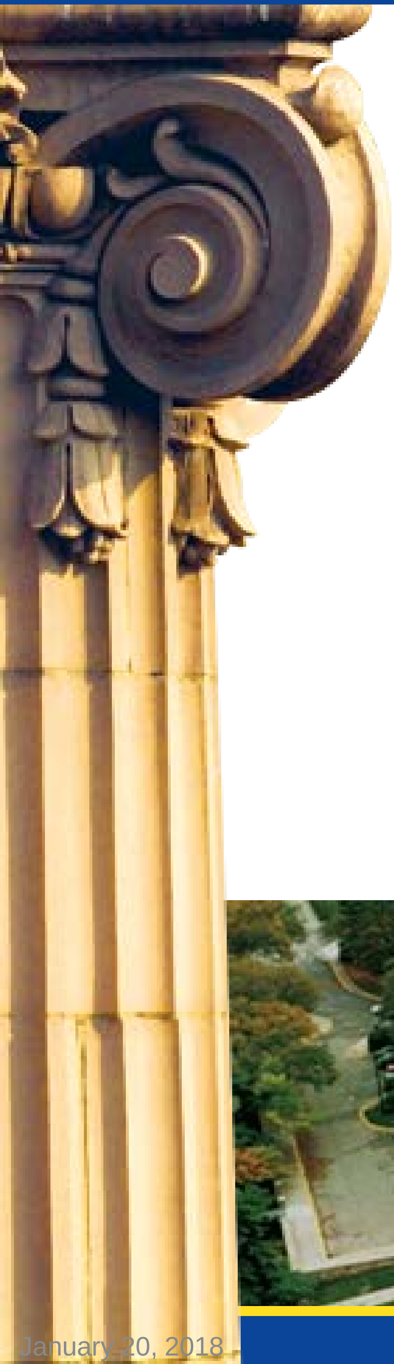
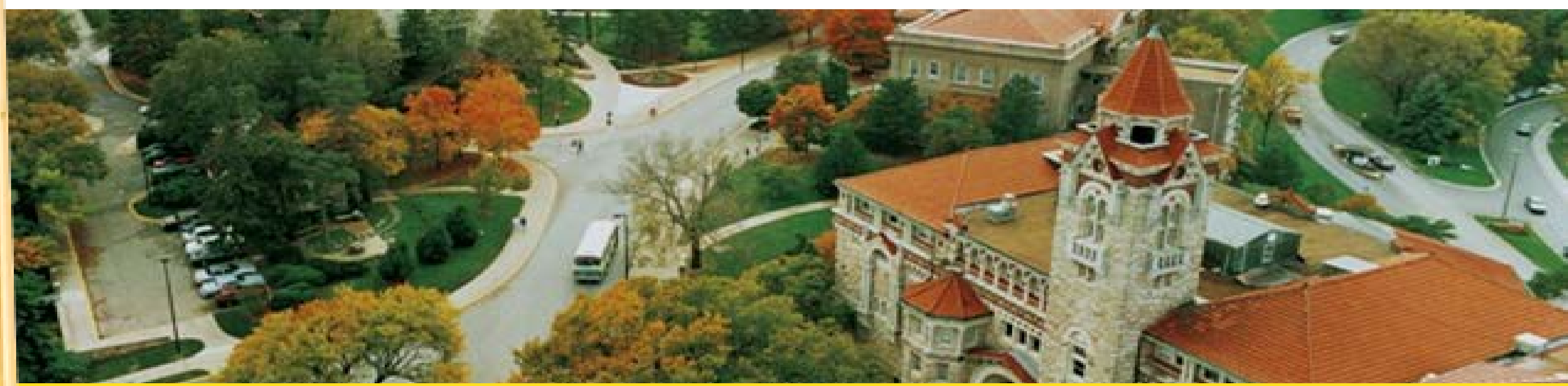


