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Engine Downsizing and Reduction in Exhaust Gas Velocity in Turbine with Dual Boost Turbocharger

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Abstract: ***Turbochargers are used to boost the engine power and torque with its pressure increasing capacity. The objective of this research work is to downsize the engine with same power and torque. The modification has made on compressor and on turbine impeller of turbocharger. Here dual compressor is used, in which there are two impellers. The faces of impellers are opposite to each other. Face direction of first impeller is towards the turbine while direction of second impeller is opposite to it. Both impellers are attached with each other. These dual impellers are used for dual compression of fresh air which increases pressure developed inside the turbo. Another view of this work is to reduce the exhaust gas velocity for turbine which is possible with change in turbine design. Radial flow turbine works on impulse force while axial works on reaction force. In radial turbine exhaust gas directly hits the turbine blades while in axial flow turbine exhaust forces full periphery of turbine. Hence axial turbine needs less force and less exhaust gas velocity to rotate. CATIA software is used for designing while ANSYS CFD is used for flow analysis.***

Keywords: Impeller, Compressor, Turbine, CATIA, ANSYS CFD

1. Introduction

Turbocharger uses the exhaust gas of engine for driving its turbine impeller. Exhaust gas comes from the engine at very high velocity and have a capacity to rotate the turbine. It hits the turbine blades and shifts its force to turbine blades. The revolution/min. of the turbine is approx 1,00,000 rpm. Turbocharger is an integral part of – turbine, compressor and bearing housing.

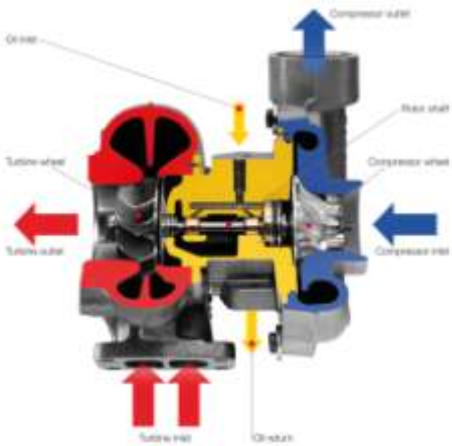

Figure 1: Cut Sectional model of Turbocharger

Turbine shaft is attached with compressor with a single shaft and also forces compressor impeller to rotate with it. Compressor is an important component of turbocharger which uses fresh atmospheric air from the atmosphere and compresses it to a specific pressure according to its design. Turbine and its shaft and compressor impeller are supported by bearing housing which is full of lubricating oil. This lubrication oil gives smooth flow to turbine shaft to rotate at very high rpm approx 1, 00,000 rpm.

2. Objectives

The main objective of this research work is to reduce engine volume which further helps in reducing weight and size of engine cylinder. As more pressure develops with the modification in turbocharger it sucks more fuel and hence develops more power. In place of increasing the power of the engine the objective of this research work is on downsizing of engine. So, with modified turbo and with reduction in engine size, it can generate the same power as it was generating modification. In this new concept of turbocharger there is a modification in impeller of compressor. A two face impeller is used which have same specifications but faces are opposite. Face of first impeller is towards the turbine while of other is opposite to it.[1] These dual face impeller is used for two stage compression of fresh air. In the first stage of compression, fresh air goes inside the turbo at atmospheric pressure. Here first impeller compress it and move it towards the second impeller. Again second impeller compresses it and push it towards the manifold of engine.[1] Another objective of this paper is to show how axial flow turbine affects the exhaust gas velocity at entry in turbine over radial flow turbine. Objectives –

1) Reduction in engine volume with modification in turbocharger.
2) Reduce the exhaust gas velocity at entry in turbine with axial flow turbine over radial flow turbine.

