DESIGN AND ANALYSIS OF COMPRESSED AIR TURBINE VEHICLE

A Thesis Submitted in partial fulfilment of the requirements for the award of degree of

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In

MECHANICAL ENGINEERING

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CERTIFICATE

*This is to certify that the thesis entitled "**DESIGN AND ANALYSIS OF COMPRESSED AIR TURBINE VEHICLE**" being submitted by "**Mr. AKHIL K (1601-15-736-016), Mr. RUSHYANTH T (1601-15-736-036) and Mr. UDAY CHANDRA R (1601-15-736-122)**" for the award of the degree of **Bachelor of Engineering [B.E] in MECHANICAL ENGINEERING** to this institute is a record of the bonafide work carried out by them under my supervision. The thesis has fulfilled the requirements according to regulations of this institute and in my opinion has reached the standard of my submission. The results embodied in the Thesis have not been submitted in any other University or Institute for the award of any degree.*

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DECLARATION

We hereby declare that the work described in this thesis, entitled "Design and Analysis of Compressed Air Turbine Vehicle" which is being submitted by us in partial fulfillment for the award of Bachelor of Engineering [B.E] in Mechanical Engineering to the Chaitanya Bharathi Institute Of Technology (Autonomous), Gandipet, Hyderabad – 500 075 is the result of investigations carried out by us under the guidance of Dr. M.V.S Murali Krishna, Professor and Head, Mechanical Engineering Department, Chaitanya Bharathi Institute of Technology, Gandipet, Hyderabad – 500 075. The work is original and has not been submitted for any Degree/Diploma of this or any other university.

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ABSTRACT

The fossil fuel engines which were good enough for us before 30-40 years but now they are one of the sources of contributor of global warming and pollution with fossil fuel crisis. India's vehicular pollution is estimated to have increased eight times over the last two decades. This source alone is estimated to contribute about 70 per cent of the total air pollution in India. The Compressed Air Vehicle is an eco-friendly vehicle which works on compressed air. Compressed air as an alternative for running light vehicles using air turbines has no harmful effect on the environment and thus less health hazards.

The compressed air turbine vehicle is eco-friendly that uses compressed air as the source of energy. Here the normal piston engine is replaced with a turbine. The turbine is used as the energy converter in this vehicle, the pneumatic energy of compressed air is converted into mechanical work with help of turbine. The air under pressure which have energy is given into the turbine As this compressed air enters into the turbine the compressed air expands and the energy is released which is used to move the turbine vane and produce work output through the turbine shaft The turbine output shaft is coupled to the rear wheel shaft with the help of gear arrangement.

Main aim of present research work is to design a novel compressed air turbine and develop it for functional use as air engine. It shall require design and development of micro impulse / reaction turbines which can run on compressed air and convert compressed air energy to shaft work for producing adequate torque. This will be zero pollution or emission free air engine. Air is a natural resource that can be easily compressed and cylinders of smaller size with lightweight can be filled at air filling stations created for this purpose.

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NOMENCLATURE

P_1	Pressure of Cylinder
P_2	Pressure at Outlet of Cylinder
v_1	Velocity inside cylinder
v_2	Velocity at outlet of cylinder
Q	Cylinder flow rate
A_N	Area of Nozzle of Cylinder
T_1	Temperature at Inlet of Nozzle
T_2	Temperature at Exit of Nozzle
T_s	Static Temperature
P_s	Static Pressure
M_1	Entry Mach Number
M_2	Exit Mach Number
C_1	Sound Velocity at Entry of Nozzle
C_2	Sound Velocity at Exit of Nozzle
A_1	Area at Inlet of Nozzle
A_2	Area of Outlet of Nozzle
A_t	Area of Throat of Convergent Divergent Nozzle
D_1	Diameter of Inlet of Nozzle
D_2	Diameter of Outlet of Nozzle
D_t	Diameter of Throat of Nozzle
P	Power of Turbine
N	Speed of Turbine
F	Force on Turbine
T	Torque generated by Turbine

CHAPTER 1

INTRODUCTION

1.1 Historic Perspective

History shows that the compressed air as an energy and locomotion vector is not a recent technology. In fact, at the end of the 19th century the first approximations to what could one day become a compressed air driven vehicle already existed, through the arrival of the first pneumatic locomotives. Yet even two centuries before that Dennis Papin apparently came up with the idea of using compressed air (Royal Society London, 1687).

The first recorded compressed-air vehicle in France was built by the Frenchmen Andraud and Tessie of Motay in 1838. A car ran on a test track at Chaillot on the 9th July 1840, and worked well, but the idea was not pursued further. In 1872 the Mekarski air engine was used for street transit, consisting of a single-stage engine. It represented an extremely important advance in terms of pneumatic engines, due to its forward thinking use of thermodynamics, ensuring that the air was heated, by passing it through tanks of boiling water. Numerous locomotives were manufactured and the first in Nantes in 1879. The H. K. Porter Company in Pittsburgh sold hundreds of these locomotives to coal-mining companies in the eastern U.S. With the hopeful days of air powered street transit over, the compressed air locomotive became a standard fixture in coal mines around the world because it created no heat or spark and was therefore invaluable in gassy mines where explosions were always a danger with electric or gas engines.

In 1926, Lee Barton Williams of Pittsburg USA presented his invention: an automobile which he claimed run on air. The motor starts on gasoline, but after it has reached a speed of ten miles an hour the gasoline supply is shut off and the air starts to work. At the first test his invention attained a speed of 62 miles an hour.

Another perspective in reference to the present civilization is the excessive transportation requirements which have led to exhaustive use of hydrocarbon fuels and thus their fast depletion. An American geologist, Marion King Hubbert [1] projected in 1956 that the hydrocarbon fuel will peak within 20 years and thereafter it will deplete within 40 years (around 1995) in United States. In the recent study, it is also noticed that if the hydrocarbon fuel / oil is consumed at the current rates, then by 2020, the 80% of the available resources will be consumed in the most of countries. This necessitates the search for alternatives of fossil fuel / oil as energy source or preserving existing fossil fuel by tapping some other alternatives such as non-conventional energy sources like battery operated vehicles, wind mills, photocells etc.

India's vehicular pollution is estimated to have increased eight times over the last two decades. This source alone is estimated to contribute about 70 percent of the total air pollution in India. With 243.3 million tons of carbon released from the consumption and combustion of fossil fuels in 1999, India ranked fifth in the world behind the U.S., China, Russia and Japan. India's contribution to world carbon emissions is expected to increase in the coming years due to the rapid pace of urbanization, shift from non-commercial to commercial fuels, increased vehicular usage and continued use of older and inefficient coal-fired power-plants. It is essential to reduce carbon emissivity due to higher rate of utilization of fossil fuel in transport and to increase efficiency of energy usage. Thus, there are four distinct reasons to go for alternative energy namely; depletion of fossil fuel and necessity to preserve it, emission control to preserve global warming, sustainable energy future and economic impacts.

The worldwide researches are also going on for other alternatives such as use of hydrogen fuel cell (which is presently very costly), use of bio-diesel, use of solar energy, use of photo voltaic cell and use of compressed air vehicle engines made of light material. Research and development work on compressed air engines is in progress since 1979.

1.2 Compressed Air as Potential Alternative

The increased use of fossil fuel driven engines for transport systems has resulted in the rising of pollution levels and greenhouse effect due to emission of hot toxic gases and suspended particles. This environmental threat has made it imperative to look for a viable alternative to fossil fuels for running transport vehicles. Ideally, such an alternative should have a zero or minimal pollution level and low initial cost, low running expenses, high degree of reliability, convenience and versatility of use. It should have ease of storage within the vehicle and convenience of recharge for long range uses. It should also have performance comparable with the existing conventional engines. Such a zero-pollution vehicle (ZPV) will be readily acceptable by the user.

Various alternatives such as battery power-operated vehicles, hydrogen fuel cell-based vehicles, bio-diesel driven internal combustion engines, etc. are being constantly tried across the world. Looking upon the emission status of these various alternatives, it is apparent that each option has its own limitations. For example, blending of bio-diesel augments the naturally available fossil fuel, but it still remains a limited resource and does not meet the ZPV requirements. Battery operated engines / motors suffer from the drawback of limited operating range due to the requirement of frequent recharge, and periodical high replacement cost. Hydrogen fuel cells have not met the economic viability and easy recharge criteria so far. Liquid nitrogen vehicles could not gain popularity in view of their high cost.

All these issues have made it imperative to look for some other method or source. The technology of compressed air energy storage and its utilization in transport vehicles and other domestic utilities is an attractive option in view of its potential to offer ZPV alternatives. Air is freely available and can be conveniently compressed and stored. In view of these attractive features and experimental studies available, the compressed air engines / turbines appear to be a future dominant technology.

1.3 Recent Developments

Since last two decades rigorous research is going on for storage of energy systems and for development of compressed air engine. Some of the significant development works in compressed air-based transport technology are as follows:

Guy Negre, a French technologist and inventor developed the four-cylinder compressed air engine, which can run a vehicle at 60–80 miles per hour speed, without tail pipe emission. About 52 patents were made during 1998 to 2006, and recently, Moteur Development International and Tata Motors have entered into an agreement to develop such vehicles for commercial use. These highly compressed air energy storage systems can be filled up to 20 bar pressure within 15-20 min and can be used for running compressed air engine [2].

Saint Hilaire, G. et al. developed a Quasiturbine with a set of 14- engines parameters, zero pollution cars using gasoline and demonstrated in the festival at Le Lundi, [Montreal Gazette, 26th September 2005]. The Quasiturbine is a pressure driven turbo-machine producing continuous torque with symmetrically deformable spinning wheel. Excluding conventional turbines, the next step in the world of engine research is to make the gas engines as efficient as the diesel engines and the diesel engines as clean (or better) as the gas engines. Turbine characteristics help achieving this goal. The Quasiturbine (QTurbine or Kyoto engine) is a new engine technology that was conceived in early 1990 and patented in 1996.

Quasiturbine has very little low-power-efficiency penalty with multi-fuel compatibility (including direct hydrogen combustion), offering a drastic reduction in the overall propulsion system weight, size, maintenance and cost. Because Quasiturbine cycle is pressure driven instead of aerodynamically driven, it has a comparatively flat high efficiency characteristic in regard to rpm, load and power, which makes it most suitable for power modulation applications like in transportation, windmill energy storage and recovery systems [3].

For the last two decades, much research has been done to tap the air freely available in the atmosphere and to compress it for storage in cylinders for further use. Apart from other uses of compressed air, this can also be used to run combustion engines with the mixture of gas and air getting fired after the compression stroke at top dead center. The use of compressed air eliminates the need of having a separate compression stroke. Compressed air helps in the attainment of the expansion stroke after ignition takes place. Thus, the efficiency of the internal combustion engine is improved, and it runs on two stroke cycles. The air engines developed so far are basically running on hybrid systems such as compressed air and gases and are not 100 per cent pollution free. The concept of micro or mini compressed air engine can be one of the best alternatives for light vehicles, if it runs using air alone and thus causing no pollution.

1.4 Scope of Compressed Air Vehicle

India being a developing country, the per capita income of a person is very low. The majority of the population of the country still lives in rural and suburban areas where the means of transport is either bicycle or motorbike. The continuous hikes of fossil fuel prices at the rate of around 20–30 per cent every year are making the situation miserable. Extrapolation shows that at this rate, by 2010-12, prices may be double as what they were in 2005, and by 2030–40, it may touch Rs.1000 per liter. A time will come when the common person will not be able to purchase fuel to run motorbikes. This is not only due to the high demand for vehicles or its increasing numbers worldwide, but also due to the cost of fossil fuel going high because of high consumption up to 80 per cent of the available fossil fuel in transport and thus leading to its fast depletion. Thus, it is imperative to explore the possibility of alternatives to fossil fuel to make the environment free from emission for keeping the present and future generations healthy.

Air is a natural resource available freely in the atmosphere. Air can be suitably stored after being compressed to desired pressures such as 6–20 bar approximately without any change in its property. In fact, it is one working fluid that can be stored at very high pressure and can be retained without any loss after lapse of time. Compressed air can drive many domestic appliances such as vacuum cleaners, mixers, pumps, or electric generators when electric power fails, instead of using inverters to having clumsy battery arrangements, etc.

