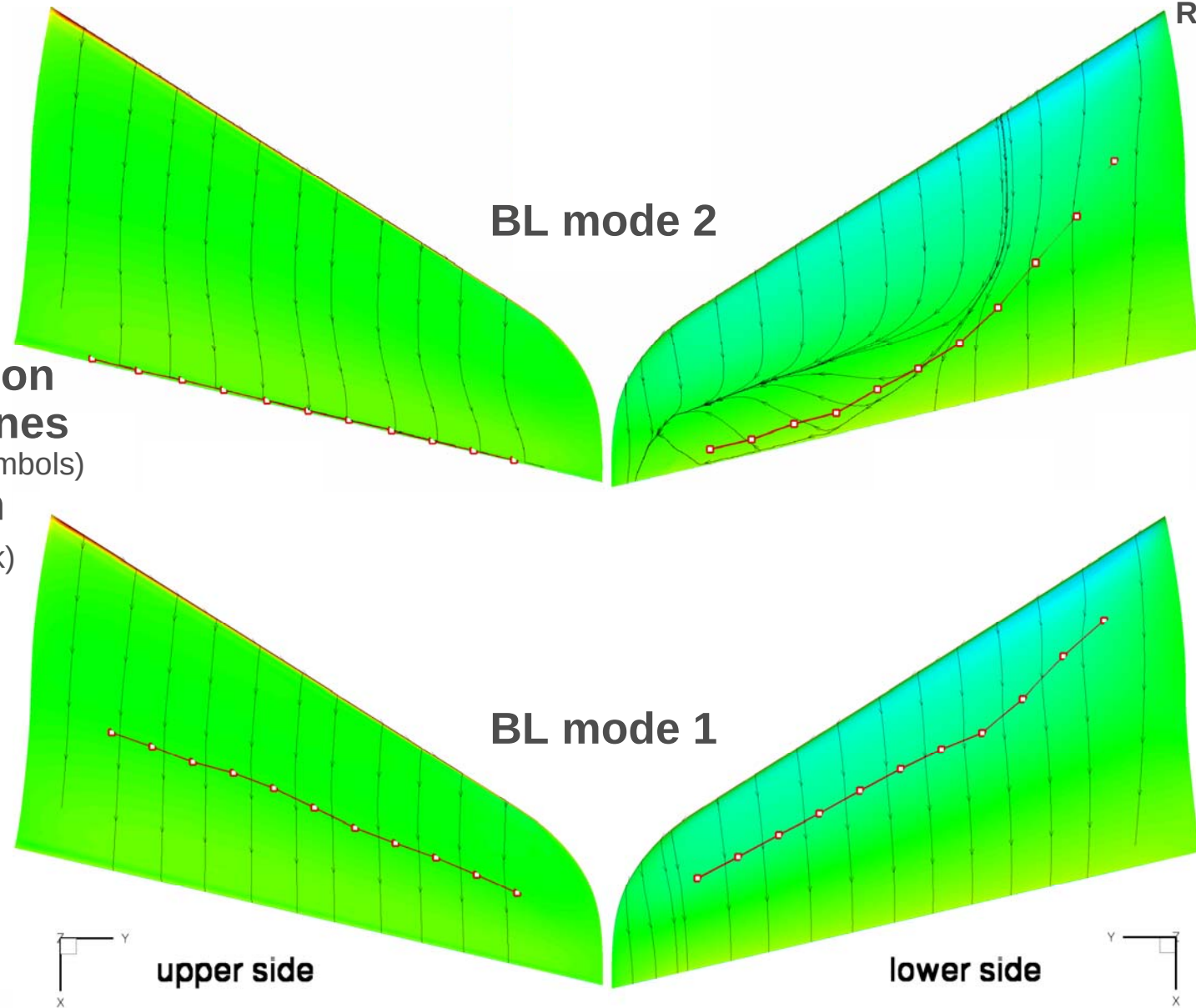


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Results

- c_p -distribution
- transition lines
(thick red with symbols)
- skin friction
lines (thin black)





