CS1 - Tandem Spheres $Re=3900$

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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
  - \( \Delta y = 0.024 \) (\( y+ \approx 7.4 \), 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
- $\Delta t = 0.0001s$ (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
- $\Delta t = 0.0001s$ (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
Numerical Results (P2&P3)

- Integral quantities – Upstream sphere:

  - **P2**
    - Mean: $C_D = 0.3667$, $C_{LY} = -6.412e-04$, $C_{LZ} = 1.000e-03$
    - RMS: $C_D = 0.3668$, $C_{LY} = 1.234e-2$, $C_{LZ} = 1.190e-02$

  - **P3**
    - Mean: $C_D = 0.3741$, $C_{LY} = -6.035e-04$, $C_{LZ} = 7.932e-04$
    - RMS: $C_D = 0.3741$, $C_{LY} = 4.098e-03$, $C_{LZ} = 4.067e-03$
Profiles – Center line or Sphere Surface

![Graphs showing profiles](image)

- Profiles for different conditions (P2, P3)
- Variables: $U_{ave}$, $C_p$
- Axes: $X$
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