Modern light vehicles running on fossil fuel release tail pipe emission hazardous to public health. These emissions contribute significantly to creating ecological imbalances. But compressed air as an alternative for running light vehicles using air turbines has no harmful effect on the environment and thus less health hazards.

1.5 Present Work

Main aim of present work is to design and analysis of a nozzle and air turbine and develops it for functional use as air engine. It shall require design and development of micro impulse / reaction turbines which can run on compressed air and convert compressed air energy to shaft work for producing adequate torque. This will definitely be zero pollution or emission free air engine. Air is a natural resource that can be easily compressed and cylinders of smaller size with lightweight can be filled at air filling stations created for this purpose.

CHAPTER 2

LITERATURE REVIEW

2.1 Depletion of Fossil Fuel

A United States based noted geophysicist Hubbert Marion King (1903-1989) published the predictive analysis for the projection of future oil production in 1956 using combined principles of geology, physics and mathematics. Aleklett, K. et al. projected that with the current rate of consumption, most of the countries will pass through Peak Oil year by 2010 and 80% of globally available resources of fossil fuel would exhaust by 2020 [4].

Robert et al., submitted a report that oil is the lifeblood of modern civilization. It fuels the vast majority of mechanized transportation equipment automobiles, trucks, airplanes, transships, farm equipment, etc. This study deals with upcoming physical shortage of world conventional oil - an event that has potential to inflict disruptions and hardships on the economies of every country. The earth's endowment of oil is finite and demand for oil continues to increase with time. Accordingly, geologists know that at some future date, conventional supply will no longer be capable of satisfying world demand [5].

2.2 Global Warming and Emission Regulations

Rose Adam stated that international agreement on global warming mitigation is likely to prove difficult. Efficiency-based policies will result in disparate costs and benefits among nations and thus hinder cooperation. It is suggested that consideration be given to an equitable sharing of the economic impacts of global warming policy. Acknowledging that there is no universally held concept of equity, the policy implications of several alternatives are explored. Because there is considerable variation in these implications, it will be important for decision-makers to clarify their preferred concepts of equity during the course of their negotiations on policies to address global warming [6].

Baxter et al., focuses on the heating and cooling of buildings and the pumping and transport of water for farms and cities. They estimated the changes in California's annual electricity use and peak demand by 2010 under two global warming scenarios. Each warming scenario is to produce an electricity demand projection with end-use energy models. The results suggested that global warming has a moderate effect on electricity demand. Under the worst scenario, for a 1.9°C increase, they projected statewide electricity requirements will increase by about 7500GWh (2.6%) and 2400MW (3.7%). Global warming, the theory which says that increased concentration of greenhouse gasses in the atmosphere will lead to higher global temperatures, has sparked widespread interest in the possible impacts of climate change [7].

Richard, H. S., states that over the 2- decades U.S. Congress has passed four acts relating to clean air. The 1970 act set out a comprehensive plan for federal state partnership to require all areas in the country to meet National Ambient Air Quality Standards. In 1977, the act was amended and expanded, both to address many of the problems encountered in the 1970 act and to reorient the law to limit emissions of any sort significantly, even if there were no currently identified health-related reasons. In 1986, the Emergency Planning and Community Right-to know Act were passed, as an amendment to a solid waste law, in response to the desire to prevent chemical release tragedies. After 10 years of effort, Congress finally passed the 1990 Clean Air Act amendments which require a number of new programs aimed at curbing urban ozone, rural acid rain, stratospheric ozone, toxic air pollutant emissions and vehicle emissions, and establishing a new, uniform national permit system [8].

Honjo K. describes that Global warming is a problem in which the combustion of coal, oil, and other fossil fuels causes the atmospheric concentrations of greenhouse gases, such as carbon dioxide (CO_2), to increase. These result in mounting global air temperatures that leads to climatic change. Specifically, global warming will cause a rise in sea levels, changes in the rain-fall patterns, and other problems. In order to secure the route to solutions for global warming that requires new responses in ways that are compatible with economic growth, it is essential to achieve breakthroughs with innovative technologies. In addition to energy-related Research and Development, also important are the research and developments for CO_2 absorption and fixation for fundamental solution to global warming. Japan has started the development of innovative environmental technologies, such as technologies for CO_2 fixation and utilization [9].

The global warming potential (GWP) index has been proposed by Luiz et al., to quantitatively compare the integrated greenhouse effect of different gases. However, the use of the GWP index is still subject to major conceptual difficulties. An alternative index has been proposed [10].

Yasuhiro et al., mentioned in their study that the rapid development of the developing countries will hasten global warming and exacerbate resource problems. An attempt is made to show that, on the contrary, the fast development of these countries might very well bring about a long-term solution of the global warming problem. A model incorporating development stage theory is built and used to calculate by region the world's economic growth, population growth, energy supply and demand**,** CO_2 emissions and other items up to the end of the 21st century. Results indicated that if in 2100 world population is about 10 billion (it was 5.1 billion in 1990), world GDP is US$200 trillion (1987 prices; it was US$20 trillion in 1990) and CO_2 emissions are 10 billion tons (carbon equivalent; they were 5.8 billion tons in 1990), there will be fairly good prospects for solving the North-South, fossil fuel exhaustion and global warming problems. Making this scenario happen will require accelerating development of the developing countries so that they quickly join the ranks of the developed countries, expediting the shift to renewable energy in the developed countries by imposing carbon taxes, transferring energy saving technologies from the developed to the developing countries, and other efforts [11].

Qader-Mirza, M. M., states that global warming caused by the enhanced greenhouse effect is likely to have significant effects on the hydrology and water resources of the Ganges, Brahmaputra and Meghna (GBM) basins and might ultimately lead to more serious floods in Bangladesh. It is very prone to flooding due to its location at the confluence of the GBM Rivers and because of the hydro meteorological and topographical characteristics of the basins in which it is situated [12].

2.3 Alternative Energy Sources

Knowlen et al., mentioned that the investigation of the use of cryogens as energy storage media for zero emission vehicles has found that using liquid nitrogen to liquefy the working fluid of one or more closed Rankine power cycles can be an effective means for increasing motive power. System configurations are presented which can realize specific energy greater than 400kJ/kg-LN^2 (110Whr/kg-LN^2) without relying on isothermal expanders. A zero-emission vehicle utilizing such a propulsion system would have an energy storage reservoir that can be refilled in a few minutes and offer power output in a range comparable to conventional automobile [13].

Rose-Robert et al., carried out the world Fuel Cell vehicle survey in 2003. A snapshot of the fuel cell vehicle industry as it existed at the end of 2003 is provided in this report. It is useful for policymakers, businesses, and others interested in exploring and developing fuel cell vehicles. This include nearly all of the world's 20-major vehicle manufacturers, such as Toyota, Daimler Chrysler, Ford, General Motors, Honda, and Mitsubishi etc., and also identified at least 12 companies or partnerships developing or demonstrating fuel cell buses [14].

Hussein et al., developed a wind turbine simulator for wind energy conversion systems with a view to design, evaluate and test of actual wind turbine drive trains including generators, transmissions, power-electronic converters and controllers. The simulator consists of a 10kW variable speed drive inverter and real-time control software for driving a 10 HP induction motor (IM) which drives a generator. The inverter driven induction motor acts like a real wind turbine to the energy conversion system. The drive is controlled using the measured shaft torque directly, instead of estimating it as conventional drives do [15].

Yurdusev et al., expressed that **w**ind turbine blade design depends on several factors, such as turbine profile used, blade number, power factor, and tip speed ratio. The key to designing a wind turbine is to assess the optimal tip speed ratio (TSR). This will directly affect the power generated and in turn the effectiveness of the investment made. TSR is suggested to be taken between 7 and 8 and in practice generally taken as 7 for a 3-blade network-connected wind turbine. However, the optimal TSR is dependent upon the profile type used and the blade number and could fall out of the boundaries suggested [16].

Edmonds Ian describes a solar powered reciprocating engine based on the use of a tethered hot air balloon filled by hot air from a glazed collector. The basic theory of the balloon engine is derived and used to predict the performance of engines in the 10kW to 1 MW range. The engine can operate over several thousand meters altitude with thermal efficiencies higher than 5%. The engine thermal efficiency compares favorably with the efficiency of other engines, such as solar updraft towers, that also utilize the atmospheric temperature gradient but are limited by technical constraints to operate over a much lower solar power altitude range [17].

2.4 Compressed Air Utilization

Aniraj et al., expressed that measurement of air velocity when flow is oscillating is required in ocean wave energy studies. A special type of self-rectifying air turbine called 'Wells turbine', coupled with induction generator is used for converting the air column movement in a wave energy basin to electrical energy. Some efforts for measurement of oscillating air column at laboratory using hot-wire anemometer have been reported. Oscillating flow was generated by a butterfly valve, operated through a function generator [18].

Pandian et al., described that pneumatic actuators are among a variety of actuators under active study by the robotics community, for the advantages they offer over conventional electric actuators widely used in the present-day robots. So far, however, only pneumatic cylinders which provide linear actuation have been mainly studied in literature. Air motors are the pneumatic counterparts of electric motors, providing rotary actuation. They have several advantages over electric motors, especially high power-to-weight and power-to-size ratios, good compliance, and resistance to environmental hazards. Results of experimental implementation on an industrial vane-type air motor illustrate the effectiveness of the air motor as a high-performance rotary actuator [19].

Knowlen et al., investigates the means to extend the range of cryogen (liquid nitrogen or liquid air) powered automobiles via burning a small amount of fossil fuel (gasoline or liquid methane). By utilizing both an ambient air-heat exchanger to vaporize the cryogen and a fossil fuel-fired super heater to elevate the temperature of the gaseous product, the range of the vehicle can be three times that of ambient-heated propulsion system while not exceeding current ultra-low emission standards. Internal and external combustion power cycles using either liquid air or nitrogen as the working fluid were found to be more fuel efficient than an internal combustion engine operating on the standard Otto cycle. Fossil fuel consumption per mile of dual-fuel systems are projected to be over 40% less than that of conventional gasoline automobiles, thus offering the potential of significant reductions in greenhouse gas and pollutant tailpipe emissions [20].

Setoguchi et al., reviewed impulse turbine for wave energy conversion and mentioned that oscillating water column-based wave energy plants convert wave energy into low pressure pneumatic power in the form of bi-directional air flows. Air turbines which are capable of rotating uni-directionally in bi-directional air flows, otherwise also known as self-rectifying turbines, are used to extract mechanical shaft power which is further converted into electrical power by a generator. This reviews the state of the art in self-rectifying impulse air turbines. Starting characteristics and conversion efficiencies of two types of impulse turbines are compared with the well-known Wells turbine [21].

Mikhail Korobitsyn stated in the paper that an air bottoming cycle (ABC) was proposed in the late 1980s as an alternative for the conventional steam bottoming cycle. Now this cycle is being considered as a compact and simple bottoming cycle in various applications: as an upgrading option for simple-cycle gas turbines in the offshore industry; as a hot air cogeneration plant; or as a heat recovery installation at high-temperature furnaces. This evaluates the technical and economic feasibility of the ABC in the cogeneration scheme, where hot air from the air turbine is supplied to food processing industries (industrial bakeries and milk powder factories) [22].

2.5 Air Turbines / Engines

Hitoshi et al., demonstrated a general-purpose system for torque measurement using air turbine that can measure very low torques. The new method proposed uses wind pressure to apply a load to a turbine attached to the output shaft of the device. It can therefore be used for all rotating micro-devices. The use of wind pressure reduces the loss during measurement and makes it possible to measure low levels of torque easily by simply attaching the turbine to the device [23].

Govardhan et al., mentioned in their paper that a Wells turbine is a self-rectifying air flow turbine capable of converting pneumatic power of the periodically reversing air stream in Oscillating Water Column into mechanical energy. The Wells turbine has inherent disadvantages; lower efficiency, poor starting characteristics, higher axial force and low tangential force in comparison with conventional turbines. Guide vanes before and after the rotor suggest a means to improve the tangential force, hence its efficiency. Experimental investigations are carried out on a Wells turbine with the constant chord and variable chord blade rotors fitted with inlet and outlet guide vanes to understand the aerodynamics. In addition, the starting and running characteristics of the rotors have been studied and compared with the case without guide vanes. The efficiency, starting characteristics of the turbines with guide vanes have improved when compared with the respective turbines without guide vanes [24].

