Numerical Study of a Turbulent Single-Stage Axial Flow

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Abstract: This paper studies the flow in an axial fan with a rotor in front and stators (vanes) in the rear. This configuration is typical of a single-stage axial flow turbo machine. The standard $k-\varepsilon$ model with enhanced wall treatment. Interaction between these components is determined considering the rotor and stator together in a single calculation. Numerical calculations have been performed to investigate the effects of different angular velocities on pressure contours, mass flow rates and total pressure and the results have been shown and discussed through figures. The results show that the increase of angular velocity has a significant effect on the governing physical parameters.

Keywords: Axial flow, turbomachinary, angular velocity, turbulence model, CFD.

1. INTRODUCTION

The axial flow gas turbine is used in almost all applications of gas turbine power plant. Development of the axial flow gas turbine was hindered by the need to obtain both a high-enough flow rate and compression ratio from a compressor to maintain the air requirement for the combustion process and subsequent expansion of the exhaust gases. There are two basic types of turbines: the axial flow type and the radial or centrifugal flow type. The axial flow type has been used exclusively in aircraft gas turbine engines. Axial flow hydrokinetic turbines have been shown to be responsive to a specific range of turbulence scales present in the approaching flow [1]. Foad *et al*. studied the swirling flow in a model rectangular gas turbine combustor experimentally. They investigated the flow development axially and radially in various off-axis planes to study the flow development not only in the center but also outside the swirler. They results show that the average axial and radial velocity distribution at off-axis planes differs from that of the center. This deviation grew weaker as the flow moves downstream [2]. Azimi and Bart investigated the erosion of the blades of a radial inflow turbine due to the ingested steam flow containing solid particles. Their results indicated that there are several surface areas in a radial steam turbine where higher rates of erosion occur. On one hand, the most affected part of the turbine is the stator blades, more precisely the inward trailing edge of the stator blades [3]. Zou *et al*. studied the multi-dimensional coupling simulation approach for evaluating the flow and aero-thermal performance of shrouded turbines. Their proposed models can estimate and consider most of the shroud leakage flow features, including the mass flow rate, radial and circumferential momentum, temperature, jet width and turbulent characteristics [4]. And there are some other works that can be found in [5-11]. In the present work the flow in an axial fan turbomachine has been studied numerically using K-e turbulence model. The effects of various angular velocities has been studied on mass flow rate and pressure distributions.

2. PROBLEM DEFINITION

Figure **1** shows the mesh and geometry of the problem in the present study. The numerical scheme for advection is second order upwind and power law is for turbulence kinetic and dissipation. The convergence criteria is 10e-3 for continuity, velocity and turbulence schemes. The rotor and stator consist of 9 and 12 blades, respectively. A steady-state solution for this configuration using only one rotor blade and one stator blade is considered. The mesh is set up with periodic boundaries on either side of the rotor and stator blades. A pressure inlet is used at the upstream boundary and a pressure outlet at the downstream boundary. Ambient air is drawn into the fan (at 0 Pa gauge total pressure) and is exhausted back out to the ambient environment (0 Pa static pressure). The hub and blade of the rotor are assumed to be rotating at 1300, 1800 and 2300 rpm. For the present analysis, air as an incompressible fluid with a density of 1.225kg/m3 and a dynamic viscosity of 1.7894 10-5kg/m-s is modeled.

3. RESULTS AND DISCUSSIONS

Figure **2** shows the contours of total pressure for the rotor blade for different angular velocities of 1300, 1800

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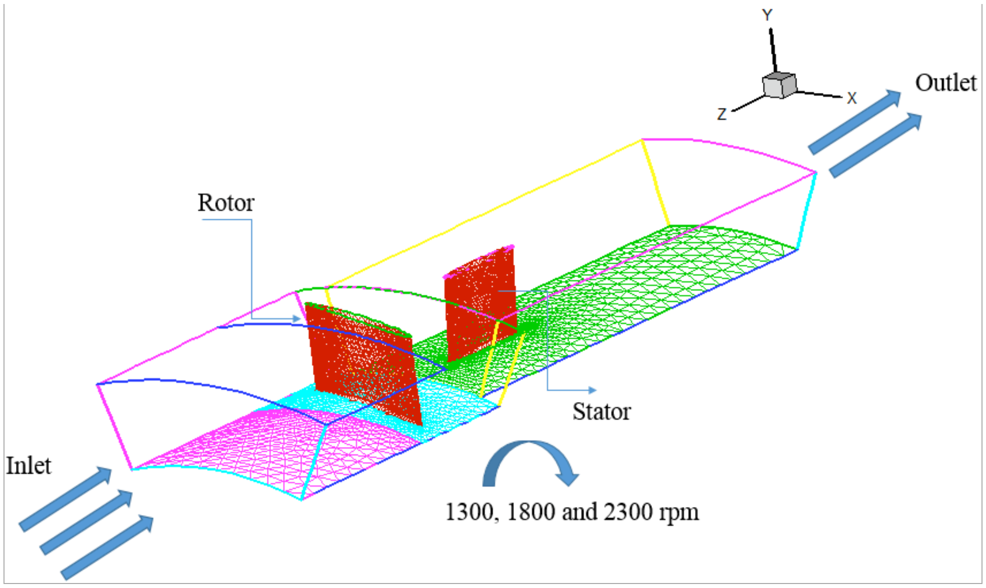

