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Research Paper

NUMERICAL SIMULATION OF STATIC INFLOW DISTORTION ON AN AXIAL FLOW FAN

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The present CFD analysis is aimed at studying the performance and flow characteristics in an axial flow fan under uniform and distorted inflow conditions. Inlet flow distortions are flow non-uniformities that cause a reduction in performance and operating flow ranges of axial flow fan. CFD simulations were carried out for the following configurations: (a) Uniform inlet condition, (b) 90° circumferential extent steady total pressure distortion. Total pressure values have been noted down from Ansys CFX post at the exit of the axial fan, both in distorted and uniform regions. The simulation results are analysed to obtain axial fan performance parameters like the pressure rise coefficient, flow coefficient. It is observed that the fan performance deteriorated substantially under static inflow distortion than uniform inflow. The pressure rise is reduced by 13.7% due to static inflow distortion.

Keywords: Uniform inflow, Static inflow distortion, Axial flow fan, Pressure rise coefficient, Flow coefficient

INTRODUCTION

Inlet flow distortions in fluid machinery are referred as non-uniformities in flow properties as a function of space and time. The non-uniformities include variations in vorticity, turbulence, total and static pressures, velocity, temperature and flow angle. There are two major types of inlet flow distortions: inlet total pressure distortion and inlet total temperature distortion. The most common type of distortion which can occur in an axial compressor is inlet total pressure distortion. There are many factors which contribute to inlet total pressure distortion in aircraft engines such as extreme aircraft manoeuvre's, inlet boundary interactions, atmospheric turbulence, engine-inlet configuration and wakes from nearby aircraft. If a compressor is operating in a pressure distorted inflow then it may lead to the following results such as reduction in stall margin, performance degradation, and unsteady blade vibrations.

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Nie *et al.* (2006), found out experimentally that the speed at which the non-uniform flow passes the annulus decides the effect of rotating inlet distortion on compressor stability margin. They also found that the Co-rotating distortion reduces the compressor performance more than the Counter-rotating distortion.

Hendrick *et al.* (2005) discusses the propagation of total pressure and total temperature distortion at the fan or compressor face and its effect on upstream and downstream stages. The author found analytically that the counter rotating inlet distortion can influence the surge margin in a positive or negative way. It is also found that surge margin will be mainly depending on distortion frequency and compressor pressure oscillation frequency.

Objective of the Study

- Understand the flow physics in an axial flow fan under uniform and distorted flow conditions.
- Demonstrate the detrimental effects of inlet flow distortion on the fan performance in terms of pressure rise coefficient and stall margin.

GEOMETRY MODEL AND FLOW DOMAIN DISCRETISATION

Computational Domain

The analysis of inlet flow distortion has been carried out using commercial ANSYS CFX solver and grid generation has been done using ANSYS turbo grid. The computational domain consists of 3 domains (inlet, outlet, passage). The length of the inlet, outlet and passage domain is 85%, 140%, and 175% in-terms of chord respectively as shown in Figure 1. For the present analysis the domains are connected using frozen rotor interface model. The blade profile is generated using C4 profile equation. The details of axial flow fan geometry considered for present analysis is shown in Table 1.

Figure 1: Computational Domain for Full Annulus Rotor

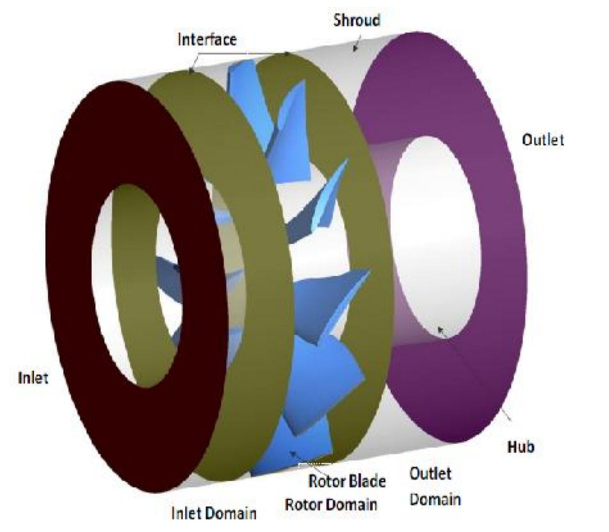


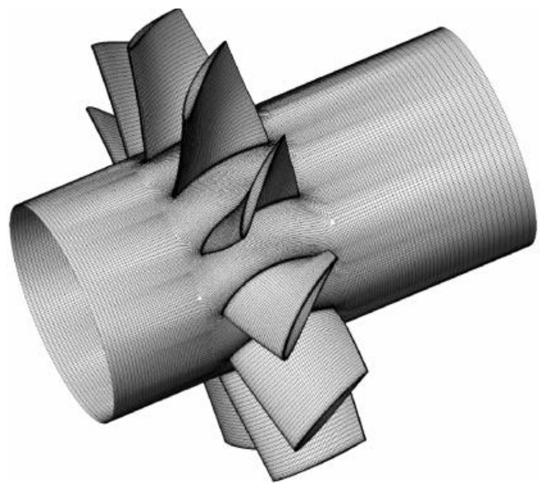
Table 1: Details of Axial Flow Fan Geometry

Aspect ratio	1
Chord length	10 cm
Hub diameter	20 cm
Shroud diameter	40.6 cm
Total number of blades	11
Design total pressure rise	1000 Pa
Design mass flow rate	3.5 Kg/s
Design rotational speed	2400
Rotational axis	X
Tip clearance (% of span)	0.02

Grid Generation

For a full annulus rotor analysis, the grid has been generated using ANSYS turbo Grid as shown in Figure 2. Structured grid with multiple blocks is used. The entire flow within a single passage is captured by approximately 7,00,000 nodes. The O-grid around the blade surface is created with 48 elements and its width from hub to tip is created with an expansion ratio of 1.2.

