Case 1.4 Vortex transport by uniform flow

Third International High-Order CFD Workshop

January 3rd-4th 2015, Kissimmee, Florida, USA

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Case 1.4 Vortex transport by uniform flow

High-Order methods for LES/DES turbulent flows :

- *Resolve the extremely large variety of turbulence space/time scales,*

- *Exhibit <u>also</u> correct vorticity and kinetic energy transport (the latter*
- *especially important in incompressible LES/DES simulation),*

- *Provide robustness and preserve accuracy on meshes w/ large grid-size*
- *changes, stretching and skewness,*

- *Be able to cope with extreme time-step limitations due to the viscous*
- *stability restrictions (need implicit schemes ?)*

- *Allow implementation into current (commercial CFD) architectures ?*

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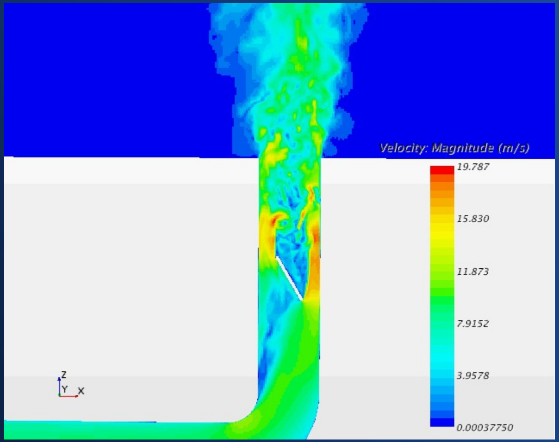
We need canonical test cases to assess:

- Efficiency of HO discretization methods for LES/DES of turbulent flows,
- Relative efficiency of different HO time-integration methods,
- Compare various HO algorithms efficiency w/ state-of-art FV algorithms.



Example of HVAC turbulent flow (MUSCL 3rd order/CD FVM)

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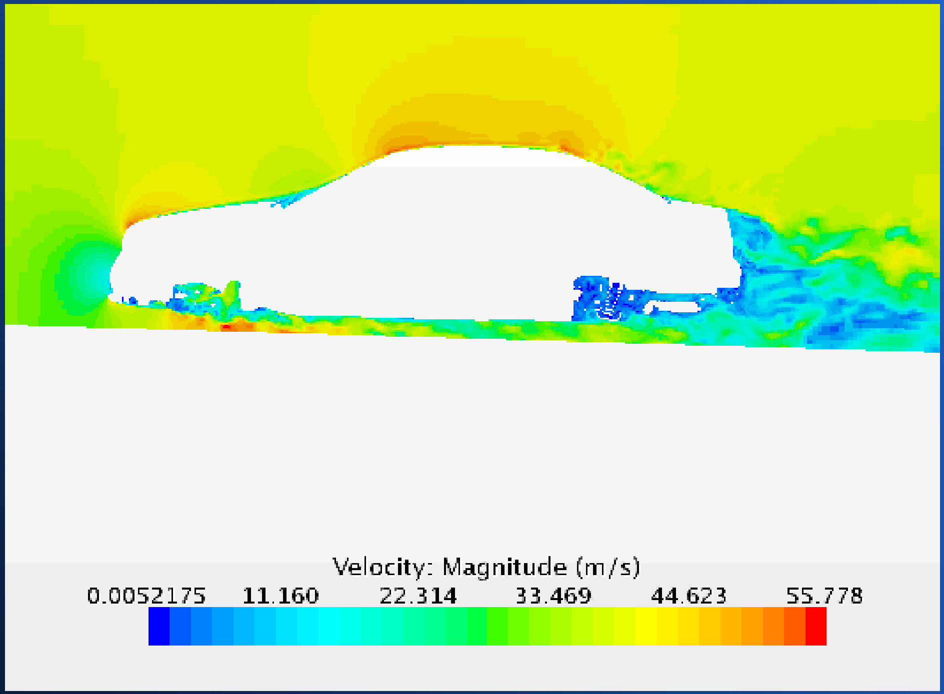

Detached Eddy Simulation of turbulent flow around a complete car (MUSCL 3rd order/CD FVM)

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Case definition:

$[0, L_x] \times [0, L_y] = [0, 0.1] \times [0, 0.1]$

pressure $P_\infty = 10^5 N/m^2$, temperature $T_\infty = 300K$ and Mach number $M_\infty = 0.05, 0.5$

a vortex of characteristic radius $R = 0.005$ and strength $\beta = 0.02, 0.2$

$(X_c, Y_c) = (0.05, 0.05)$

$$u_0 = U_\infty (1 - \beta \frac{y - Y_c}{R} e^{-r^2/2})$$
$$v_0 = U_\infty \beta \frac{x - X_c}{R} e^{-r^2/2}$$

$$r = \sqrt{(x - X_c)^2 + (y - Y_c)^2}/R$$
$$U_\infty = M_\infty \sqrt{\gamma R_{\text{gas}} T_\infty}$$

$$T_0 = T_\infty - 0.5(\beta U_\infty e^{-r^2/2})^2/C_p$$
$$\rho_0 = \rho_\infty (T_0/T_\infty)^{1/(\gamma - 1)}$$

$C_p = \gamma R_{\text{gas}}/(\gamma - 1)$

ratio of specific heats $\gamma = 1.4$

$P_0 = \rho_0 R_{\text{gas}} T_0$

gas constant $R_{\text{gas}} = 287.15 J/kg\,K$

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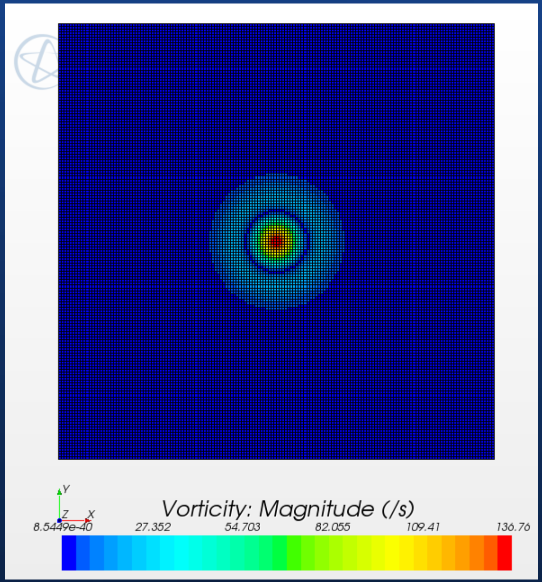

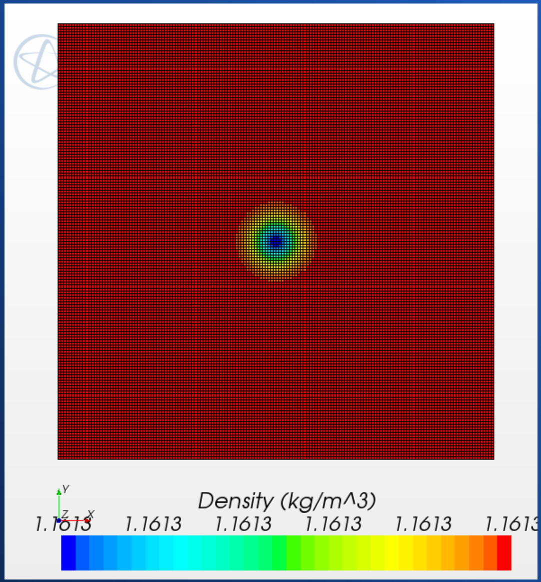

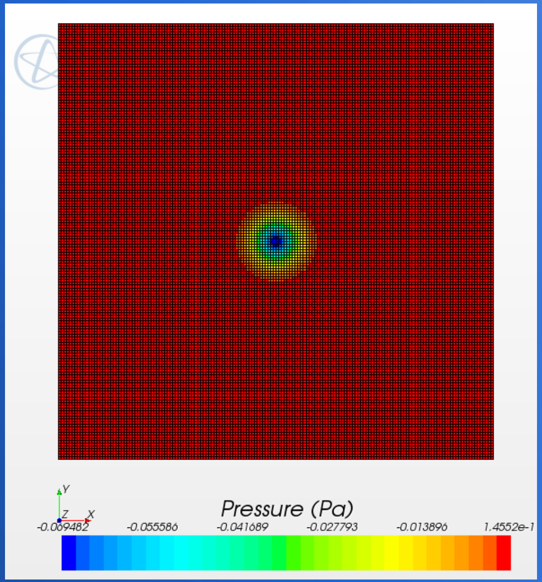

- Very low Mach number flow (Mach = 0.05)
- Large disparity between the sound and flow speed
- Difficulties expected for explicit compressible solvers
- due to time-step restriction

