Case 1.6 Vortex transport by uniform flow

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Case 1.6 Vortex transport by uniform flow

LES/DES of turbulent flows: HO methods challenges

- *Resolve a large variety of turbulent/vortical scales,*
- *Vorticity preservation and kinetic energy preservation (in incompressible flows) are an essential element of success,*
- *Grid size changes, cell's stretching and skewness can be affect HO algorithms robustness and accuracy,*
- *Explicit schemes are most probably not able to cope with extreme time-step limitations due to the viscous stability restrictions,*
- *How these HO algorithms are going to be fitted into the current (commercial) CFD codes architectures ?*

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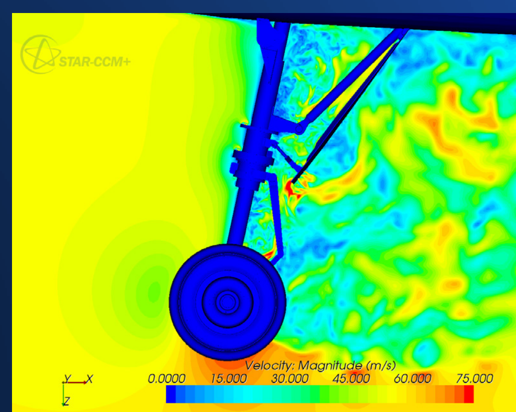
Canonical test case to assess:

- Efficiency of HO methods for LES/DES of turbulent flows,
- Relative efficiency of different unsteady HO methods,
- HO algorithm's efficiency w.r.t state-of-art 2nd order FV algorithm.



Example of turbulent flow behind an aircraft landing gear

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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 $M_\infty = 0.05$,

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

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

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

$$v_0 = U_\infty \beta \frac{x - X_c}{R} e^{-r^2/2}$$

$$r = \sqrt{(x - X_c)^2 + (y - Y_c)^2}/R$$

$$U_\infty = M_\infty \sqrt{\gamma R_{\text{gas}} T_\infty}$$

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

$$\rho_0 = \rho_\infty (T_0/T_\infty)^{1/(\gamma-1)}$$

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

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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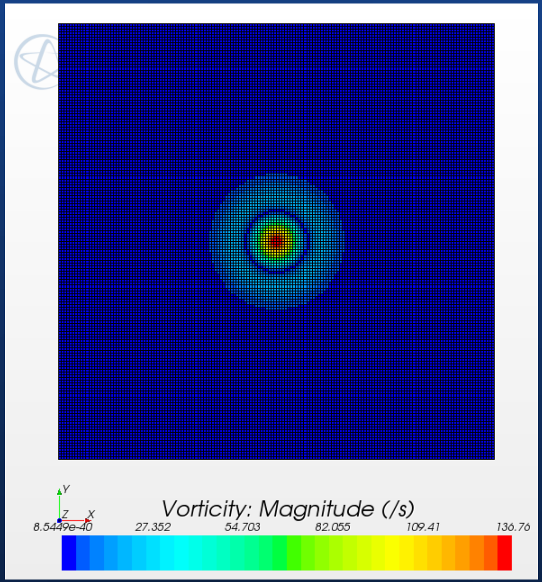

