Flow Through and Around Groups of Bodies

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Complex Unbounded Multibody Flow Problems
Characteristics

- The group of bodies is in unbounded flow.
- Individual bodies interact and form a group.
- Any individual body’s position is not critical.
- There is no dominant body.
Research Focus

Conduct fundamental investigations, to isolate and understand the effect of varying the void fraction, on unbounded multibody flows.
Approach

- Fixed parameters:
  - Group shape: Cylinder
  - Individual body shape: Cylinder
  - Flow conditions: Uniform & steady
  - Distribution of Individual bodies: Equidistant
- Develop frameworks to provide analysis of the flow field.
  - Numerical simulations
  - Experimental extension
- Interpret and evaluate the flow field using a series of diagnostics.
Numerical Investigation

Development of new code
- Very large and long simulations
- Diagnostics to be done on the fly
- Fully resolved
- Validated with 3 test cases

Solver
- Unstructured mesh
- CBS (Characteristic based scheme)
- FEM
- Real time step
Numerical Studies

- Case studies 8
- Total Processor hours 250,000 or 10,000 Day
- Cylinder 1-133
- Void fraction 0.01 – 0.3
- \( \text{Re} = 100 \)
- \( \text{Re}_G = 2100 \)
- Nodes 4m
- Element 8m
- Time steps 2m
- Processors 32 – 256
- Domain length 3000D
- Domain width 250D
Legion Resource

- Legion is the new UCL Supercomputer
- Cluster of 640 1U servers
- 2560 processors
- 4 GB of memory per core
- Bi-directional InfiniPath chip to chip connectivity
Numerical Code

Code Style
- C++
- Object oriented
- Late binding
- Script driven
- Parallel
- Distributed memory

Numerical Libraries
- Intel MKL
- MPI 2.0
- PETSc
- ParaMETIS
Diagnostics

- Lift & drag force on individual / group
- Flow field diagnostics (vorticity, strain, E)
- Lagrangian / Eulerian average velocity
- Vorticity maximum decay
Force Scatter Plots

- 3 Regimes
  (top 2) - Individual body wakes
  (mid 2) - Zero lift single wake
  (bottom 2) - Comparable to solid body wake
Group Force

- Drag coefficient
- Lift coefficient

Graphs showing the relationship between void fraction and drag coefficient, as well as lift coefficient.
Flow Diagnostics
Low void fraction

20 cylinder case
Void fraction 0.0454

RED: Irrotational
Green: Shearing
Blue: Vortical
Medium void fraction

39 cylinder case
Void fraction 0.0884
High void fraction

133 cylinder case
Void fraction 0.3016
Downstream Vorticity

Low void fraction

Medium void fraction

High void fraction
Eulerian and Lagrangian Average Velocities

Mathematical Equation

\[ \langle u_1 \rangle_E = \frac{1 - \phi - \frac{1}{v}}{1 - \phi} \sum_{i=1}^{N_C} L_{W_i} Q_i \]

Numerical Equations

\[ \langle u_1 \rangle_L = \left\langle \frac{L_k}{T_k} \right\rangle \]

\[ \langle u_1 \rangle_E = \frac{\sum_{e \in V-V_b} \frac{1}{2} (u_{1i} + u_{1j} + u_{1k}) A_e}{\sum_{e \in V-V_b} A_e} \]
Stream Lines through the Array
Experimental Apparatus

- Channel is 3m long 0.5m wide and 0.2m high.
- Flow rate to 0.5m/s.
- Centrifugal pump 5.5 kW.
- High grain AC inverter control.
- 3.5 Tons of water.
- Visual access 4 sides of channel.
Group Gantry

- 2D force measurement
- 8 load cell (4/axis)
- 24 bit resolution
- Computer data logging
- Temperature and force balanced
- Interchangeable plate for different cylinder arrangements.
Instrumented Cylinder

- Drag and lift force measurement
- Integrated PG-ADC
- Local data caching with time stamp
- Noise cancellation
- Minimum signal paths
- Submersible
Experimental Results

(left) Experimentally measured average drag force in mV against void fraction for four different \( \text{Re}_G \)

(right) Experimentally measured rms lift force normalized by \( E_{S1} \) against void fraction for four different \( \text{Re}_G \)
Experimental Imaging

Low void fraction

Medium void fraction

High void fraction
Conclusion

This work has:

- Developed new tools to investigate multibody flows.
- Conducted DNS resolution numerical studies for large groups of cylinders.
- Identified three flow regimes for increasing void fraction.
- Compared groups of bodies with a solid representation.
- Identified similar flow features between 3-D experimental and 2-D numerical data.