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Algorithms proposed:

- Renac, F, Blanchard, R (**ONERA**): DG, LF, P3 , RK3 (4steps), quasi-2D hex
- Friedlander, D (**NASA Glenn**): CE/SE 2nd order, Diagonal-split 2D quads
- Giangaspero, van der Weide, Svard, Carpenter, Mattson (**Twente**): High-order FD-SBP SAT-BC, RK4, structured meshes only
- Zhang,S., Fidkowski, C. (**Michigan**): DG, P1-P4, RK5, diag-split 2D quads
- Zwanenburg, P., Vermeire, B., and Nadarajah, S.(**McGill**): CPR-DG, Roe, P2-P4, DI-RK (3 stages), 2D quads

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Compare results with state-of-art 2^{nd} order FVM

- Roe FDS flux,
- Low Mach preconditioning,
- Implicit 2^{nd} order time discretization,
- W-LSQ data reconstruction
- Gradients limiting, using a low dissipation differentiable limiter
- Time-step was “sufficiently small” to not affect accuracy

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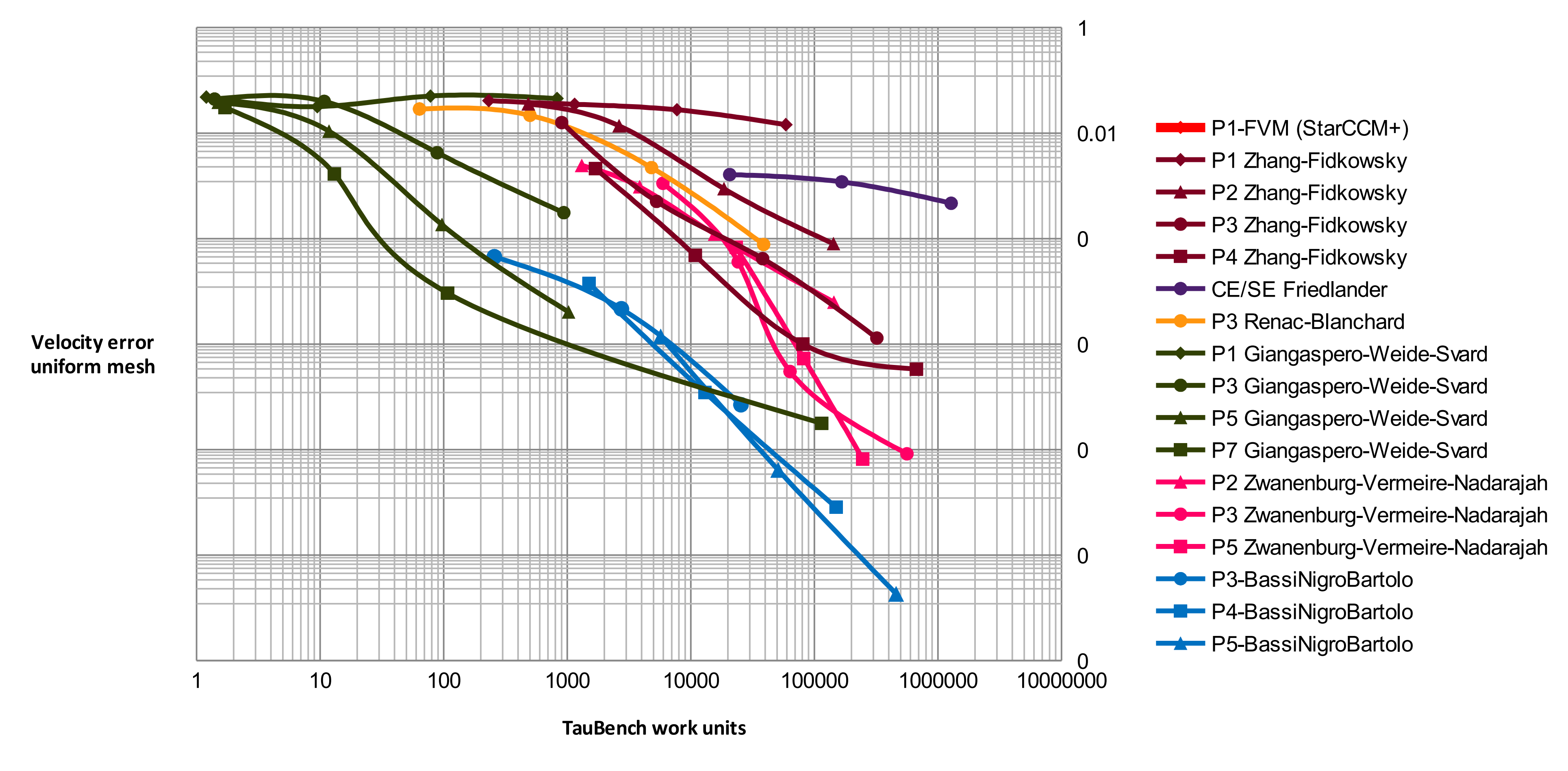

