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Unsteady Flow Past a Circular Cylinder Using Advanced Turbulence Models

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Abstract: This work deals with the numerical simulation of unsteady compressible turbulent flow past a circular cylinder. Turbulent flow is modeled by two different methods. The first is based on the system of URANS equations closed by the two equation TNT model or modified EARSM model. Second method is based on the X-LES model which is a hybrid RANS-LES method. Numerical solution is obtained by the finite volume method. Presented results are for the subcritical turbulent flow characterized by Re=3900.

Introduction

Compressible turbulent flows are described by the system of Navier-Stokes equations [1]. Numerical solution leads to the direct numerical simulation which resolves all turbulent scales. Unfortunately, this approach is usually unusable even for the cases with low Reynolds numbers because very accurate numerical method and very fine mesh are required. Another option is modeling of turbulent effects. The first modeling aproach in this work is based on the unsteady Reynolds averaged Navier-Stokes equations (URANS, [2]) where all turbulent scales are modeled by the model of turbulence. Second approach is a hybrid method which uses URANS equations together with model of turbulence when computational mesh is coarse and large eddy simulation (LES, [2]) when computational mesh is fine enough for direct resolution of turbulent scales.

Models of turbulence and numerical method

We are using two different models of turbulence in the case of full URANS approach. The first model is Kok's two equation TNT k-ω model [3]. Second one is explicit algebraic model of Reynolds stresses (EARSM, [4]) which is based on the TNT model equations with recalibrated model constants which are more suitable in conjunction with the EARSM model [5]. Hybrid RANS-LES method is the XLES model [6] which consists from the k-equation subgrid-scale model used in the LES regions and TNT model [3] used in the URANS regions.

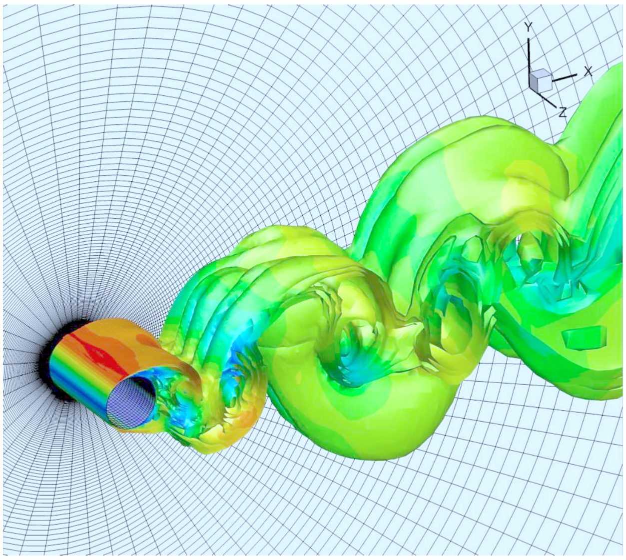
Numerical solution is obtained by the second order finite volume method. Inviscid fluxes are approximated by the HLLC scheme [7] with MUSCL reconstruction [8]. Viscous fluxes are approximated by central differencing on the dual mesh [7]. For advancing in time the explicit two stage TVD Runge-Kutta method is used [7].

Results and conclusion

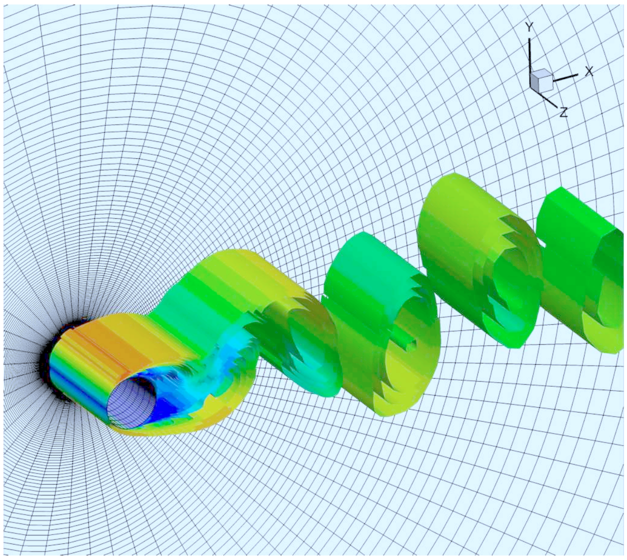
Solved case is a flow of the air past a circular cylinder with diameter $D = 6.18 \cdot 10^{-4}$ m and inlet Mach number $M_\infty = 0.3$. This regime corresponds to Reynolds number $Re = 3900$. For the numerical

Table 1: Evaluation of Strouhal number for the flow past a circular cylinder with $Re = 3900$.

Model	URANS TNT	URANS EARSM	X-LES	Experiment
St	0.197	0.215	0.212	0.215± 0.005



(a) Instantaneous vorticity magnitude isosurfaces in time $t = 10^{-3} s$, X-LES model.



(b) Instantaneous vorticity magnitude isosurfaces in time $t = 10^{-3} s$, EARSM model.

Fig. 1: Numerical solution of turbulent flow past a circular cylinder, $Re = 3900$.

solution is used structured O-type grid with 290304 cells. Fig. 1 shows comparison of instantaneous vorticity magnitude colored by velocity magnitude. Strouhal number is evaluated in Table 1. Results show that both X-LES and EARSM models are able to predict correct Strouhal number but X-LES model provides more detailed full three-dimensional flow field.

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