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COMAPARISON OF UNSTRUCTURED MESH WITH MAPPED MESH FOR TURBOCHARGER TURBINE STATOR OPTIMIZED FOR PRODUCER GAS USING CFD APPROACH

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Abstract

Downsizing of engine has become a trend in the overall development in the engines section that has not only enabled to have better efficiency alongside also decrease the harmful exhaust gas emissions. A typical normal engine for producer gas run mode is being studied. The latest development in the engine section owes to alternate fuels that can be used as a source of primary fuel for better sustainability and efficiency. Development is also going on in the field of producer gas based engines. Owing to its more eco- friendly nature towards environment compared to diesel and petrol engines, exhaustive research is been carried out. It is observed and studied that the exhaust gas emissions that take place are not completely efficient in nature, but there is still some discrete quantity of enthalpy remaining that could possibly be harnessed to increase the overall efficiency. This enthalpy of the exhaust gas as a result of combustion is utilized by Turbo-charging. As the properties of fuel changes, in turn the properties associated with the exhaust gas also change, which makes it inevitable to study a wide range of parameters to suitably account for different components. As there is no commercially available turbocharger for producer gas run engine, this research work makes an attempt to analyze the stator part of the turbocharger for different key parameters to match the entire system for producer gas run engine. For the said work, two different stator meshes, unstructured mesh and mapped mesh (one of the types of structured mesh) are selected for simulation in ANSYS V.15 of CFX.

Key Words: **Turbocharger, Producer Gas, CFD, Un-structured mesh, Mapped mesh, Grid Independence study.**

1. INTRODUCTION

These days, a significant amount of attention is been given to decrease the overall gas emissions resulting from the combustion process that the engines undergo. This in turn helps the environment from the repercussions that might take place in the near future. Various techniques are developed and researched upon by scientists to improve the overall efficiency of systems, reduce emissions and produce more clean energy. Techniques like supercharging, magnetization of fuels, harnessing solar, tidal, geothermal energy etc. One of the effective techniques which harnesses the residual enthalpy of the working fluid is by the use of turbocharger. Turbo-charging is forced induction method, where in more amount of compressed air is sent through the inlet manifold of the engine to increase the output horsepower.[1] It consists of basically four elements- Stator(casing), turbine, compressor, common shaft. The exhaust gas from the engine outlet is made to pass through the stator and then finally discharge on the rotor which rotates the complete common shaft assembly, which in turn makes the compressor run and pressurize the air and pump it back into the IC engine chamber. So here, the residual enthalpy possessed by the exhaust gas is being harnessed. Lot of research work has been carried out on turbocharger used for petrol and diesel as primary fuels for engines. Due to recent advancement, it is observed that producer gas is a feasible solution to ever demanding and quickly exhausting fossil fuels. Researchers are optimizing or making changes to current engines, to account or run the engine on producer gas which has similar results with better emissions and reasonable power output [2,3].

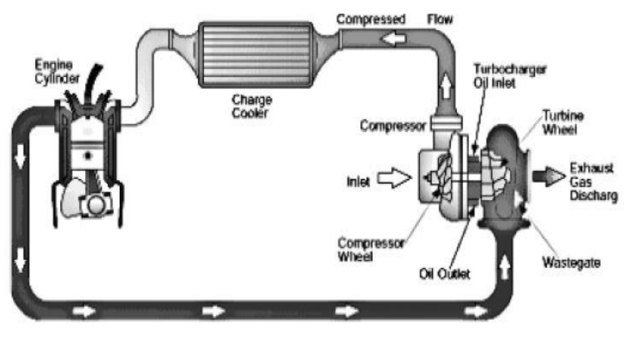

Figure 1: Working of turbocharger.

As the most important factors influencing the turbo-charging are related to the stator and rotor part, it is inevitable to conduct good study to justify effect of turbo-charging for producer gas. CFD analysis uses the famous Navier-Stokes equations converted into mathematical models through numerical methods and commercial softwares help to simulate certain conditions on the components [1,2,4].

Stator or casing is one of the most important parts of the turbocharger. It is the one responsible for converting the high pressure energy that is obtained from the exhaust of the engine to high kinetic energy and in turn high velocity at the outlet of the stator, which then makes the turbine rotate at high speeds.

A most important part of the geometry modeled and used in simulation softwares is the meshing that is been done, number of nodes, elements, through which the flow is simulated. With change in mesh quality and grids, there are relevant and noticeable changes observed in the parameters of concern. It is very important to study the meshing characteristics and their impact on the parameters of concern. A grid independence study is defined as that study where a suitable meshing technique is employed with certain definite number of nodes, elements and grids, which when kept higher or equal to a certain number would not have any effect on the parameters or properties that are associated with the simulation. So to say, a component with higher number of nodes, would not necessarily produce more fine results beyond a certain specific optimum number, instead it would just increase the time of simulation and would require more computational properties to converge. The results obtained with these can be verified experimentally in order to validate.

There are various types of meshing, but primarily there are two types- Structured and Unstructured Mesh. Here in this analysis, we have considered two types of meshing- Unstructured and Mapped Mesh. An unstructured mesh is a type where the grids, cells, nodes are not perfectly aligned neither are they accurately placed at locations, making the surface of the mesh very wavy and non-linear. The biggest advantage of this type is that the time required for meshing components is less, but the results obtained are crude and not very fine. Similarly, the mapped mesh is a mesh very close to structured mesh but with a layer of masking which holds the entire mesh together and makes averages out the un-even surfaces to make a smooth finished mesh.

Producer gas is a combination of combustible and non-combustible gases. It is a low density gas. The main constituents of producer gas are CO_2, N_2, CO, H_2. When producer gas is made to combust, the following shows the chemical reaction and products of combustion obtained [2].

1 mole (Producer Gas) + 0.2469 (O_2 + 3.7619 N_2) → 0.3475 CO_2 + 0.2465 H_2O + 1.3850 N_2

The products of combustion are nothing but the exhaust gases released, which are in turn made to pass over the turbocharger assembly.