Slow vortex (Mach 0.05), uniform mesh

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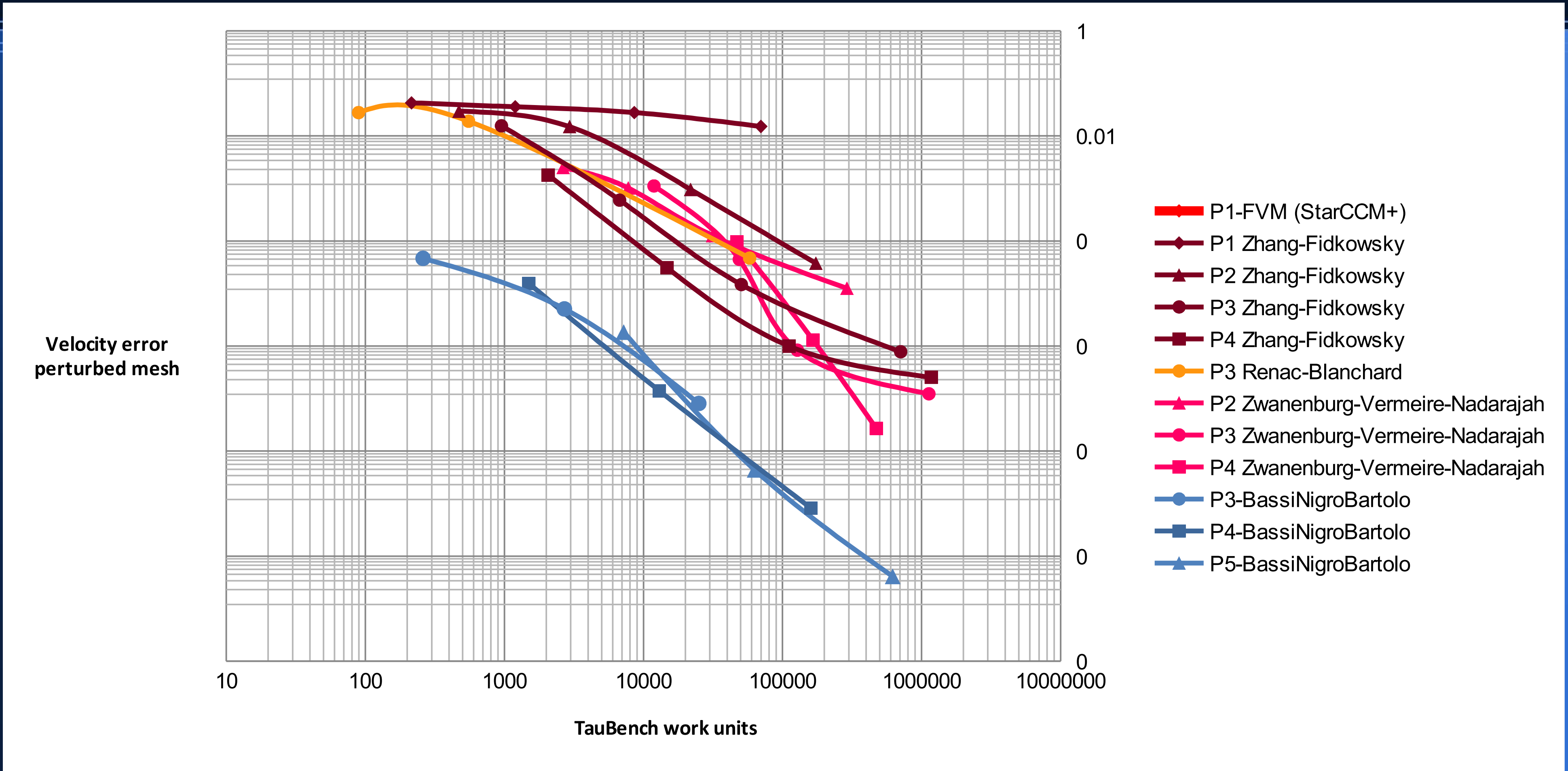

