Case 1.6 Vortex transport by uniform flow

Case summary

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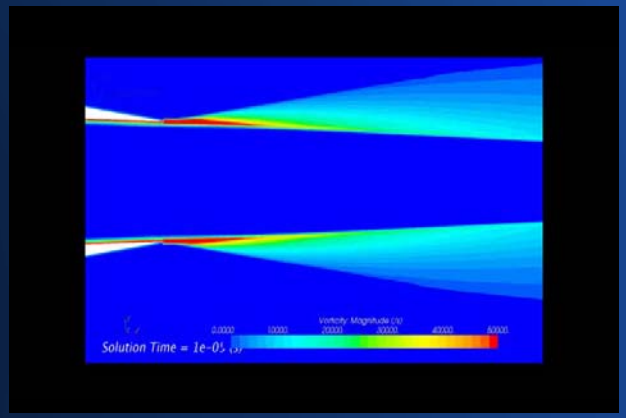
Case 1.6 Vortex transport by uniform flow

Canonical test case to:

- Assess efficiency of HO methods for LES/DES of turbulent flows,
- Compare relative efficiency of different unsteady HO methods,
- Compare HO algorithm's efficiency with state-of-art 2nd order FV algorithm.



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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 $\beta = 0.02$,

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

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

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

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

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

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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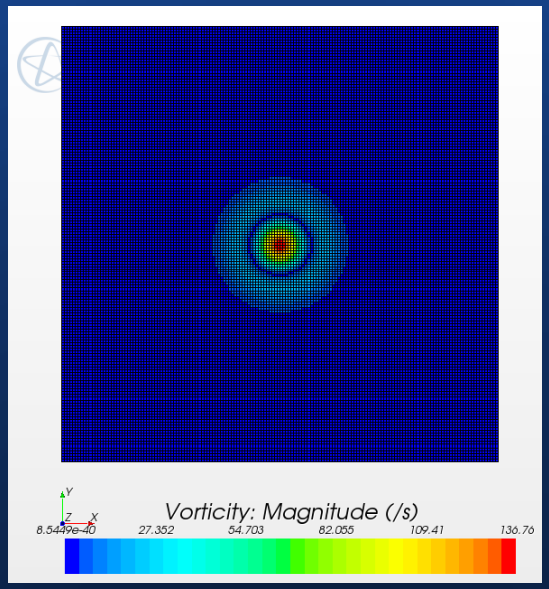

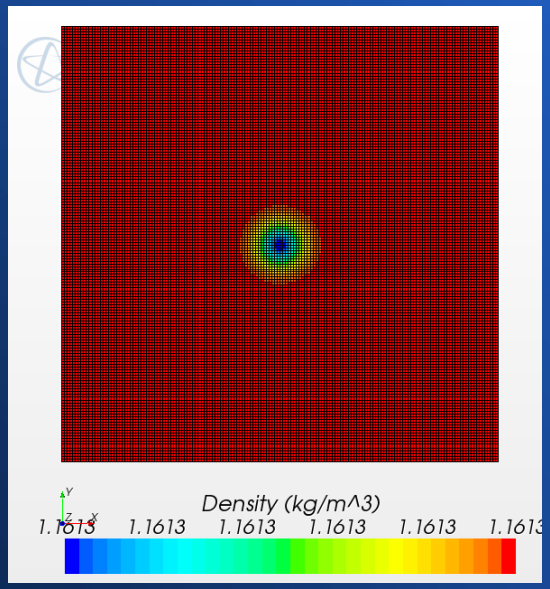

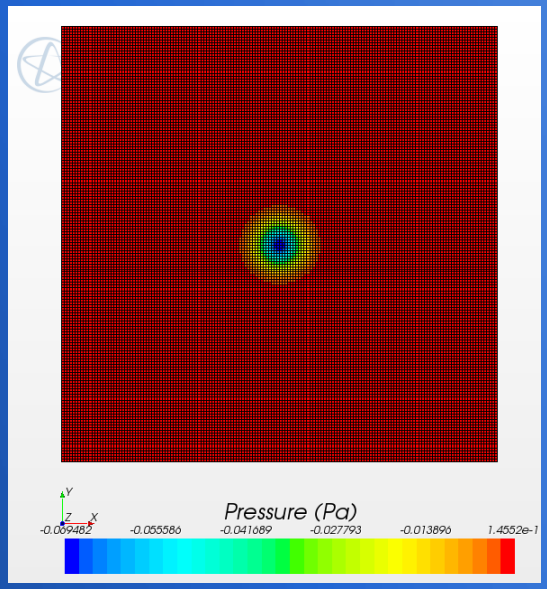

- Very low Mach number flow (Mach = 0.05)
- Large disparity between the sound and flow speed
- Difficulties expected for explicit solvers due to time-step restriction

