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3D Computational Studies of Low Speed Axial Flow Compressor Rotor Incorporating Tandem Blades

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Abstract:- The tandem blade compressor rotor configuration is where two separate blades are mounted on a common rotating wheel. The premise of this study is that a tandem blade rotor can do more work at the same loss level as a single blade, which would reduce the number of required stages in a compressor. While tandem blades are commonly used in centrifugal impellers, they have yet to be applied to a commercial axial-flow rotor. This project presents some results of a 3-D computational study of the axial tandem configuration in a fully subsonic flow field. It was found that the tandem blade begins to offer benefits over a conventional blade when highly loaded (i.e. Lieblein D-Factor greater than 0.55). This project also includes the numerical investigation of the steady, three-dimensional flow field in a tandem compressor rotor. The interaction mechanism has been investigated between these blades. The comparison has been made based on the conventional and tandem blades by the static and total pressure distribution along the blades.

Keywords:- axial flow compressor; high loading; tandem blade rotor; conventional blade rotor; 3D computational; c_p

I. INTRODUCTION

The axial-flow compressor designers should face the challenges is that of using as few stages as possible to achieve the desired pressure rise without compromising efficiency. The obvious benefits to using fewer stages are improved engine power-to-weight ratio and a reduction in manufacturing parts. For example, a typical stage in a 9- stage subsonic compressor will have a pressure ratio (PR) of around 1.22. By using dual airfoils in the last two stages, it may be possible to increase their individual Pressure ratios to a level such that only eight stages---six conventional and two dual---are required instead of nine. It is with this ultimate goal in mind that the present research has been undertaken.

While there is a fair amount of literature on the subject, much of it focuses on a particular geometry or very specific flow conditions. From the designer's standpoint, it is desirable to have information available that summarizes more general airfoil geometries and flow conditions that are found in a compressor. This paper presents some of the results of an ongoing project that will ultimately deliver both fundamental and practical knowledge of the dual airfoil rotor.

Prior to any discussion of the dual-airfoil, it is necessary to have basic understanding of the lexicon used to describe it. Fig shows a 2-D view of a dual-airfoil configuration.

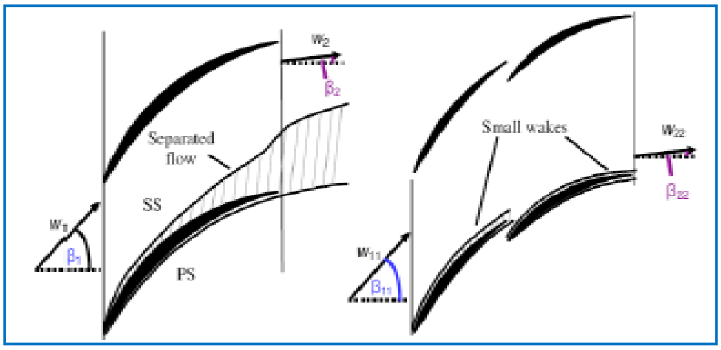

Fig.1. 2-D Profile view of highly loaded axial-flow single and tandem Airfoil (R)

II. NUMERICAL ANALYSIS OF THE TANDEM BLADE ROTOR

A. Solid Modeling of The Flow Domain

The 3D solid modeling's of the four different cases of axial pitch and percent pitch in tandem blade arrangements of the research compressor design were made with the help of CAD tools CATIA V5 as shown in Figure below. The following table mentioned below is the design parameters were used to make the models. The flow field domain for the baseline configuration has a choice of hybrid grid generation and fixing up the boundary conditions appropriately.

Table I. Tandem Blade Rotor Compressor Specifications

Type of compressor	Low speed axial flow compressor
Corrected rotational speed	12930 rpm
Corrected mass flow rate	22 kg/s
Rotor tip diameter	450 mm
Blade profile	NACA 65A006
No. of blades	36

1) *Tandem Profile Design at AP=0% And PP=5%:* The 3d modeling of the tandem blade is done by the CATIA V5 by the following steps.

a) *CATIA V5*: Part design

b) *Module Used:*Part design

c) *Tools Used For Sketching:*Circle, Rectangle, Spline, Curves

d) *Part Designing:* Pad, Pocket, Circular pattern, Multipad.

