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Numerical Investigation of Single Stage of an Axial Flow Compressor for Effects of Blade Aspect Ratio

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ABSTRACT

In present work, a compressor configuration is taken from literature which will be studied for aspect ratio (ratio between length of blade to chord length) influence over performance. Performance in the sense is pressure ratio of compressor. The aspect ratio of the blade is an important parameter and has a strong influence on the performance of axial flow compressor. There are so many literatures available on influence of design parameters of axial flow compressor over its performance. Few literatures only are available for effects of aspect ratio of blade over performance of compressor. A study is proposed to be carried out to verify the effect of aspect ratio on the performance of single stage subsonic compressor through ANSYS-CFX software. The analysis will be carried out for the constant tip diameter of the compressor rotor blade having an aspect ratio 1, 2 and 3 and to obtain the pressure loss and flow parameters of the compressor stage. Further increase in aspect ratio will lead to structural problem of compressor. Therefore, there will be optimum aspect ratio between 2 and 3. Simulation will be conducted to aspect ratios of 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8 and 2.9 to find optimum ratio using ANSYS-CFX commercial CFD software.

***Keywords* –** aspect ratio, pressure rise, flow parameters, optimum value

I. INTRODUCTION

Turbo- machines

A device transfers energy to or from a continuously flowing fluid through a casing by the dynamic action of a rotor is called turbo- machine. Turbo--machinery, in mechanical engineering, describes machines that transfer energy between a rotor and a fluid, including both turbines and compressors. While a turbine transfers energy from a fluid to a rotor, a compressor transfers energy from a rotor to a fluid. The two types of machines are governed by the same basic relationships including Newton's second Law of Motion and Euler's energy equation for compressible fluids. Centrifugal pumps are also turbo--machines that transfer energy from a rotor to a fluid, usually a liquid, while turbines and compressors usually work with a gas.

In general, the two kinds of turbo-machines encountered in practice are open and closed turbo-machines. Open machines such as propellers, windmills, and enshrouded fans act on an infinite extent of fluid, whereas, closed machines operate on a finite quantity of fluid as it passes through housing or casing.

Turbo-machines are also categorized according to the type of flow. When the flow is parallel to the axis of rotation, they are called axial flow machines, and when flow is perpendicular to the axis of rotation, they are referred to as radial (or centrifugal) flow machines. There is also a third category, called mixed flow machines, where both radial and axial flow velocity components are present.

Turbo-machines may be further classified into two additional categories: those that absorb energy to increase the fluid pressure, i.e. pumps, fans, and compressors, and those that produce energy such as turbines by expanding flow to lower pressures. Of particular interest are applications which contain pumps, fans, compressors and turbines. These components are essential in almost all mechanical equipment systems, such as power and refrigeration cycles and gear oriented machines. Here rotor and stator are going to act for a single stage.

II. LITERATURE SURVEY

Kumbhar Anil et. al presents performance of single-stage axial flow compressors has been observed to be adversely affected by an aspect ratio (the ratio of blade height to axial chord length). The current investigation deals with a numerical based analysis for the effects of aspect ratio for single stage subsonic axial flow compressor through CFD analysis using commercial code Ax-Stream. The investigation aims to identify the effect of varying aspect ratio for single stage axial flow compressor with fixed aspect ratio through the stage and change the AR for IGV and stator blade while AR for rotor blade are same . First the analysis has been carried out for the single stage axial flow compressor having an AR2 through the stage (IGV, Rotor &stator) and then rotor blade AR2 kept constant and change the AR3 for stator blade and IGV. The study has predicted for estimating the performance characteristics, such as power, pressure rise and diffusion factor of the compressor stage is presented. This study shows that best operating conditions is getting in case of AR 323 for the referred single stage axial flow compressor .

Chan Lee et. al presents aero-acoustic performance prediction method of axial flow fan. The present study presents an aero-acoustic performance analysis method where fan flow field and aerodynamic performance are analyzed by through-flow modelling technique, and the acoustic performances such as sound pressure and power levels are predicted by combining discrete frequency and broadband noise models with fan flow prediction data. The present method are applied to high and low speed fans, and its prediction results are well agreed with the measurement results for air flow field, performance and noise levels. Therefore, the present method is expected to be a useful tool for high efficiency and low noise fan development at the actual design practice .