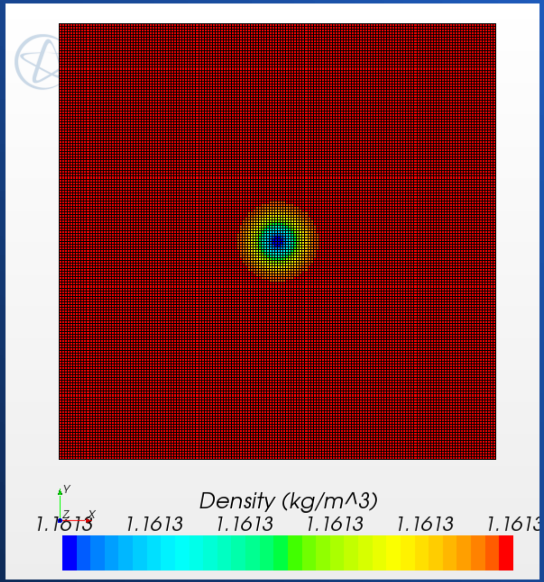

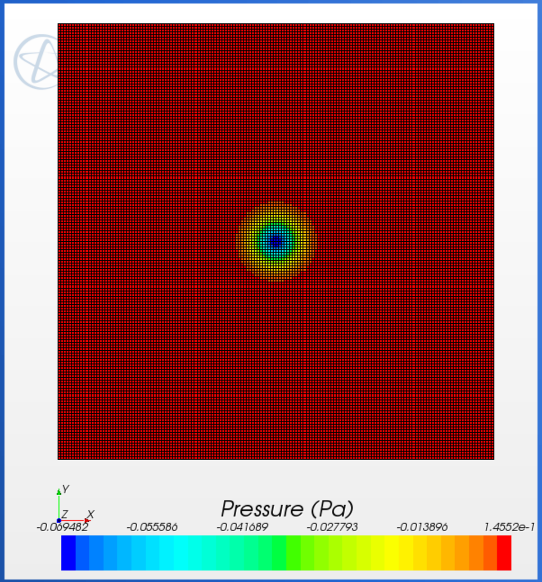

- Very low Mach number flow (Mach = 0.05)
- Large disparity between the sound and flow speed
- Difficulties expected for explicit solvers due to time-step restriction

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High-order algorithms proposed:

- De Bartolo, Nigro & Bassi: **DG, P3-P5, 6th-order A-stable 5-step TIAS scheme**

- Diosady & Murman : **DG-SEM, Roe-FDS fluxes, P<=15, RK 4.**

- Ferrero & de Larocca : **DG, Osher fluxes, P1-P3, (TVD/SSP) RK (2-3/4)**

- Van der Weide, Svaerd & Giangaspero : **(block-structured) FD SBP-SAT scheme, RK 4**

- Villedieu, Puigt & Boussuge : **SD, P2-P4, 6 step RK**

- Le Gouez: **W-LSQ reconstruction-based FVM, ONERA NXO method,**
- **P2-P5, RK 4.**

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Compare HO results with state-of-art 2nd order FVM

- Roe FDS flux,
- Low Mach preconditioning,
- Implicit 2nd 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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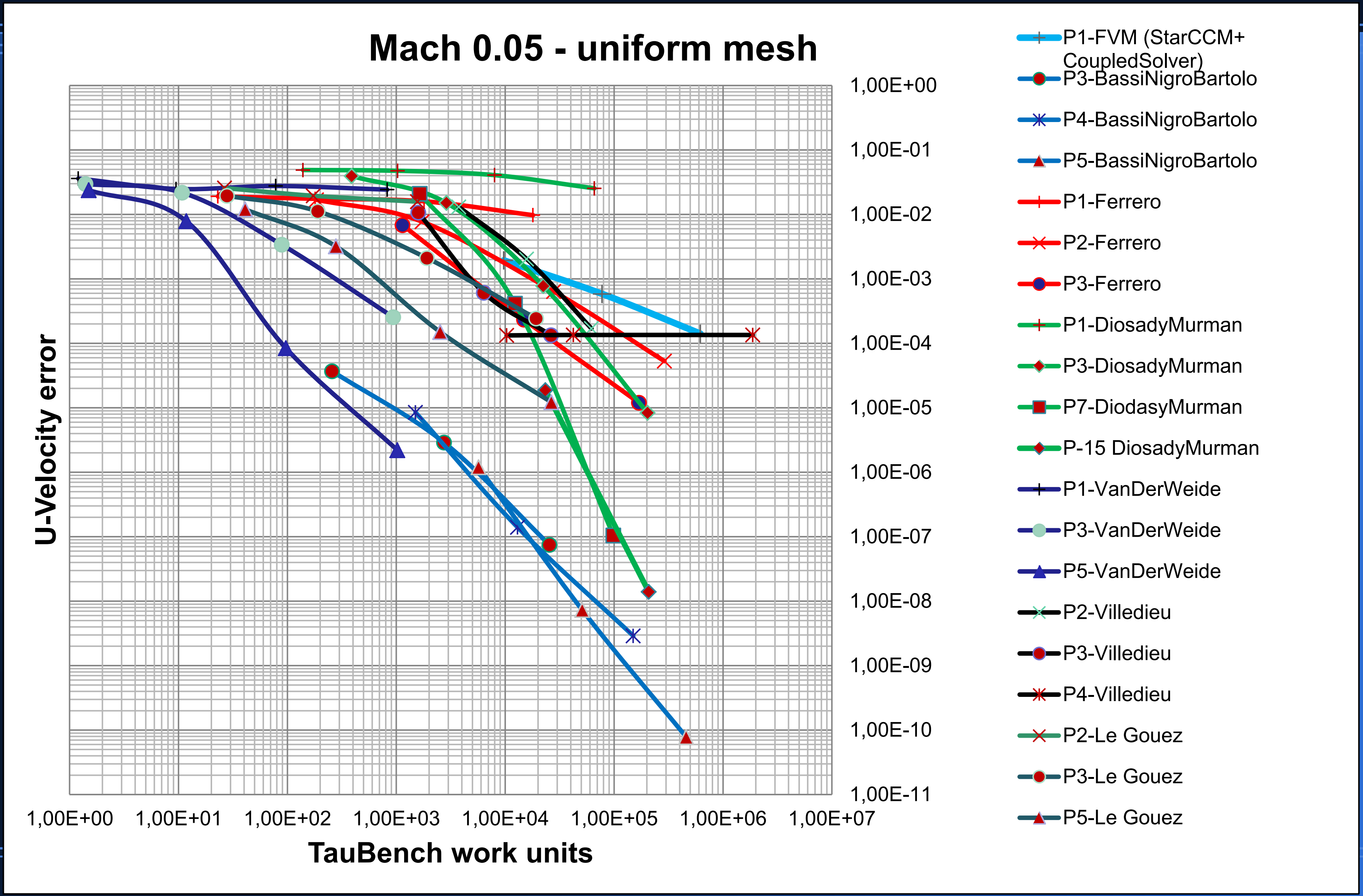