3. Design of Turbocharger

Designing of the turbocharger has done on CATIA software –

3.1 Dual Impeller Compressor

Dual impeller compressor is a new concept in which a two face impeller is used for dual compression. The compressor

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has same specification as Garett turbo model GT4088R. Specifications of the compressor design [1] are as follow –

Inducer diameter = 63.5mm
Exducer diameter = 88mm
No.of blades (in both impeller)= 22
Manifold diameter = 38.16mm
Housing Area/Radius = 0.72
Blade angle at periphery = 30^0
Flow angle at rotor exit = 60^0

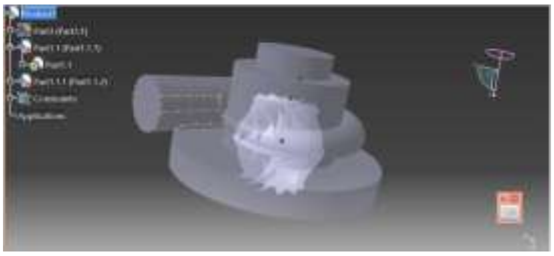


Figure 2: Dual Impeller Compressor

3.2 Single Impeller Compressor

In this type of model single impeller is used in compressor it face is towards the turbine as conventional turbo have. This impeller is conventional type which was using from the development of turbocharger. Specifications of compressor design [1] as follow –

Inducer diameter = 63.5mm
Exducer diameter = 88mm
No.of blades = 11
Manifold diameter = 38.16mm
Housing Area/Radius = 0.72
Blade angle at periphery = 30^0 [6]
Flow angle at rotor exit = 60^0 [6]

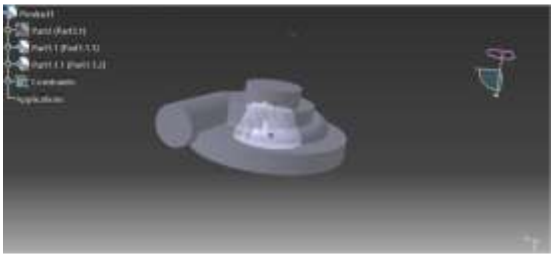


Figure 3: Single Impeller Compressor

3.3 Axial Flow Turbine

Axial flow turbine works on reaction force, in which the fluid forces turbine to rotate. Exhaust gas which comes from high velocity in turbine force full turbine body to spin. The specifications of this turbine are same as eppler airfoil 376. Specifications of turbine [1] as below –

Inducer diameter = 68mm
Exducer diameter = 77mm
Manifold diameter = 38.16mm
Housing Area/Radius = 0.85, 0.95, 1.06, 1.19
No.of blades = 11
Blade angle at periphery = 8.25^0
Flow angle at rotor exit = 0^0

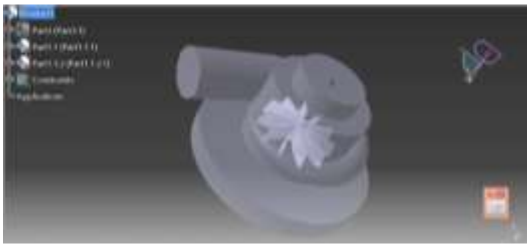


Figure 4: Axial Flow Turbine

3.4 Radial Flow Turbine

In Radial turbine the fluid gases directly hits the blade of turbine. It is based on impulse force and this forces it to rotate at high rpm. High velocity of exhaust gases which is hitting the turbine also increases the temperature of turbine casing. Specifications of turbine [1] are as below -

Inducer diameter = 68mm
Exducer diameter = 77mm
No.of blades = 11
Manifold diameter = 38.16mm
Housing Area/Radius = 0.85, 0.95, 1.06, 1.19
Blade angle at periphery = 0^0
Flow angle at rotor exit = 90^0

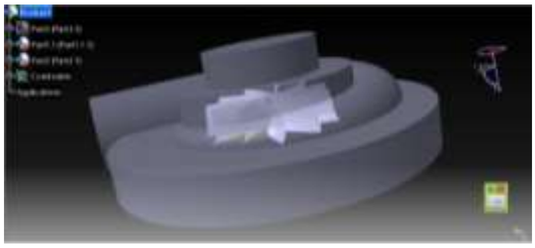


Figure 5: Radial Flow Turbine

4. Analysis of Turbocharger

Flow analysis of turbocharger has done on ANSYS CFD. Input parameters for analysis are as below-

1) RPM of turbine shaft(Approx) = 100000 rpm
2) Fresh air velocity at inlet in compressor = 160m/s[1]

4.1 Dual Impeller Compressor

In this compressor model fresh air enters in compressor parallel to shaft, axially in which first impeller compress it and send it towards second impeller with periphery of casing where again second impeller compress it. This fresh compressed air then goes to engine where it is utilized by engine for generating power.

