Simulation of wing-body junction flows with hybrid RANS/LES methods

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Introduction

- Junction flow occurs when a boundary layer encounters an obstruction
- At realistic large Reynolds number, the adverse pressure gradient in the streamwise direction imposed by the wing often causes the upwind boundary layer on the body to separate and form multiple horseshoe vortices around the wing
- Better understanding and accurate prediction of the junction flows can effectively help the design of lower drag and high-efficiency flight vehicles

Viewed objects

- Rood wing-body junction (3:2 elliptical nose and a NACA 0020 tail model) – have experimental results
- NASA TN D-712 – has interference flows at high angles of attack with a low-Re two-equation k–g model which requires no parameterization of the distance to the wall

Numerical methods. Flow equations

- The computations here are all based on a compressible solver using a Roe flux-difference splitting scheme with a 3rd order monotone upstream scheme
- A modified fully implicit lower–upper symmetric Gaussian Seidel (LUSGS, Yoon and Jameson, 1987; Xiao et al., 2006) model with Newton-like sub-iteration in pseudo time is taken as the time marching method when solving the mean flow and the turbulence model equations
- Global non-dimensional time stepping is implemented to capture the unsteady properties of the separation flows

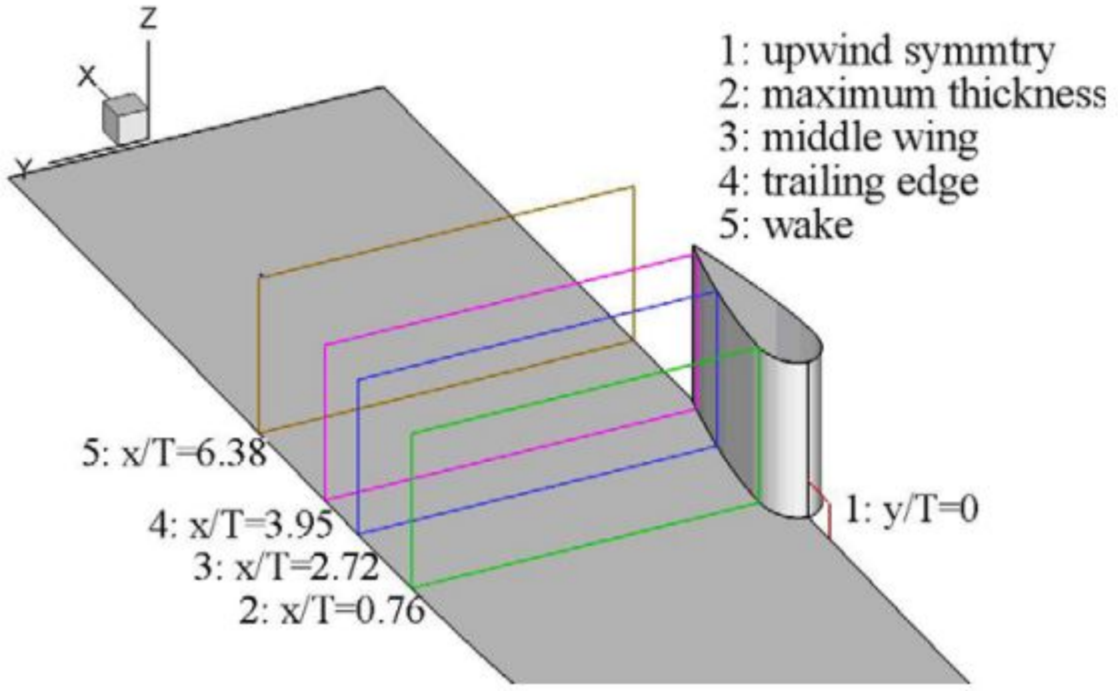
Numerical methods. Energy and dissipation equations

- Using the LU-SGS method
- The production terms are treated explicitly, lagged in time while the dissipation and diffusion terms are treated implicitly
- The advective terms are discretized using second order upwind scheme. The diffusive terms are discretized using a second-order central scheme.

