# THERMAL AND AERODYNAMIC DESIGN, FABRICATION AND FLOW ANALYSIS OF AN AXIAL COMPRESSOR USING INNOVATIVE INVERSE TECHNIQUE

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## ABSTRACT

**Turbo machines are used extensively in Aerospace, Power Generation, and Oil & Gas Industries. Efficiency of these machines is often an important factor and has led to the continuous effort to improve the design to achieve better efficiency. The objective of work presented is to design Axial flow compressor by using mean line method for a given mass flow rate and required pressure ratio. The parameters determined also include thermodynamic properties of the working fluid, stage efficiency, number of rotor and stator blades, tip and hub diameters, blade dimensions (chord, length and space) for both rotor and stator, Mach number, flow and blade angles (blade twist). NACA 4 digit profiles are used to generate coordinates of the blade. Further, in the process the first stage of axial flow compressor blade is developed using Solid works modeling.**

**KEYWORDS: Ideal cycle analysis, NACA series, axial compressor blades**

## INTRODUCTION

Axial-flow compressors are used in medium to large thrust gas turbine and jet engines. The compressor rotates at very high speeds, adding energy to the airflow while at the same time compressing it into a smaller space. The design of axial flow compressors is a great challenge, both aerodynamically and mechanically. [1] The aerodynamic compressor design process basically consists of mean line prediction calculation, through flow calculation, and blading procedures. The mean line prediction is the first step within compressor design. It is a simple one dimensional calculation of flow parameters along the mid-height line of the compressor where global parameters as the annulus geometry, the number of stages, and the stage pressure ratios are scaled. These calculations also include thermodynamic properties of the working fluid, stage efficiency, and number of rotor and stator blades, tip and hub diameters, chord, length and space of blade for rotor and stator, Mach number, flow and blade angles. A repeated stage calculation is made to calculate the above parameters along compressor stages. The usual way of designing the compressor blades would require blade parameters including inlet, outlet, stagger, camber and deflection angles. a suitable aerofoil would be extracted through the above mentioned parameters. But the challenge one would face is the testing of aerodynamic stability of such airfoils. Hence, this work presents an innovative collaboration between the turbo machine prerequisites of a compressor and aerodynamic stability of the blades by fitting the suitable NACA 4 digit series aerofoil co ordinates. The paper also throws light on the range of the NACA series that can be used for respective performance requirements.

## I. IDEAL CYCLE ANALYSIS:

$$\text{Thrust} = m*((1+f)*ue-u) + (Pe-Pa)\,Ae$$

Based on the required thrust and velocity of aircraft, pressure ratio and mass flow rate is calculated using the above relationship.