Schreck et al., mentioned in the study that under zero yaw conditions, rotational effects substantially and routinely augment HAWT blade aerodynamics response. In Unsteady Aerodynamics Experiment (UAE), a full scale HAWT was tested in the NASA Ames 80ft x 120ft wind tunnel. These surface pressure data were processed to obtain normal force and flow field topology data. Further analysis was carried out in a manner that allowed tip speed ratio effects to be isolated from the other confounding influences [25].

2.6 Recent Developments of Air Turbines / Motors

David et al., in 2004 developed and applied many complex type technologies to improve the energy efficiency and exhaust emission of an engine under different driving conditions. The overall thermal efficiency of an internal-combustion engine, however, can be maintained at only about 20–30%, with aggravated problems in the design and development, such as overall difficulty, excessive time consumption or excessively high cost. For electric cars, there is still no major technological breakthrough for the rapid recharging of a large capacity battery and detection of remaining power in it. Although all currently available hybrid-power engines are able to lower the amount of exhaust emissions and the fuel consumption of the engine, they are still unable to achieve a stable and optimal running condition immediately after ignition; hence the engine's thermal efficiency remains low. To solve the aforementioned problems, an innovative concept – a hybrid pneumatic power-system (HPPS), which stores 'flow work' instead of storing electrochemical energy of the battery – is introduced. This innovative power system not only ensures that the internal-combustion occurs optimally but also recycles the exhaust flow to propel the vehicle. The optimization of the internal-combustion and recycling of the exhaust energy can increase the vehicle's efficiency from an original 15% to 33% [26].

David, H.K. et al., proposed in 2005 that the hybrid pneumatic power system (HPPS) replaces the battery's electro-chemical energy with flow work and optimizes the management and utilization of the energy. This power system is able to keep the internal-combustion engine working at its optimal condition and turn its waste energy into effective mechanical energy and thus enhance the thermal efficiency of the whole system [27].

David et al., in 2009 designed a hybrid pneumatic power system (HPPS) which was integrated by an internal combustion engine (ICE), a high efficiency turbine, an air compressor and an energy merger pipe, that can not only recycle and store exhaust gas energy but also convert it into useful mechanical energy. Moreover, it can make the ICE operate in its optimal state of maximum efficiency; and thus, it can be considered an effective solution to improve greatly the exhaust emissions and increase the overall energy efficiency of the HPPS. However, in this system, the flow energy merger of both high pressures compressed air flow and high temperature exhaust gas flow of the ICE greatly depends on the merging capability of the energy merger pipe. If the compressed air pressure (P) at the air inlet is too high, smooth transmission and mixture of the exhaust gas flow are prevented, which will interfere with the operation condition of the ICE. The purpose of this paper is to study the effect of the level of P air pressure and the contraction of cross-section area (CSA) at the merging position on the flow energy merger and determine their optimum adjustments for a better merging process by using computational fluid dynamics (CFD). Under these optimum adjustments, the exhaust gas recycling efficiency can reach about 83% [28].

2.7 Compressed Air Storage Tank

Anupam published an article on compressed air motorbike and is storing compressed air in the bike's on-board carbon fiber tanks. It is projected that once it is produced in mass, the bike will have solar panels that will generate enough energy to compress air and store it in the bike's tanks, which will increase its range indefinitely [29].

2.8 Gaps in Existing Literature

Literature review shows that in view of fossil fuel depletion and growing concern about clean environment the scattered efforts have been made for developing potential alternative which is run on alternative fuel and is environment friendly. Numerous researches have been made for developing hybrid system but none of these are emission free. Compressed air has been used as working fluid for various applications. Also, certain engines have been developed to run on compressed air and fossil fuel combined. Thus, there exists gap in terms of compressed air utilization for running an engine which offers nearly zero emission.

CHAPTER 3

METHODOLOGY

For finalizing the requirements of the air engine, the study of the lightweight motorbike engines was undertaken. A study of some of the existing two wheelers on Indian roads was carried out. The two wheelers manufactured by Bajaj Automobiles and Kinetic Honda were considered.

The specifications and other technical details of motorbike engines are given in the chart shown below:

Table 3.1: Specifications of various motorbike engines

Sl. No.	Make and Manufacturer Details	Parameters	Specification
1	**Kawasaki Bajaj** (Bajaj Automobiles, Pune, Maharashtra)	Engine	Two/Four Stroke, Single Cylinder, Natural air-cooled.
		Engine Displacement	99.35 CC
		Max. Net Power	7.02 HP at 8500 rpm
		Ignition	CDI
		Spark Plug	Mico / Bosch
		Transmission	4 Gear –Box, Front / Rear brakes
		Fuel Tank	12 liters

		Vehicle Weight	109 kgs
		Maximum Speed	85 kmph
2	**Bajaj CT 100 Dlx** (Bajaj Automobiles, Pune, Maharashtra)	Engine	4 Strokes, Single Cylinder, Air Cooled
		Cubic Capacity (Engine Displacement)	99.35 CC
		Max. Net Power	7.02 HP at 8500 rpm
		Ignition	CDI
		Spark Plug	Mico / Bosch
		Transmission	Gear Box– 4 Speed, Front / Rear brakes (110mm Drum)
		Fuel Tank	12 liters
		Vehicle Weight	109 kgs
		Maximum Speed	85 kmph

3	**Bajaj Discover Kick Start** (Bajaj Automobiles, Pune, Maharashtra)	Engine	Four Strokes, Single Cylinder, Natural Air Cooled.
		Engine Displacement (Cubic Capacity)	124.52cc
		Max. Net Power	11.51 BHP @ 8000 rpm
		Ignition	CDI
		Spark Plug	Mico / Bosch
		Transmission	Gear Box – 4 Speed, Front / Rear Brakes (130mm Drum)
		Fuel Tank	10 liters
		Vehicle Dry Weight	125 kgs
4	**Bajaj Chetak 2- Stroke** (Bajaj Automobiles, Pune, Maharashtra)	Engine	Two Stroke, Single Cylinder, Forced Air Cooled
		Engine Displacement	145cc

		Max. Net Power	7.5 BHP @5500 rpm
		Max. Torque	10.8 Nm @3500 rpm
		Ignition	CDI Electronic
		Carburetor	Spaco SI - 20 - 20 mm Venturi Carburetor
		Transmission	4 Speed Constant Mesh
		Electric System	12 V AC

Based on the available specifications of existing motorbike the desired range of engine parameters are identified as under;

i) Maximum Net Power: 7.0- 7.5 HP

ii) Maximum Torque: 9.4- 10.8 Nm

iii) Speed: 4500-7500 rpm

With the aim of developing an engine for getting the desired power for a motorbike the parameters as detailed below were considered for power output, torque, speed, working air pressure of the air engine.

i) Power output (minimum): 5.25 to 6.50 HP (4-5 kW)

ii) Torque: 9.4–10 Nm

iii) Speed: 2500–7500 rpm

iv) Working air pressure (assumed): 45–105 psi (3-7 bar)

3.1 Compressed Air Cylinder

The storage tank may be made of steel or aluminum or carbon fiber or Kevlar and or other materials or combinations of the above. The fiber materials are considerably lighter than metals but generally more expensive. Metal tanks can withstand many pressure cycles but must be checked for corrosion periodically.

Many companies store air in tanks at 4,500 pounds per square inch (about 30 MPa) and hold nearly 65 cubic feet (around 1900 liters) of air. The tanks may be refilled at a service station equipped with heat exchangers, or in a few hours at home or in parking lots, plugging the vehicle into the electrical grid via an on-board compressor. The cost of driving such a vehicle is typically projected to be around €0.75 per 100 km, with a complete refill at the tank-station" at about US$3.

Compressed air systems have advantages over conventional batteries including longer lifetimes of pressure vessels and lower material toxicity. Compressed air costs are potentially lower; however advanced pressure vessels are costly to develop and safety-test and at present are more expensive than mass produced batteries. As with electric storage technology, compressed air is only as clean as source of the energy that it stores. Life cycle assessment addresses the question of overall emissions from a given energy storage technology combined with a given mix of generation on a power grid.

3.2 Turbine

The air turbine is considered to work on the reverse principle of vane type compressor. It is assumed that the total shaft work of the air turbine is cumulative effect of compressed air jet on vanes and the expansion of high-pressure air. The compressed air at 20 bars is utilized for running air turbine which is stored in a storage cylinder. It is proposed to have storage capacity of 30 minutes duration. The compressed air cylinder is attached with filter and regulator for regulating and maintaining the constant pressure during air admission so as to produce high torque at low speed of revolution.

In present study the thermodynamic modeling of the air turbine has been carried out for the considered model. Theoretical analysis is carried out considering the air injection pressure, number of blades, casing diameter, rotor diameter and speed of rotation. Based on the theoretical result and analysis, the final dimensions of the air turbine were fixed. A prototype of air turbine was developed and checked for its functionality. It has a casing of SS material with liner of high tensile steel. The vane rotor is aluminum (7075) which is light in weight and also has sufficient strength to withstand the high pressures. The fiber vanes are radial and curved to lower the bending stresses.

3.3 Nozzle

A nozzle is a device which is used to give the direction to the gases coming out of the storage tanks. Nozzle is a tube which has a capacity to convert the thermo-chemical energy generated in the combustion chamber (in our case storage cylinders) into kinetic energy. The nozzle converts the low velocity, high pressure, high temperature gas into high velocity gas of lower pressure and low temperature.

A convergent- divergent nozzle is used if the nozzle pressure ratio is high. High performance engines in supersonic aircrafts generally incorporate some form of a convergent-divergent nozzle. The convergent nozzles are used to increase fluid velocity and thus convert most of the fluid energy into its kinetic energy. Such nozzles are used to run turbine blades in impact turbine electric generators.

The present work aims to study the behavior of flow in convergent divergent nozzle and convergent nozzle by analyzing various parameters like pressure, temperature and velocity using computational fluid dynamics software (C.F. D). These results were further plotted comparing them with analytical values. By observing the results of both nozzles, the suitable one is chosen for our project.

3.4 Vehicle Steering

Ackermann steering geometry is a geometric arrangement of linkages in the steering of a car or other vehicle designed to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radii. The intention of Ackermann geometry is to avoid the need for tires to slip sideways when following the path around a curve.

The geometrical solution to this is for all wheels to have their axles arranged as radii of a circle with a common center point. As the rear wheels are fixed, this center point must be on a line extended from the rear axle. Intersecting the axes of the front wheels on this line as well requires that the inside front wheel is turned, when steering, through a greater angle than the outside wheel. As the steering moved, the wheels turned according to Ackermann, with the inner wheel turning further. If the track rod is placed ahead of the axle, it should instead be longer in comparison, thus preserving this same "toe out".

3.5 Chassis

A car chassis may refer to either the frame of a car that holds together its components or to a rolling chassis. A rolling chassis consists of the frame, engine and drivetrain. That is, it includes almost all components except the body. (Papson et al 2010) Most modern automobiles are not built with a rolling chassis, as unibody construction is more common. It is common for people to refer to the skeletal frame of a car as the chassis, although in some cases this may not be entirely accurate. For many vehicles made in the early-to-middle 20th century, the chassis was simply the car minus the body. Antique vehicles will generally be constructed this way, making the chassis easily identifiable. Later, a technique called monocoque was developed, in which parts of the body and frame were welded together to form a single unit. For our project we used tadpole design instead of delta type since it is clearly the best option on three wheels. However, the delta will always have value for niche applications.

3.6 Power Transmission

The power is transmitted from one shaft to the other by means of belts, chains and gears. The belts and ropes are flexible members which are used where distance between the two shafts is large. The chains also have flexibility, but they are preferred for intermediate distances.

The gears are used when the shafts are very close with each other. This type of drive is also called positive drive because there is no slip. If the distance is slightly larger, chain drive can be used for making it a positive drive. Belts and ropes transmit power due to the friction between the belt or rope and the pulley. There is a possibility of slip and creep and that is why, this drive is not a positive drive.

3.7 Wheels

A car wheel contributes a lot to the overall performance and handling of a vehicle. There’s the divided rim type that’s used in industry and agricultural vehicles. Drop-center rims, on the other hand, are for passenger cars, light trucks, and buses that use tubeless tires; while wide-base and flat-base rims are used only in buses and trucks that have tube-type tires. In terms of construction, a car wheel is of two types—stamped sheet metal and machine cast. A cast alloy wheel is lighter;

it dissipates heat and withstands higher temperatures better, too. A stamped metal wheel, on the other hand, is more commonly used because of its suitability for different functions.