Andreas Lesser et. al investigates two transonic axial compressor stages for the peak efficiency operating point under uniform as well as under non-uniform inflow conditions. The compressor stages under investigation have very similar global parameters, but different design philosophies. The first one has a high aspect ratio and a small tip clearance gap resulting in a weak tip clearance vortex and secondary flow influence. In contrast to this first one, the second compressor was designed for a 3D dominated passage flow with a small aspect ratio and a large tip clearance gap. Both compressors were simulated in 2D as well as in full 3D, with a total pressure distortion that was steady, constant in radial, but varying in circumferential direction. The objective of this study is to investigate the influence of a total pressure distortion on two different compressor stages in terms of flow field deviation and mechanical blade loading .

Ramzi Mdouki et. al presents that Numerical experimentations were performed in the highly loaded linear compressor cascade with NACA 65(18)10. The influences of location, width and slope of the slot were successively analysed in two-dimensional configuration. Under off design condition, the maximum relative reduction of loss coefficient was up to 28.3%, when the slot jet was located approximately halfway between the minimum pressure point and the separation point, the slot width reached the threshold value and the slot slope became less stiff. Moreover, a difference of about 5° between the turning angles with and without slot can be observed. In three-dimensional situation, the optimal slot marks their ability to reduce the secondary flow structures and eliminate the boundary layer separation at mid-span and the corner stall. This benefit appears in the case where the incoming flow angle was large and the boundary layer separation was occurred. Thus, another work under design condition might be proposed to explore the potential of slotted balding to control end-wall flows. In the end, because the slot jet is exhausted with the same direction of the main flow, it has the capability to energize the boundary layer and control the separated flow on the suction surface of blade. But as the secondary flows have a different structure and different direction the slot jet loses its impact to manipulate the secondary flow. Therefore, the solution to control the secondary flow structures is to use an active tool on the lateral end-walls. Like suction or blowing, these tools can be proposed in the future works in parallel with slotted balding to improve aerodynamic performances of the axial compressors. Hence axial compressors perform well when compared to other compressors compared to centrifugal.

III. DESIGN

Input Parameters

i. Inlet Stagnation Temperature : 290K
ii. Inlet Stagnation Pressure : 1 bar
iii. Temperature Rise : 24K
iv. Mass flow rate : 15.5 Kg/s
v. Axial velocity : 160 m/s
vi. Rotational speed : 246 rev/ s
vii. Work done factor : 0.93
viii. Mean blade Speed : 220 m/s
ix. Reaction : 50%

Aspect ratio	Chord length(mm)
2.1	49
2.2	46.36
2.3	44.34
2.4	42.5
2.5	40.8
2.6	39.23
2.7	37.78
2.8	36.43
2.9	35.17

