Go4Hybrid

Grey Area Mitigation for Hybrid RANS-LES Methods

Status of complex test cases for non-zonal methods

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NLR

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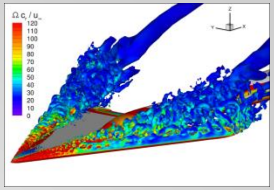
Complex test cases for non-zonal methods

	CFDB	NTS	DLR	FOI	NLR	ONERA	UniMAN
I.1 Helicopter	P						P C
I.2 Delta wing	R				Ref C		
I.3 3-element airfoil		R	C	R	P		P
I.4 2D hump		R Ref C		R			
I.5 Round jet	R C	R Ref			R		

R = (initial) Results
P = Planned
Ref = Reference result
C = Coordinator
CFDB, FOI, NLR: planned according to DoW
NTS, UniMAN: additional contributions

Non-zonal GAM approaches used for complex test cases so far

- NTS:
  - modified length scale $\Delta_{max} \Rightarrow \Delta_{\mathrm{SLA}} = \widetilde{\Delta}_{\omega} F_{KH}$
  - length scale $\widetilde{\Delta}_{\omega}$ sensitized to direction of vorticity vector
  - F_{KH}: Kelvin-Helmholtz sensor / detection quasi 2D regions
- CFDB:
  - σ (and WALE) algebraic eddy-viscosity models of Nicoud *et al.*
  - plus $\widetilde{\Delta}_{\omega}$
- NLR:
  - High-Pass Filtered (HPF) SGS model
  - plus stochastic backscatter SGS model
- FOI:
  - Energy-backscatter function + HYB0
  - $\delta_{\mathrm{min}(\quad)}$ used to redefine LES length scale
  - energy scale transfer + HYB0



I2 Delta wing

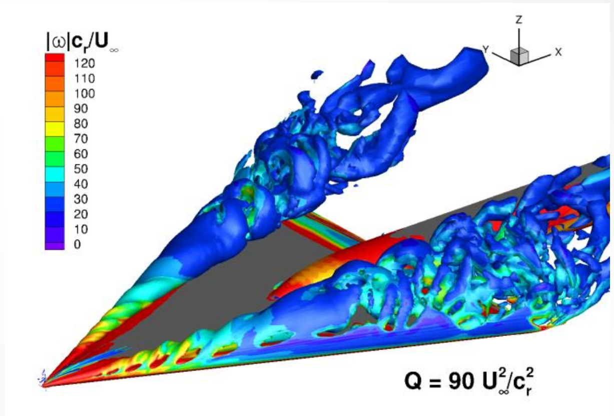
- NASA delta wing with sharp leading edge used in VFE-2
  - vortex breakdown ($\alpha = 23°$, $M_\infty = 0.07$, $Re_{mac} = 10^6$)
  - experiment of TU Munich
  - common grid (6.3 M cells)

- CFDB: Results
  - standard SA-DDES + Δ_{max}
  - SA-σ-DDES + $\tilde{\Delta}_\omega$

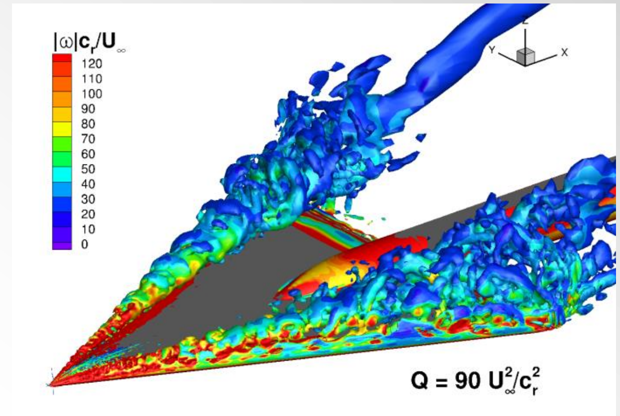
- NLR: Results
  - standard SST-DDES (*Reference*)
  - DX-LES + HPF SGS model (*Reference*)
  - DX-LES + HPF + stochastic backscatter SGS model (*Running*)

I2 Delta wing

New results (CFDB)

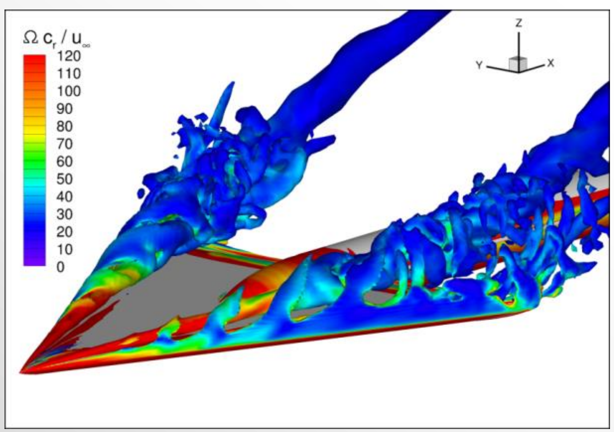


SA-DDES + Δ_{max}

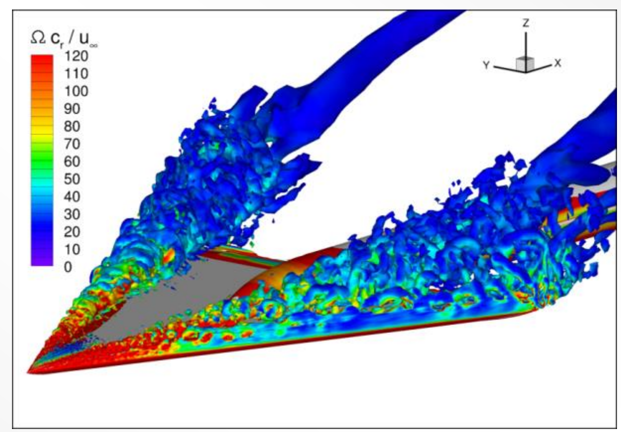


SA-σ-DDES + $\widetilde{\Delta}_{\omega}$

Reference results (NLR)