3.8 Auxiliary Parts

3.8.1 Pressure Regulator

A pressure regulator's primary function is to match the flow of gas through the regulator to the demand for gas placed upon it, whilst maintaining a constant output pressure.

If the load flow decreases, then the regulator flow must decrease as well. If the load flow increases, then the regulator flow must increase in order to keep the controlled pressure from decreasing due to a shortage of gas in the pressure system. High pressure regulators are used in the project.

3.8.2 Flow Meter

Both gas and liquid flow can be measured in volumetric or mass flow rates, such as liters per second or kilograms per second, respectively. These measurements are related by the material's density. The density of a liquid is almost independent of conditions. This is not the case for gases, the densities of which depend greatly upon pressure, temperature and to a lesser extent, composition.

The energy flow rate is the volumetric flow rate multiplied by the energy content per unit volume or mass flow rate multiplied by the energy content per unit mass. Energy flow rate is usually derived from mass or volumetric flow rate by the use of a flow computer.

3.8.3 Ball Bearing

Deep groove ball bearings are particularly versatile. They are suitable for high and very high speeds, accommodate radial and axial loads in both directions and require little maintenance. Because deep groove ball bearings are the most widely used bearing type, they are available from SKF in many designs, variants and sizes.

In the present project we used SKF 629 type which has inner race of 9 mm and outer diameter of 26 mm.

CHAPTER 4

THEORETICAL MODELING

4.1 Assumptions

The high-pressure jet of air when injected into the rotor of vanned air turbine causes its rotation. Rotor movement is caused due to impact of air jet and the expansion of high-pressure air admitted in turbine. Thus, the high-pressure air entering through the inlet passage pushes the vane for producing rotational movement through this vane and thereafter air so collected between two consecutive vanes of the rotor is gradually expanded till the rotation brings vanes in front of exit passage. This can be considered like isobaric admission and adiabatic expansion of high-pressure air both contributing in producing the shaft work from air turbine. Compressed air leaving the air turbine after expansion is sent out from the exit passage.

It is assumed that the scavenging of the rotor is perfect, and the work involved in recompression of the residual air is absent. The assumptions made for thermodynamic analysis are as under:

a) Admission of air takes place isobarically.

b) High pressure air admitted in turbine rotor expands adiabatically.

c) There is no residual air in rotor after the expanded air is discharged from rotor. Thus, no recompression of air takes place.

d) Mechanical losses due to shaft friction are negligible.

e) Loss due to throttling of air at admission and exit is negligible.

f) Exit of expanded air occurs isochorically

g) Flow across the turbine is of steady flow type.

4.2 Compressed Air Cylinder

VELOCITY AT OUTLET OF CYLINDER PRESSURE VALVE:

Service pressure of compressed air cylinder = 300 bar,

Volume of free air present in cylinder = 1875 liter,

Density of air at 300K & 30 bar = 35.0846 kg/m^3,

Density of air at 300K & 300 bar = 314.25 kg/m^3,

Cylinder Nozzle Diameter = M 18×1.5

ENERGY EQUATION: - $\frac{P}{\varrho g} + \frac{v^2}{2g}$

Here,

P_1 = 300 bar = $300\times10^5 \frac{N}{m^2}$

ϱ_1 = $314.25\frac{kg}{m^3}$

v_1 = $0\frac{m}{s}$

P_2 = 30bar = $30\times10^5\frac{N}{m^2}$

v_2 =?

$$\frac{300\times10^5}{314.25} - \frac{30\times10^5}{35.0896} = \frac{{v_2}^2}{2}$$

v_2 = $141.22\frac{m}{s}$

Discharge Q = $A_N\times v_2 = \frac{\pi}{4}\times\left(\frac{14}{1000}\right)^2\times 141.122$

$= 0.036\frac{m^3}{s} = 2160\ \frac{lit}{min}$

Since 2160 Lit/min highly uncontrollable and not practically measurable, we assume 30 lit/min which can be measured by a flow meter and controllable.

$$\therefore Q = 18 \text{ lit/min}$$

$$V = 1.984 \text{m/s}$$

4.3 Nozzle

4.3.1 Convergent - Divergent Nozzle Calculations

At entry of nozzle, following notations are observed,

$$P_1 = 30\text{bar} = 30\times10^5 \frac{N}{m^2},$$

$$v_1 = 1.984\frac{m}{s}, \text{ (Q=18Lit/min)}$$

$$T_1 = 320\text{K},$$

$$A_1 = 1.539 \times10^{-4} \text{ m}^2, \text{ [For } d_1 = 14\text{mm]}$$

$$C_1 = \sqrt{\gamma RT1} = 358.574\frac{m}{s},$$

$$\text{Entry Mach } M_1 = \frac{V1}{C1} = 0.00553$$

$$T_S = T_1 + \frac{{v_1}^2}{2C_P} = 300 + \frac{1.984^2}{2\times1000} = 320.006$$

$$\frac{P_S}{P_1} = (\frac{T_S}{T_1})^{\frac{\gamma}{\gamma-1}} = 1.0005377$$

$$P_S = 30.002\times10^5\frac{N}{m^2},$$

$$\frac{P_S}{P_2} = [1 + \left(\frac{\gamma - 1}{2}\right) {M_2}^2]^{\frac{\gamma}{\gamma-1}}$$

Assuming Supersonic at exit M_2=1.1

$$P_2 = 14.057\text{bar},$$

$$\frac{T_2}{T_S} = [\frac{P_2}{P_S}]^{\frac{\gamma-1}{\gamma}}$$

$T_2 = 257.682K$

$C_2 = \sqrt{\gamma R T_2} = 321.769\frac{m}{s}$,

$v_2 = M_2 \times C_2 = 353.469\frac{m}{s}$;

Continuity Eq^n $P_1A_1v_1 = P_2A_2v_2$

$$A_2 = \frac{P_1 A_1 v_1 T_2}{T_1 P_2 v_2}$$

$$A_2 = \frac{30 \times 1.539 \times 10^{-4} \times 1.984 \times 257.682}{300 \times 14.057 \times 353.469}$$

$A_2 = 1.589 \times 10^{-6} m^2$

$d_2 = 0.00142m$

$$\frac{T_s}{T_t} = [1 + \left(\frac{\gamma-1}{2}\right) {M_t}^2]$$

$T_t = 266.671K$;

$P_t = 19.866bar$

$3.838A_t = 1.172x10^{-6}m^2$

$D_t = 1.224mm$

4.3.2 Convergent Nozzle Calculations

If we assume T_2=288K

From previous calculations, P_2=20.7 bar

M_2=0.745

D_2=1.423mm

As the temperature in convergent divergent type of nozzle reaches to subzero conditions where air freezes and the flow is restricted. Hence, we use convergent type of nozzle where the required conditions would be attained.

4.4 Turbine Power Calculations

The power obtained from the turbine is calculated taking the pressure force and velocity into considerations while assuming the rotational speed of the turbine.

$$P = \frac{2 \times \Pi \times N \times T}{60}$$

$$= \frac{2 \times \Pi \times N \times \rho \times A \times V \times (V - u) \times D \times 0.5}{60}$$

N=2500rpm

$$\rho = 30 \frac{Kg}{m^3}$$

$$A = 1.256 \times 10^{-5} m^2$$

$$V = 353.42 \frac{m}{s}$$

$$D = 0.1m$$

$$u = \frac{\Pi \times D \times N}{60}$$

$$= 1.308 \frac{m}{s}$$

$$\therefore P = 614.2W$$

CHAPTER 5

DESIGN

5.1 Design of Compressed Air Cylinder

Design codes and application standards and the cost of materials dictated the choice of steel with no welds for most gas cylinders; the steel is treated to be anticorrosive. Some newly developed lightweight gas cylinders are made from stainless steel and composite materials. Due to the very high tensile strength of carbon fiber, these vessels can be very light, but are more difficult to manufacture.

Gas cylinders are often color-cooled, but the codes are not standard across different jurisdictions, and sometimes are not regulated. Cylinder color cannot safely be used for positive product identification; cylinders have labels to identify the gas they contain. Color code for a compressed air cylinder is dark yellow.

Gas cylinders are available in various sizes according to their volume and pressure. The following chart shows different sizes for a compressed gas cylinder.

Figure 5.1 Compressed air cylinder size chart

For the present work, we have chosen 30 MPa and 65cf compressed air cylinder. From the chart we can observe that for a 65cf cylinder the dimensions are 7inch (177.8mm) diameter and 24-inch (609.6mm) height. According to standards, cylinder nozzle is of size M18X1.5.

Figure 5.2 CAD model of Compressed Air Cylinder

Table 5.1: Mass properties of model

Density	7800.000 kilograms per cubic meter
Mass	8.356 kilograms
Volume	0.001 cubic meters
Surface area	509707.672 square millimeters

5.2 Design of Nozzle

From theoretical calculations, we have considered a convergent nozzle over a convergent -divergent nozzle due to various factors.

The following table shows the nozzle dimensions obtained from theoretical calculations.

Table 5.2: Nozzle dimensions

Inlet diameter	17mm
Outlet diameter	7.5mm
Length before inlet	35mm
Length after outlet	30mm
Convergent angle	33^o

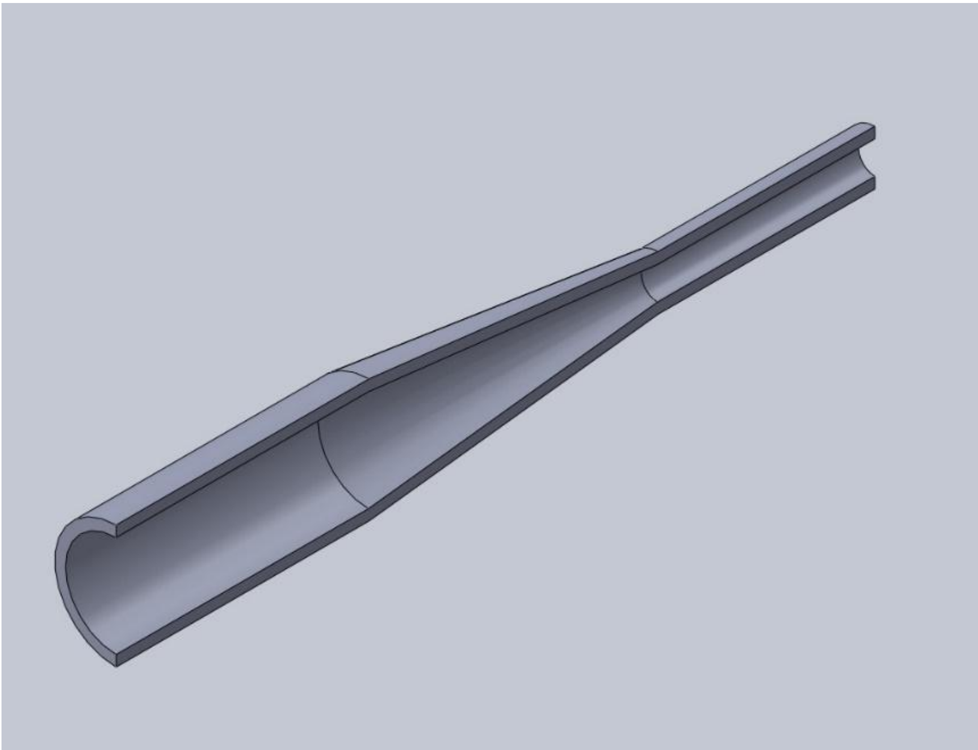

Figure 5.3 CAD model of Nozzle

5.3 Design of Turbine and Casing

Designing of turbine involves the following parameters

i. Selection of turbine rotor diameter
ii. Selection of turbine blade profile
iii. Selection of turbine shaft.

5.3.1 Selection of Turbine Rotor Diameter

From theoretical calculations, it was found that rotor diameter can be optimally selected as 70.30mm and thickness as 23.5mm. Turbine material is chosen as AL7075 alloy.

