Amsterdam March 2015

Go4Hybrid

Grey Area Mitigation for Hybrid RANS-LES Methods

FOI

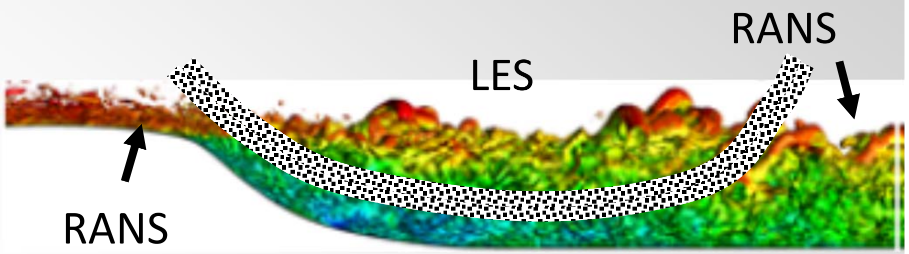
02/06/2013

FOI work progress

Shia-Hui Peng & Stefan Wallin

Variable resolution – non-zonal

- Smooth variation of resolution: RANS – LES – RANS
- Grey area problem:
  - delay of initial shear-layer growth
  - “double-counting” of turbulence



Approaches

- Energy conservation principle
  - Transfer of energy:
    resolved ↔ SGS
- Backscatter
  - Mixed Gradient/Leonard model
  - 1-equation model – HYB1

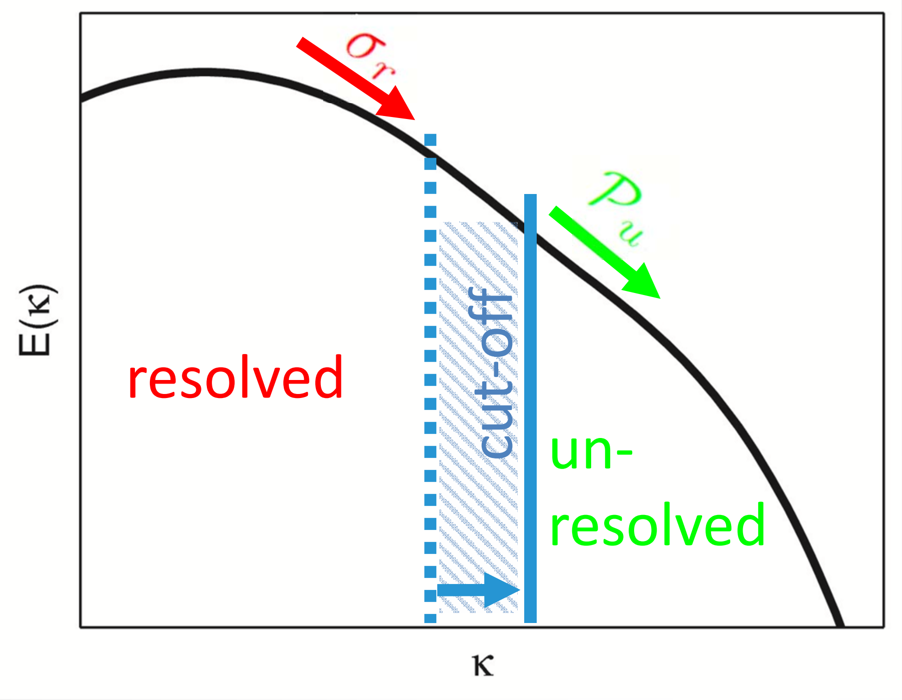
Ref:

- Wallin & Girimaji, AIAA-2011-3105
- Wallin, Reyes & Girimaji, THMT-12
- Girimaji & Wallin, JoT, 2013
- Wallin & Girimaji, HRLM5 2014