TABLE II. PARAMETERS

Parameter	Design 1	Design 2	Design 3	Design 4
Airfoil	NACA 65A006	NACA 65A006	NACA 65A006	NACA 65A006
Blade angle row 1	50 deg	50 deg	55 deg	55 deg
Blade angle row 2	25 deg	30 deg	25 deg	30 deg

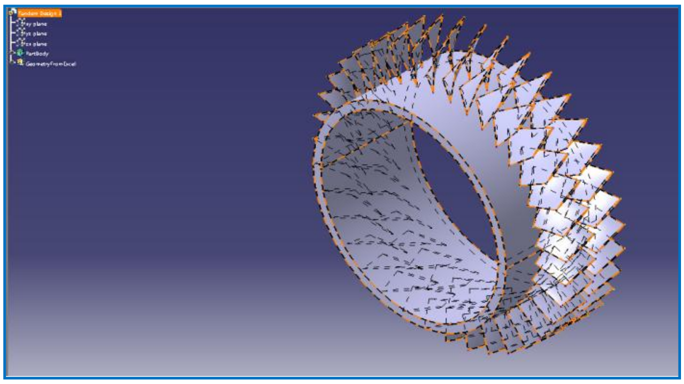

Fig. 2 Tandem design Profile 1 at AP=0% and PP=5%

B. Meshing

All computational domains were set up as passage-centered H-meshes. The inlet and exit planes of each mesh were situated one axial chord upstream and downstream of the particular airfoil geometry being modeled. Single airfoil meshes were single-block. The tandem meshes were created by first generating the forward and aft airfoil meshes separately.

The FORTRAN program that created the tandem meshes had a subroutine that would as nearly as possible distribute *k* points in the Upper and Lower Passages proportional to the pitch wise position of the aft airfoil. For example, at high percent pitch the Upper Passage would have fewer *k*-points than the Lower Passage. The mesh file created in ansys geometry was imported to fluent. The mesh was successfully read and grid checking was done to ensure that all the meshes are exported. The figures of the imported meshes are given below.

C. Boundary Conditions

The boundary layer control mechanism of a tandem blade must be given due consideration whereby flow separation can be avoided. To explain his characteristic the diffusion factor separation criterion for turbulent boundary layers defined by Lieblein is used.

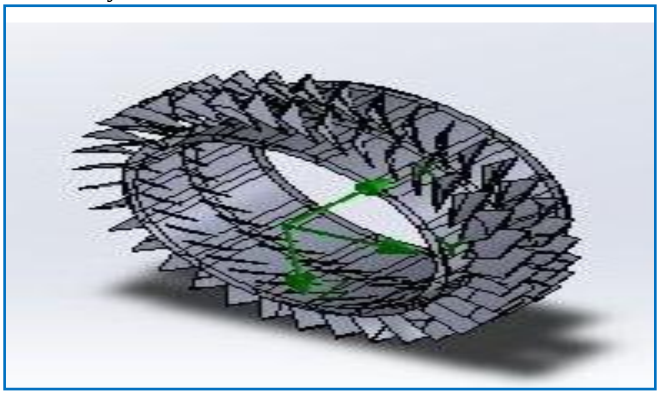

Fig. 3. Meshing of tandem profile at AP=0% and PP=5%

In a single profile, under highly loaded requirements, the rise in pressure could be sufficiently great that the growth of the momentum thickness in generates a separation zone near the trailing edge of the blade.
Whereas in a tandem blade row, the momentum thickness is refreshed by the formation of a new boundary layer at the aft airfoil of the downstream cascade while it is expected that the flow and boundary layer of the forward airfoil do not disturb the rear blade. Thus, the flow through a tandem blade avoids early flow separation resulting in larger values of flow deflections when compared with single airfoils.

TABLE III. BOUNDARY CONDITIONS

Pressure (pa)	Velocity (m/s)	Temperature (k)	Flow angle (front blade) (deg)	Flow angle (aft blade) (deg)
140000	30	300	54	30

D. Results for Tandem design profile1 at AP=0% and PP=5%

1).Contour Pressure Profile: The fig shows that the contour pressure profile of the tandem arrangements. The colors indicate that the respective values of the pressure on the rotors blades