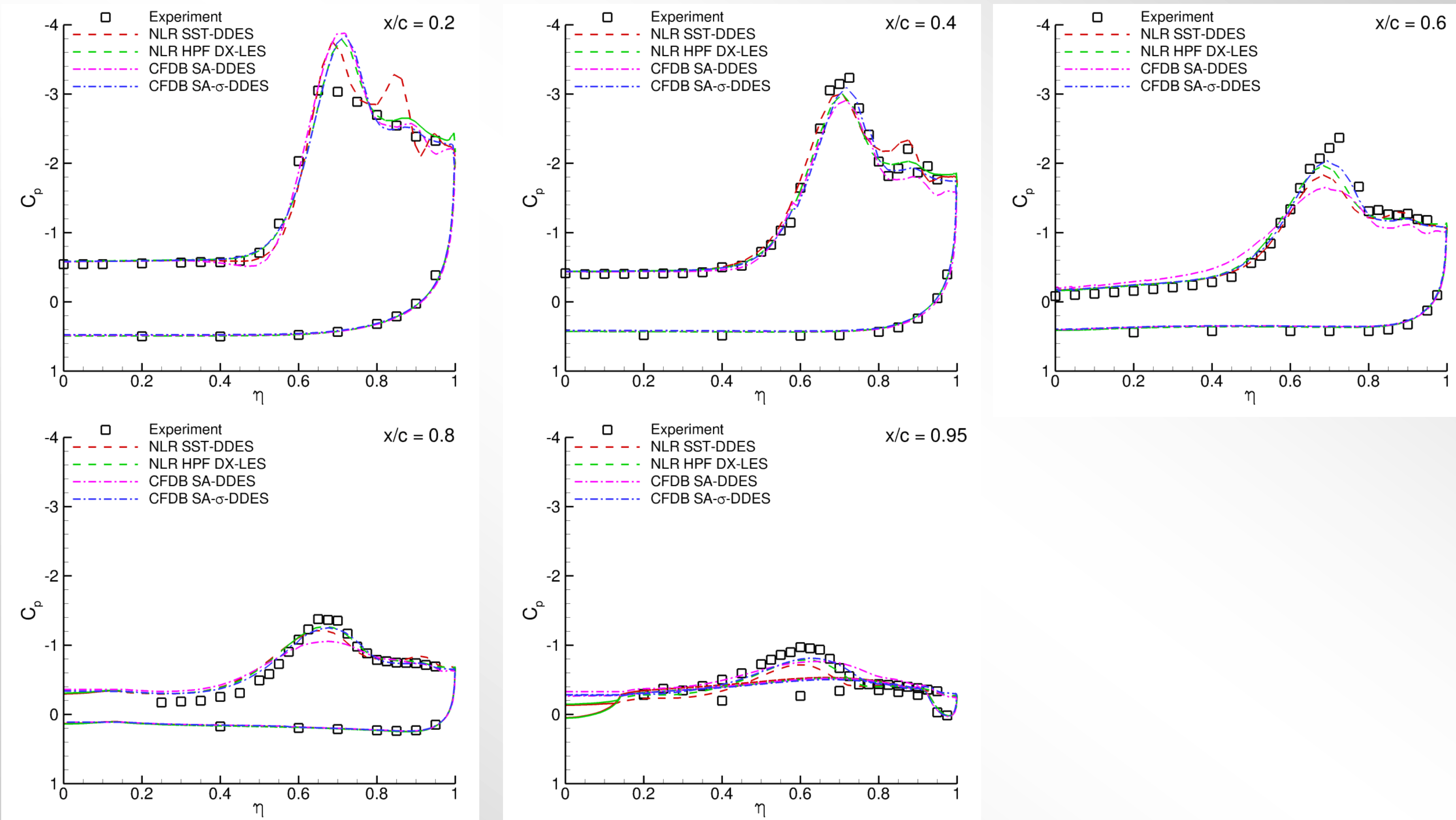


SST-DDES

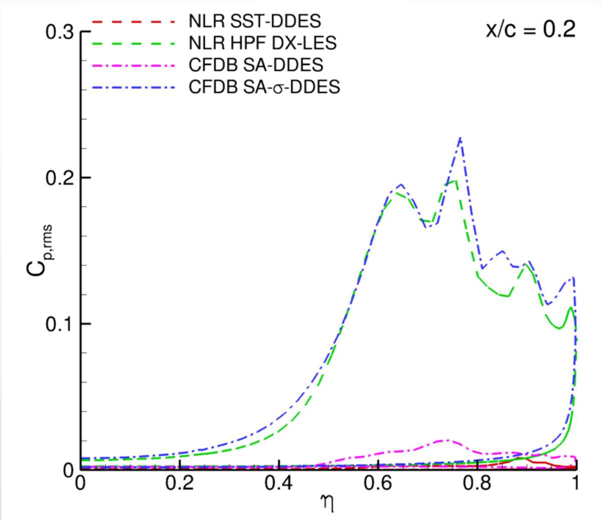


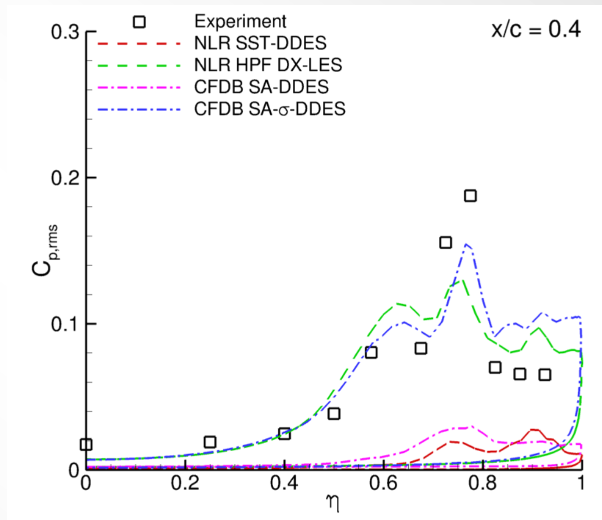
HPF DX-LES

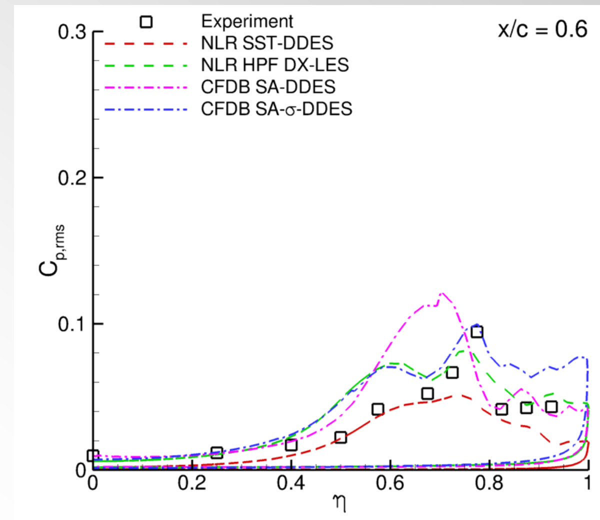
I2 Delta wing: Mean Cp

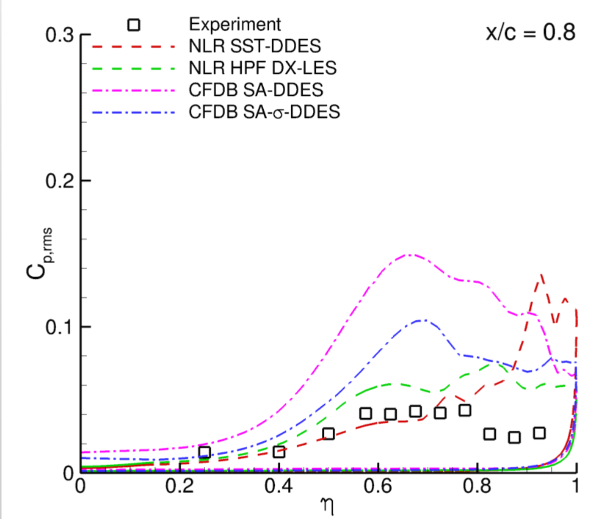


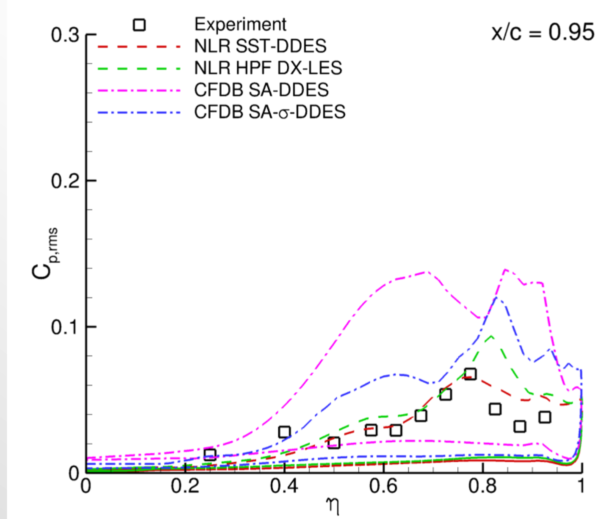
I2 Delta wing: RMS Cp



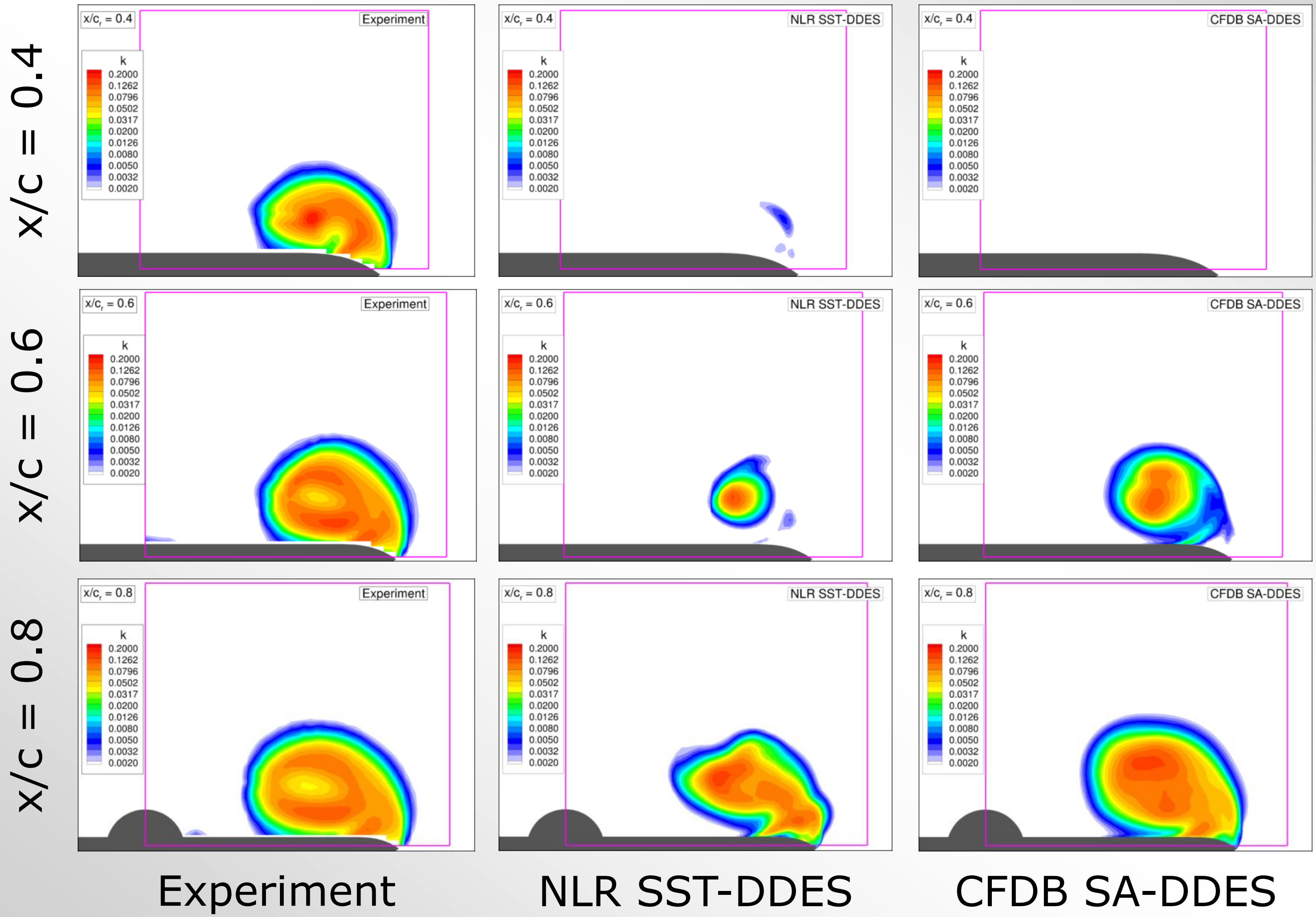








I2 Delta wing: Resolved Turbulent kinetic energy



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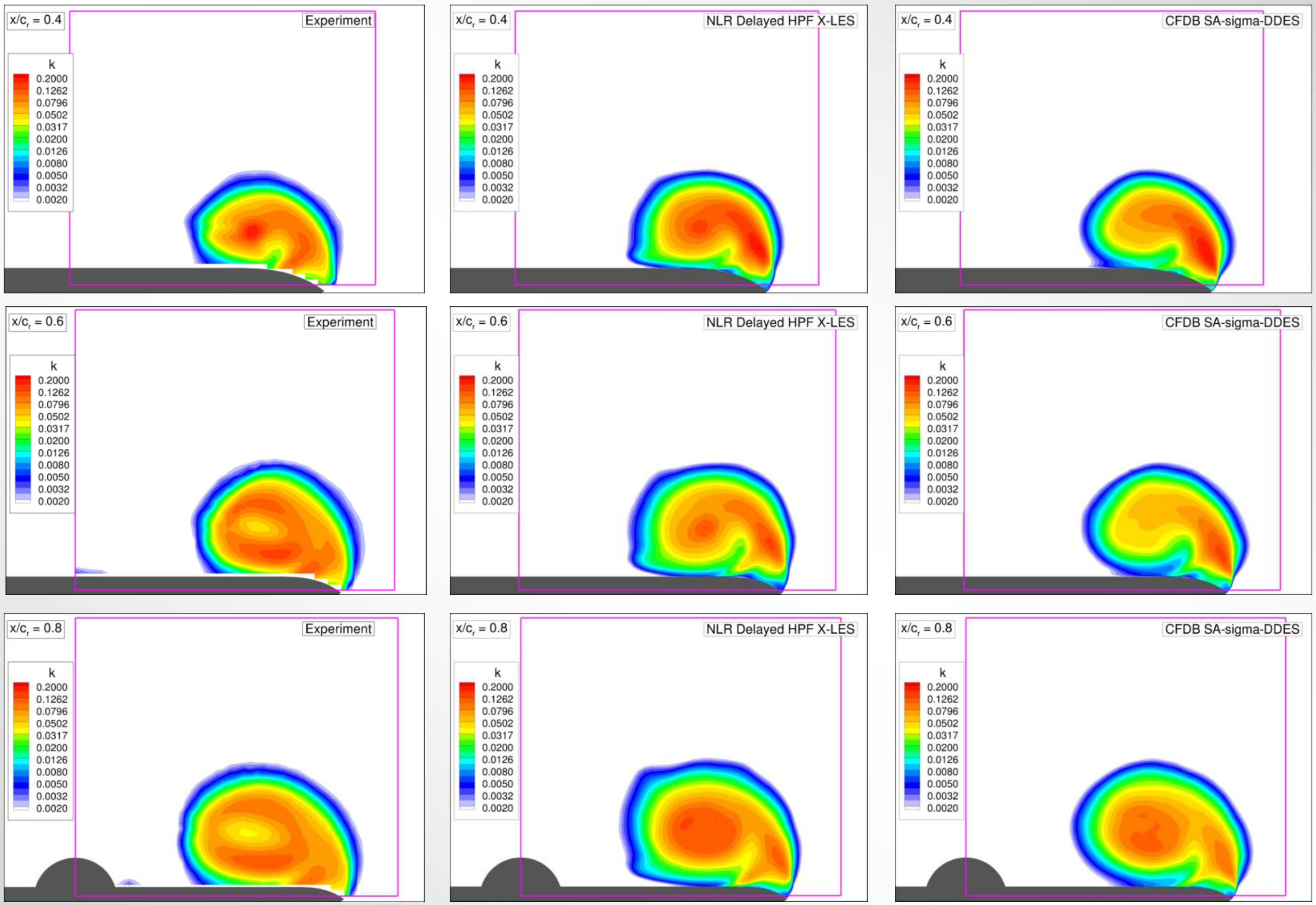
I2 Delta wing: Resolved Turbulent kinetic energy

