NMM3519 – ADVANCED THERMOFLUIDS

OPTIMAL DESIGN OF A VOLUTE FOR A COMPRESSOR

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Abstract

The purpose of this report is that the optimisation of turbo machines compressor design utilising computational fluid dynamics (CFD), with a particular emphasis on volute designs. Aerodynamic effectiveness was assessed for several volute designs using SolidWorks and Ansys Workbench Fluent. Proposing an optimised volute geometry to improve compressor effectiveness while the research emphasises the critical role that CFD plays in contemporary engineering. This study provides useful insights for enhancing the performance of turbomachinery and emphasises the importance of CFD in the design process. And to give a new optimal volute design for better aerodynamic characteristics and performance of the compressor.

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Introduction

Within the field of fluid mechanics known as computational fluid dynamics (CFD), situations involving the movement of fluids are analysed and solved through the application of algorithms and mathematical analysis. The computations needed to model the interactions of liquids and gases against surfaces determined by boundary conditions must be carried out by computing. Software that improves the speed as well as precision of complicated simulation circumstances, such as turbulent or transonic flows, is being developed because of current studies. Numerous sectors of engineering, including aviation, architectural, automotive, biological, electronic devices, and machines, as well as climate computations, oceanic flows, and cardiovascular fluxes utilise computational fluid dynamics (CFD). Compared to other engineering applications, CFD is more important in the aerodynamic design, pressure recovery, velocity, and of turbomachinery. With growing dependence on mathematical estimation of flow, it is now impossible to build an advanced compressor or turbine without the assistance of computational fluid dynamics (CFD). The benefits of CFD in turbomachinery include decreased design cycles, higher efficiency, lighter weight, and lower costs (Pinto et al., 2016).

In this report, the entire turbomachine compressor components have been designed using SolidWorks, such as impellers and impeller blades, with different types of volute design to evaluate optimal values, as well as an inducer and diffuser. And then, to get optimal solution for different designs of the volute, the compressor has been imported in Ansys workbench, there carried out detailed analysis of the compressor by computing performance characteristics values such as pressure recovery, friction co-efficient, and overall efficiency.

Objectives

- To design various types of volutes for the same boundary conditions.
- To understand aerodynamic flow of the volute for their performance characteristics.
- To quantitatively evaluate the different volutes by their aerodynamic characteristics.
- To propose the optimised volute geometry for its improved performance.
- To have a systematic understanding on flow analysis using mathematical principles.
- To demonstrate critical understanding of techniques utilized in CFD analysis.

Geometry Overview

SolidWorks Models

Utilized SolidWorks CAD software to design components of turbomachine compressor such as impeller and volute with different cross-sectional area.

Impeller

A liquid that receives energy from an impeller in a compressor that uses centrifugal force. The impeller is made up of two main parts which are the radial blades, how centrifugal force transfers power and an inducer, which could be an axial-flow rotors. The axial path of circulation approaches the impeller, while the radial path of flow releases it. The alterations in flow patterns lead to variances in acceleration between hubs to shroud, which affect the compressor design process (Boyce, 2012).

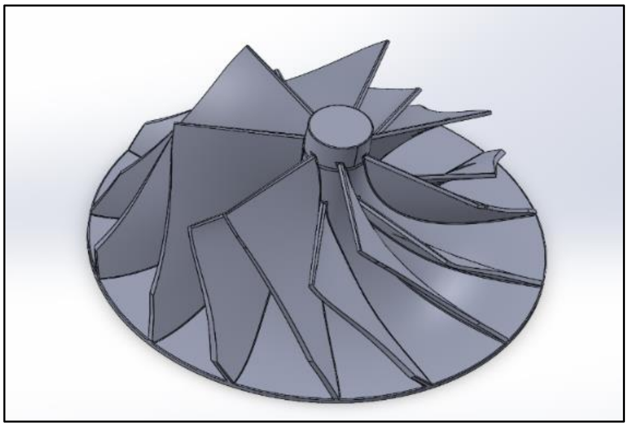


Figure 1 Impeller.

Volute

Among the essential parts of a compressor is its volute. The working range is determined by the volute's design in addition to the compressor's performance. The comprehensive simulation of flow assists with enhancing understanding of the volute flow mechanics and offers design recommendations for volute structure that achieves performance objectives. The motion of air within the vaneless diffuser and volute is simulated in this work using the turbulent Navier-Stokes equations (Xu & Müller, 2005).

Circular

Figure 2 Circular Volute

Figure 3 Circular Volute (+12% area)

Figure 4 Circular Volute (-12% area)

Table 1 Dimension of circular volutes

Type of Volute	Circle 1 (radius in mm)	Circle 2 (radius in mm)	Circle 3 (radius in mm)	Circle 4 (radius in mm)	Area
Circular	15	12.5	10	7.5	706
Circular +12%	15.86	12.70	10.06	7.40	790
Circular -12%	14.06	11.25	9.49	6.55	622

Ellipse

Figure 5 Elliptical Volute

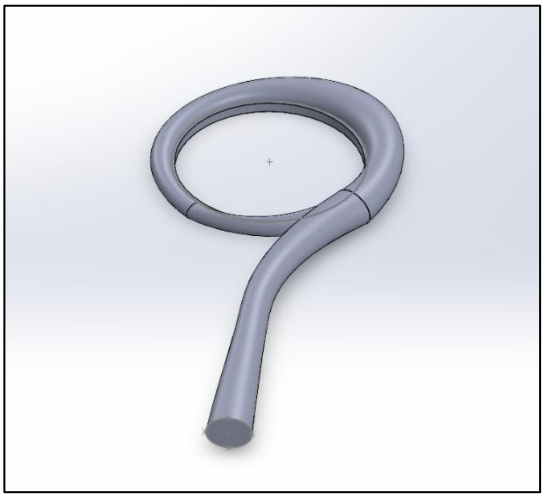


Figure 6 Elliptical Volute (+12% area)

Figure 7 Elliptical Volute (-12% area)

Table 2 Dimensions of elliptical volutes

Type of Volute	Ellipse 1 (mm)	Ellipse 2 (mm)	Ellipse 3 (mm)	Ellipse 4 (mm)	Area
Elliptical	a – 14 b - 10	a – 13.5 b - 8	a – 7 b – 5.81	a – 6.21 b – 4.50	503
Elliptical +12%	a - 14.90 b – 10.5	a – 14 b – 8.50	a – 7.40 b – 6.14	a – 6.50 b – 4.80	644
Elliptical -12%	a – 13.50 b – 9.12	a – 12.55 b – 7.45	a – 6.50 b – 5.45	a – 6 b – 4	402

New Volute

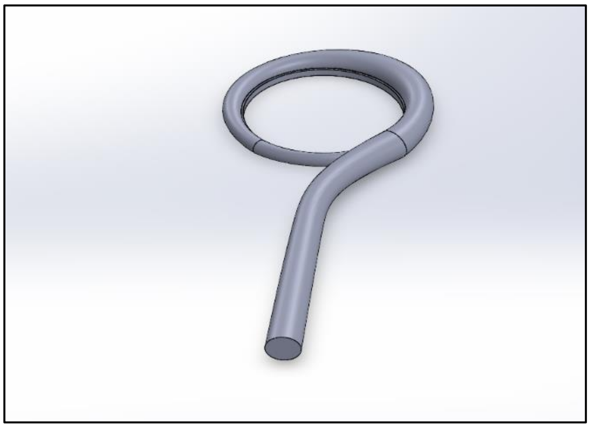


Figure 8 New Optimal Volute

Table 3 Dimensions of new volute

Optimal volute	Ellipse 1	Ellipse 2	Ellipse 3	Ellipse 4
New volute	A – 14 B – 11.50	A – 12 B – 9.50	A – 8 B – 6.54	A – 6.50 B - 6

Computational Fluid Dynamics Analysis- 350

Utilized Ansys Workbench Fluent software to simulate the turbomachine compressor with different cross-sectional area of the volute to determine pressure recovery, velocity, friction loss, aerodynamic characteristics, and overall performance of the compressor.

Methodology

Ansys Geometry

The components that are designed in SolidWorks such as impeller and volute are imported in Ansys software (fluid fluent) in geometry section. Further designing inducer and diffuser in Ansys geometry and adding them with other components to form as a compressor. For this outcome freeze, unfreeze, boolean, and translate commands are utilized.

Circular

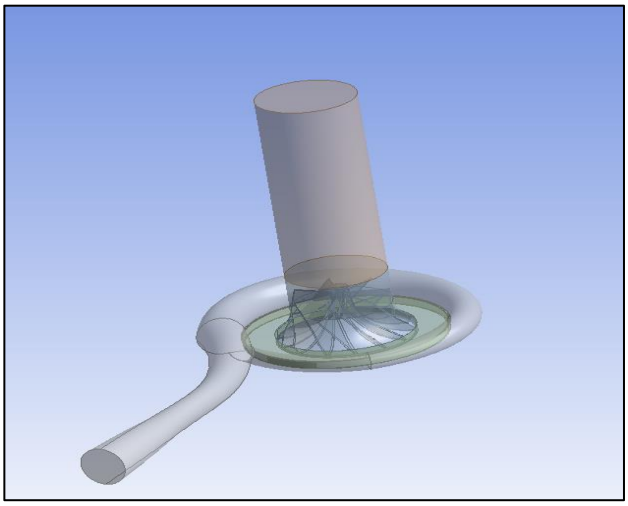


Figure 9 Compressor with Circular volute.

Details of Face	Circular volute cross-section
Body Name	volute
Surface Type	B Surface
Edges	2
Vertices	2
Face Surface Area	706.79 mm²
Details of Face	**Circular volute area with +12%**
Body Name	Volute
Surface Type	B Surface
Edges	2
Vertices	2
Face Surface Area	790.16 mm²
Details of Face	**Circular volute area with -12%**
Body Name	Volute
Surface Type	B Surface
Edges	2
Vertices	2
Face Surface Area	622.75 mm²

Figure 10 Details of Circular area.

Ellipse

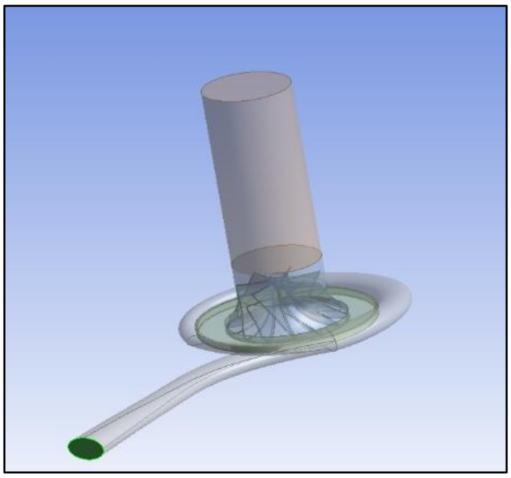


Figure 11 Compressor with Elliptical Volute

Details of Face	Elliptical volute cross-section area
Body Name	Volute
Surface Type	B Surface
Edges	2
Vertices	2
Face Surface Area	503.51 mm^2
Details of Face	**Elliptical volute area with +12%**
Body Name	volute
Surface Type	B Surface
Edges	2
Vertices	2
Face Surface Area	644.35 mm^2
Details of Face	**Elliptical volute area with -12%**
Body Name	Volute
Surface Type	B Surface
Edges	2
Vertices	2
Face Surface Area	402.3 mm^2

Figure 12 Details of Elliptical area.

This process will be carried out in each different type of volute in the geometry section.