2. METHODOLOGY

The main objective of this paper is to analyze the stator part of the turbocharger for producer gas as the main working fluid with certain set of boundary conditions, with this, a grid independence or mesh independence study also is done in order to finalize the number of nodes, elements, grids used for meshing which with increase would not affect the results. Simultaneously, a comparison based investigation of certain keen properties is also done for mapped stator and unstructured mesh stator to finalize the best mesh which has good accordance with respect to experimental results.

The main stator used here was a part of an existing turbocharger used for diesel engine by TATA motors. CMM machine was used to obtain the coordinates, curvatures in order to import those to design modeling software to produce a CAD model. CATIA was used to model the stator. For meshing and analysis of the stator, ANSYS V 15.0 was used. Packages like ICEM CFD, CFX were used to do the meshing and simulation respectively.

An unstructured mesh was used to mesh the stator, the main reason being, it is very difficult to use a structured mesh for stator due to minute variations that are seen in the stator geometry. An unstructured mesh is relatively less difficult to obtain. Similarly, a mapped meshed stator was also modeled and meshed to do the comparative study.

The un-structured mesh stator was meshed with six different numbers of nodes to be used. This enabled totally six files with different mesh sizes to be studied and analyzed. Following Table 1 mentions the number of nodes for each file type.

Table 1: Details of nodes for different files

Type of File	Number of Nodes
FILE 1	187910
FILE 2	372683
FILE 3	453749
FILE 4	541915
FILE 5	625436
FILE 6	861470

2.1 Creation of Producer gas as primary fluid and Boundary conditions

The exhaust gas contents as seen from the combustion reaction earlier show that the products contain carbon dioxide, nitrogen and H_2O. Each component's mass fraction was obtained to create the gas library in ANSYS. Gas Phase combustion, Fixed Composition Mixture technique was used to generate the gas for simulation.

Boundary conditions were also defined with mass flow rates being varied from 0.05 kg/s to 0.12 kg/s, because beyond this, it was observed that there was phenomenon of choking that happened. Turbulence model used was SST, with primary working fluid as exhaust gas of producer gas. Figure 2 shows inlet outlet region and path of fluid flow.

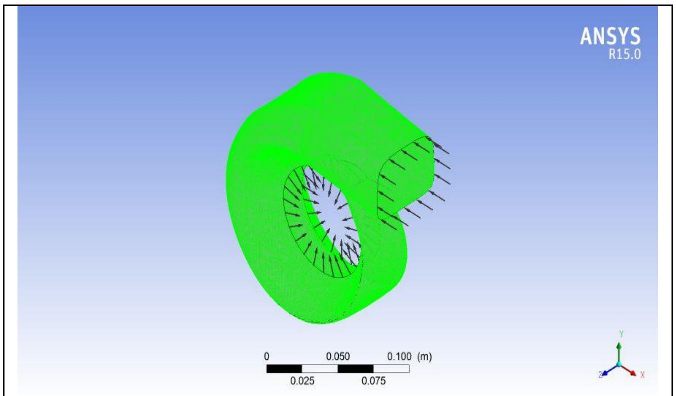

Figure 2: Boundary conditions establishment in the form of fluid flow direction at inlet and outlet.

3. RESULTS

3.1 Grid Independence Study

After selecting the best and more realistic turbulence model for the analysis of stator that is the SST model, grid independence study was carried out. Few of the most important parameters that are germane from stator point of view are- variation of pressure from inlet to outlet, pressure ratio (P_{in}/P_{out}), velocity of the fluid at the outlet. These are the decisive factors for studying the grid independence of the stator.

3.1.1 Variation of pressure

Here, a line passing through different vertical planes at almost 20% after inlet was constructed so as to ensure steady flow and analyze the variation of pressure along the length of the line. The colors of the line show the pressure variation. Similarly a line perfectly parallel to it at nearly the outlet was constructed in order to verify the pressure trend. Figure 3 shows the front view of the stator, with those lines representing the pressure variation. It can be observed that the pressure along both line decreases as the fluid moves towards the outlet portion.

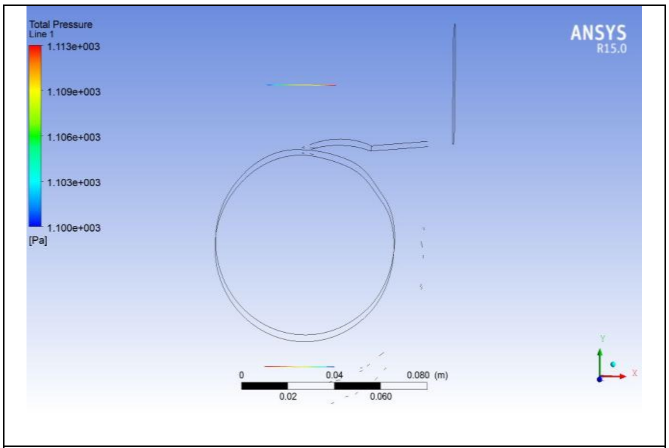

Figure 3: Pressure variation along top line and bottom line.

3.1.2 Pressure Ratio (P_{in}/P_{out})

It is defined as the ratio of inlet pressure in the stator to the pressure at the outlet. Higher the pressure ratio, better is the conversion efficiency of the stator in terms of kinetic energy. With change in size of the mesh, increase in number of nodes, elements, there is a change observed in pressure ratio. Figure 4 shows the variation of pressure ratio with respect to stators with different nodes numbers. From figure 4 it can be observed that there is an increase in the pressure ratio with increase in the node count for stator files. There is a significant rise in the pressure ratio from almost 1.05 to a peak value of 1.4 for 187910 and 453749 node files. Further it can be observed that the pressure ratio remains nearly same at 1.4 with a slight decrease of around 2%. From this it can be concluded that 453749 nodes are sufficient enough to obtain a pressure ratio which would be almost entirely grid independent, meaning further increase in node count would not bear any change in pressure ratio but would just increase the computational time.