Figure 2: Grid for Full Annulus Rotor Analysis



Boundary Conditions

The boundary conditions for an axial flow fan with uniform inflow and distortion inflow is given in Tables 2 and 3.

Table 2: Boundary Conditions for Uniform Flow

Parameter	Value
Total pressure at inlet (P_{01})	101325 Pa
Mass flow rate at outlet	As per operating point
Inlet turbulent intensity	10%

Table 3: Boundary Conditions for Inflow Distortion

Parameter	Value
Total pressure profile at rotor inlet (P_{01})	Distortion coefficient of 0.233
Mass flow rate at outlet	As per operating point

Turbulence Model

The standard *k*-£ model is used for most turbulent flow calculations because of its reasonable accuracy and robustness. However this model performs poorly when there is stall in the flow. It will predict the stall too late and also will under predict the amount of separation. To solve this type of problems SST turbulence model is used. The model works by solving turbulence based model (*k*-µ) at the wall and *k*-£ in the bulk flow.

Convergence Criteria

A Convergence criterion of 1×10^{-5} RMS is used for the full annulus rotor simulations. But for the inlet distortion, a convergence criterion of 1×10^{-4} RMS is considered.

RESULTS AND DISCUSSION

Inlet flow distortion can cause instabilities to the blade. It increases the incident flow angle and hence causes the inlet flow distortion. The effect of inlet flow distortion on fan performance can be understood by chord-wise Total Pressure in relative frame contour and span-wise Mach number contour.

Variation of Total Pressure for a Full Annulus Rotor with Uniform Inflow and Distorted Inflow

To understand the propagation of distortion, various chord wise planes have been created. The details of the planes and distance from rotor leading edge are shown in Table 4.

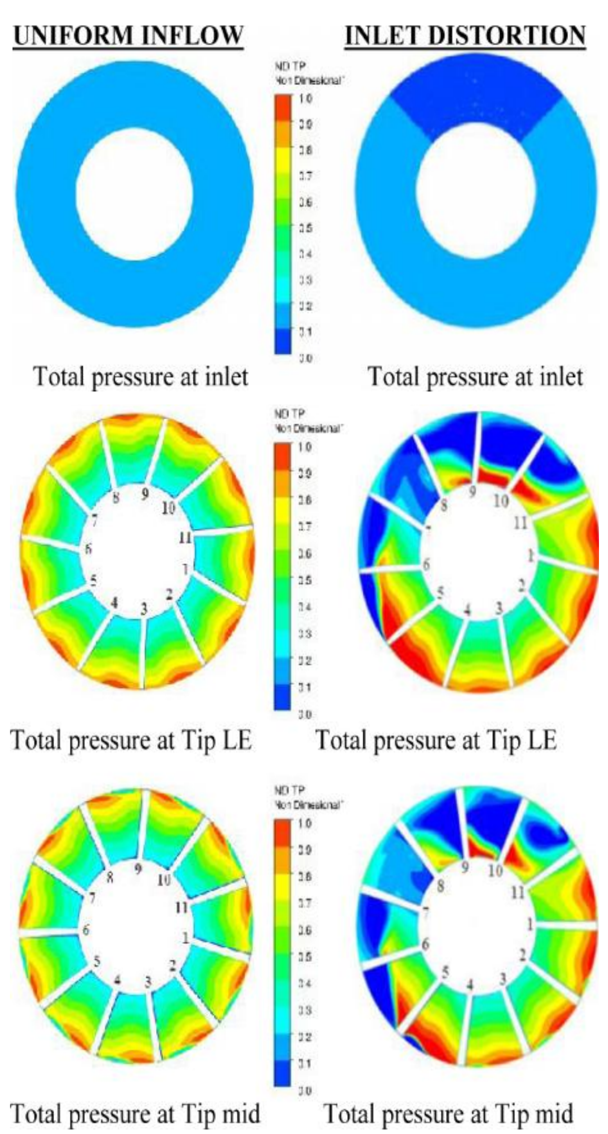
Table 4: Plane at various locations

Plane Names	Distance from Rotor Leading Edge in % of Chord
Inlet	70
Tip LE	12
Tip Mid	40

From Figure 3, it is shown that the distortion propagates from one blade to another when we travel from rotor entry face till rotor exit face.

In inlet face, distortion extends on the passages in-between blade 8-9-10 and extension remains till rotor entry face. Inlet distortion propagation increases in circumferential direction when moving towards the trailing edge.