Mesh Independence

After the geometry process, meshing process is primarily carried out for the overall compressor, after that mesh element sizing is carried out in the areas where the initial mesh generated for element size – 20mm was not accurate for the required solution. To reduce the elements of the whole compressor body sizing, face sizing has been generated again. Where, the element size would differ for each component such as for inducer – 4mm, diffuser, impeller blade, and volute to diffuser contact region – 0.75mm has been generated to maintain the elements of the compressor. After that created named selection for each

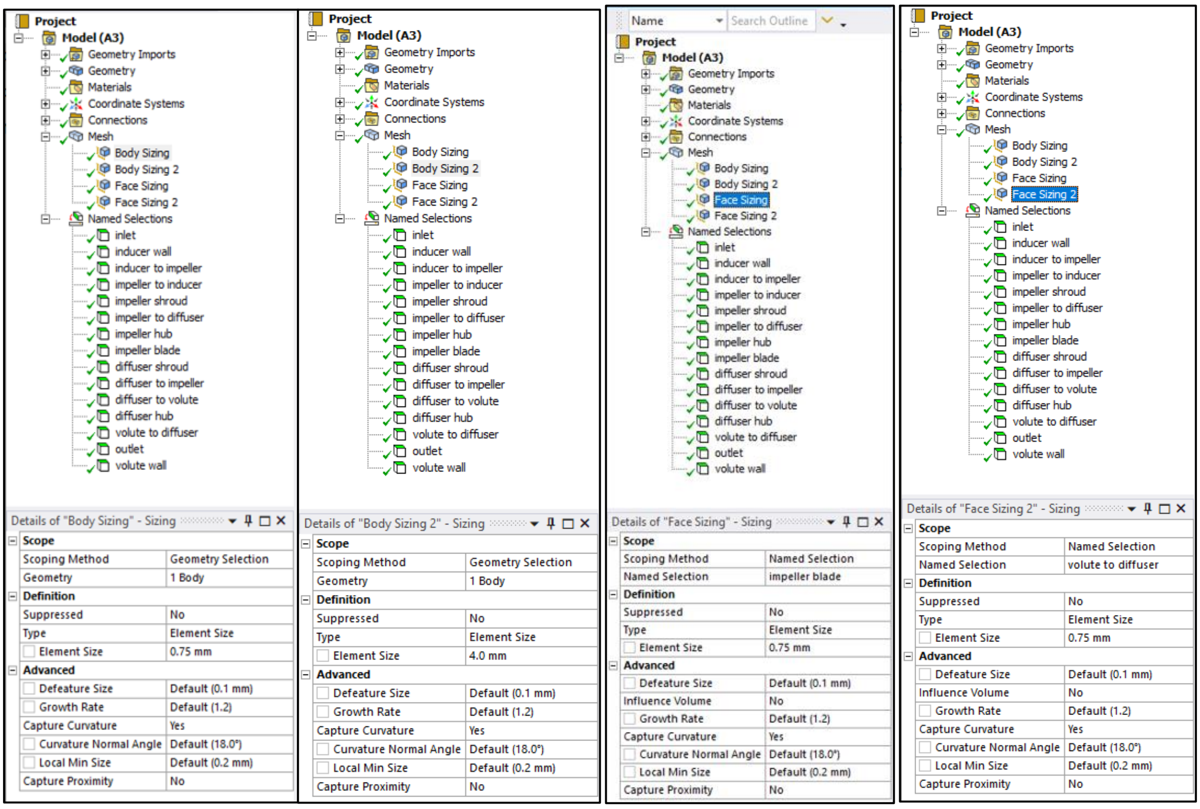


Figure 13 Mesh Independence process.

component in the compressor and their contact region.

Mesh process is followed by every different type of voluted created, with same steps to get optimal solution for the compressor.

Setup

Once mesh is generated completely and updated, setup process is carried out. In this process, the following steps are carried out:

- In general section, energy equation must be turned on.
- Must change the units of pressure and angular velocity to atm and rpm respectively.
- In materials section, in fluid – air type: constant gas must be changed to ideal gas.
- Then to calculate Co-efficient of friction piecewise polynomial is selected.
- Must input rotational velocity in impeller blade of 62000 rpm in a framed motion with Z axis rotational path.
- In boundary conditions, inlet, outlet, and other boundary conditions are created.
- After that, initialization is taken place, where we must initialize from inlet with necessary values.
- Then running the calculation with required iterations will be the final step in setup process.

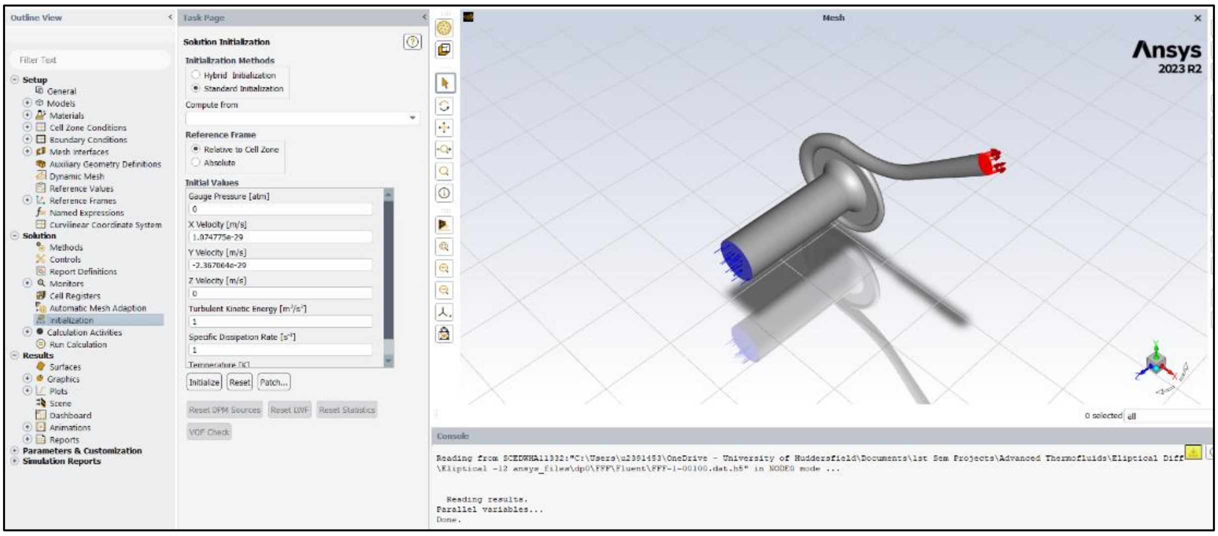


Figure 14 Setup process.

Solution

After running calculation in setup process, solution is carried out. Where graphs, determines the number of iterations. Furthermore, through contours, vectors, and path lines computation determined static pressure, co-efficient of pressure, velocity, static temperature, and co-efficient of temperature will be displayed in the results section. And, in reports calculation of pressure recovery, Cp, and skin friction co-efficient has been determined through area-weighted average in surface integrals.

Case 1 – Volute with circular cross section area

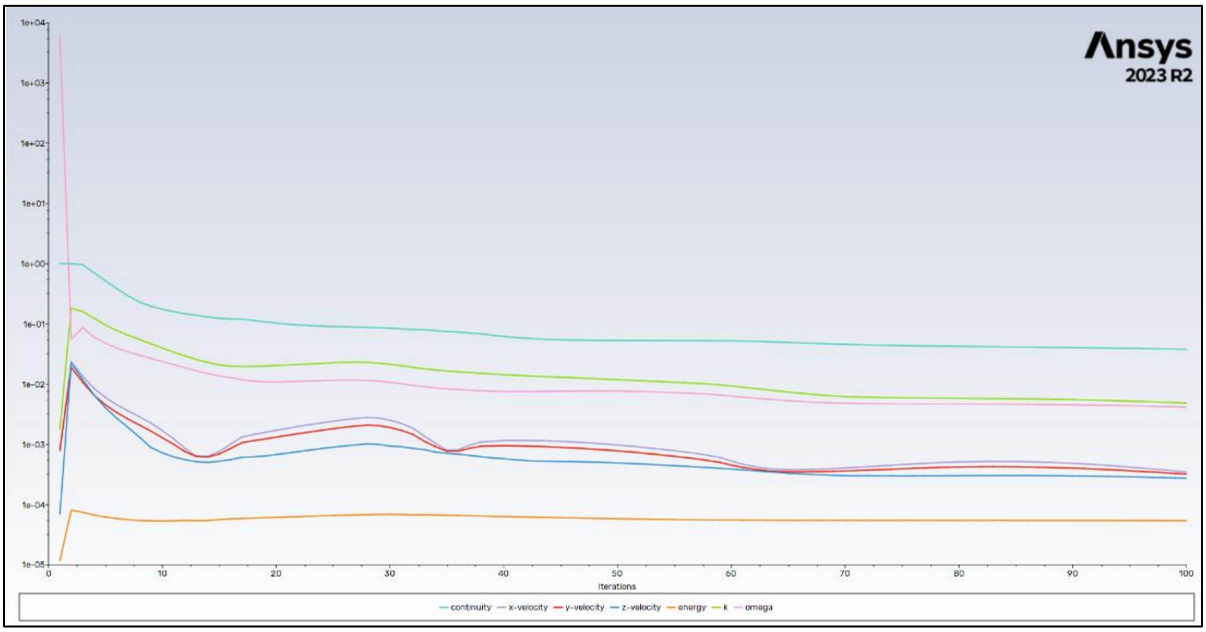


Figure 15 Scale residuals of circular volute.

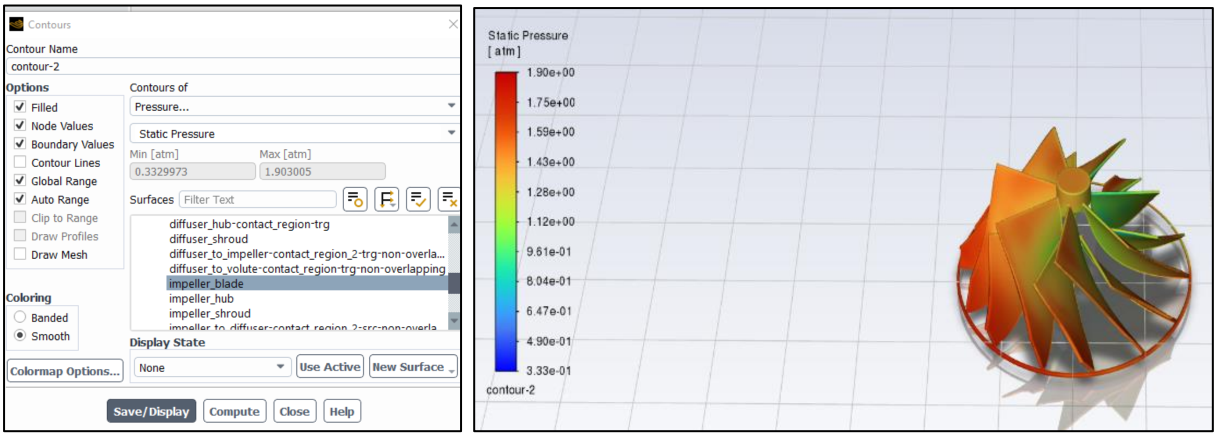


Figure 16 Static pressure of Impeller blade.

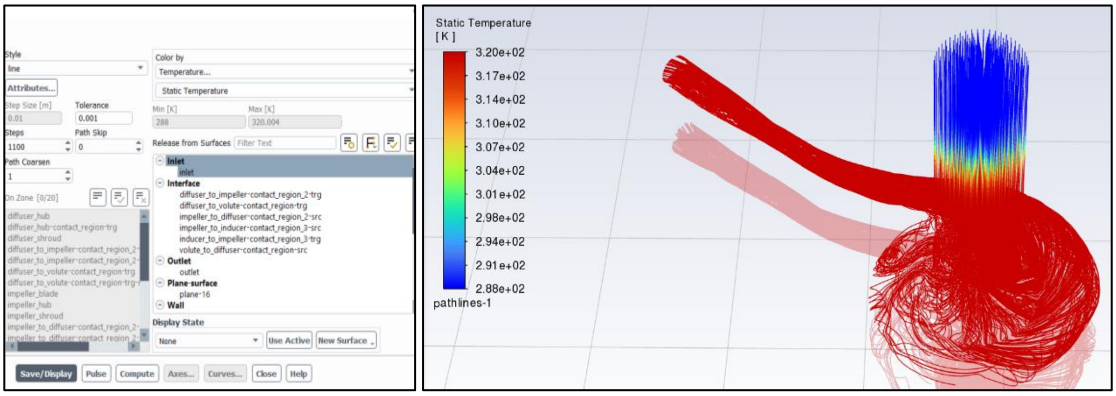


Figure 17 Temperature on circular volute.

