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Design and Analysis of Stator, Rotor and Blades of the Axial Flow Compressor

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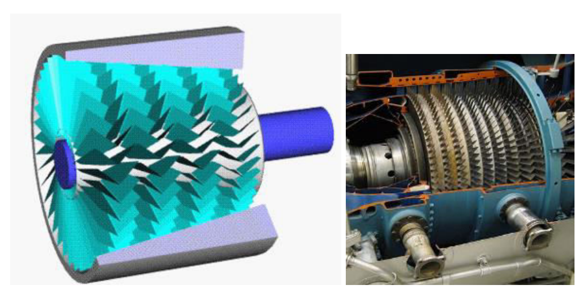
ABSTRACT: An axial flow compressor is one in which the flow enters the compressor in an axial direction (parallel with the axis of rotation), and exits from the gas turbine, also in an axial direction. The axial-flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase.Now a day research and developmental efforts in the area of axial flow compressors for gas turbine application are aimed to improving its operating range without sacrificing efficiency. An increase in aspect ratio (the ratio of blade height to chord length) has been observed to have an adverse effect on the performance of single-stage axial flow compressors.In this thesis, an axial flow compressor will be designed and modeled in 3D modeling software Pro/Engineer. The present designs will be modified by changing the aspect ratios. The present used material is Chromium Steel, it will be replaced with Titanium alloy and Nickel alloy.Structural analysis will be done on all the compressor models using steel, titanium alloy and nickel alloy to verify the strength of the compressor using finite element analysis software Ansys. CFD analysis will also be done to determine the fluid behavior in Ansys Fluent.

(I) INTRODUCTION TO AXIAL FLOW COMPRESSOR

An axial compressor is a compressor that can continuously pressurise gases. It is a rotating, airfoil-based compressor in which the gas or working fluid principally flows parallel to the axis of rotation, or axially. This differs from other rotating compressors such as centrifugal compressors, axi-centrifugal compressors and mixed-flow compressors where the fluid flow will include a "radial component" through the compressor. The energy level of the fluid increases as it flows through the compressor due to the action of the rotor blades which exert a torque on the fluid. The stationary blades slow the fluid, converting the circumferential component of flow into pressure. Compressors are typically driven by an electric motor or a steam or a gas turbine.

Axial compressors are integral to the design of large gas turbines such as jet engines, high speed ship engines, and small scale power stations. They are also used in industrial applications such as large volume air separation plants, blast furnace air, fluid catalytic cracking air, and propane dehydrogenation. Due to high performance, high reliability and flexible operation during the flight envelope, they are also used in aerospace engines.



The compressor in a Pratt & Whitney TF30 turbofan engine.

(i) WORKING

As the fluid enters and leaves in the axial direction, the centrifugal component in the energy equation does not come into play. Here the compression is fully based on diffusing action of the passages.The diffusing action in stator converts absolute kinetic head of the fluid into rise in pressure. The relative kinetic head in the energy equation is a term that exists only because of the rotation of the rotor. The rotor reduces the relative kinetic head of the fluid and adds it to the

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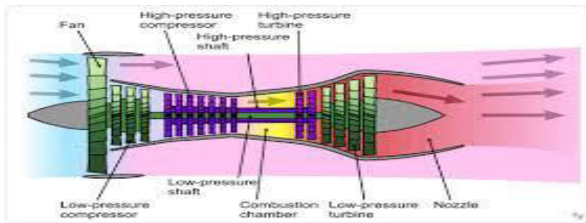
absolute kinetic head of the fluid i.e., the impact of the rotor on the fluid particles increases its velocity (absolute) and thereby reduces the relative velocity between the fluid and the rotor. In short, the rotor increases the absolute velocity of the fluid and the stator converts this into pressure rise. Designing the rotor passage with a diffusing capability can produce a pressure rise in addition to its normal functioning. This produces greater pressure rise per stage which constitutes a stator and a rotor together. This is the reaction principle in turbomachines. If 50% of the pressure rise in a stage is obtained at the rotor section, it is said to have a 50% reaction.



(ii) ROTATING STALLING

Non-uniformity of air flow in the rotor blades may disturb local air flow in the compressor without upsetting it. The compressor continues to work normally but with reduced compression. Thus, rotating stall decreases the effectiveness of the compressor.