- Peng, 2002
- Peng & Davidson, 2009, 2012

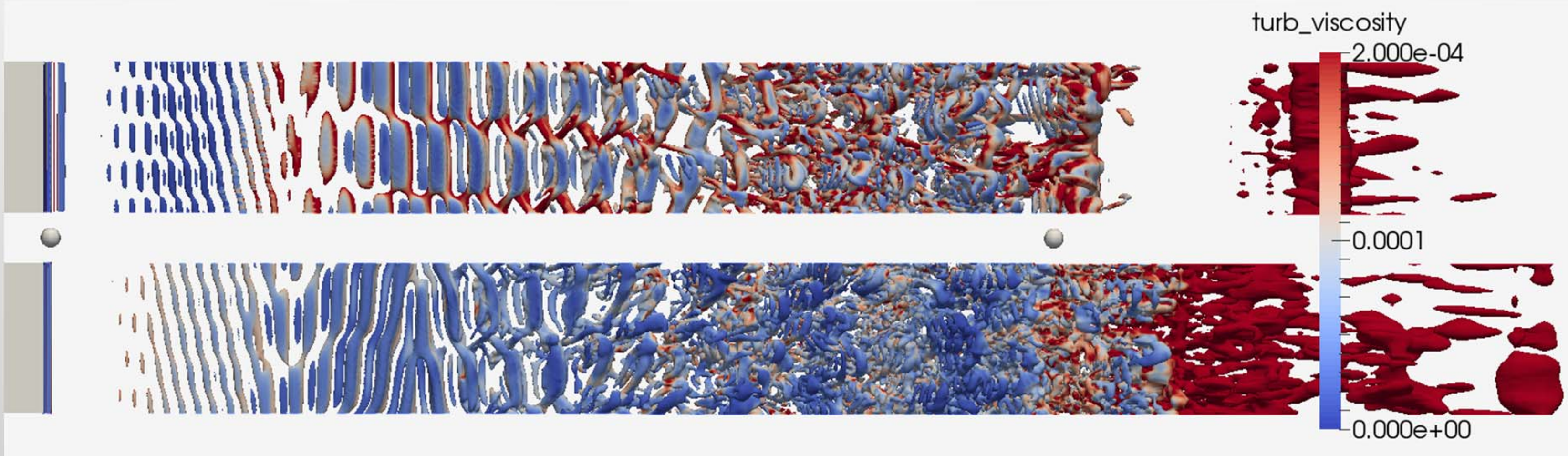
Scale energy transfer

- PANS modelling
  - Advective and transport (cross stream) terms
  - Severe GA problems not solved
- Δ–based modelling
  - Transport equation for Δ
  - Limit $\partial\Delta/\partial t$ so $|\mathcal{P}_{Tr}| < \varepsilon$
  - Relaxation to Δ_0 (Peng HYB0)
  - Arbitrary baseline model