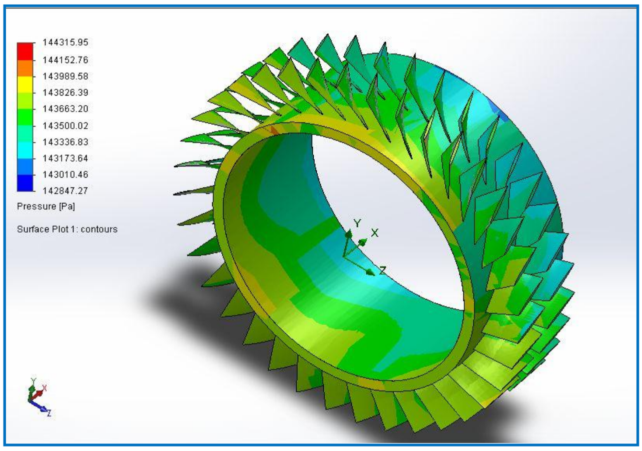

Fig. 4. Pressure Profile (AP=0, PP=5%)

2) Contour Velocity Profile: The fig shows that the contour Velocity profile of the tandem arrangements. The colors indicate that the respective values of the velocity on the rotors blades

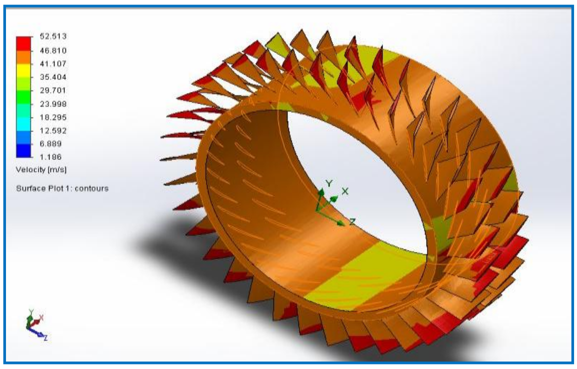

Fig. 5. Velocity Profile (AP=0,PP=5%)

3) C_P Profile (AP=0%,PP=5%): The figure shows that the plot cp vs chord length of the blade. From this plot the maximum value of the cp for the condition (AP=0%, PP=5%) is 0.5.

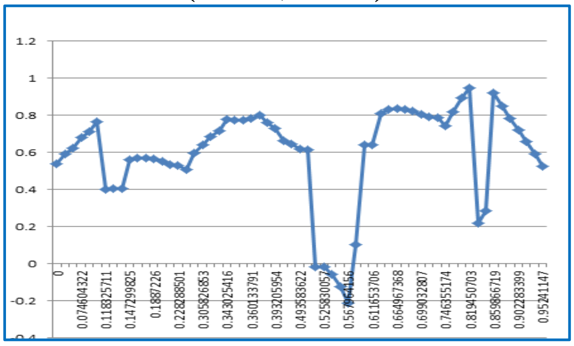

Fig. 6. C_p Profile (C_p Value Vs Chord Length)

E. Results for Tandem design profile2 at AP=0% and PP=50%

1) Pressure Profile: The fig shows that the contour pressure profile of the tandem arrangements. The colors indicate that the respective values of the pressure on the rotors blades

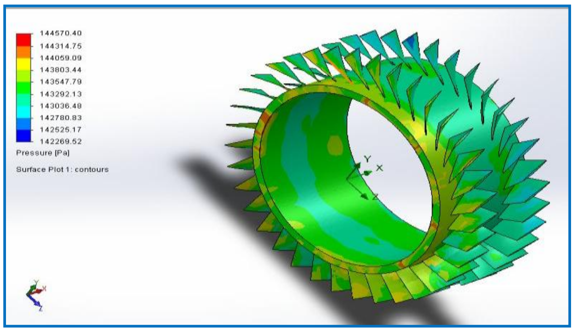

Fig. 7.Pressure Profile (AP=0, PP=50%)

2) Contour Velocity Profile: The fig shows that the contour velocity profile of the tandem arrangements. The colors indicate that the respective values of the velocity on the rotors blades

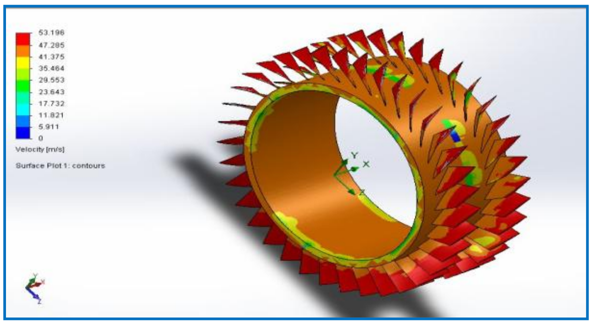

Fig. 8.Velocity Profile (AP=0,PP=50%)

2) CP Profile (AP=0%, PP=50%): The figure shows that the plot cp vs chord length of the blade. From this plot the maximum value of the cp for the condition (AP=0%, PP=50%) is 1.5.

