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Performance analysis of the centrifugal pump impeller by modifying the vane profile

Dr. T. Prabu, Professor
Mechanical Engineering
PSG College of Technology
Coimbatore, Tamil Nadu.
prabu.thangavel@gmail.com

Dr. P. Vishwanathan, Assistant Professor
Mechanical Engineering
PSG College of Technology
Coimbatore, Tamil Nadu.
vichu.cbe22@gmail.com

Mr. R. Krishna Kumar M.E.,
Energy Engineering
PSG College of Technology
Coimbatore, Tamil Nadu
krishnaravi1604@gmail.com

Mr. M. Kailash M.E.,
Energy Engineering
PSG College of Technology
Coimbatore, Tamil Nadu
kailashvasanthi@gmail.com

ABSTRACT

Centrifugal pumps are inevitable part of the modern industrial world and are significant consumer of the energy resource globally. Operating the pump at its maximum possible efficiency is the best way to reduce the energy wastage. This article is devoted to study the impeller of the centrifugal pump by changing the nature of impeller shape and how the efficiency of the impeller changes when compared to the existing design. With the help of commercial 3-D numerical software called Ansys CFX the modified impellers are analyzed. Comparison of computation results of the modified and conventional vane profile provides the good insight on how the head development and efficiency is affected by vane profile.

KEY WORDS

Centrifugal pump; Impeller; CFD.

1. Introduction

A pump is a devise, which converts mechanical energy to hydraulic energy. Pumps play an important role in numerous household and industrial applications. A centrifugal pump is the most commonly employed in industrial areas, such as water, sewage, drainage and the chemical industry. The researchers have performed various studies to understand the design parameters. Due to the necessity of the pump for the industry, optimization using mechanical concepts has recently been studied in order to make higher-efficiency pumps with higher heads [5]. An impeller, among all of the components of the pump, has the biggest influence on performance of the pump.

Computational fluid dynamics (CFD) analysis is being progressively applied in the design of centrifugal pumps. With the help of the CFD approach, the complex internal flows in water pump impellers can be visualised which are not fully understood yet. It is also used to speed up the pump design process. Thus, CFD plays an important role for pump design.

Ansys CFX is a high-performance computational fluid dynamics (CFD) software tool that delivers reliable and accurate solutions quickly and robustly across a wide range of CFD and multi-physics applications. CFX is recognized for its outstanding accuracy, robustness and speed with rotating machinery such as pumps, fans, compressors and hydraulic turbines.

2. CFD Governing Equations

Basically the fluid flow is governed by continuity, momentum and energy equations. As pump is a liquid turbo machinery, during the operation there is a negligible variation in temperature so in this case energy equation is not concerned for simulation. The flow of fluid inside the impeller channel is turbulent. Hence in order to capture the turbulence phenomenon turbulence equation is also incorporated.

A. Continuity Equation

Continuity equation is based on the fact that the mass is conserved in a flow. This can be represented by,

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0$$

B. Momentum Equation

Momentum equation is based on the fact that the momentum is conserved in the fluid flow. This can be expressed as,

$$\frac{\partial(\rho u)}{\partial t} + \nabla \cdot (\rho u \mathbf{V}) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x$$

$$\frac{\partial(\rho v)}{\partial t} + \nabla \cdot (\rho v \mathbf{V}) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y$$

$$\frac{\partial(\rho w)}{\partial t} + \nabla \cdot (\rho w \mathbf{V}) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z$$

C. Turbulence Equation

k-ϵ model is used to capture the turbulence phenomenon in the fluid flow inside the impeller.

$$\frac{Dk}{Dt} = \frac{1}{\rho}\frac{\partial}{\partial x_j}\left[\left(\frac{\mu_t}{\sigma_k} + \mu\right)\frac{\partial k}{\partial x_j}\right] + \frac{\mu_t}{\rho}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j} - 2\upsilon\left(\frac{\partial k^{1/2}}{\partial x_j}\right)^2 - \varepsilon$$

The above equation is the k-equation where 'k' represents the turbulence kinetic energy in the fluid flow.

$$\frac{D\varepsilon}{Dt} = \frac{1}{\rho}\frac{\partial}{\partial x_j}\left[\left(\frac{\mu_t}{\sigma_\varepsilon} + \mu\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{C_{1\varepsilon}\mu_t}{\rho}\frac{\varepsilon}{k}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j} - C_{2\varepsilon}\frac{\varepsilon^2}{k} - 2\frac{\upsilon\mu_t}{\rho}\left(\frac{\partial^2 U_i}{\partial x_j \partial x_i}\right)^2$$

This equation is known as ϵ-equation where 'ϵ' represents dissipation rate of kinetic energy in the fluid flow.

3. Impeller Design

a. Existing Vane Profile

The existing impeller from the industry is selected as a base model. The details of the impeller are specified below in table 1.

Inlet vane angle	31.95 deg
Outlet vane angle	35.11 deg
Outer diameter	90 mm
Eye diameter	57 mm
Hub diameter	27 mm
Breath	7 mm
Outlet area	0.00169658 m^2
No. of blades	8

Table.1

The existing vane profile provides a basis for analyzing different advancement in the impeller design and pump's performance. The existing vane is modeled using a commercial modeling tool SOLIDWORKS.

The 3D CAD design for the vane profile is specified below in Figure 1.

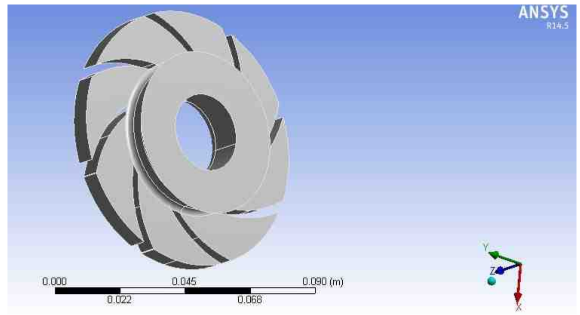

Figure.1 CAD model (Existing impeller)

b. Forward deflected vane profile

In forward deflected impeller model, the vane profile is given a positive deflection of 3 mm from the existing vane profile position and gradually decreased towards the central point to zero and then it is given a negative deflection of 3 mm from the central position of the vane profile and decreased gradually towards the tip. Due to the change in vane profile the inlet and outlet vane angle got changed.

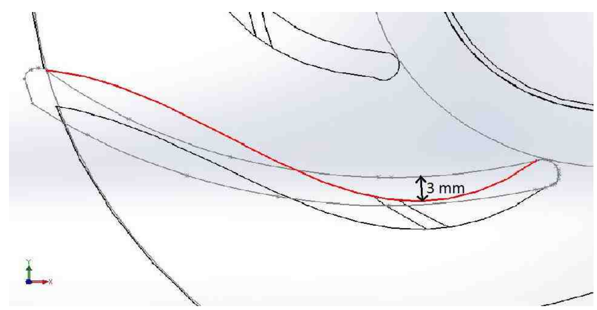

Figure.2 Vane profile of forward deflection

The specification for the forward deflected impeller is given in the table 2.

Inlet vane angle	55.48 deg
Outlet vane angle	70.55 deg
Outer diameter	90 mm
Eye diameter	57 mm
Hub dia.	27 mm
Breath	7 mm
Outlet area	0.00177795 m^2
No. of blades	8

Table.2

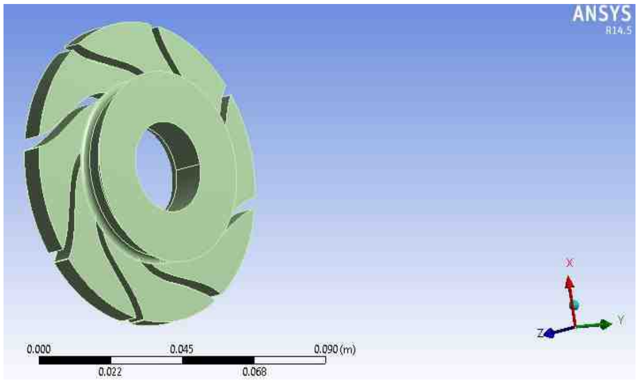

Figure.3 CAD model (Forward deflection)

c. Backward deflected vane profile

In the backward deflected model, the vane profile is gradually decreased to the deflection of 3 mm and then increased to zero at the midpoint and then the vice versa is done for the next half of the profile.