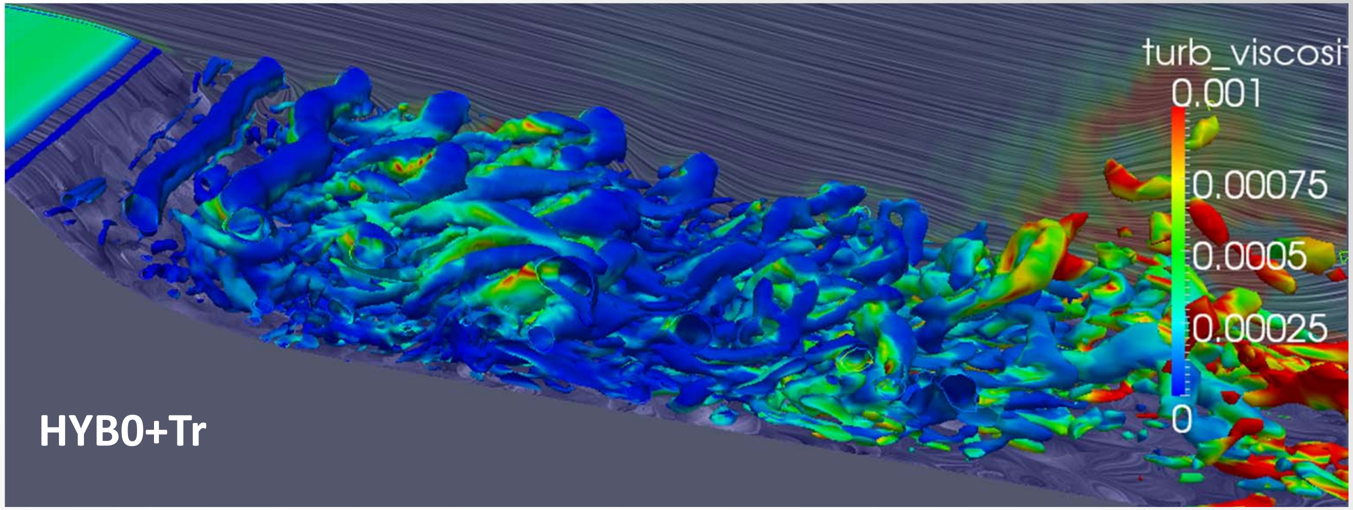
Mixing layer case

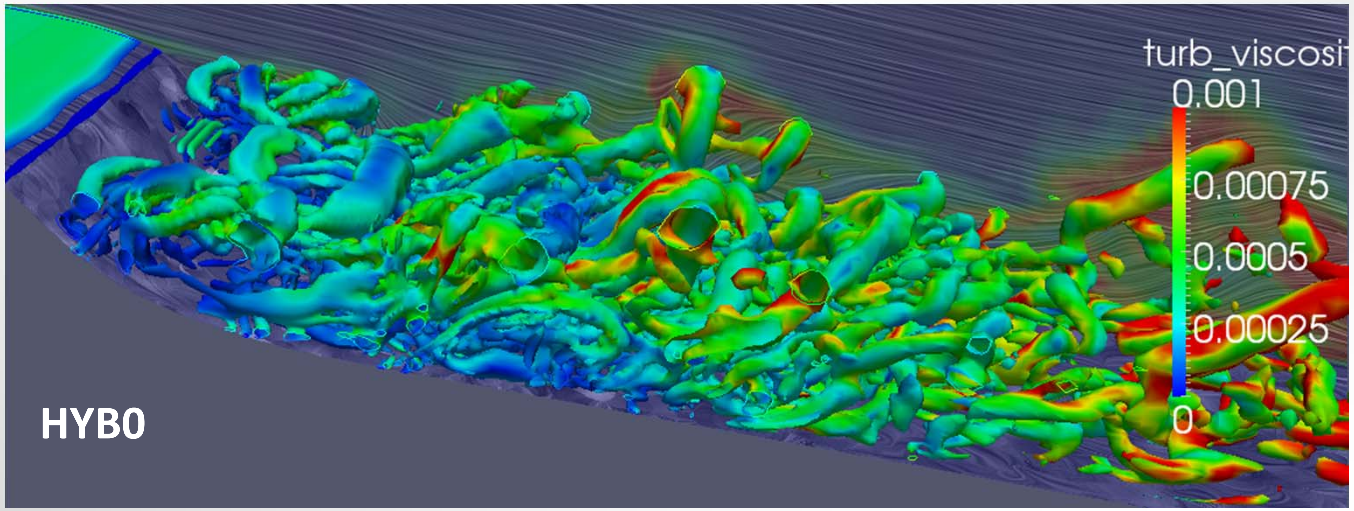
- Δ transported into shear layer
- ν_{SGS}
  - reduced in early shear layer
  - enhanced downstream
- No difference in mean profiles
- Contamination by numerical dissipation?



2D bump case

- Δ–based modelling
- ν_{SGS}
  - reduced in shear layer
  - enhanced in recovery region
- Smaller structures





Improved LES mode for Peng HYB0 and HYB1

- Exploring further the energy-backscatter function in LES mode through Leonard term formulation
  - HYB0 – instabilities, limitation of backscatter
  - HYB1 – backscatte connected with SGS energy (limited effort for now)
  - Leonard term decomposed into dissipative (ν^*) and deviatoric (L_{ij}^d) parts

- Exploring re-adaption of length scales
  - HYB0 mixed ”max” and ”volume” length scale
  - ”min” length scale replacing ”max”
  - Some needs to redefine/recompute the incoming BL

Formulation of the Leonard term in hybrid modelling

- The turbulent stress tensor in a hybrid model read, in general,

$$\tau_{ij} = L_{ij} + R_{ij} = (C_l\Delta)^2 f_d \frac{\partial \bar{u}_i}{\partial x_k}\frac{\partial \bar{u}_j}{\partial x_k} - 2\nu_h \bar{S}_{ij}$$

where $f_d = 0$ in RANS region and $f_d = 1.0$ in LES region

- The Leonard term is then split in to two parts,

$$L_{ij} = L^*_{ij} + L^d_{ij}$$

where L^*_{ij} is assumed to be responsible for the overall energy transfer, and is modelled with an effective eddy viscosity, ν^*.