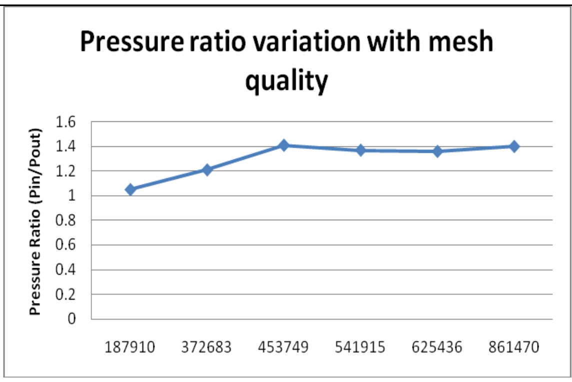

Figure 4: Pressure ratio variation with mesh quality.

3.1.3 Velocity of fluid at outlet

With increase in pressure ratio value, it goes with the physics that there must be an increase in the velocity value at the outlet, which provides a proof of pressure energy being converted into kinetic energy. Figure 5 shows the variation of outlet velocity with respect to mesh quality. Even here it can be observed that the output velocity increases upto third file (453749 nodes) and then on remains nearly the same with a slight decrease within 2% range. Thus from the above Figures 4 and 5, it can be concluded that, to be on safer side, the fourth file (541915 nodes) can be finalized as the grid independent file for the stator.

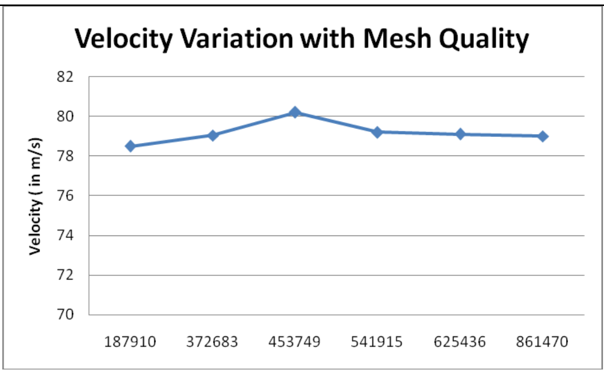

Figure 5: Exit velocity variation with mesh quality.

Below, are set of contour profile images obtained for total pressure for six different types of node files. From figures 6-11, it can be observed the pressure varies along the contour or the periphery of the stator. In the beginning, from figure 5, it can be observed that the pressure is high at inlet, slowly starts converting as the cross section varies, but is still high at nearly the outlet region of it. From each successive figures thereafter, it can be seen that the pressure distribution is far better as the number of nodes present in the mesh with each stator increases up-to a certain file number.

Later on, for file 5,6 it was observed that there is loss of pressure in the near beginning region or near inlet, hence the pressure conversion is not so efficient, which explains through the figure why the pressure ratio slightly decreases.

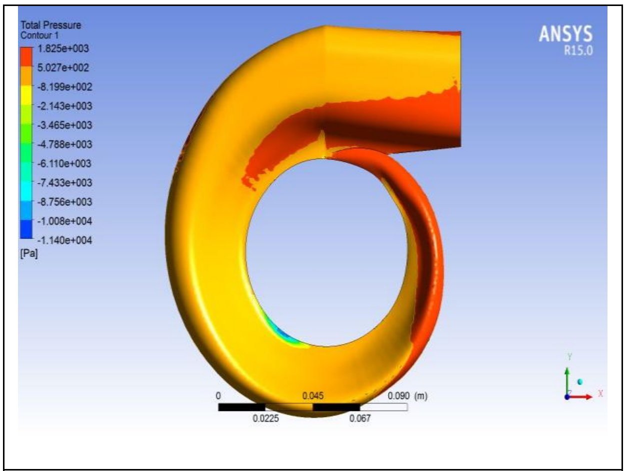

Figure 6: Pressure Contour for file-1 (187910 nodes)

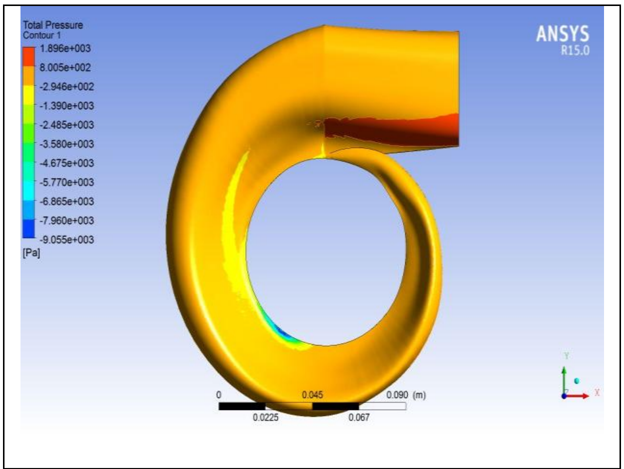

Figure 7: Pressure Contour for file-2 (372683 nodes)

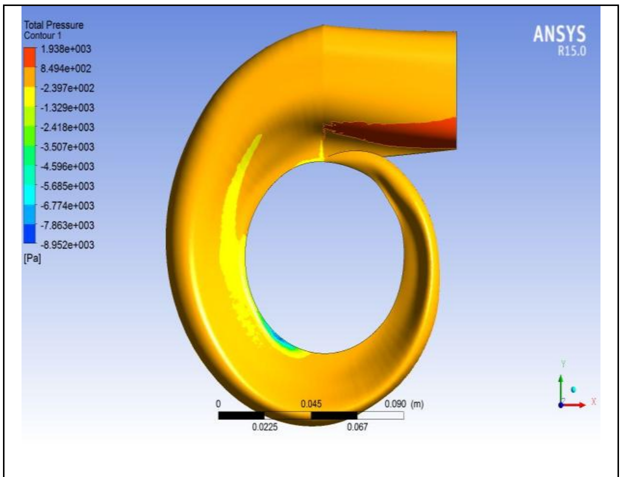

Figure 8: Pressure Contour for file-3 (453749 nodes)