Tab.no.1: Blade design values

IV. CAD MODELS

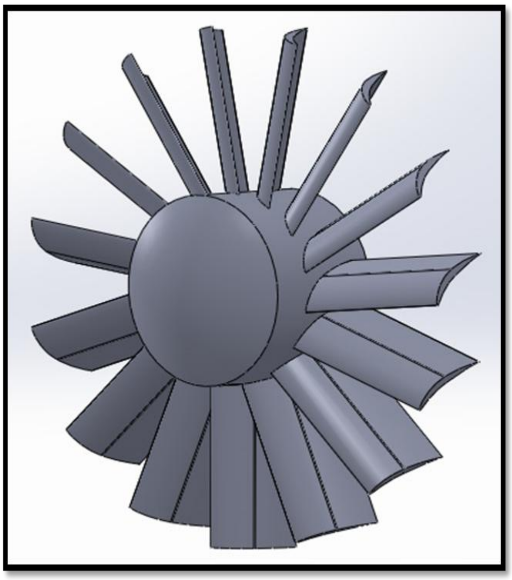

Fig.no.1: Rotor

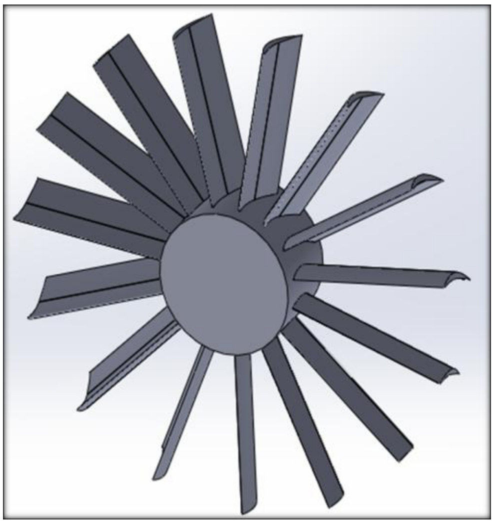

Fig.no.2: Stator

V. SIMULATION

Computational fluid dynamic technique is used for analyzing. Navier-stokes equation is governing equation of this technique. This equation is solved using finite volume method in commercial CFD codes. In this work, SOLIDWORKS-COSMOS FLOW WORKS is used. For turbulent, The K-epsilon model is a relatively simple model which is available in COSMOS. It was specially developed for turbulent flow in turbo-machinery.

Boundary Condition:

i. Inlet - Atmospheric pressure (1 bar)
ii. Outlet - Total pressure (1.21 bar)

VI. MESHING

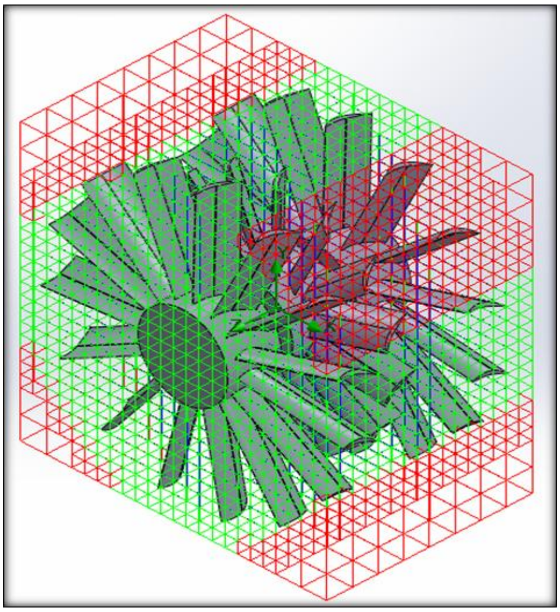

Fig.no.3: Meshing conditions

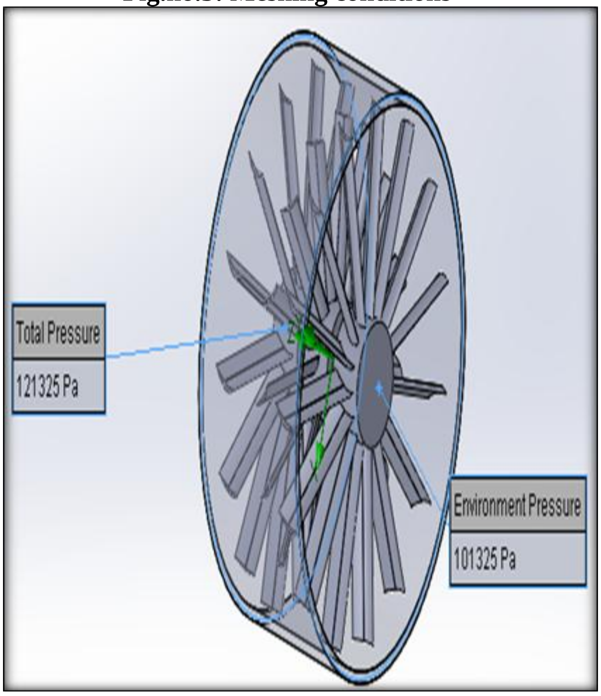

Fig.no.4: Boundary conditions

i. Fluid Cells 2170
ii. Solid Cells 932
iii. Partial Cells 5358

VII. RESULTS

For everry aspect ratio, its corresponding pressure values are calculated in CFX software and the respective graph is shown.