Figure 1: Geometry and grid generation of the problem.

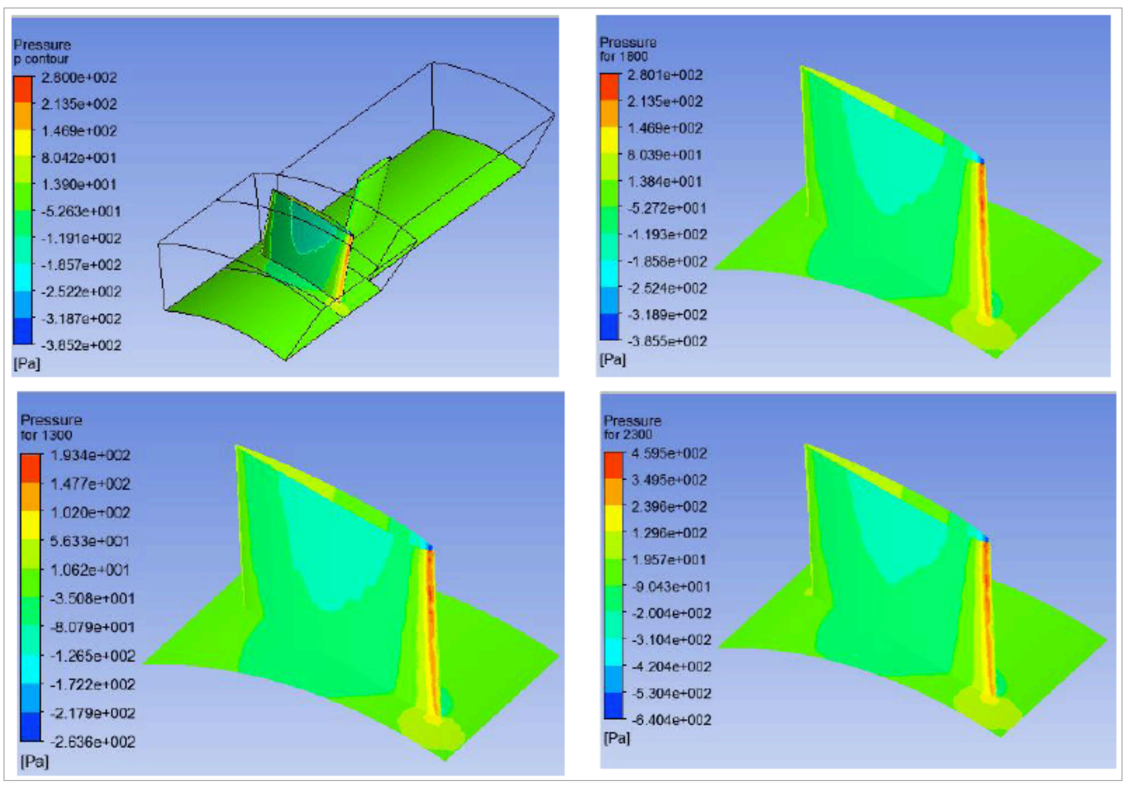

Figure 2: Contours of total pressure for the rotor blade and hub for different angular velocities of 1300, 1800 and 2300(rpm).

and 2300 (rpm). As the angular velocity increases the value of pressure increases, As shown in the figure for angular velocity value of 1300rpm the maximum value of the pressure is 193 Pa and this value increases to 280 and 460 Pa for velocity values of 1800 and 2300 respectively. The high pressure that occurs on the leading edge of the rotor blade is due to the motion of the blade.