x/c = 0.4

x/c = 0.6

x/c = 0.8



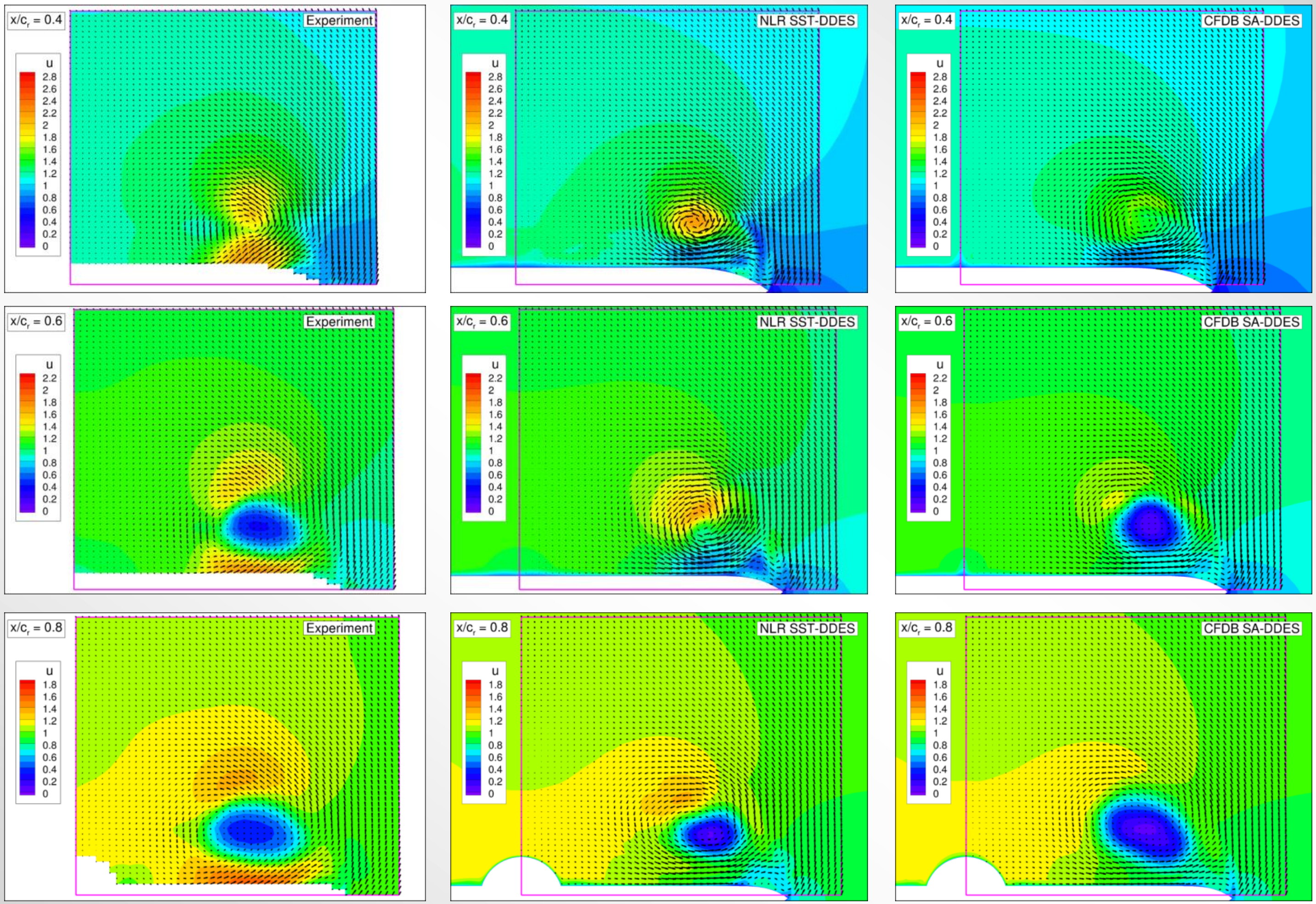
Experiment | NLR HPF DX-LES | CFDB SA-σ-DDES

I2 Delta wing: Time-averaged velocity field

x/c = 0.4

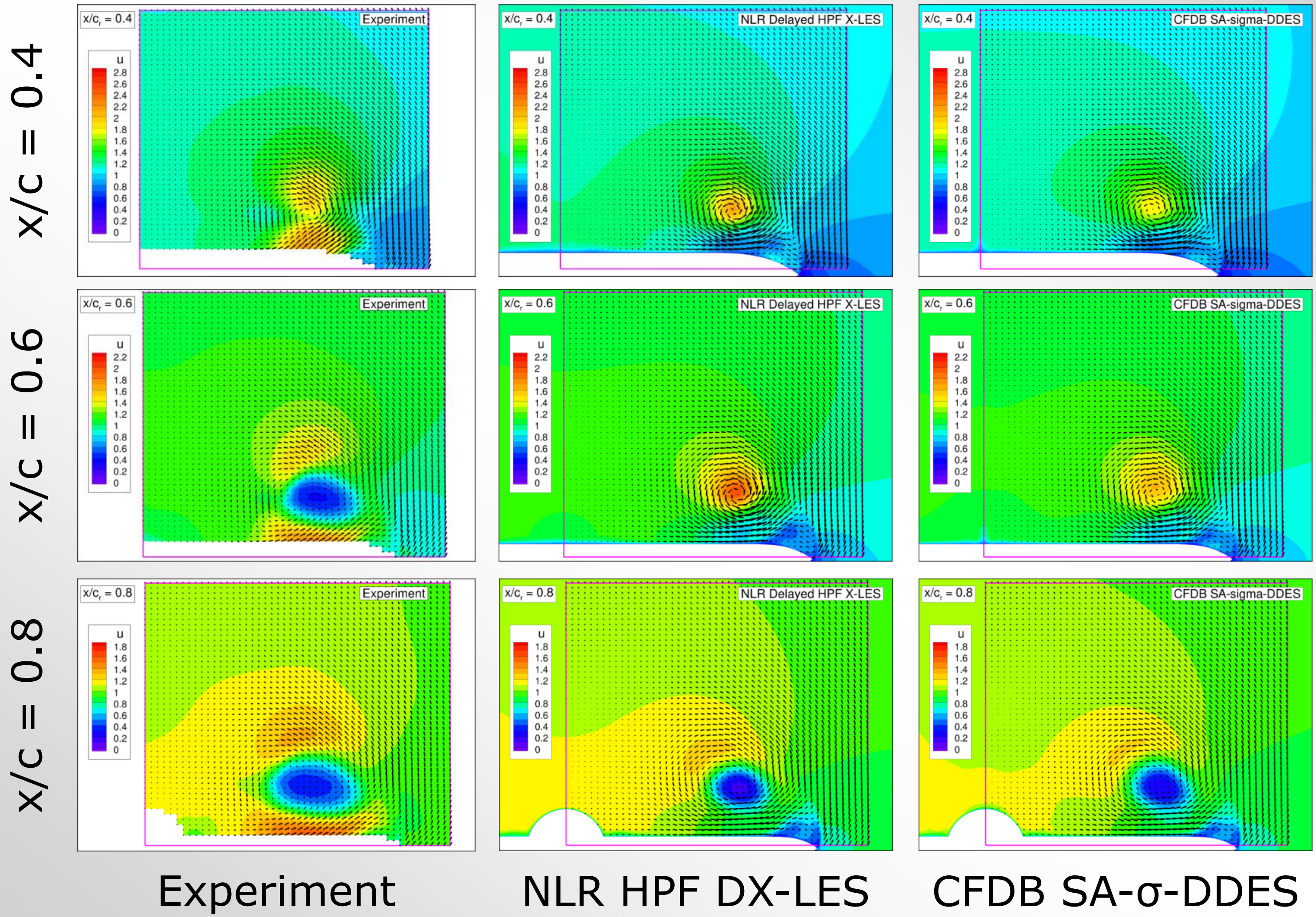
x/c = 0.6

x/c = 0.8



Experiment NLR SST-DDES CFDB SA-DDES

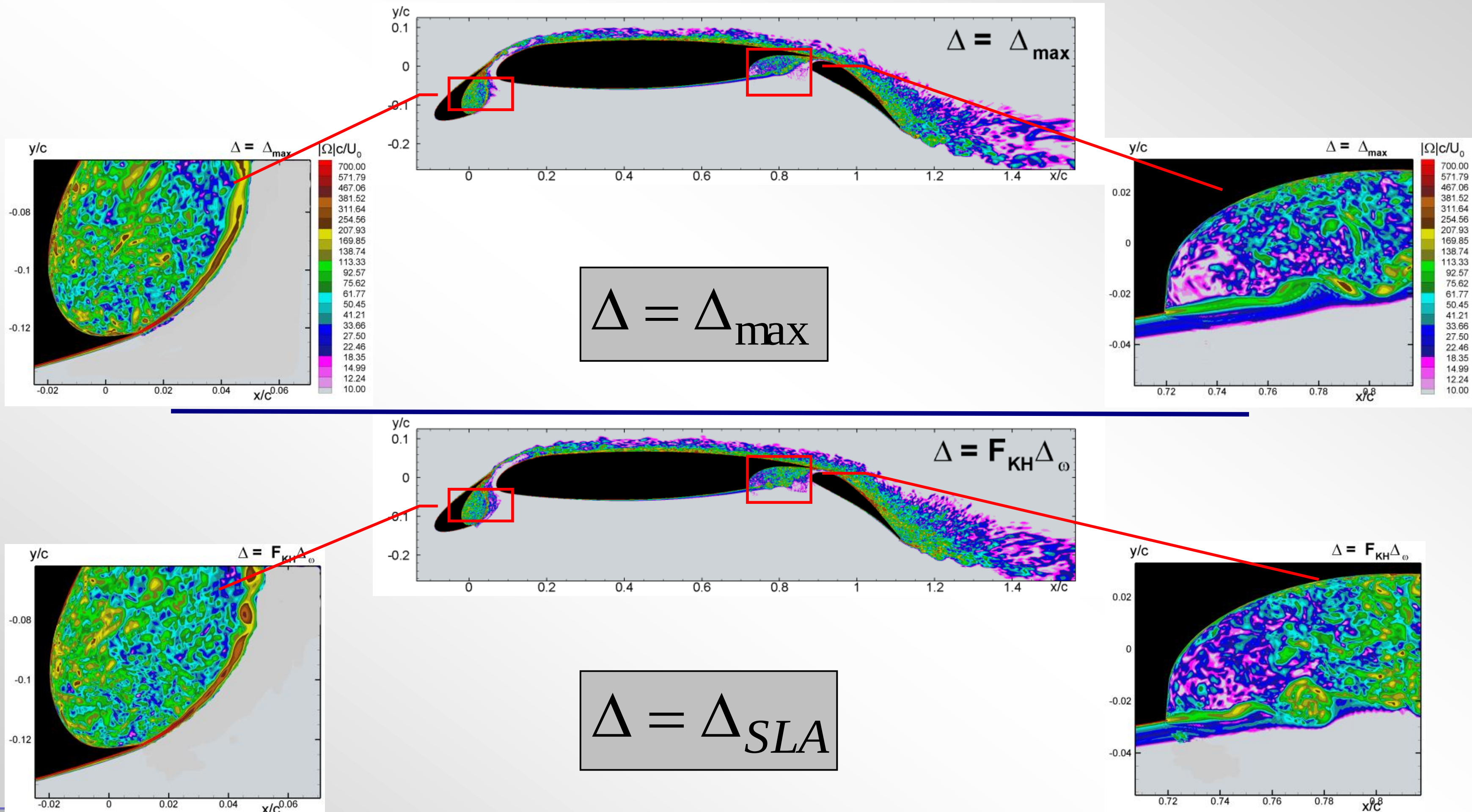
I2 Delta wing: Time-averaged velocity field



I2 Delta wing – Conclusions

- GAM methods of CFDB (SA-σ-DDES + $\widetilde{\Delta}_{\omega}$) and NLR (HPF DX-LES) give very similar results
- Strong improvement in terms of levels of pressure fluctuations and resolved turbulence
- Does not lead to improved prediction of location of vortex breakdown

