Numerical study of swirling flows

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ABSTRACT

Swirling flows are encountered in many engineering applications. In the present work, we simulate swirling flows using sonic Foam, a transonic solver in the open source toolbox Open FOAM. We consider swirling flow in an axisymmetric duct. We compare the computation results with experiments and DNS results from the literature. We find that RANS computations using the standard $k-\epsilon$ *model agree well with DNS results from the literature.*

Keywords: swirl, cfd, open foam, sonic foam, turbulence.

INTRODUCTION

Swirling flows are widely used in several industrial application like for heat exchangers as a heat transfer augmentation technique, mixers, separators, combustion chambers, etc. In gas turbine engines, swirl assists in thorough mixing of the flow and also enhances the heat transfer rate thus increases the time for complete combustion. Thus the ability to compute such flows allows us to contribute towards the design of equipment with the swirl like arc-heaters, plasma torches, etc. It is well established in the existing literature that, as swirl travels it dissipates, thus the decay rate of swirl has been an important area for researchers. Steinberger et al. [1, 2] and Ayinde [5] have modelled the swirl distribution and correlated the decay as a function of flow as well as geometrical parameters.

The effect of high-temperature on the evolution of swirl as in case of arc-heaters, which help in generating high enthalpy flows is an area of immediate relevance. In this paper, we present laminar and Reynolds-averaged turbulent flow simulations of swirling flows in a duct. Computations were performed using sonic Foam, a compressible flow solution module from the open source toolbox Open FOAM [6]. We compare our computed velocity profiles with DNS results of Vaidya et al. [3]. We also compare our computed swirl decay rates with the generalized correlation given by Ayinde [5]. In the full paper, we will include results of our study on the effect of high temperatures on the swirl decay. We also intend to compare the results of computations using AUSM+-UP scheme, done using our in-house 3-D finite volume code developed by Veda Krishna et al. [4].

Non-dimensional parameters

In addition to the flow Reynolds number (Reynolds number indicates the ratio of inertia to viscous forces and is expressed as Re = $(\rho UD)/\mu$ with U being the inlet flow velocity, D the hydraulic diameter of the duct, and μ the dynamic viscosity), we can define the swirl number (N) and swirl intensity (S) respectively as follows,

$$N = \frac{\Omega R}{U_{ave}} \quad (1)$$

Where, Ω is the angular velocity, R is the radius of the pipe and U_{ave} is the mean axial velocity

$$S = \frac{\text{Axial flux of the tangential momentum}}{\text{Axial flux of the axial momentum . Radius}} = \frac{2\pi \int_0^R \rho \omega U_z r^2 \, dr}{R \, . \, 2\pi \int_0^R \rho U_z^2 r \, dr} \quad (2)$$

Where, ω is the local tangential velocity, U_z is the axial velocity and R is the radius of the pipe. S is the measure of the local swirl intensity at the downstream.

RESULTS

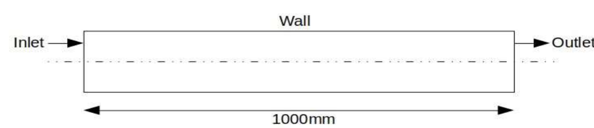
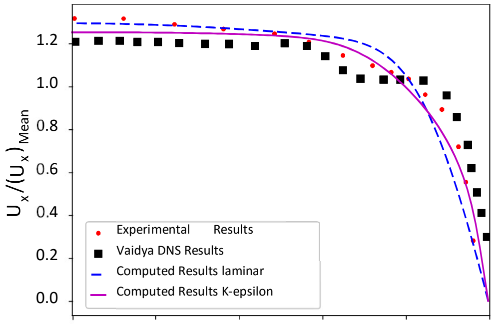
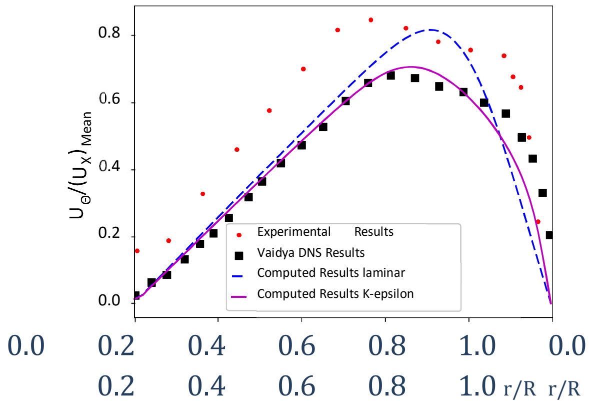


FIGURE 1: COMPUTATIONAL DOMAIN AS PERVAIDYA [3]

Numerical simulations were carried out to validate our results with those obtained by Vaidya et al. [3]. The test case consists of incompressible and unsteady flow in a duct of diameter 50 mm and length to diameter ratio (L/D) of 20. The Reynolds number considered as 1700 based on the diameter and the gas used is perfect gas with γ = 1.4, R = 287 J/molK. The inlet conditions are P_{in} = 1 bar, T_{in} = 298 K, U_{in} = 0.135 m/s, and ρ_{in} = 1.12 kg/m^3. The inlet swirl intensity (S) and inlet Swirl number (N) are considered to be 0.5 and 1, respectively.