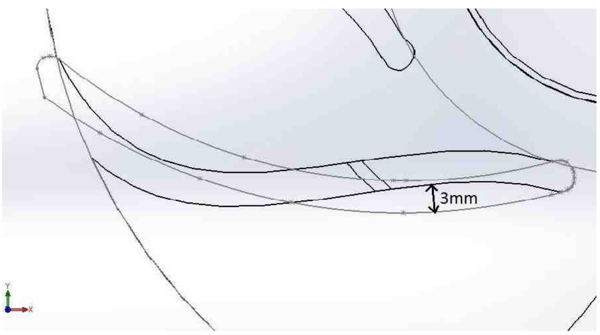

Figure.4 Vane profile of backward deflection

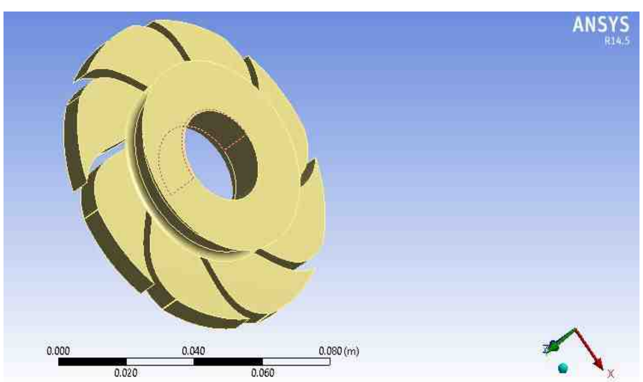

Figure.5 CAD model (Backward deflection)

The specification of the modified impeller is given in the table.3

Inlet vane angle	0.2 deg
Outlet vane angle	23.07 deg
Outer diameter	90 mm
Eye diameter	57 mm
Hub diameter	27 mm
Breath	7 mm
Outlet area	0.00150763 m^2
No. of blades	8

Table.3

4. MESHING

The eight bladed impeller used in the analysis is meshed using Ansys14.5 Software. Unstructured tetrahedral cells are used for meshing the fluid domain. Mesh independent analysis also done to make sure the result is unaffected by the mesh size. The meshed model of existing, backward and forward deflected impellers is given in the figure 6, 7 and 8 respectively.

a. Existing vane profile

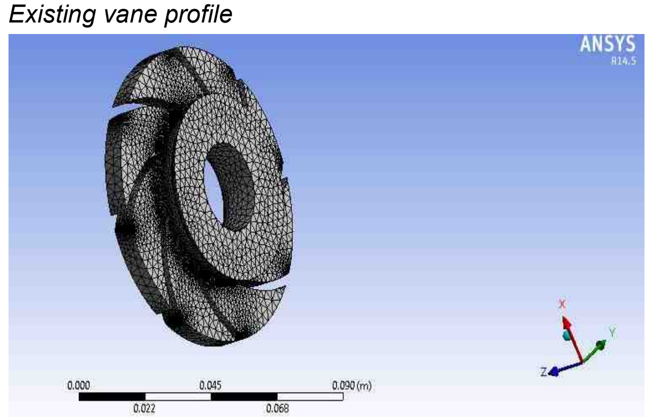

Figure.6 Meshed model (Existing impeller

Nodes	58567
Elements	303165

Table.4

b. Forward deflected vane profile

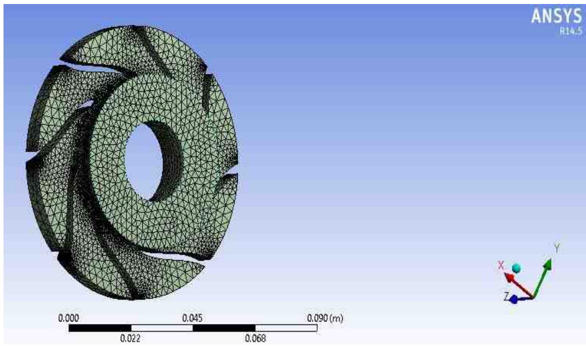

Figure.7 Meshed model (Forward deflection)

Nodes	77805
Elements	409518

Table.5

c. Backward deflected vane profile

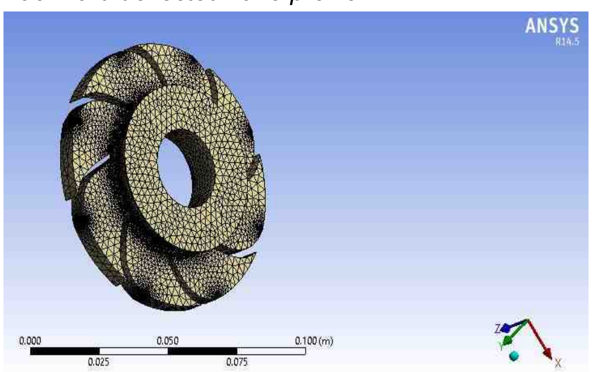

Figure.8 Meshed model (Backward deflection)

Nodes	81875
Elements	433041

Table.6

5. Boundary Conditions

Boundary conditions are set of conditions specified for the behavior of the solution to a set of differential equation at the boundary of its domain. Mathematical solutions are determined with the help of boundary conditions to many physical problems. These conditions specify the flow and thermal variables on the boundaries of a physical modal.

The boundary conditions specified for the analysis are tabulated below.

Boundary Conditions	
Rotational speed of the impeller	2880 rpm
Inlet Pressure	1 atm. (submersible pump)
Mass flow rate	3.5 kg/s

Table.7

6. Results And Discussions

a. Existing vane profile

The CFD analysis of the existing impeller is carried-out for analysing the pressure development and also to find the efficiency of the impeller at the specified boundary conditons. The results from the CFD analysis is specified below,

Head developed	10.05 m
Torque required	1.276 Nm
Impeller efficiency	90.10%

Table.8

The pressure and velocity distribution of the existing vane impeller is shown in figure.

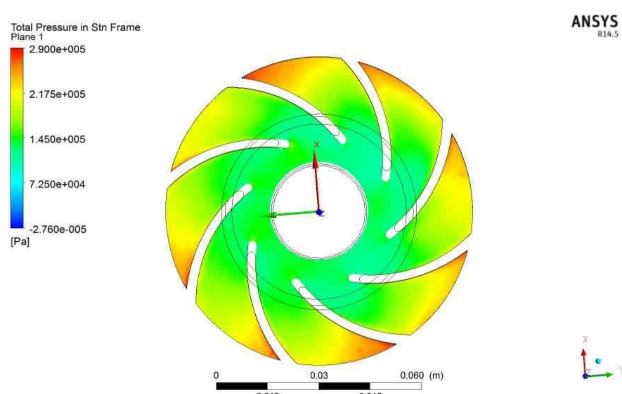

Figure.9 Pressure distribution of existing vane

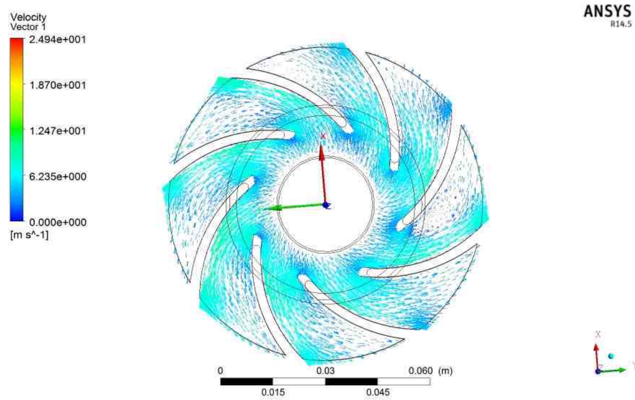

Figure.10 Velocity distribution of existing vane

Velocity distribution shows the recirculation and secondary loses occurs near the outlet of the impeller which leads to the loss of energy imparted by the impeller to fluid.

b. Forward deflected vane profile

The CFD results shows that the positive deflection on the vane profile gives the higher head at the outlet compared to the existing vane profile. Though the impeller gives higher head, it requires more torque for developing pressure of the fluid. In turn this needs a higher power input for operation. Such that the hydraulic efficiency is lower than that of the existing vane profile.