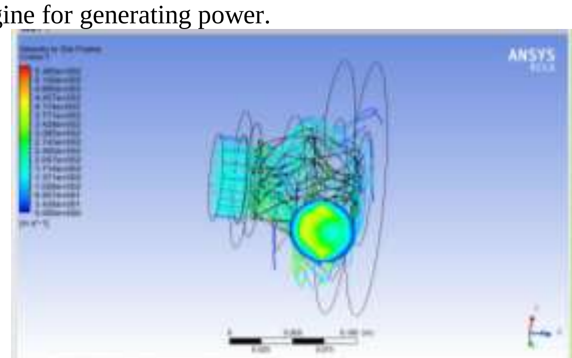


Figure 6: Analysis of Dual Impeller Compressor

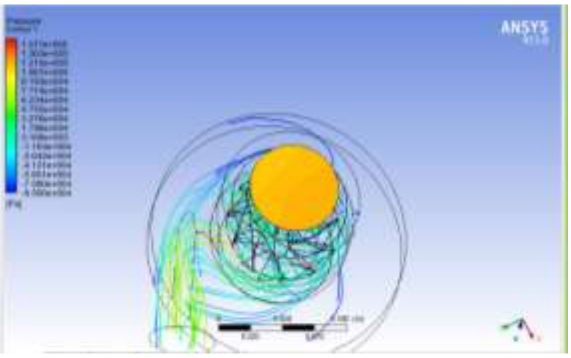


Figure 7: Analysis of Dual Impeller Compressor

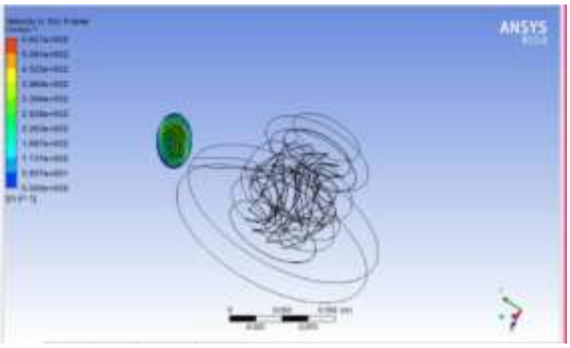


Figure 8: Analysis of Dual Impeller Compressor

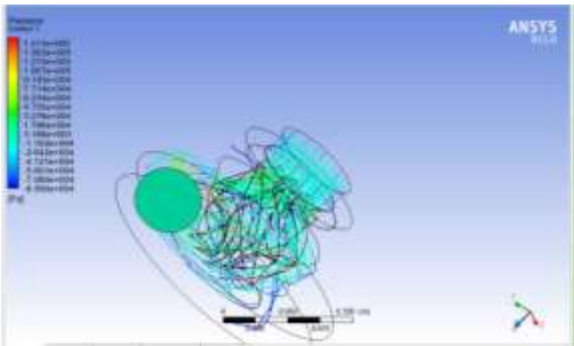


Figure 9: Analysis of Dual Impeller Compressor

Average pressure at entry of fresh air = 131055 Pa
Average pressure at exit = 211318 Pa

4.2 Single Impeller Compressor

In this compressor model the direction of fresh air is same as dual i.e. parallel to compressor shaft and it leaves compressor radially. This is a conventional type compressor of turbo which is used in turbo with development of turbo.