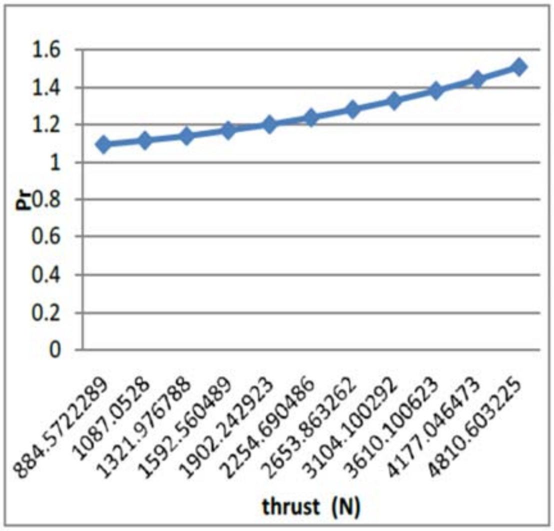
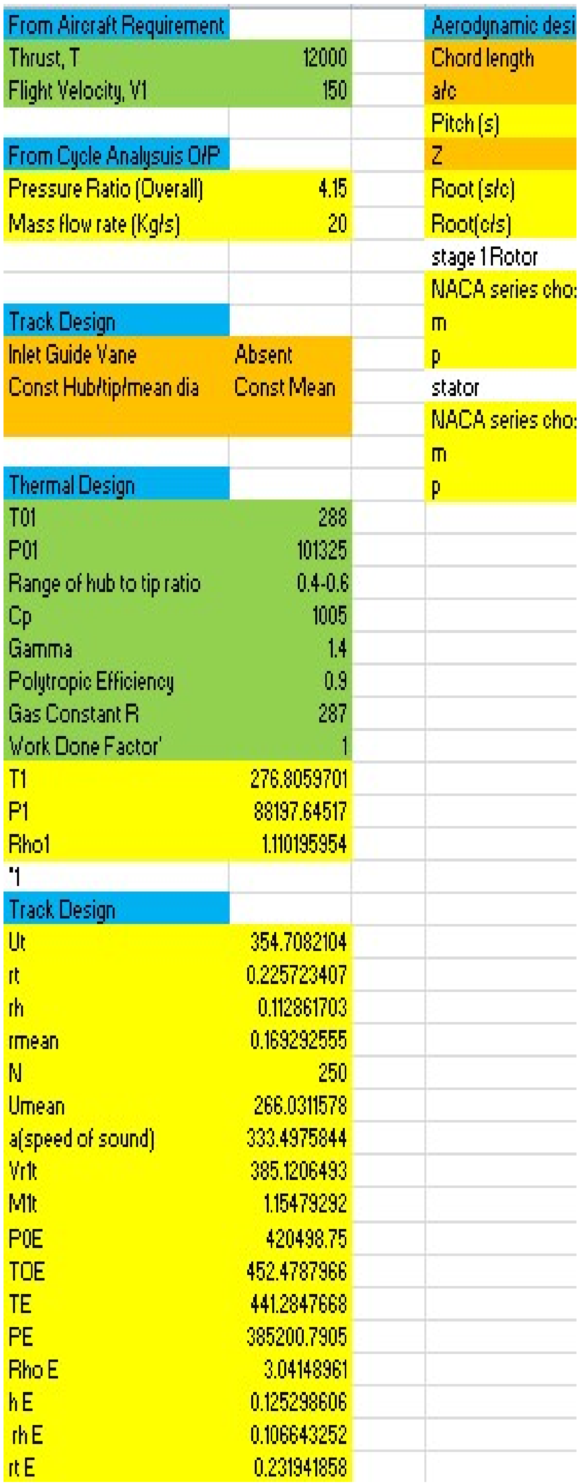


Fig 1: Variation of pressure co efficient with respect to thrust values

## II. TRACK DESIGN

From cycle analysis, pressure ratio is 4.15 and air mass flow rate is 20 kg/sec. Also, Axial velocity Ca=150 m/s and blade speed of 250rpm is considered. The type of annulus is decided and the radius of the track, thermodynamic properties at inlet and outlet, are calculated



| | | |
|---|---|---|
| From Aircraft Requirement | | Aerodynamic desi |
| Thrust, T | 12000 | Chord length |
| Flight Velocity, V1 | 150 | a/c |
| | | Pitch (s) |
| From Cycle Analysuis O/P | | Z |
| Pressure Ratio (Overall) | 4.15 | Root (s/c) |
| Mass flow rate (Kg/s) | 20 | Root(c/s) |
| | | stage 1 Rotor |
| | | NACA series cho: |
| Track Design | | m |
| Inlet Guide Vane | Absent | p |
| Const Hub/tip/mean dia | Const Mean | stator |
| | | NACA series cho: |
| | | m |
| Thermal Design | | p |
| T01 | 288 | |
| P01 | 101325 | |
| Range of hub to tip ratio | 0.4-0.6 | |
| Cp | 1005 | |
| Gamma | 1.4 | |
| Polytropic Efficiency | 0.9 | |
| Gas Constant R | 287 | |
| Work Done Factor' | 1 | |
| T1 | 276.8059701 | |
| P1 | 88197.64517 | |
| Rho1 | 1.110195954 | |
| '1 | | |
| Track Design | | |
| Ut | 354.7082104 | |
| rt | 0.225723407 | |
| rh | 0.112861703 | |
| rmean | 0.169292555 | |
| N | 250 | |
| Umean | 266.0311578 | |
| a(speed of sound) | 333.4975844 | |
| Vr1t | 385.1206493 | |
| M1t | 1.15479292 | |
| P0E | 420498.75 | |
| T0E | 452.4787966 | |
| TE | 441.2847668 | |
| PE | 385200.7905 | |
| Rho E | 3.04148961 | |
| h E | 0.125298606 | |
| rh E | 0.106643252 | |
| rt E | 0.231941858 | |