I3 SA-based IDDES of 3-element airfoil

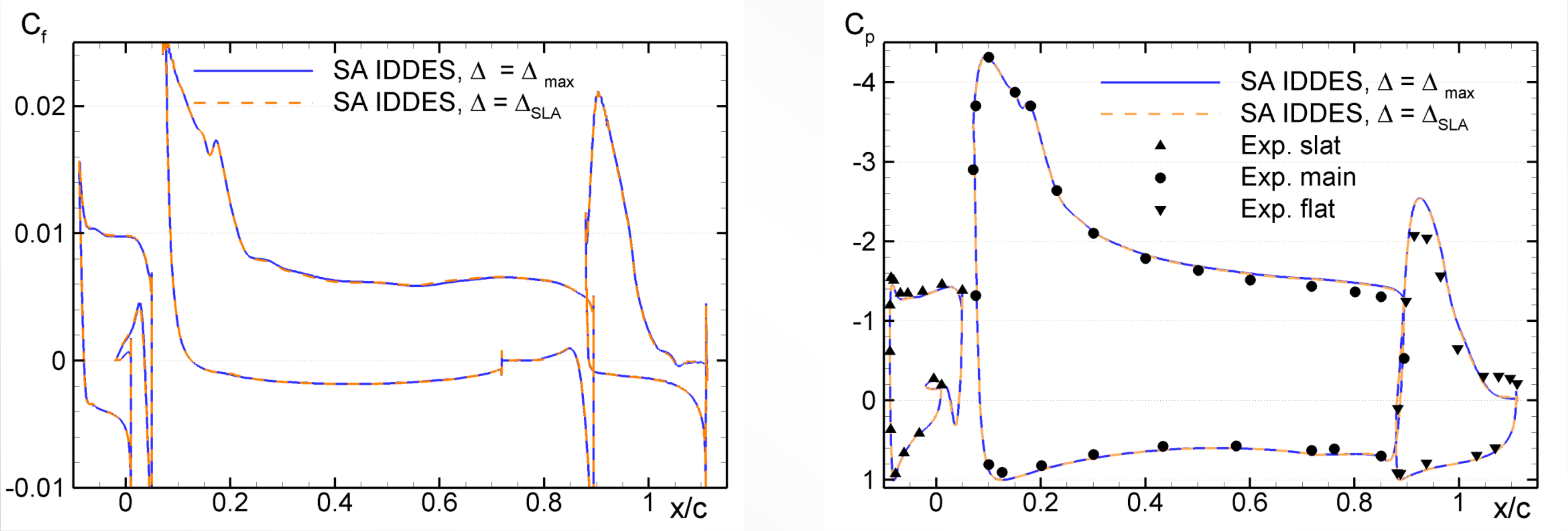


$$\Delta = \Delta_{max}$$

$$\Delta = \Delta_{SLA}$$

The use of $\Delta = \Delta_{SLA}$ leads to some acceleration of KH instability in shear layers…

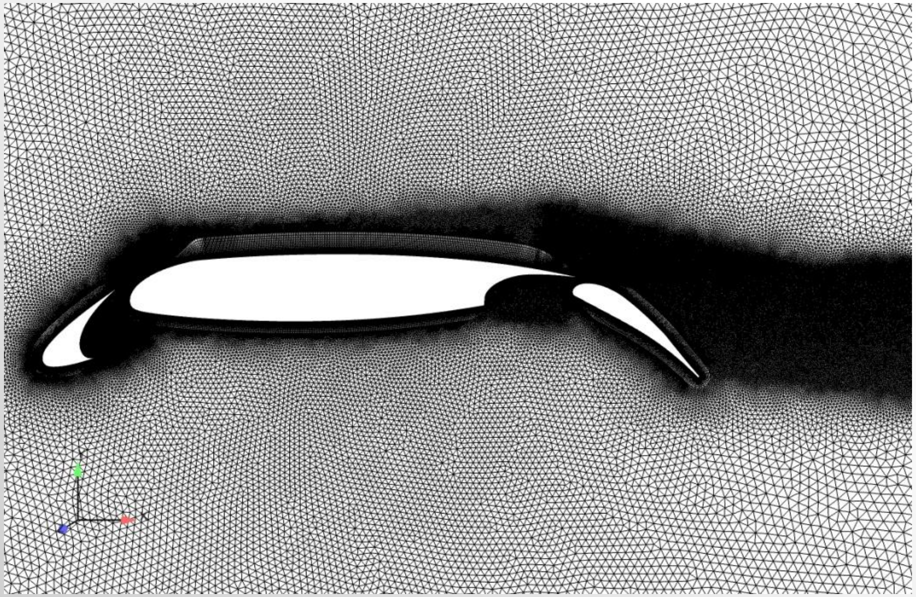
I3 SA-based IDDES of 3-element airfoil

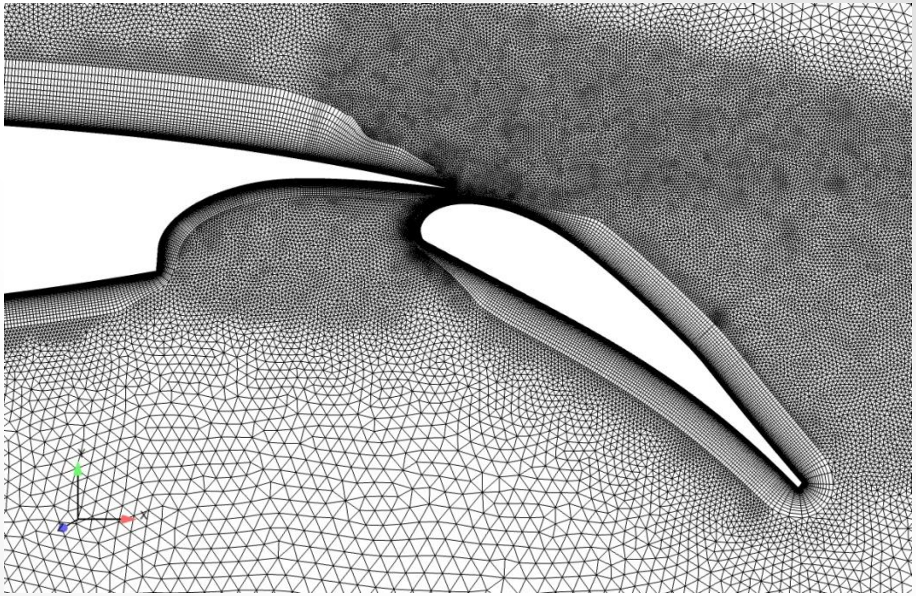


… but does not cause any visible alteration of the mean Cf and Cp

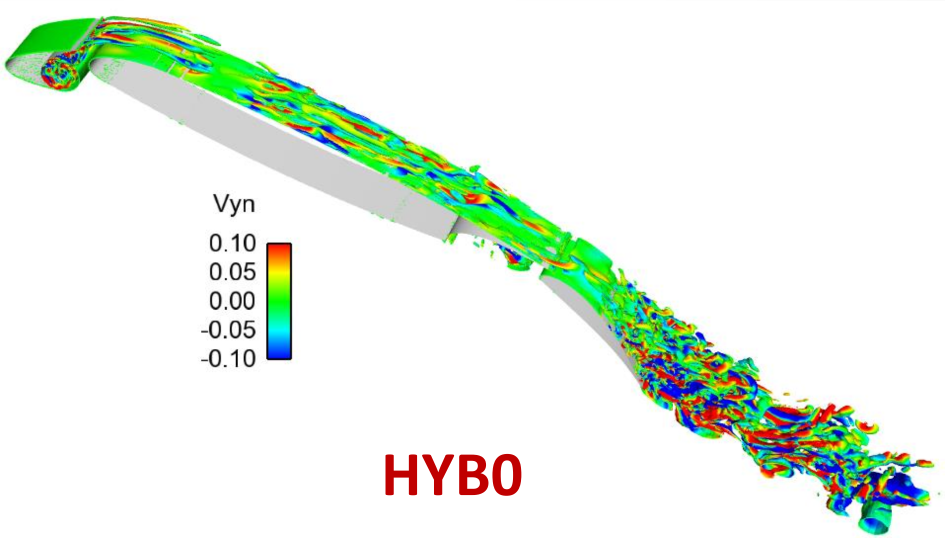
I3 LEISA F15 HL flow case (FOI)

- Grid taken from the ATAAC project, from which the HYB0 computation is take as reference (AoA = 6^o, local laminar BL)
- ~19700 2D unstructured grid with 8%C spanwise extension and Nz = 40)

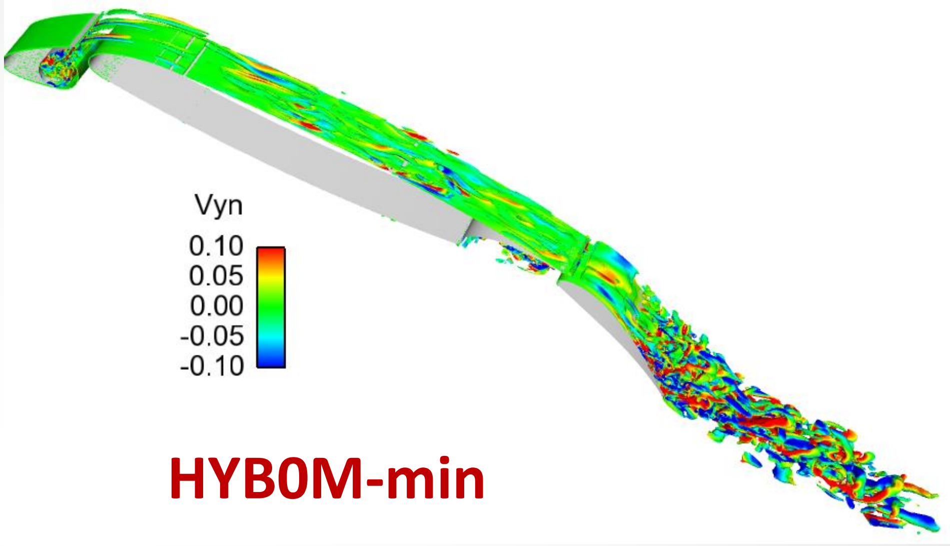




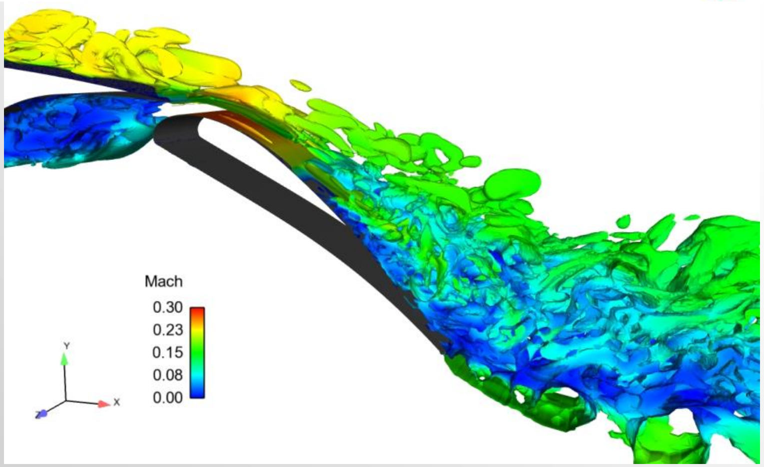
- HYB0 compared to HYB0M-min (with δ_{min})