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High-order algorithms proposed

- Wang & Li : CPR-DG, p =1..5, RK 4th order
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- Bassi & Nigro : DG, p = 2 ..6, TVD-RK 3rd order, SSP-RK 4th order
- Fidkowski : DG, p = 0 .. 3, RK
- Tu : DG-CVS, p = 3, space-time formulation

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State-of-art 2nd order FVM solver:

- *Roe FDS flux discretization,*
- *Low Mach number preconditioning,*
- *Implicit 2nd order time discretization (dual time stepping),*
- *Solution reconstruction using LSQ*
- *Reconstruction gradients limiting using a low dissipation differentiable limiter*
- *Time-step was selected “sufficiently small” to not affect accuracy (for a convective Courant ~0.25)*

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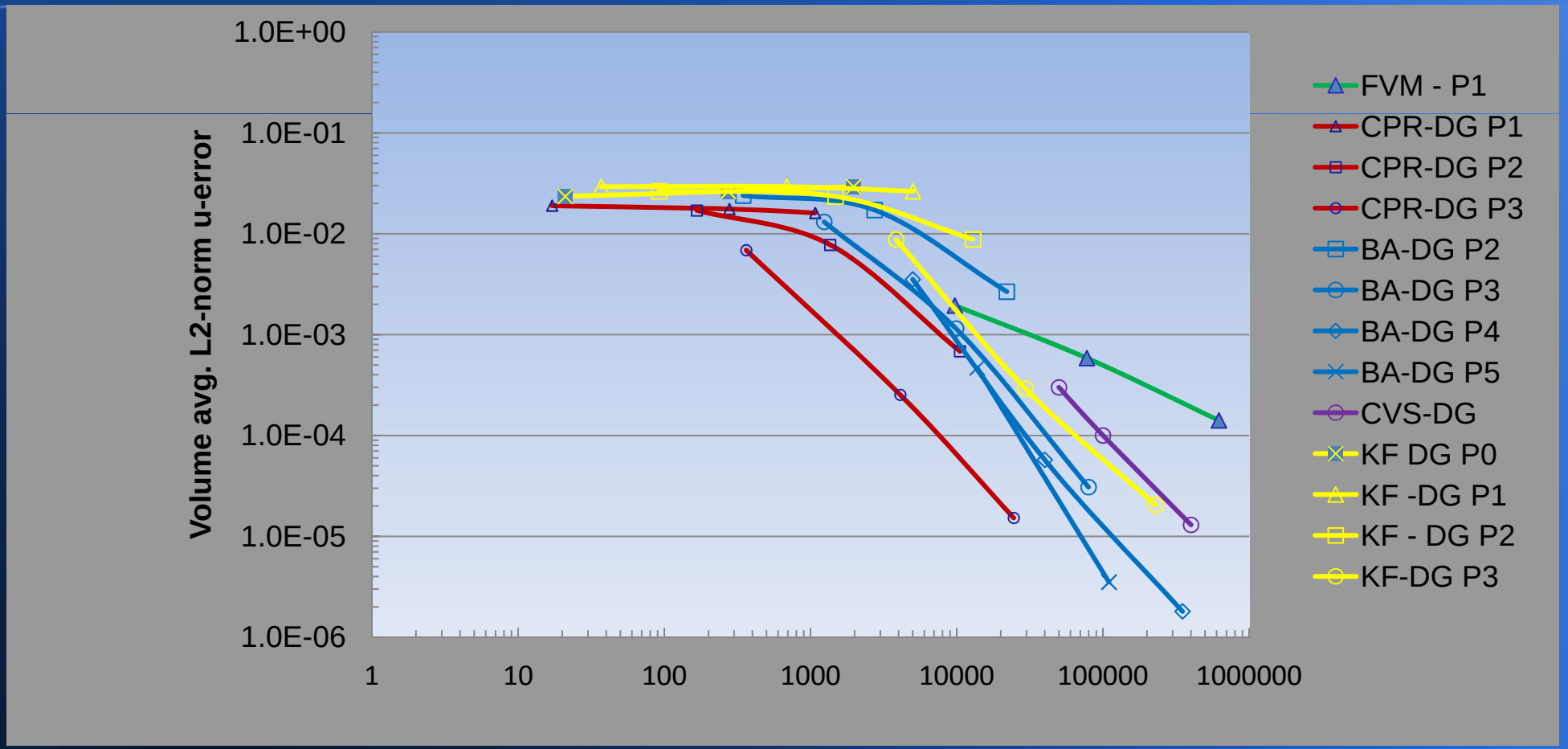