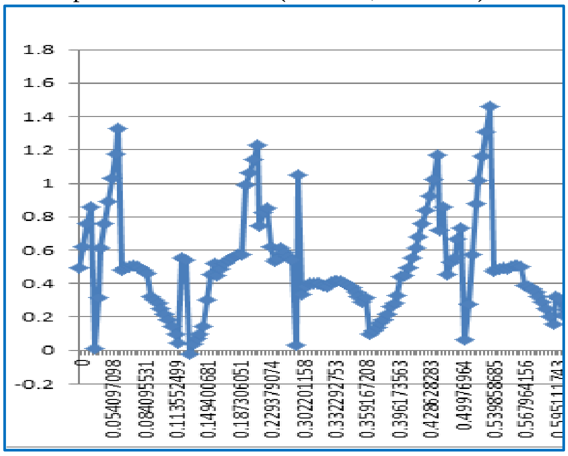

Fig. 9. C_p Profile (C_p Values Vs Chord Length)

F. Results for Tandem design profile3 at AP=10% and PP=90%

1) Pressure Profile: The fig shows that the contour pressure profile of the tandem arrangements. The colors indicate that the respective values of the pressure on the rotors blades

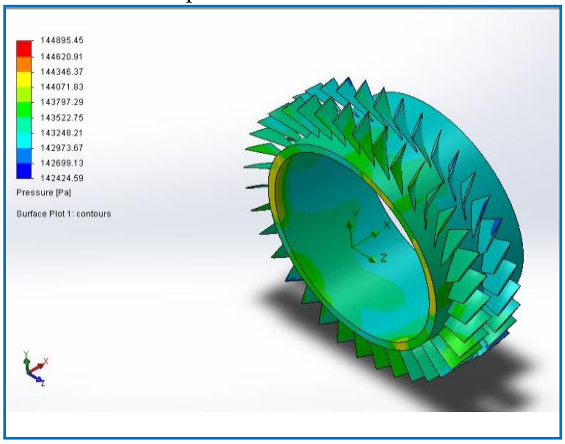

Fig. 10. Pressure Profile(AP=10%,PP=90%)

2) Velocity Profile: The fig shows that the contour velocity profile of the tandem arrangements. The colors indicate that the respective values of thevelocity on the rotors blades

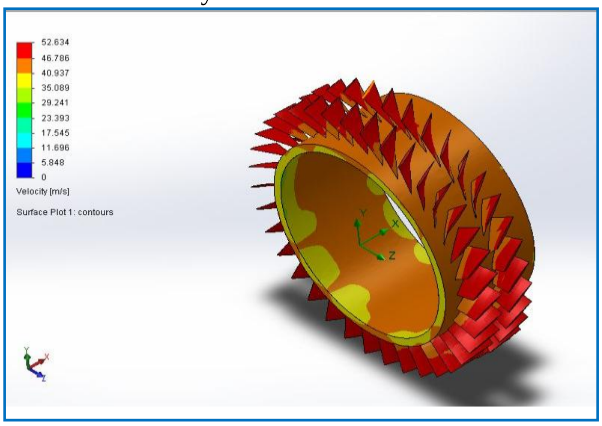

Fig. 11. Velocity Profile (AP=10%,PP=90%)

3) CP Profile (AP=10%,PP=90%): The figure shows that the plot cp vs chord length of the blade. From this plot the maximum value of the cp for the condition (AP=10%,PP=90 %) is 0.3.