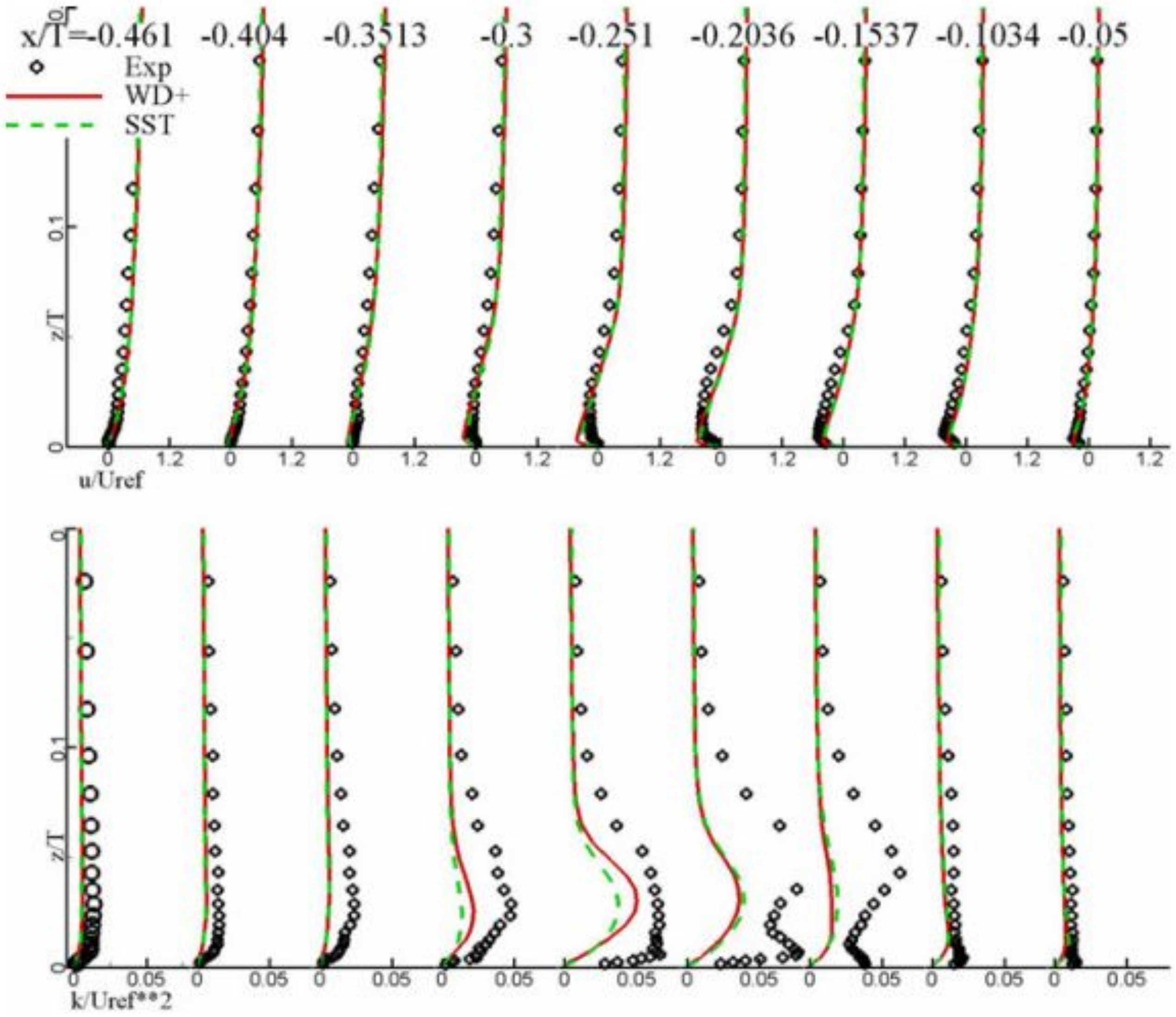
Results. Rood

Boundary conditions:

- at x/T = -18.24: inlet (from experiment)
- at x/T = 16: outflow (zero streamwise gradients)
- at y/T = 0, y/T = 7 and z/T = 3: symmetric
- at z/T = 0: wall (no-slip)