- pre-prediction until cycle:
500
every 20
cycles

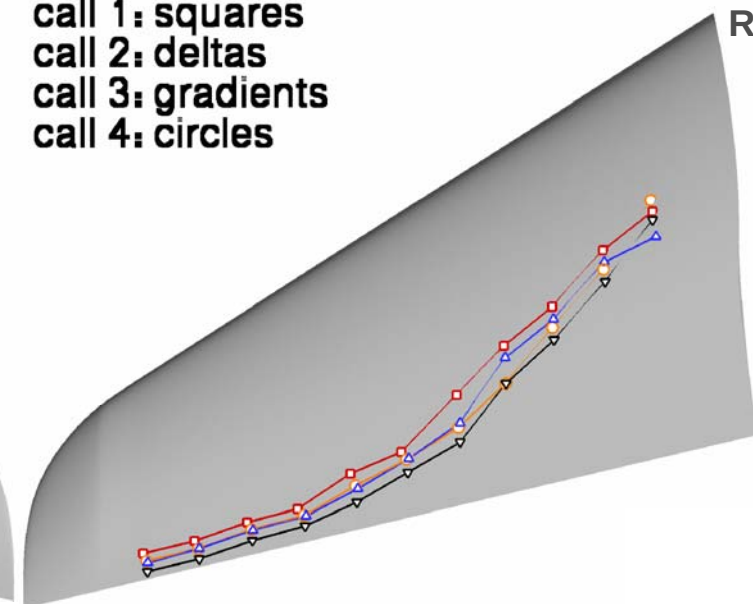
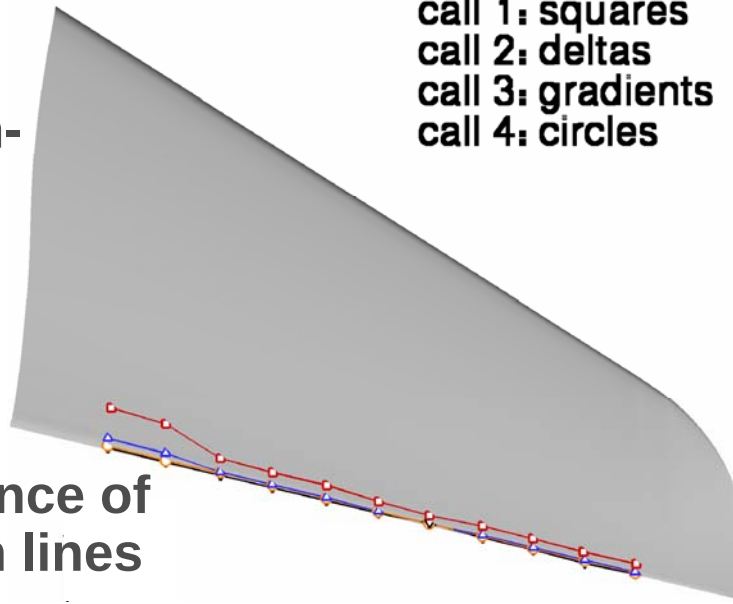
- convergence of
transition lines

