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Numerical Investigation of High Reynolds Number Von Karman Flow

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ABSTRACT

In this paper, the flow between two counter-rotating smooth disks enclosed by a cylinder is investigated numerically for different high Reynolds numbers and different ratios of the rotating speeds of two disks. Numerical predictions are based on standard k-ε and RSM model and the results are compared with experimental data i.e. velocity measurements performed at CEA (commissariate al'Energe atomique). The infuences of the rotational Reynolds number and the rotating disk speed ratio are investigated to get knowledge of both the dynamic and the turbulence properties in the Von Karman configuration. It is concluded that turbulence can primarily affect on velocity profile.

INTRODUCTION

The flow between rotating disks, or von Karman swirling flows, occur in a variety of situations, from industrial to geophysical applications, such as rotating machining. Moreover, this configuration is often used for studying fundamental aspects of developed turbulence. The steady flow generated by plane disks of large diameter rotating with uniform angular velocity in contact with an incompressible viscous fluid was first investigated by Von Karman (1921) [1]. Cochram obtained a numerical solution of this problem which was improved upon by Ostrich, Thornton and Benton. The relative motion of the disks and the fluid sets up viscous stress, which tend to drag the fluid round the disks. This geometric studies are used for two aspects of developed turbulent and laminar flow. Batchelor [2] and Stewarston (1951) were two persons that have justified many works about the two aspects. In laminar case, Batchelor demonstrated that the distribution of tangential velocity is symmetrical about the midplane. In turbulent case, the flow remains axisymmetric. In this case Faure (1992) reported measurements of pressure fluctuation. Batchelor solved the system of differential equations relative to the steady rotationally-symmetric viscousflow between two infinite disks. In the exactly counter-rotating regime, the distribution of tangential velocity is symmetrical about the mid-plane and exhibits five distinct zones: two boundary layers developed on each disk, a transition shear layer at mid-plane, where the axial and tangential velocities change sign and two rotating cores on

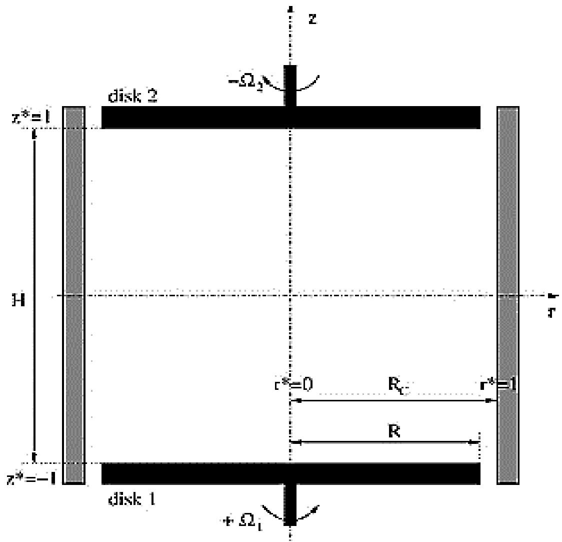

Figure 1. Sketches of the cavity with relevant notation

either side of the transition layer. The central cores rotate with a tangential velocity proportional to the disk velocities. The proportionality coeficient is always inferior to 1. In 1953, Stewartson [3] found that the flow is divided into only three zones for large values of the Reynolds number based on the interdisk space H: one boundary layer on each disk separated by a zone of zero tangential velocity and uniform radial inflow. In this work, numerical predictions are performed using standard k-ε and RSM turbulence model and the obtained results are compared to the measurements [4] performed at CAE for turbulent flow between two counter rotating discs.

EXPERIMENTAL SET-UP

Velocity measurements using a laser Doppler velocimeter have been performed at CEA in the Von Karman geometry during the PhD thesis of Ravelet [5] and then by Romain Monchaux [6] in two cases: viscous and inertial stirrings.

