Simulation of turbulent flow around cylinders

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Statistical flow modelling does not provide enough detail for many flows of engineering relevance in which unsteadiness is a central feature. This applies particularly to bluff-bodies and assemblies comprising bluff components for which the resolution of peak forces, unsteady loading, acoustics and fatigue are of interest as part of the design process. An example application which has been studied by the TFMS group and in which unsteady loading and acoustics are primary issues is shown in Fig. 1.

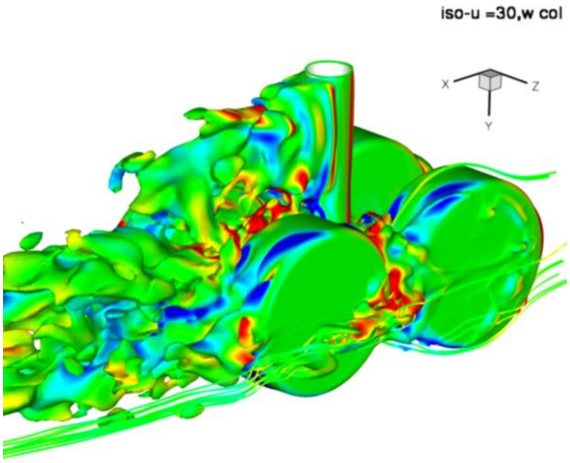

Fig. 1: Flow snapshot from a simulation of the flow around a simplified aircraft undercarriage (Tessicini and Leschziner, unpublished)

Large Eddy Simulation (LES) offers, in principle, the required level of detail required to describe the complex interactions between a bluff body and the flow around it. However, great care is required in its application to ensure that the resolution is sufficiently good and the predicted features faithfully reflect the physical processes, especially in multi-body configurations involving separation from curved surfaces.

The present study (Fishpool et al (2007)) is related to applications of the type shown in Fig. 1. It focuses on simple geometric arrangements, and it explores fundamental numerical and physical issues associated with the flow around single and twin-cylinder configurations. The configurations studied are shown in Fig. 2. In both cases, the Reynolds number, based on cylinder diameter and approach flow, is 10000, a value for which detailed experimental data are available.

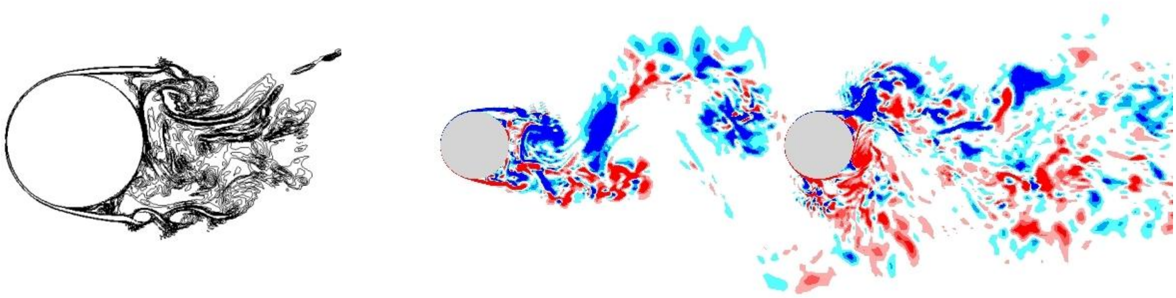

Fig. 2: Single and tandem-cylinder configurations studied

The study has placed particular emphasis on grid quality and required resolution, and Fig. 3 shows, for the case of the tandem cylinder, the type of structured multi-block grid used to secure high accuracy in important parts of the flow.

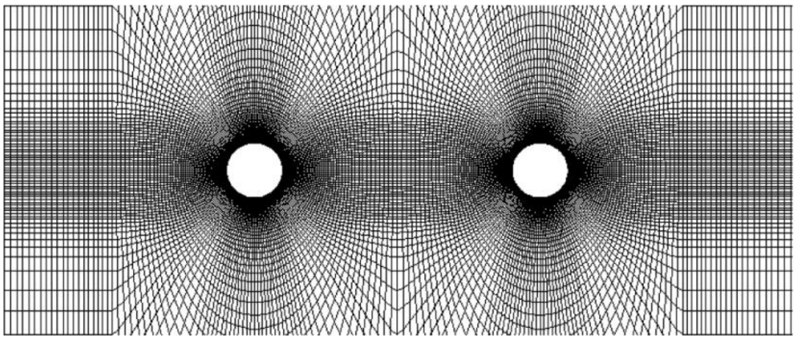

Fig. 3: Block-structured grid used to mesh the tandem cylinder configuration

Fig. 2 illustrates the wide range of scales that arises in the flow. A very thin laminar boundary layer develops on the cylinder from the point on the front of the cylinder at which the flow first meets it – i.e. from the *forward stagnation point*. This layer extends around most of the upstream face of the cylinder, until it separates from the surface a little under 90 degrees from the forward stagnation point. Thereafter the resulting thin free-shear layer remains laminar over a short distance before becoming unstable. This instability – manifesting itself by Kelvin-Helmholtz waves – gives rise to regular small vortices, examples of which may be seen on both of the shear layers in Fig. 2. The process by which the shear layer becomes turbulent is significantly complicated by the fact that, whilst the Kelvin-Helmholtz vortices are forming, the shear layer is itself rolling up on a larger scale to become the next von Kármán vortex. Hence, the transition to turbulence is breaking the flow up into smaller-scale structures at the same time as the shear layer is rolling up to form a large-scale structure.