(iii) PROBLEM DESCRIPTION

An axial flow compressor is one in which the flow enters the compressor in an axial direction (parallel with the axis of rotation), and exits from the gas turbine, also in an axial direction. The axial-flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase.

Models	analysis	materials
Case 1: rotor angle 12.1^0, stator angle 24.9^0	Static analysis Fatigue analysis CFD analysis	Steel Titanium alloy Nickel alloy
Case 2: rotor angle 26.4^0, stator angle 29.0^0		
Case 3: rotor angle 39.8^0, stator angle 33.1^0		
Case 4: rotor angle 45.9^0, stator angle 35.2^0		

(II) LITERATURE REVIEW

Design and Optimization of Axial Flow Compressor
Koduru. Srinivas1, Kandula. Deepthi2, K.N.D.MalleswaraRao3
An axial flow compressor is one in which the flow enters the compressor in an axial direction (parallel with the axis of rotation), and exits from the gas turbine, also in an axial direction. The axial-flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase. In an axial flow compressor, air passes from one stage to the next, each stage raising the pressure slightly. The energy level of air or gas flowing through it is increased by the action of the rotor blades which exert a torque on the fluid which is supplied by an electric motor or a steam or a gas turbine. In this thesis, an axial flow compressor is designed and modeled in 3D modeling software Pro/Engineer. The present design has 30 blades, in this thesis it is replaced with 20 blades and 12 blades. The present used material is Chromium Steel; it is replaced with Titanium alloy and Nickel alloy. Structural analysis is done on the compressor models to verify the strength of the compressor. CFD analysis is done to verify the flow of air.

INTRODUCTION TO CAD

Throughout the history of our industrial society, many inventions have been patented and whole new technologies have evolved. Perhaps the single development that has impacted manufacturing more quickly and significantly than any previous technology is the digital computer. Computers are being used increasingly for both design and detailing of engineering componentsin the drawing office. Computer-aided design (CAD) is defined as the application of computers and graphicssoftware to aid or enhance the product design from conceptualization to documentation.

(III) INTRODUCTION TO PRO/ENGINEER

Pro/ENGINEER, PTC's parametric, integrated **3D CAD/CAM/CAE solution**, is used by discrete manufacturers for mechanical engineering, design and manufacturing.

Created by Dr. Samuel P. Geisberg in the mid-1980s, Pro/ENGINEER was the industry's first successful parametric, 3D CAD modeling system. The parametric modeling approach uses parameters, dimensions,

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features, and relationships to capture intended product behavior and create a recipe which enables design automation and the optimization of design and product development processes.

(IV) INTRODUCTION TO FINITE ELEMENT METHOD

Finite Element Method (FEM) is also called as Finite Element Analysis (FEA). Finite Element Method is a basic analysis technique for resolving and substituting complicated problems by simpler ones, obtaining approximate solutions Finite element method being a flexible tool is used in various industries to solve several practical engineering problems. In finite element method it is feasible to generate the relative results.

In the present day, finite element method is one of the most effective and widely used tools. By doing more computational analysis the approximate solution can be improved or refined in Finite element method. In Finite element method, matrices play an important role in handling large number of equations. The procedure for FEM is a Variation approach where this concept has contributed substantially in formulating the method.

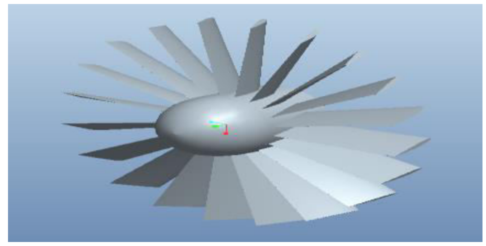
ANSYS Software:

ANSYS is an Engineering Simulation Software (computer aided Engineering). Its tools cover Thermal, Static, Dynamic, and Fatigue finite element analysis along with other tools all designed to help with the development of the product. The company was founded in 1970 by Dr. John A. Swanson as Swanson Analysis Systems, Inc. SASI. Its primary purpose was to develop and market finite element analysis software for structural physics that could simulate static (stationary), dynamic (moving) and heat transfer (thermal) problems. SASI developed its business in parallel with the growth in computer technology and engineering needs. The company grew by 10 percent to 20 percent each year, and in 1994 it was sold. The new owners took SASI's leading software, called ANSYS®, as their flagship product and designated ANSYS, Inc. as the new company name.