CS1 - Tandem Spheres Re=3900

Yifei Xue and Z.J. Wang
University of Kansas

Presented at HOW5

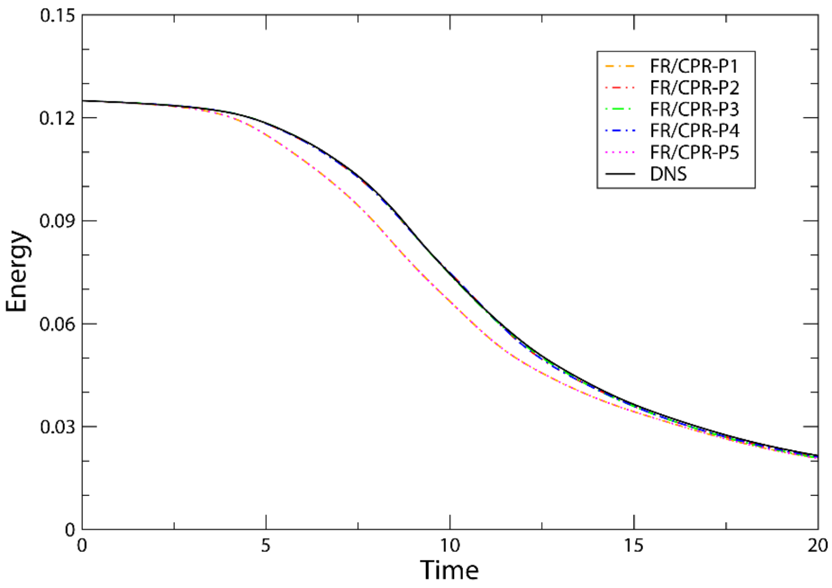


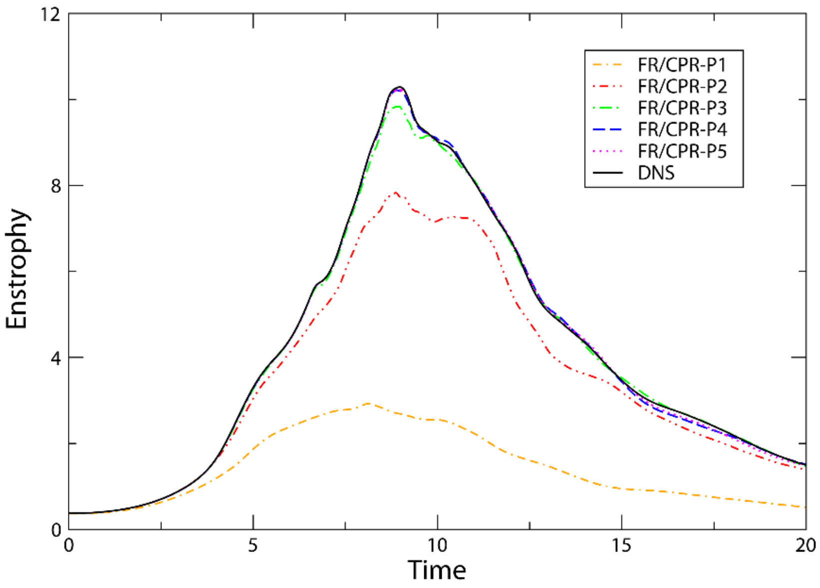
Discretization Scheme

- Space: FR/CPR (p2 & p3)
  - Gauss points as solution points and flux points
  - Roe Riemann solver
  - BR2 for viscous flux
- Time: BDF2 optimized
  - Block-preconditioned LU-SGS solver
  - Unsteady residual reduced by 2 orders at each time step
- Implicit LES
- P2 mesh generated by GridPro