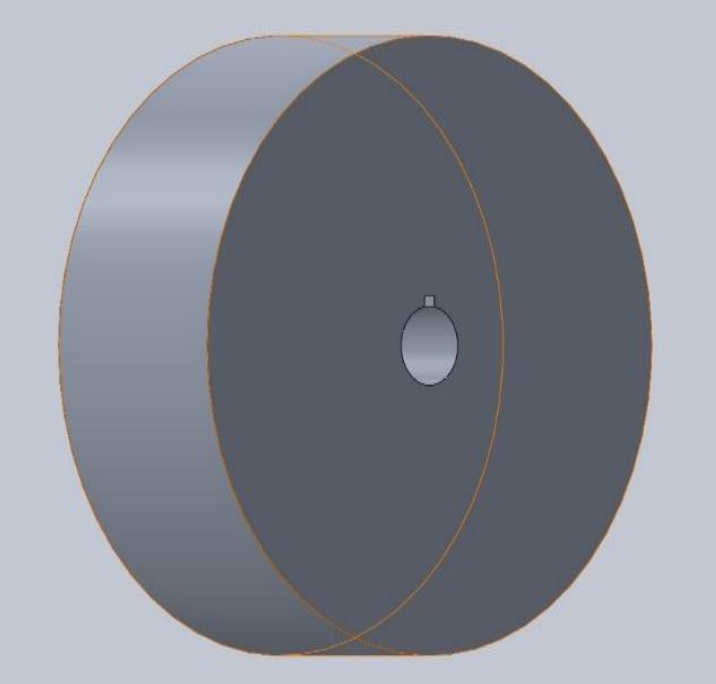

Figure 5.4 Turbine Rotor

Table 5.3 AL7075 alloy material properties

Property	Value	Unit
Elastic modulus	72000	MPa
Yield Strength	505	MPa
Poisson Ratio	0.33	--
Ultimate Strength	570	MPa

5.3.2 Selection of Turbine Blade Profile

Various blade profiles like forward, backward and radial profiles are available. Depending on the application of the turbine, blade profile can be chosen accordingly. From literature review, radial blade profile was optimal blade profile. Blade profile chosen is similar to the NACA 7425 airfoil. Blade material is taken similar to turbine rotor material.

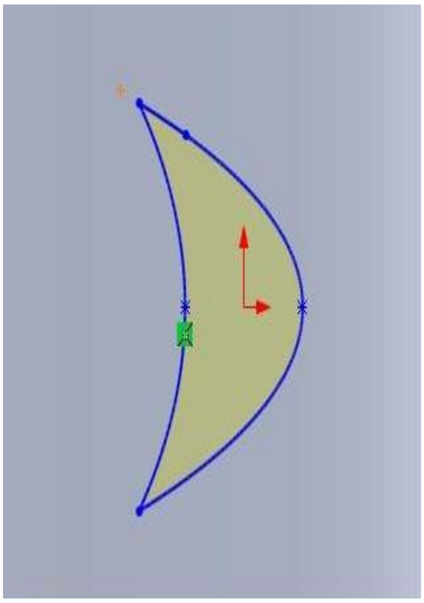

Figure 5.5 Blade Profile

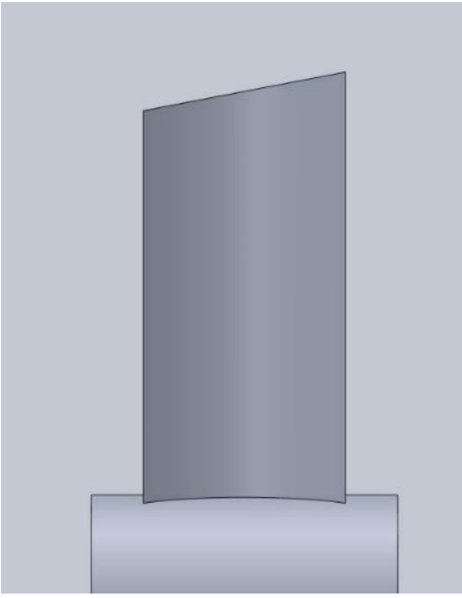

Figure 5.6 Extruded Blade Profile

Blade profile is extruded to 27.3mm to intersect the rotor at surface.

5.3.3 Selection of Turbine Shaft

From previous arithmetic computation to obtain the required power, the ideal shaft diameter will be 9mm and the shaft material is taken as AL6081 alloy.

Table 5.4 AL6081 alloy material properties

Property	Value	Unit
Elastic modulus	69	GPa
Yield Strength	270	MPa
Poisson Ratio	0.33	-
Ultimate Strength	310	MPa

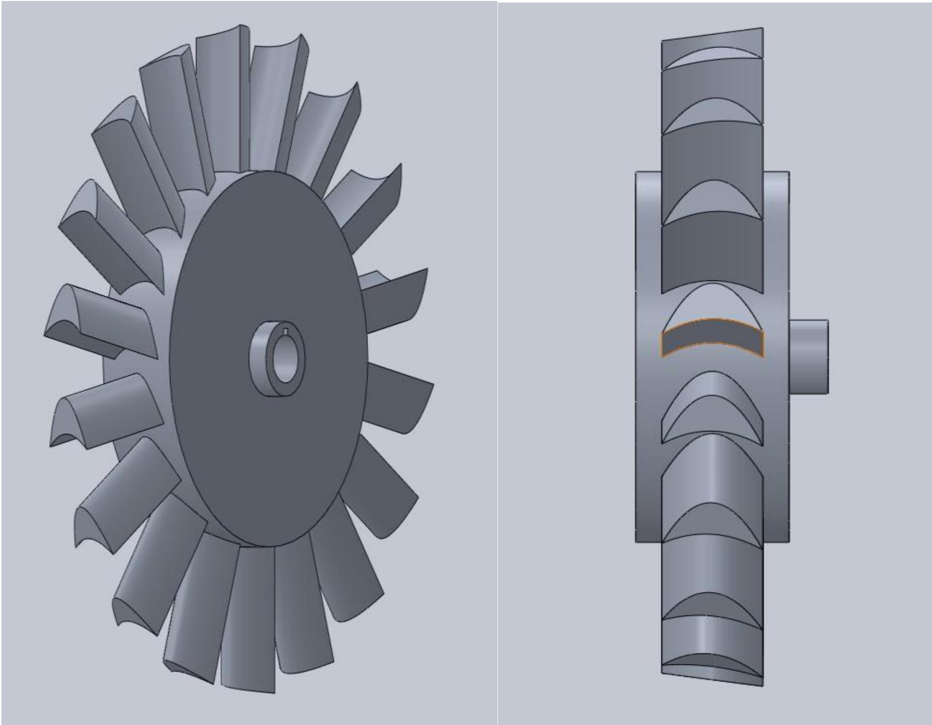

Figure 5.7 Isometric View and Side View of Turbine

Table 5.5 Mass properties of Turbine

Density	2810 kilograms per cubic meter
Mass	0.347 kilograms
Volume	0.000124 cubic meters
Surface area	0.036664 square meters

5.3.4 Design of Turbine Casing

Casing is divided into 3 parts they are:

i) Middle cover

ii) Top cover

iii) Bottom cover

The parts of casing are made of AL6061 alloy and middle cover is a hollow cylinder which when assembled contains the turbine wheel in the center. It also has inlet and outlet of turbine.

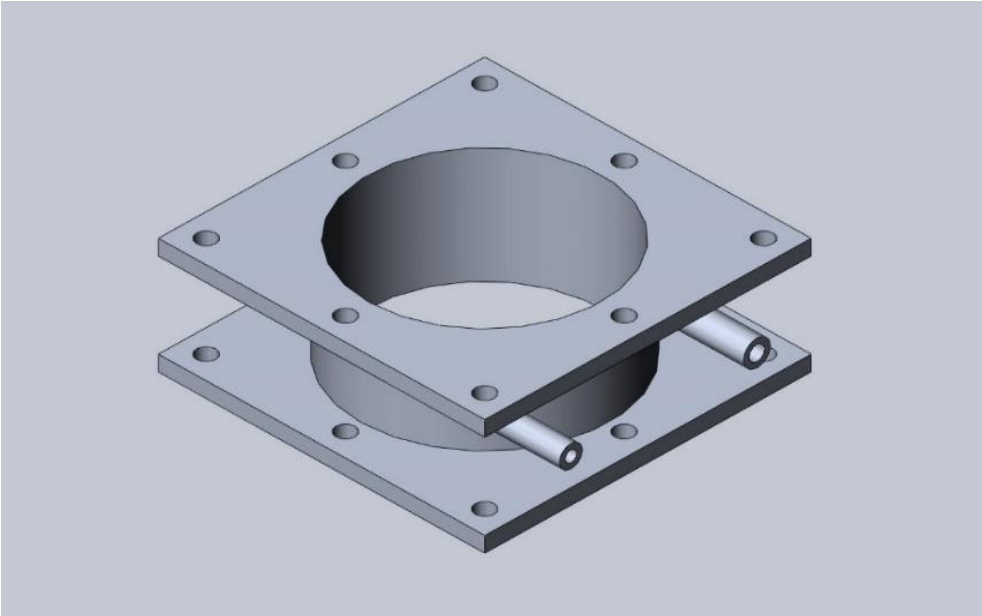

Figure 5.8 Isometric View of Middle Cover

Top cover and bottom are used to seal the air entering into the turbine and these are also used to hold the turbine and turbine shaft in position. For this purpose SKF Deep Groove Ball Bearing 629 are inserted one in each of the top and bottom covers.

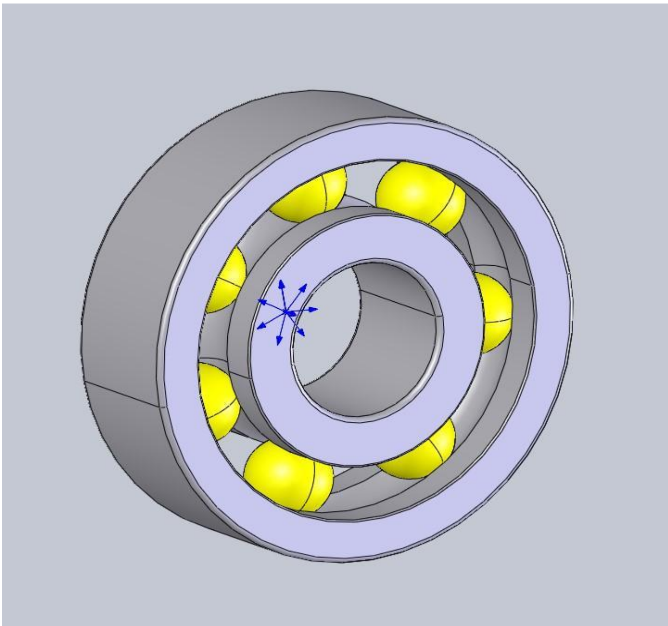

Figure 5.9 SKF Deep Groove Ball Bearing 629

Table 5.6 SKF Deep Groove Ball Bearing 629 properties

Property	Symbol	Value
Basic dynamic load rating	C	4.75 kN
Basic static load rating	C_0	1.96 kN
Fatigue load limit	P_u	0.083 kN
Reference speed		60000 r/min
Limiting speed		38000 r/min
Calculation factor	k_r	0.025
Calculation Factor	f_0	12
Mass		0.019kg

Table 5.7 AL6061 alloy material properties

Property	Value	Unit
Elastic modulus	69000	MPa
Yield Strength	55.148	MPa
Poisson Ratio	0.33	--
Ultimate Strength	124.018	MPa