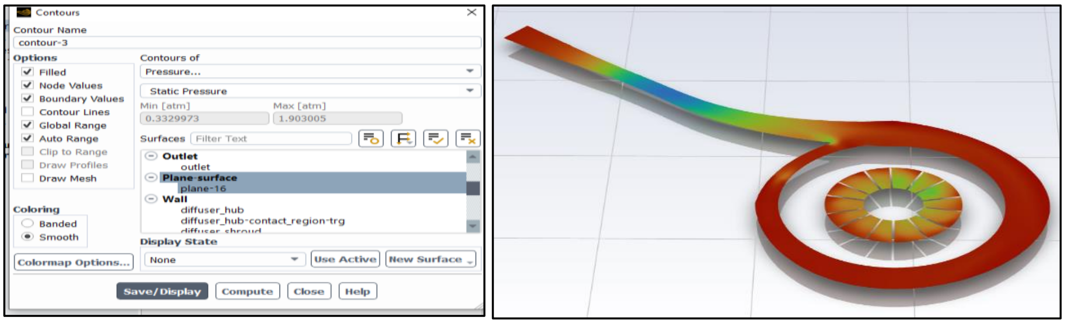


Figure 18 Pressure on plane 16.

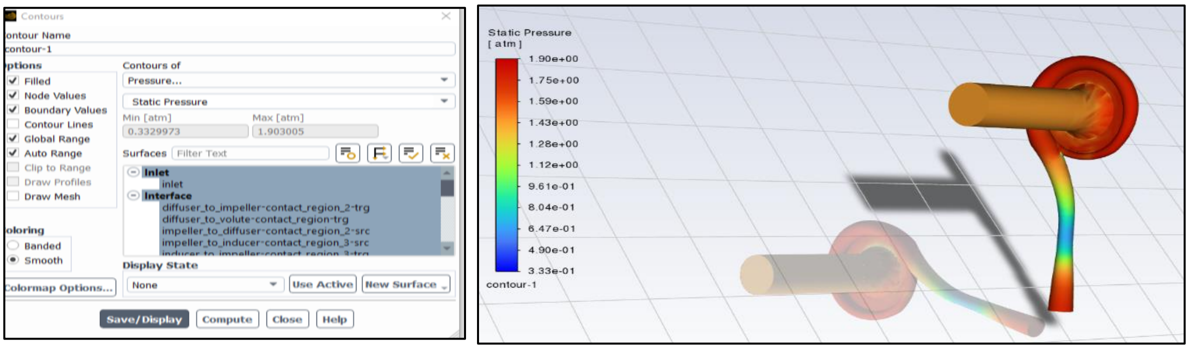


Figure 19 Static pressure of circular volute.

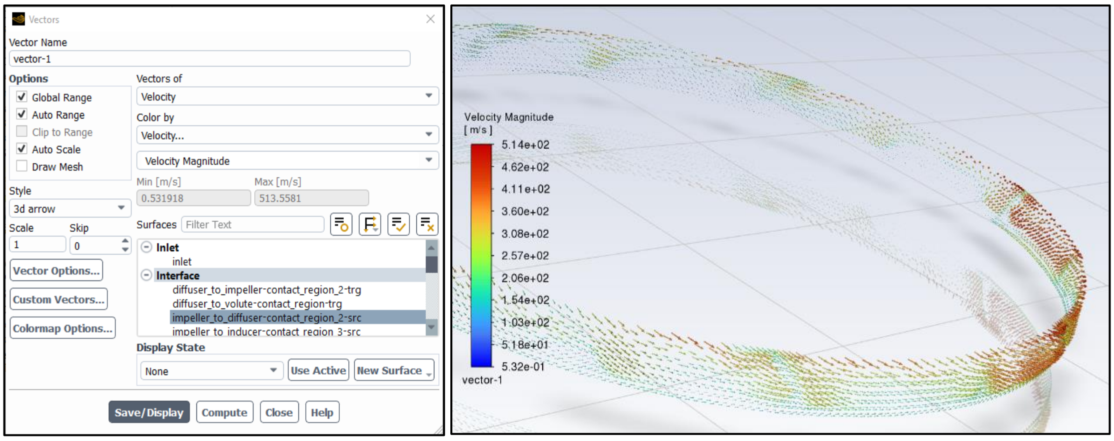


Figure 20 Vector magnitude of diffuser.

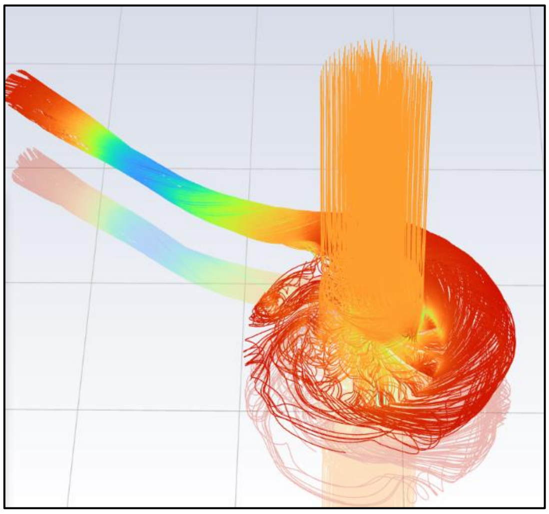
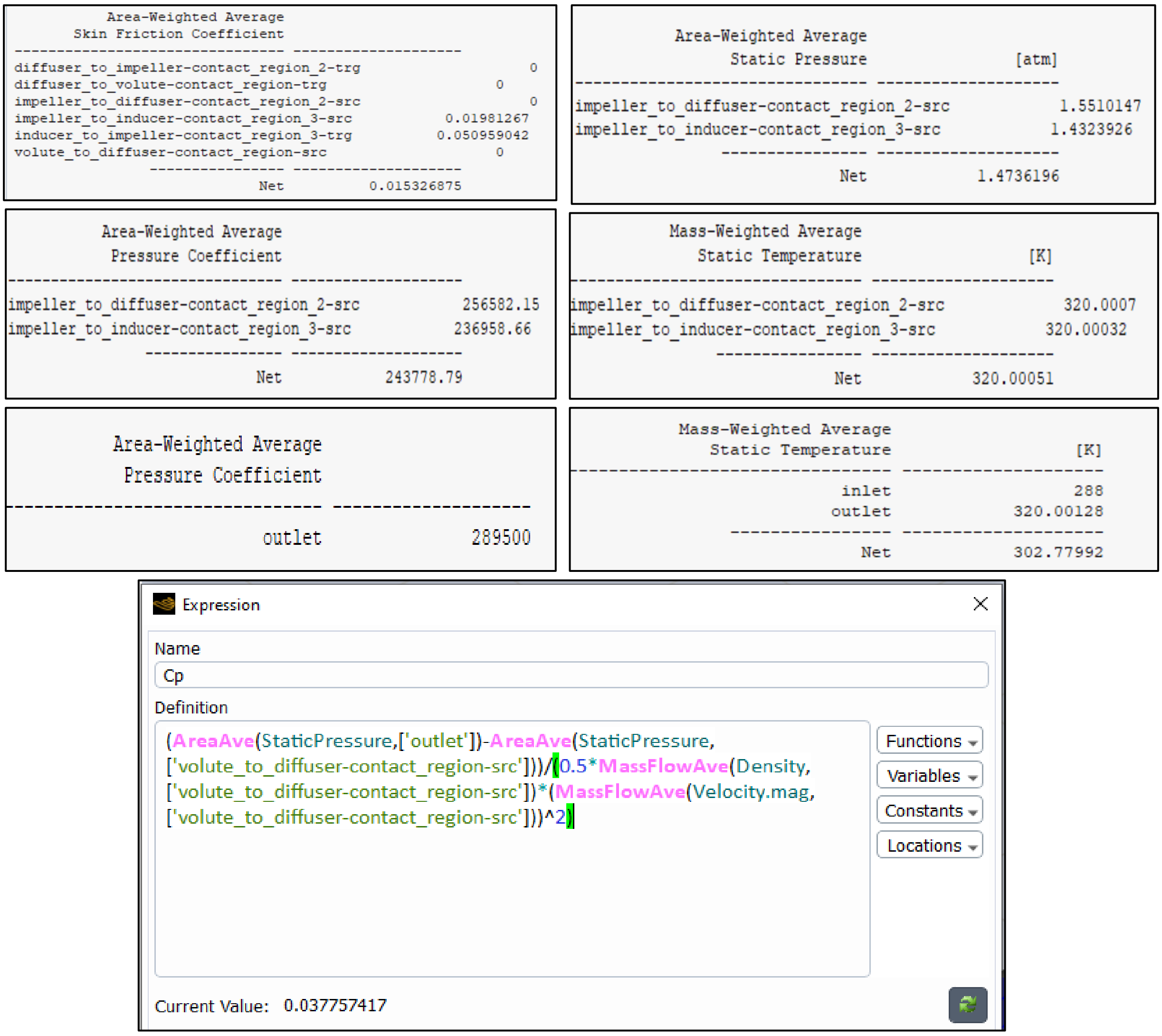


Figure 21 Path lines of circular volute.



Area-Weighted Average Skin Friction Coefficient	
diffuser_to_impeller-contact_region_2-trg	0
diffuser_to_volute-contact_region-trg	0
impeller_to_diffuser-contact_region_2-src	0
impeller_to_inducer-contact_region_3-src	0.01981267
inducer_to_impeller-contact_region_3-trg	0.050959042
volute_to_diffuser-contact_region-src	0
Net	0.015326875

Area-Weighted Average Static Pressure	[atm]
impeller_to_diffuser-contact_region_2-src	1.5510147
impeller_to_inducer-contact_region_3-src	1.4323926
Net	1.4736196

Area-Weighted Average Pressure Coefficient	
impeller_to_diffuser-contact_region_2-src	256582.15
impeller_to_inducer-contact_region_3-src	236958.66
Net	243778.79

Mass-Weighted Average Static Temperature	[K]
impeller_to_diffuser-contact_region_2-src	320.0007
impeller_to_inducer-contact_region_3-src	320.00032
Net	320.00051

Area-Weighted Average Pressure Coefficient	
outlet	289500

Mass-Weighted Average Static Temperature	[K]
inlet	288
outlet	320.00128
Net	302.77992

Figure 22 Results of Circular volute compressor.

Case 2 – Volute with elliptical cross section area

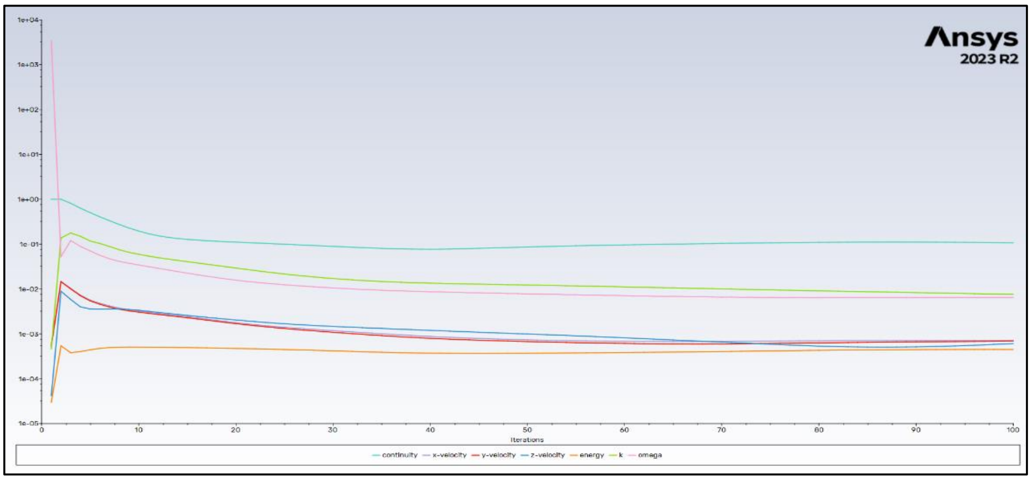


Figure 23 Scale Residuals for elliptical volute.