Verification Case – Taylor-Green Vortex

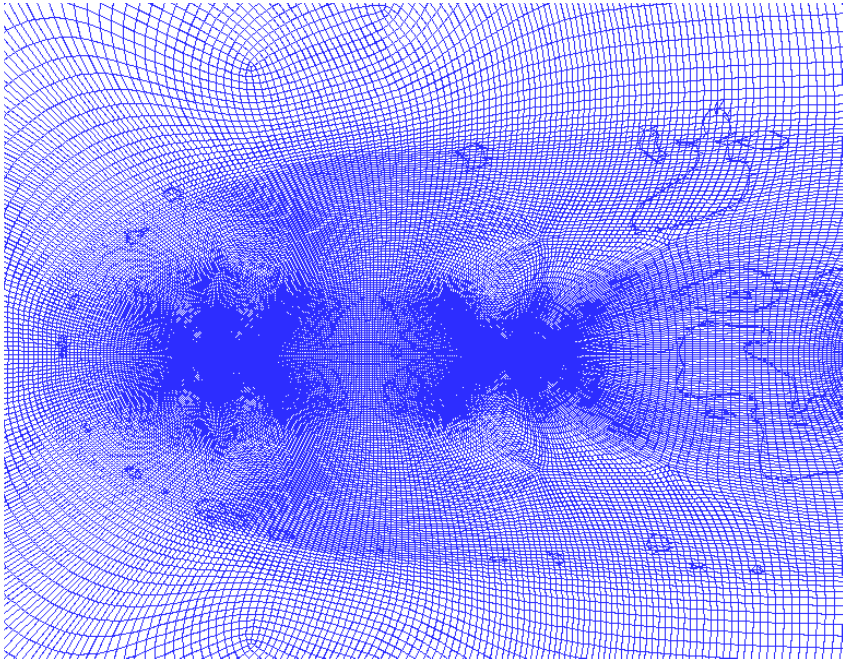
64x64x64 uniform mesh used

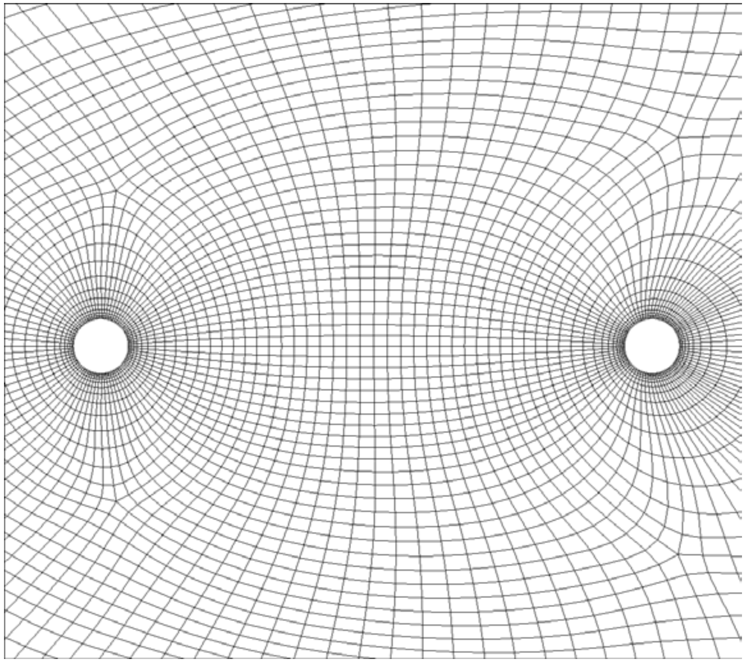




Test Case

- P2 mesh generated by GridPro used
  - 192,640 elements
  - $\Delta y = 0.024$ (y+ ~ 7.4, based on element height)
  - Similar to Mesh 5, but not exactly the same





Test Case (cont.) – Intel CPU Cluster 400 Cores

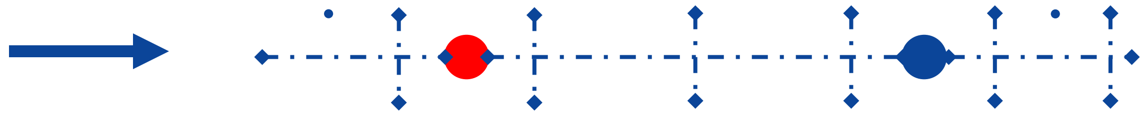
- P2 simulation details
  - nDOFs/equ: 5.2M
  - Δt = 0.0001s (or 0.0035 t*) implicit or 4.8e-6s (1.7e-4) explicit.
  - Total CPU core hours: 2.01e4 (explicit) and 3.97e3 (implicit)
  - Work units: 12.8M and 2.53M
- P3 simulation details
  - nDOFs/equ: 12.3M
  - Δt = 0.0001s (or 0.0035 t*) implicit
  - Total CPU core hours: 1.02e4 (1.06 days wall time)
  - Work units: 6.5M
- TauBench: 5.65s

Intel Xeon(R) CPU E5-2680 v3 @ 2.50GHz

THE UNIVERSITY OF KANSAS

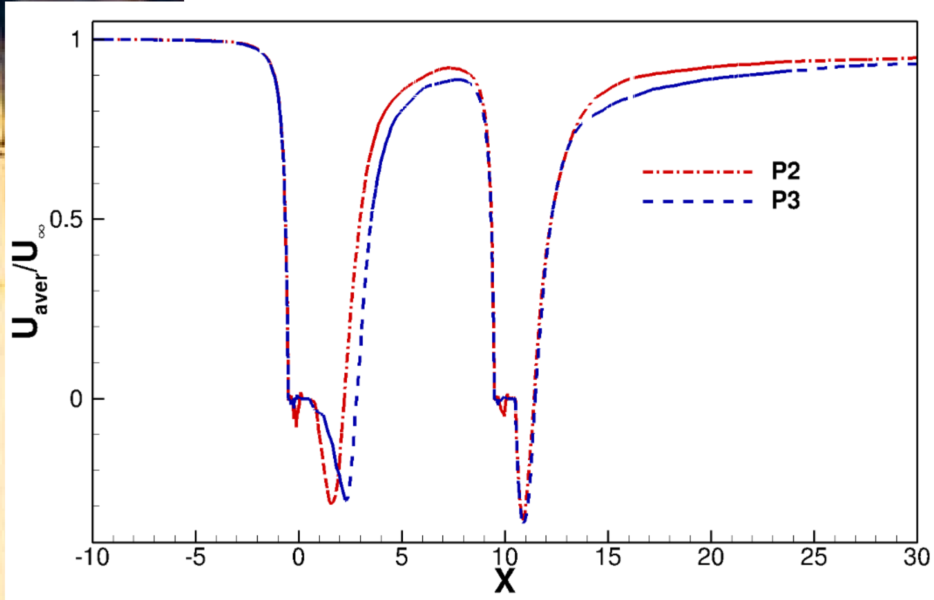
Numerical Results (P2&P3)