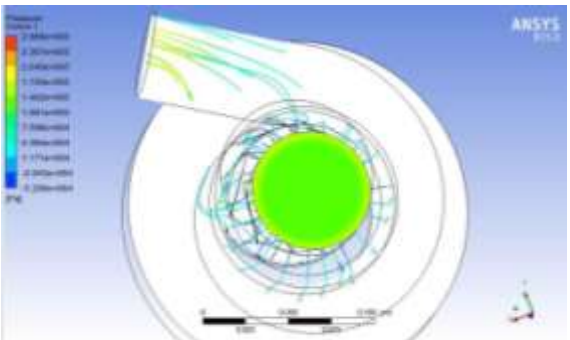


Figure 10: Analysis of Single Impeller Compressor

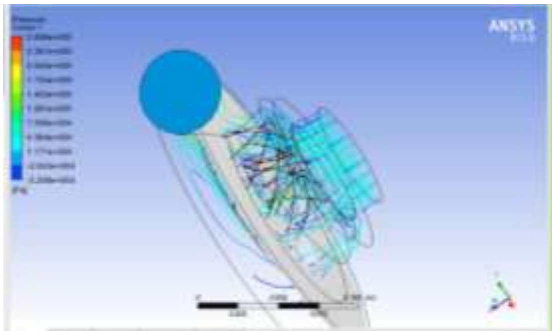


Figure 11: Analysis of Single Impeller Compressor

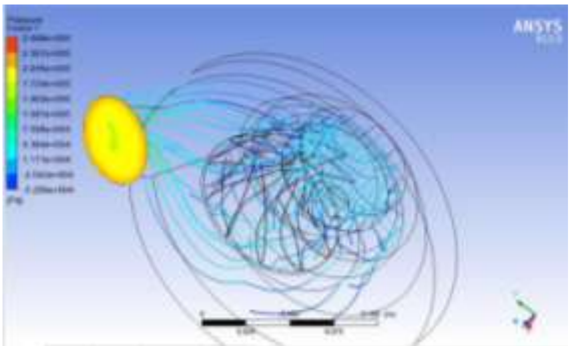


Figure 12: Analysis of Single Impeller Compressor

Average pressure at entry of fresh air = 131055 Pa
Average pressure at exit =198288.42 Pa

4.3 Axial Turbine

Axial turbine works on the basis of reaction force where reaction force of fluid forces turbine to rotate. In this axial turbine model exhaust gases enters into turbine axially and forces turbine impeller to rotate at higher rpm approx 100000 rpm and also leaves axially towards exit. High exhaust gas velocity is responsible to rotate the impeller.

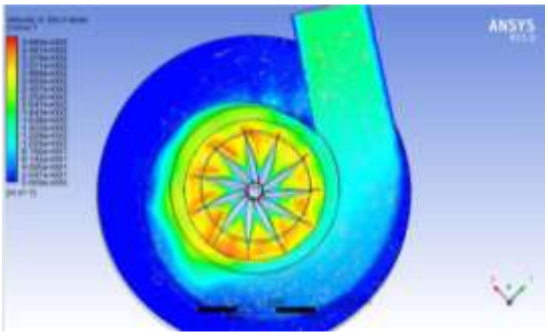


Figure 13: Analysis of Axial Flow Turbine

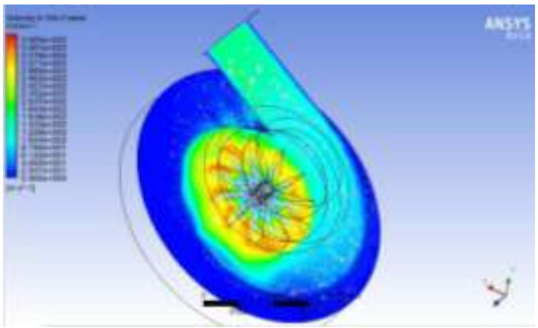
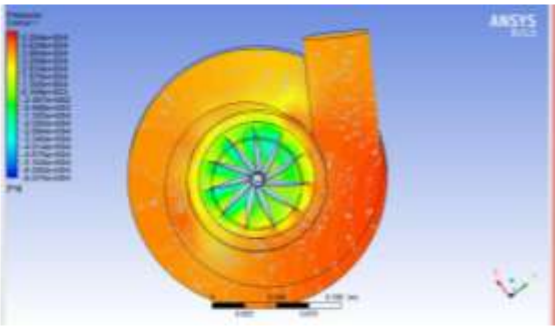