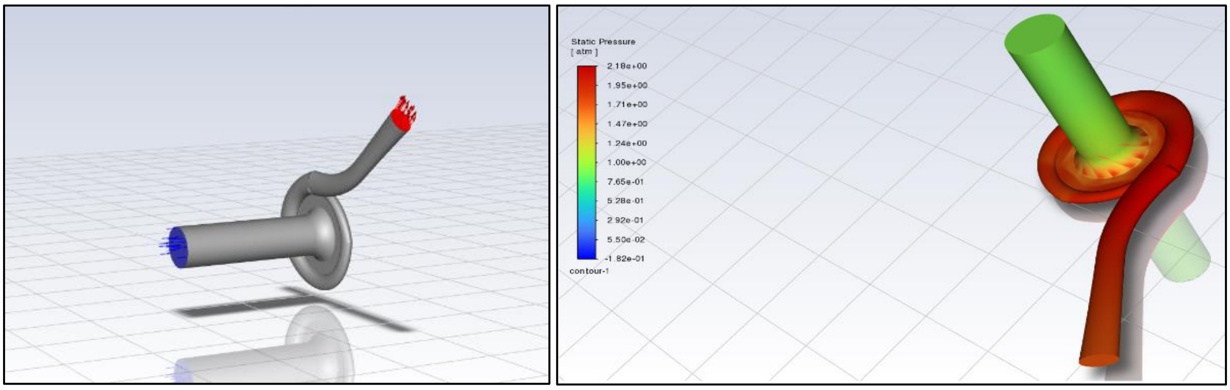


Figure 24 Static pressure of elliptical volute.

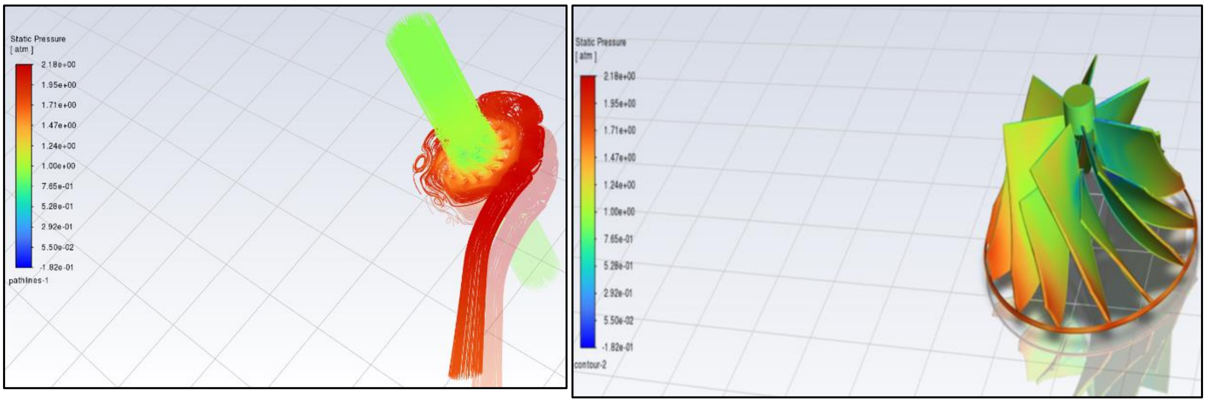


Figure 25 Static pressure through path line and impeller blades.

Area-Weighted Average Static Temperature	[K]
inlet	287.61646
outlet	299.27048
Net	289.65694

Area-Weighted Average Static Temperature	[K]
inlet	287.61646
outlet	299.27048
Net	289.65694

Static Pressure	[atm]
inlet	0.92880448
outlet	1.7262355
Net	1.0684255

Area-Weighted Average Pressure Coefficient	
inlet	153650.8
outlet	285568.66
Net	176748.1

Figure 26 Results of elliptical volute compressor.

Case 3 – Volute with +12% and -12% of original area

Circular +12%

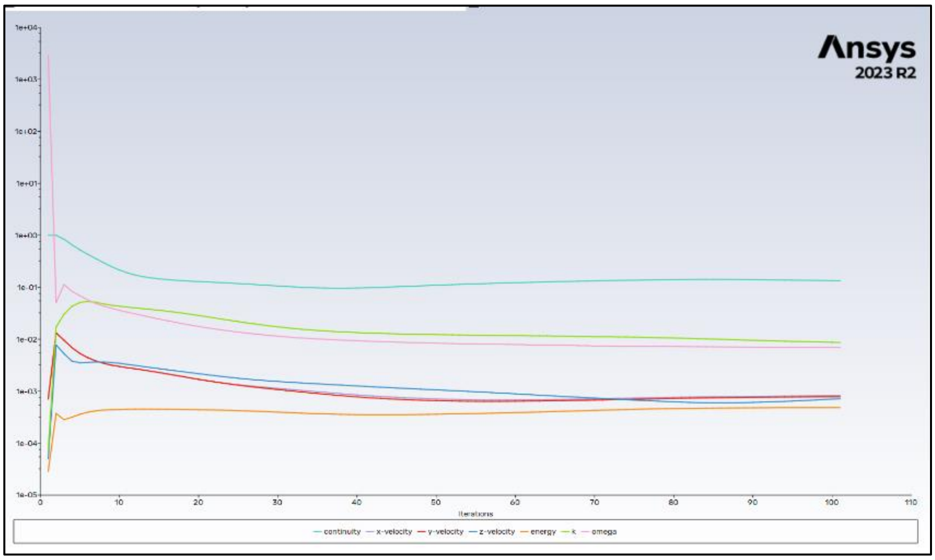


Figure 27 Scale Residual for +12% circular volute.

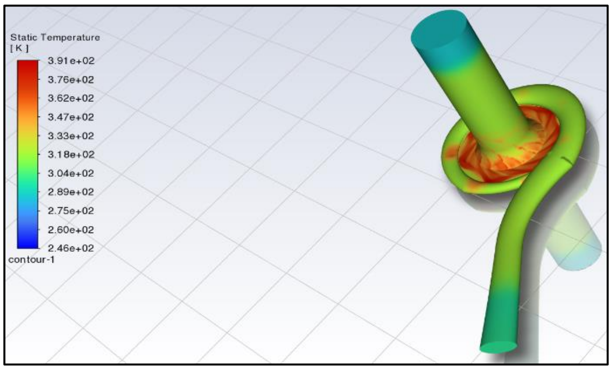


Figure 28 Static temperature of elliptical volute.

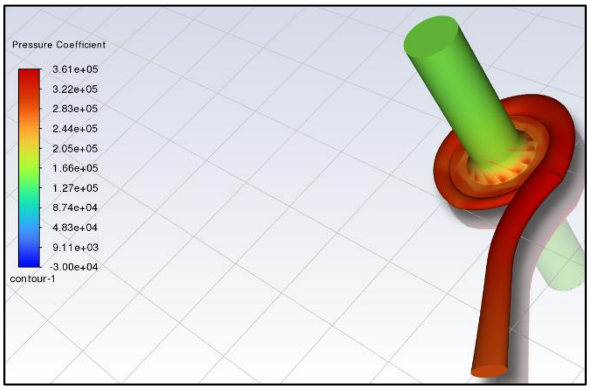


Figure 29 Pressure co-efficient of elliptical volute.

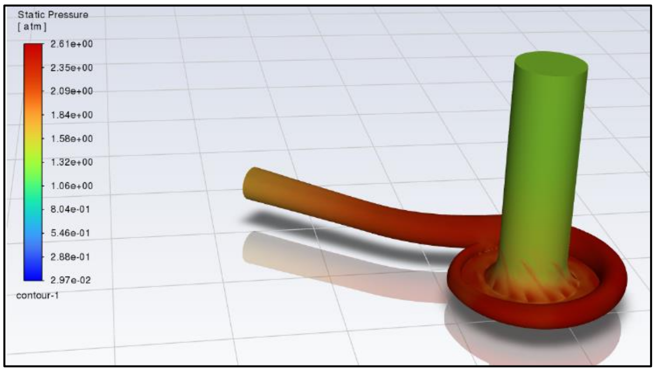


Figure 30 Static pressure of +12% Circular volute.

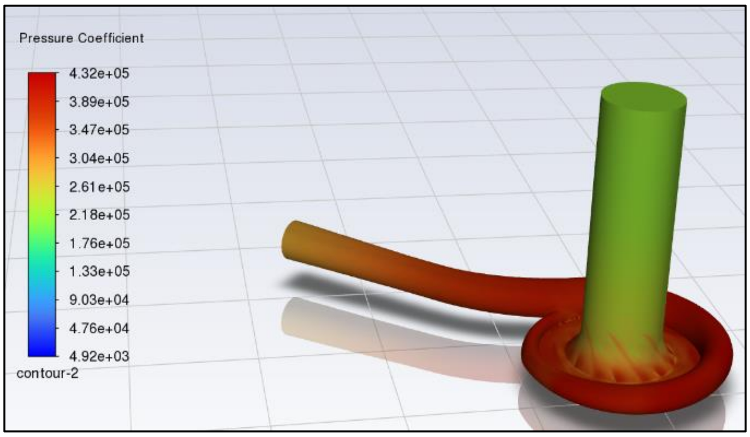


Figure 31 Pressure co-efficient of +12% circular volute.

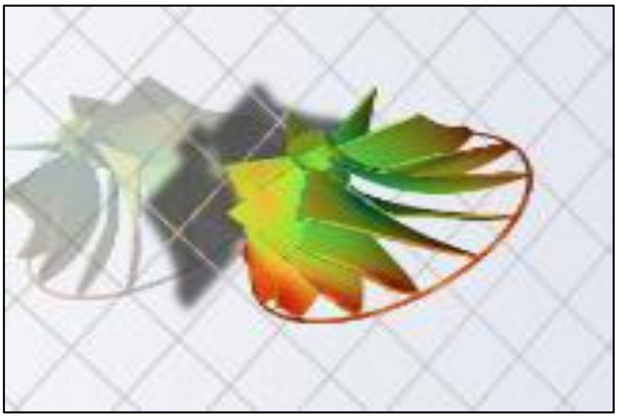


Figure 32 Impeller blade pressure in +12% circular volute.

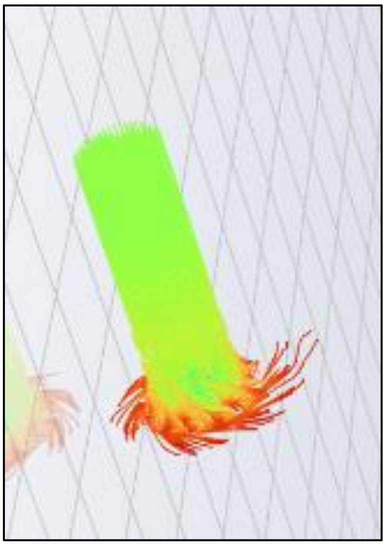


Figure 33 Path line pressure in +12% circular volute.

Area-Weighted Average Static Temperature	[K]
inlet	287.73987
outlet	299.98178
Net	290.2522

Area-Weighted Average Relative Total Pressure	[atm]
inlet	1.3499082
outlet	1.7527579
Net	1.4325825

Area-Weighted Average Static Pressure	[atm]
inlet	1.3430635
outlet	1.7498269
Net	1.426541

Area-Weighted Average Pressure Coefficient	
inlet	222181.08
outlet	289471.36
Net	235990.64

diffuser_to_impeller-contact_region_2-trg	0
diffuser_to_volute-contact_region-trg	0
impeller_to_diffuser-contact_region_2-src	0
impeller_to_inducer-contact_region_3-src	0.029288959
inducer_to_impeller-contact_region_3-trg	0.042174881
volute_to_diffuser-contact_region-src	0
Net	0.015476399

Figure 34 Results of +12% Circular volute compressor.

Circular -12%

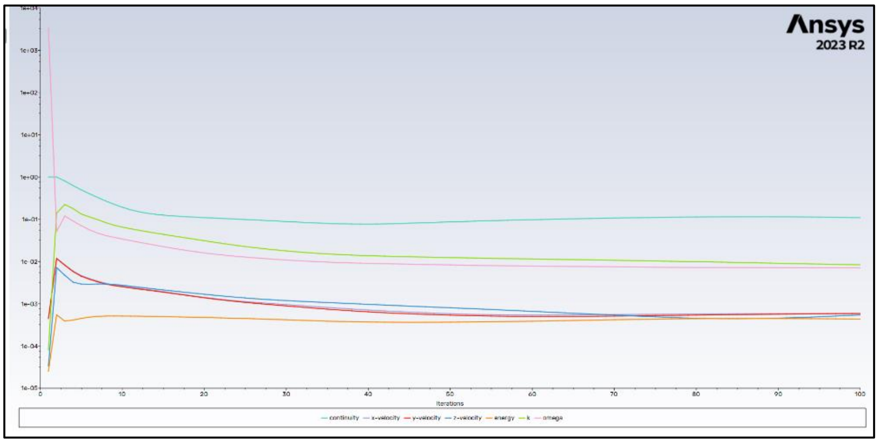


Figure 35 Scaled residual of -12% circular volute.