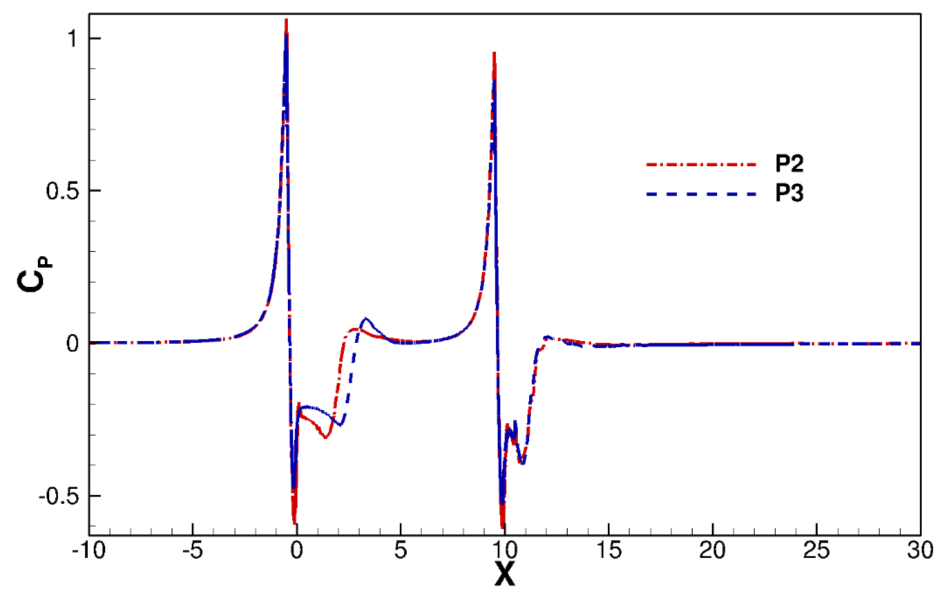
- Integral quantities – Upstream sphere:



- P2
  - Mean: $C_D = 0.3667$, $C_{LY} = -6.412e\text{-}04$, $C_{LZ} = 1.000e\text{-}03$
  - RMS: $C_D = 0.3668$, $C_{LY} = 1.234e\text{-}2$, $C_{LZ} = 1.190e\text{-}02$
- P3
  - Mean: $C_D = 0.3741$, $C_{LY} = -6.035e\text{-}04$, $C_{LZ} = 7.932e\text{-}04$
  - RMS: $C_D = 0.3741$, $C_{LY} = 4.098e\text{-}03$, $C_{LZ} = 4.067e\text{-}03$

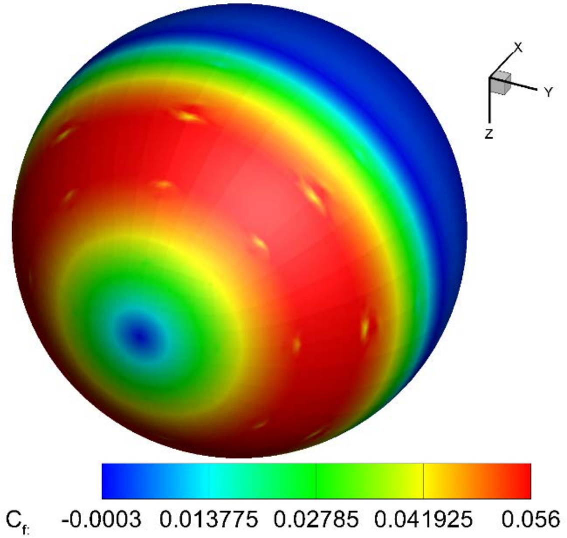
Profiles – Center line or Sphere Surface

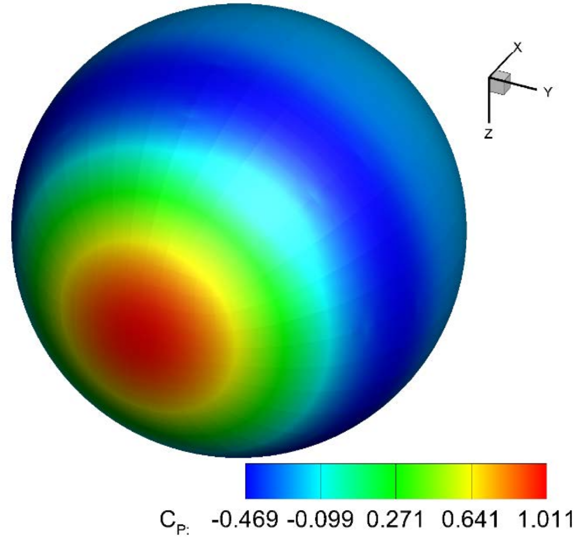




Numerical Results (P3)

- Surface quantities– Upstream sphere:



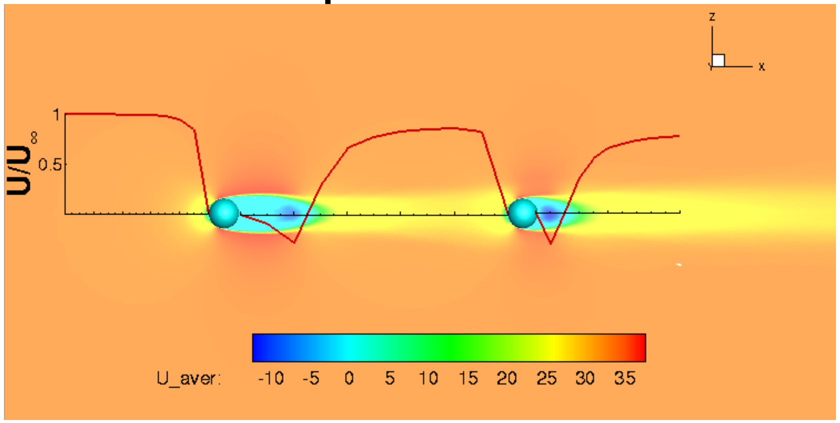


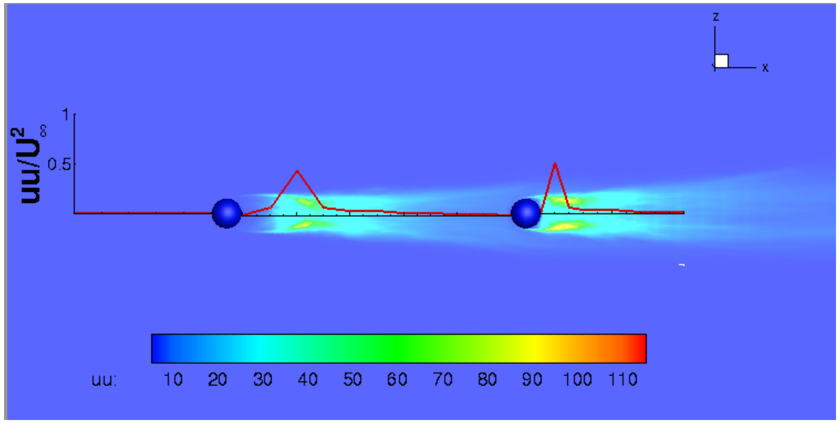
- High shear stress at the Leading hemisphere
- Low shear stress at the stationary point
- Negative at the posterior hemisphere

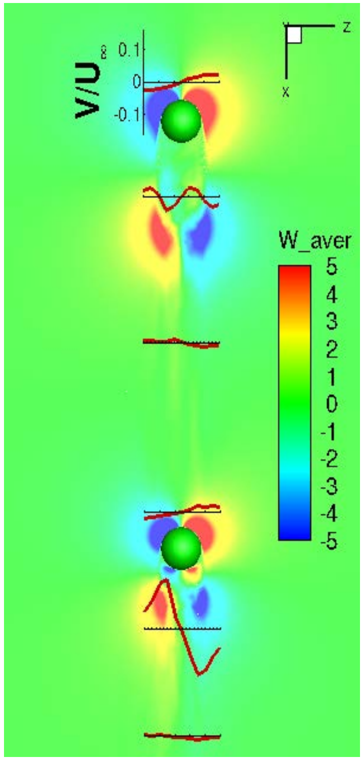
- High pressure coefficient at the stationary point
- Decrease at the separation region