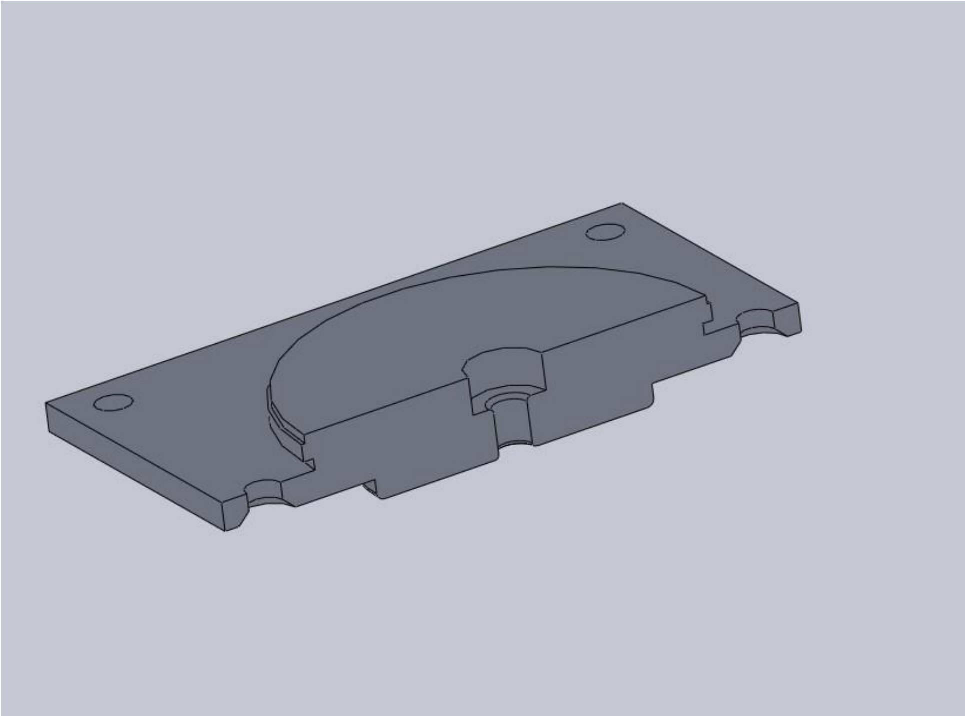

Figure 5.10 Isometric Sectional View of Bottom Cover

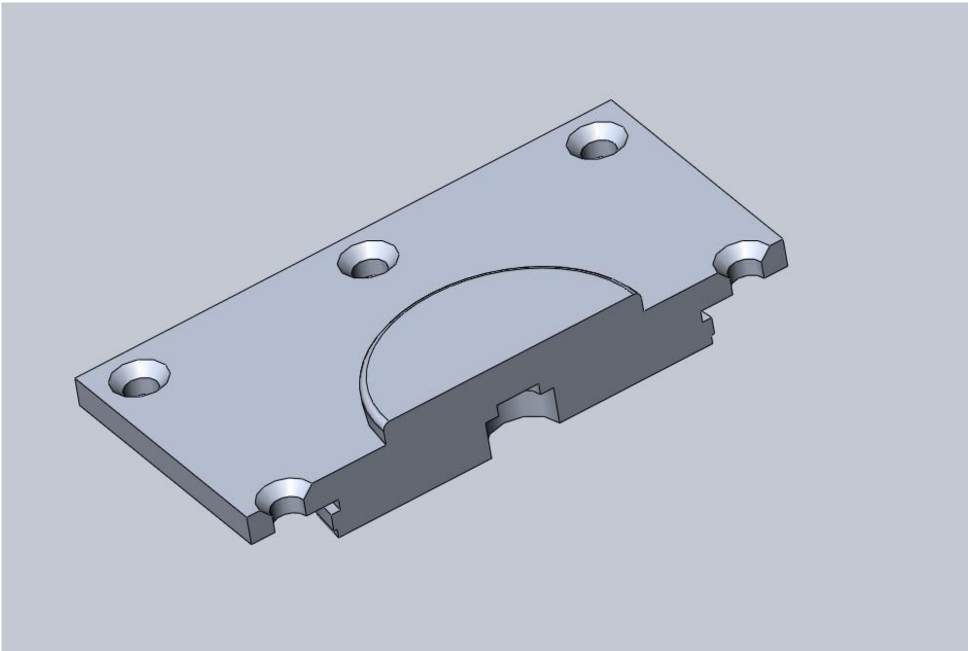

Figure 5.11 Isometric Sectional View of Top Cover

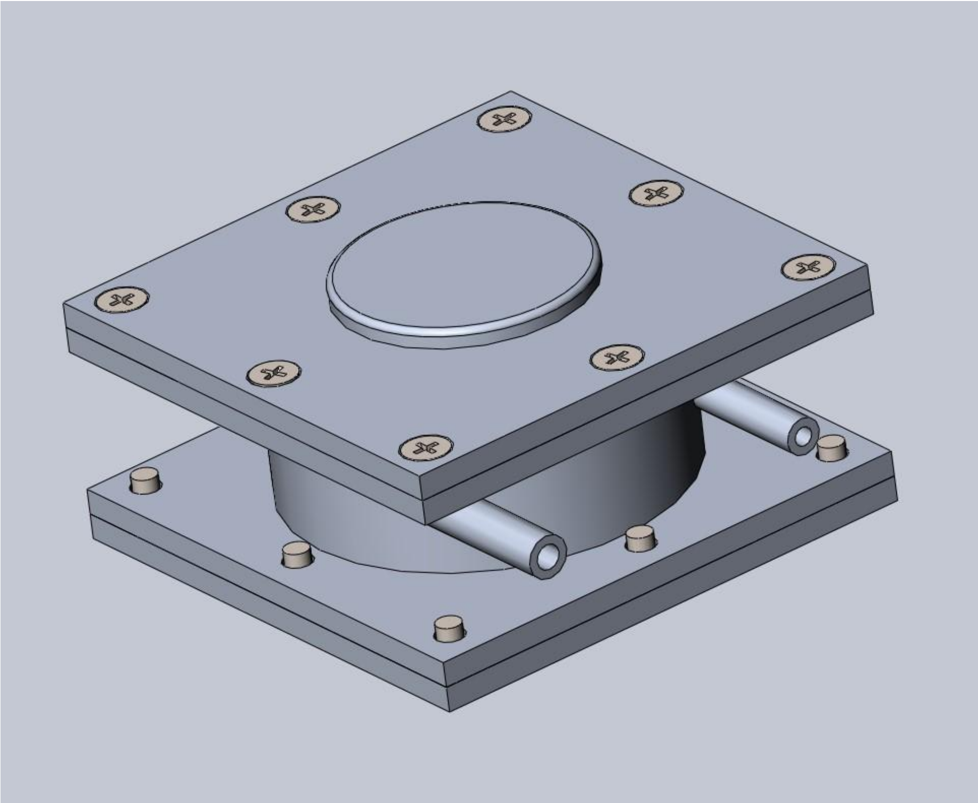

Figure 5.12 Isometric view of Assembled Casing

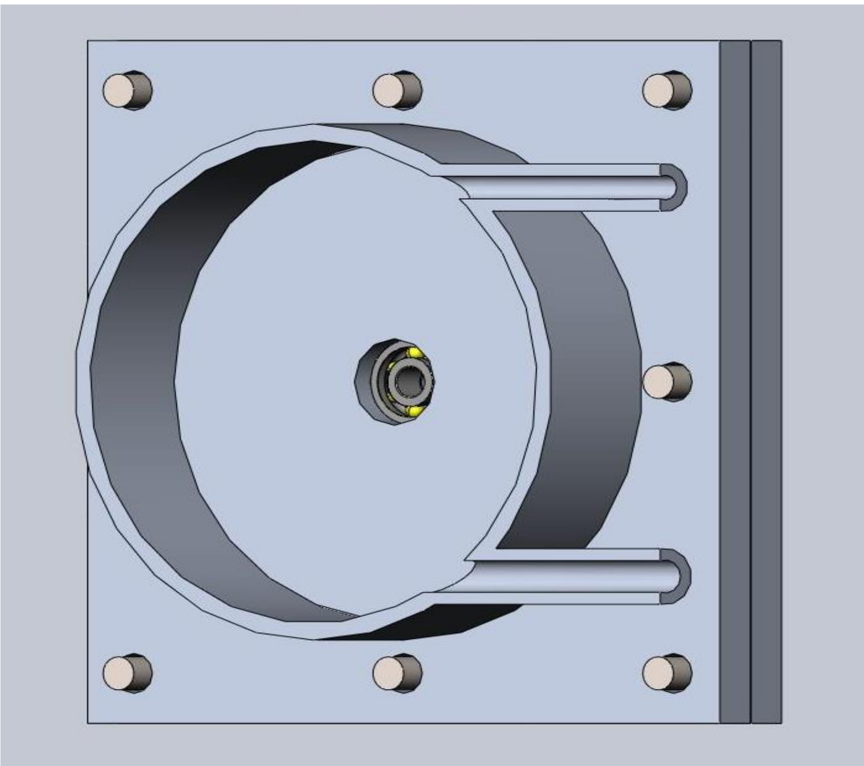

Figure 5.13 Isometric Sectional view of Assembled Casing

Table 5.8 Mass properties of Assembled Casing

Density	2700.00 kilograms per cubic meter
Mass	5.390 kilograms
Volume	0.002 cubic meters
Surface area	0.4196 square meters

