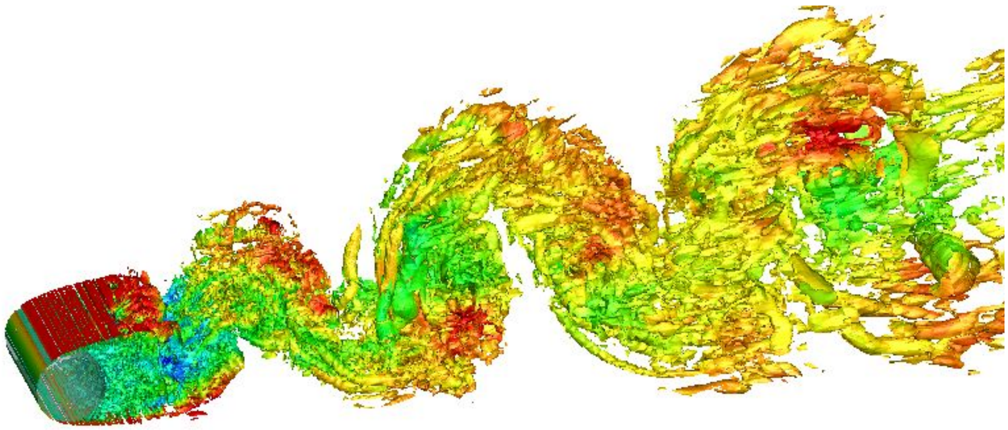
AS1 - LES of the transitional flow around an infinite cylinder at Re=3900



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General description

This test case is aimed at characterizing the accuracy and efficiency of high-order solvers for the prediction of complex unsteady multi-scale problems under low Reynolds number conditions. An infinitely smooth initial condition with a bias in the span-wise and vertical direction is employed, and the unsteady solution at a time (t_1) before any chaos or turbulence starts will be used to assess the spatial and time accuracy of the flow solver. The bias is designed to ensure that the non-symmetric flow is not a consequence of round-off or truncation errors. After the flow reaches a statistically periodic state at t_2, averaged quantities and Reynolds stresses are computed until t_3 for comparison purposes. Since t_1 is expected to be relatively small, hp-refinements or adaptations will be employed to obtain accurate Cl and Cd (error < 0.01 count) values at t_1 to assess solution accuracy.

The following non-dimensional times are specified:

$t_1 = 1$, $t_2 = 100$, $t_3 = 800$

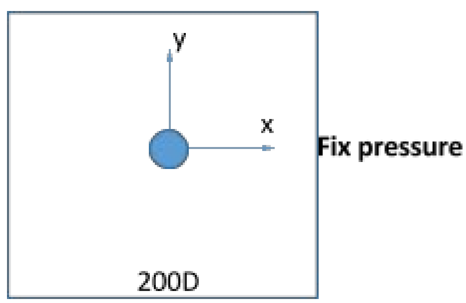
The Cl and Cd values obtained by several groups are: Cl = 0.070603 and Cd = -0.151505, for your reference. All times are non-dimensionalized based on the characteristic time scale: $t^* = D / U_\infty$.

Governing Equations

The governing equations are the full 3D compressible Navier-Stokes equations with a constant ratio of specific heats of 1.4, a constant viscosity, and a Prandtl number of 0.71 with inflow Mach of 0.3. Given the low value of Reynolds number being considered, emphasis is placed on ILES approaches; however, methodologies which incorporate dynamic sub-grid-scale (SGS) models are also of interest.

Geometry

The diameter of the cylinder is D = 1. In order to minimize computational cost, the span-wise dimension is L = 2xD, and the far-field is a square 100D away from the center of the cylinder, as shown in the following figure. The Reynolds number based on the diameter is 3,900.



Flow Conditions

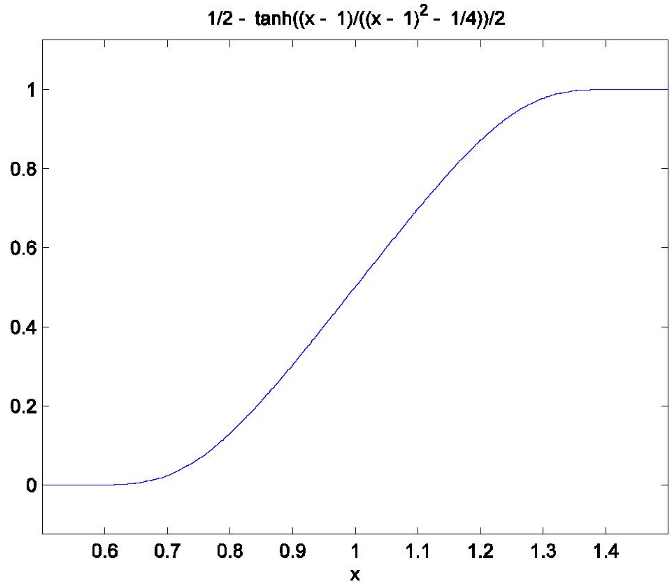
The upstream Mach number is M=0.3, the Reynolds number based on D is 3,900, and the angle of attack is 0°.