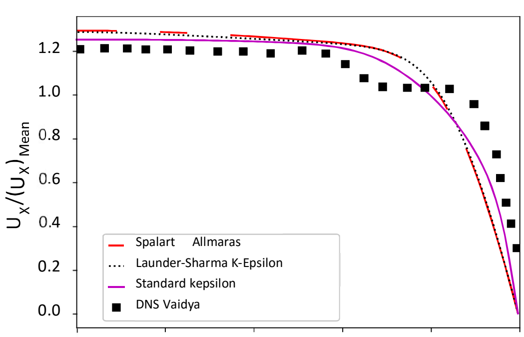
(a) Axial Velocity at X/D = 3



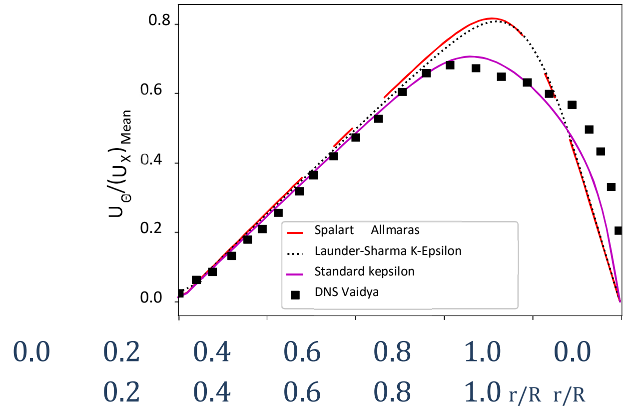
(b) Swirl Velocity at X/D = 3

FIGURE 2: COMPARISON OF VELOCITY PROFILES

Fig. 2 compares the computed results (RANS) with the DNS and experimental values from the literature. We see that our RANS results agree with the DNS values from the literature. However, both the computed results (RANS and DNS) disagree with the experimentally measured values from literature. This is either due to the simplified inflow conditions (solid-body rotation) assumed in both the computations or the swirl number considered for the experimental measurement is 1.2. Fig. 3 compares the profiles computed by different RANS models. We observed that the standard $k-\epsilon$ model out-performs Spalart-Allmaras and Launder-Sharma $k-\epsilon$ models in computing swirling flows.



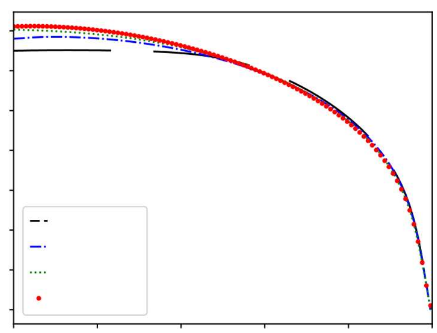
(a) Axial Velocity for N = 1



(b) Swirl Velocity for N = 1

FIGURE 3: VELOCITY PROFILES FOR DIFFERENT TURBULENCE MODELS at X/D = 3

From Fig. 4, it can be noticed that the local normalized swirl velocity is decreasing along the length of the pipe. At the outlet, the swirl velocity is almost deteriorated although as per Ayinde [5] the swirl to disappear altogether an infinite length of the duct will be required. Swirl is expected to decay exponentially along with the flow [5]. While this suggests that the complete loss of swirl only at an infinite distance from the inlet, in practice the swirl



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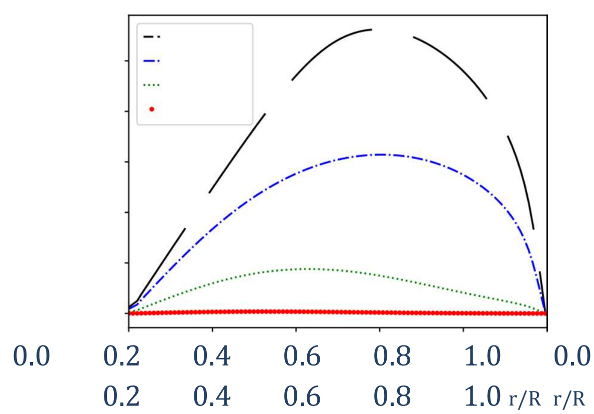

(b) Swirl Velocity for N = 1

FIGURE 4: VELOCITY PROFILES AT DIFFERENT AXIAL LOCATIONS

CONCLUSION

In the present study, numerical results were verified for Reynolds number 1700 and local inlet swirl intensity (S) 0.5. We observed that the results with standard $k-\epsilon$ agree well with the DNS [3]. In the full paper, a comparative study between results obtained from the 3D simulation will be presented along with the addition of the effect of high temperature over decay rate.

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