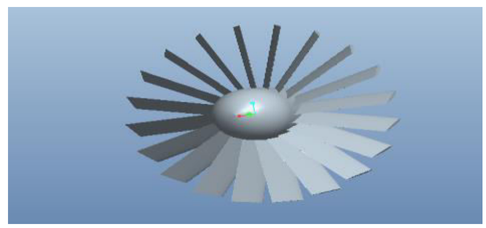
(V) MODELLING AND ANALYSIS

Models of narrow plate using pro-e wildfire 5.0

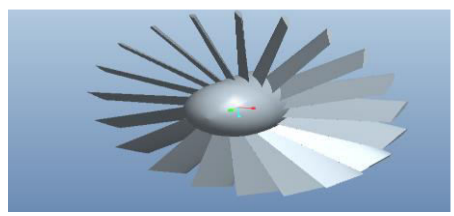
Case 1: rotor angle 12.1^0, stator angle 24.9^0



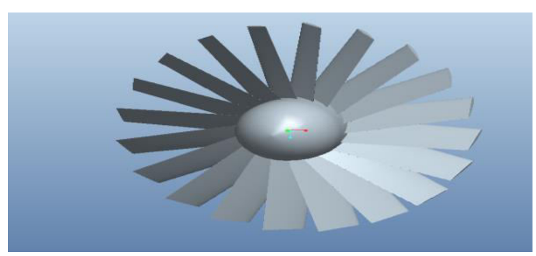
Case 2: rotor angle 26.4^0, stator angle 29.0^0



Case 3: rotor angle 39.8^0, stator angle 33.1^0



Case 4: rotor angle 45.9^0, stator angle 35.2^0



STATIC ANALYSIS OF AXIAL FLOW COMPRESSOR

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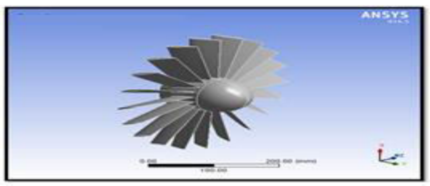
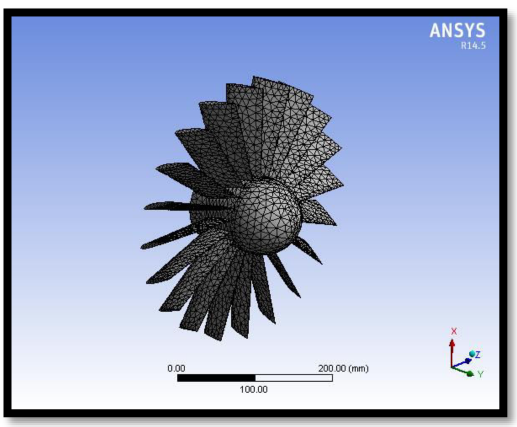
Case 1: rotor angle 12.1^0, stator angle 24.9^0