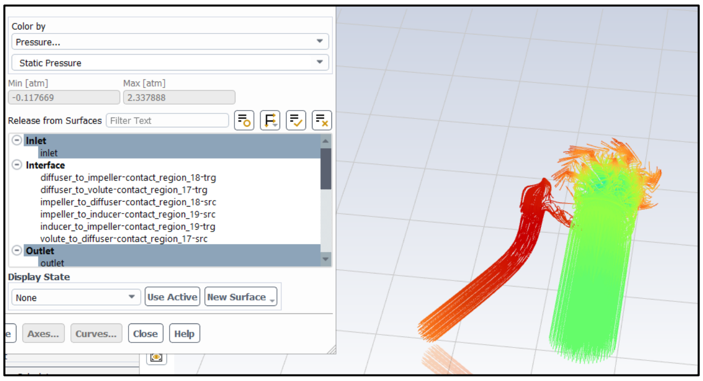


Figure 36 Pressure path line of -12% circular volute.

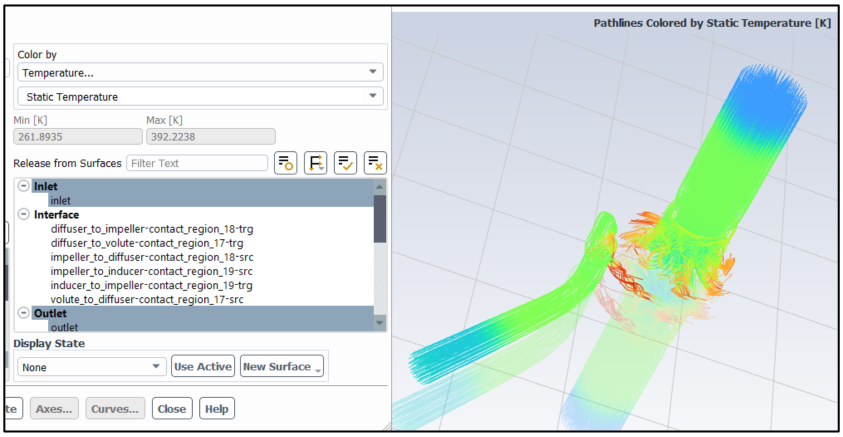


Figure 37 Temperature path line of -12% circular volute.

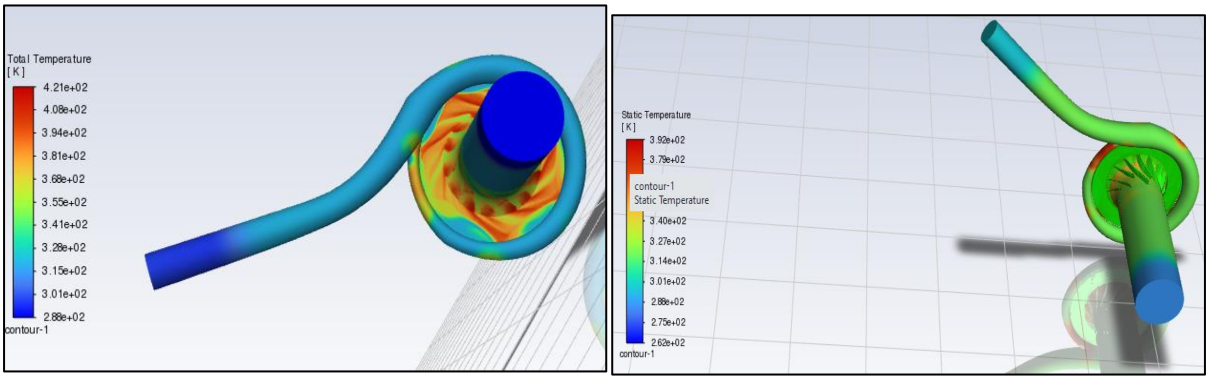


Figure 38 Temperature of -12% circular volute.

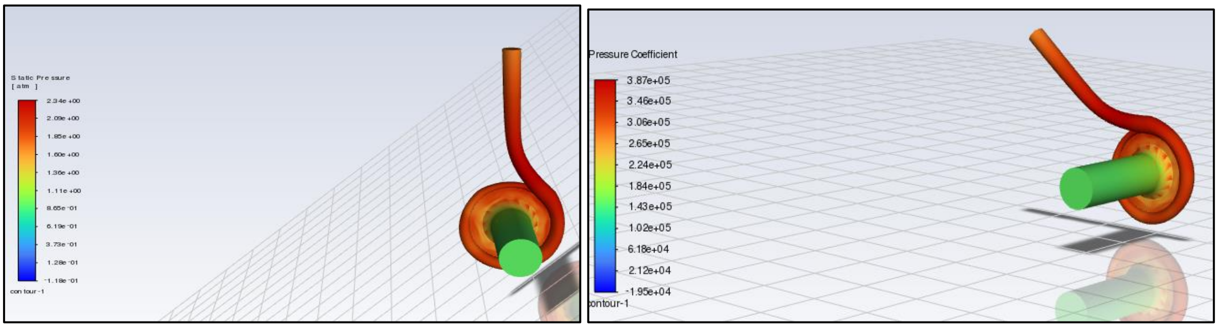


Figure 39 Static and co-efficient of pressure of -12% circular volute.

Area-Weighted Average Total Temperature	[K]
inlet	288.01672
outlet	299.9386
Net	290.03266

Area-Weighted Average Static Pressure	[atm]
inlet	0.93563296
outlet	1.7150769
Net	1.0674336

diffuser_to_impeller-contact_region_18-trg	0
diffuser_to_volute-contact_region_17-trg	0
impeller_to_diffuser-contact_region_18-src	0
impeller_to_inducer-contact_region_19-src	0.015751756
inducer_to_impeller-contact_region_19-trg	0.082647619
volute_to_diffuser-contact_region_17-src	0
Net	0.021312209

Figure 40 Results for -12% circular volute.

Elliptical +12%

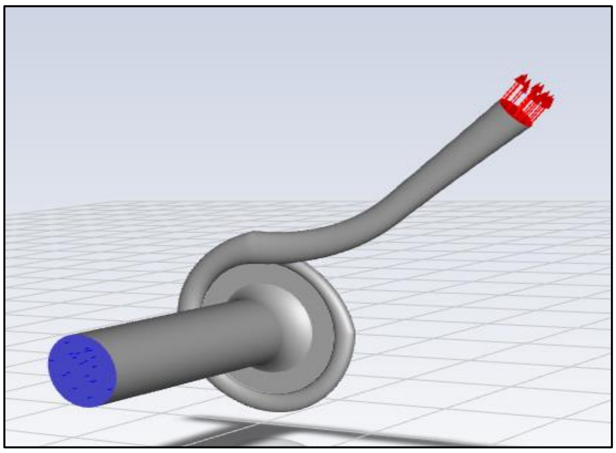


Figure 41 Runing calculation of +12% elliptical volute.

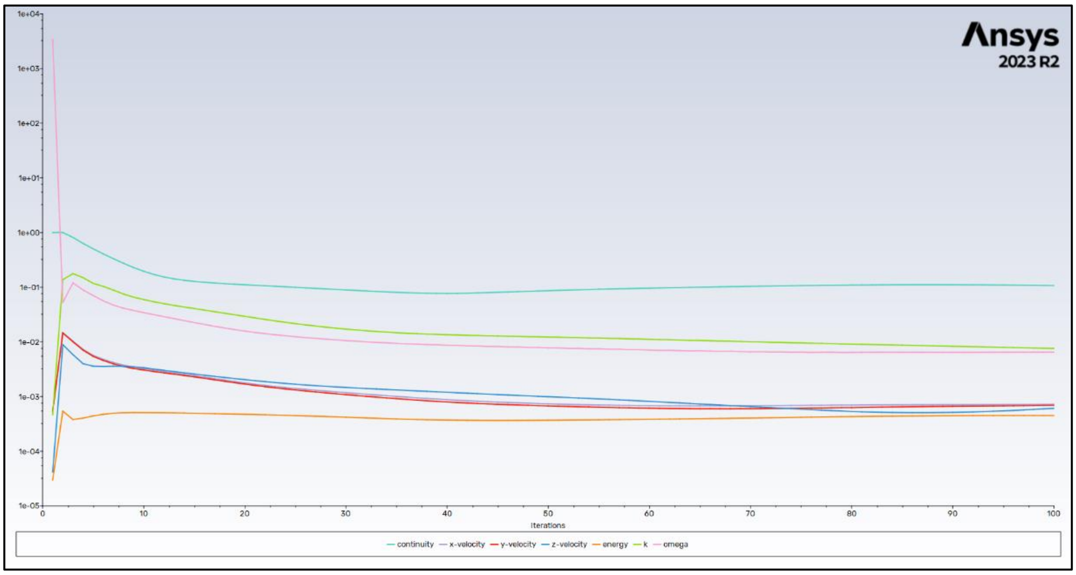


Figure 42 Scaled residual of +12% elliptical volute.

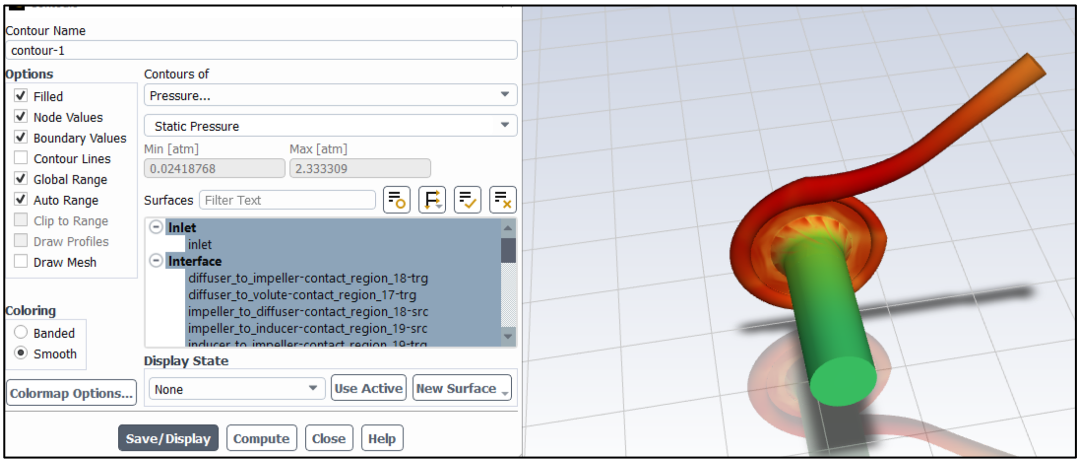


Figure 43 Static pressure of +12% elliptical volute.

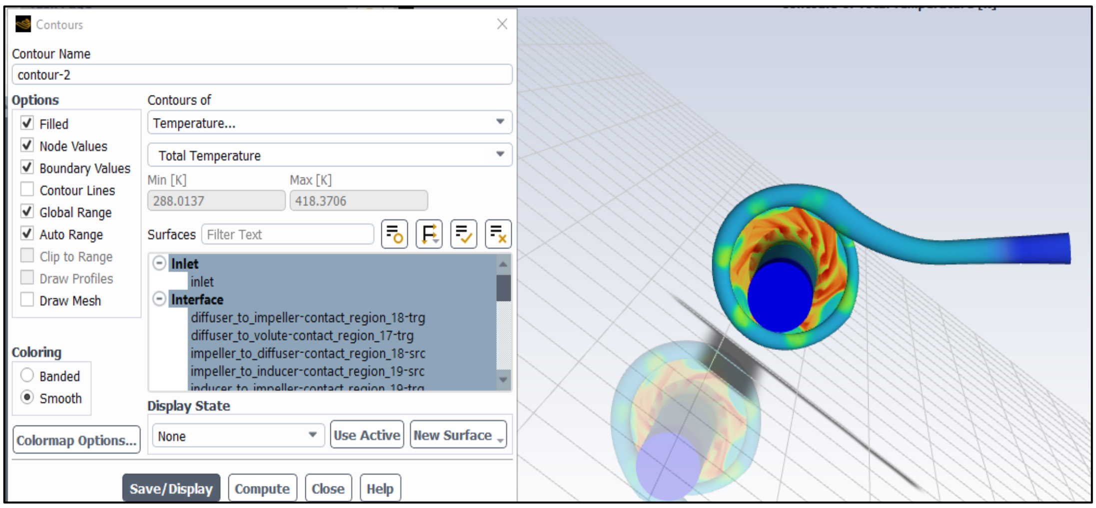


Figure 44 Total temperature of +12% elliptical volute.