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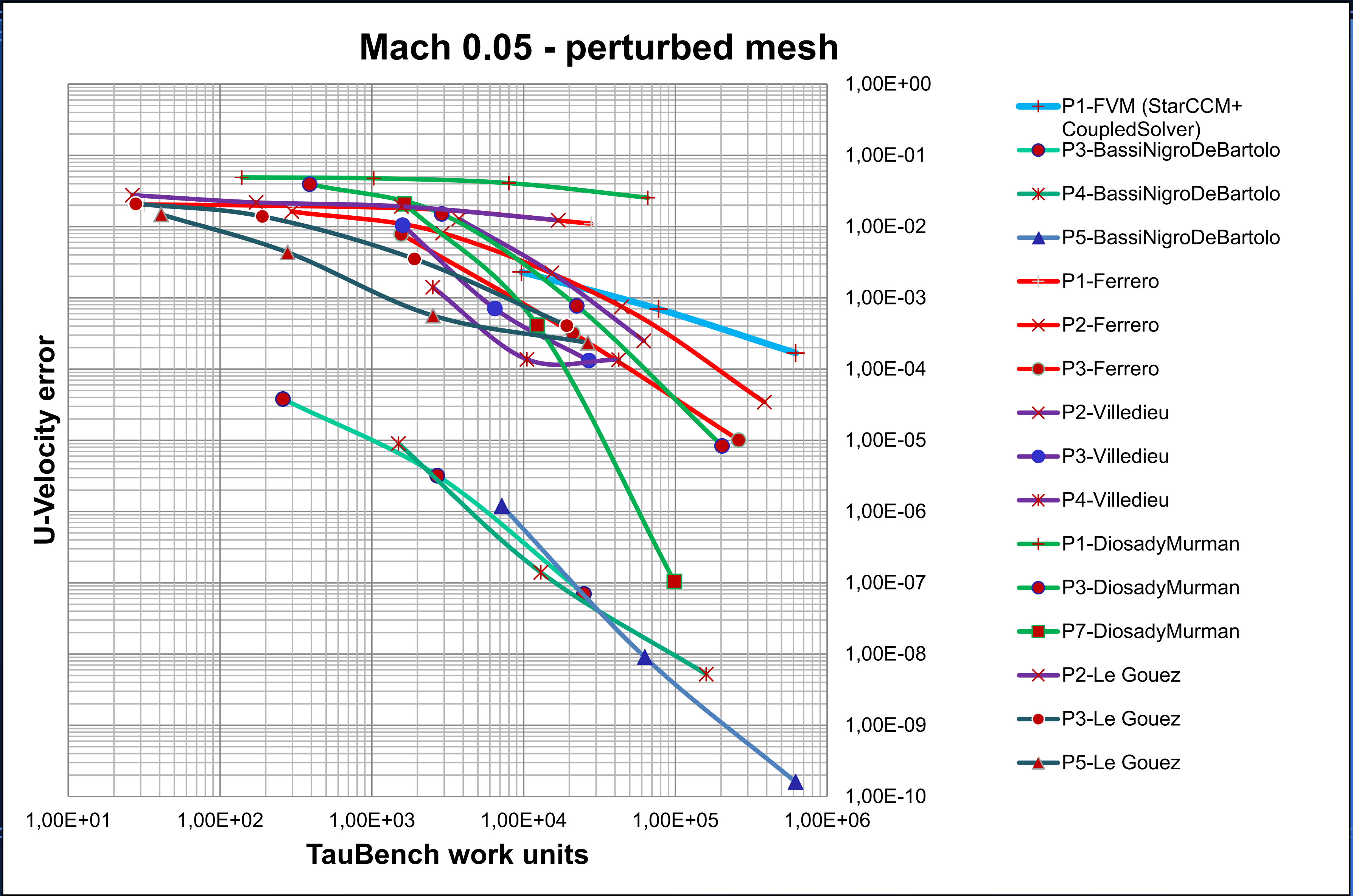