calls at
cycles:
500,
1000,
1500,
2000
out of
2500

call 1: squares
call 2: deltas
call 3: gradients
call 4: circles

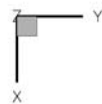
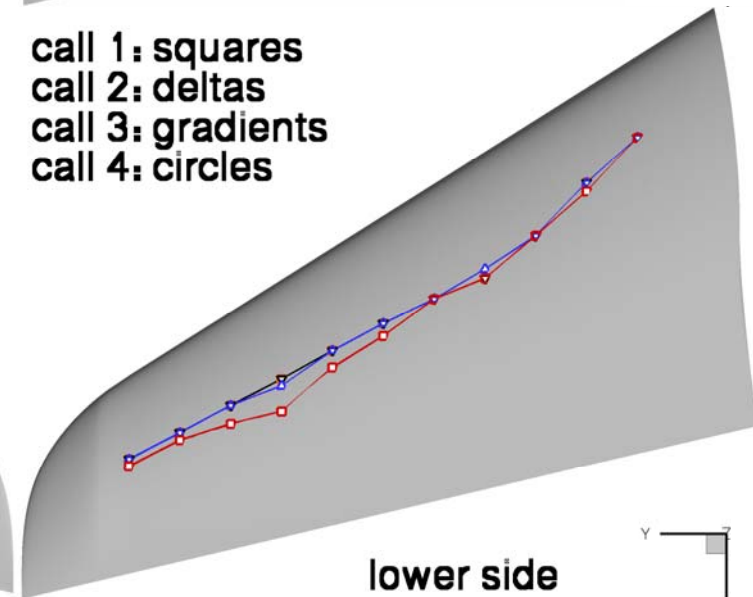
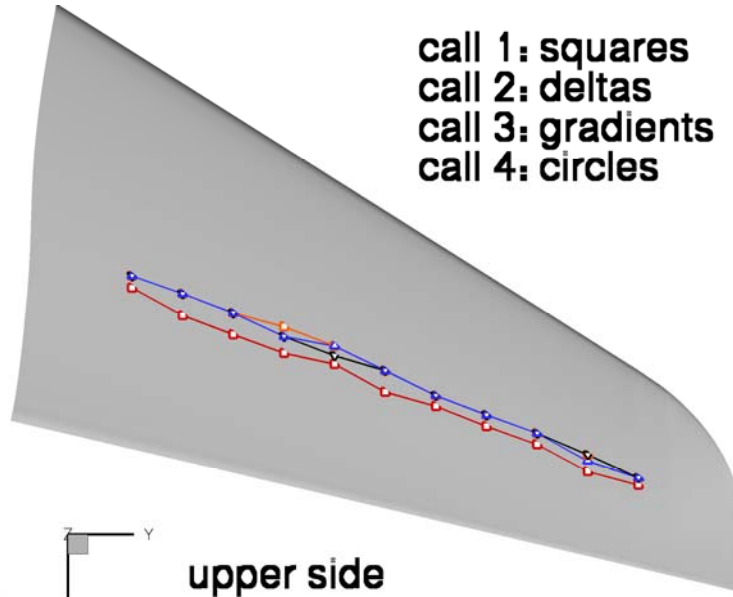
call 1: squares
call 2: deltas
call 3: gradients
call 4: circles