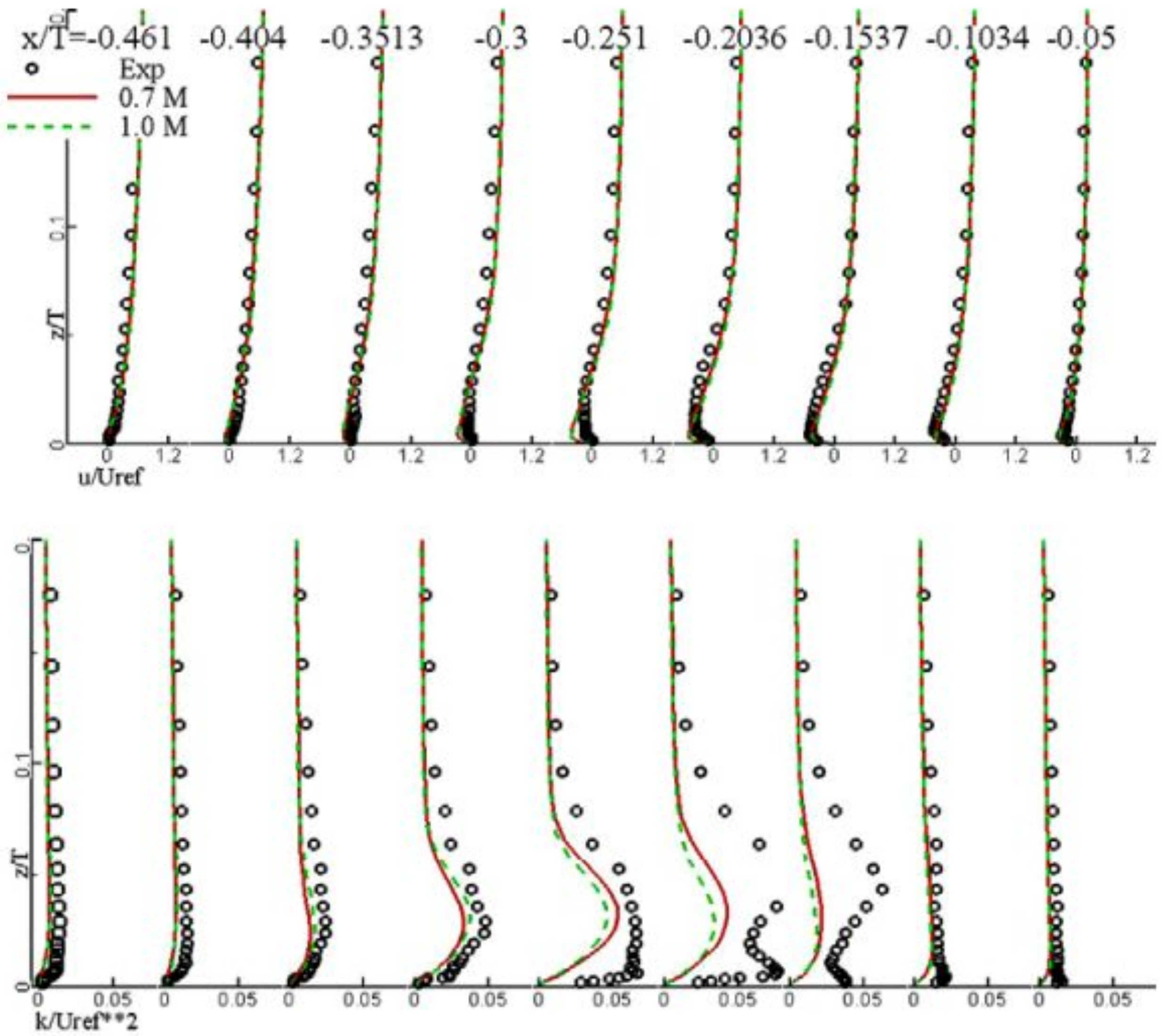


Difference between SST and WD+



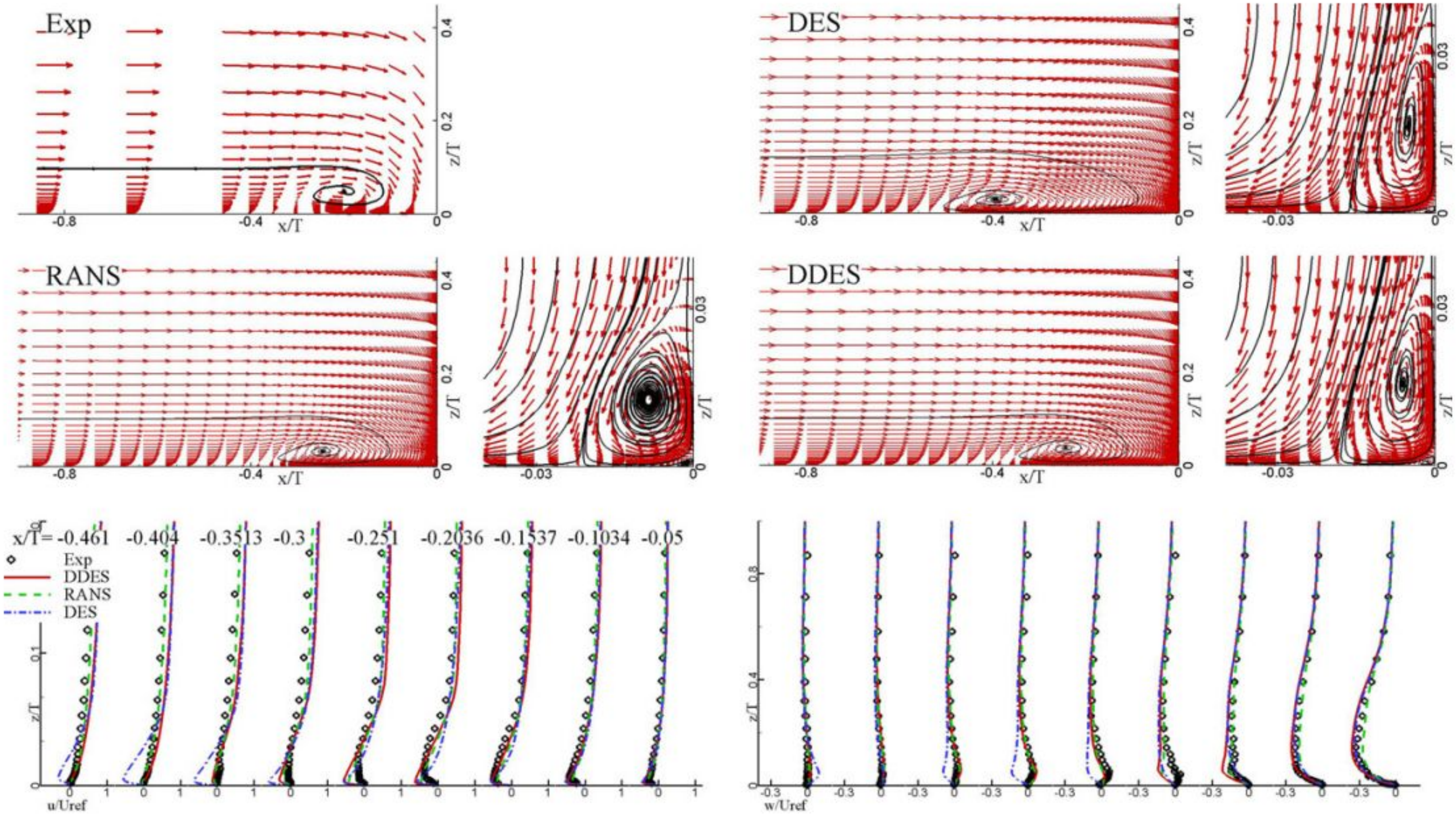
Comparisons on U and k with the WD+ and SST

Difference on grid



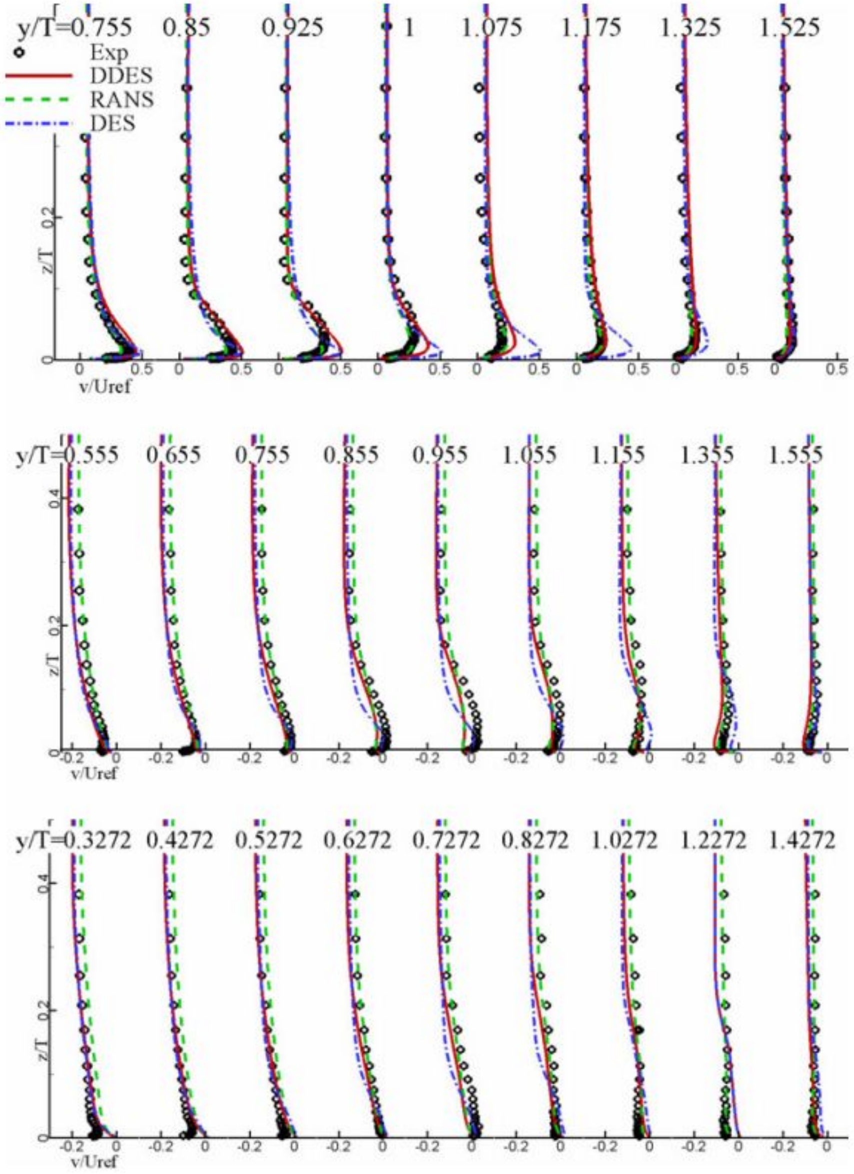
Comparisons on U/Uref and k/U^2_{ref} based on two grids