MATERIAL- CHROMIUM STEEL

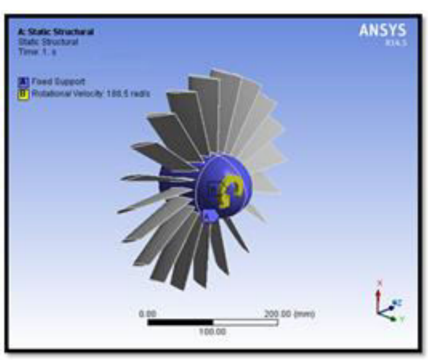
IMPORTED MODEL



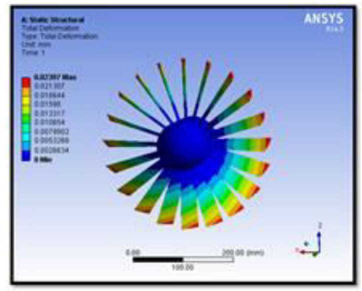
MESHED MODEL



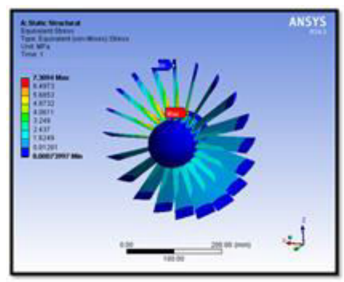
BOUNDARY CONDITIONS



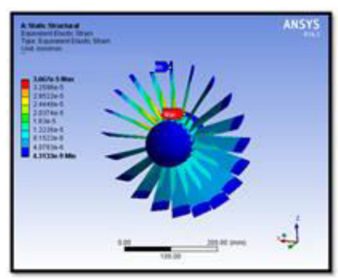
DEFORMATION



STRESS

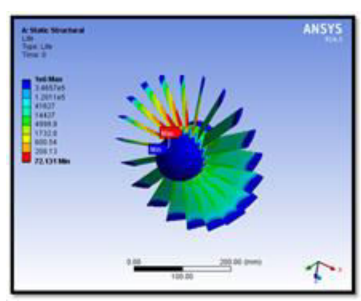


STRAIN



MATERIAL- NICKEL ALLOY

LIFE



DAMAGE

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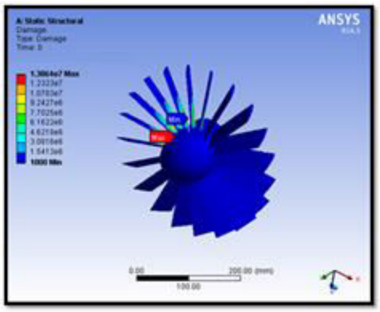
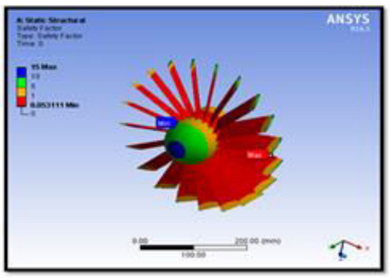


SAFETY FACTOR



STATIC ANALYSIS RESULTS TABLE

Case 1: rotor angle 12.1^0, stator angle 24.9^0

Material	Deformation(mm)	Stress(MPa)	strain
Steel	0.02397	7.3094	3.667e-5
Titanium alloy	0.02654	4.4743	4.0818e-5
Nickel alloy	0.035879	12.557	5.3577e-5

Case 2: rotor angle 26.4^0, stator angle 29.0^0

Material	Deformation(mm)	Stress(MPa)	strain
Steel	0.041448	9.2789	4.6479e-5
Titanium alloy	0.045884	5.6591	5.1544e-5
Nickel alloy	0.062088	16.23	6.9165e-5

Case 3: rotor angle 39.8^0, stator angle 33.1^0

Material	Deformation(mm)	Stress(MPa)	strain
Steel	0.056658	11.996	6.0042e-5
Titanium alloy	0.06273	7.326	6.6677e-5
Nickel alloy	0.084821	20.864	8.8846e-5

Case 4: rotor angle 45.9^0, stator angle 35.2^0

Material	Deformation(mm)	Stress(MPa)	strain
Steel	0.062991	12.837	6.4299e-5
Titanium alloy	0.069759	7.8331	7.1341e-5
Nickel alloy	0.094202	22.417	9.5533e-5

FATIGUE ANALYSIS RESULTS TABLE

Case 1: rotor angle 12.1^0, stator angle 24.9^0

Material	life		Damage	Safety factor	
	Max.	Min.		Max.	Min.
Steel	$1\times e^6$	3574.4	2.7976e5	15	0.23586
Titanium alloy	$1\times e^6$	17179	58212	15	0.38531
Nickel alloy	$1\times e^6$	798.15	1.25529e6	15	0.1373

Case 2: rotor angle 26.4^0, stator angle 29.0^0

Material	life		Damage	Safety factor	
	Max.	Min.		Max.	Min.
Steel	$1\times e^6$	289.01	3.4601e6	15	0.092899
Titanium alloy	$1\times e^6$	1045.6	9.5638e5	15	0.15232
Nickel alloy	$1\times e^6$	72.131	1.3864e7	15	0.053111