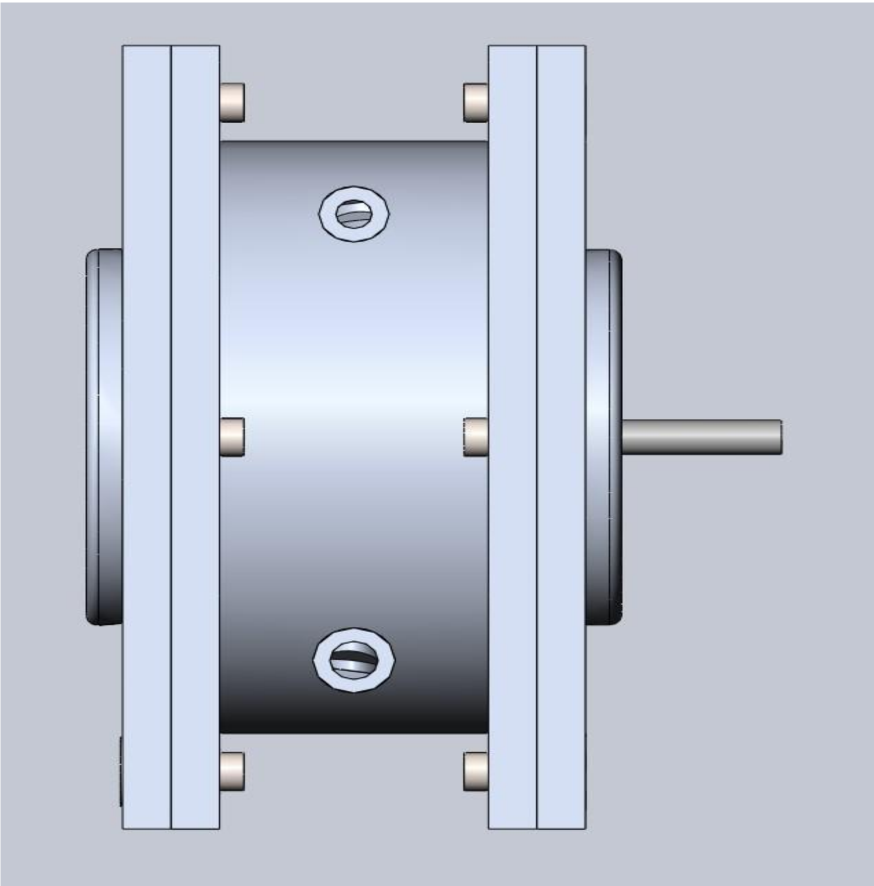

Figure 5.14 Side View of Assembled Casing and Turbine

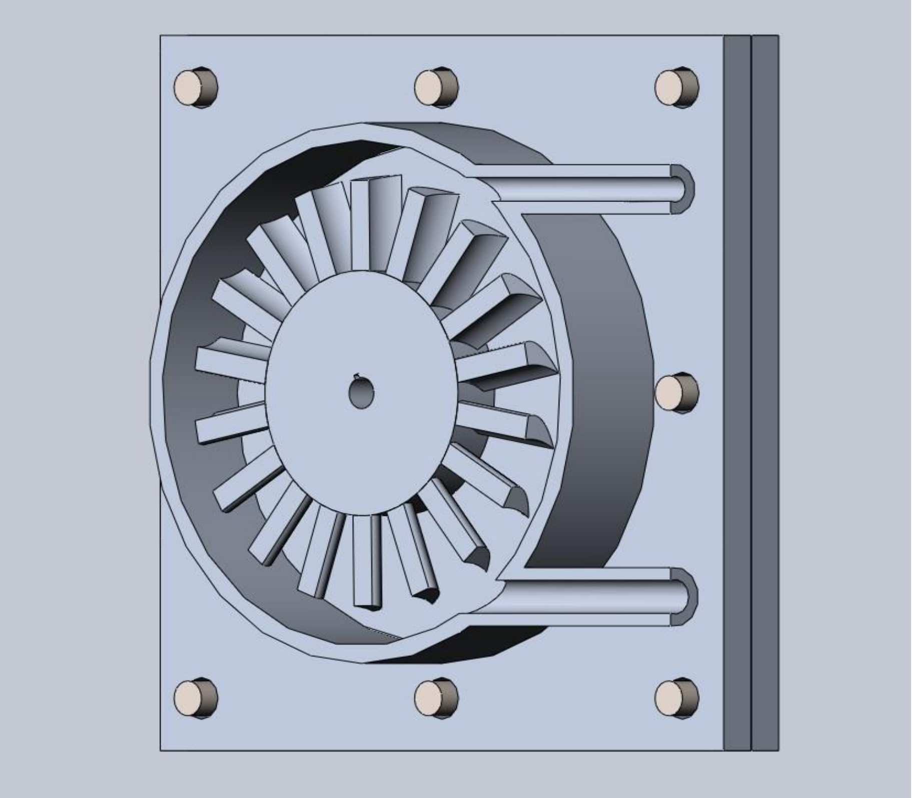

Figure 5.15 Isometric Sectional view of Assembled Casing with Turbine inside

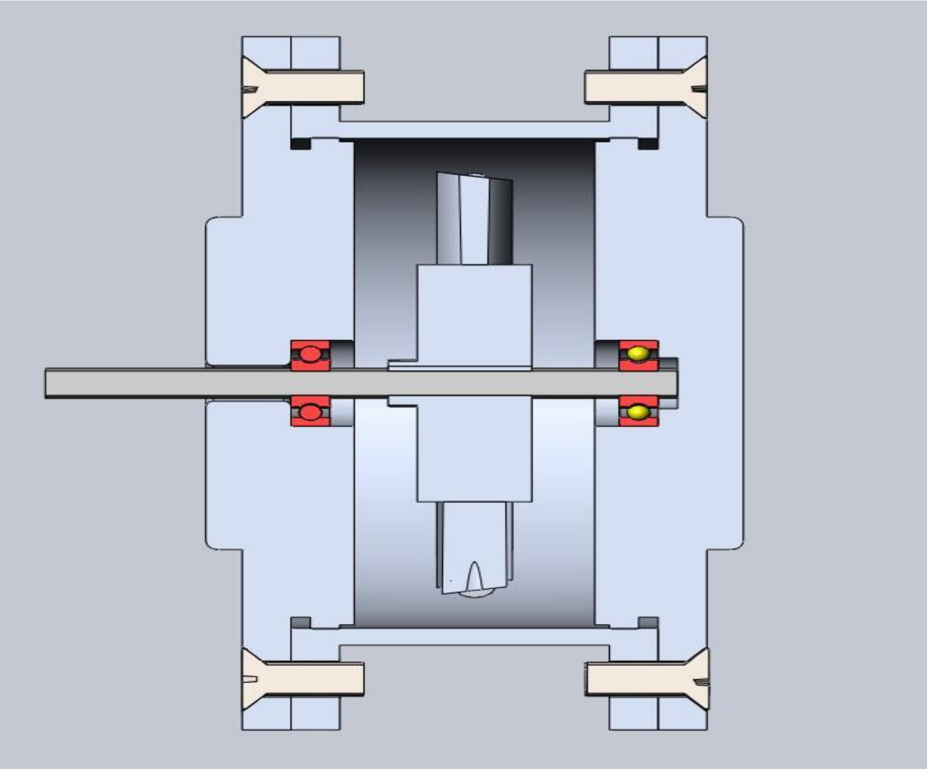

Figure 5.16 Sectional Side view of Assembled Casing with Turbine inside

Table 5.9 Mass properties of Assembled Casing with Turbine

Density	2751.00 kilograms per cubic meter
Mass	5.747 kilograms
Volume	0.002138 cubic meters
Surface area	0.4600 square meters

5.4 Vehicle Design

The objective of the project is to utilize the power output of a turbine shaft to drive an automobile. Vehicle design involves designing of the following parts

i) Chassis
ii) Power Transmission
iii) Steering Mechanism and suspension
iv) Acceleration and braking
v) Wheels

5.4.1 Design of Chassis

Tadpole vehicle is 3-wheeler vehicle with two wheels at front and one wheel at rear and the shaft is connected to the rear wheel by suitable power transmission mechanism. From previous literature Pokala Sai Prasanna Kumar et al (xx) reviewed tadpole and delta vehicle design for a compressed air vehicle. In this paper, they discussed the advantages of tadpole design over delta taking into considerations the aspects of Dynamic Stability, Braking, Simplicity of Design and Powertrain. To avoid any accidents, front bumper is used and as the cylinders are exposable, side structural members are used.

According to the FSAE standards, the material for formula-1 chassis is 4130 tubes can be used but taking cost aspects into consideration, we can use AISI1020 as a standard alternative for 4130

Table 5.10 AISI1020 material properties

Property	Value	Unit
Elastic modulus	200	GPa
Yield Strength	351.571	MPa
Poisson Ratio	0.29	---
Ultimate Strength	420.507	MPa

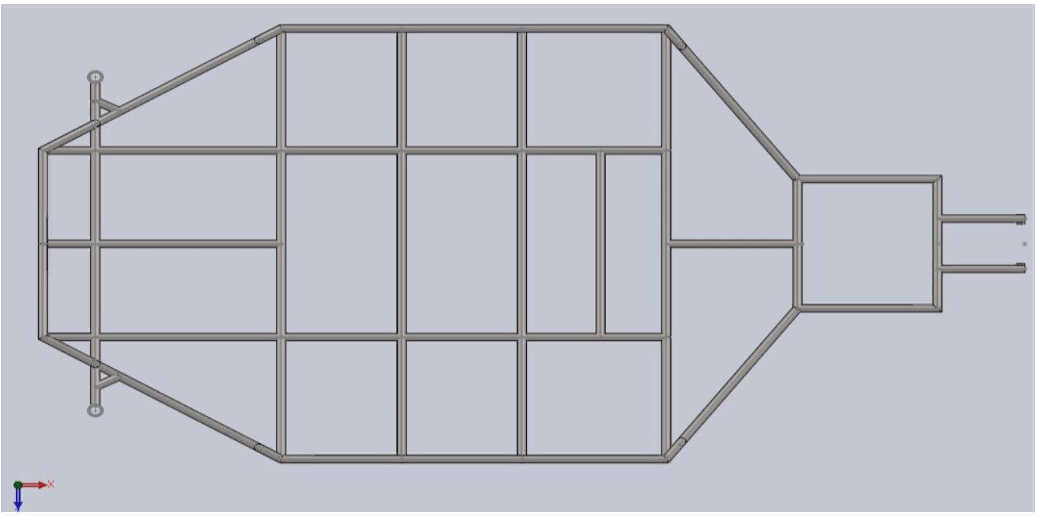

Figure 5.17 Chassis Top View

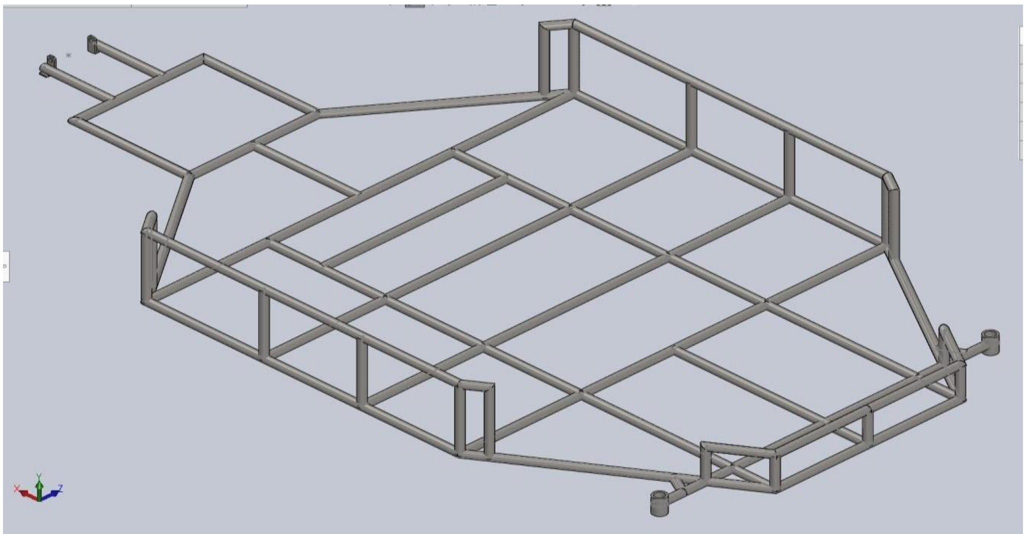

Figure 5.18 Chassis Isometric View

Table 5.11 Mass properties of Chassis

Density	7900.00 kilograms per cubic meter
Mass	24.436 kilogram
Volume	0.003093 cubic meters
Surface area	2.686777square meters

5.4.2 Power Transmission

Since most of the light motor vehicles have sprocket and chain mechanism, we used the same.

Table 5.12 Technical details of chain drive

Sprocket at turbine	50mm diameter
Sprocket at wheel	26mm diameter
Chain length	180mm
Centre to center length	65mm

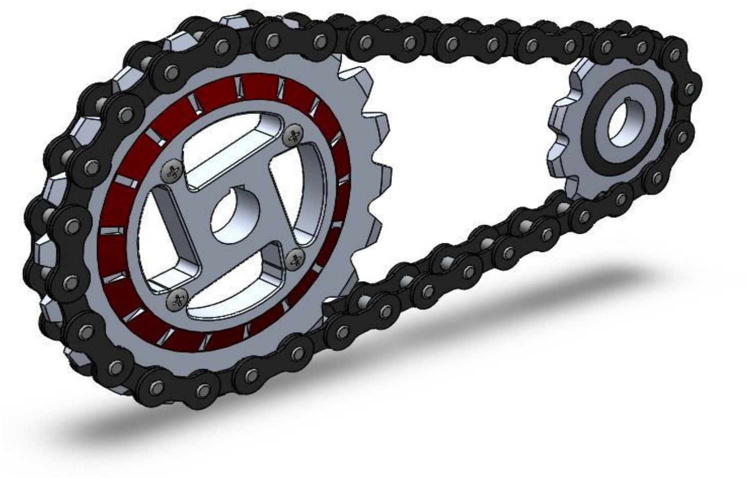

Figure 5.19 Power transmission assembly

5.4.3 Steering Mechanism and Suspension

Since our main objective of the project is to run a vehicle using compressed air technology, steering mechanism was decided to be Ackerman Steering Mechanism. Though rack and pinion steering mechanism is much widely used due to its advantage of more steering ratio, but in cost aspects it is expensive. Considering construction and cost aspects, Ackerman steering mechanism is much preferred for such type of projects.

Since vibrations at the turbine are high, to control them suspension springs are used. Here in this project we are using Compressive springs attached above and beneath where chassis mates with the steering mechanism. These are also used for absorbing vibrations from the ground and also to reduce the effect of chassis and driver weight on the wheels. Compressive spring is MDL India SS11032051, this is according to ISO 10243.

Figure 5.20 Steering Mechanism

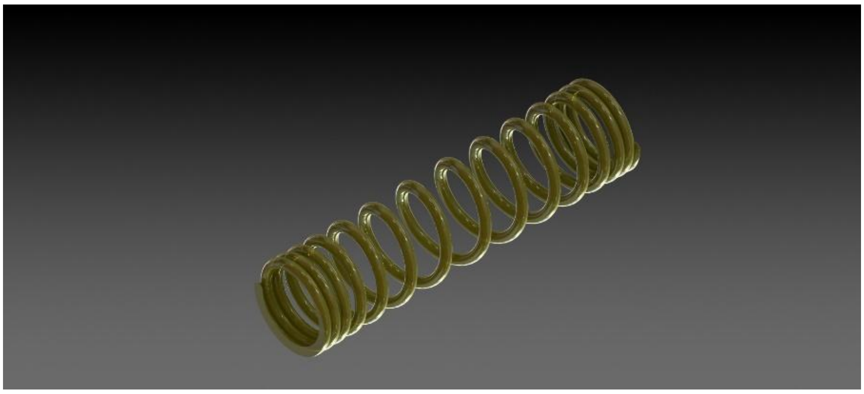

Figure 5.21 Compression Springs for Suspension

5.4.4 Acceleration and Braking

To control vehicle speed and to stop the vehicle in motion, accelerator and brakes are used. For braking purpose, we are using a single brake disc at the rear wheel and its brake pedal is at the front nearing steering rod. Brake disc radius is 160mm. For accelerating, we are using a spring-loaded valve just before nozzle inlet and its pedal is placed beside brake pedal. Spring loaded valve is a valve which is controlled using a spring attached to valve disc. Here valve used is 3/4” Ball Valve.