Fig 2: Track design data

## III. STAGE BY STAGE DESIGN

The conventional way of designing each stage follows that, air exits from the previous row of stator blades at angle of α1with absolute velocity C1.The rotor rows has tangential velocity, and combining the two velocity vectors gives the relative inlet velocity vector W1 at angle β1.At rotor row outlet the velocity triangles are similar to those draw for the axial flow pump, and absolute velocity vector C2 moves into the stator row where the flow direction is changed to C3 with the absolute velocity C3The diagram have been drawn showing a large gap between the rotor and stator blades. In practice, the clearance between the rotor and stator is very small. If the following stage is the same as the preceding one the stage is said to be normal. For a normal stage C1=C3 and α1 = α3. V2 is less than V1, showing that diffusion of relative velocity has taken place with some static pressure rise across the rotor blades. The air is turned towards the axial direction by the blade camber and the effective flow area is increased from inlet to outlet, thus causing diffusion to take place. Similar diffusion of the absolute velocity takes place in the stator where the absolute velocity vector is again turned towards the axial direction and further pressure rise occurs.

If Rotor inlet is considered as Station 1, from the set of equations as below, Air inlet angle can be determined: As no inlet guide vane α1 is considered as Zero.

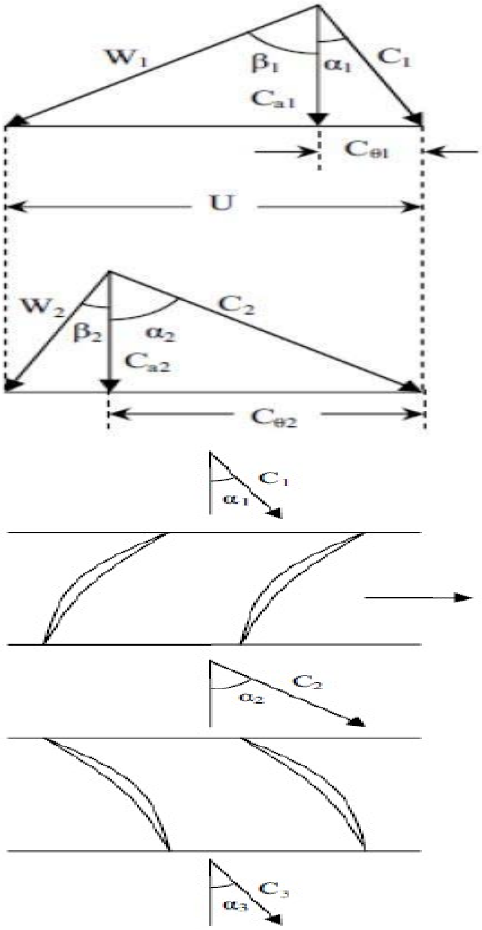
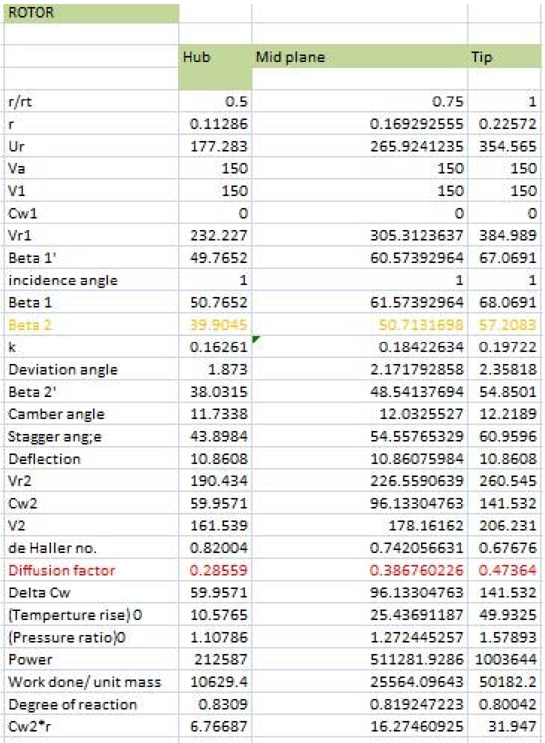