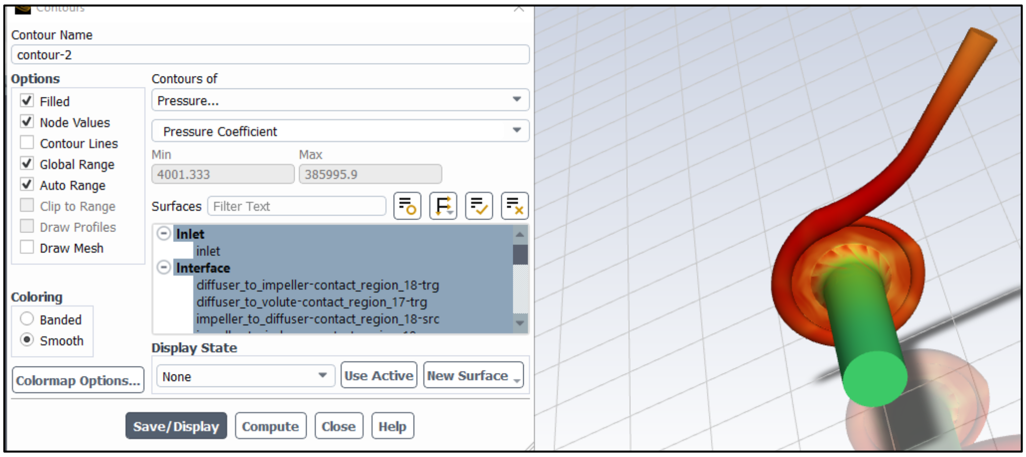


Figure 45 Pressure co-efficient of +12% elliptical volute.

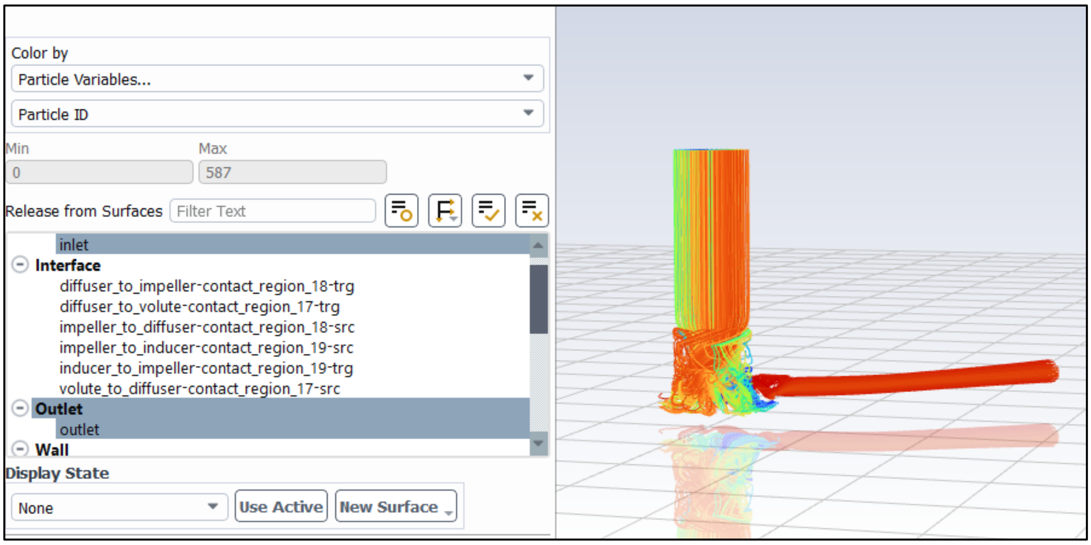


Figure 46 Particle variables of +12% elliptical volute.

```
             Area-Weighted Average
                   Static Pressure                  [atm]
-------------------------------- --------------------
                             inlet           0.95558734
                            outlet            1.7283268
                  ---------------- --------------------
                               Net            1.0653615
```

```
             Area-Weighted Average
                 Total Temperature                    [K]
-------------------------------- --------------------
                             inlet            288.01496
                            outlet            299.97182
                  ---------------- --------------------
                               Net            289.71354
```

Figure 47 Results of +12% elliptical volute.

Elliptical -12%

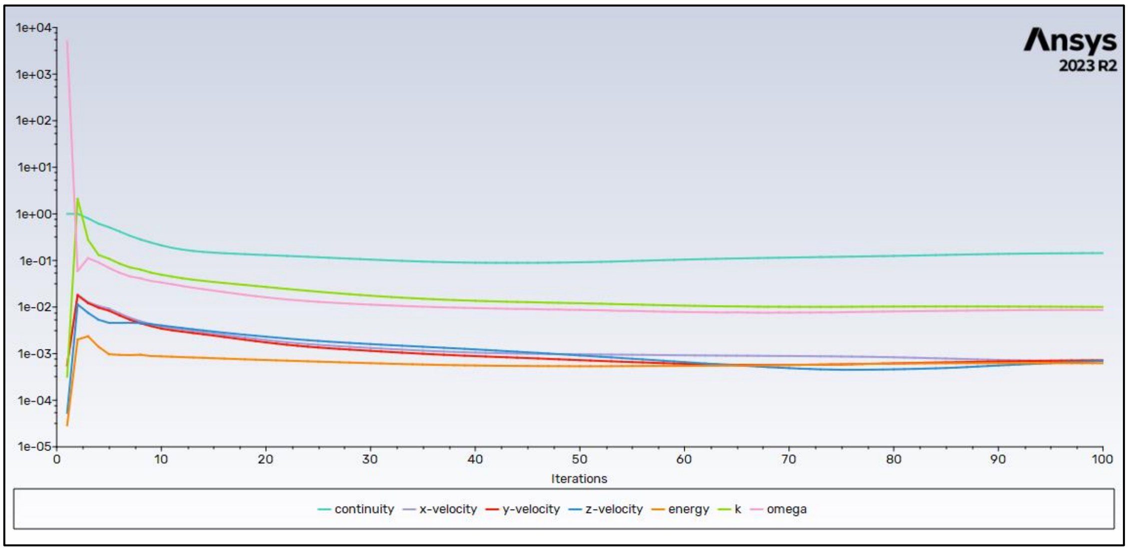


Figure 48 Scaled residual of -12% Elliptical volute.

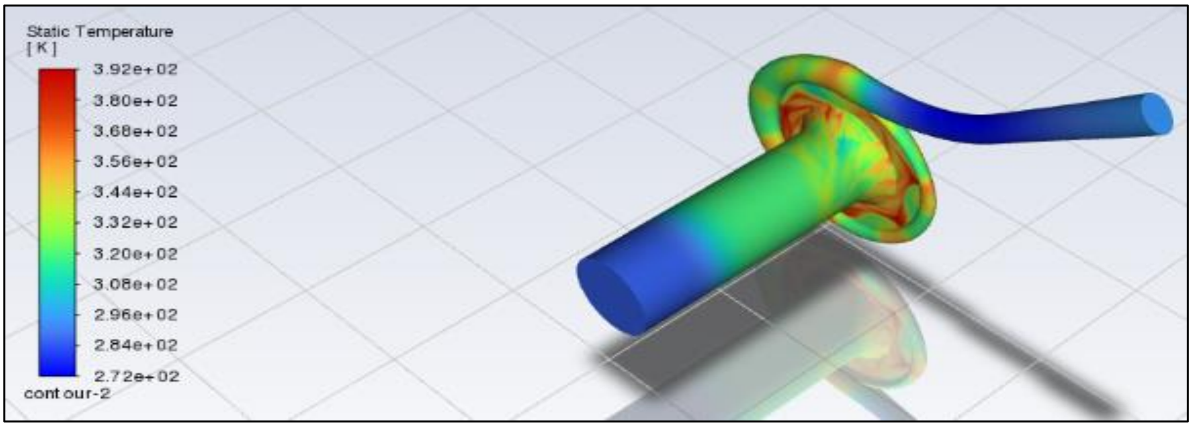


Figure 49 Static temperature of -12% elliptical volute.

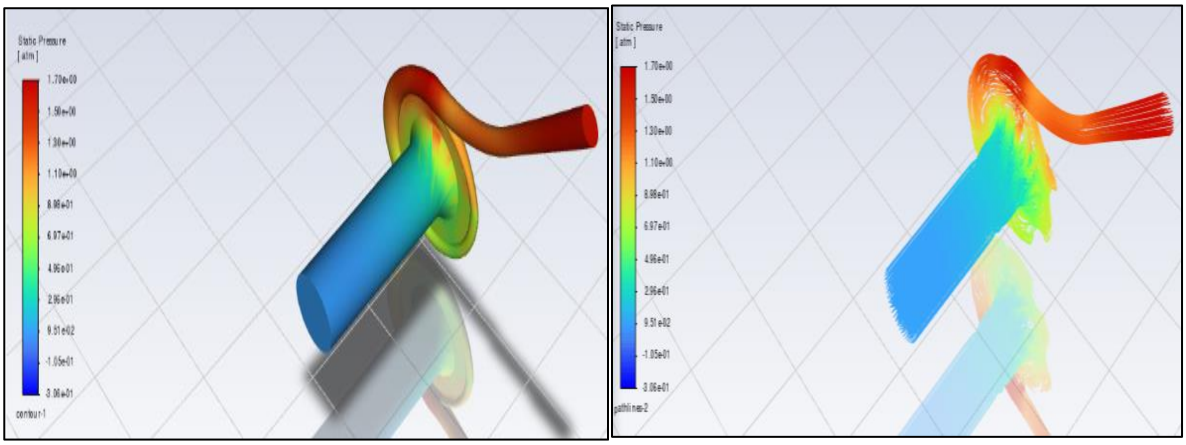


Figure 50 Static pressure of -12% elliptical volute.

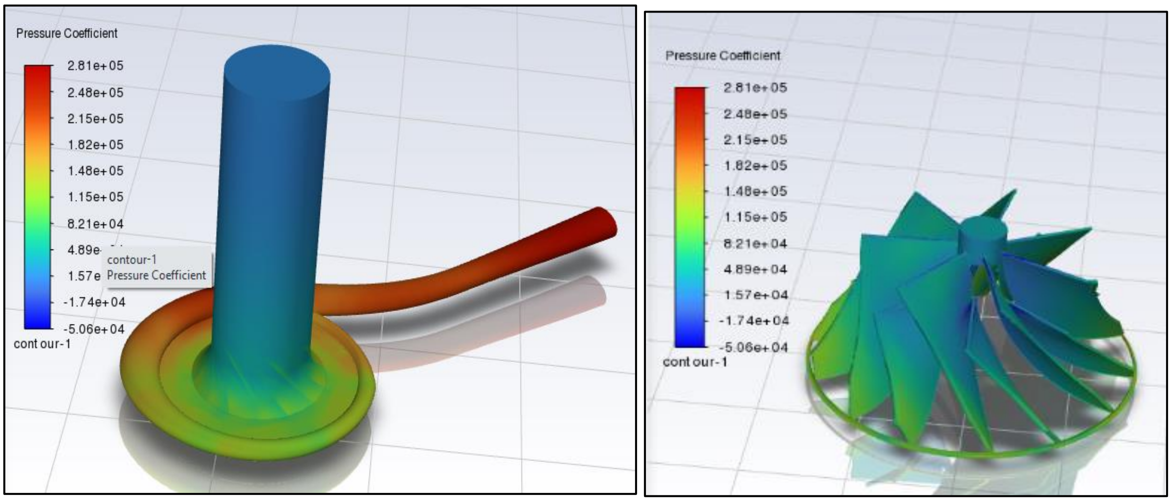


Figure 51 Pressure co-efficient of -12% elliptical volute.

