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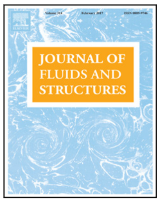

On the numerical simulations of captive, driven and freely moving cylinder

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ABSTRACT

This paper presents the application of turbulence and laminar–turbulent transition models and fluid–structure capabilities to address the flow and response of captive, driven and free moving rigid cylinder for several Reynolds numbers.

An investigation on the performance of the turbulence modeling with k–ω SST is presented, verifying the modeling deficiencies for this flow. The Scale Adaptive Simulations (SAS) and the Local Correlation Transition Model (LCTM or $\gamma - Re_\theta$), both combined with the SST, improved the agreement with experimental results for the captive cylinder flow. These studies also involve verification and validation exercises in order to quantify modeling errors of the results herein.

In a second step, the use of SST with driven cylinder motions is presented, as well as with the SAS and LCTM. Finally, aiming at free-moving cylinder behavior, this work presents the study of different turbulence modeling practices for the free-moving cylinder in two degrees of freedom (DOF) with low mass ratio.

The importance of turbulence effects on the moving cylinder in comparison with the fixed case is investigated. A natural conjecture is that the turbulence modeling strategy is less decisive when the cylinder is moving with driven motion and even less stringent for free motions, as the body response would filter most of the higher order turbulence effects. This issue is investigated as it would allow modeling simplifications in the application of CFD to a range of engineering problems.

1. Introduction

With its simple geometry, the cylinder flow encompasses several issues related to the evolution of the turbulent wake and shear layers, instabilities, transition, all changing appreciably with Reynolds numbers. The modeling simplification of the Reynolds averaging thus brings important consequences to flow prediction when using usual viscous-flow Unsteady Reynolds-Averaged Navier–Stokes (URANS) approaches. These issues are widely present in the literature regarding captive cylinder flow, but not quite as present in the case of moving cylinder.

Traditional URANS calculations for the captive cylinder flow were performed in Liu et al. (1998), Ong et al. (2007), Tutar and Holdø (2001), Catalano et al. (2003), Elmiligui et al. (2004), Vaz et al. (2007), Rosetti (2015) and Rosetti et al. (2012), to cite a few. It was observed that these eddy-viscosity based turbulence models must be improved to capture both qualitatively

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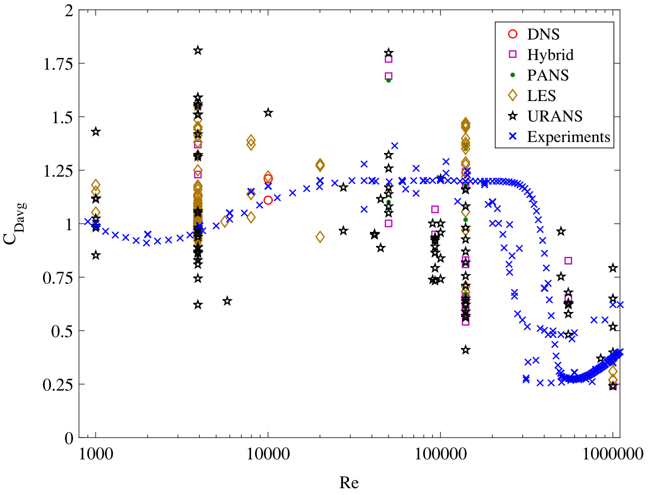

Fig. 1. Drag coefficients from calculations with different numerical approaches (taken from Eça et al. (2014)) in comparison with experiments from Schlichting and Gersten (2000), ESDU (1985), Franzini et al. (2012) and Achenbach and Heinecke (1981) and from MARIN. Captive cylinder case.

and quantitatively all subtle characteristics of such an intricate type of flow. It is clear that the main direction of research for the captive cylinder flow modeling within an engineering cost-effective approach points to improvements in turbulence and transition modeling, as they are the main shortcomings of most approaches within URANS.

In Rosetti et al. (2012), the monochromatic behavior of the traditional two-dimensional modeling was identified as one of the important issues that makes comparison with experimental results more troublesome in moderate Reynolds numbers. The cylinder flow displays important three-dimensional features throughout the pre-critical range influencing the loads and other flow quantities. The same issue was also explored in moderate and high Reynolds numbers with SST by Vaz et al. (2007) and Klaij (2008).

It is well accepted that the so-called Scale Resolving Simulations (SRS) are able to improve URANS predictions, as they work in lowering the eddy viscosity in flow regions where the gradients are high, thus allowing the formation and breakdown of eddies and a turbulent spectrum, bringing the flow solutions closer to physical observation. In the last years, different models have been developed with that objective, such as the Partially-Average Navier–Stokes (PANS) equations (Girimaji, 2006), Detached Eddy Simulations (DES) (Travin et al., 1999), Delayed Detached Eddy Simulations (DDES) (Spalart et al., 2006) among others. For the cylinder flow behavior the von Kármán length is particularly relevant, which served as motivation for using the Scale Adaptive Simulations (SAS), one of the early SRS models (Menter and Egorov, 2004; Menter et al., 2006; Menter and Egorov, 2010).

Laminar–turbulent transition is another important issue and a research topic in its own. To date, the most accurate prediction approach is based on DNS, as only then the fine scale disturbances and structures that feature the transition process are accurately captured. Large Eddy Simulations (LES) were also carried out, however, to predict boundary-layer transition, the small-scale turbulence must be captured, requiring very refined grids in that region thus approaching the DNS requirements.

A more engineering-oriented approach was developed based on an empirical approach, as proposed by Langtry and Menter (2009) and Menter et al. (2006). In this Local Correlation Transition Model,[2] a framework for empirical correlations obtained from experiments is set and coupled with a turbulence model in order to predict transition onset and length as function of flow quantities. In fact, Langtry and Menter (2009) showed results for different applications, including few results for the cylinder flow in the drag crisis region, but without assessment of numerical errors or much exploration of modeling issues. Reasonable improvement is observed compared to traditional turbulence modeling.

As an illustration to the different approaches conducted along several years, Fig. 1 shows the compilation of numerical results in comparison with the experiments. The numerical data is widespread in the complete range of Reynolds numbers, highlighting the difficulties in the present application.

The connection between some of the above observations regarding turbulence models and fluid–structure modeling (in particular, cylinder under imposed and free motions) was done by Placzek et al. (2009), Blackburn and Henderson (1999), Dong and Karniadakis (2005), Carmo (2009), Shiels et al. (2001) and Saltara (1999), among others. In a similar direction as adopted in the present work, Mittal and Kumar (2001) carried out CFD calculations to study two degrees-of-freedom VIV of light structures. They did not observe the super-upper response branch in the results (see Jauvits and Williamson (2004) for a

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[2] This model is commonly known as $\gamma - Re_\theta$ model, but herein LCTM is also used as this implementation is based on Langtry and Menter (2009), who use this denomination.

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