Figure 3: Variation of Total Pressure in Relative Frame for Uniform and Distorted Inflows



From the chord wise plane of tip LE it is observed that the distortion extends on the passages in-between blade 5-6-7-8-9-10-11 and it starts affecting the blades 5 and 4 also when moving towards the rotor exit face. The main reason for distortion propagation is due to low velocity regions in the flow. These low velocity region tries to change the angle of incidence in adjacent blades and hence it leads to propagation.

Effect of Inlet Distortion on Span-Wise Mach Number

At 50% span, the low velocity region starts propagating from one blade to another blade and there is a formation of stall cell as shown in Figure 4.

Figure 4: Mach Number Variation at 50% Span

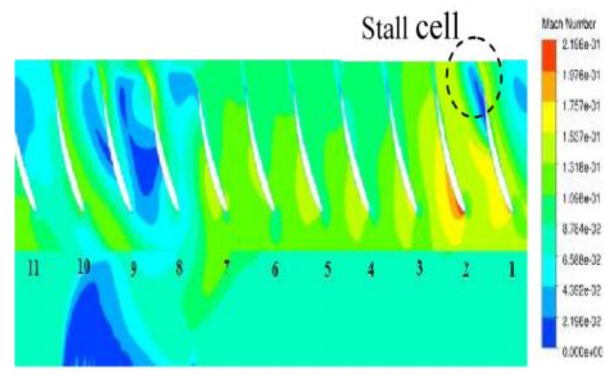


Figure 5, shows the effect of distortion at 90% span. It also gives an idea about how the rotating stall occurs in an axial flow fan. The flow separation (blue region) keeps Stall cell propagating from one blade to another and finally leads to the formation of stall cell.

Performance of Axial Flow Fan Under Uniform and Static Inflow Distortion

Figure 6, shows the performance map for fan under uniform and static inflow distortion both

Figure 5: Mach Number Variation at 90% Span

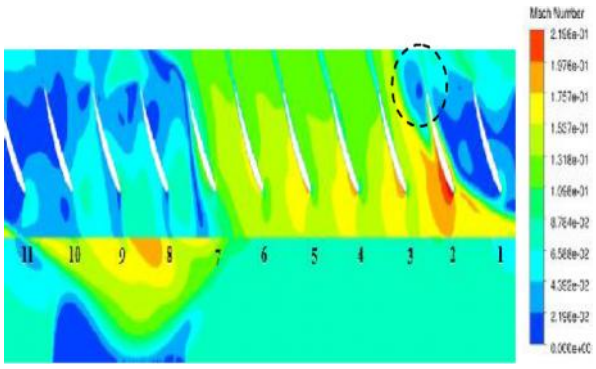
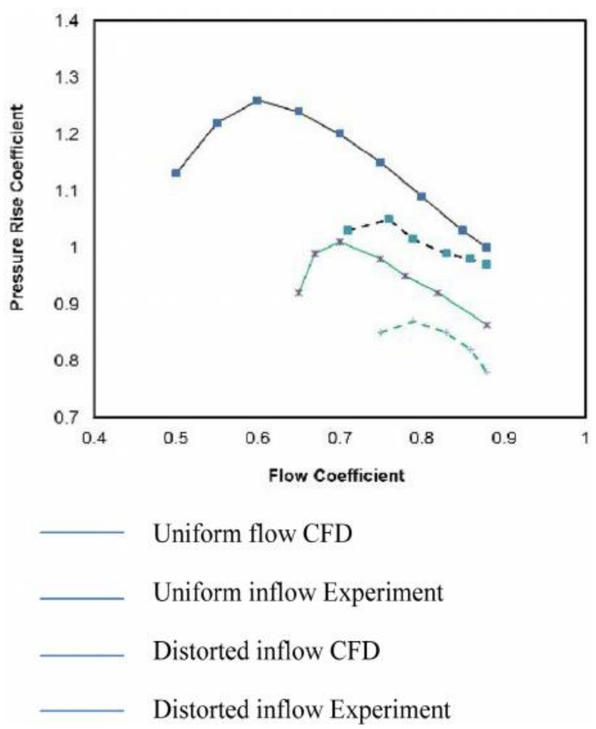


Figure 6: Performance of Axial Flow Fan Under Uniform and Static Inflow Distortion



for CFD simulation and experiment (Salunkhe *et al.*, 2010).

The trend of variation of pressure rise coefficient remains same in experiment and CFD. It is observed that the fan performance is deteriorated substantially under static inflow distortion than uniform inflow. CFD result shows that the pressure rise is reduce by 13.7% due to static inflow distortion.

CONCLUSION

This study numerically investigates axial flow fan for the operating point under uniform inflow and distorted inflow condition. The investigation involves a full annulus 3-D simulation under 2 different inflow conditions. The fan's response to the distorted inflow is investigated with the help of 3-D simulations. For a distorted inflow the simulation result shows that both inflow angle and total pressure variation have influence on the extent of distortion. It is also found that the fan performance deteriorated substantially under static inflow distortion than uniform inflow. The pressure rise is reduces by 13.7% due to static inflow distortion.

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