Figure 14: Analysis of Axial Flow Turbine



Average velocity at entry in turbine =170m/s
Average velocity at exit =156.25m/s

4.4 Radial Turbine

Radial turbine works on the basis of impulse force where high velocity exhausts gas which comes from the engine, push turbine to rotate at high approx 1,00,000 rpm. In this turbine model exhaust gas enter in radial direction while leaves axially parallel to turbine shaft.

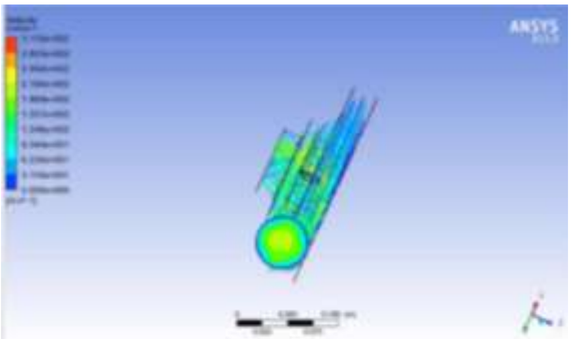


Figure 15: Analysis of Radial Flow Turbine

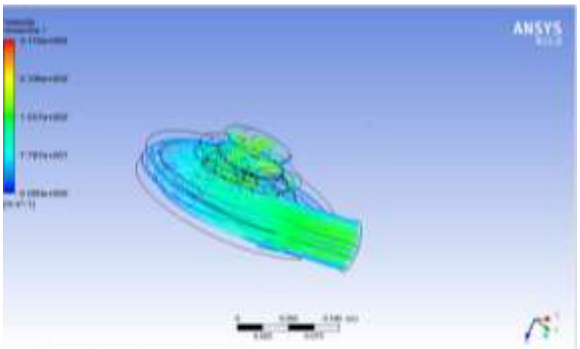


Figure 16: Analysis of Radial Flow Turbine

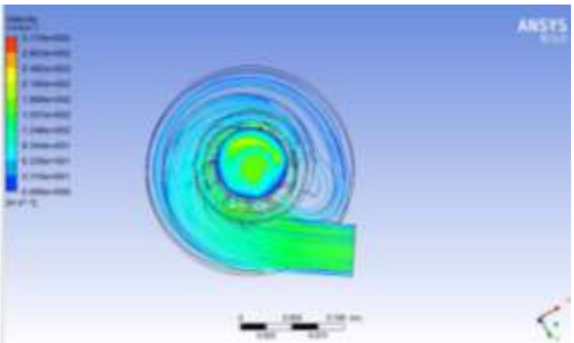


Figure 17: Analysis Radial Flow Turbine

Average velocity at entry in turbine =188.15m/s
Average velocity at exit =161.94m/s

5. Engine Downsizing calculations

Engine downsizing is defined as "Decrease in engine size without decrease in engine Power and Torque". For calculation of engine volume, peak power of engine is taken as 72.97@2500RPM [1]. Maximum pressure developed inside the engine cylinder can be calculated by below formula-

⇒ p_{max} = 9 x pressure developed by turbo/mean effective pressure[2]

5.1 Dual Impeller Compressor Axial flow Turbocharged Engine Model

Average pressure developed inside the turbocharger compressor is 211318. Hence maximum pressure developed inside the engine cylinder is calculated as-

⇒ $p_{max} = 9 \times 211318$

= 1901862 Pascal

The power developed inside the engine cylinder is calculated by below formula –

$$\Rightarrow \text{Power} = \frac{p_{max}.\ L.\ A.\ n.\ K}{60000}\text{ , in kW [3]}$$

Where, p_{max} = pressure developed inside engine, in Pascal

$A = \pi /4\ D^2$, in m^2

L = length of stroke = 1.5D, in m

n = N/2, for four cylinder, in RPM

K = no. of cylinders in engine.