Work units

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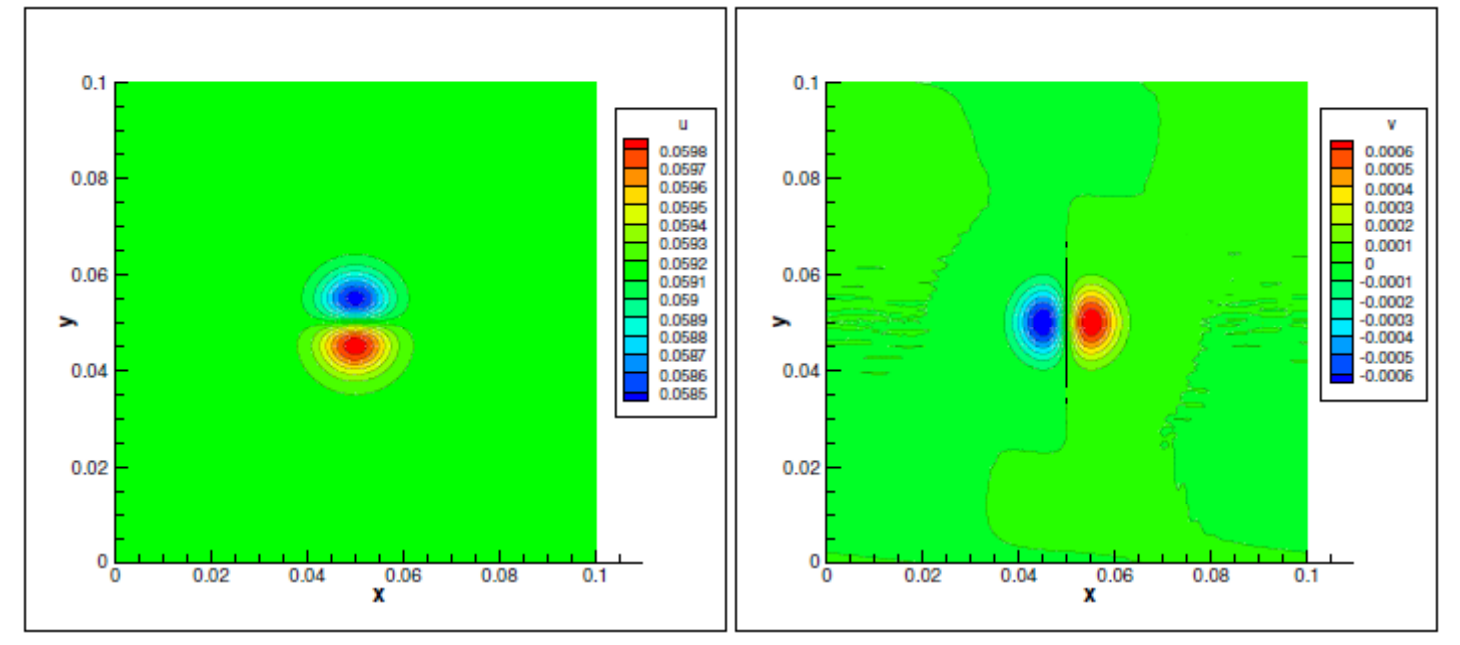