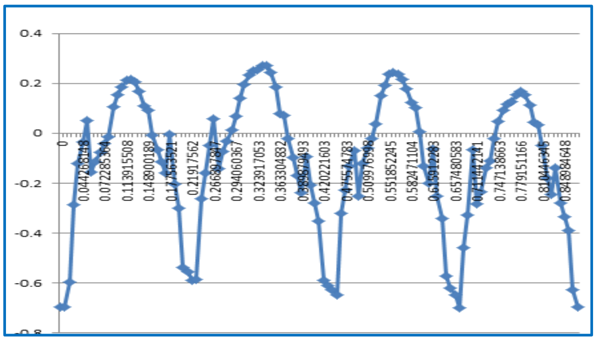

Fig. 12. C_p Profile (C_p Values Vs Chord Length)

G. Results for Tandem design profile 4 at AP=10% and PP=120%

1) Pressure Profile: The fig shows that the contour pressure profile of the tandem arrangements. The colors indicate that the respective values of the pressure on the rotors blades

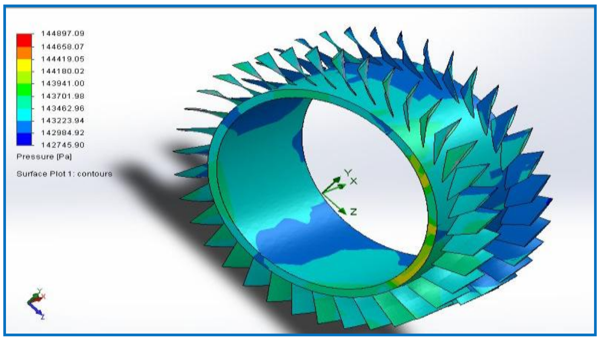

Fig. 13. Pressure Profile (AP=10%, PP=120%)

2) Velocity Profile: The fig shows that the contour velocity profile of the tandem arrangements. The colors indicate that the respective values of the velocity on the rotors blades

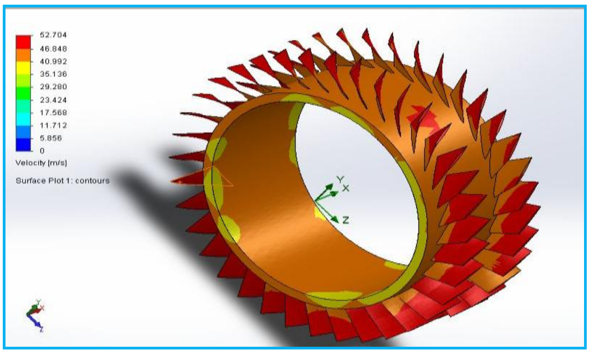

Fig. 14. Velocity Profile(AP=10%,PP=120%)

3) CP Profile (AP=10%,PP=120%): The figure shows that the plot cp vs chord length of the blade. From this plot the maximum value of the cp for the condition (**AP=10%,PP=120**) is 0.5.

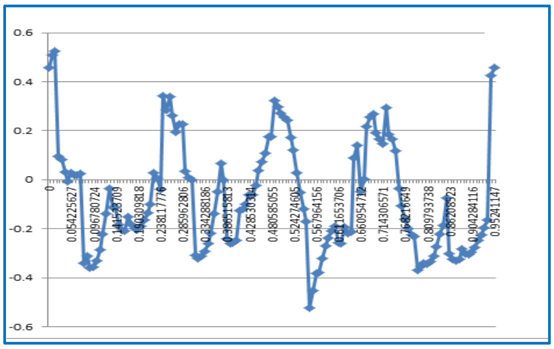

Fig. 15. C_p Profile (C_p Values Vs Chord Length)

III. NUMERICAL ANALYSIS OF THE CONVENTIONAL BLADE ROTOR

A. *Solid Modeling Of The Flow Domain*

The 3D solid modeling's conventional blade arrangements of the research compressor design were made with the help of CAD tools CATIA V5 as shown in Figure below. The following specifications mentioned below are the design parameters were used to make the models. The flow field domain for the baseline configuration has a choice of hybrid grid generation and fixing up the boundary conditions appropriately.

Table III Conventional Specifications

Type of compressor	**Low speed axial flow compressor**
Corrected rotational speed	12930 rpm
Corrected mass flow rate	22 kg/s
Rotor tip diameter	450 mm
Blade profile	NACA 65A006

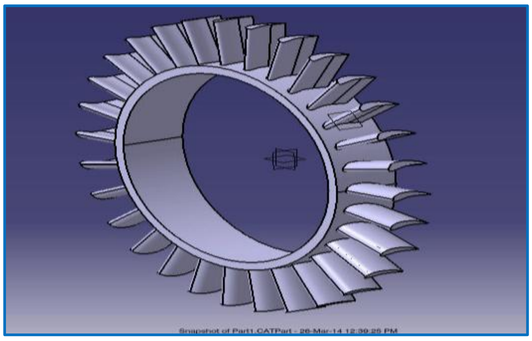

Fig. 16. Conventional Profile

A. Results for conventional profile PP=80%

1) Pressure Profile: The fig shows that the contour pressure profile of the tandem arrangements. The colors indicate that the respective values of the pressure on the rotors blades