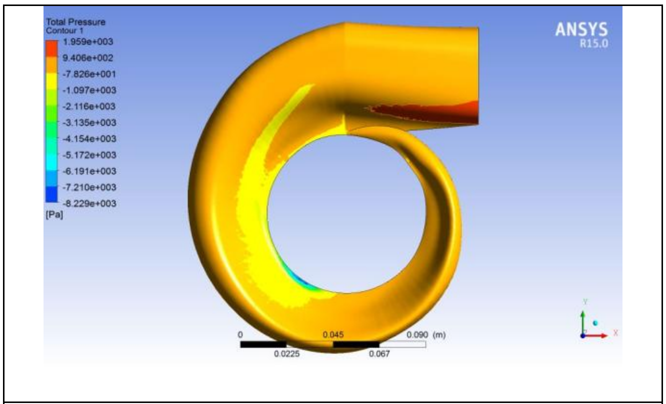

Figure 9: Pressure Contour for file-4 (541915 nodes)

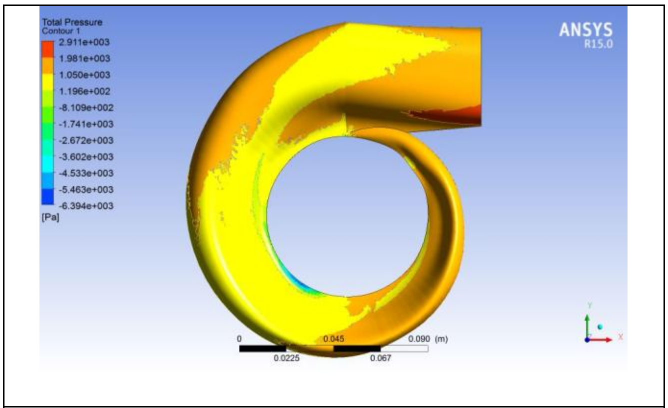

Figure 10: Pressure Contour for file-5 (625436 nodes)

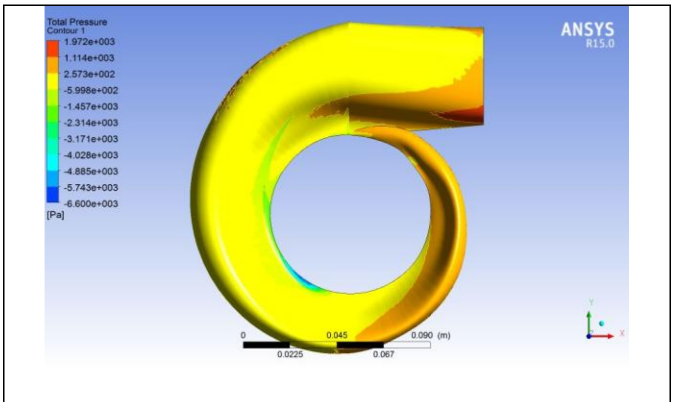

Figure 11: Pressure Contour for file-6 (861470 nodes)

3.2 Comparison of parameters for Un-structured mesh stator and Mapped mesh stator

After obtaining the grid independent unstructured mesh file with 541915 nodes, a mapped stator was generated with 600,000 nodes with a layer of masking on the inner periphery of the stator. As mentioned similar boundary conditions were defined for comparison. Most important parameter that was considered here was the velocity at the outlet of the stator which would be re-directed over the rotor.

3.2.1 Comparison for outlet velocities for un-structured mesh and mapped mesh

Following figure 12, clearly describes the variation of outlet velocity with change in mass flow rate. The observations noticed were that with increase in the mass flow rate of the exhaust gas, there was a continuous increase in the outlet velocity. Also, it was noticed that the outlet velocities for mapped mesh stator were higher than unstructured mesh, were more accurate and close to actual values. It was also observed that at higher mass flow rates, the outlet velocities were nearly the same, with difference by about 5-7%, but at lower flow rates, there was observable difference. The entire range of velocities at outlet varied from the lowest of 47 m/s to nearly 102 m/s.

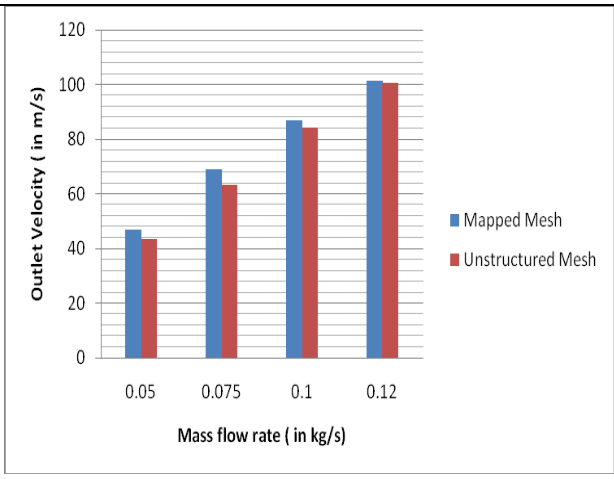

Figure 12: Shows the variation of outlet velocity v/s mass flow rate for mapped and unstructured mesh.

3.2.2 Comparison for pressure ratios for un-structured mesh and mapped mesh

Similarly, from figure 13, an explanation can be provided with regards to the effectiveness of pressure conversion in both types of meshed stator - unstructured and mapped mesh. It is observed that, the conversion of pressure for mapped stator is better in terms of looking at the values of pressure at the outlet region. Ideally, the value of pressure at outlet must be in close range with inlet values and in accordance with the pressures available, which completely depend upon the boundary conditions set for inlet region. Although, the pressure ratios obtained for unstructured mesh are high compared to mapped mesh, it does not necessarily mean better conversion, because the values of inlet and outlet pressures seems to be in-consistent compared to set pressures at inlet of the stator in boundary conditions. Also, it was observed that the velocity at outlet is higher for mapped stator that gives a clear indication that due to in-consistency in the type of mesh used or the grid sizes in the unstructured mesh, there are aberrations in the values pertaining to pressures.

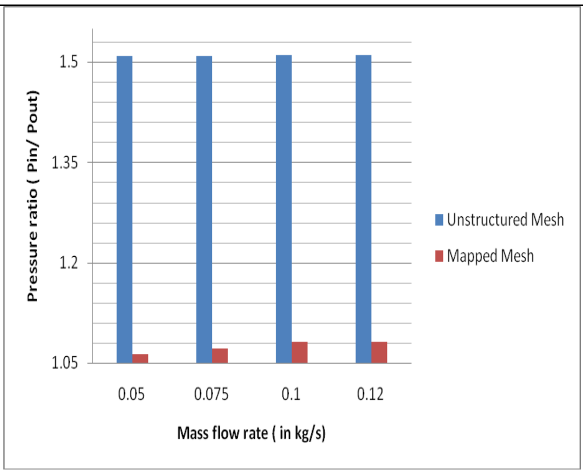

Figure 13: Shows the variation of pressure ratio vs mass flow rate for mapped and unstructured mesh.