Head developed	12.82 m
Torque required	1.569 Nm
Impeller efficiency	87.58%

Table.9

The figures show the pressure and velocity distribution on the forward deflected vane profile respectively.

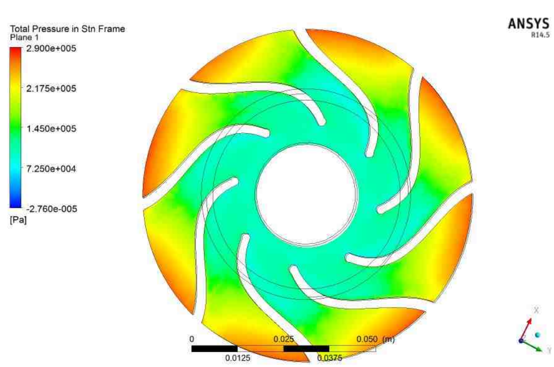

Figure.11 Pressure distribution of forward deflected vane profile

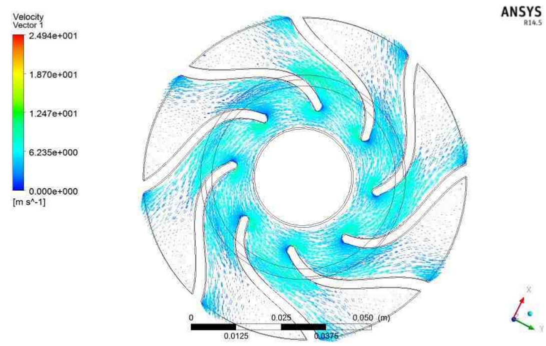

Figure.12 Velocity distribution of forward deflected vane profile

Due to the change in vane profile the length of the vane has been increased so that the energy imparted by the impeller on the fluid also increases. Due to change in vane profile the point at with the separation take place is moved little further than existing impeller.

c. Backward defleclected profile

In the backward deflected vane profile model, it is observed that the head developed is much lower than both existing and forward deflected vane profiles and the torque required for developing the pressure is also low. The power required for operating the impeller is obviously low and shows a lower hydraulic efficiency than both the existing and forward deflected vane profiles.

Head developed	5.46 m
Torque	0.9149 Nm
Impeller efficiency	68.20%

Table.10

The figures shows the pressure and velocity distribution on the vane profile in backward deflected impeller respectively.

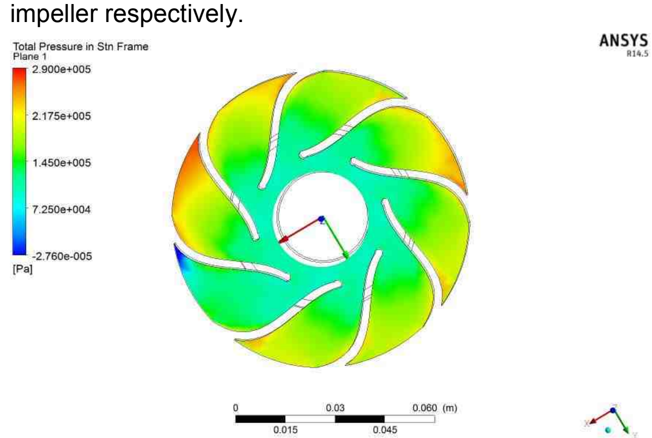

Figure.13 Pressure distribution of backward deflected vane profile

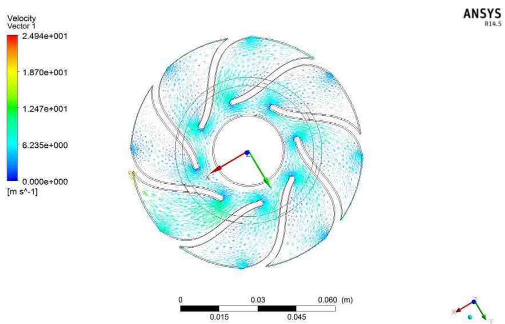

Figure.14 Velocity distribution of backward deflected vane profile

In backward deflected vane profile even-though the length of the vane is high when compared to existing vane the energy imparted by the impeller to fluid is decreased this may be due to the sudden change in cross section area of flow passage with leads to larger flow recirculation.

7. Conclusion

Parameters	Normal Vane profile	Forward deflected vane profile	Backward deflected vane profile
Head developed	10.05 m	12.82 m	5.46 m
Torque required	1.27 Nm	1.569 Nm	0.9149 Nm
Impeller efficiency	90.10%	87.58%	68.20 %

Table. 11

This analysis gives an idea on impeller vane profile over the performance and efficiency of the impeller. From the table, we can conclude that the forward deflected vane profile shows better head development for same speed and flow rate compared with normal vane and backward deflected vane profile. Even though the power required for developing the pressure in the forward deflected profile is higher, it develops higher head.

8. Reference

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LIST OF FIGURES:

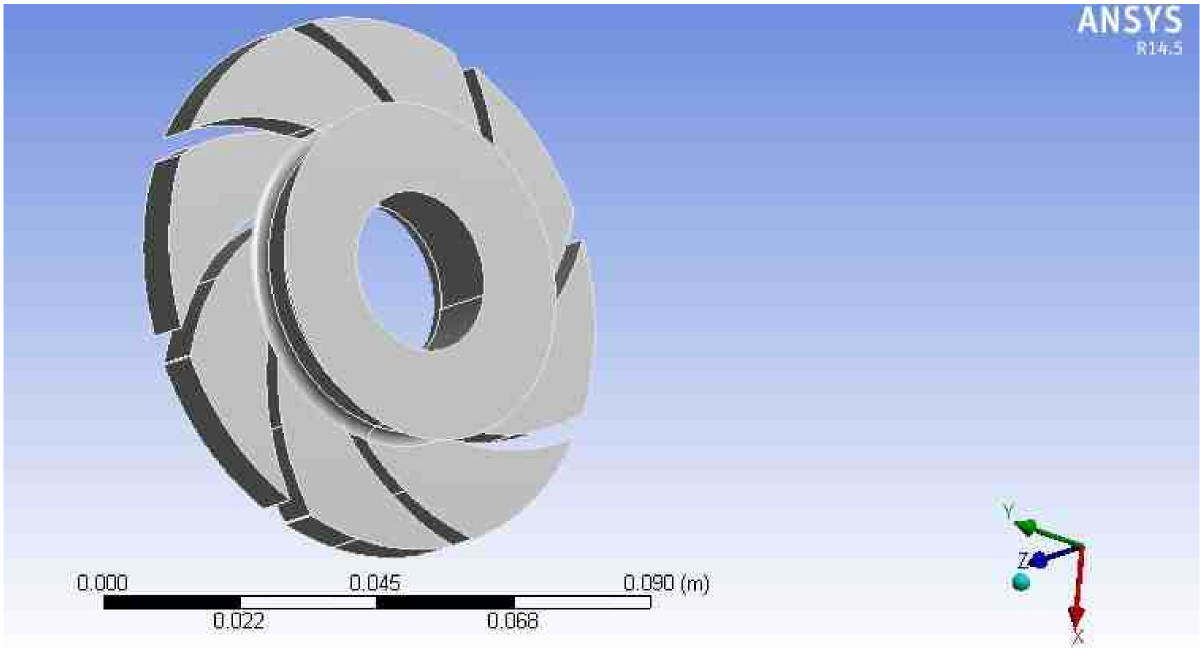


Figure.1 CAD model (Existing impeller)