Figure **3** displays the mass flow rate at the exit of the domain. These values are only for one blade of stator. The total value of the mass flow rate would be multiply by 12 as stator consists of 12 blades. Mass flow rate increases as the value of angular velocity grows. The mass flow rate at the domain exit is near 0.016kg/s for velocity of 1300rpm. As the velocity enhances to 1800 and 2300rpm, the mass flow rate

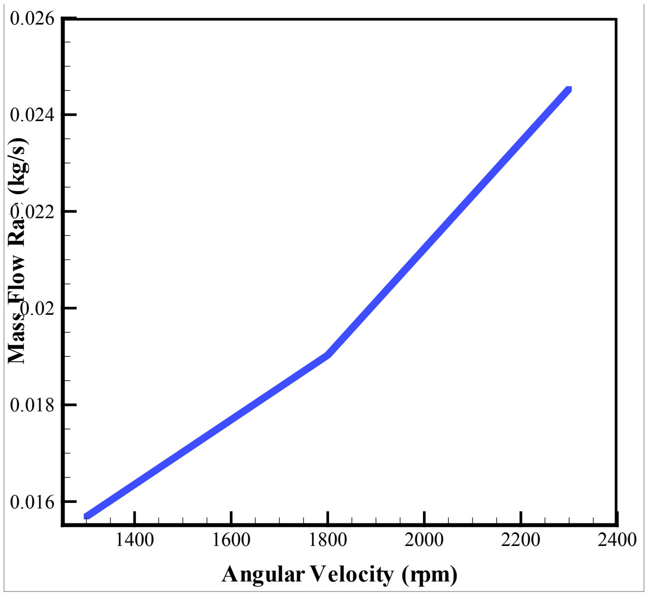

Figure 3: Mass flow rate at the exit of the domain for different angular velocities of 1300, 1800 and 2300(rpm).

value increases to about 0.019kg/s and 0.025kg/s respectively.

Total pressure profiles of rotor for different angular velocities of 1300, 1800 and 2300(rpm) are demonstrated in Figure **4**. The total pressure value drops at the beginning as it reaches its lowest value at the location of 0.1and then it grows gradually for velocity values of 1300 and 1800 but more sharply for 2300rpm to reach its peak at the location of 0.135. This value the drops at 0.14. As can be seen from the figure, growth of angular velocity has a significant effect on the value of total pressure. Total pressure profiles

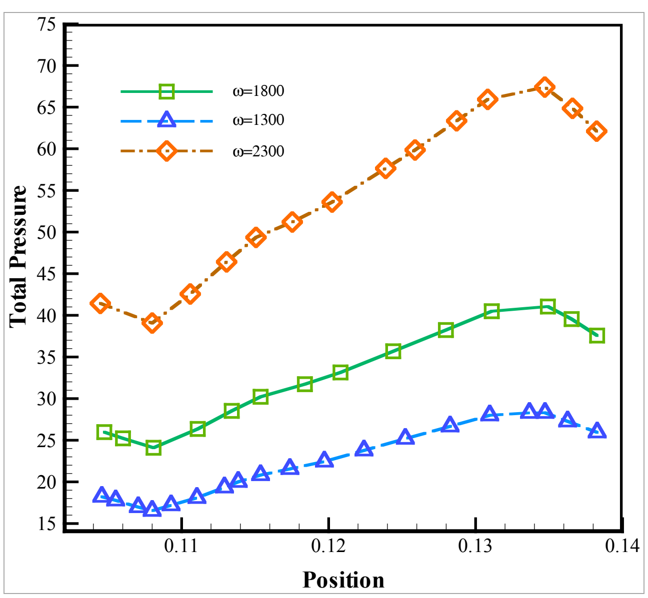

Figure 4: Total pressure profiles of rotor for different angular velocities of 1300, 1800 and 2300(rpm).

show that the maximum value increases form 25 Pa to 40 Pa and 70 Pa as the values of velocity increases from 1300rpm to 1800rpm and 2300rpm respectively.

CONCLUSIONS

In this study a numerical modeling of a steady-state solution for rotor and stator blades is performed using turbulence $k-\varepsilon$ model [12]. The numerical results have been shown and described through graphs. The effects of angular velocity has been studied on pressure contours, mass flow rates and total pressure. Results reveals that increasing the angular velocities has a significant impacts on these physical governing parameters. Numerical results showed that the value of total pressure noticeably enhances as the values of the velocity increases from 1300rpm to 1800rpm and 2300rpm. And also the mass flow rate shows a similar increasing trend as the values of angular velocities increase.

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