Flowfields on the symmetric plane



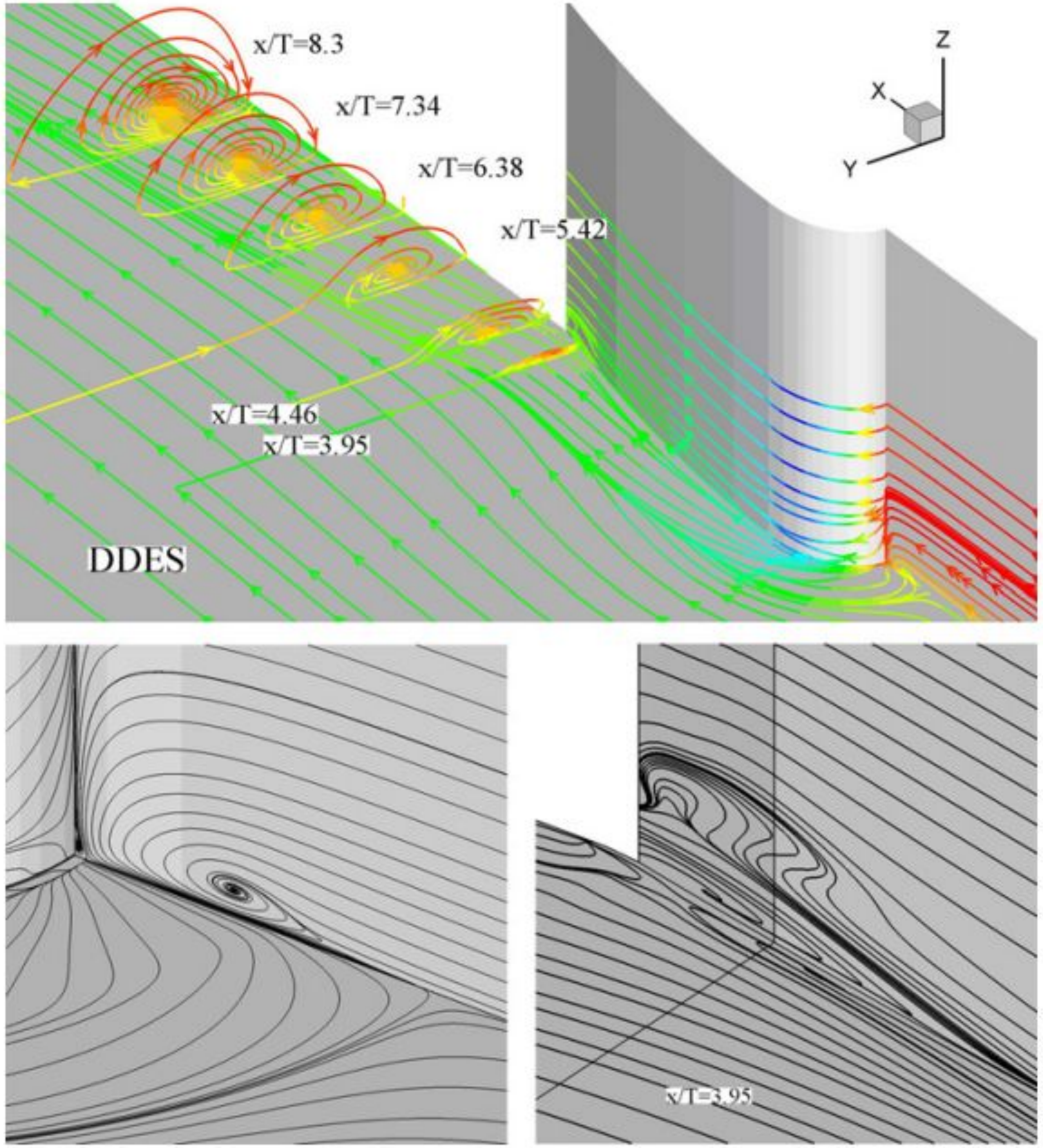
Comparison of velocity vectors on the symmetric plane