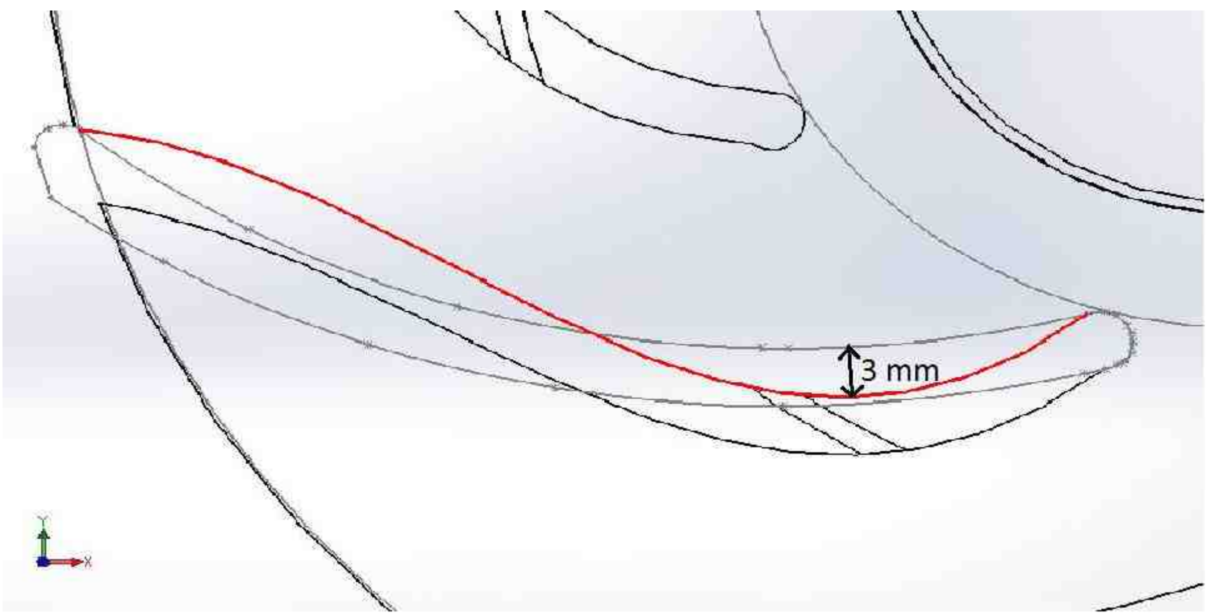


Figure.2 Vane profile of forward deflection

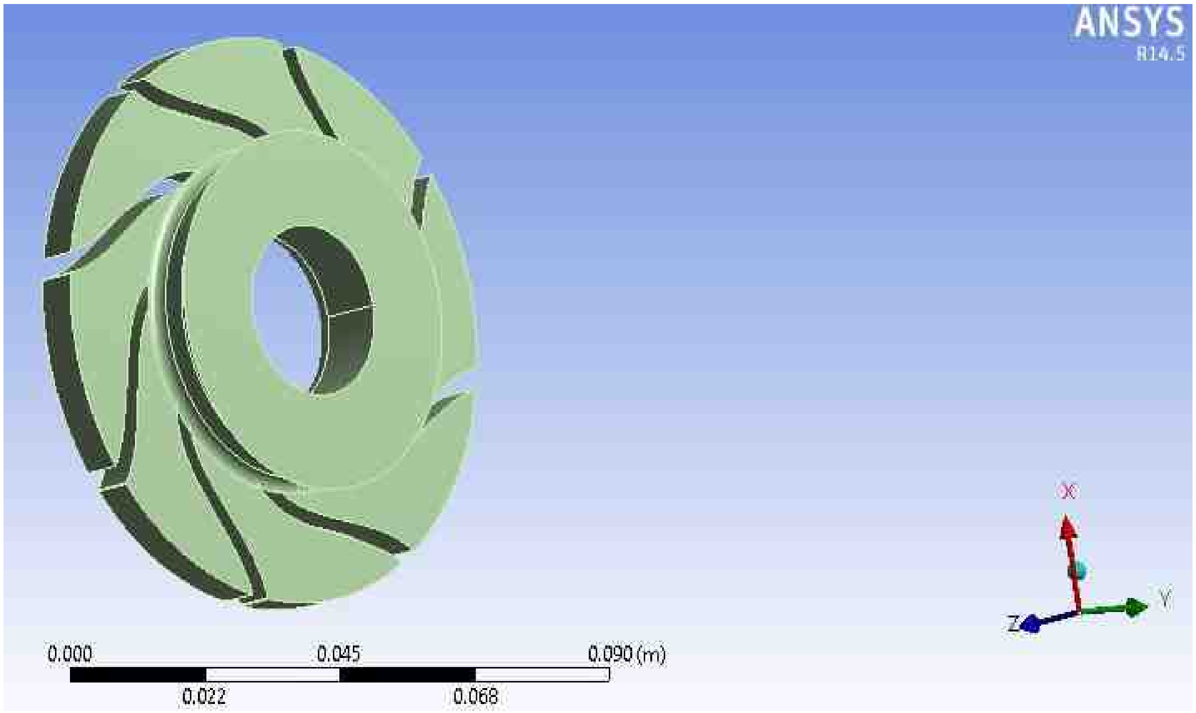


Figure.3 CAD model (Forward deflection)