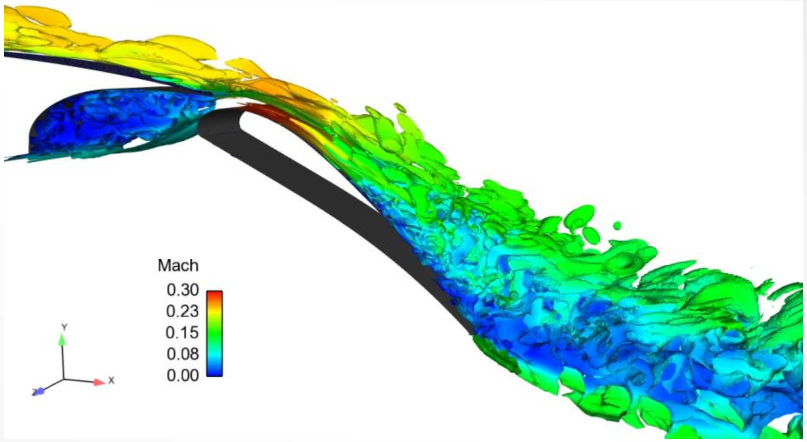


HYB0

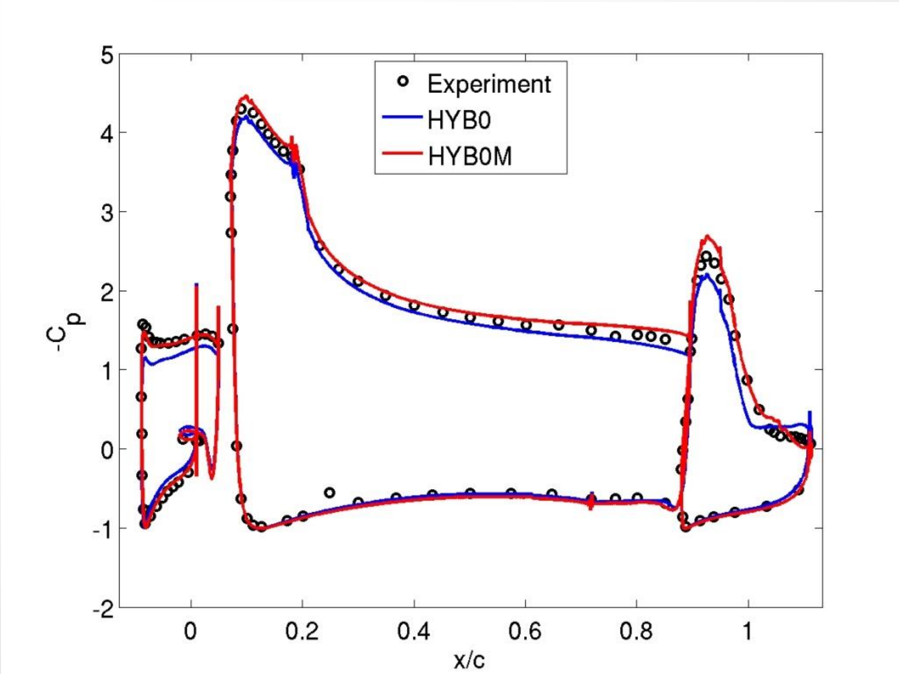


HYB0M-min

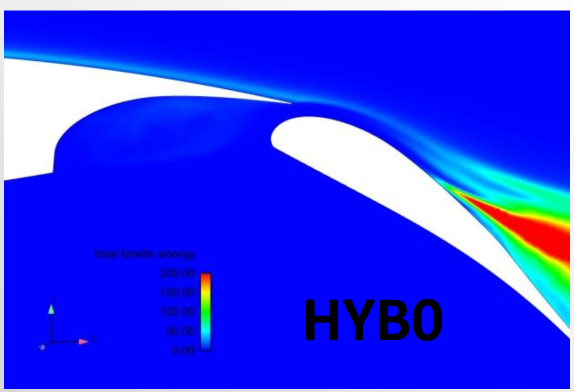


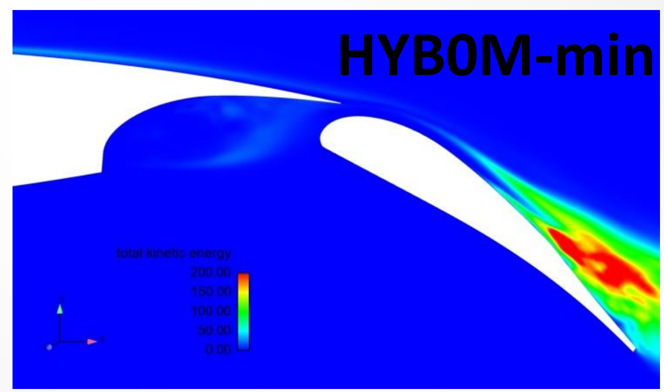


Resolved turbulent structures



- Relatively high energy resolved in the cove of main wing
- More shallow flap T.E separation
- HYB0M computation needs to run more time steps for statistical analysis
- Mandatory grid and settings will be used

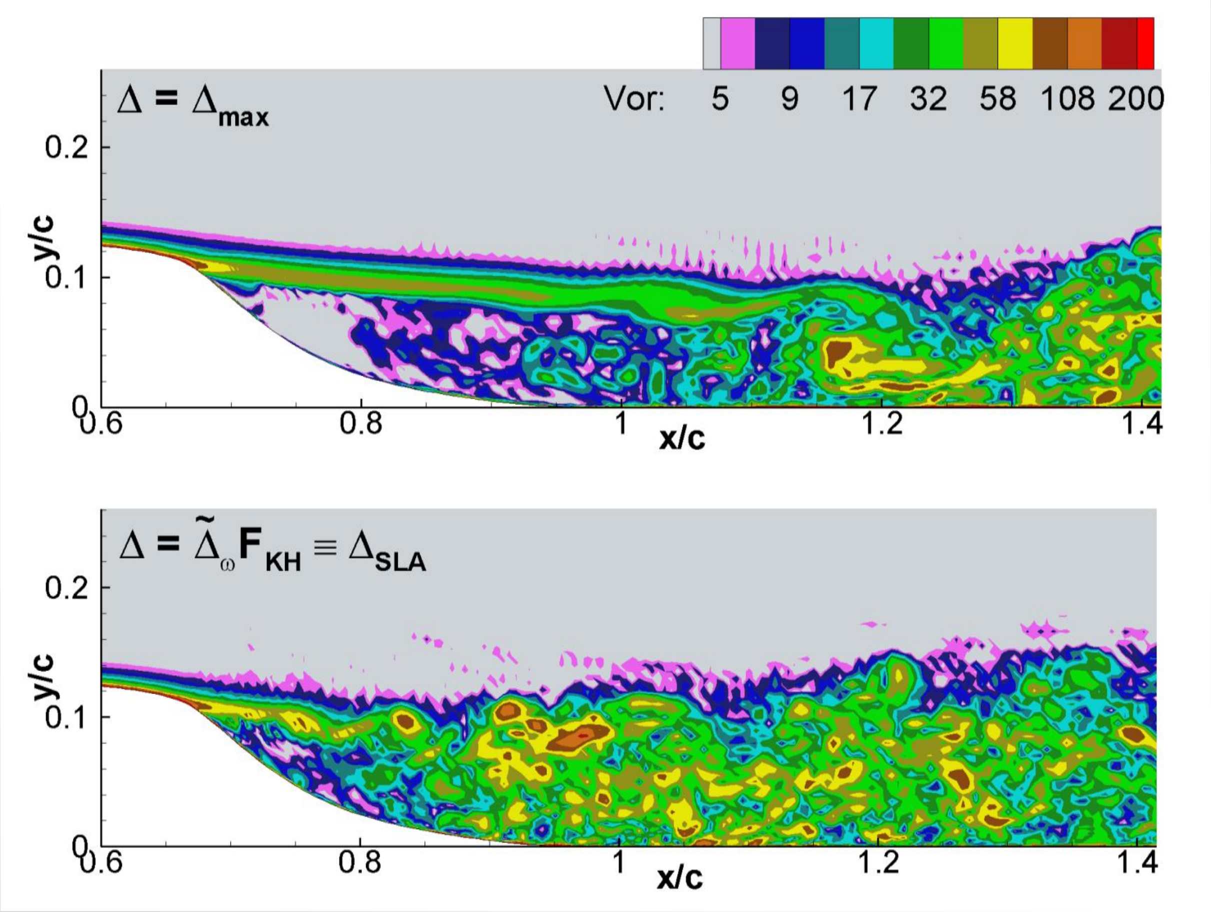




Resolved turbulent kinetic energy

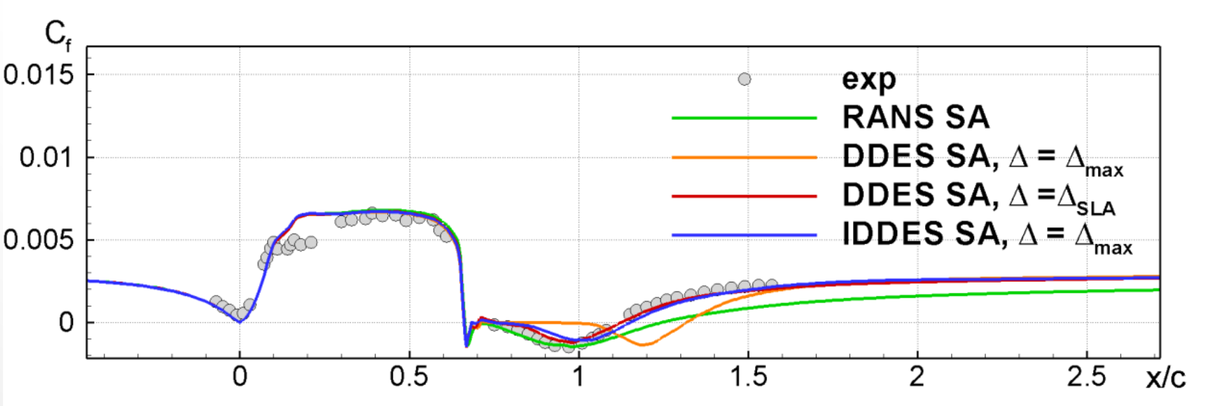
17

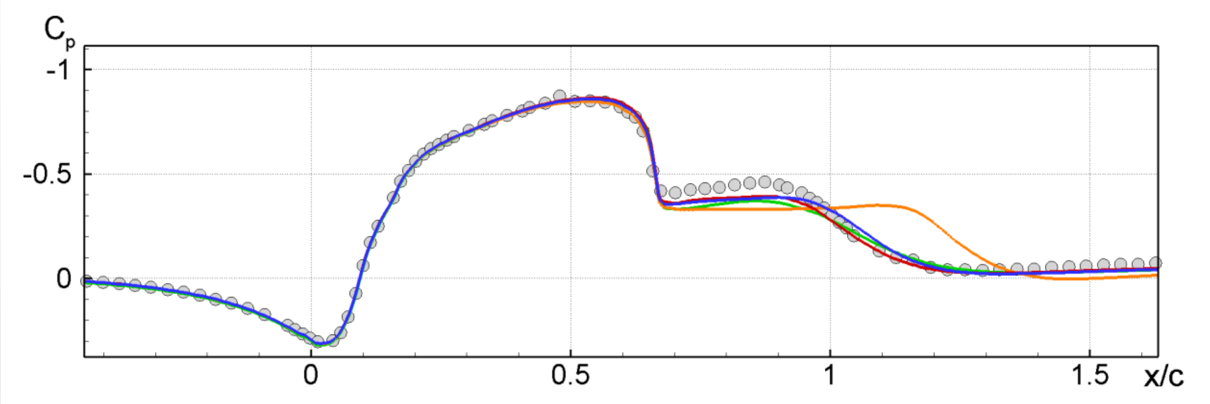
I4 SA-based DDES of hump flow



The use of $\Delta=\Delta_{SLA}$ results in unlocking KH instability and acceleration of transition to developed 3D turbulence

I4 SA-based DDES of hump flow





As a result, mean Cp and Cf prediction tangibly improves and gets close to that of IDDES with $\Delta=\Delta_{max}$