- L^*_{ij} is then modelled with an effective eddy viscosity, ν^*

$$L^*_{ij} = -2\nu^* S_{ij}$$

- Using S_{ij} to contract L_{ij}, and let $L^d_{ij} S_{ij} = 0, \nu^*$ can then be computed by

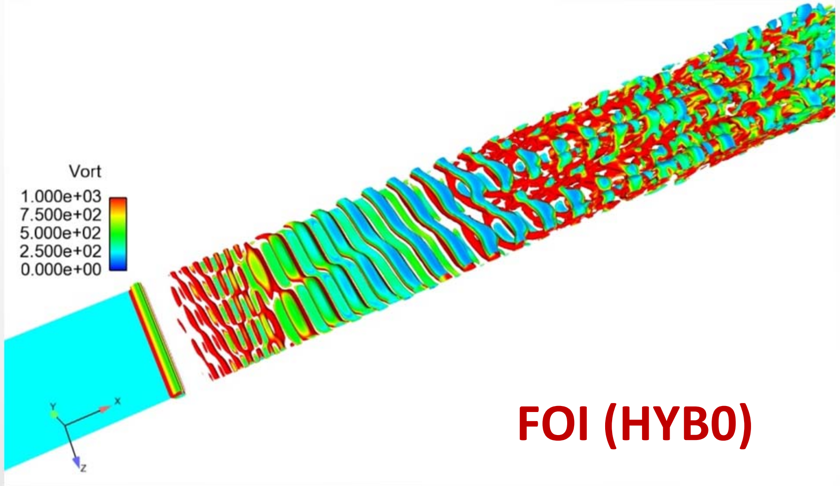
$$\nu^* = -\frac{L_{ij} S_{ij}}{2 S_{ij} S_{ij}}$$

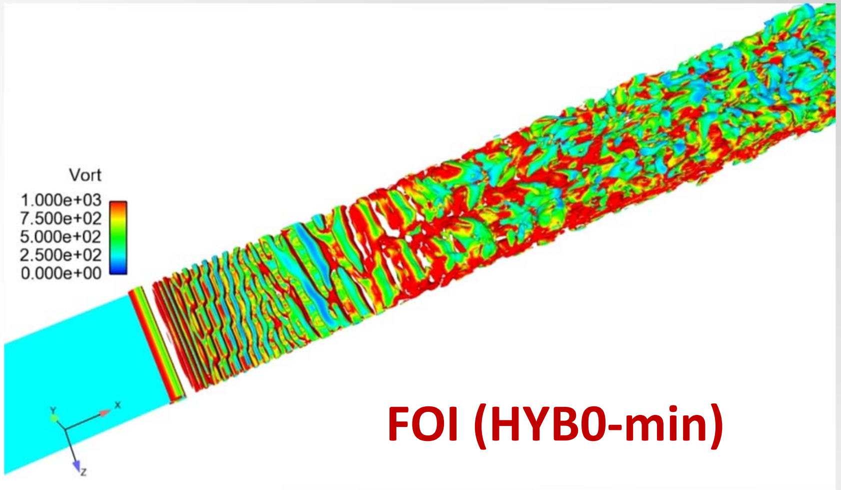
- L^d_{ij} is then computed by $L^d_{ij} = L_{ij} - L^*_{ij}$.