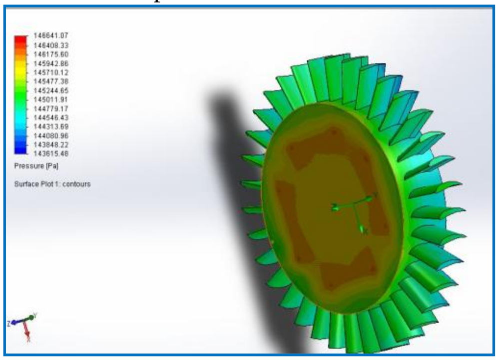

Fig. 17. Pressure Profile PP=80%)

2) Velocity Profile: The fig shows that the contour Velocity profile of the tandem arrangements. The colors indicate that the respective values of the velocity on the rotors blades

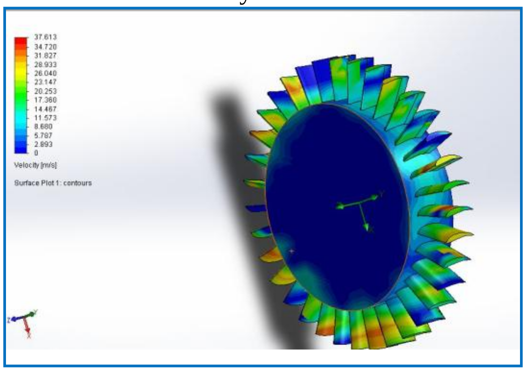

Fig. 18. Velocity Profile PP=80%)

2) CP Profile (PP=80%): The figure shows that the plot cp vs chord length of the blade. From this plot the maximum value of the cp for the condition (AP=0%, PP=80%) is 0.8.

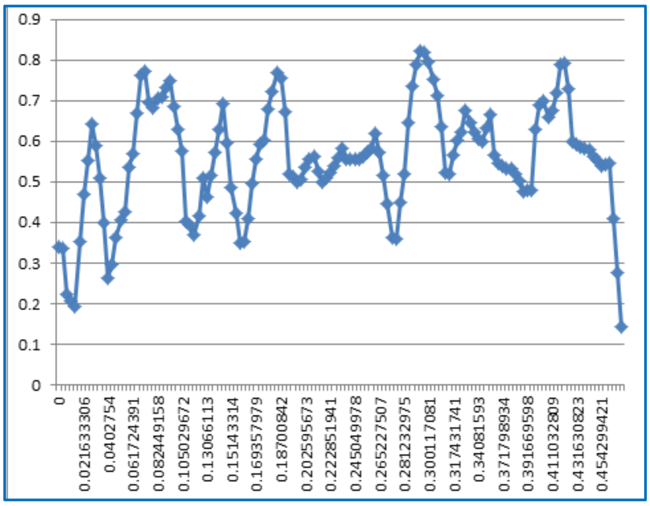

Fig.19. Cp Profile (C_p Values Vs Chord Length)

IV. RESULT AND DISCUSSION

A. Performance Characteristics

From the figure the overall performance characteristics of the compressor at four different cases of tandem arrangements and one conventional arrangement were obtained at off-design rotational speeds of the rotor gives the better performance is tandem profile 2 The table shows that the consolidated comparative Cp value for the four different cases of tandem arrangements and the one conventional arrangement at off design speed, as compared to the design point Parameters.

Table IV. COMPARISONS OF RESULTS

Type of Profile	Parameters	
	Velocity (m/s)	Pressure (Pa)
Tandem Profile 1	30	143500.02
Tandem Profile 2	30	144570.14
Tandem Profile 3	30	143522.75
Tandem Profile 4	30	143223.94
Conventional Profile	30	142546.43

From the Above results it's cleared that the Tandem Profile configuration of the second type is more efficient than the others

V. CONCLUSIONS

The 3-D modeling of the tandem blade rotor is designed in CATIA V5 and then the model is taken for the analysis in ANSYS 12.0 and it was analyzed. The results obtained from the plots values are tabulated. Through this study it has been clearly brought out that the tandem arrangement with AP=0%, PP=50% conditions of the compressors rotor blades are more efficient than the conventional arrangements.

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