Results

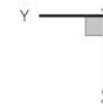


call 1: squares
call 2: deltas
call 3: gradients
call 4: circles

call 1: squares
call 2: deltas
call 3: gradients
call 4: circles



upper side



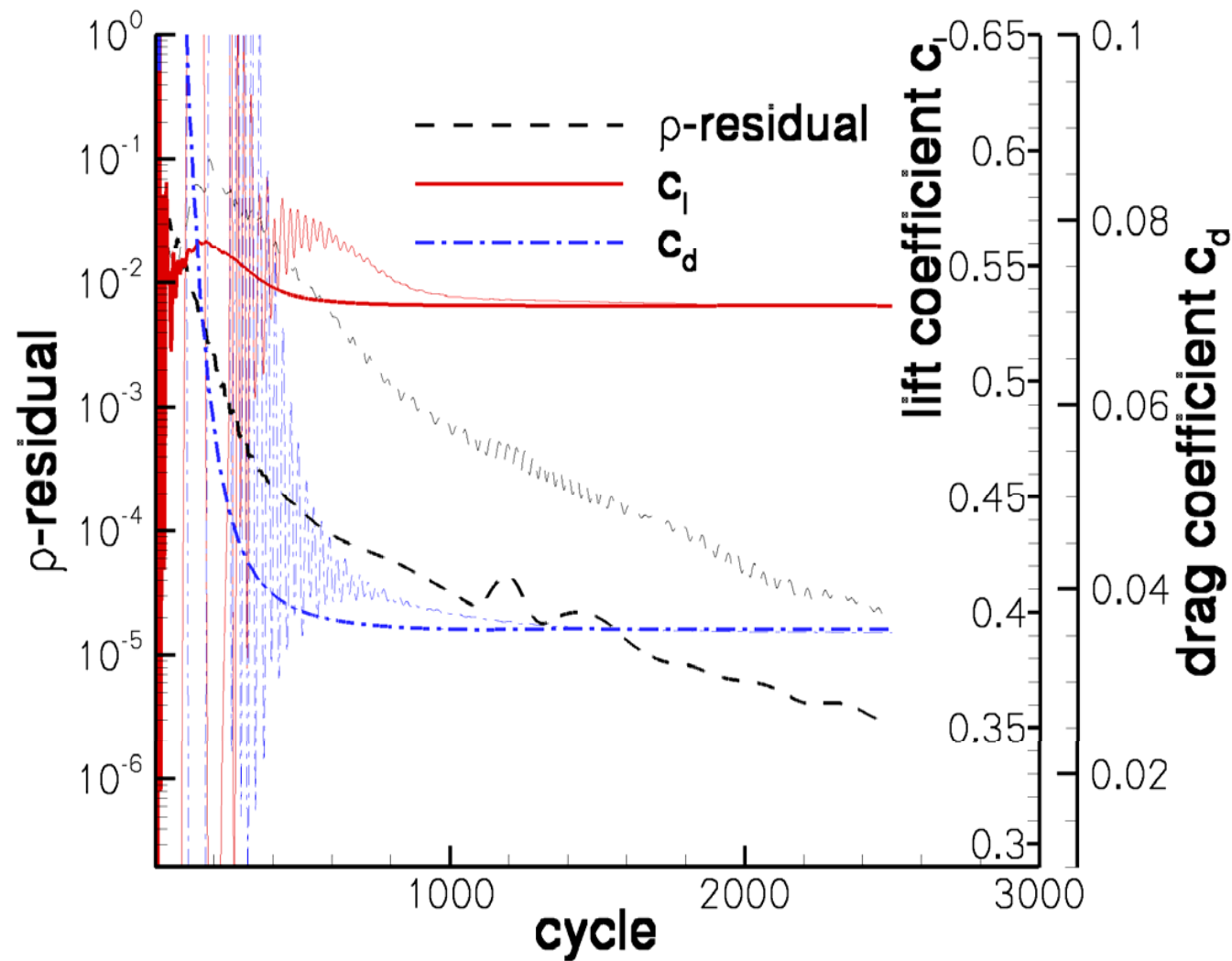
lower side



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- convergence history of the coupled RANS computations:



Conclusion and Outlook

- RANS computations with integrated transition prediction were carried out without intervention of the user.
- The transition tools work fast and reliable.
- Complex cases (e.g. transport aircraft) can be handled; experience up to now limited to one component of the aircraft.
- Use of lam. BL code leads to fast convergence of the transition prediction iteration; not always applicable, because transition may be located significantly downstream of lam. separation; extrapolation may help when amplified modes exist upstream of laminar separation
- Use of internally computed lam. BL data can lead to numerical instabilities when laminar separations are treated
 - interaction between different separations can occur
 - interaction of separation points and transition points: oscillation of separation can lead to oscillation of transition
 - ⇒ automatic shut down of transition iteration individually for each wing section or component of the configuration necessary



- In the nearest future:
 - Much, much more test cases
 - generic aircraft case:
 - α variation
 - different N factors
 - transition on all wings of the aircraft
 - inclusion of fuselage
 - transonic cases
 - physical validation, e.g. F4, F6 (AIAA drag prediction workshop)
 - complex high lift configurations, e.g. from European EUROLIFT projects
 - Setup of Best Practice guidelines