NUMERICAL SOLUTION

The computational procedure is based on a finite volume method. We consider two counter rotating disks enclosed by a cylinder (Figure 1). The cylinder radii is R_c = 100 mm and disks radii are R = 92.5 mm. The distance between two disks is H=180 mm. Disks 1 and 2 rotates respectively clockwise Ω_1 and counter clockwise Ω_2 where $\Omega_1 >= \Omega_2$. There are some nondimensional numbers such as $G = H/Rc, Re = \omega_1 R_c/\vartheta$, $\Gamma = -\Omega_2 / \Omega_1$, $r^* = r/R_c$, $Z^* = 2z/H$. The computational domain is discretized with 200000 nodes. Nodes are closer near the disks. Turbulence modeling is based on standard k-ε (launder and Sharma) and RSM. Cylinder is considered as a stationary wall boundary condition with no slip condition. The gap between cylinder and disks is assumed as a stationary wall. The disks are considered as a rotating wall with no slip condition with roughness constant 0.5. The fluid that fill between these two counter rotating disks is liquid water with density of 998.2 kg/m^3, C_p=4182 j/kg^{o}k, viscosity= 0.001003 kg/(m.s).

RESULTS

The fuid at the top and the bottom of the cavity is forced into two opposite rotation speeds, and is then entrained by the disks. Consequently, a shear layer develops in the equatorial plane. This is perceptible in Figure 2, which presents axial variations of the tangential velocity component for $\Gamma = -1$, Re=6.25×10^5, G=1.8 at three various radial locations in the range r*=0.346-0.865. As illustrated in this figure, the tangential component is quite weak except in two very thin boundary layers, which developed on each disks. The radial and axial velocity components are not presented here because they are almost zero in the whole cavity both in the experiments and in the calculations. For r*<=0.476 a quasi-zero tangential velocity enclosed by two boundary layers on each disks is observed. Also r*>0.476 is characterized by a weak but nonzero tangential velocity component. A good agreement between the numerical results and the experimental data is obtained even the values are quite weak.

We also investigate the influence of the Reynolds number on the mean flow. As illustrated in Figure 3 and 4, low Re number has a laminar velocity profile and the profile changes dramatically due to Re increment. For Re = 2e10^5, a significant increase of the magnitude of V_θ is observed whatever the axial position, which is characteristic of the laminar regime.

Another interesting feature in counter-rotating disk flows is the influence of the ratio Γ between the two rotating disk speeds. Varying the ratio Γ displaces the shear layer towards the slower disk (Figure 5).