3.2.3 Comparison for velocity of fluid at inlet and outlet for both meshes

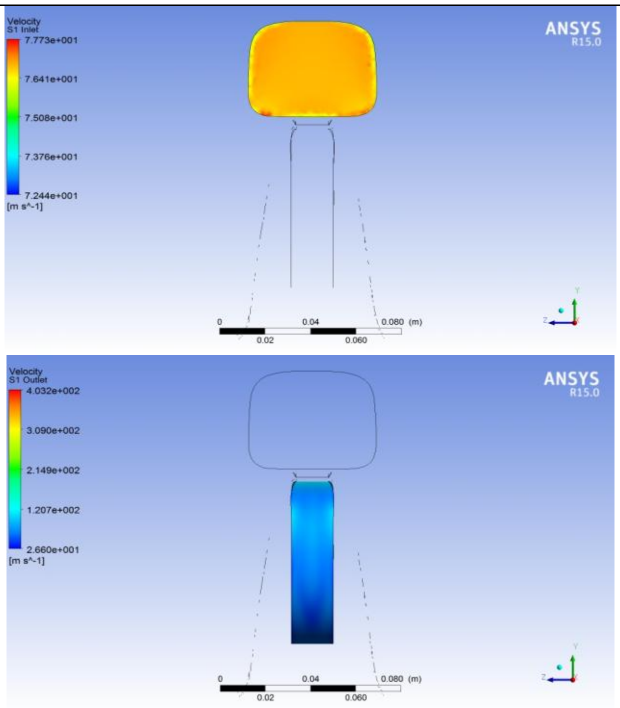

Figure 14: Velocity of fluid at inlet (top), and outlet (bottom) for mapped mesh.

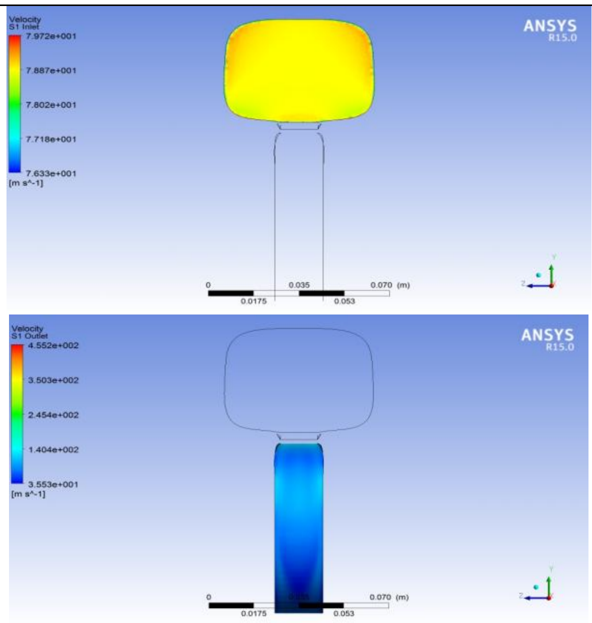

Figure 15: Shows the velocity of fluid at inlet (top), and outlet (bottom) for unstructured mesh.

From figure 14 and 15, it is noticed that velocities at inlet and outlet are certainly different for each mesh, with values also changing. It can be observed that the outlet velocity color for both the stators is nearly same, but the values associated with them are different, as is observed in figure 12. Also from the previous graphs of velocity, it can be corroborated that velocity conversion and in turn rise in kinetic energy at the outlet of the stator is higher in case of mapped mesh rather than the unstructured mesh.

3.2.4 Comparison for temperatures at inlet and outlet for both meshes

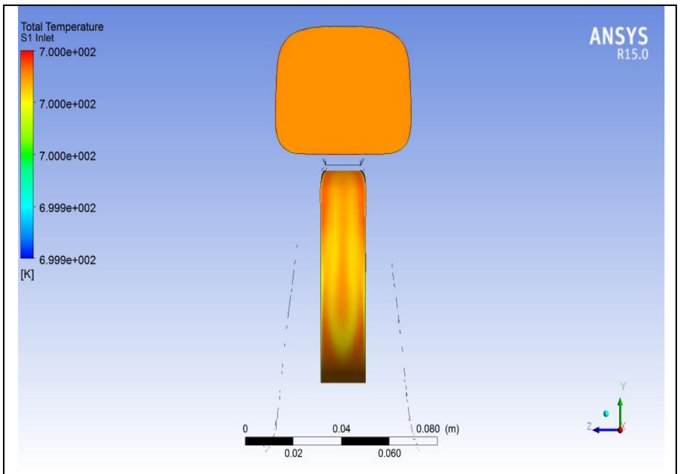

Figure 16: Temperature distribution for mapped mesh at inlet and outlet regions of the stator.

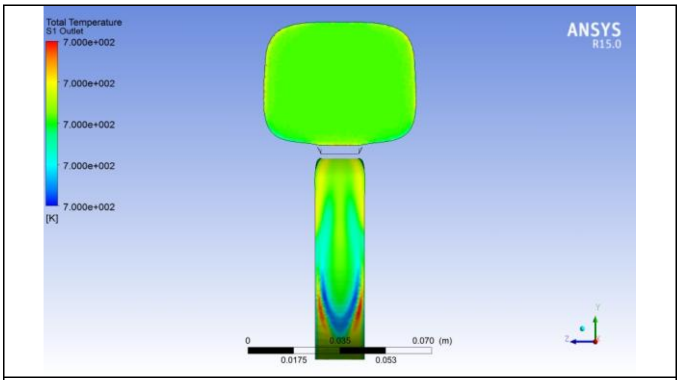

Figure 17: Temperature distribution for unstructured mesh at inlet and outlet regions of the stator.