Case 3: rotor angle 39.8^0, stator angle 33.1^0

Material	life		Damage	Safety factor	
	Max.	Min.		Max.	Min.
Steel	$1\times e^6$	150.2	6.6578e6	15	0.071858
Titanium alloy	$1\times e^6$	534.33	1.8715e6	15	0.11766
Nickel alloy	$1\times e^6$	40.145	2.491e7	15	0.041315

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Case 4: rotor angle 45.9^0, stator angle 35.2^0

Material	life		Damage	Safety factor	
	Max.	Min.		Max.	Min.
Steel	1xe^6	126.92	7.87e6	15	0.067148
Titanium alloy	1xe^6	448.97	2.2273e6	15	0.11005
Nickel alloy	1xe^6	34.049	2.9369e7	15	0.038452

GRAPHS

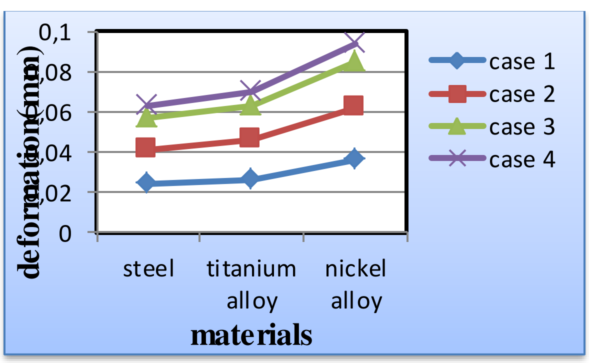
Case 1: rotor angle 12.1^0, stator angle 24.9^0

Case 2: rotor angle 26.4^0, stator angle 29.0^0

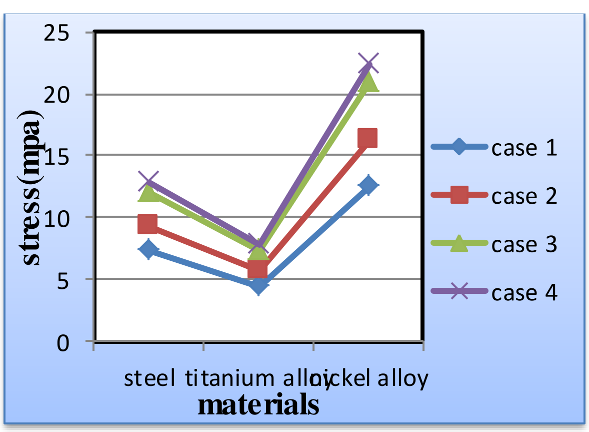
Case 3: rotor angle 39.8^0, stator angle 33.1^0