5th order DG uniform mesh results

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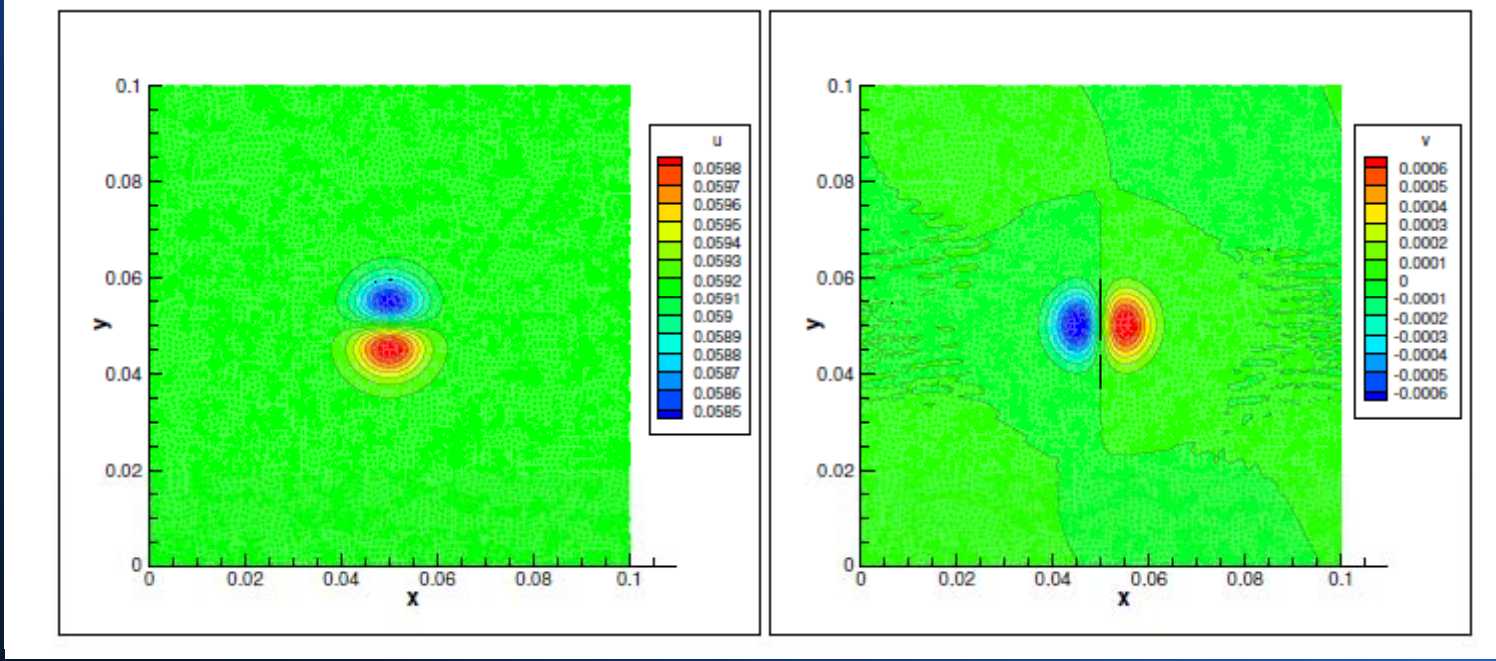

5th order DG Perturbed mesh results (some wiggleness)

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Summary of results:

- *Three versions of DG algorithms were compared*
- *The big absents are :*
  - *High order (reconstruction based) FVM ?*
  - *High-order Multidimensional-Upwind schemes,*
  - *Spectral elements, High-order spectral finite differences, etc.*
- *All HO results show a big advantage of using HO time/space discretization.*
- *Results show that HO methods can bring a leap in efficiency of solving unsteady flows (LES/DES,URANS)*

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Challenges of LES/DES of turbulent flows:

- *Large variety of turbulent/vortical scales,*
- *Vorticity preservation and kinetic energy preservation (in incompressible flows) is essential for success,*
- *Grid size changes, cell stretching and skewness can be important,*
- *Explicit schemes are probably not be able to cope with extreme time-step limitations due to viscous stability conditions,*
- *How the new HO algorithms are going to be fitted into current commercial CFD codes architecture ?*