Tandem Spheres: Motivation and Case Specification

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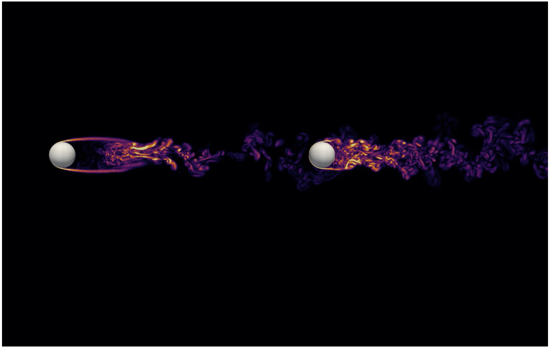
Outline



Goal

A case that features:

- Accessible geometry
- Spacing large enough to asses wake growth and interaction
- Tractable run times
- Minimal far-field boundary interactions
- Prediction

Why?

- Look beyond Figures of Merit on bodies
- Impactful and interesting flow physics in off-body regions
- Wake propagation is central to many control and design problems
  - down stream control surfaces
  - minimum interval takeoff / landing
  - swarms
  - wind and solar arrays
  - pedestrian safety and comfort

BANC-I Tandem Cylinders

Benchmark problems for Airframe Noise Computations-I Workshop: Tandem Cylinders [1–3]

- Accessible geometry
- Spacing large enough to asses wake growth and interaction
  - 3.7 D separation [1]
  - Important spanwise variation occurs over many cylinder diameters [1–3]
- Tractable run times
  - Resolution challenges: Small-scale, Kelvin-Helmholtz instabilities grow in the shear layers ... the wake must be propagated to the downstream cylinder without excessive diffusion [1]
  - Grid points needed can easily be in the hundreds of millions [1–3]
  - Requires a sufficiently long sample to compute the statistics [1–3]
- Minimal far-field boundary interactions
  - Periodic boundary conditions employed in nearly all the simulations undoubtedly have some nonphysical effect on the flow [1]
- Prediction
  - Experimental data sets were available to the 15 participants [1–3]

Approach

A case that features:

- Accessible geometry
- Spacing large enough to asses wake growth and interaction
- Tractable run times
- Minimal far-field boundary interactions
- Prediction

Tandem Spheres

- Analytic or geometric
- 10 D separation
- Geometry does not require extended domain
- No periodic boundaries
- Is there an experiment? $C_D = 0.39$ for a single sphere [4].

Participants

- ZJ Wang, Kansas Univ.
- Johan Jansson, KTH/BCAM
- Marian Zastawny, Siemens
- Philip Johnson (WS1), Univ. of Michigan
- Kevin Holst, Univ. Tennessee - Space Institute

Grids

Hexahedral and tetrahedral girds were provided by **Steve Karman** of **Pointwise** and **Samuel James** of **GridPro** in CGNS and gmsh file formats [5].

Prerequisite

Why focus on wake physics? To quantify

- Energy dissipation rate
- Kinetic energy spectrum
- Vorticity transport and distribution
- Agreement between transient / steady state
- Difference between up stream / down stream bodies

HOW5: WS1 Taylor-Green Vortex [6]

- Energy dissipation rate
- Enstrophy
- Kinetic energy spectrum
- Vorticity traces
- Code verification and order assessment

Case Specification

Prediction of complex unsteady multi-scale flow under low Mach and low Reynolds number conditions [5].

- Two spheres of diameter D whose centers are separated by $10D$ along the stream wise centerline
- Far field boundaries: characteristic
- Sphere surface boundaries: adiabatic wall
- Mach number ($M_\infty = 0.1$)
- Temperature is ($T_\infty = 300\,K$)
- Density ($\rho_\infty = 1.225\,kg/m^3$)
- Reynolds number based on single sphere diameter, D, ($Re_D = 3900$)
- Prandlt number ($Pr = 0.72$)
- Characteristic time scale ($t^* = t\frac{U_\infty}{D}$)
- Compare quantities of interest during $t^* \in [100, 200]$

Figures of Merit

Converged average drag coefficient (C_D) and Strouhal Number (St) based on lift for the down stream sphere during $t^* \in [100, 200]$

- Integral quantities for both spheres:
    1. Mean values: lift coefficient C_L, drag coefficient C_D
    2. Root-means-squared values: C_L, C_D
- Surface quantities on $x - y$, $x - z$, and $y - z$ planes passing through the center of each sphere:
    1. Mean values: pressure coefficient C_P, skin friction coefficient C_f
    2. Root-means-squared values: C_P, C_f

Flow Quantities

- Quantities
  1. Mean values on stream wise and transverse transects:
     1. u, v, and w velocity components (non-dimensionalized by U_∞)
     2. Reynolds stresses $(u'u', u'v', v'v')$ (non-dimensionalized by U_∞^2)
  2. Root-means-squared values on stream wise and transverse transects:
     1. u, v, and w velocity components (non-dimensionalized by U_∞)
     2. Reynolds stresses $(u'u', u'v', v'v')$ (non-dimensionalized by U_∞^2)
  3. Frequency spectra at points:
     1. Total velocity
     2. Pressure coefficient C_P
     3. Turbulent kinetic energy
- Locations
  1. Three Stream wise sample lines
  2. Six y Transverse samples lines
  3. Six z Transverse samples lines
  4. Three Points
- Provide details of the computational resources utilized in terms of DOF, work units, and time marching scheme.
- Provide details of the computational hardware and parallelization strategy utilized.

Presentation References I

[1] Lockard, D. P., "Summary of the tandem cylinder solutions from the benchmark problems for airframe noise computations-I workshop," *AIAA paper*, Vol. 353, 2011, p. 2011.

[2] Palau-Salvador, G., Stoesser, T., and Rodi, W., "LES of the flow around two cylinders in tandem," *Journal of Fluids and Structures*, Vol. 24, No. 8, 2008, pp. 1304–1312.

[3] Brès, G. A., Freed, D., Wessels, M., Noelting, S., and Pérot, F., "Flow and noise predictions for the tandem cylinder aeroacoustic benchmark a," *Physics of Fluids*, Vol. 24, No. 3, 2012, p. 036101.

[4] Constantinescu, G., and Squires, K., "Numerical investigations of flow over a sphere in the subcritical and supercritical regimes," *Physics of fluids*, Vol. 16, No. 5, 2004, pp. 1449–1466.

[5] "CS1 - Tandem Spheres Re=3900," , 2017. URL `https://how5.cenaero.be/content/cs1-tandem-spheres-re3900`.

[6] "WS1 DNS of the Taylor-Green vortex at Re=1600," , 2017. URL `https://how5.cenaero.be/content/ws1-dns-taylor-green-vortex-re1600`.