Case 4: rotor angle 45.9^0, stator angle 35.2^0

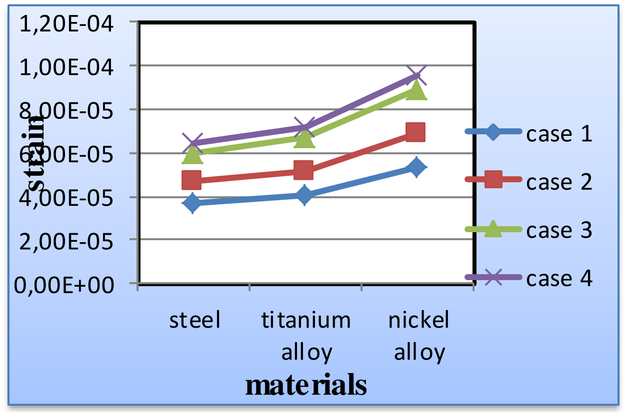
DEFORMATION PLOT



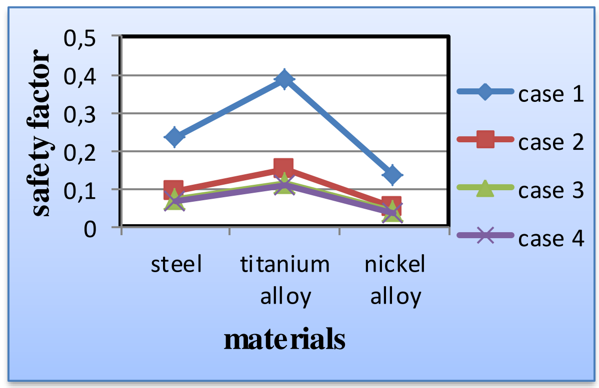
STRESS PLOT



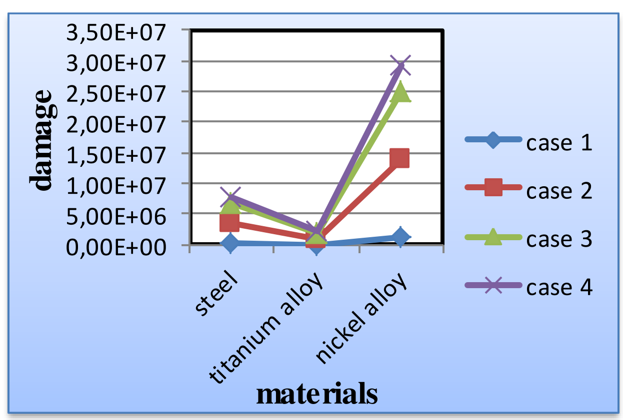
Strain plot



SAFETY FACTOR PLOT



DAMAGE PLOT



CFD ANALYSIS OF AXIAL FLOW COMPRESSOR

FLUID- AIR

SPEED 1800 RPM

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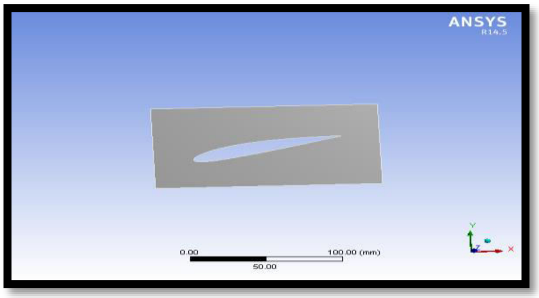
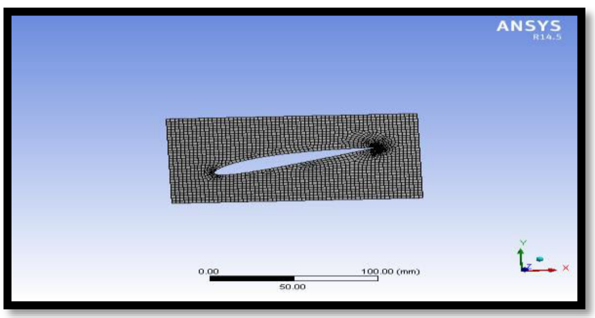
Case 1: rotor angle 12.1⁰

