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Implementation of k-kL-ω Turbulence Model for Compressible Flow into OPENFOAM

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Abstract: The article deals with the results of implementation of k-k$_L$-ω turbulence model for compressible transitional flow into OpenFOAM. This model was firstly proposed by Walters and Leylek (2005) and utilizes the approach of laminar kinetic energy in order to predict transition between laminar and turbulent flows. The performance of implemented model has been tested for the case of flow over the flat plate and flow through VKI turbine cascade. The properties of the implementation of k-k$_L$-ω model for compressible flow simulations into OpenFOAM are discussed.

Introduction

OpenFOAM is the open-source CFD software package which utilizes the finite volume method. Although OpenFOAM (version 2.3.0) includes k-k$_L$-ω model for incompressible flow calculations, this ready-made code gives us wrong results even for basic test cases. Note that the clarification of errors in this code are available in [1]. We implemented k-k$_L$-ω turbulence model for compressible flow in order to build reliable turbulence model for investigation of compressible flow through turbine cascades.

Mathematical model

The viscid flow of perfect compressible gas was described by the set of Favre-averaged Navier-Stokes equations. The transitional turbulence model k-k$_L$-ω [2] uses the Boussinesq hypothesis to determine the Reynolds stress tensor. Three transport equations are solved for the turbulent kinetic energy k_T, the laminar kinetic energy k_L and the specific dissipation rate ω.

Results

The implementation of k-k$_L$-ω into OpenFOAM was applied for solving 2D compressible flow through VKI turbine cascade [4, 5]. The mesh consists of 62049 quadrilateral and triangular cells. The structured hyperbolic mesh is situated near the blade with $y^+ \leq 1$. M_{2is} = 0.0884, Re_{2c} = 590000, inlet turbulent intensity Tu = 1.5%, dynamic viscosity μ = 1.2984e-5 and inlet angle $\alpha = 0°$ are considered. Boundary conditions are shown in Table 1. Fig. 1 shows distribution of skin friction coefficient $C_f = 2\tau_w / (\rho_e U_e^2)$ on the suction side related to free-stream velocity U_e at y = 0.05 m and ρ_e = 1.1885 kg/m^3.

Conclusions

The comparison with experiment data [4, 5] shows that our implementation of k-k$_L$-ω model as well as standard k-k$_L$-ω model supplied in commercial CFD package FLUENT underestimate friction coefficient. The figure suggests that calculated boundary layer is near to separation, but the position of transition onset is captured well. The transition is driven by threshold constants without any dependence on pressure gradient of external flow. It can be reason of difference between CFD results and experiment data. The future development will aim to investigation of the pressure gradient dependency as well as improvement of the turbulent heat transfer model.

Table 1: Boundary conditions. The homogenous Neumann condition is marked ZG. Other boundary conditions are periodic.

	U (m/s)	p (kPa)	T (K)	k_T (m²/s²)	k_L (m²/s²)	ω (s⁻¹)
Inlet	$\alpha = 0°$	$p_{tot} = 100.548$	$T_{tot} = 293.7$	0.037922	0	16
Outlet	ZG	$p_{stat} = 100$	ZG	ZG	ZG	ZG
Blade	0	ZG	ZG	0	0	ZG

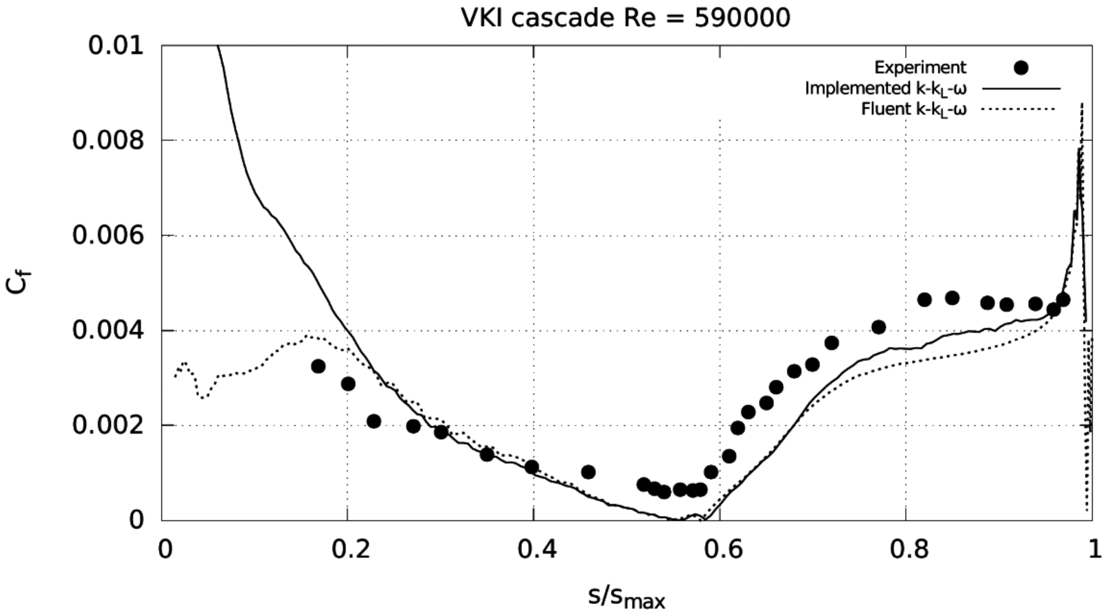

Fig. 1: Distribution of the skin friction coefficient along the suction side of the VKI blade.

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