Flow structures at three streamwise positions



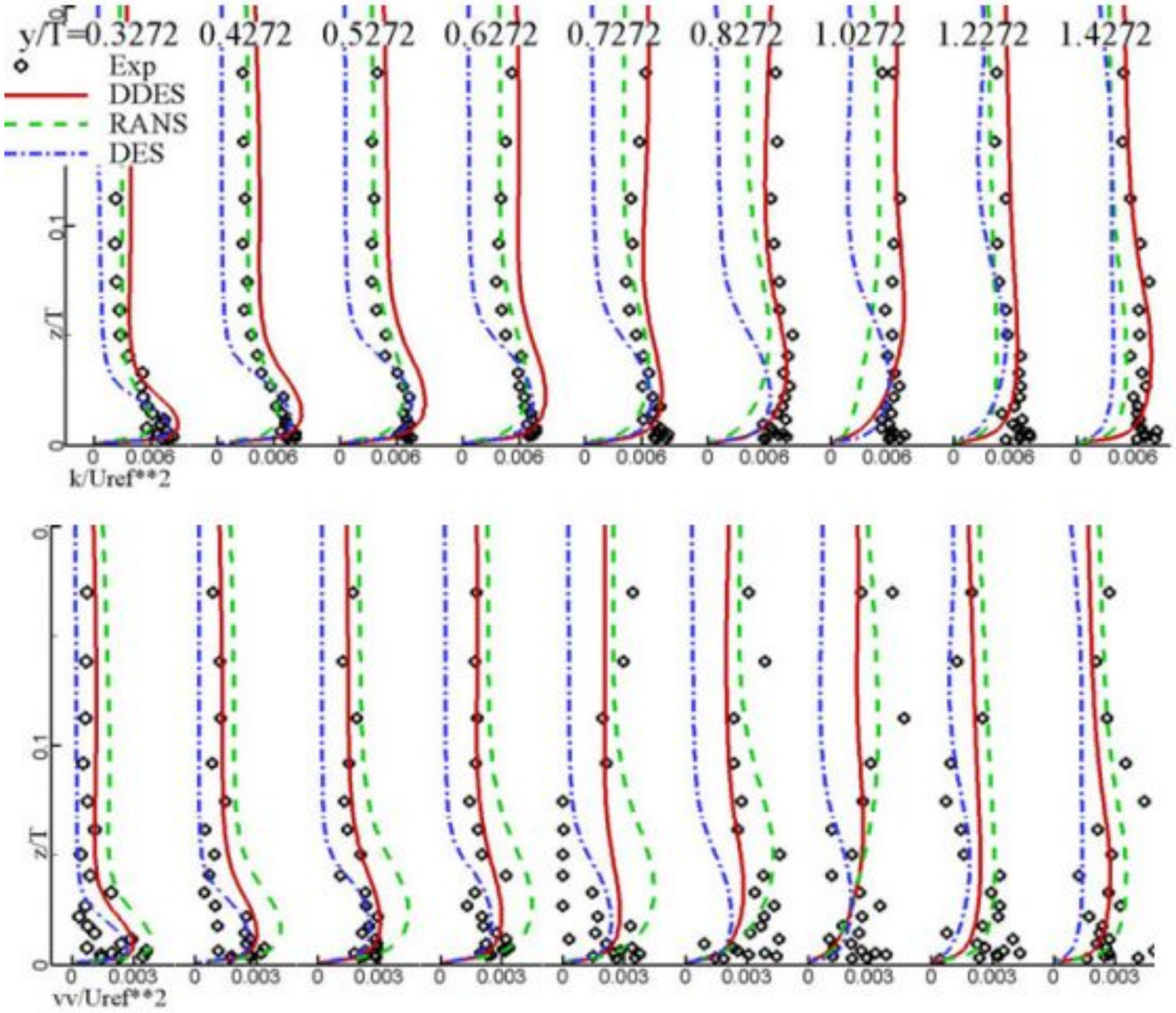
Transverse velocity at different streamwise positions (maximum thickness, middle and trailing edge of the wing)

Flow structures at three streamwise positions



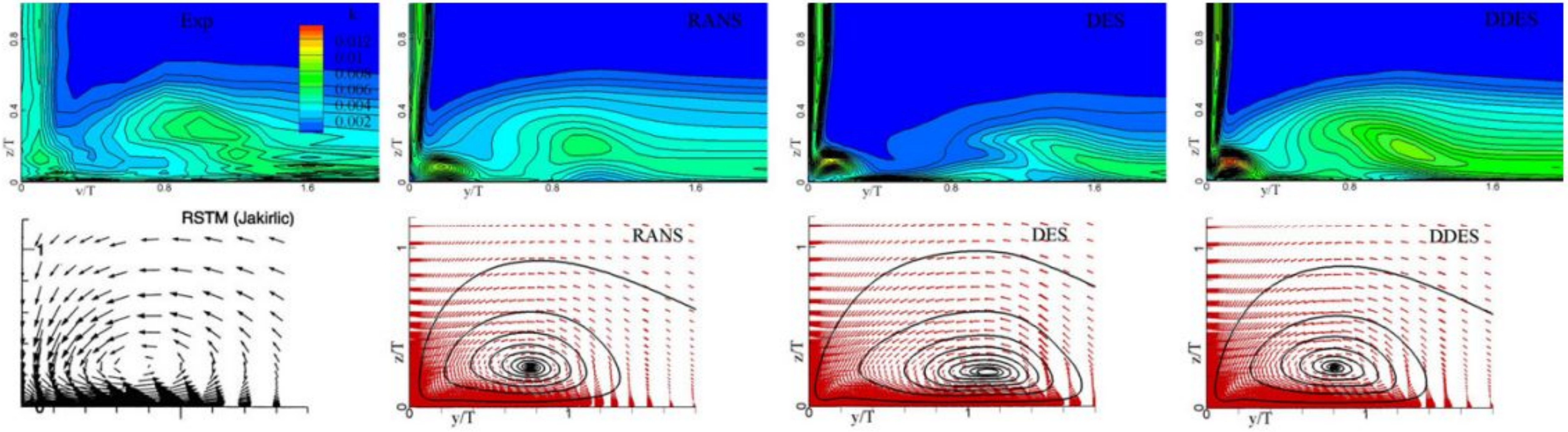
Flow patterns around the wing-body junction (a) shear stress lines and vortex in the wake; (b) upwind symmetry plane horseshoe vortex and (c) vortices near the trailing edge