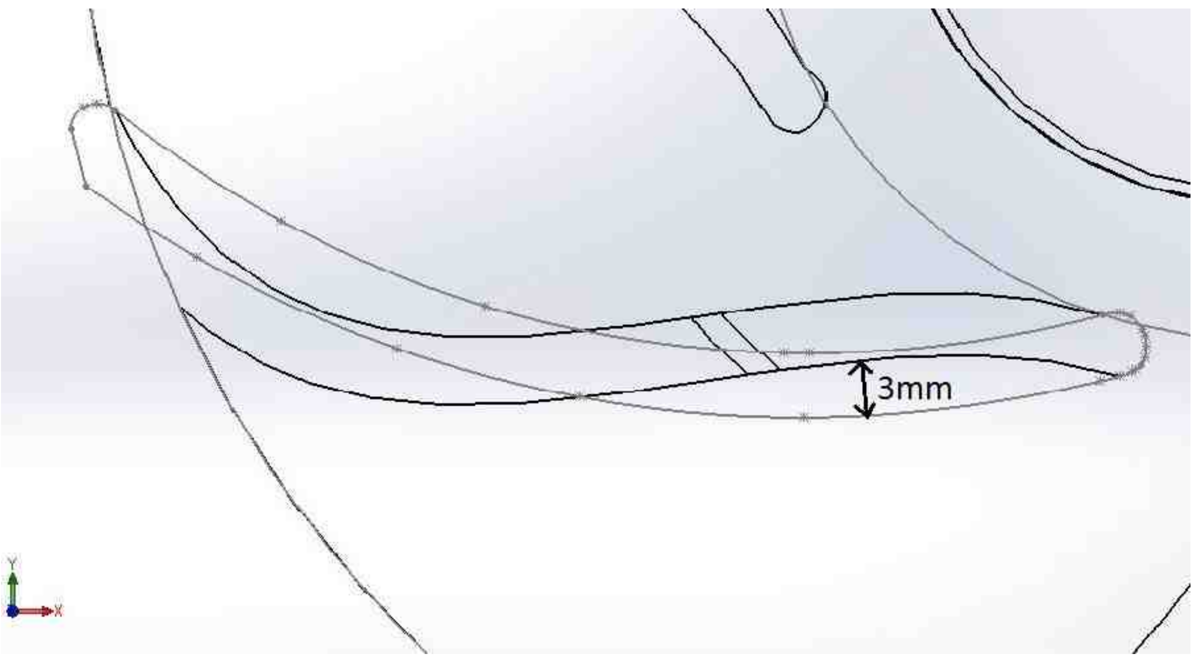


Figure.4 Vane profile of backward deflection

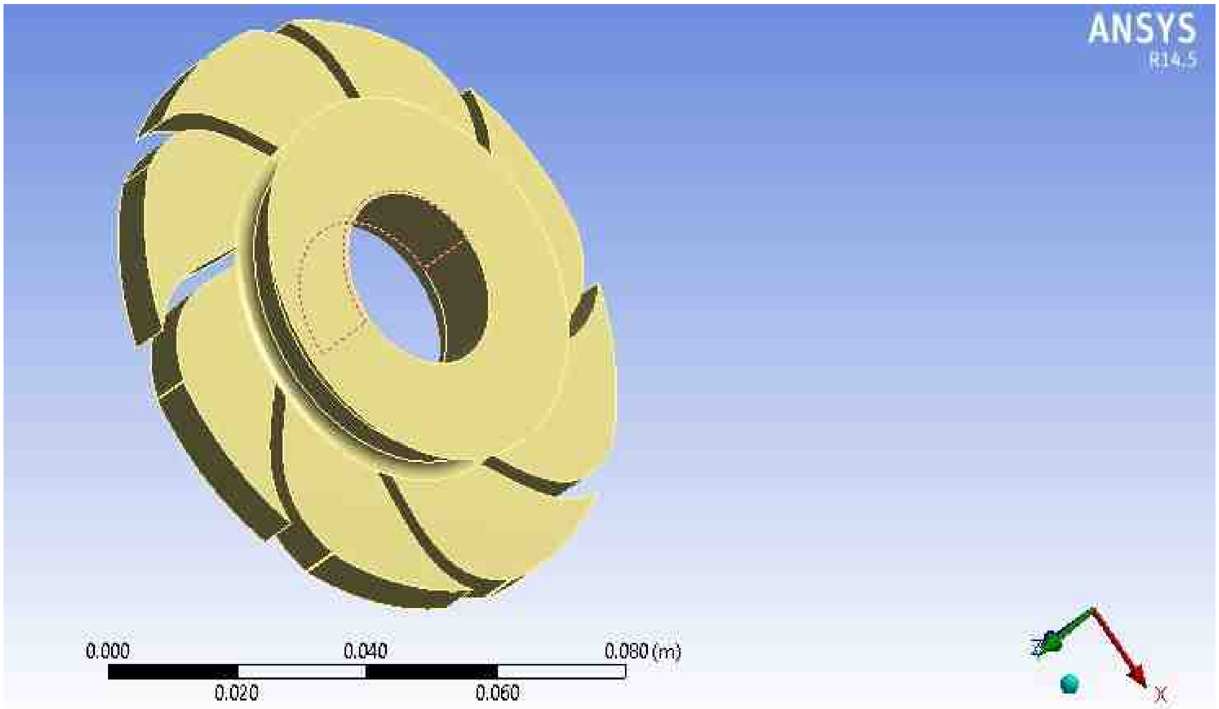


Figure.5 CAD model (Backward deflection)

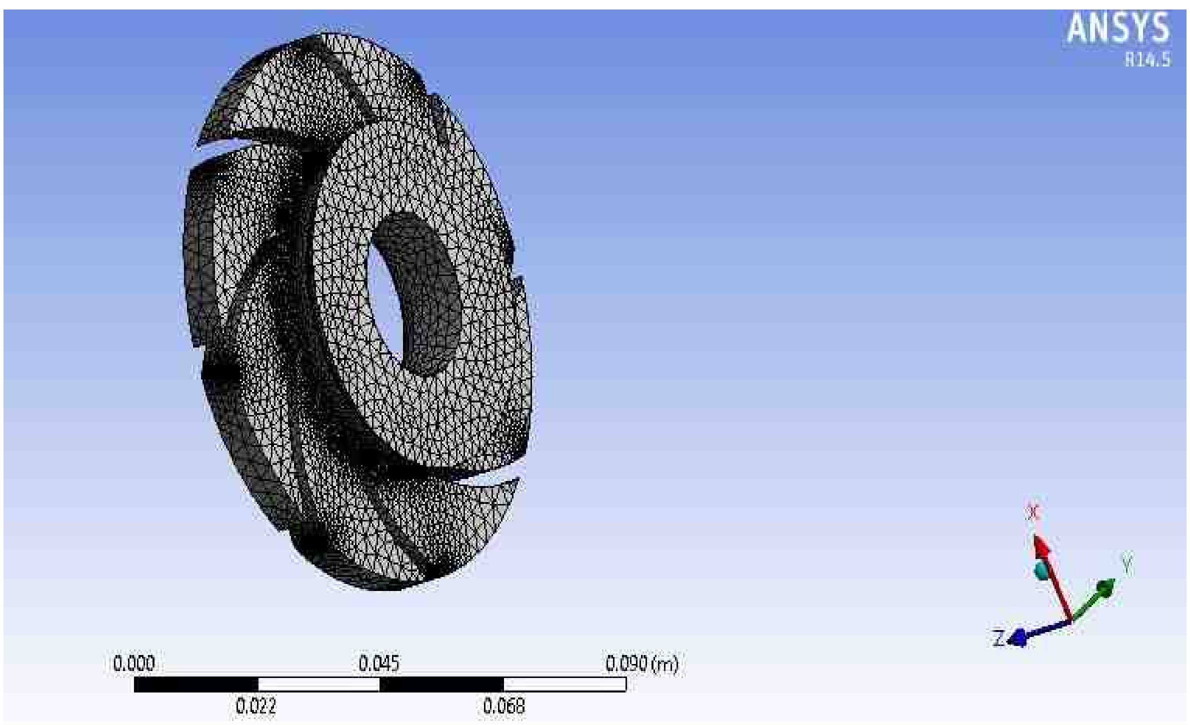


Figure.6 Meshed model (Existing impeller)