$$\Rightarrow 72.97 = \frac{1901862 \times 1.5D \times \pi \times D^2 \times 2500 \times 4}{60000 \times 4 \times 2}$$

$\Rightarrow D^3 = 3.9079 \times 10^{-4}$

$\Rightarrow D = 0.073$m or 73 mm

Then the volume of the engine cylinder will be -

$\Rightarrow V = \pi/4\ D^2 \times L \times K$, in mm^3

$\Rightarrow V = \pi/4\ (73)^2 \times 1.5 \times 73 \times 4$

$\Rightarrow V$ = 1800000cubic mm

= 1800cubic cm

= 1800CC

5.2 Single Impeller Compressor Radial flow Turbocharged Engine Model-

Average pressure developed inside the turbocharger compressor is 198288.417 Pascal. Hence maximum pressure developed inside the engine cylinder is calculated as-

⇒ $p_{max} = 9 \times 198288.47$

= 1784595.75 Pascal

The power developed inside the engine cylinder is calculated by below formula –

$$\Rightarrow \text{Power} = \frac{p_{max}.\ L.\ A.\ n.\ K}{60000}\text{ , in kW [2]}$$

Where, p_{max} = pressure developed inside engine, in Pascal

$A = \pi /4\ D^2$, in m^2

L = length of stroke = 1.5D, in m

n = N/2, for four cylinder, in RPM

K = no. of cylinders in engine.

$\Rightarrow 72.97 = \underline{1784595.75 \times 1.5D \times \pi \times D^2 \times 2500 \times 4}$

60000 x 4 x 2

$\Rightarrow D^3 = 4.16473 \times 10^{-4}$

$\Rightarrow D = 0.0746$m or 74.6 mm

Then the volume of the engine cylinder will be -

$\Rightarrow V = \pi/4\ D^2 \times L \times K$, in mm^3

$= \pi/4\ (74.6)^2 \times 1.5 \times 74.6 \times 4$

= 1956399.82cubic mm

= 1956.4cubic cm

= 1956.4CC

6. Results and Comparison

After analysis of double impeller compressor axial flow turbocharger and single impeller compressor radial flow turbocharger results can be illustrated as-

Table 1: Pressure results

Turbo Model	*Pressure at entry of fresh air, in Pascal*	*Pressure developed by turbo, in Pascal*	*Maximum pressure in engine, in Pascal*
Dual compressor axial flow	131055	211318	1901862
Single compressor radial flow	131055	198288.42	1784595.75

These values also can be illustrated on graph –

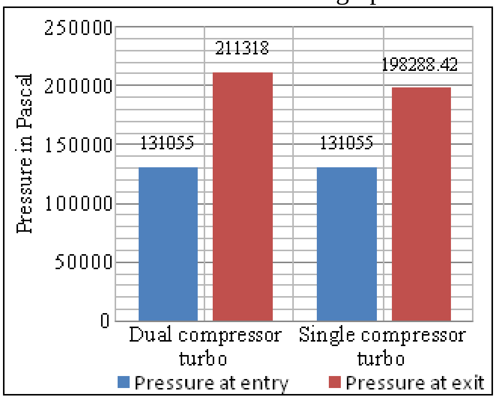


Figure 18: Graph for pressure in compressor

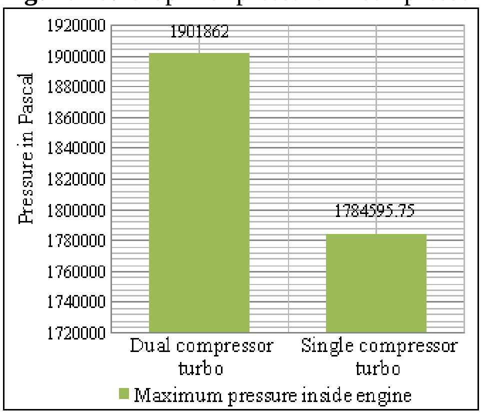


Figure 19: Graph for maximum pressure in engine

Table 2: Downsizing results

Engine Model	*Engine Bore, in mm*	*Engine Volume, in CC*
Dual compressor axial flow turbocharged engine	73	1800
Single compressor radial flow turbocharged engine	74.6	1956.4