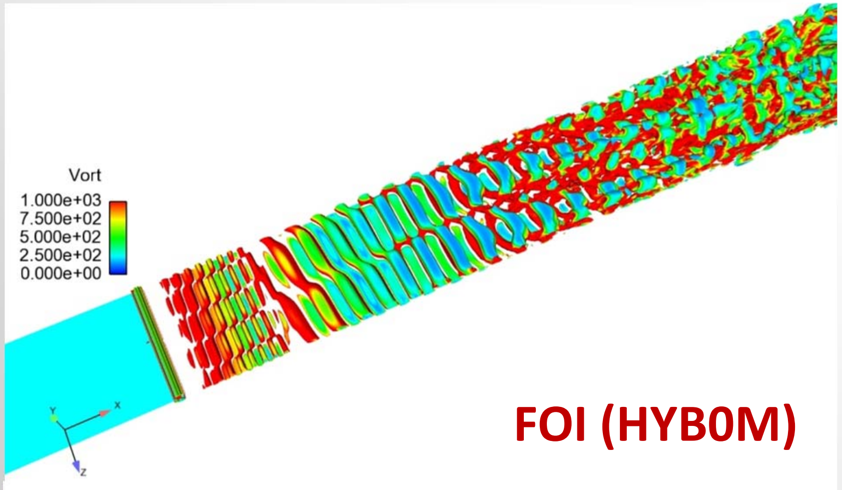
- L^d_{ij} may be further estimated in another algebraic formulation,

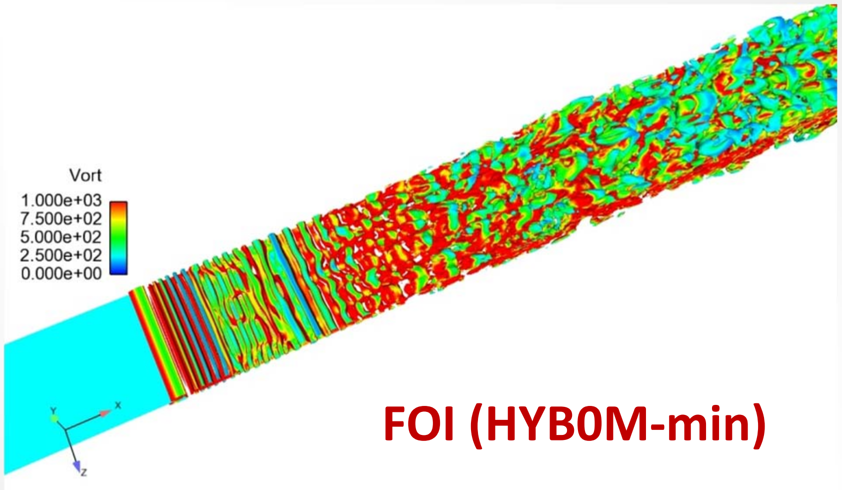
NOTE: In HYB0M, ν^* must be limited, so is actually L^d_{ij}, for numerical stability. This has restricted the GAM function. In conjunction with HYB1 model, this is much alleviated, however.

Mixing layer case (TC F2)