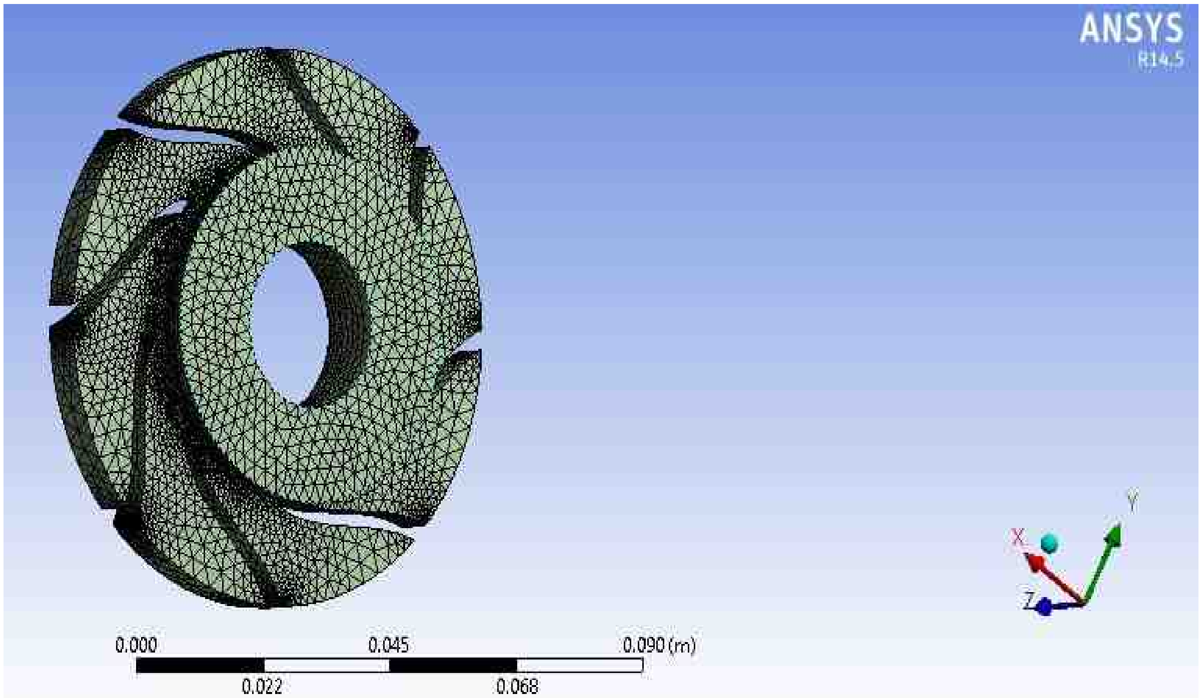


Figure.7 Meshed model (Forward deflection)

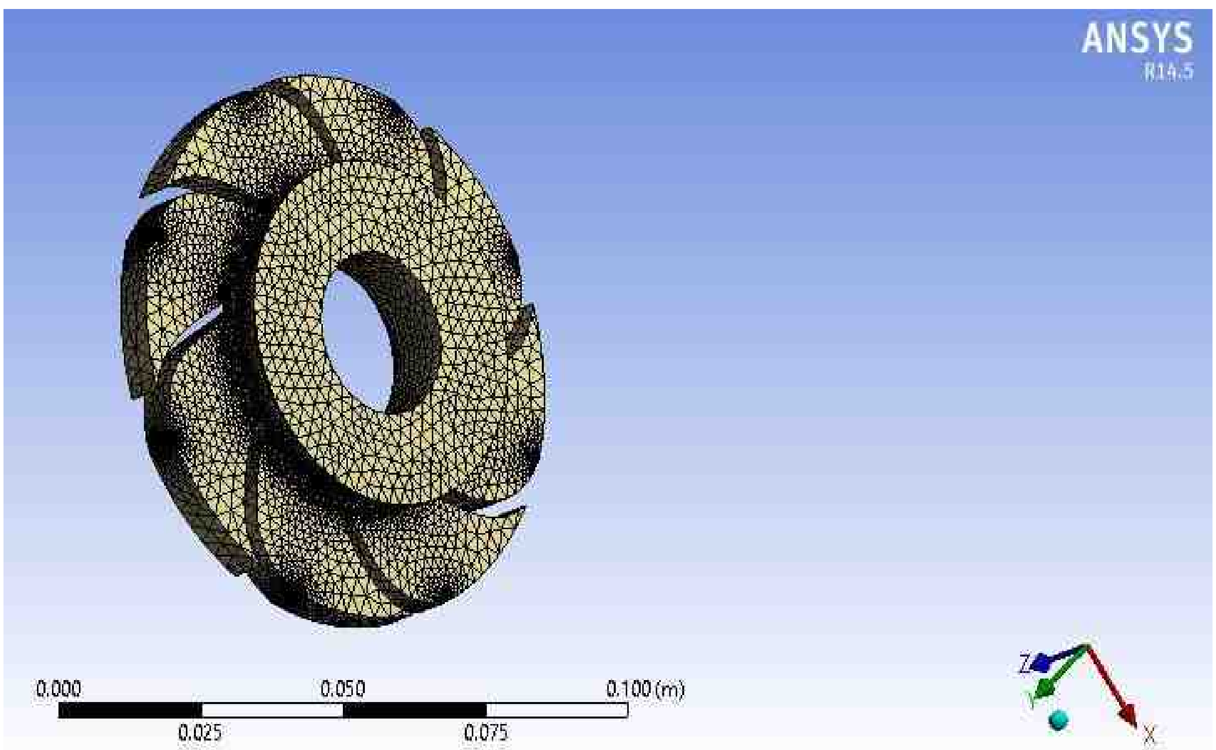


Figure.8 Meshed model (Backward deflection)