From figures 16 and 17 it can observed how the distribution of temperature takes place at the regions of key interest, that being inlet and outlet. Ideally the temperature should not vary at the inlet and outlet, as the heat transfer model is adiabatic in nature. Despite of it, there is certain variation found, which can then be associated with the mesh quality and type. It is observed that, the temperature is more evenly distributed in case of mapped stator, with almost no variation at inlet and outlet. Similarly, the temperature distribution is disturbed for unstructured mesh at inlet and outlet of the stator. It can be observed that the outlet portion of unstructured mesh stator has some uneven distribution, sudden rise or fall in the values, which is a sign of heat loss, or non-alignment with the heat transfer model. This can be hence associated with the imperfectness of the mesh, uneven meshing surfaces that come in to picture. It is observed here that mapped mesh is better in terms of this property as well.

3.2.5 Comparison for Mach number variation at inlet and outlet for both meshes

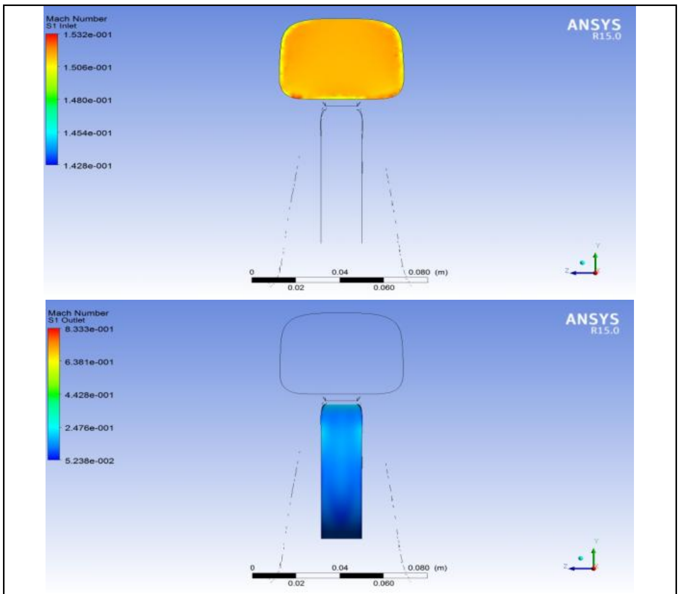

Figure 18: Mach number distribution for mapped mesh at inlet and outlet regions of the stator.

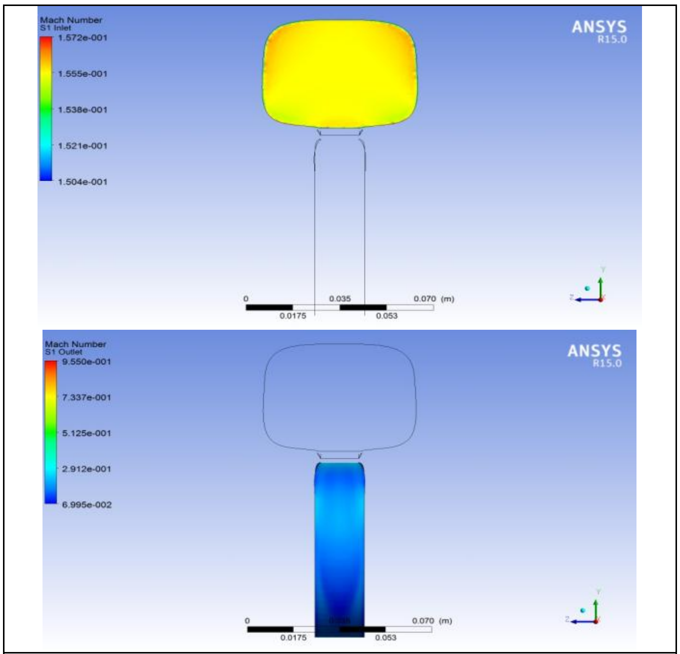

Figure 19: Mach number distribution for unstructured mesh at inlet and outlet regions of the stator.

From figures 18 and 19 it is observed that the Mach number for mapped mesh is higher compared to unstructured mesh, which can also be seen from the velocity that occurs at the inlet and outlet portion of the stator, so higher the velocity, higher is the Mach number. It is observed that the values of Mach number for both meshes is not very different, meaning there is a slight change in the values. Also effectively, the flow regime is subsonic in nature.

3.2.6 Comparison for vector diagram at key area in stator for both meshes

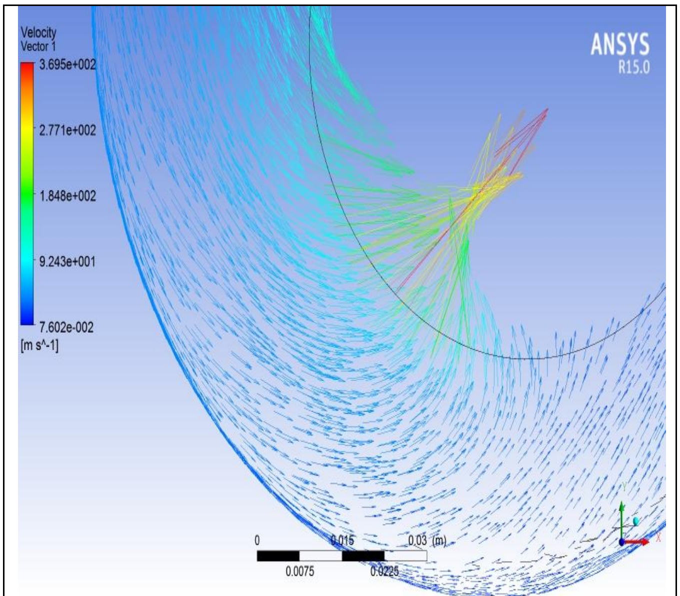

Figure 20: Vector profile of the fluid for mapped mesh.