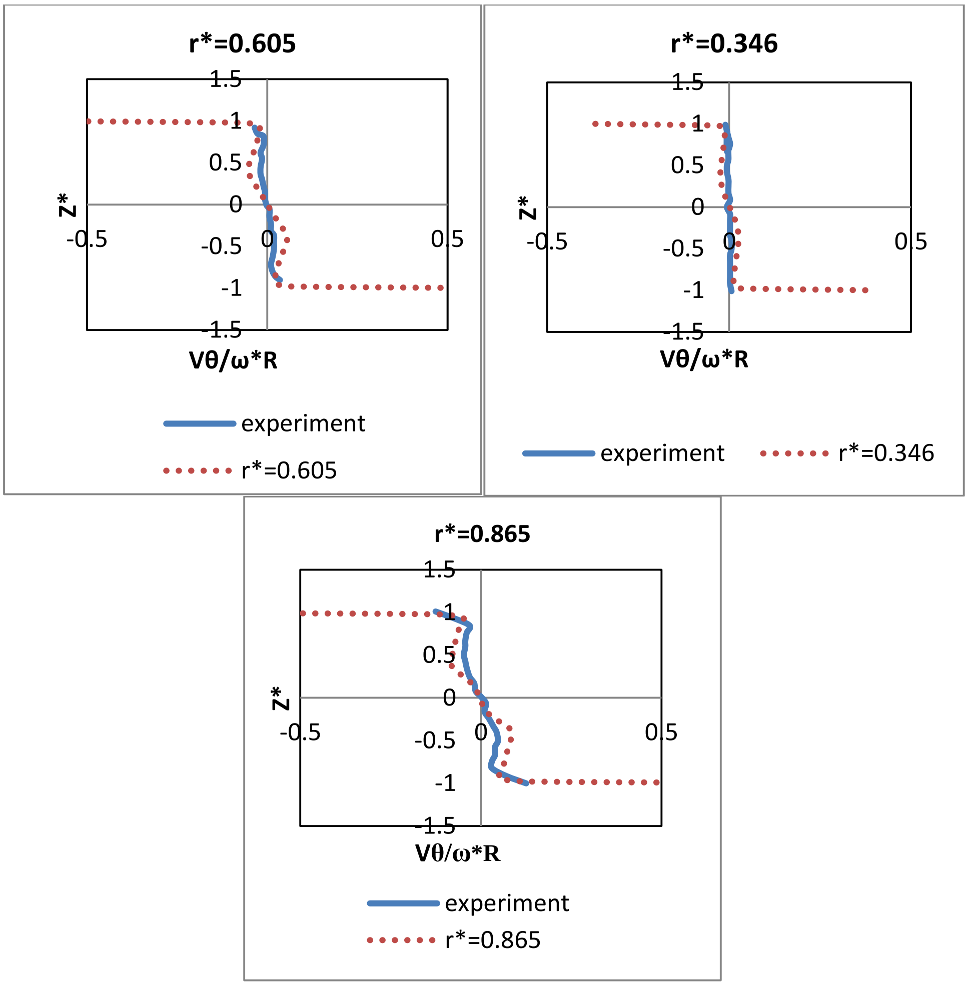

Figure 2. Axial profiles of the tangential velocity component for Γ = -1, Re = 6.28×105 and G = 1.8

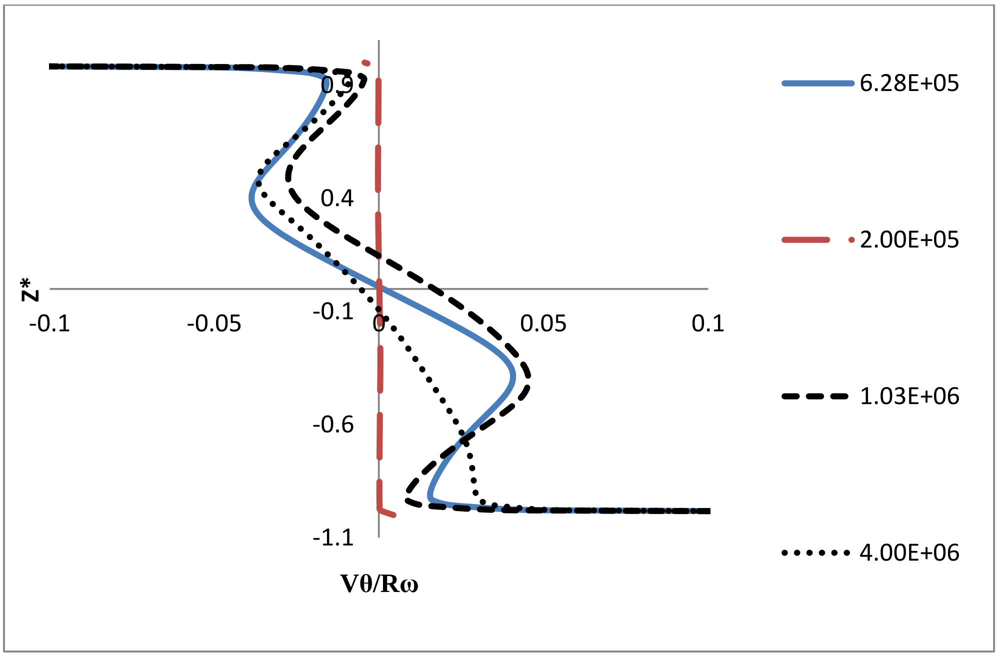

Figure 3. Axial profiles of the tangential velocity component for Γ = -1, r*=0.476 at different Re