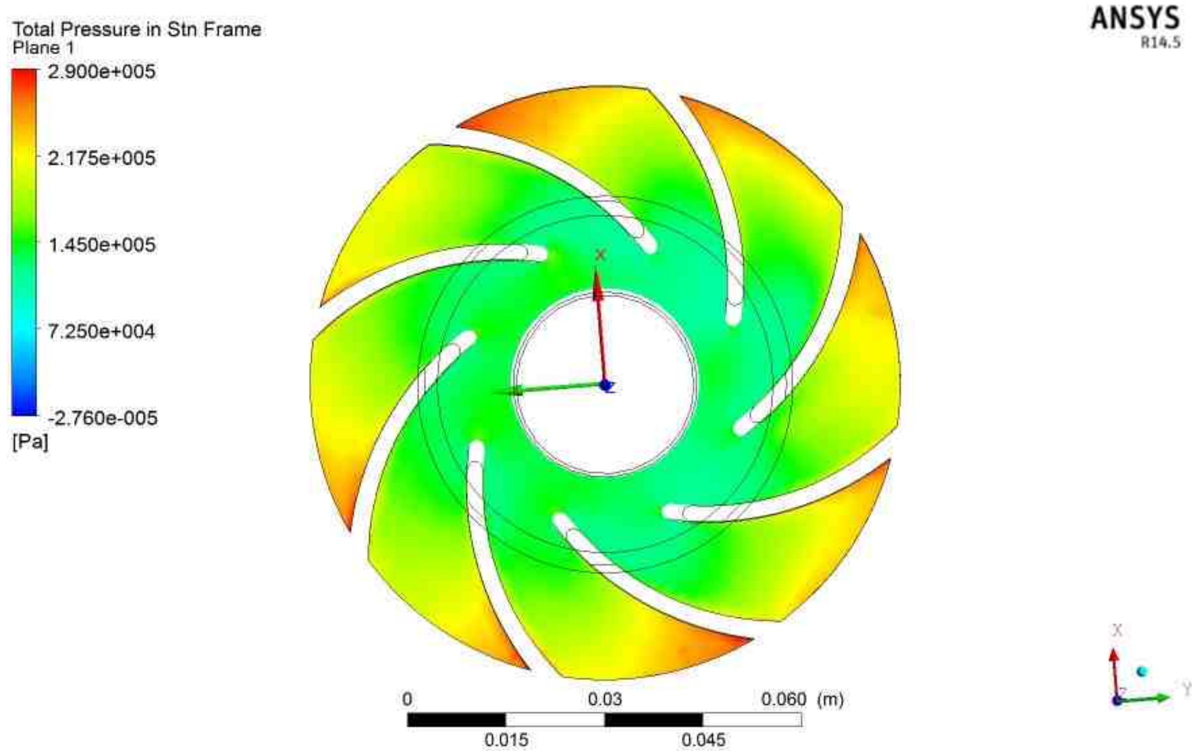


Figure.9 Pressure distribution of existing vane

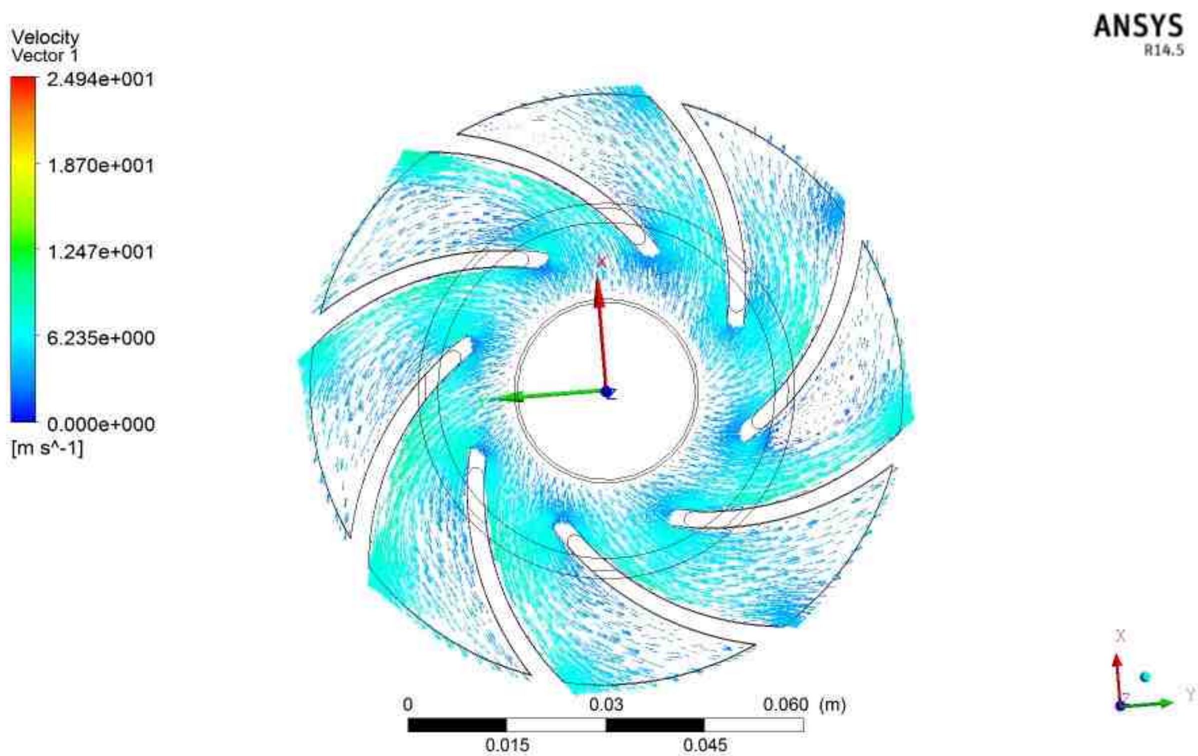


Figure.10 Velocity distribution of existing vane

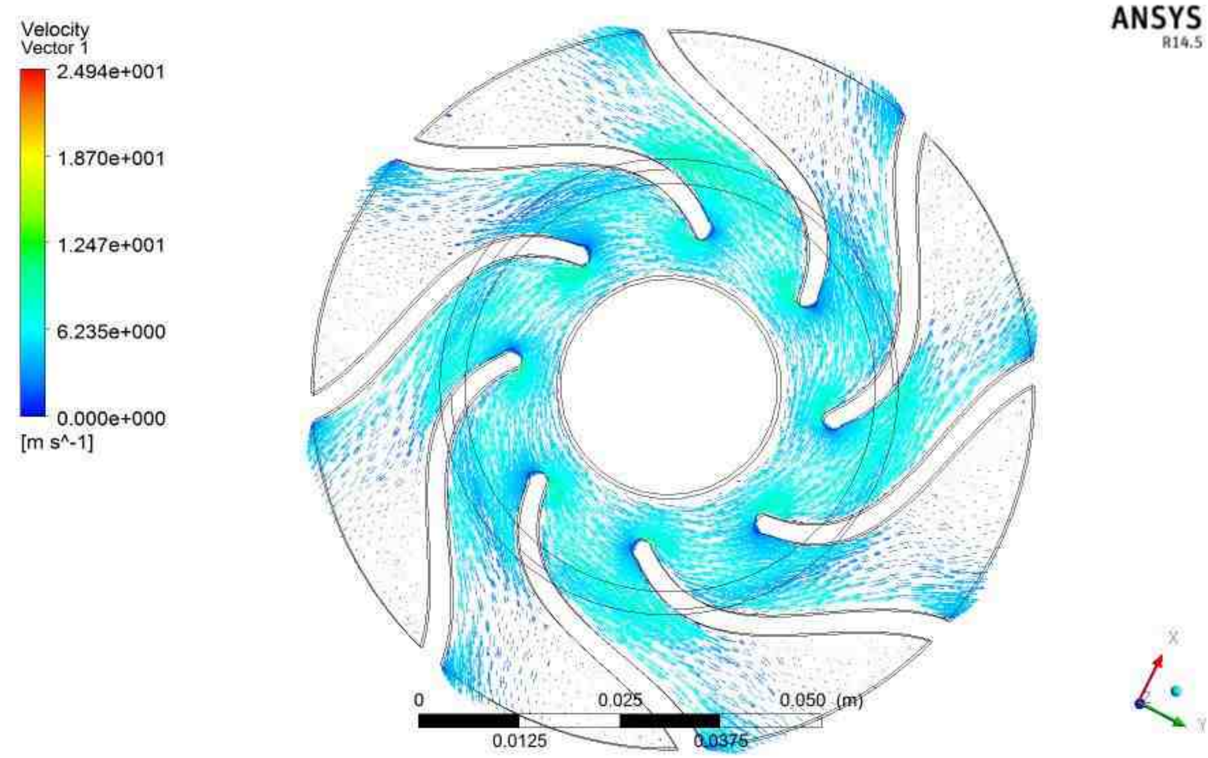
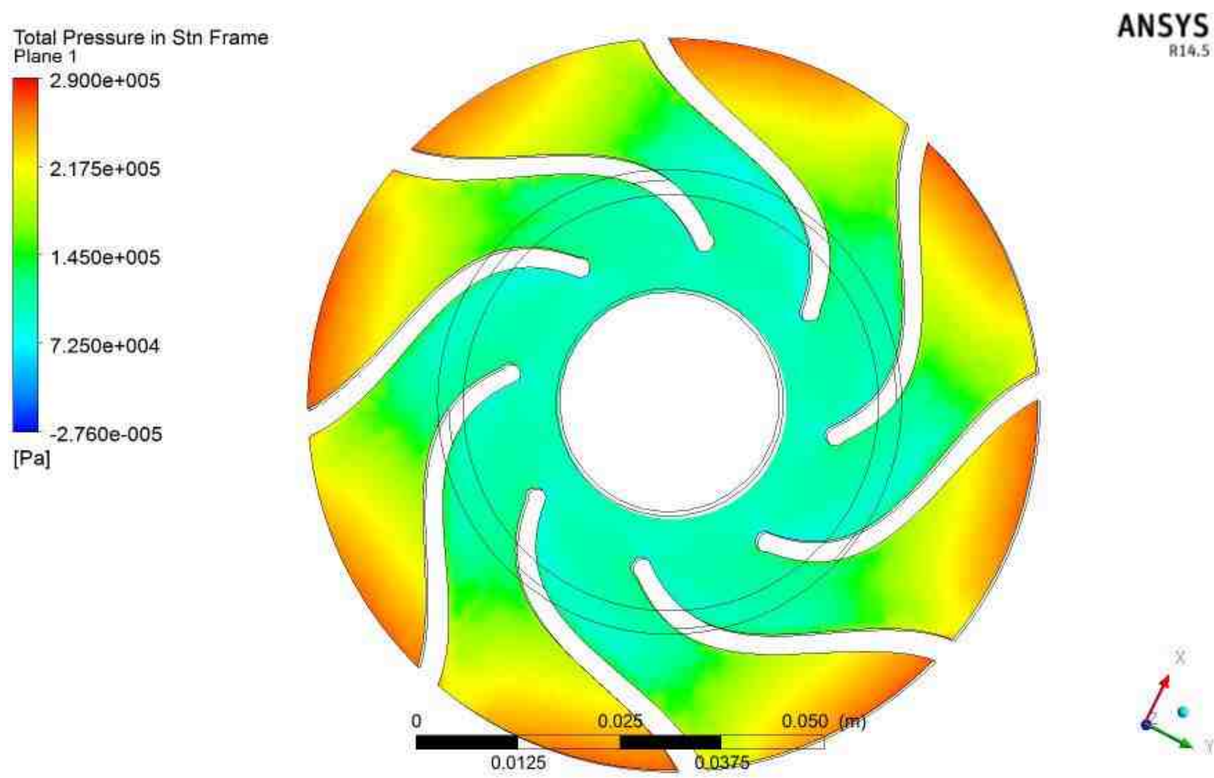