Slow vortex (Mach 0.05), perturbed mesh

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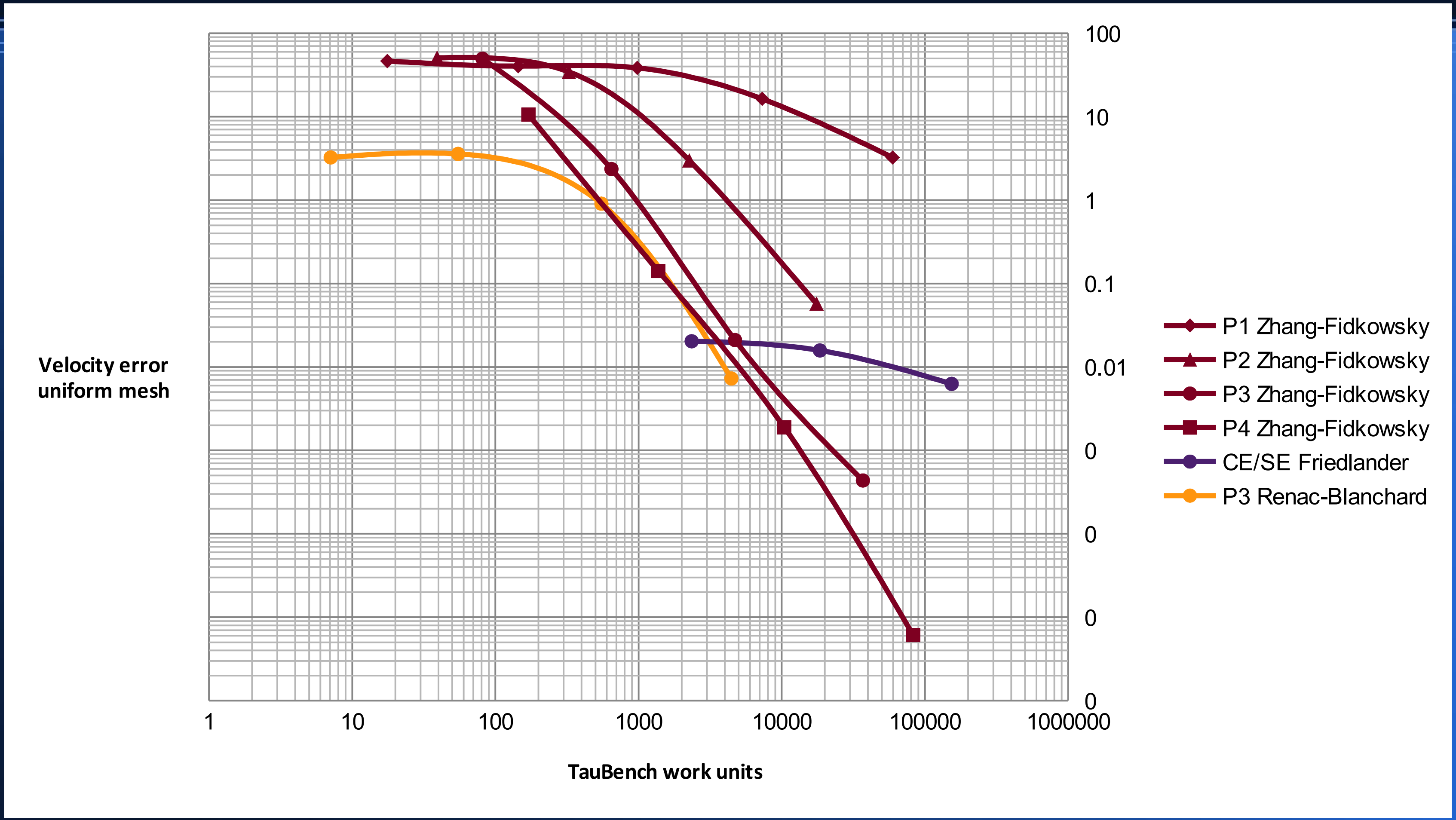

