Case 1.4 Vortex transport by uniform flow

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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 also 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?
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.
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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 \(P_{\infty} = 10^6 \text{N/m}^2\), temperature \(T_{\infty} = 300K\) and Mach number \(M_{\infty} = 0.05, 0.5\)
- A vortex of characteristic radius \(R = 0.005\) and strength \(\beta = 0.02, 0.2\)

\[
\begin{align*}
  u_0 &= U_{\infty}(1 - \beta \frac{y - Y_c}{R} e^{-r^2/2}) \\
  v_0 &= U_{\infty} \beta \frac{x - X_c}{R} e^{-r^2/2} \\
  T_0 &= T_{\infty} - 0.5(\beta U_{\infty} e^{-r^2/2})^2 / C_p \\
  \rho_0 &= \rho_{\infty} (T_0/T_{\infty})^{1/(\gamma-1)} \\
  P_0 &= \rho_0 R_{\text{gas}} T_0
\end{align*}
\]

\[
\begin{align*}
  (X_c, Y_c) &= (0.05, 0.05) \\
  r &= \sqrt{(x - X_c)^2 + (y - Y_c)^2} / R \\
  U_{\infty} &= M_{\infty} \sqrt{\gamma R_{\text{gas}} T_{\infty}} \\
  C_p &= \gamma R_{\text{gas}} / (\gamma - 1) \\
  \text{ratio of specific heats} \ \gamma &= 1.4 \\
  \text{gas constant} \ R_{\text{gas}} &= 287.15 \text{J/kg K}
\end{align*}
\]
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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 2\textsuperscript{nd} 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

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Compare 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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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
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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 ?