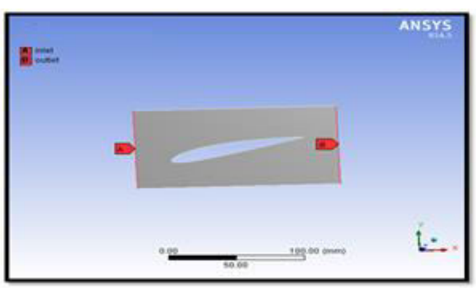
Imported model



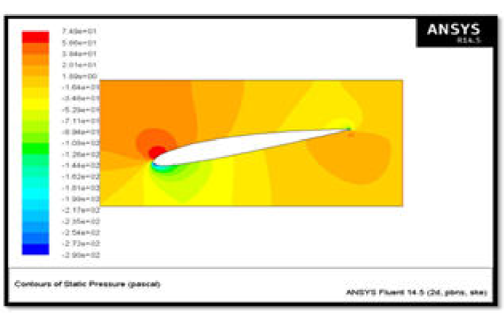
Meshed model



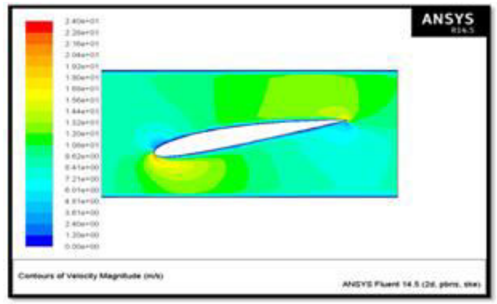
Inlet and outlet conditions



Pressure



Velocity



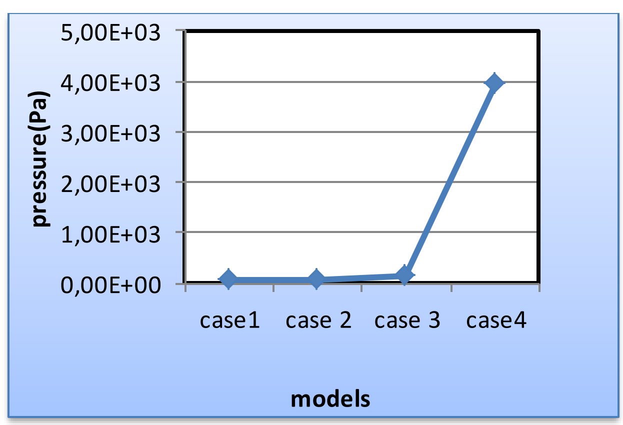
Mass flow rate

```
           Mass Flow Rate                 (kg/s)
-------------------------- --------------------
                    inlet            0.92316014
        interior-_trm_srf            -4.8381653
                   outlet           -0.92315024
             wall-_trm_srf                    0
         ---------------- --------------------
                      Net          9.894371e-06
```

CFD ANALYSIS RESULTS TABLE

models	Pressure(Pa)	Velocity(m/s)	Mass flow rate (kg/s)
Case 1: rotor angle 12.1⁰	7.49e+01	2.40e+01	9.8943e-06
Case 2: rotor angle 26.4⁰	6.49e+01	6.49e+01	0.0016580
Case 3: rotor angle 39.8⁰	1.31e+02	1.31e+02	0.00074821
Case 4: rotor angle 45.9⁰	3.94e+03	1.90e+03	0.00728

PRESSURE PLOT



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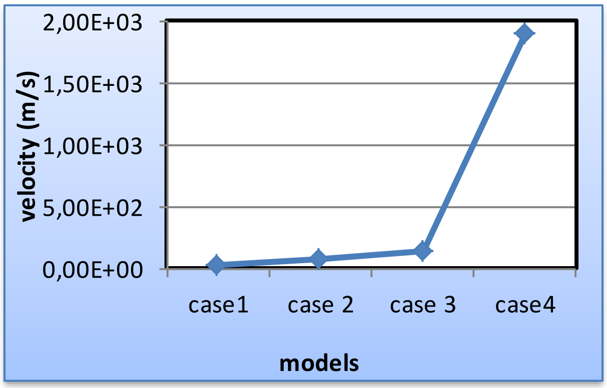
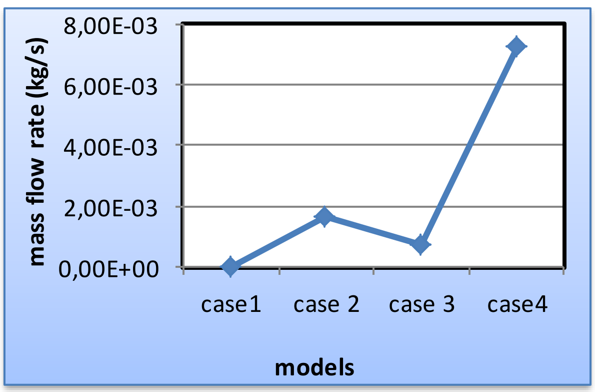
Velocity plot



Mass flow rate plot



(VI) CONCLUSION

An axial flow compressor is one in which the flow enters the compressor in an axial direction (parallel with the axis of rotation), and exits from the gas turbine, also in an axial direction. The axial-flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase.

In this thesis, an axial flow compressor will be designed and modeled in 3D modeling software Pro/Engineer. The present designs will be modified by changing the aspect ratios. The present used material is Chromium Steel; it will be replaced with Titanium alloy and Nickel alloy.

By observing the static analysis the deformation and stress increasing by increasing the angles of axial flow compressor blade and less stress value of rotor angle 12.1^0, stator angle 24.9^0 for nickel alloy and less stress value for titanium alloy.

By observing the fatigue analysis of the safety factor value less for titanium alloy compare to steel and nickel alloy for rotor angle 12.1^0, stator angle 24.9^0.

By observing the cfd analysis the pressure drop, velocity and mass flow rate increases by increasing the blade angles of the axial flow compressor.

So it can be conclude the titanium alloy is the better material for axial flow compressor.

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