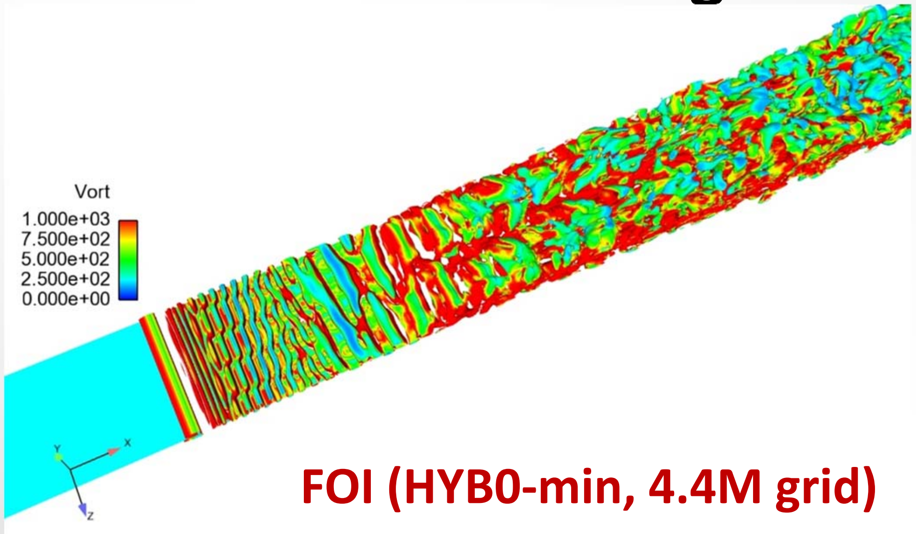


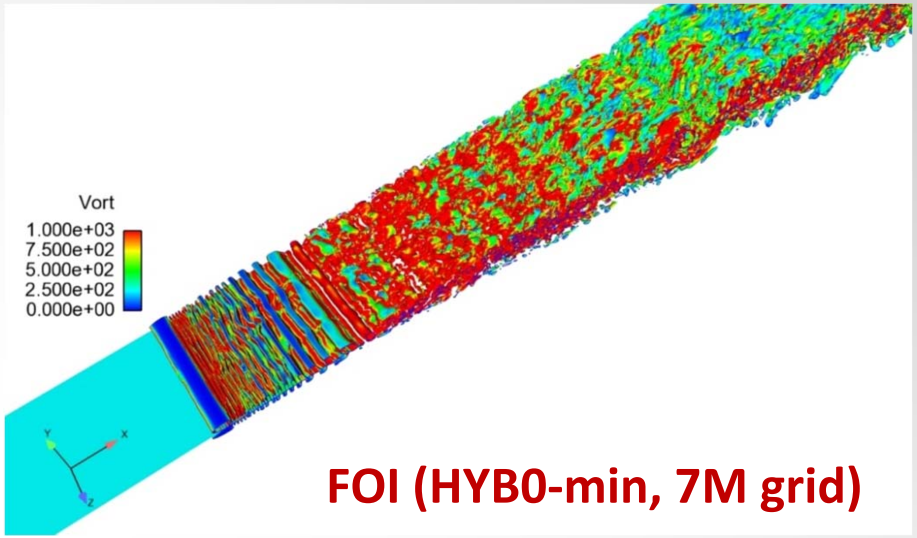






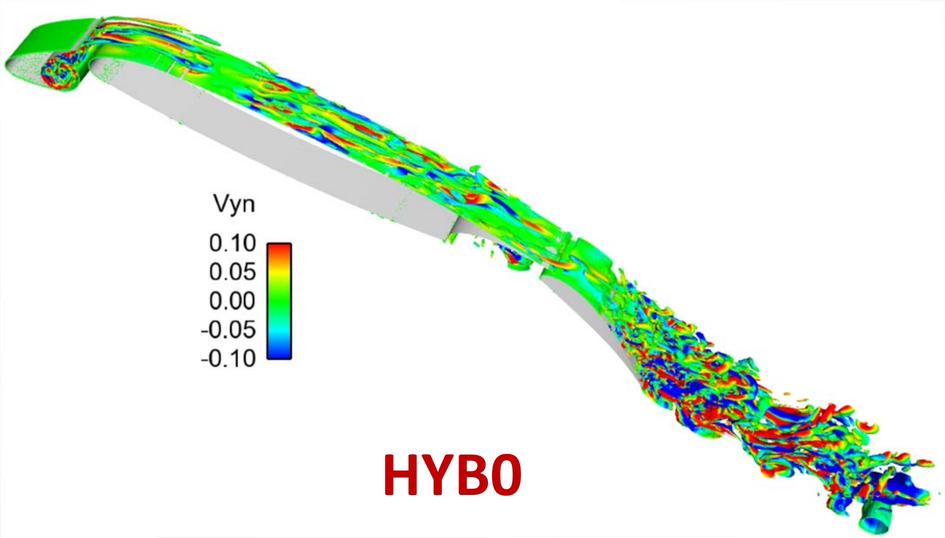
Effects grid resolution

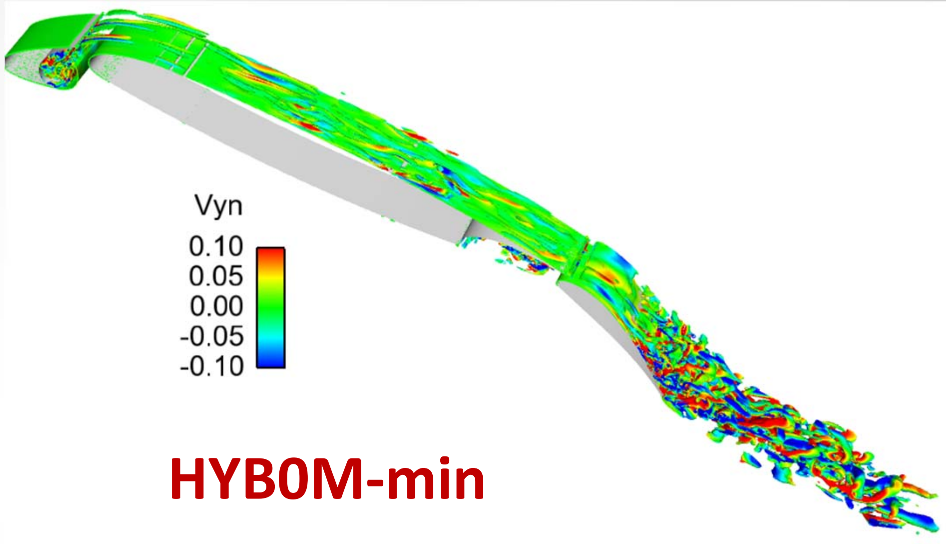


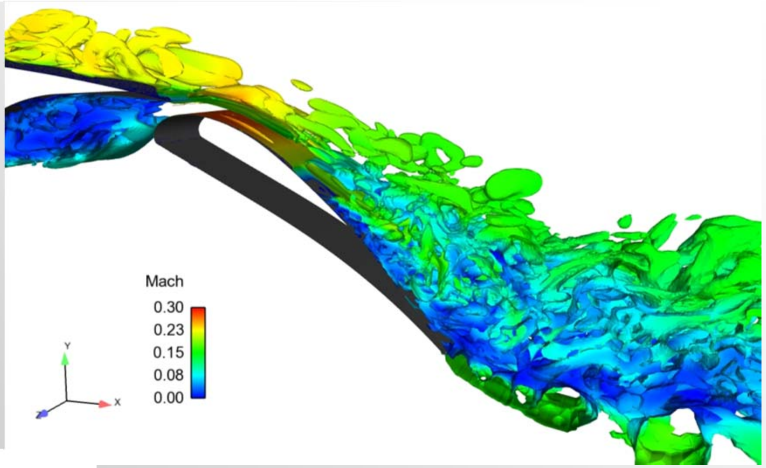


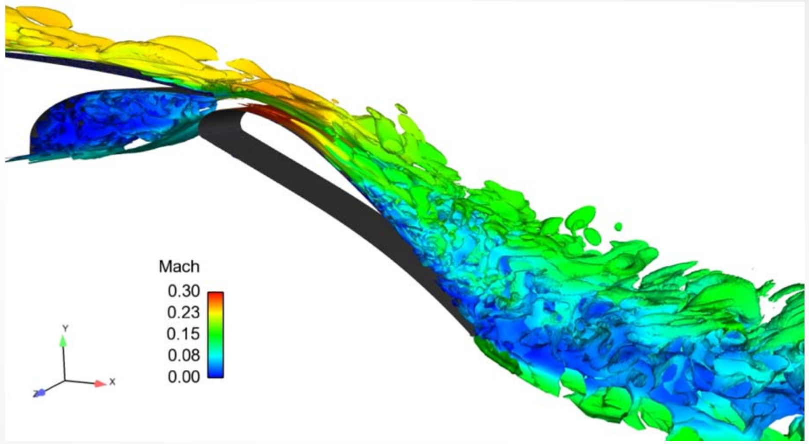
- Significant effects observed in computations using HYB0 and HYB0M (with δ_{min} in the definition of Δ)
  - To test on the mandatory grid (10.3M compared to the FOI 4.4M grid)
  - To test other length scale, Δ_{ω}
- Energy backscatter happens at small scales ….?
  - Further investigation needed
  - Incorporated in one/two-equation model (HYB1, S-A/SST DDES): entering into also the production term of turbulence transport equation(s).