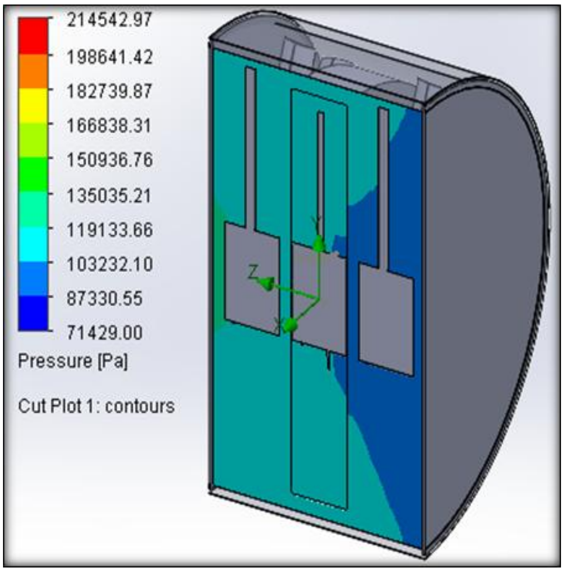

Fig.no.5: Presssure of Aspect ratio 2.1

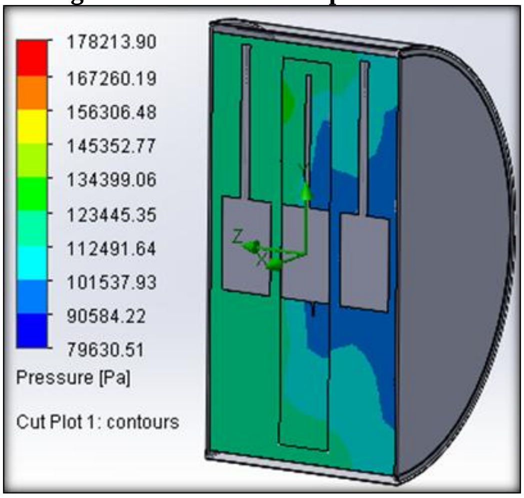

Fig.no.6: Pressure of Aspect ratio 2.2

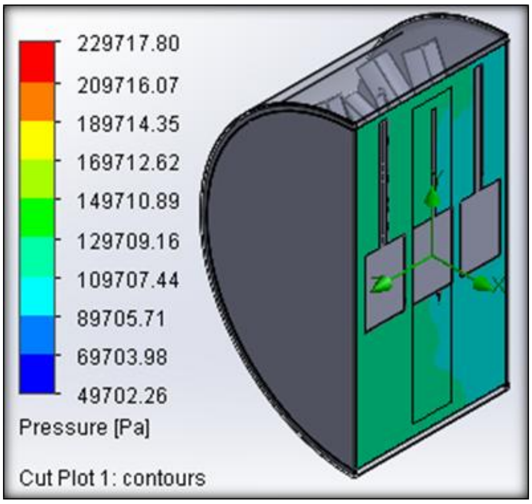

Fig.no.7: Pressure of Aspect ratio 2.3

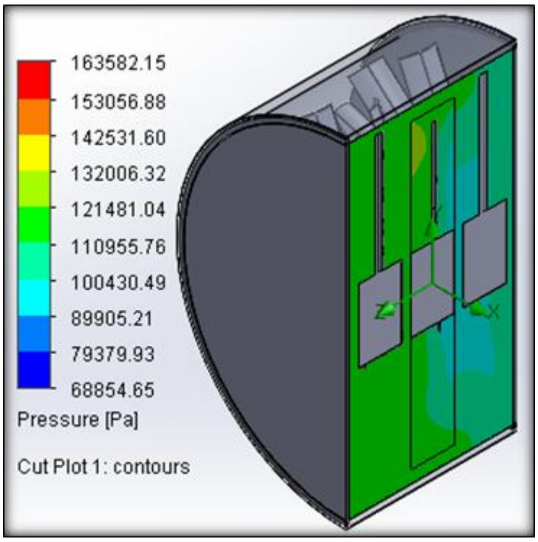

Fig.no.8: Pressure of Aspect ratio 2.4

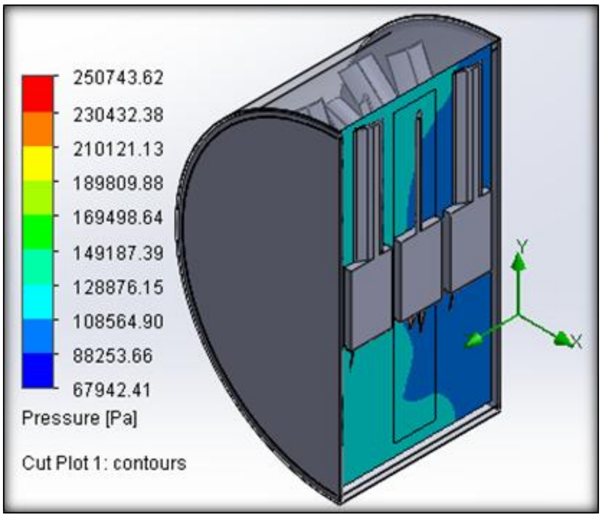

Fig.no.9: Pressure of Aspect ratio 2.5

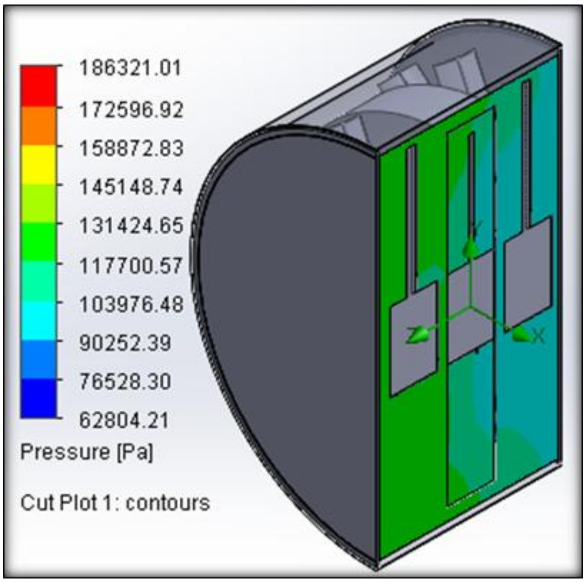

Fig.no.10: Pressure of Aspect ratio 2.6

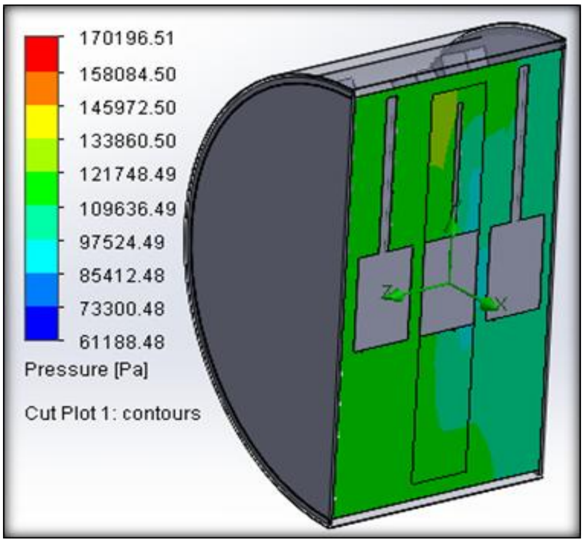

Fig.no.11: Pressure of Aspect ratio 2.7

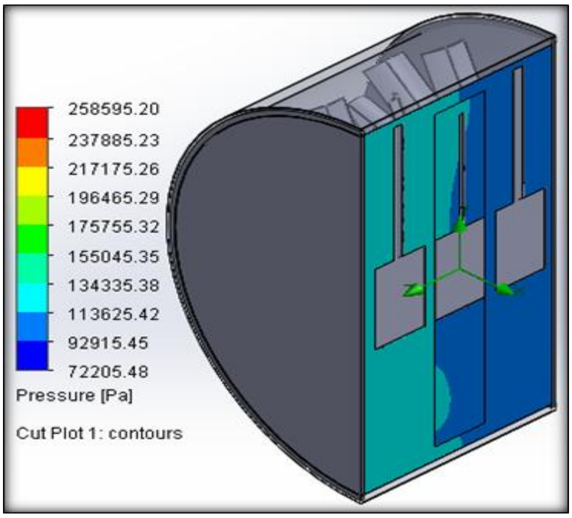

Fig.no.12: Pressure of Aspect ratio 2.8

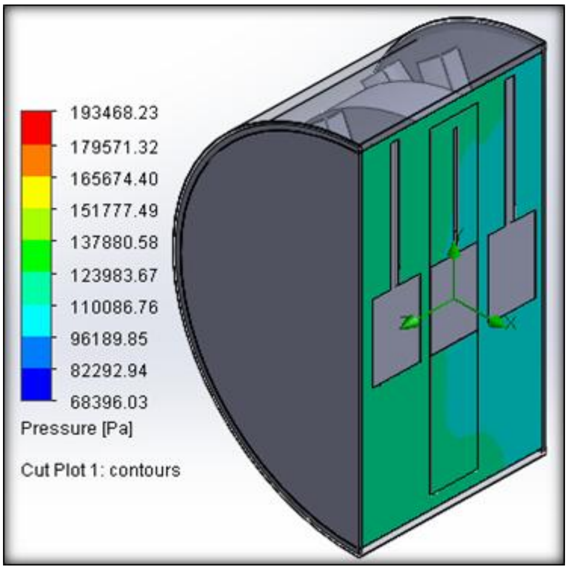

Fig.no.13: Pressure of Aspect ratio 2.9

Numerical investigation of effect of aspect ratio over axial flow compressor is proposed. To do this, commercial CFD software will be used. Optimum aspect ratio between 2 and 3 will explored based on performance of compressor at different aspect ratio. The purpose of this work is to find best blade aspect ratio of axial