Flow structures at three streamwise positions



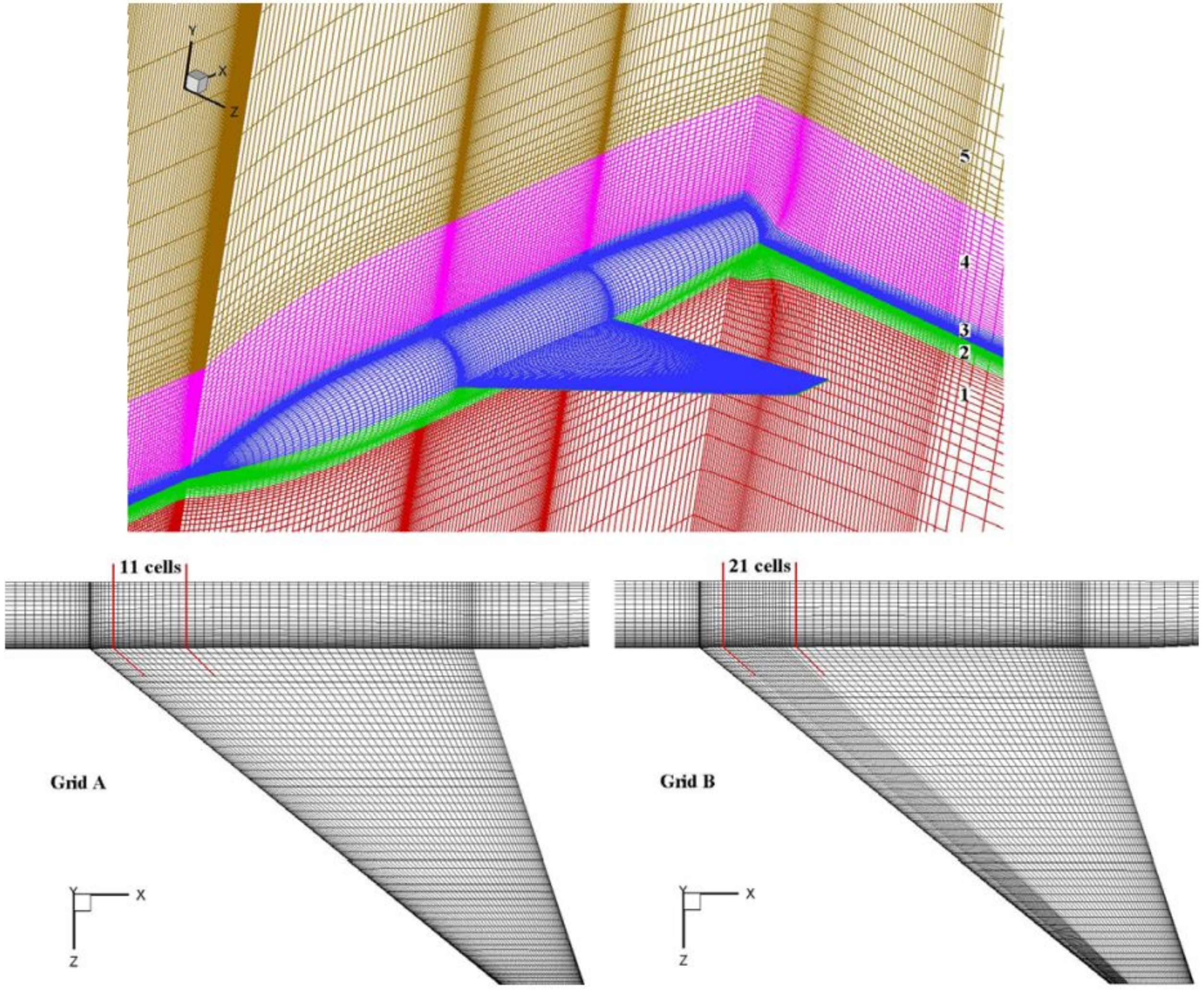
Comparisons of turbulent kinetic energy and cross-streamwise normal stress near the trailing edge (x/T = 3.95)

Flowfields in the wake



Comparisons of turbulent kinetic energy and the vertical flow vectors in the wake (x/T = 6.38)

Results. TN D-712 junction

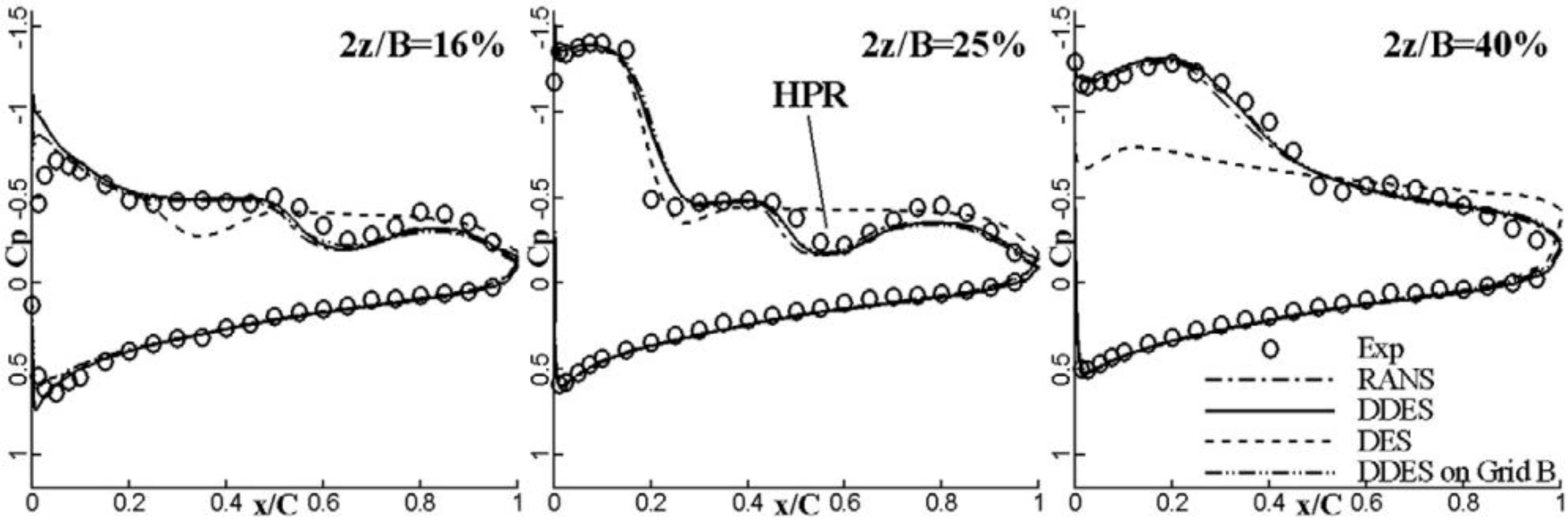


Grids around TN D-712 Wing-fuselage junction.