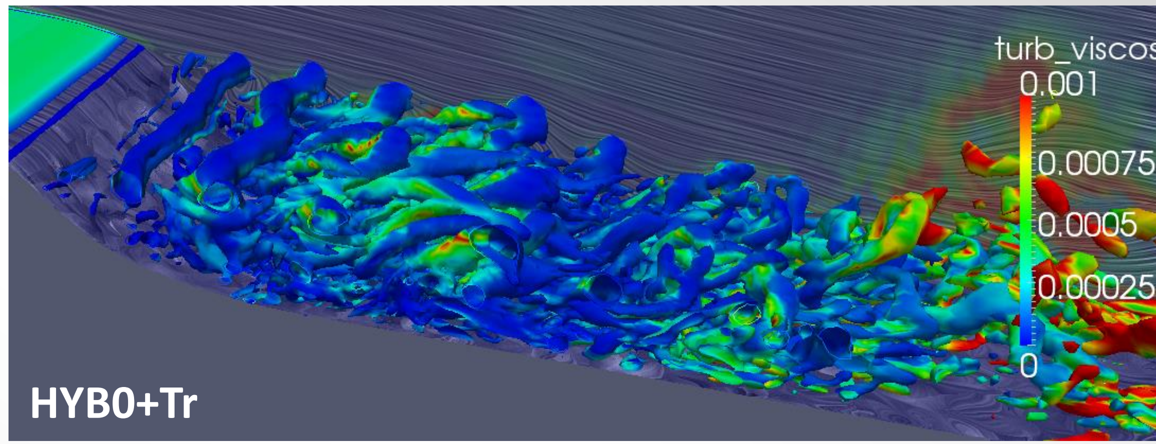
I4 SA-based DDES of hump flow

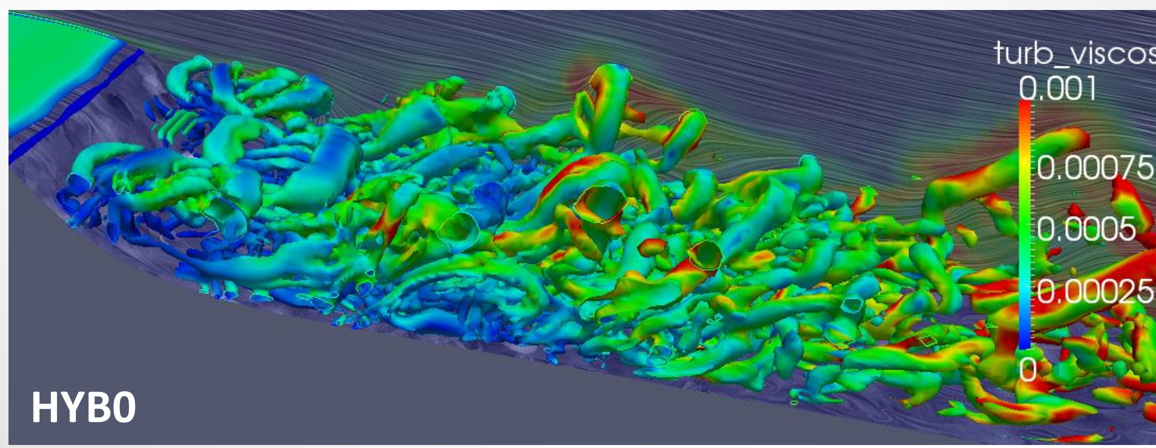
This improvement is also seen in prediction of the reattachment point

Model	Separation	Reattachment
SA RANS	0.66	1.24
SA DDES, $\Delta = \Delta_{max}$	0.66	1.32
SA DDES, $\Delta = \Delta_{SLA}$	0.66	1.13
SA IDDES, $\Delta = \Delta_{max}$	0.66	1.15
Expt.	0.67	1.12

I4 HYB0 with scale energy transfer (FOI)

- Transport equation for Δ
- Reduces SGS viscosity
- Some enhancement of initial structures
- Still not sufficiently early transition (numerical contamination?)
- Still running...





21

NTS: Conclusions I3 (3-element airfoil) and I4 (hump)

- Based on the simulations of the hump and 3-element airfoil, it can be concluded that:
  - The use of $\Delta = \Delta_{SLA}$ results in a significant improvement of DDES predictions and is “neutral” in IDDES (does not lead to any non-desirable “side-effects” caused by interaction with empirical functions of IDDES)

I5 Round jet

- Unheated, static round jet at $M_\infty = 0.9$, $Re_D = 1.1\ x\ 10^6$
  - Pronounced Grey Area for standard DES methods
  - RANS profiles prescribed at nozzle exit plane
  - Experimental data: Bridges et al.
  - common grid “G3” (8.8 M cells)

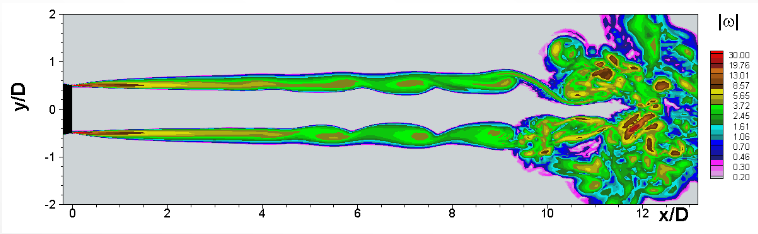
- CFDB: Initial results (short time sample / issues with numerics & BC settings)
  - SA-σ-DDES + $\widetilde{\Delta}_\omega$

- NLR: Results
  - X-LES with HPF + stochastic backscatter

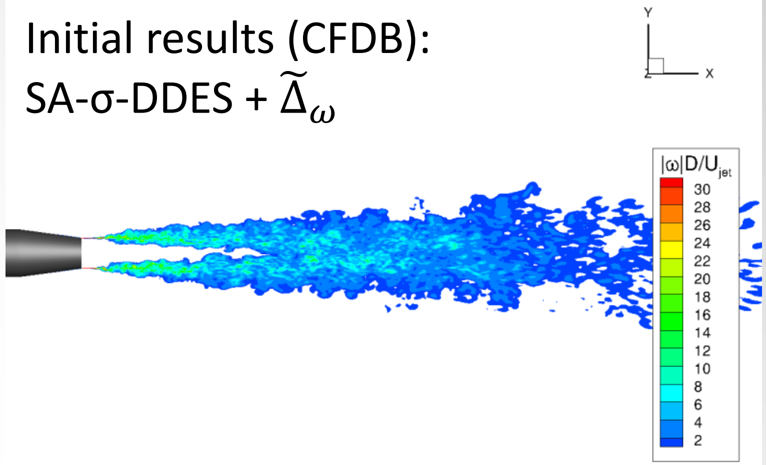
- NTS: Results
  - SA-DDES + $\widetilde{\Delta}_\omega F_{KH}$

I5 Round jet: instantaneous vorticity magnitude

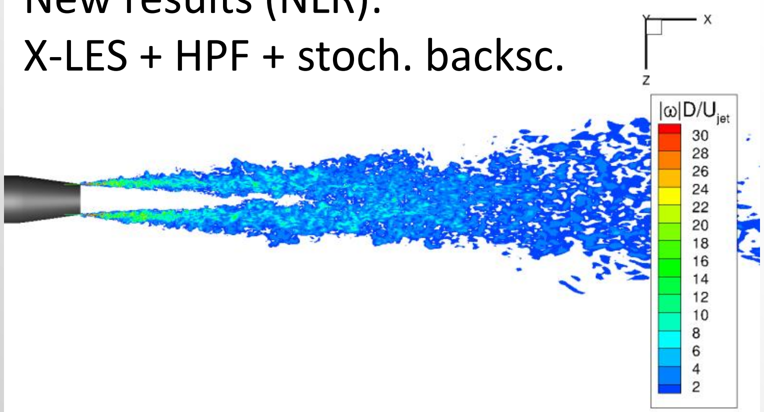
Reference model on coarser grid (NTS):
SA-DDES + Δ_{max}



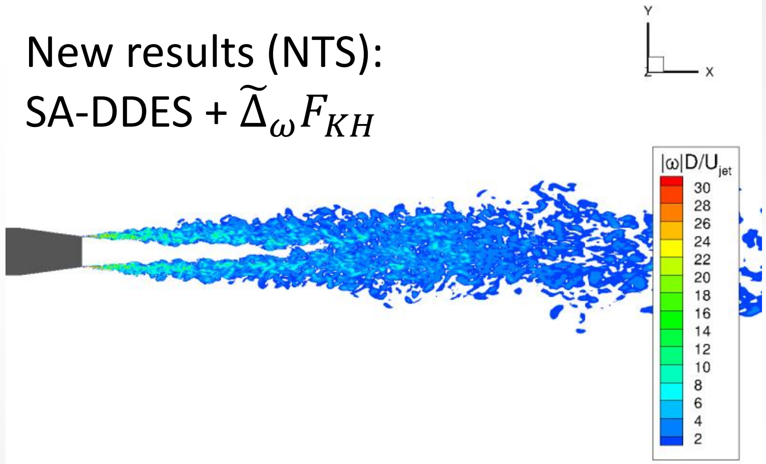
Initial results (CFDB):
SA-σ-DDES + $\widetilde{\Delta}_{\omega}$



New results (NLR):
X-LES + HPF + stoch. backsc.

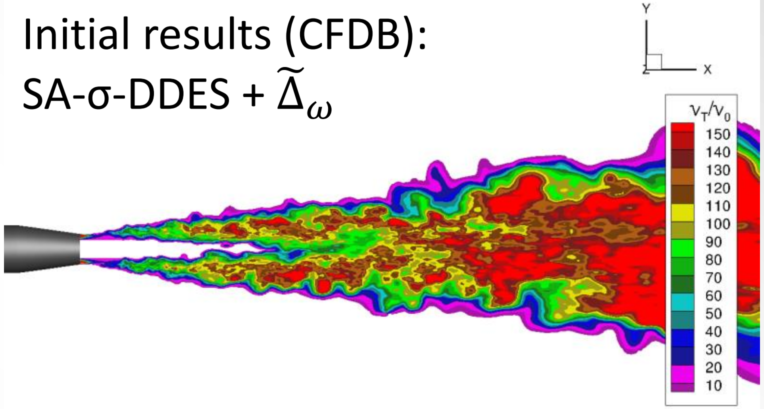


New results (NTS):
SA-DDES + $\widetilde{\Delta}_{\omega} F_{KH}$

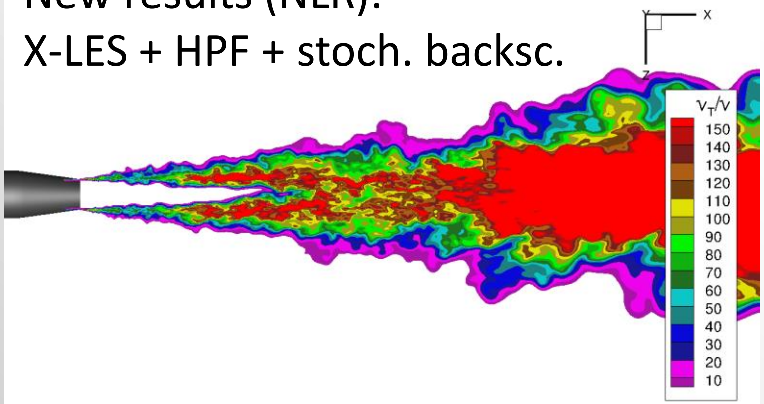


I5 Round jet: instantaneous eddy viscosity ratio

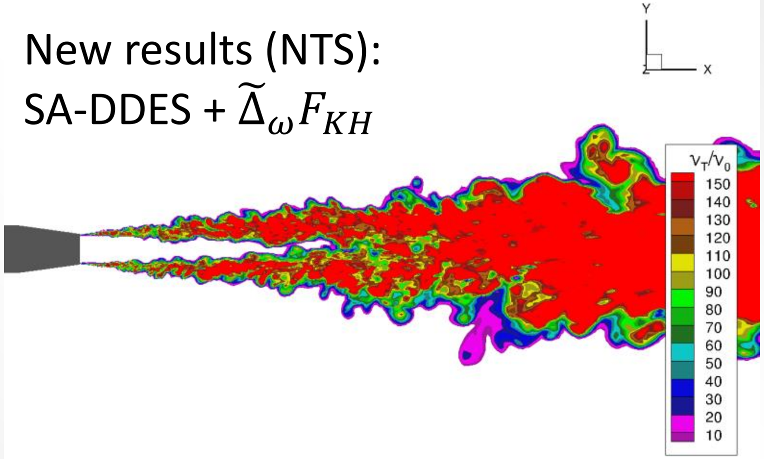
Initial results (CFDB):
SA-σ-DDES + $\widetilde{\Delta}_{\omega}$



New results (NLR):
X-LES + HPF + stoch. backsc.