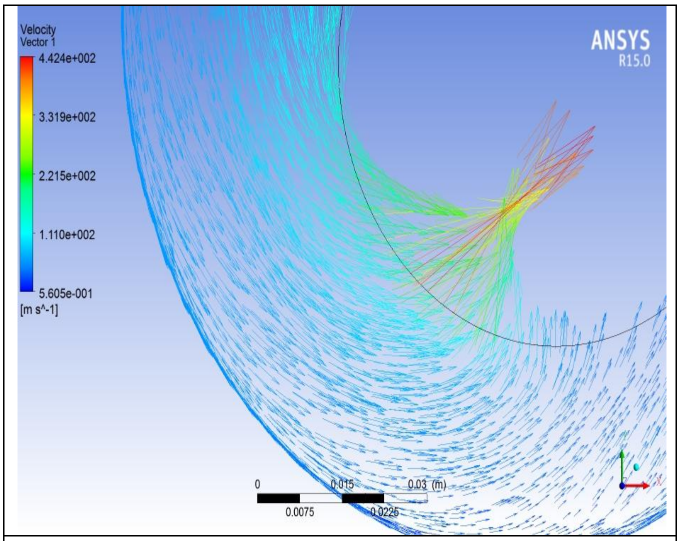

Figure 21: Vector profile of the fluid for unstructured mesh.

From figures 20,21 it is observed that at the key point of interest, there are changes in properties due to uneven surfaces or due to change in cross section. From vector plots it can be observed that, curling of velocity vector is more prominent in case of unstructured mesh than mapped mesh, resulting in low quality results for different parameters.

3.2.7 Comparison for velocity contours for both meshes

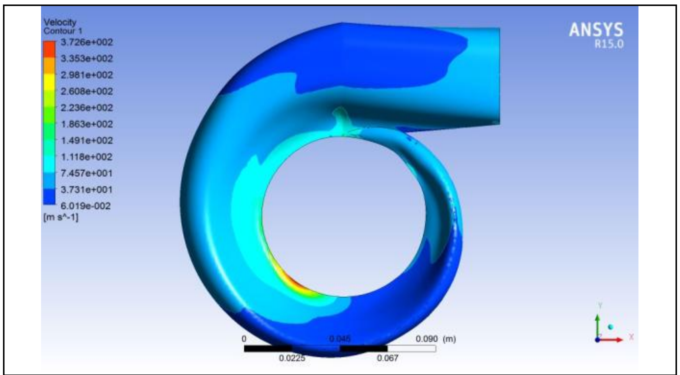

Figure 22: Velocity contour for mapped mesh.

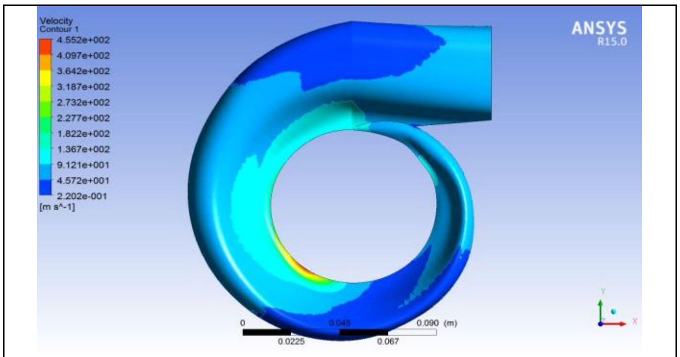

Figure 23: Velocity contour for unstructured mesh.

From figures 22,23 it can be observed how the distribution of velocity is from inlet to outlet through the profile for mapped and unstructured mesh. It can be observed that the velocity distribution is more uniform and better in case of mapped. Also, the velocity at regions of converging cross sections is increasing in nature and is high for mapped mesh than unstructured mesh. Similarly, from earlier velocity graphs, it can be proved that, mapped mesh has higher velocity magnitude than the other mesh.

3.2.8 Comparison for eddy viscosity across a plane for both meshes

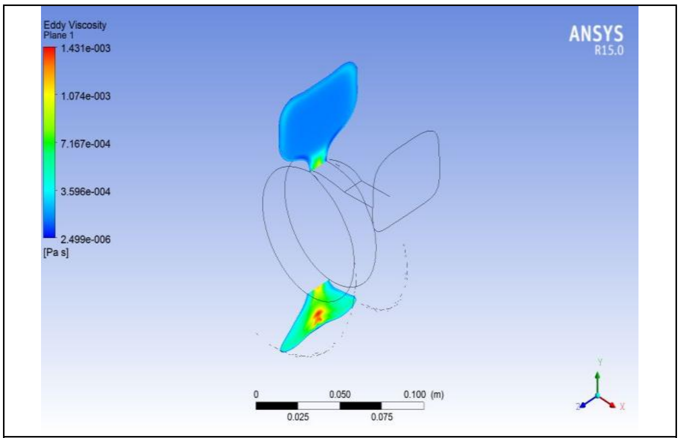

Figure 24: Eddy viscosity variation along a plane for mapped mesh.

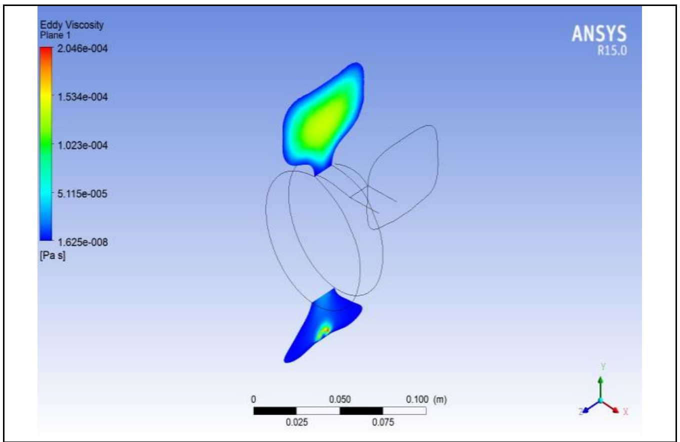

Figure 25: Eddy viscosity variation along a plane for unstructured mesh.

It can be observed from the above two figures 24 and 25, that distribution for eddy viscosity indicates the overall resistance that might occur during a given flow. Here it is observed that for mapped mesh, the eddy viscosity is less overall, and at some region, due to uneven surfaces, there is sudden rise in eddy formation. Also, for unstructured mesh, the distribution seems good, but is extremely uneven at certain regions, which makes the entire region unstable and increases the possibility of shooting up of certain properties.