Fig 3: Velocity triangles for rotor



| ROTOR | | | |
|---|---|---|---|
| | Hub | Mid plane | Tip |
| r/rt | 0.5 | 0.75 | 1 |
| r | 0.11286 | 0.169292555 | 0.22572 |
| Ur | 177.283 | 265.9241235 | 354.565 |
| Va | 150 | 150 | 150 |
| V1 | 150 | 150 | 150 |
| Cw1 | 0 | 0 | 0 |
| Vr1 | 232.227 | 305.3123637 | 384.989 |
| Beta 1' | 49.7652 | 60.57392964 | 67.0691 |
| incidence angle | 1 | 1 | 1 |
| Beta 1 | 50.7652 | 61.57392964 | 68.0691 |
| Beta 2 | 39.9045 | 50.7131698 | 57.2083 |
| k | 0.16261 | 0.18422634 | 0.19722 |
| Deviation angle | 1.873 | 2.171792858 | 2.35818 |
| Beta 2' | 38.0315 | 48.54137694 | 54.8501 |
| Camber angle | 11.7338 | 12.0325527 | 12.2189 |
| Stagger ang;e | 43.8984 | 54.55765329 | 60.9596 |
| Deflection | 10.8608 | 10.86075984 | 10.8608 |
| Vr2 | 190.434 | 226.5590639 | 260.545 |
| Cw2 | 59.9571 | 96.13304763 | 141.532 |
| V2 | 161.539 | 178.16162 | 206.231 |
| de Haller no. | 0.82004 | 0.742056631 | 0.67676 |
| Diffusion factor | 0.28559 | 0.386760226 | 0.47364 |
| Delta Cw | 59.9571 | 96.13304763 | 141.532 |
| (Temperture rise)0 | 10.5765 | 25.43691187 | 49.9325 |
| (Pressure ratio)0 | 1.10786 | 1.272445257 | 1.57893 |
| Power | 212587 | 511281.9286 | 1003644 |
| Work done/ unit mass | 10629.4 | 25564.09643 | 50182.2 |
| Degree of reaction | 0.8309 | 0.819247223 | 0.80042 |
| Cw2*r | 6.76687 | 16.27460925 | 31.947 |

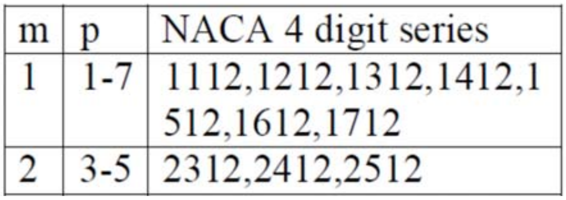
Fig 4: Rotor blade parameters

In the present work, we calculate the inlet blade angle and choose a suitable NACA aerofoil which provides us the outlet blade angles.

## IV. Choosing NACA aerofoil

Even though NACA four digit corresponds to maximum camber, maximum camber position and maximum aerofoil thickness, the latter parameter is insignificant to our current area of focus.

Considering diffusion factor < 0.5 as the criterion for credible design, from the calculations [7], the 4 digit NACA series that can be incorporated when whirl component at inlet is zero are:



| m | p | NACA 4 digit series |
|---|---|---|
| 1 | 1-7 | 1112,1212,1312,1412,1512,1612,1712 |
| 2 | 3-5 | 2312,2412,2512 |

Table 1: Range of NACA 4 digit series

For maximum camber beyond 3, we observe flow separation, hence cannot be utilized

The blade profile was designed using Solid Works software.