Fast vortex (Mach 0.5), uniform mesh

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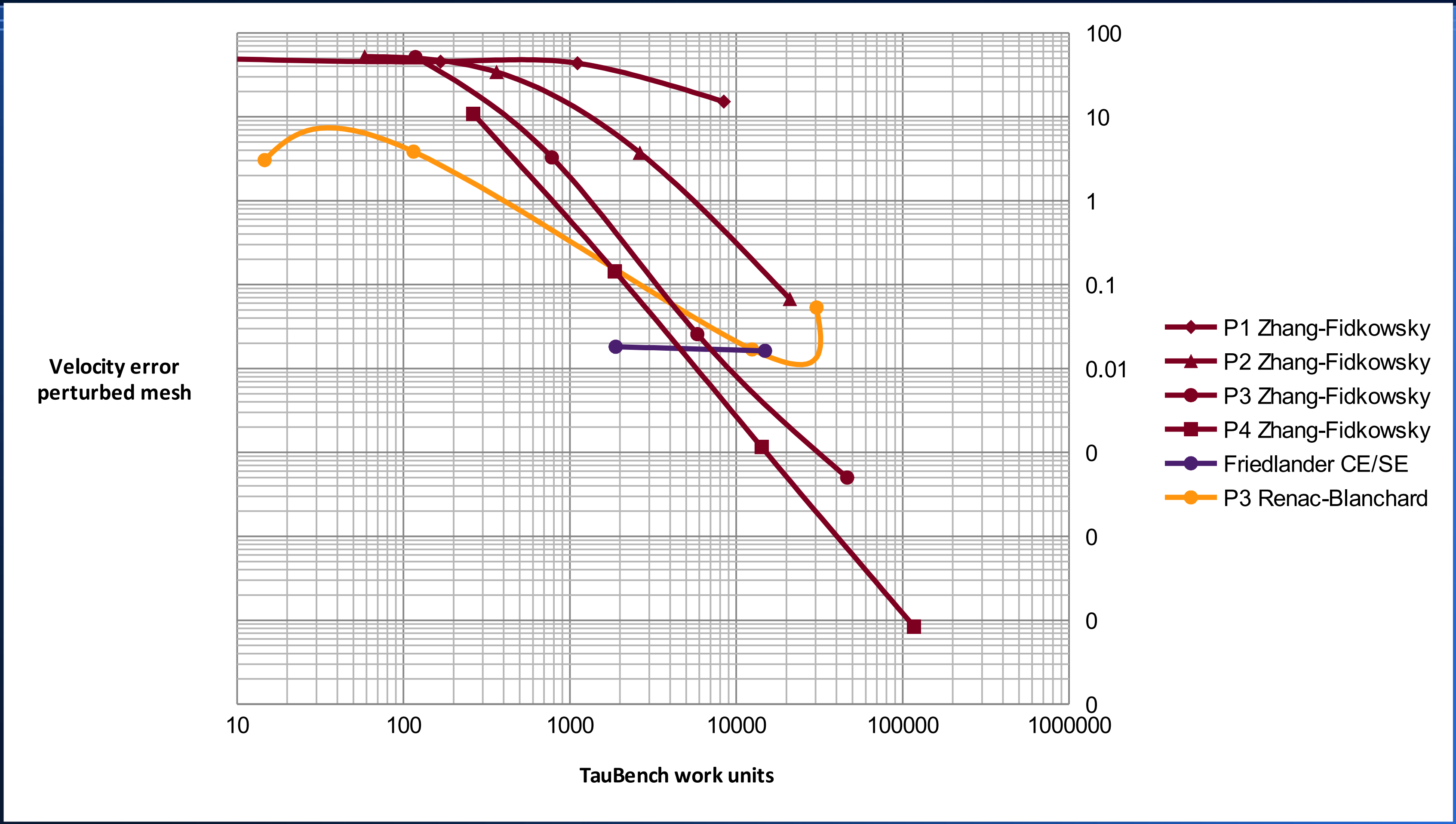

Fast vortex (Mach 0.5), perturbed mesh

Case 1.4 Vortex transport by uniform flow Summary

Four algorithms were compared:

- Discontinuous - Galerkin (ONERA, U-Michigan),
- Collocation Penalty via Reconstruction DG (McGill)
- Conservation Element/Solution Element (NASA Glenn)
- Finite-Differences w/ SBP-SAT (Twente)

Absents are (again):

- High-order Multidimensional-Upwind schemes,
- Spectral elements, High-order finite elements, etc.

Results show: a) significant advantage of using HO time/space discretization b) large variability of results for various methods

Results show HO methods provide leap in performance, when solving unsteady turbulent flows (LES/DES)

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Thank you !!

Questions ?