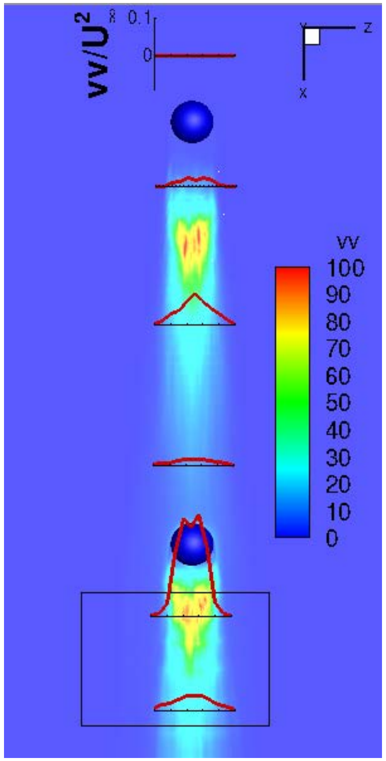
Numerical Results

- Flow samples





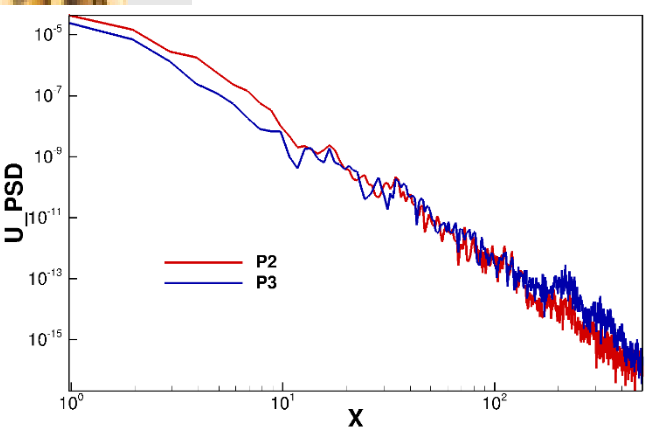


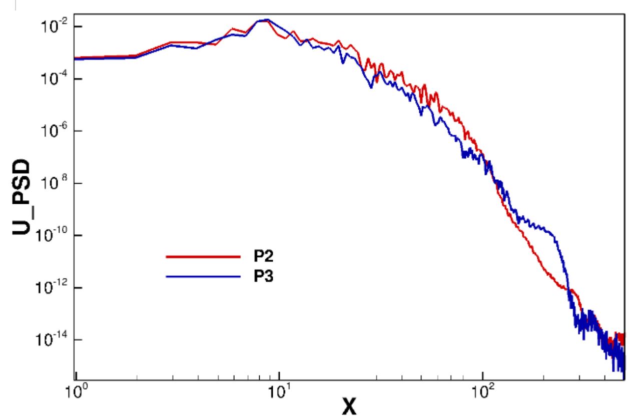


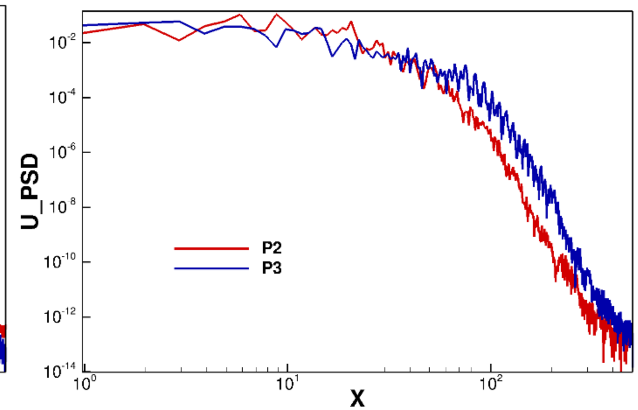
- Exported 15 transects' parameters

Numerical results and discussion

- Frequency spectra at points







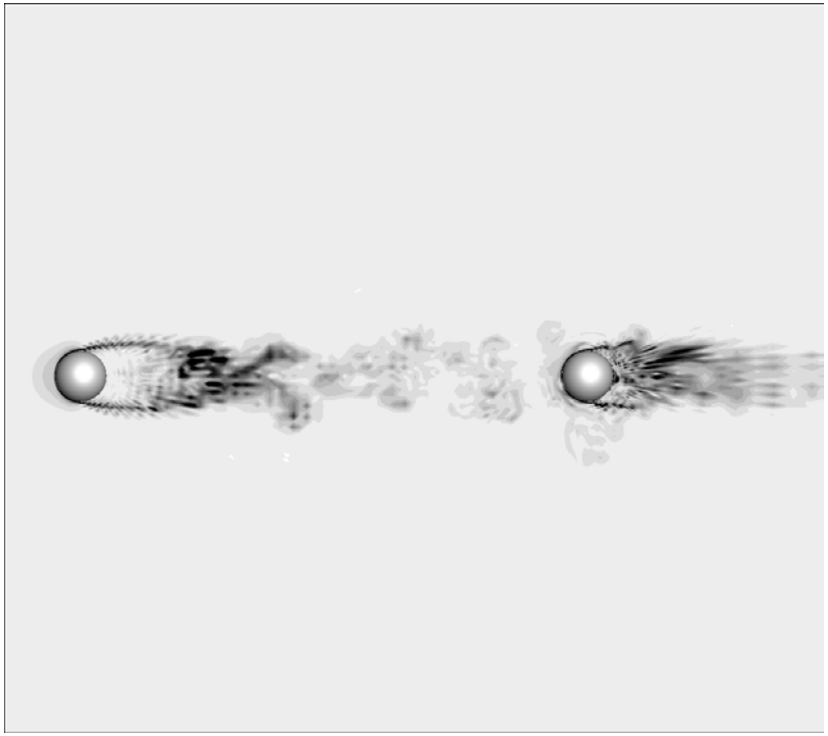
- Laminar
- No obviously character frequency

- transition
- Character frequency=8.5

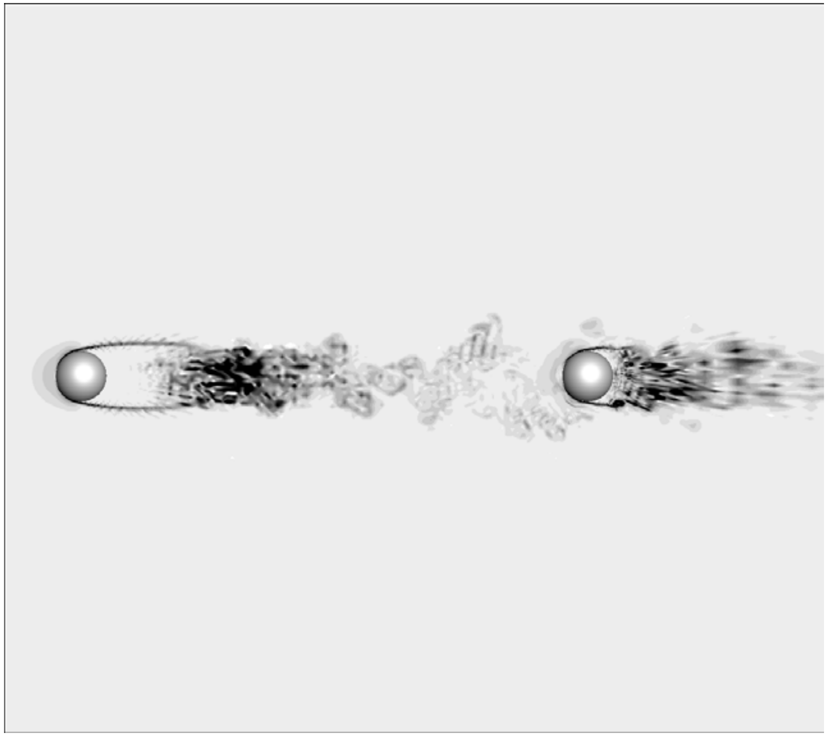
(vortex shedding)