Figure.12 Velocity distribution of forward deflected vane profile



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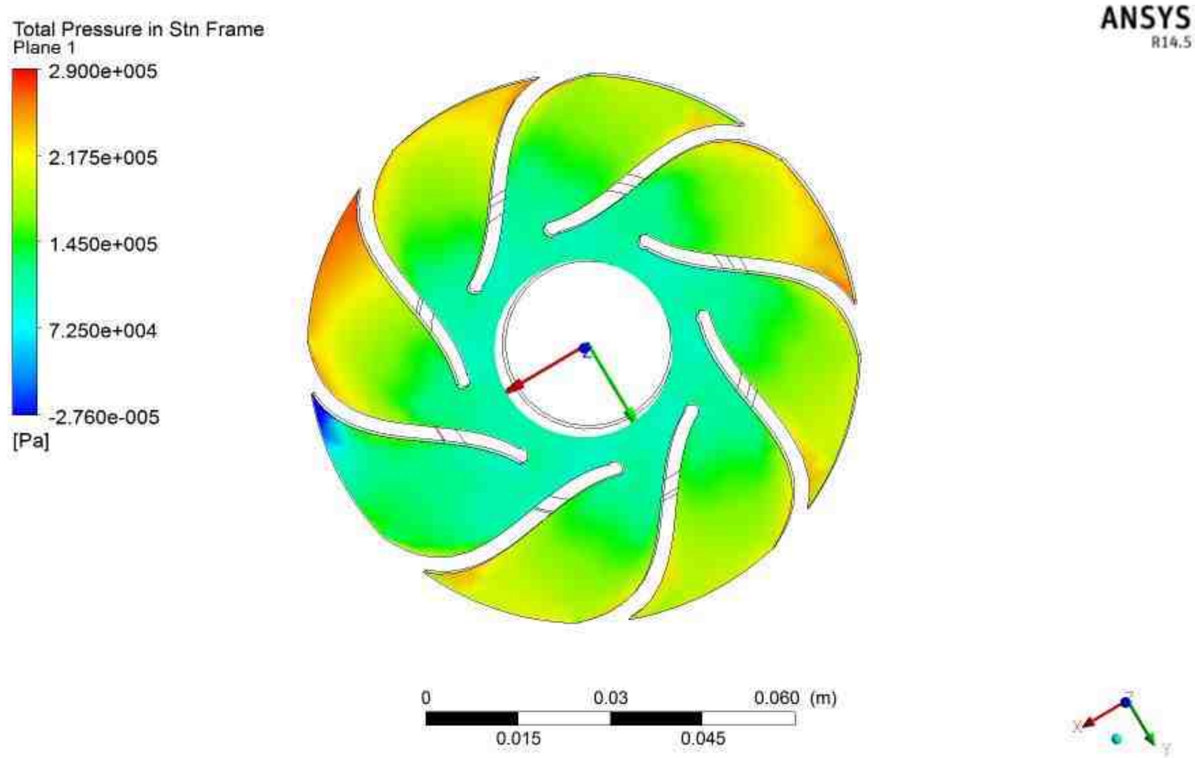

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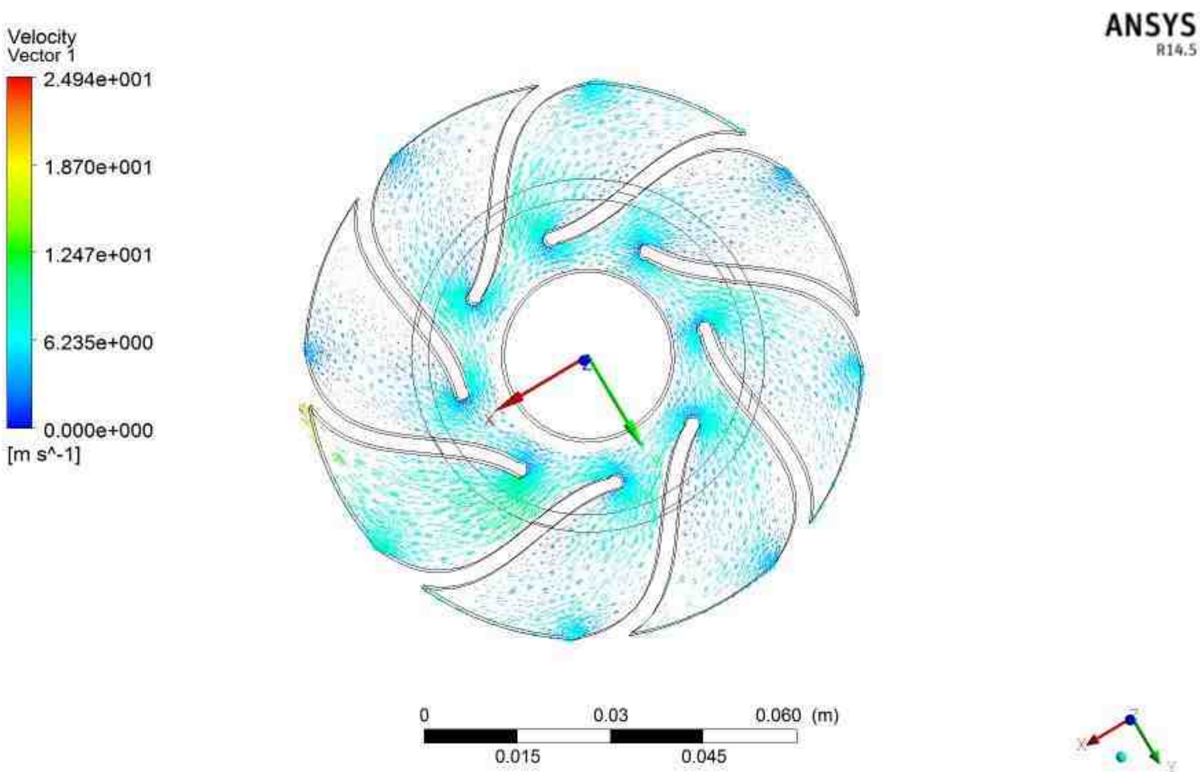

Figure.14 Velocity distribution of backward deflected vane profile

Presenting author Biodata

Name	:	KRISHNA KUMAR R
Designation	:	P G Scholar
Company	:	PSG College of technology
Qualification	:	M.E
Area of Expertise	:	Energy, Thermal and fluid science

Significant Achievements: nil

Number of Papers Published in Journals: nil

Number of Papers Published in Conferences: nil