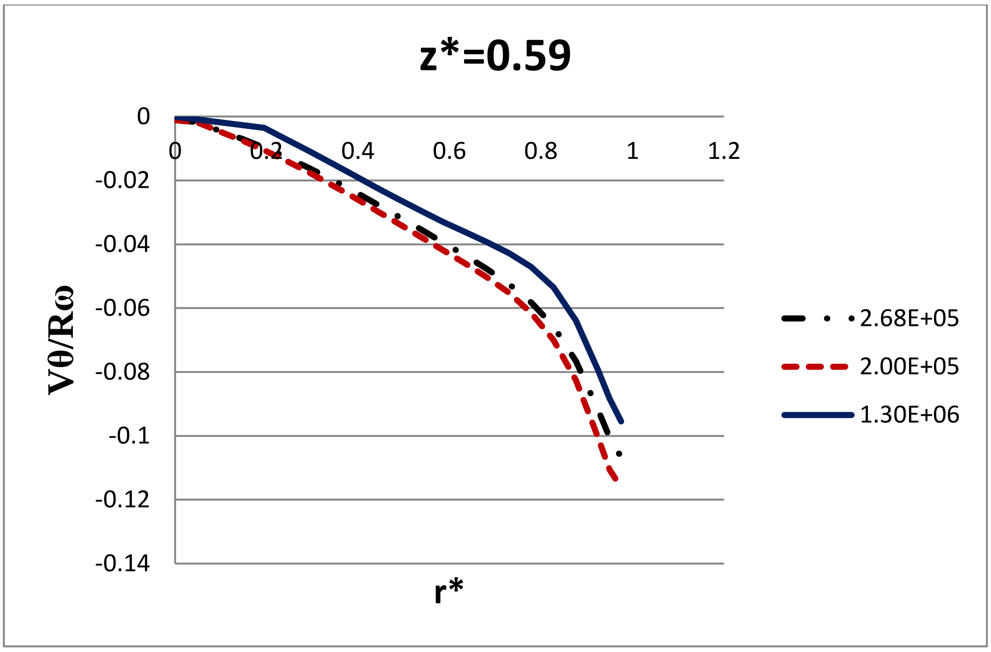

Figure 4. Radial profiles of the tangential velocity component in the smooth disk case for Γ = -1, G = 1:8 and four Reynolds numbers at different axial locations

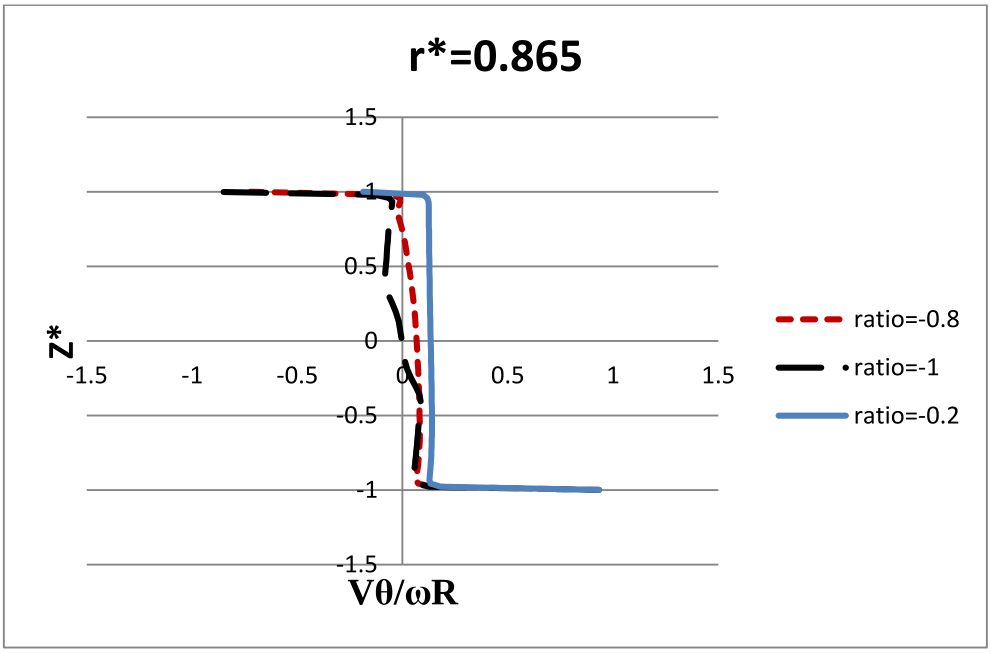

Figure 5. Axial profiles of the tangential velocity component in different rotation ratio

Conclusion

We have performed some comparisons between numerical predictions using standard k-ε and RSM model and velocity measurements considering the turbulent flow between two flat counter-rotating disks. The flow is exhibits three distinct regions: two boundary layers and one shear layer at mid-plane. The agreement between the numerical predictions and the LDV measurements is very satisfactory.

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