- F15 case: HYB0 compared to HYB0M-min (with δ_{min})





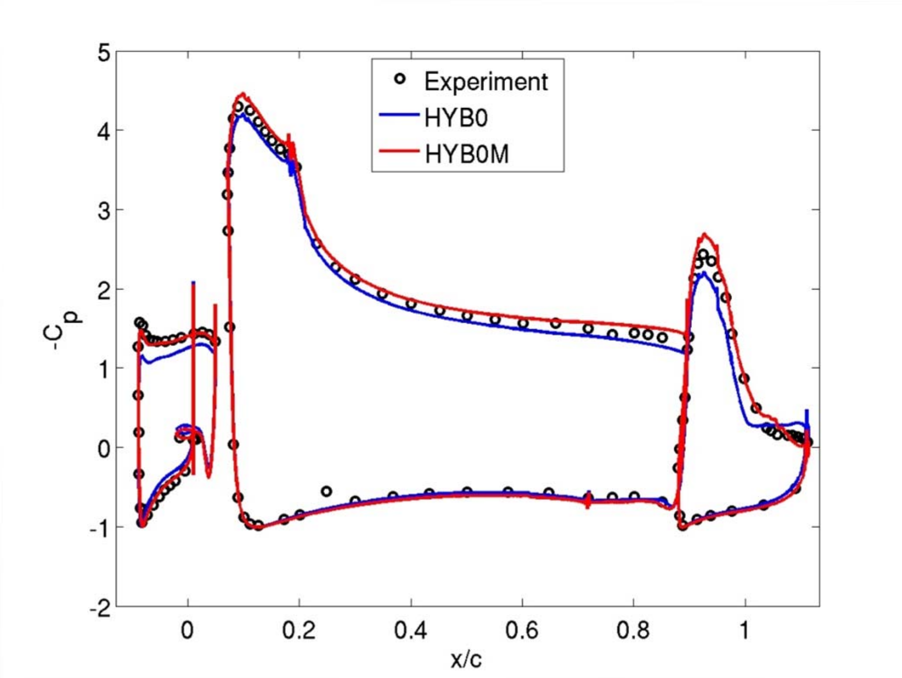




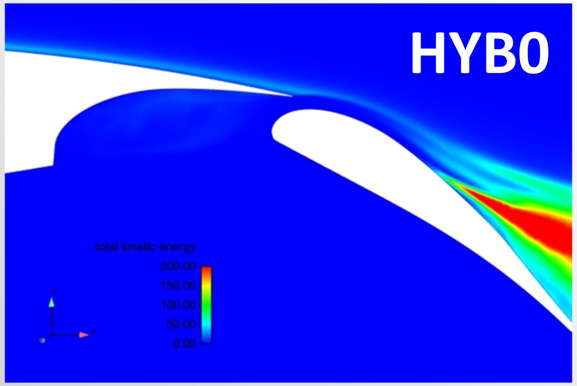
FOI

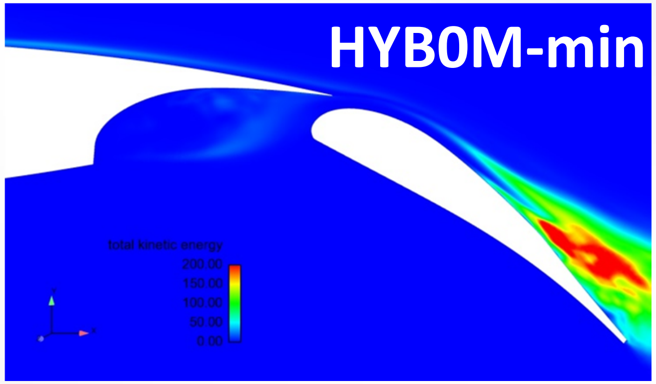
Resolved turbulent structures

Go4Hybrid



- 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 might be used





FOI

Resolved turbulent kinetic energy

Summary & outlook

- Effort is increasingly introduced in the FOI Go4Hybrid work
  - Δ–based energy transfer for HYB0 and DES (update D2.1-6)
  - Backscatter and length scale in HYB0 (HYB1)
- Ongoing computations and model testing on:
  - Mixing layer (coordinator)
  - 2D hump
  - F15 HL flow (non-zonal setup, mandatory grid will not be used)
  - Additional effort on Delta wing might be considered
- WP4.2 – Best Practice
  - Collecting input to D4.2-18 together with CFDB