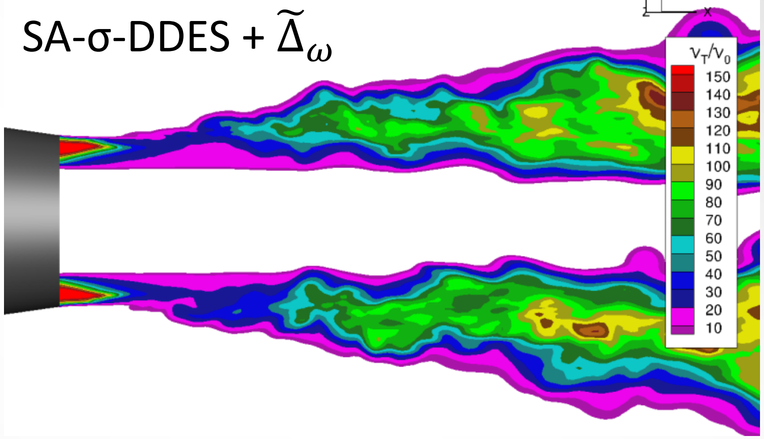


New results (NTS):
SA-DDES + $\widetilde{\Delta}_{\omega} F_{KH}$

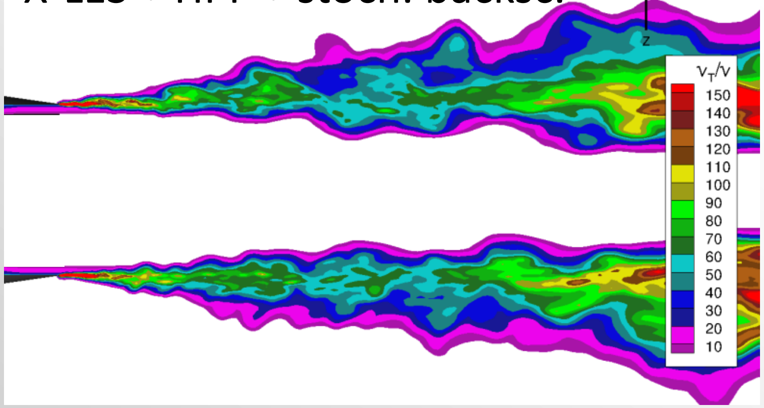


I5 Round jet: instantaneous eddy viscosity ratio (RLT region)

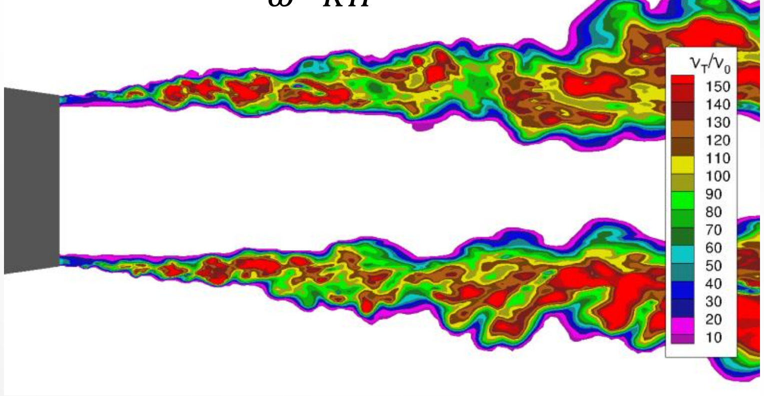
Initial results (CFDB):
SA-σ-DDES + $\widetilde{\Delta}_\omega$



New results (NLR):
X-LES + HPF + stoch. backsc.



New results (NTS):
SA-DDES + $\widetilde{\Delta}_\omega F_{KH}$



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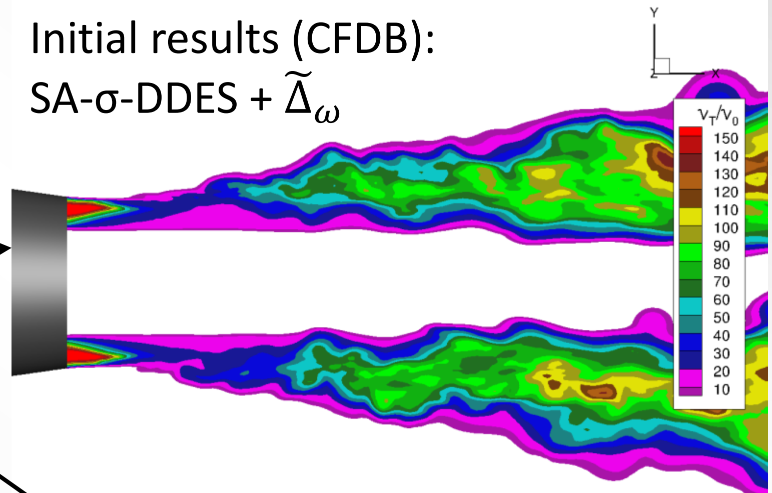
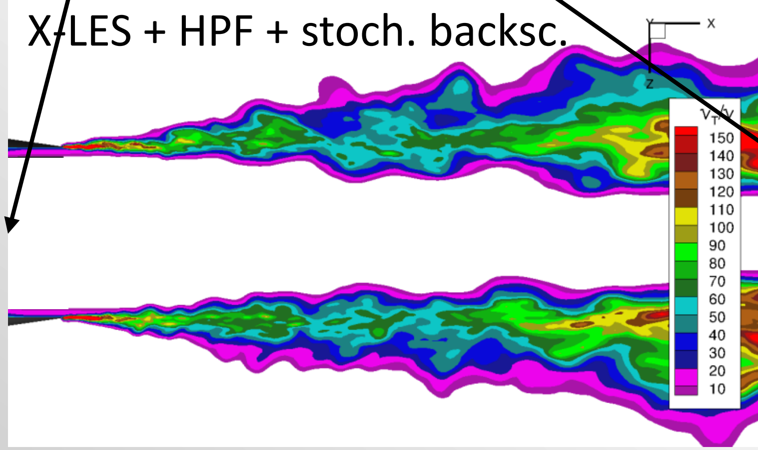
I5 Round jet: instantaneous eddy viscosity ratio (RLT region)

Slightly different nozzle geometries used between partners

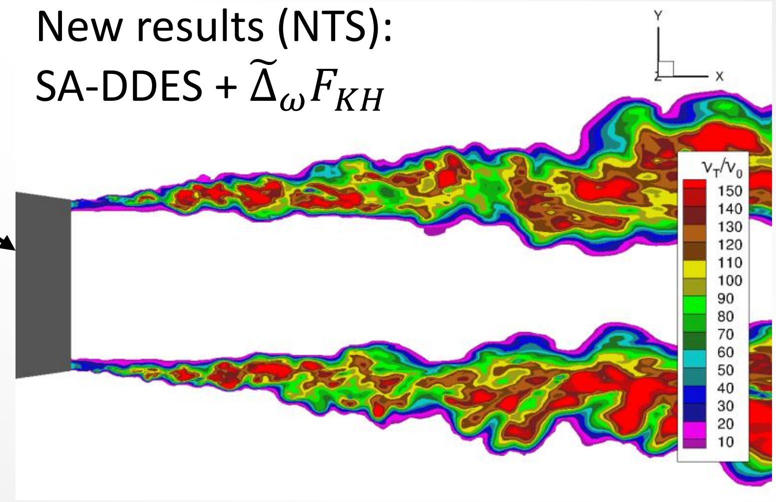
Initial results (CFDB):
SA-σ-DDES + $\widetilde{\Delta}_{\omega}$



New results (NLR):
X-LES + HPF + stoch. backsc.



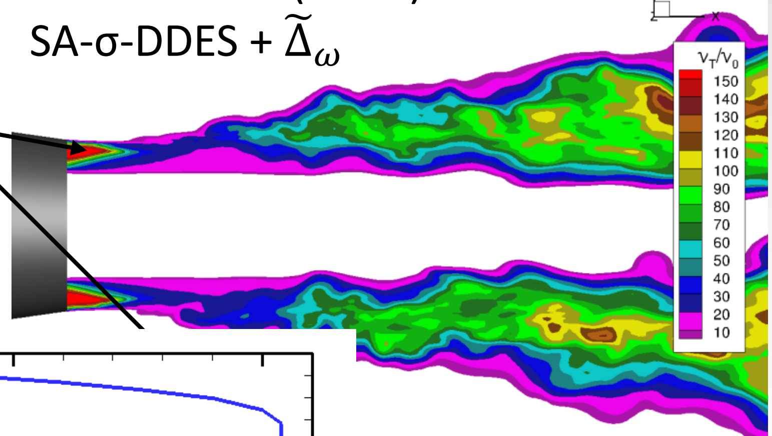
New results (NTS):
SA-DDES + $\widetilde{\Delta}_{\omega} F_{KH}$

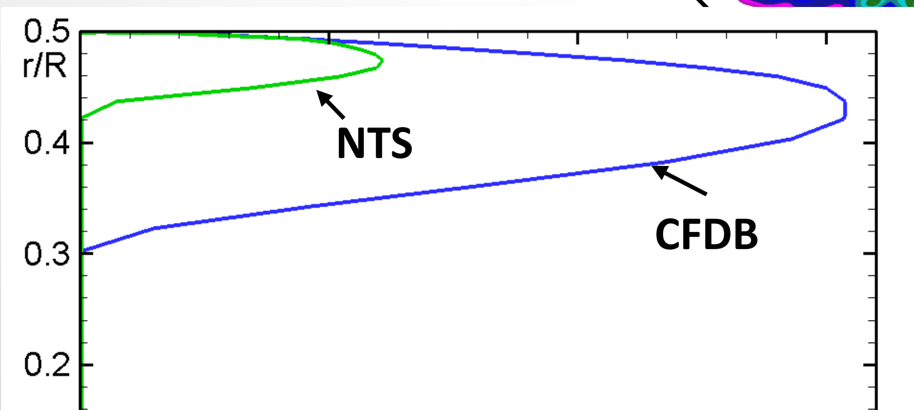


I5 Round jet: instantaneous eddy viscosity ratio (RLT region)

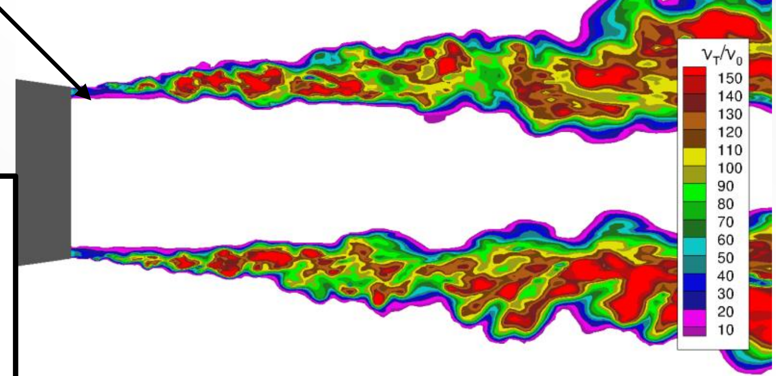
Different nozzle exit profiles used between CFDB and NTS
→ difference mainly in υ_t/υ profile