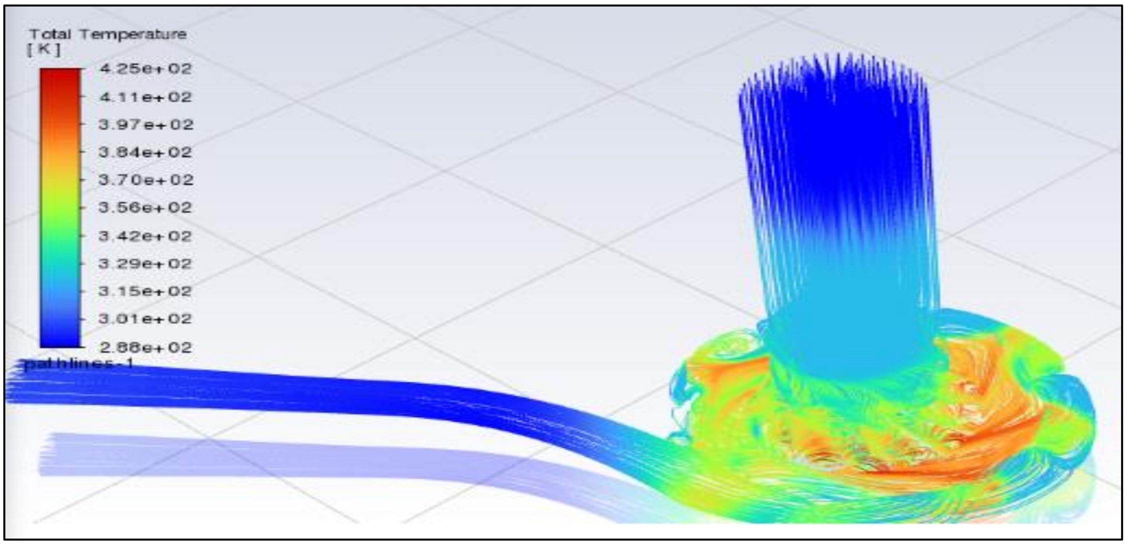


Figure 52 Total temperature of -12% of elliptical volute.

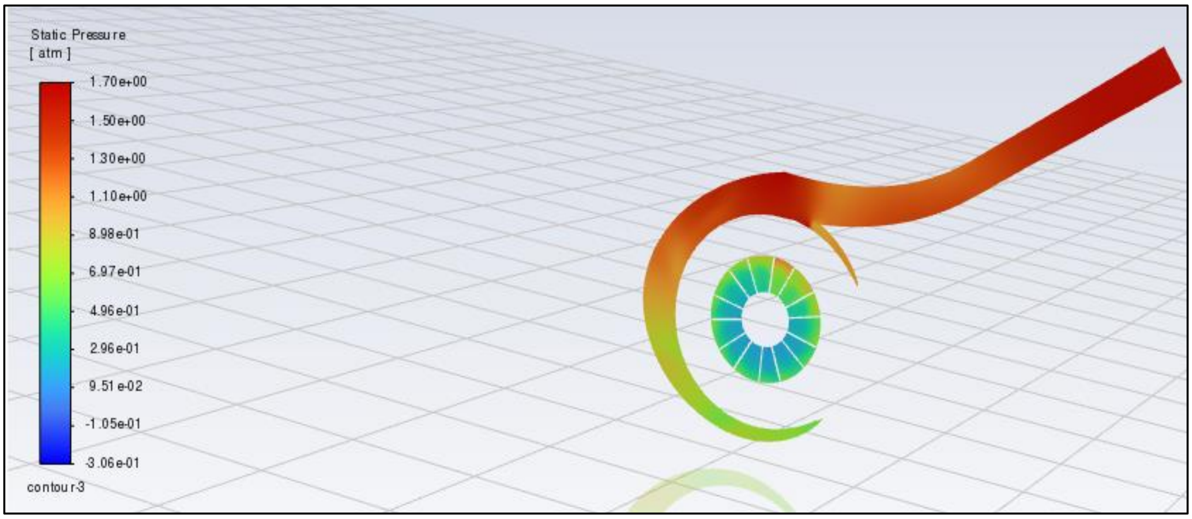


Figure 53 Pressure of xy plane in -12% of elliptical volute.

Area-Weighted Average Total Temperature	[K]
inlet	288.02207
outlet	299.96129
Net	289.41421

Area-Weighted Average Pressure Coefficient	
inlet	17558.774
outlet	265014.79
Net	46412.723

Area-Weighted Average Total Temperature	[K]
inlet	288.02207
outlet	299.96129
Net	289.41421

Area-Weighted Average Relative Total Pressure	[atm]
inlet	0.12152775
outlet	1.750257
Net	0.31144138

Area-Weighted Average Skin Friction Coefficient	
diffuser_to_impeller-contact_region_2-trg	0
diffuser_to_volute-contact_region-trg	0
impeller_to_diffuser-contact_region_2-src	0
impeller_to_inducer-contact_region_3-src	0.011225296
inducer_to_impeller-contact_region_3-trg	0.04105144
volute_to_diffuser-contact_region-src	0.0012331258
Net	0.011671308

Figure 54 Results of -12% elliptical volute.

Case 4 – New optimal Volute

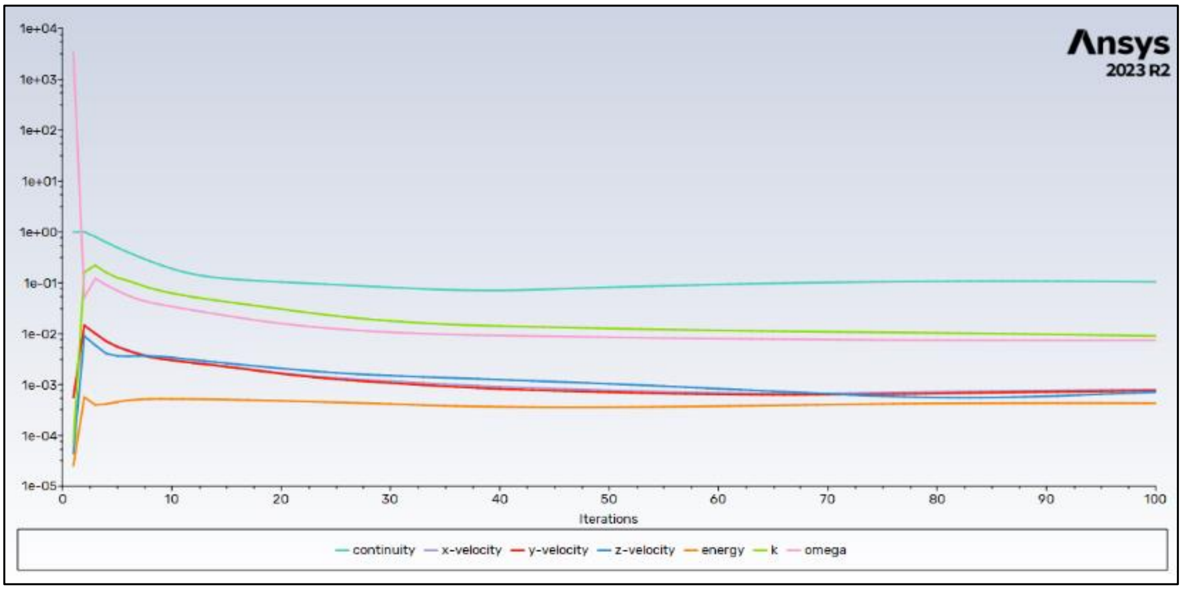


Figure 55 Scaled residual for optimal volute.

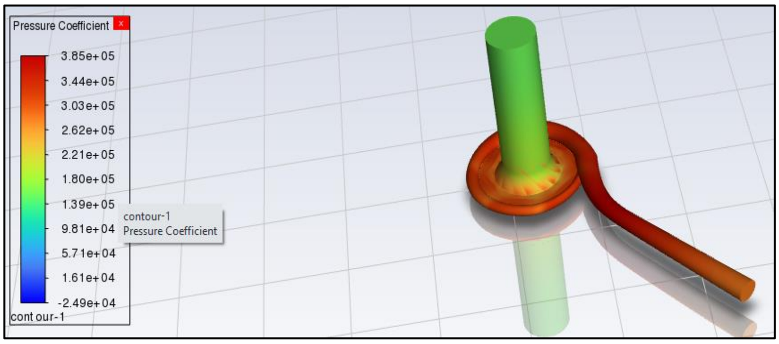


Figure 56 Pressure co-efficient of optimal volute.

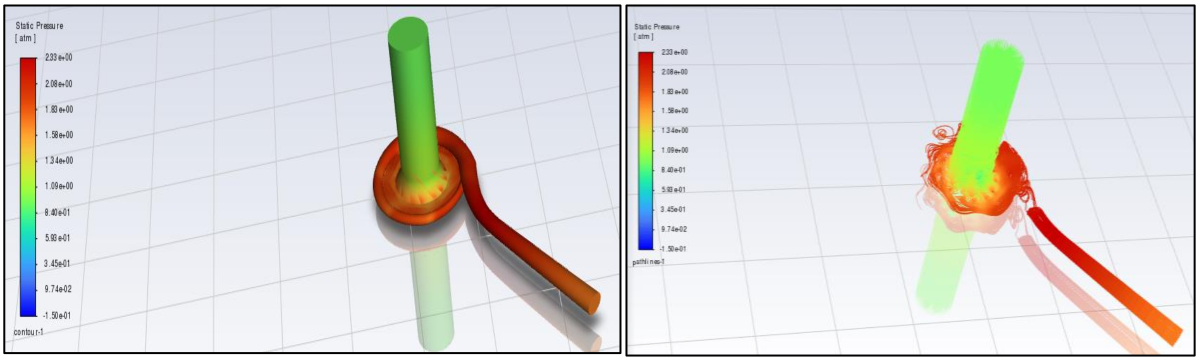


Figure 57 Static pressure for optimal volute.

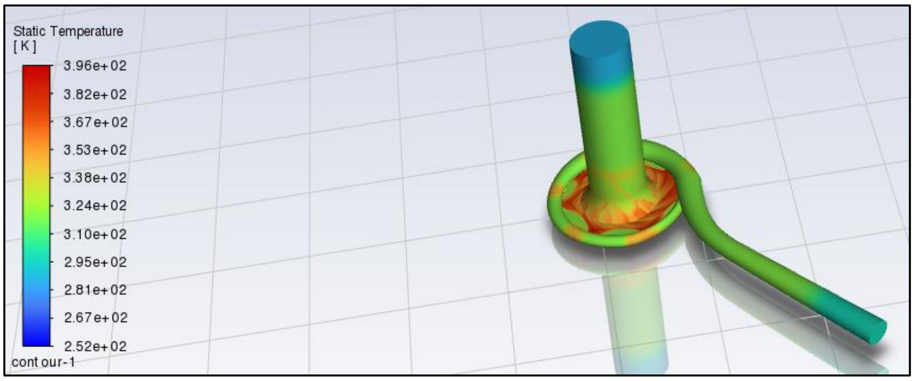


Figure 58 Static temperature of optimal volute.

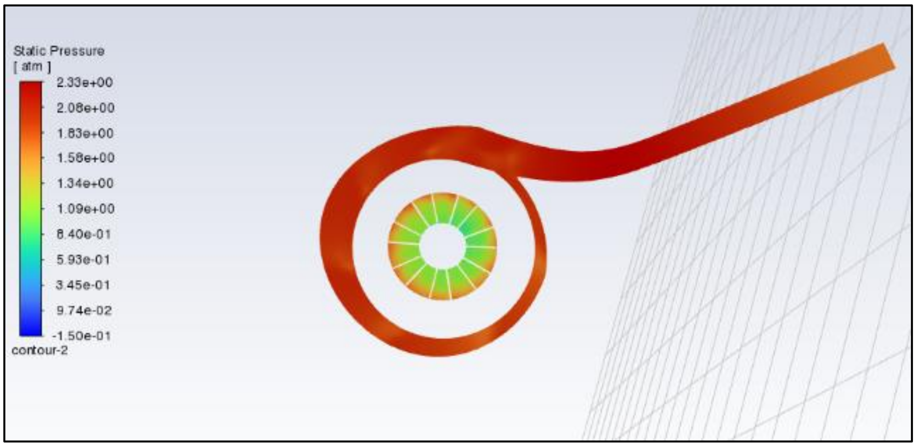


Figure 59 Plane 27 of optimal volute.