The initial condition is infinitely smooth. The free stream is blended smoothly with a no slip condition on the cylinder surface. In addition, the initial flow has a bias (non-symmetric) in the span-wise and vertical direction (y).

Let (r, θ) be the polar coordinates on the x-y plane. The cylinder surface is r = 0.5, and the span goes from 0 to L. Define a smooth function between 0 and 1.

$$S(r, r_m, r_a) = 0.5\left(1 + \tanh\left(\frac{2r_a(r - r_m)}{r_a^2 - (r - r_m)^2}\right)\right), \quad \mathrm{r}_m - r_a \le r \le \mathrm{r}_m + r_a$$

This function goes from zero to 1 between $r = r_m - r_a$ and $r_m + r_a$, with zero derivatives of any order at both end points as shown in the following figure.



The free stream is $p = p_\infty, T = T_\infty, u = U_\infty, v = 0, w = 0$. The pressure and temperature are constant in the entire computational domain.

If $r < 1.5$

$$u = U_\infty \cdot S(r, 1, 0.5)$$

If $0.5 < r \le 1$

$$w = \varepsilon \cdot U_\infty \cdot S(r, 0.75, 0.25) \cdot \sin^2(\pi z / L)$$

Else

$$w = \varepsilon \cdot U_\infty \cdot (1 - S(r, 1.25, 0.25)) \cdot \sin^2(\pi z / L)$$

End if

If $0 < \theta < \pi$

If $0.5 < r \le 1$

$$v = \varepsilon \cdot U_\infty \cdot S(r, 0.75, 0.25) \cdot S\left(\theta, \frac{\pi}{2}, \frac{\pi}{2}\right)$$

Else

$$v = \varepsilon \cdot U_\infty \cdot \left(1 - S(r, 1.25, 0.25)\right) \cdot S\left(\theta, \frac{\pi}{2}, \frac{\pi}{2}\right)$$

End if

Else

If $0.5 < r \leq 1$

$$v = \varepsilon \cdot U_\infty \cdot S(r, 0.75, 0.25) \cdot \left(1 - S\left(\theta, \frac{3\pi}{2}, \frac{\pi}{2}\right)\right)$$

Else

$$v = \varepsilon \cdot U_\infty \cdot \left(1 - S(r, 1.25, 0.25)\right) \cdot \left(1 - S\left(\theta, \frac{3\pi}{2}, \frac{\pi}{2}\right)\right)$$

Endif

Endif

Endif

The parameter ε is 0.1.

The freestream flow conditions are : $p_\infty = 1, T_\infty = 1/1.4, \rho_\infty = 1.4, U_\infty = 0.3$

Boundary Conditions

Exit plane: fix pressure
Cylinder surface: no slip adiabatic wall
Span-wise: periodicity
Rest: characteristic inflow and outflow.

Mandatory computations and results

1. Run the simulation until t_1, and find the Cl and Cd. Perform time and mesh refinement studies to find accurate values with 0.01 count accuracy, and use the values to compute Cl and Cd errors. For the short term simulation, you may be able to use a much finer resolution than for the long term simulation. For the long term simulation, you can choose any mesh resolution and order.
2. Plot Cl and Cd histories vs. non-dimensional time
3. Compute the mean flow and Reynolds stresses with spanwise averaging between t_2 and t_3.

4. Compute the mean u-velocity and Reynolds stresses (u'u', u'v', v'v') at prescribed wake stations between $-3 < y < 3$, at x/D = 0.58,1.54, 6, 10. Again average the results in the spanwise direction.
5. Compute the mean pressure and surface skin friction coefficients with spanwise averaging on the cylinder surface between t_2 and t_3.
6. Frequency spectra for total velocity, pressure coefficient, and turbulent kinetic energy at selected wake points (0.58, 0, L/2), (1.54, 0, L/2), (5, 0, L/2), (10, 0, L/2)
7. Provide computational resources in terms of dof and work units. In addition, provide the Cl and Cd errors at t1, which serve as an error indicator.

Note: For all outputs, use non-dimensional data. For example, scale Reynolds stresses by the square of the freestream velocity.