These values also can be illustrated on graph –

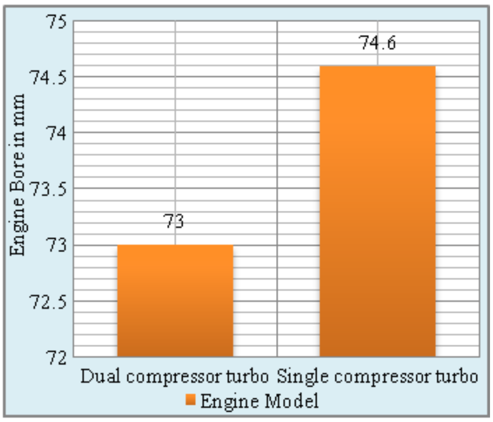


Figure 20: Graph for Engine Bore

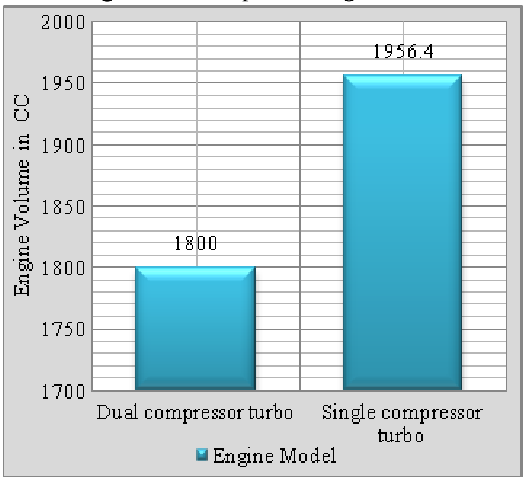


Figure 21: Graph for Engine Volume

Table 3: Velocity results

Turbo Model	*Velocity at entry,in m/s*	*Velocity at exit, in m/s*
Dual compressor axial flow	170	156.25
Single compressor radial flow	188.15	161.94

These values also can be illustrated on graph –

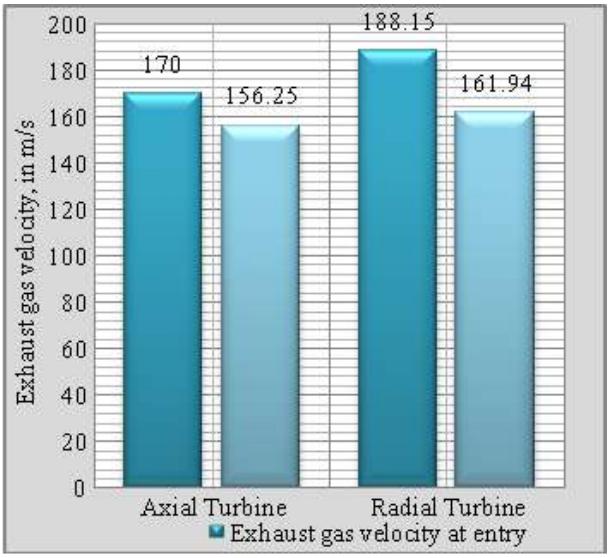


Figure 22: Graph for velocity in turbine

7. Conclusion

1) This research paper shows how dual impeller compressor axial flow turbocharger is more beneficial over single impeller compressor radial flow turbocharger for engine downsizing.
2) With modifications in compressor of turbocharger, the pressure developed by the compressor can be increased.
3) For same peak value of engine power i.e. 72.97kW@2500RPM, both models of engine gives different engine bore and volume which is possible by generating different fresh air pressure by turbo.
4) This increased pressure of fresh air can reduce the engine size. So, it can reduce the engine size with same power and torque.
5) This paper also shows that for rotation of turbo shaft in axial flow turbo, needs less exhaust gas velocity compare to radial flow turbo.

8. Acknowledgment

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