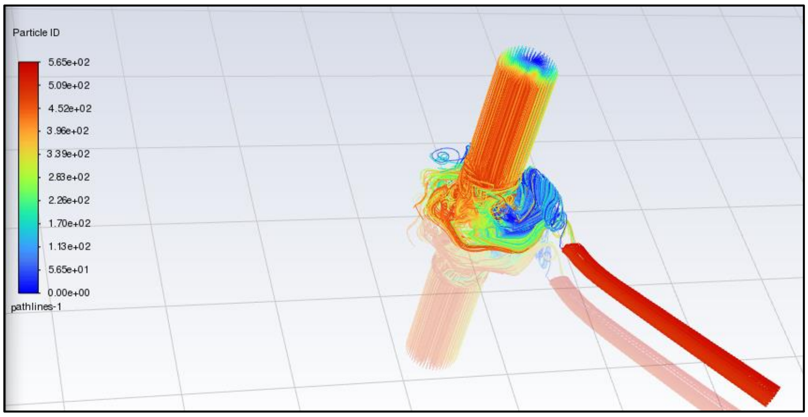


Figure 60 Particle variables of optimal volute.

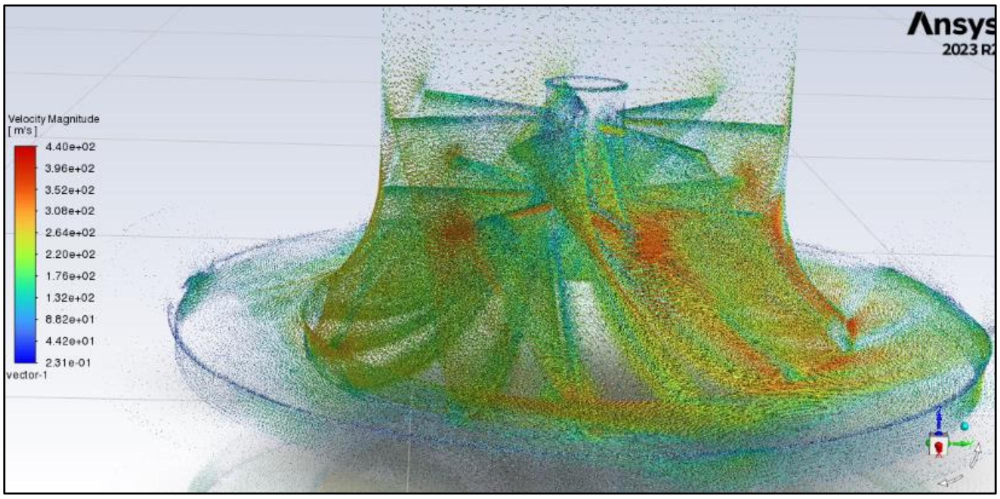


Figure 61 Velocity magnitude of impeller in optimal volute.

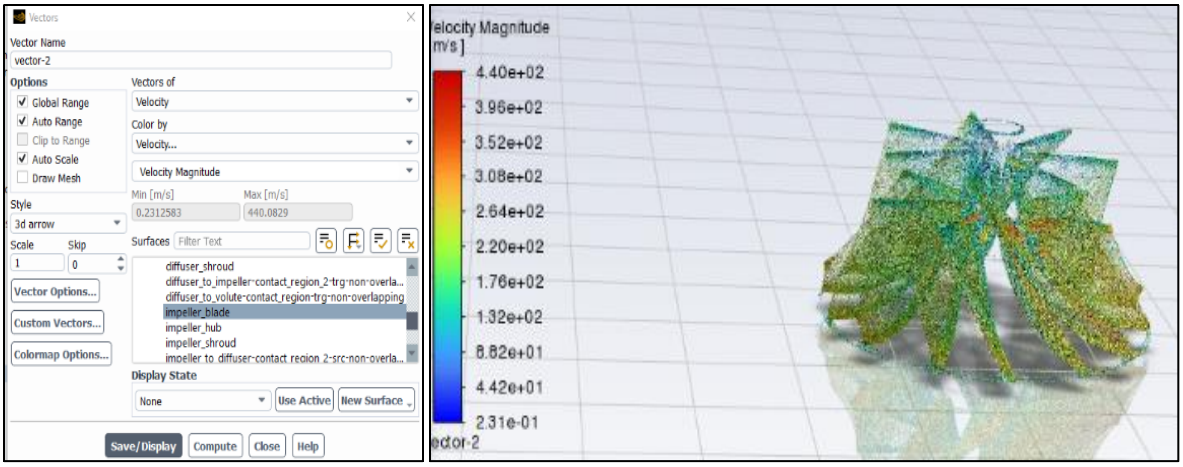
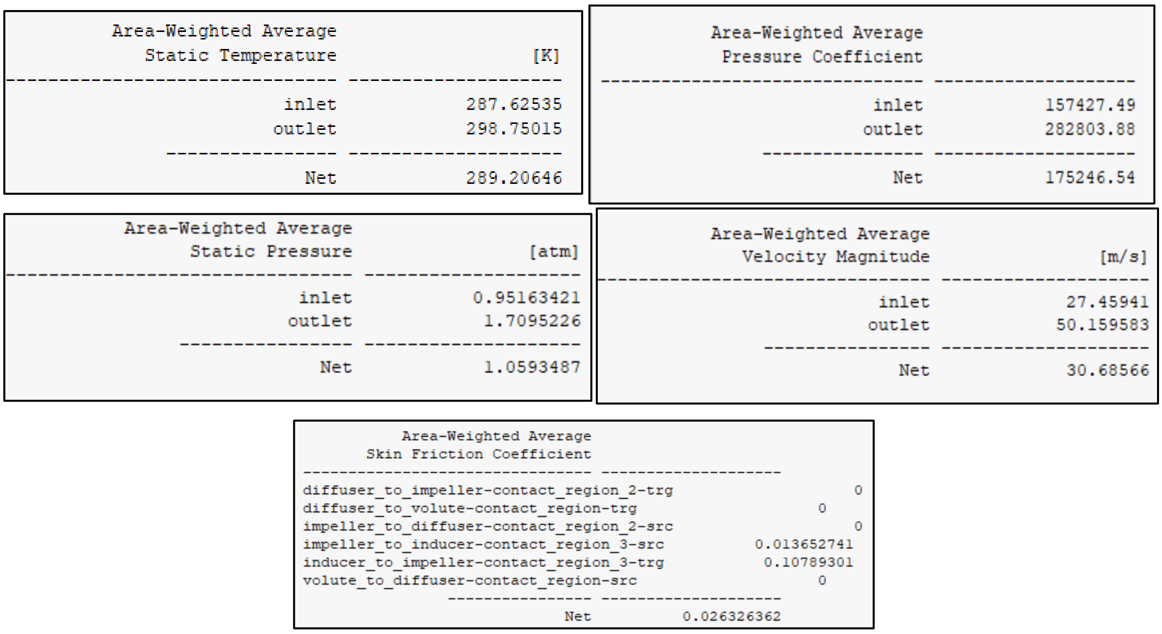


Figure 62 Velocity magnitude of impeller blade in optimal volute.



Area-Weighted Average Static Temperature	[K]
inlet	287.62535
outlet	298.75015
Net	289.20646

Area-Weighted Average Pressure Coefficient	
inlet	157427.49
outlet	282803.88
Net	175246.54

Area-Weighted Average Static Pressure	[atm]
inlet	0.95163421
outlet	1.7095226
Net	1.0593487

Area-Weighted Average Velocity Magnitude	[m/s]
inlet	27.45941
outlet	50.159583
Net	30.68566

Area-Weighted Average Skin Friction Coefficient	
diffuser_to_impeller-contact_region_2-trg	0
diffuser_to_volute-contact_region-trg	0
impeller_to_diffuser-contact_region_2-src	0
impeller_to_inducer-contact_region_3-src	0.013652741
inducer_to_impeller-contact_region_3-trg	0.10789301
volute_to_diffuser-contact_region-src	0
Net	0.026326362

Figure 63 Results of optimal volute.

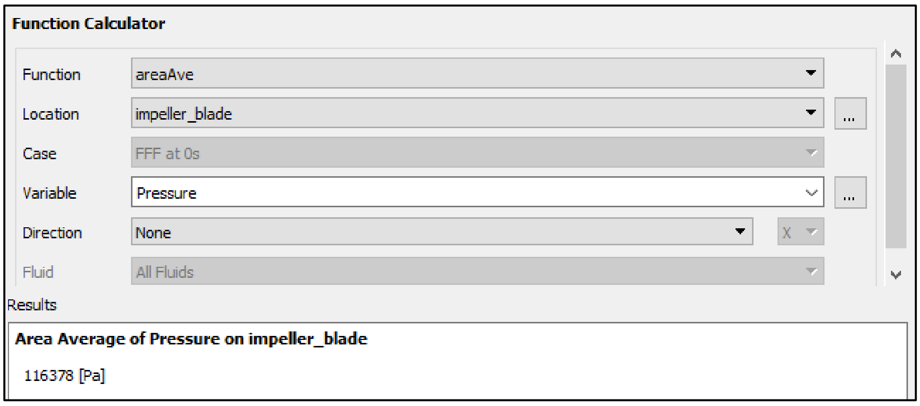


Figure 64 Function result of optimal volute.

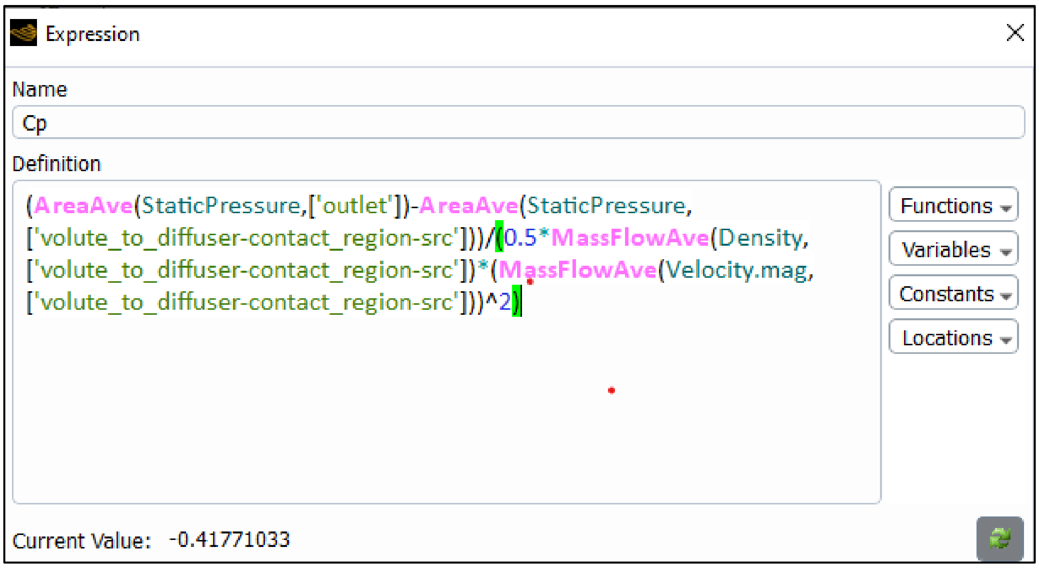


Figure 65 Cp value for optimal volute.

Conclusion

In conclusion, this report analyses the use of computational fluid dynamics (CFD) to optimise the design of turbomachinery compressors, with a particular emphasis on volute designs. It continuously analyses aerodynamic factors to suggest effective volute designs utilising SolidWorks and Ansys Workbench Fluent. The research emphasises how important computational fluid dynamics (CFD) is to contemporary design in engineering and provides useful advice for improving compressor effectiveness and reliability. Thus, the optimal volute for the compressor is the new volute which is submitted along with the report which has accurate meshing size and aerodynamic characteristics required for the compressor.

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Boyce, M. P. (2012). *Gas Turbine Engineering Handbook*. ScienceDirect. https://www.sciencedirect.com/topics/engineering/impeller#:~:text=An%20impeller%20in%20a%20centrifugal,leaves%20in%20the%20radial%20direction.

Xu, C., & Müller, M. (2005). Development and Design of a Centrifugal Compressor Volute. *International Journal of Rotating Machinery*, *2005*(3), 190–196. https://doi.org/10.1155/ijrm.2005.190