3.2.9 Comparison for iterations required for complete convergence for both meshes

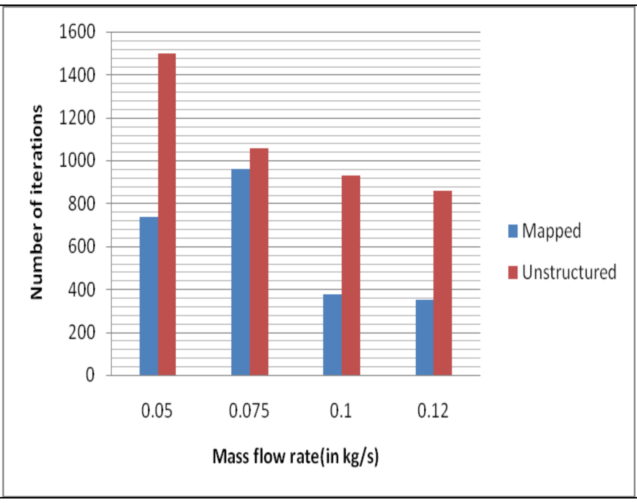

Figure 26: Convergence iterations for both meshes with respect to mass flow rate for similar conditions.

From the above Figure 26, it is observed that for each given mass flow rate, the iteration at which convergence occurs is significantly lower for mapped mesh than unstructured mesh. The highest percentage difference between iterations at which mapped mesh converges with respect to unstructured mesh is by about 60%, and the lowest percentage difference is around 10%. This difference in the convergence iterations directly translates to less simulation time for mapped mesh, for set standard RMS value of $1x10^{-6}$ and other conditions remaining same.

3.2.10 Fluid dissipation study in stator for both meshes

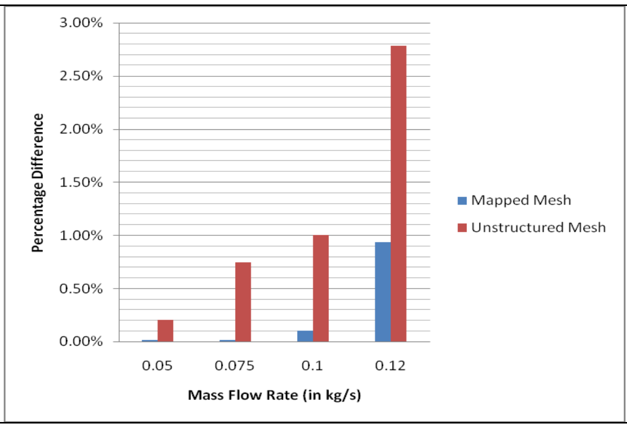

Figure 27: Fluid dissipation percentage at outlet with respect to inlet portion for different mass flow rates.

From the above graph, it can be observed that there is certain dissipation of fluid that is occurring within the stator while the fluid moves from inlet to outlet. The above figure represents the dissipation percentage for both meshes. It can be observed that percentage dissipation increases with increase in mass flow rate, and that dissipation percentage is higher for unstructured mesh compared to mapped mesh. This leads to lower energy conversion, less torque and hence less power output in unstructured mesh as compared to mapped mesh.

3.2.11 Comparison for mesh information for both meshes

Table 2: Different mesh statistics for both meshes

Mesh Information	Mapped Mesh	Unstructured Mesh
Number of nodes	639265	541915
Number of elements	2916090	2665625
Tetrahedral	2523997	2665625
Wedges	391959	0
Pyramids	134	0

It can be observed from Table 2 that the mesh quality owing to the statistics for mapped mesh is more stable, which further reduces fluid losses such as flow reversal near the lofted surfaces, sudden transient flows etc., as compared to unstructured mesh.

4. CONCLUSIONS

1) For grid independence study, it can be concluded from the above figures and values that, beyond the third file (453749 nodes), there is no much increase in the pressure ratio nor is there any change in the value of velocity at the outlet, ensuring that the mesh independent state of the stator has been achieved. To be on a more accurate side, the fourth file (541915 nodes) is considered to be mesh independent, which will produce the same results as other files with optimum convergence time and more accurate flow characteristics, and that increasing the number of nodes for study further would not contribute to any enhancement or change in the results but merely increase the computational time.

2) For the comparison of mapped & unstructured mesh quality, it can be concluded that the mapped mesh is better and more nearer to the applied physics in terms of the parameters taken into account for study. Mapped mesh also provided better energy conversion in quality as compared to unstructured mesh, like, higher available kinetic energy at the outlet of the stator which would be re-directed over the rotor to obtain more torque and hence more power, at the cost of appreciable drop in pressure energy at the inlet of the stator.

3) After comparison of mapped mesh and unstructured mesh for convergence study, it can be concluded that

implementing mapped mesh reduces the overall simulation or computational time.

4) In unstructured mesh stator, it is observed that steady conditions are not obtained strictly as per the boundary conditions, due to dissipation of fluid flow.

5) Finally the various results obtained from mapped mesh are more accurate, acceptable and more meaningful compared to unstructured mesh on all counts.

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REFERENCES

[1] Shalini Bharadwaj, Yashwant Buke, "Computational Fulid Dynamics Analysis of a turbocharged system" published in International Journal of Scientific Research (IJSR) Vol-3,Issue-5,May-2014. ISSN:2277-8179

[2] Naveen B, Kallu Raja Sekhar "CFD Analysis of Turbine" published in International Journal in IT and Engineering (IJITE), Vol-3 Issue-4, April-2015. ISSN: 2321-1776

[3] Shaik Magbul Hussain et.al "CFD analysis of combustion and emissions to study the effect of compression ratio and biogas substitution in a diesel engine with experimental verification" published in International Journal of Engineering Science and Technology (IJEST) Vol-4, Issue-02, February-2012. ISSN:0975-5462

[4] S Gavudhama Karunanidhi et al. "CFD studies of combustion in diesel engines" published in International Journal of Engineering Research and Applications (IJERA) Vol-3, Issue-4, pp-827-830. ISSN:2248-9622

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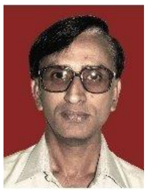

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