Computation parameters

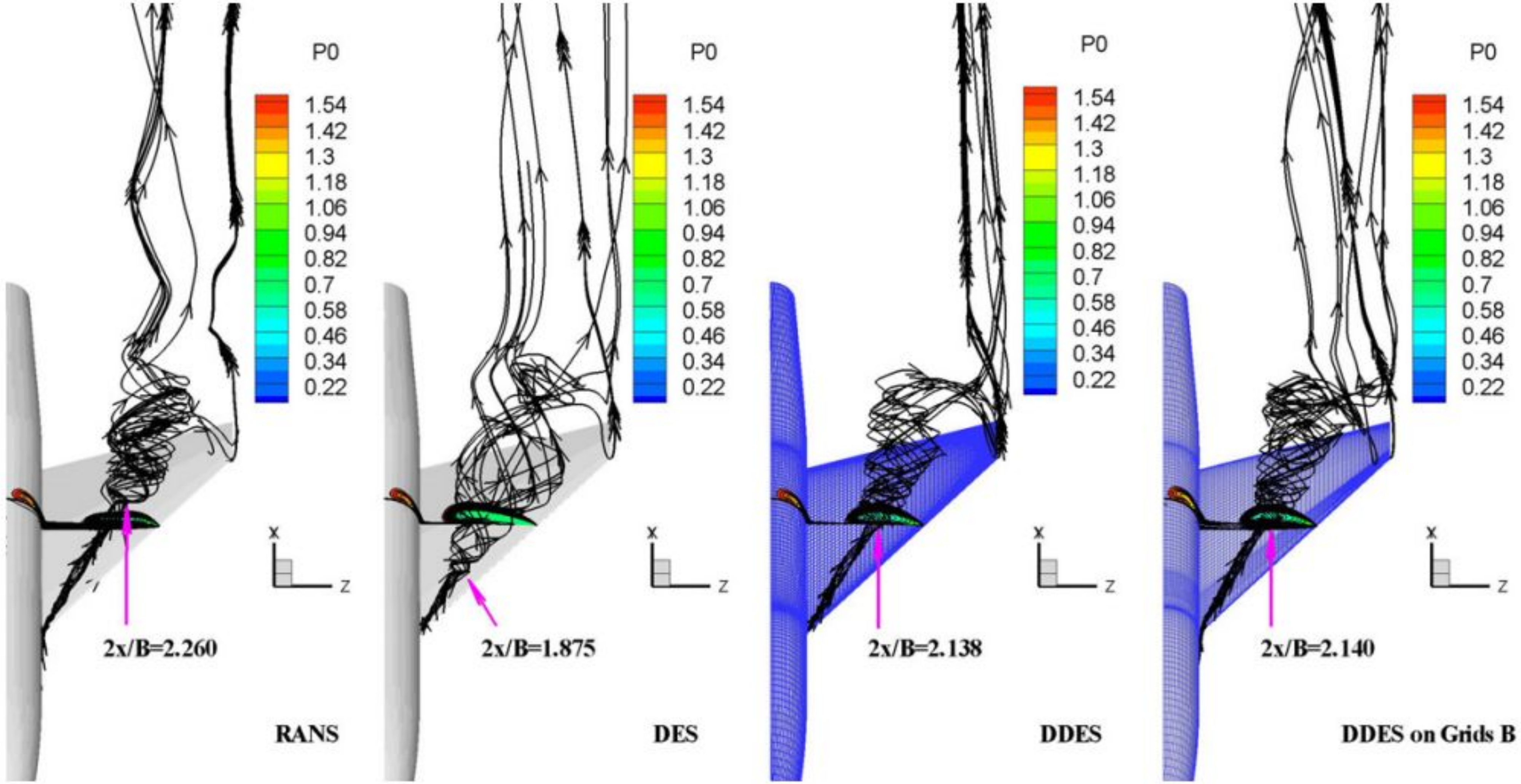
- Mach number - 0.9
- Reynolds number is $7.5 \cdot 10^6$ (based on halfspan)
- Angle of attack is 12.5^o