Initial results (CFDB):
SA-σ-DDES + $\widetilde{\Delta}_\omega$





New results (NTS):
SA-DDES + $\widetilde{\Delta}_\omega F_{KH}$

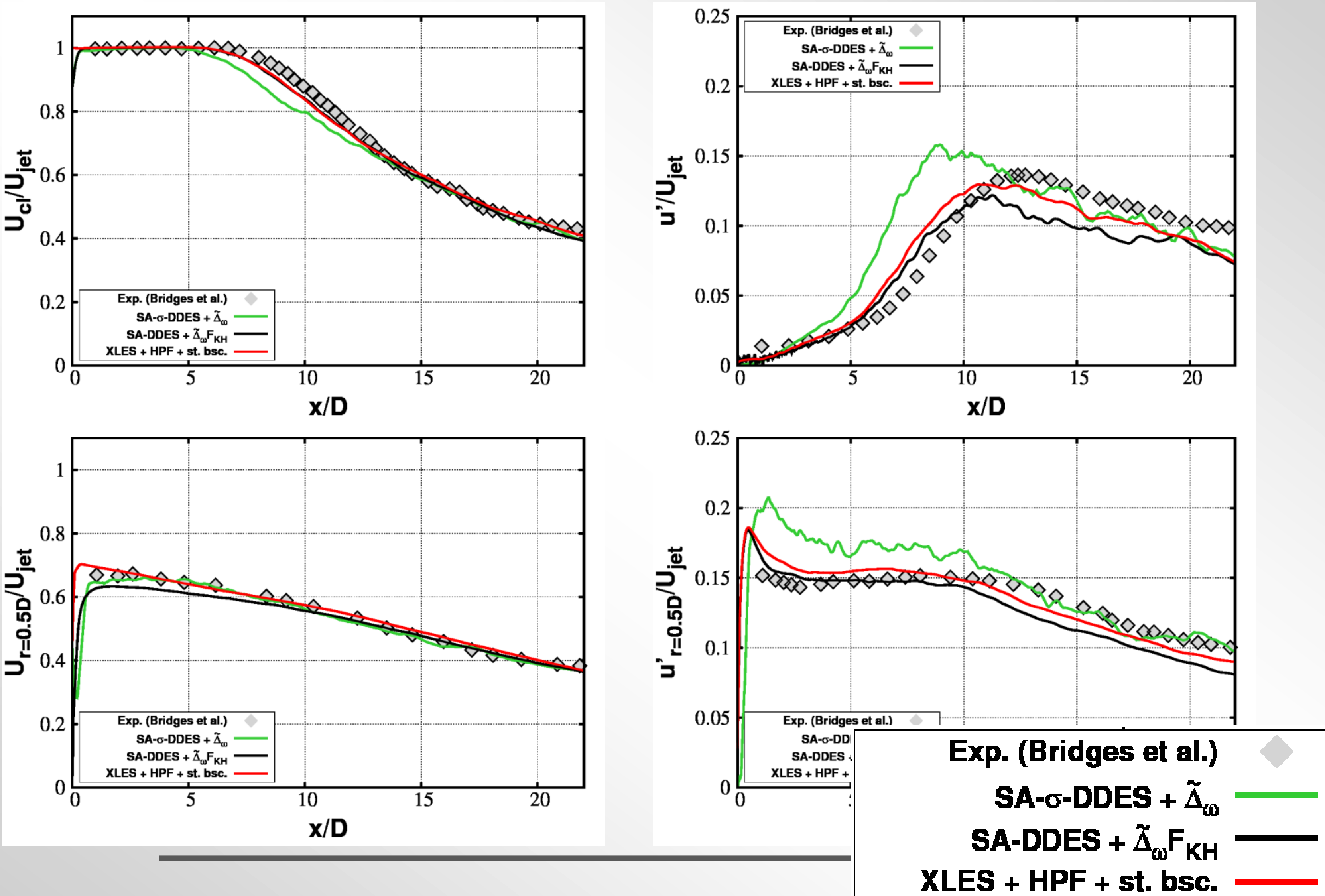


Note: RANS υ_t-92 was used in previous jet noise computations of NTS, and was provided to CFDB at a very early project stage before TC description was completed

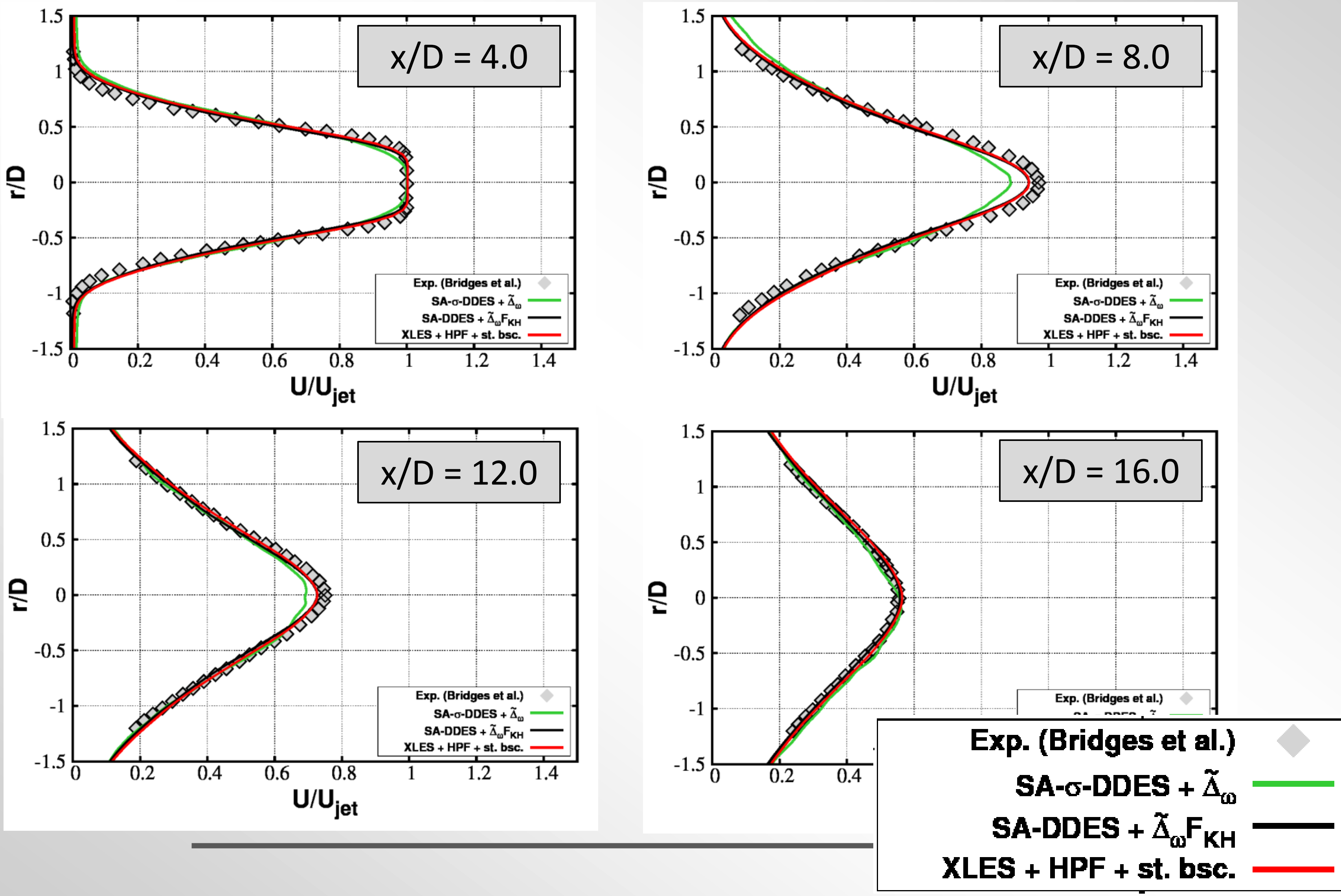
I5 Round jet: mean velocity and RMS

centreline

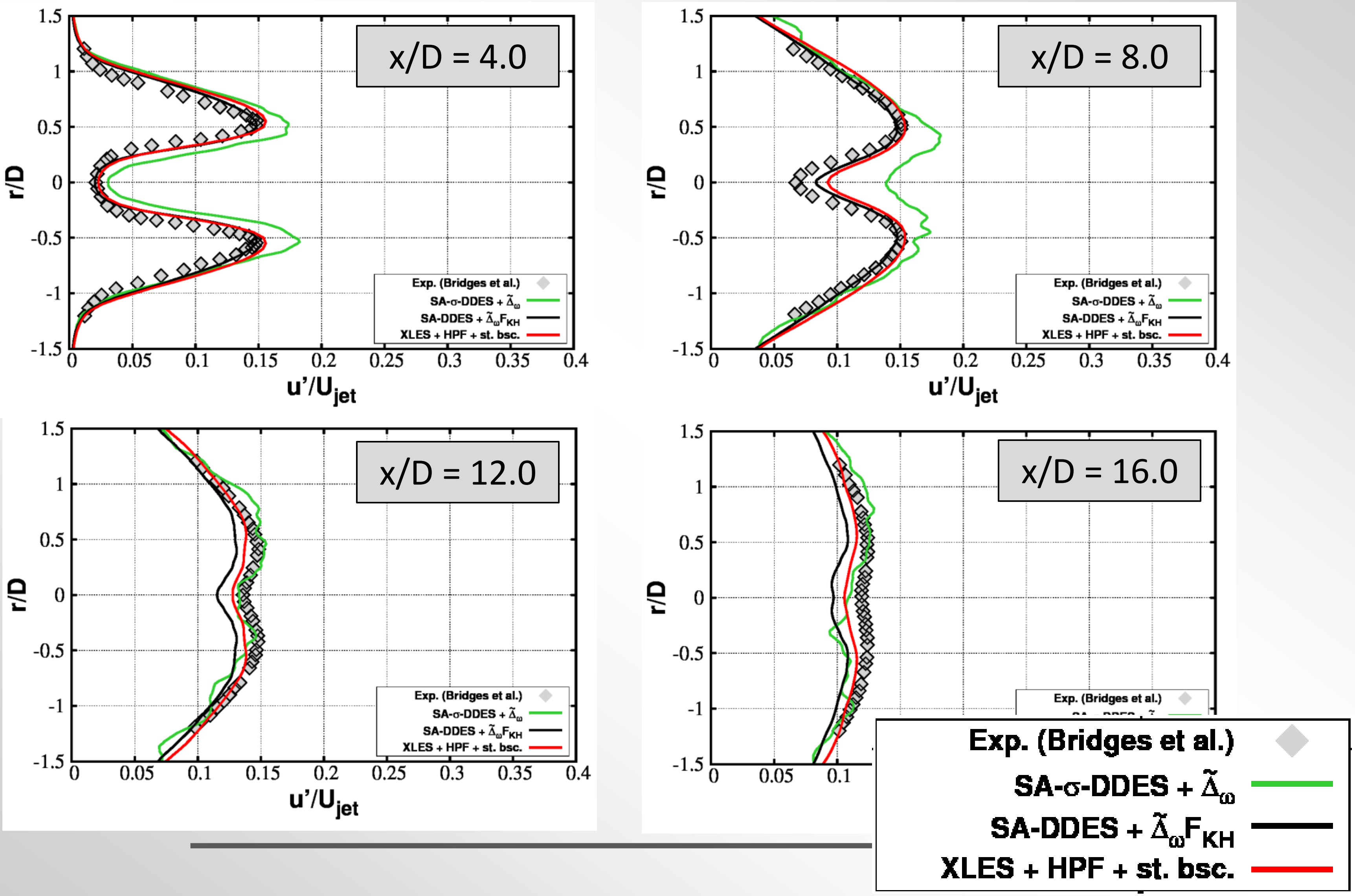
lip line



I5 Round jet: mean velocity profiles



I5 Round jet: u-RMS profiles



I5 Round jet: preliminary conclusions

- Very comparable results between NTS and NLR → excellent prediction of aerodynamic jet characteristics
- CFDB results differ somewhat, open issues remain:
  - New computations planned for final cross-plotting with improved case settings / solver:
    - Same nozzle exit profiles as NTS (from std. SA-RANS)
    - Sufficiently long time sample
    - Improved numerical settings
    - Improved compressible OpenFOAM solver for aeroacoustics
- Acoustic results were defined as optional in TC description, however NTS has the data readily available, NLR and CFDB have stored FWH data, so that cross-plotting for this task is considered for the final meeting