flow compressor. From literature, subsonic compressor with 1.2 pressure ratio is taken which was studied previously with aspect ratio of 1, 2 and 3. Good performance is at 2 and 3 aspect ratio. It is known from literature, there will be optimum aspect ratio is in between 2 and 3 which will explored in present work using CFD. Simulation details and plots have been given in previous chapter.

Aspect Ratio	Static Pressure (Pa)	Total Pressure (Pa)	Mass Flow Rate	Temp
2.1	119079	121325	16.38	313
2.2	119829	121325	13.36	313
2.3	118667	121325	17.87	314
2.4	119689	121325	14.12	314
2.5	118714	121325	17.71	313
2.6	119587	121325	14.56	314
2.7	119726	121325	14.01	314
2.8	118101	121325	19.53	314
2.9	119570	121325	14.62	314

Tab.no.2: Flow parameters at outlet

When mass flow rate increases, stage outlet Mach number also increases. This is because increase in fluid velocity at outlet. It is varied aspect ratio to aspect ratio. There are so many losses associated with axial flow compressor. CFD simulation can predict only turbulence losses and pressure losses. Other losses are influenced by friction over compressor surface. Software not considers friction over surfaces.

At aspect ratios 2.3, 2.5 and 2.8, more flow mass flow rate than required (15.5Kg/s). At other aspect ratios, low mass flow rate than required. But, they aren't much more or less. Here, we have applied narrow range of aspect ratios. It isn't right way to select optimum aspect ratio by considering only the mass flow rate at outlet for 1.21 pressure rise. Purpose of axial flow compressor is giving pressure rise to air in air breathing engines. Therefore, we have to account static pressure at outlet too; at the same time mass flow rate required is important to achieve good combustion at combustion chamber.

From table 7.1, it is concluded that aspect ratio 2.9 is optimum one because it has close mass flow rate 14.62 Kg/s to required one and good static pressure rise than others. From this project again it is explored that aspect ratio is sensible parameter in axial flow compressor design.

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