- turbulence
- High frequency part increase

Schlieren

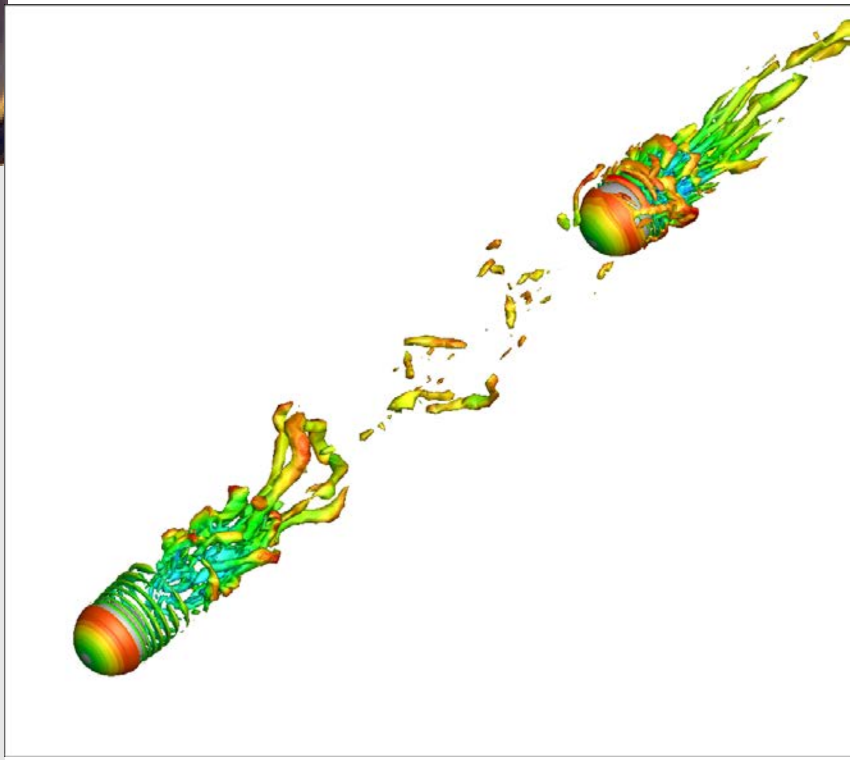


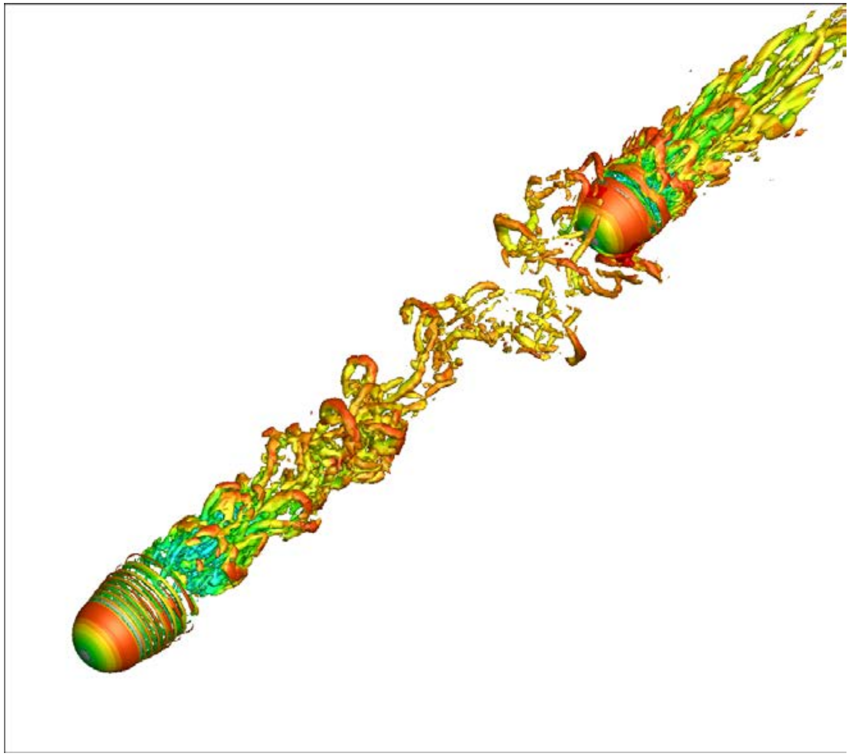
P2



P3

Q-criterion

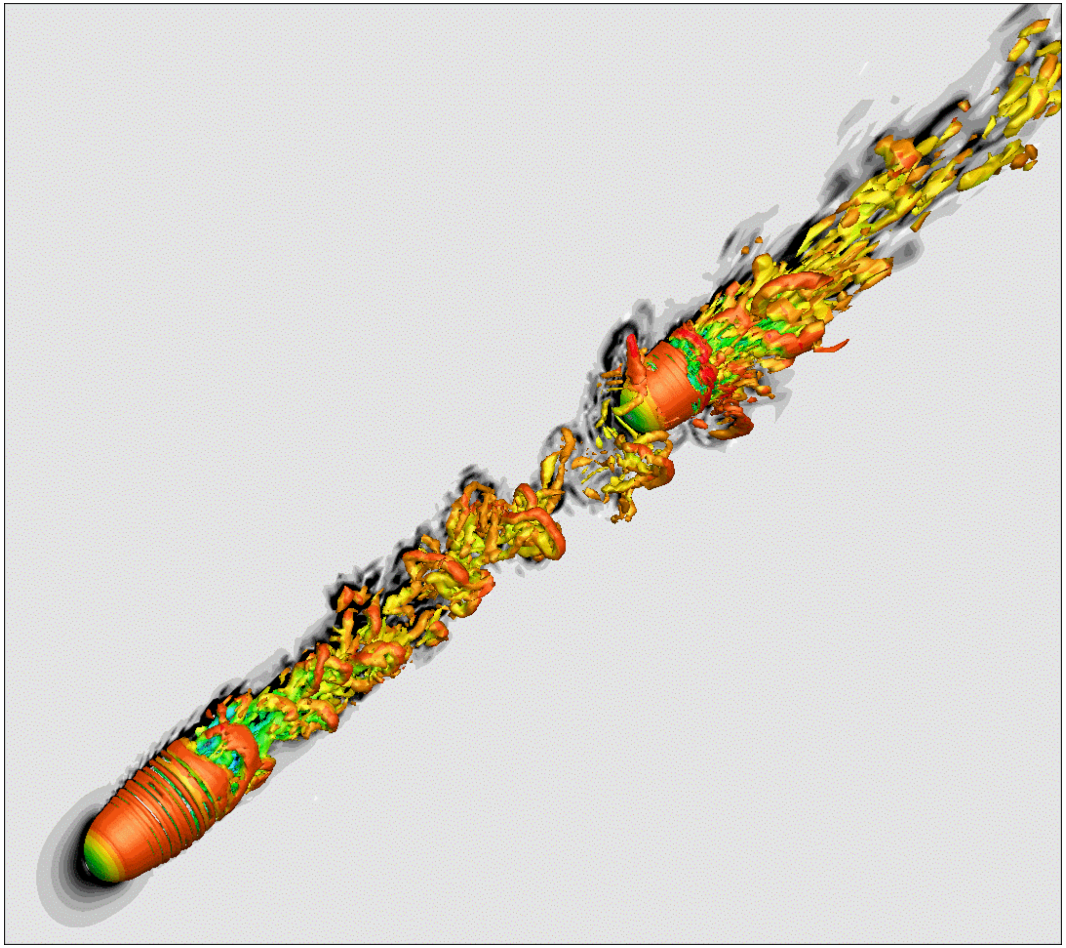




P2

P3

Q-criterion + Schlieren Movie



P3

Conclusions

- The verification case is useful
- Too much data asked, which may deter participation
- The method/solver appears to handle this problem very well without any difficulty
- Implicit scheme improved efficiency by a factor of 5

References

- F. Jia; J. Ims; Z.J. Wang; J. Kopriva; G.M. Laskowski, An Evaluation of a Commercial and a High Order FR/CPR Flow Solvers for Industrial Large Eddy Simulation, AIAA-2018-0827. In Session FD-24
- Veer N. Vatsa, Mark H. Carpenter, David P. Lockard, Re-evaluation of an Optimized Second Order Backward Difference (BDF2OPT) Scheme for Unsteady Flow Applications, AIAA-2010-0122
- Huynh, H. T. (2007, June). A flux reconstruction approach to high-order schemes including discontinuous Galerkin methods. In 18th AIAA Computational Fluid Dynamics Conference (p. 4079).
- Z.J. Wang, Y. Li, F. Jia, G.M. Laskowski, J. Kopriva, U. Paliath, R. Bhaskaran, Towards industrial large eddy simulation using the FR/CPR method, Computers and Fluids, Volume 156, 12 October 2017, Pages 579-589.