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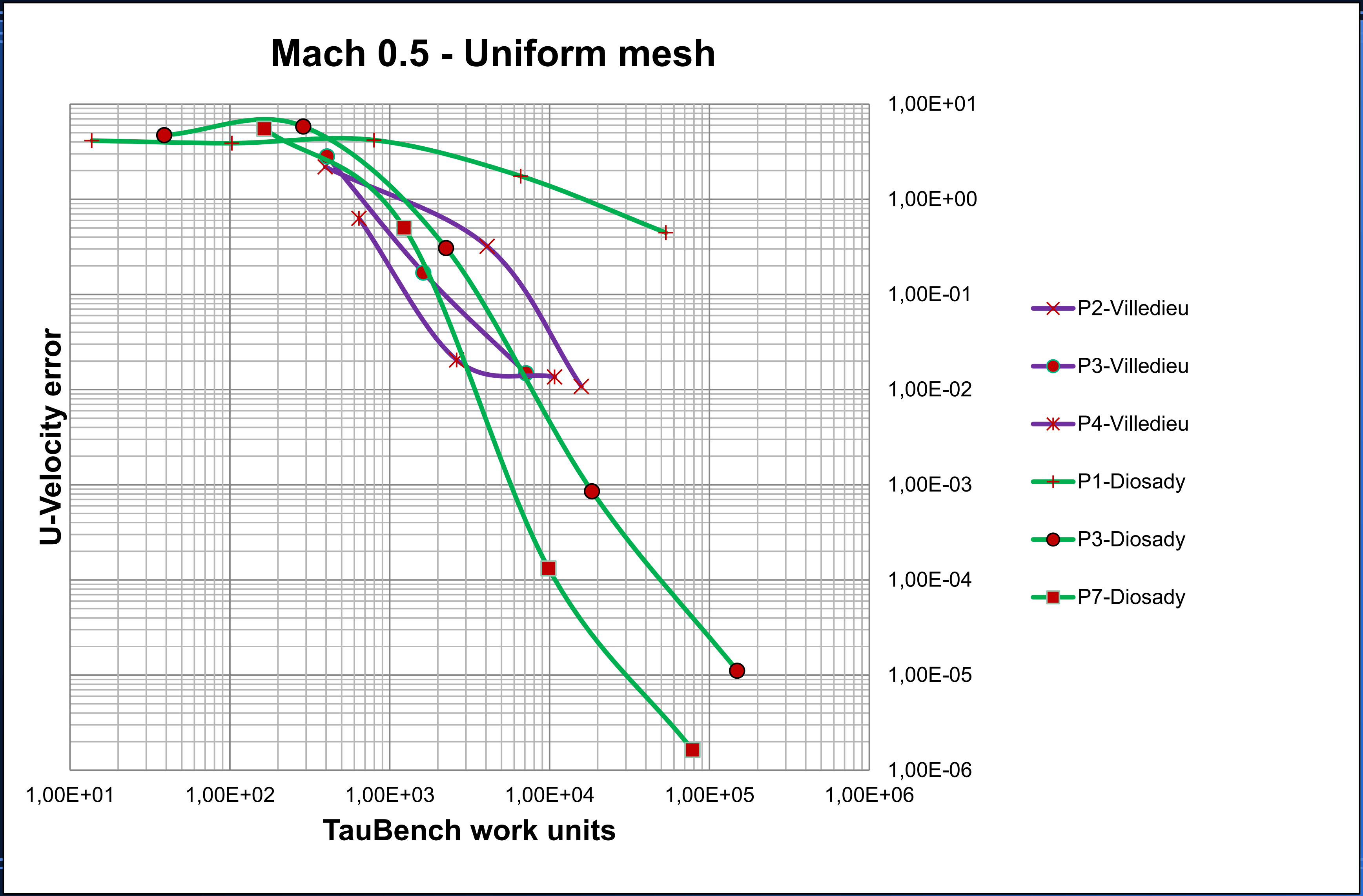

Case 1.6 Vortex transport by uniform flow Summary of results

- *Three versions of DG,*
- *W-LSQ based HO-FVM NXO,*
- *Spectral-Differences and*
- *Finite-Differences w/ SBP-SAT*

algorithms were compared.

- *The big absents are :*
  - *High-order Multidimensional-Upwind schemes,*
  - *Spectral elements, High-order finite elements, etc.*

- *Results show significant advantage of using HO time/space discretization w.r.t state-of-the-art 2nd order FVM.*

- *Results show HO methods can bring a leap in efficiency for solving unsteady flows (targeting LES/DES,URANS)*