Fig. 4 shows the effect on the time variation of drag and lift coefficients for the two cylinders. These coefficients are the standard normalisation of the respective forces using the projected area and the dynamic pressure of the oncoming stream. There are several interesting properties of the system that are seen in these traces. Most obvious is the oscillation of the lift traces – showing the effect of the periodic vortex shedding. In addition, the lower time-averaged drag of the rear cylinder reflects its being immersed in the wake of the front cylinder – an effect used in motor racing to gain speed by following the car in front very closely.

Although the cylinder is nominally infinitely long, the computational simulation has to be restricted to a finite length – ~3 diameters, in the present case – with periodicity boundary conditions applied at the spanwise (i.e. in the direction of the cylinder axis) boundaries. In such circumstances, the time-averaged solution is assumed to be statistically spanwise-homogeneous, i.e. "two-dimensional", as is the case in an infinitely long cylinder. Fig. 5 illustrates the fact that the *instantaneous* spanwise structure is extremely complicated and very far from being spanwise-homogeneous. The Kelvin-Helmholtz waves are clearly recognised in the shear layer separating from the front cylinder. Although not purely "two-dimensional", these structures show a fair degree of correlation in the spanwise direction. There follows the evolution of large three-dimensional structures including the streamwise-oriented braids and the von Kármán vortices (the latter, not easily seen in this visualisation – but see Fig. 2), and fully three-dimensional turbulence over a wide range of scales. This example brings out well the challenges that arise from the need to resolve scales that are highly disparate: the very thin laminar boundary and shear layers, with thickness of order 1% of the cylinder diameter; the transitional features in the separated shear layer, of order 2-5% of the diameter, the large-scale vortical structures shed from the cylinder, of order 200% of the cylinder diameter, and the resolved turbulent scales of size as small as 1% of the diameter; and the fine-scale structure in the spanwise direction.

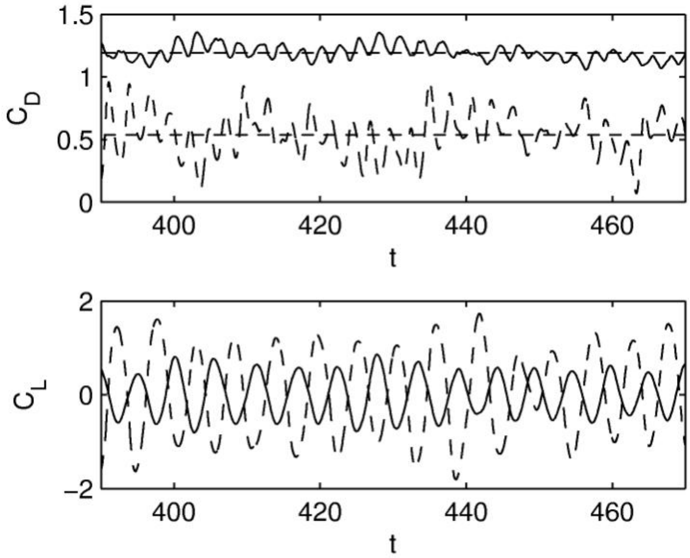

Fig. 4: Time-variation of drag, C_D, and lift, C_L, coefficients for front (solid) and rear (dashed) cylinders in tandem configuration. The abscissa is in “time units”, each unit being the time taken for the oncoming, unperturbed flow to travel a distance of one cylinder diameter.

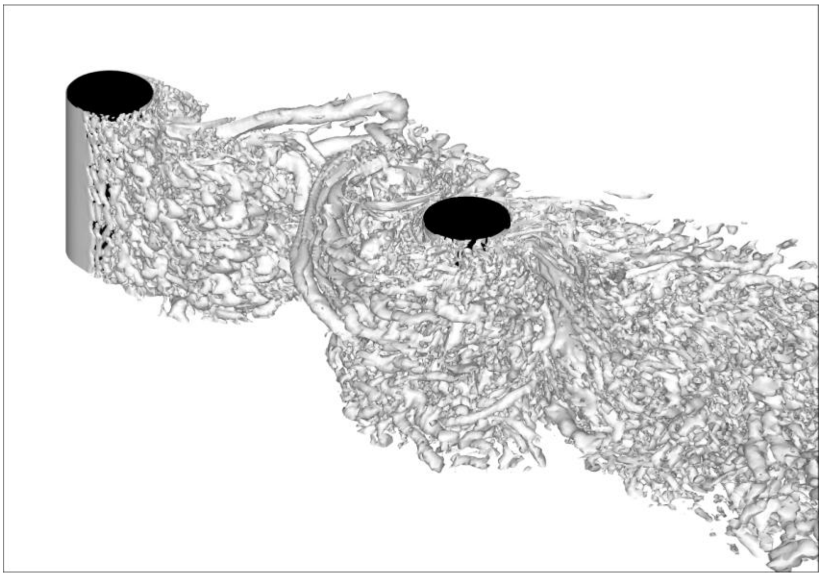

Fig. 5: Perspective view of the instantaneous spanwise structure of the flow around two cylinders in tandem at *Re*=10,000 (structure visualised by the vortex-identification *Q*- criterion).

Reference

Fishpool, G.M., Li, N. and Leschziner, M.A. (2007), Simulation of turbulent flow around two cylinders in tandem, *Proc. 5th Int. Symposium on Turbulence and Shear Flow Phenomena*, Aug. 2007, Munich, pp. 873-877.