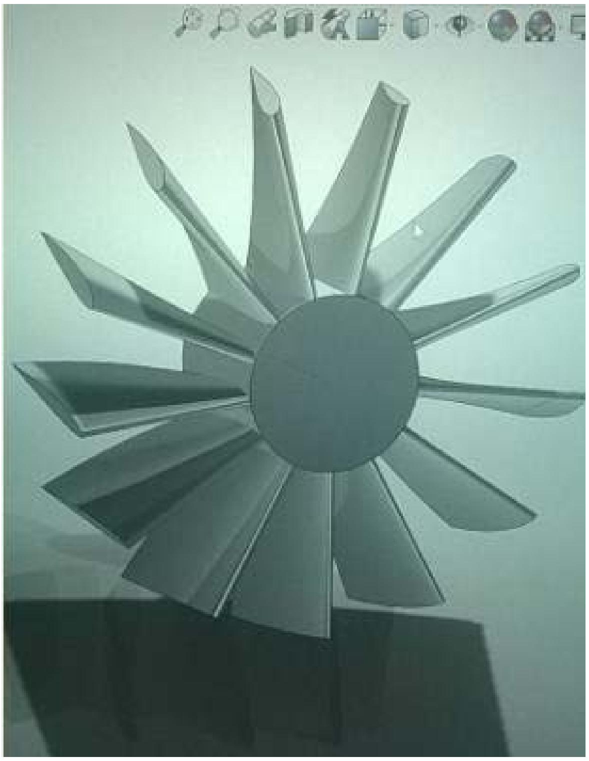


Fig 5: CAD model of rotor blade using Solid Works

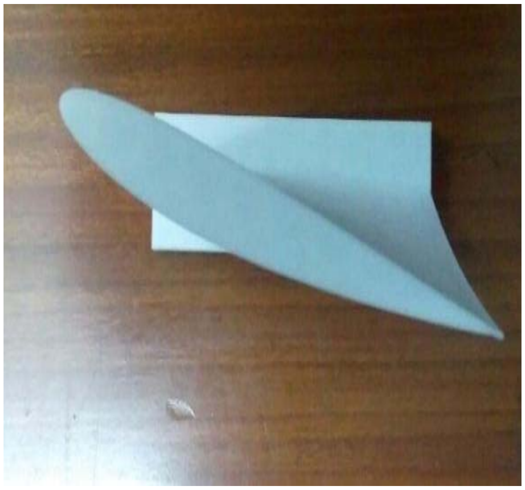


Fig 6: 3D printed model of rotor blade

## V. VALIDATION OF NACA AEROFOIL

Even though the diffusion factor helps us in checking the flow separation condition, validation study through CFD analysis helps in obtaining the pressure distribution over the blade. The validation data of drag and lift co efficient characteristics mentioned is obtained by experiments in wind tunnel conducted on NACA 2412 aerofoil [7].

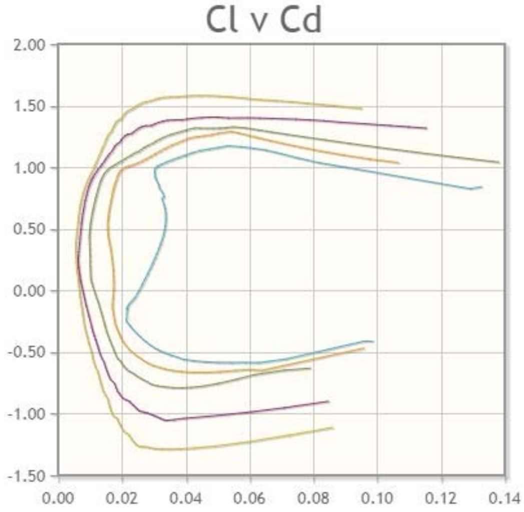


Fig 7: Cl vs Cd characteristics of NACA 2412[7]

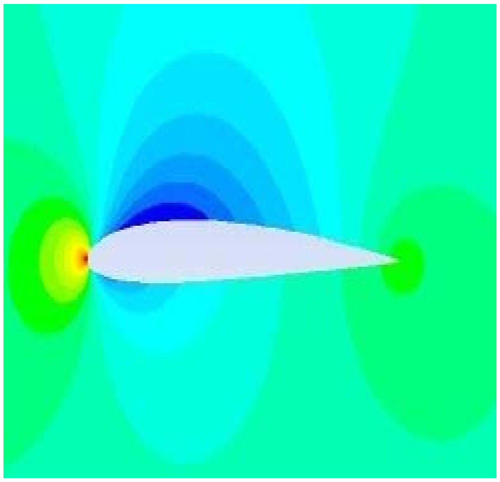


Fig 8: Pressure distribution over NACA 2412 for 0 angle of attack[7]

## CONCLUSION

This work presented a new method of designing axial compressor blades. The work was carried out broadly in two segments;

- Calculations of the input parameters to satisfy the requirements
- Designing of blades by choosing suitable NACA 4 digit series and obtaining the corresponding output parameters

Thus, with known value of thrust and jet velocity, rotor and stator blade profiles can be generated using this method which also provides validation for the designed blade profiles. CFD analysis has been carried out for the identification of the domain of the flow separation and it was seen that the blade does not have any severe adverse pressure gradient regions.

## FUTURE WORK

This work can be extended to higher digit NACA series for different initial assumptions by analyzing the influence of aerofoil thickness on the performance of the axial compressor. The effect of blade profile on the efficiency and performance can be analyzed.

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