Pressure coefficients

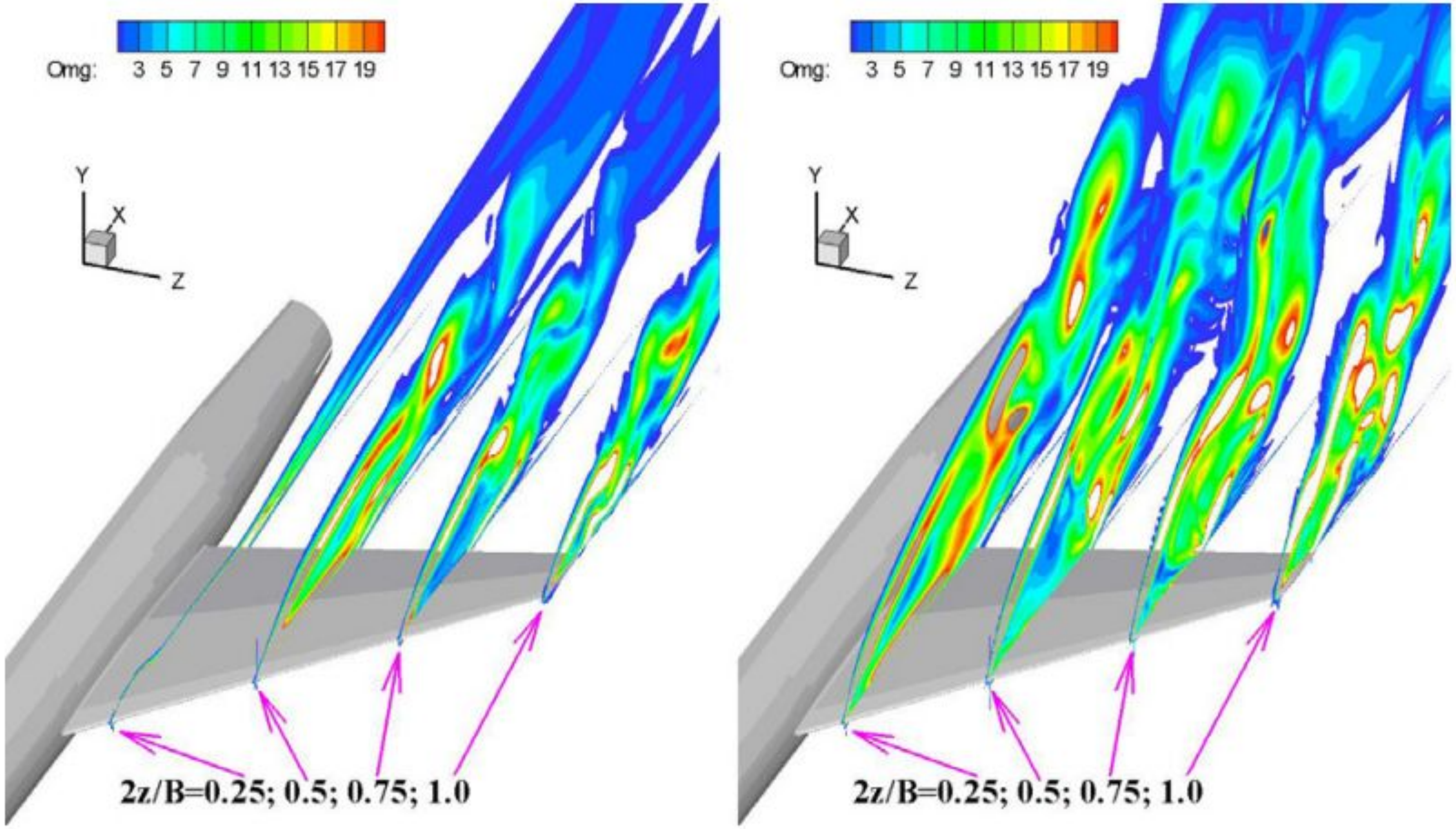


Comparisons of pressure coefficients of different turbulence methods near the junction

Vortex over the wing

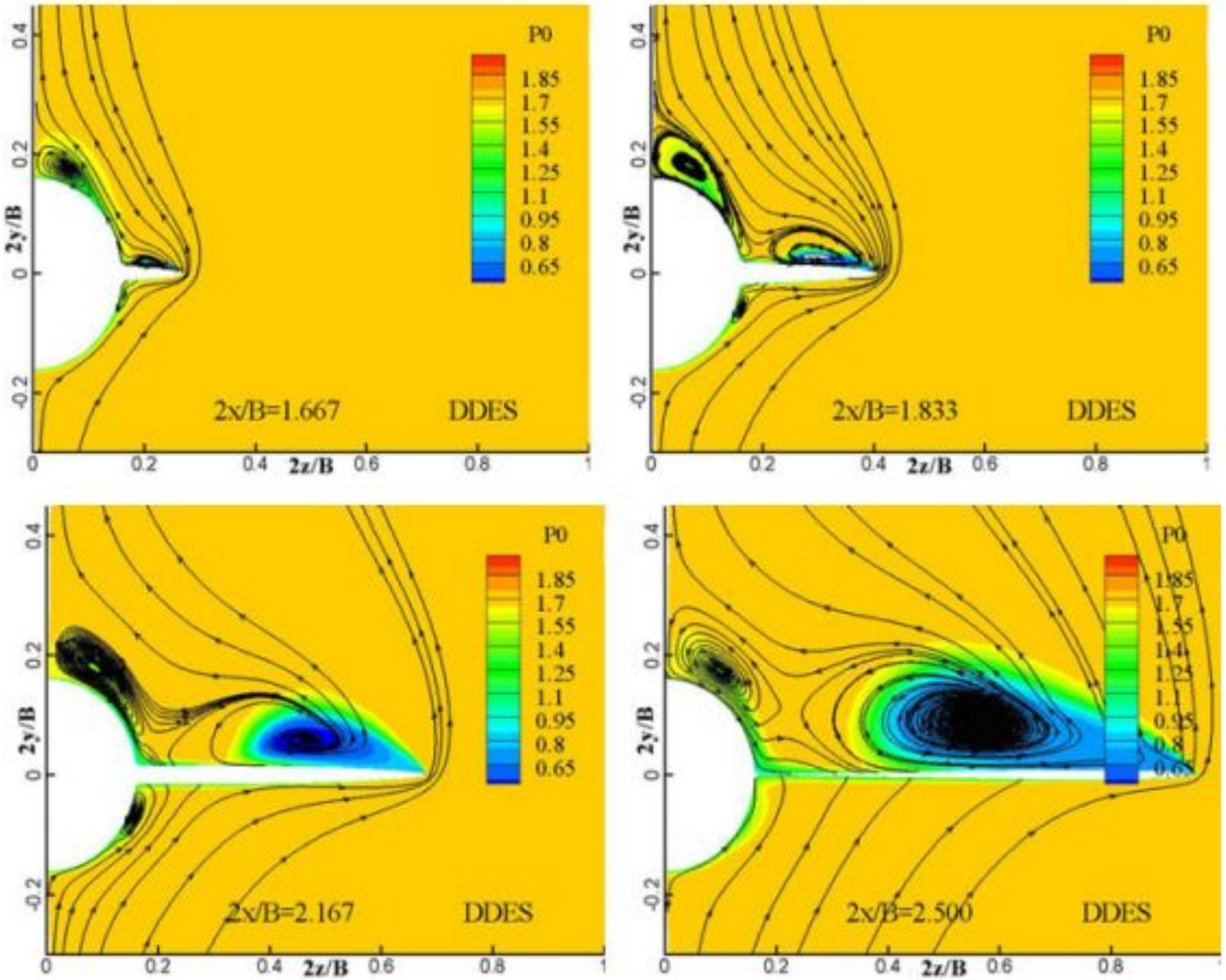


Comparison on vortex over the wing with RANS, DES and DDES methods.



The instantaneous DDES vorticities over the wing at different AoAs (Left: 12.5; Right: 26.2)

Flow patterns of DDES



Transverse flow structure at different streamwise positions by DDES. 2x/B = 1.667, 1.833, 2.167 and 2.500.

Conclusion

- Weakly nonlinear correction k–x model (WD+) can effectively predict the flows past wing-body junctions with adverse pressure gradients at zero and middle angle of attack
- But one has to go to DDES to capture the large eddies detached from the leading edge of the wing in NASA TN D-712 case at 12.5^{o} angle of attack
- DES delivers the primary horseshoe vortex for the Rood case and the vortex breakdown for the TN D-712 case too far upstream as compared to the measurements
- Among the models studied here DDES provides a reliable tool in the modeling of the wing-body junction flows