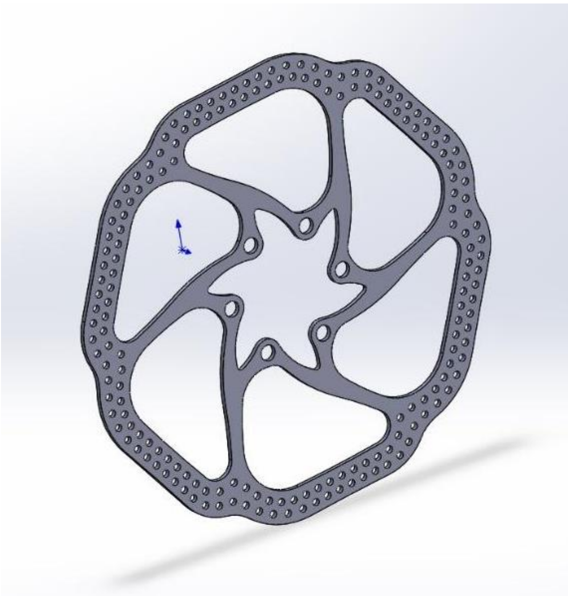

Figure 5.22 Brake Disc

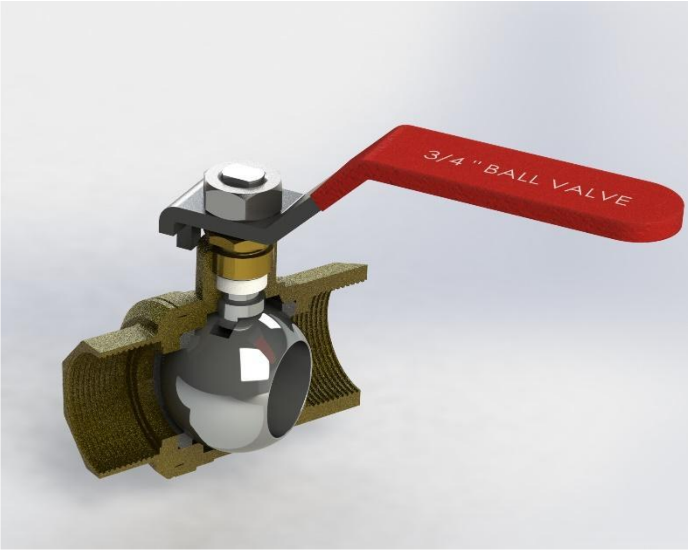

Figure 5.23 ¾" Ball Valve

5.4.5 Wheels

Wheels are the driving parts which take the motion of turbine shaft using suitable power transmission device and they connect the vehicle with the ground. Wheel size decides the ground clearance of the vehicle. Here in this project since there are three wheels, two in front and one in rear. The front wheels size is decided as 16" bicycle wheels and the rear wheel as 20" bicycle wheel. The sizes of the front and rear wheel are different because in front suspension are used due to which the chassis axis and front wheel axis are offset to each other. To compensate this difference at back a larger wheel is used as a rear wheel.

Figure 5.24 Front Wheel **Figure 5.25 Rear Wheel**

CHAPTER 6

ANALYSIS

Analysis is an important project of any project as it proves the theoretical assumptions and calculations made. In this project also, analysis of different parts was made to prove the assumptions and calculations made.

Following analysis were made in this project, they are:

i. CFD Analysis of Nozzle
ii. Static Analysis of Turbine Blade
iii. CFD Analysis of Turbine in Casing
iv. Static Analysis of Chassis

6.1 CFD Analysis of Nozzle

In the following analysis, nozzle model which was made in solid works was imported into CFD/Fluent as a step file. Since Nozzle made was a 3D Model for simplicity, 2D model can also be used for analysis which gives same results with a minimum deviation of 1-3%. The model was meshed, and the following boundary conditions were applied and solved with a good number of iterations for more accurate solution.

a) Inlet – Velocity Inlet – 2m/s
b) Outlet – Pressure Outlet
c) No of Iterations – 250

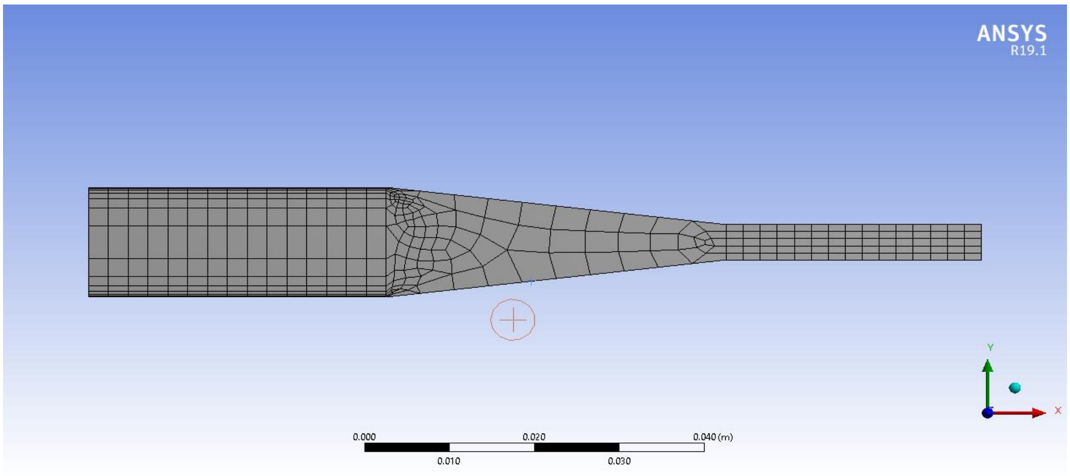

Figure 6.1 Meshed Model of Nozzle

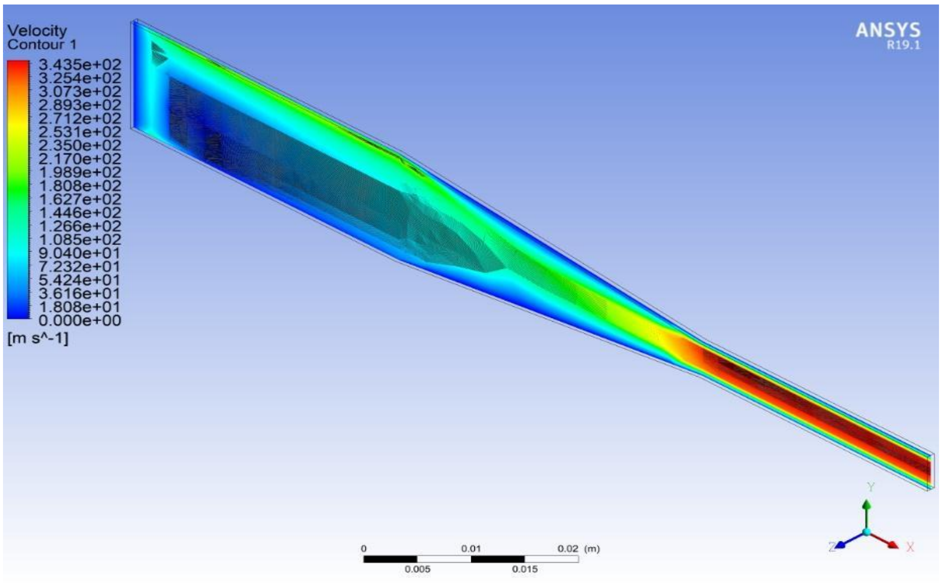

Figure 6.2 Velocity contour of Nozzle

Velocity Min: 0m/s Max: 346.981m/s

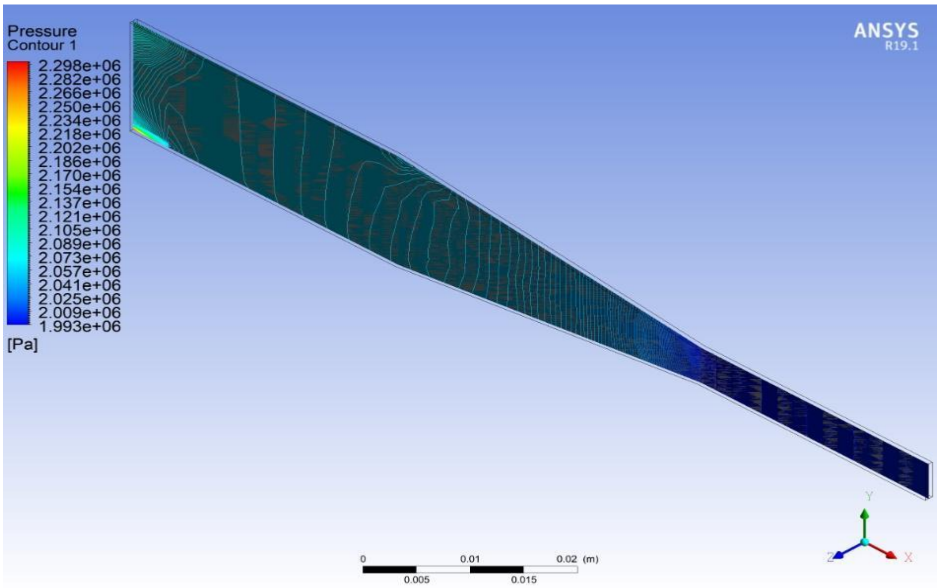

Figure 6.3 Pressure contour of Nozzle

Pressure Min: 1.992e6 Pa Max: 2.310e6 Pa

6.2 Static Analysis of Turbine Blade

If the blades can withstand the maximum pressure impinging on the surface of blade, then turbine blades don't break within the entire process. For this purpose, single blade is considered for analysis rather than the entire wheel.

In Workbench Static Structural module is used for this purpose. Model is imported into the module as a STEP File.

Figure 6.4 CAD Model for Static Analysis

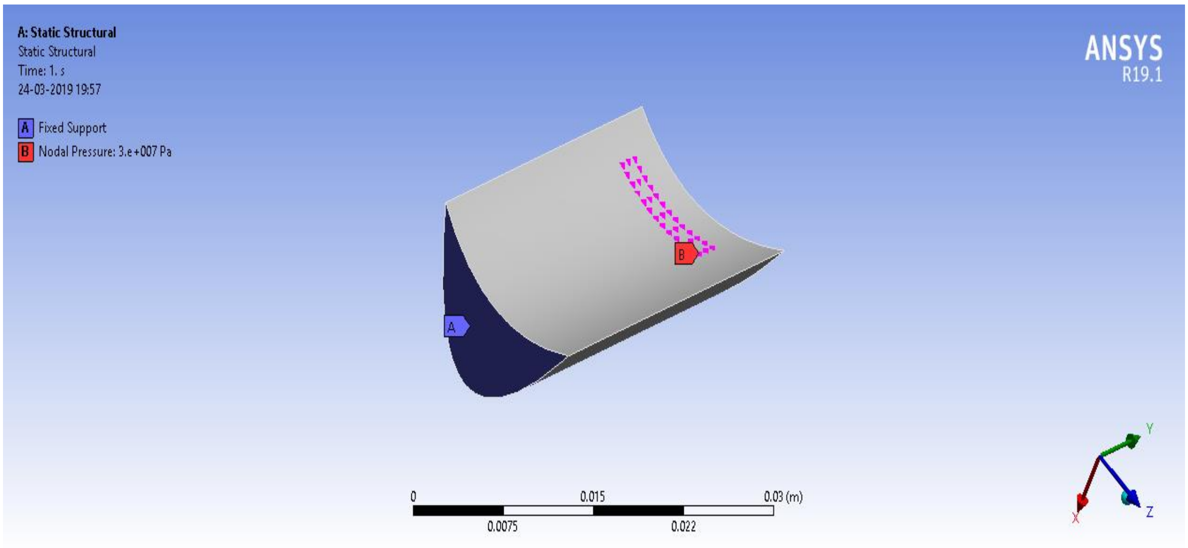

Figure 6.5 Load Conditions

Nodal Pressure - 3e7 Pa, Fixed Support/Displacement-0

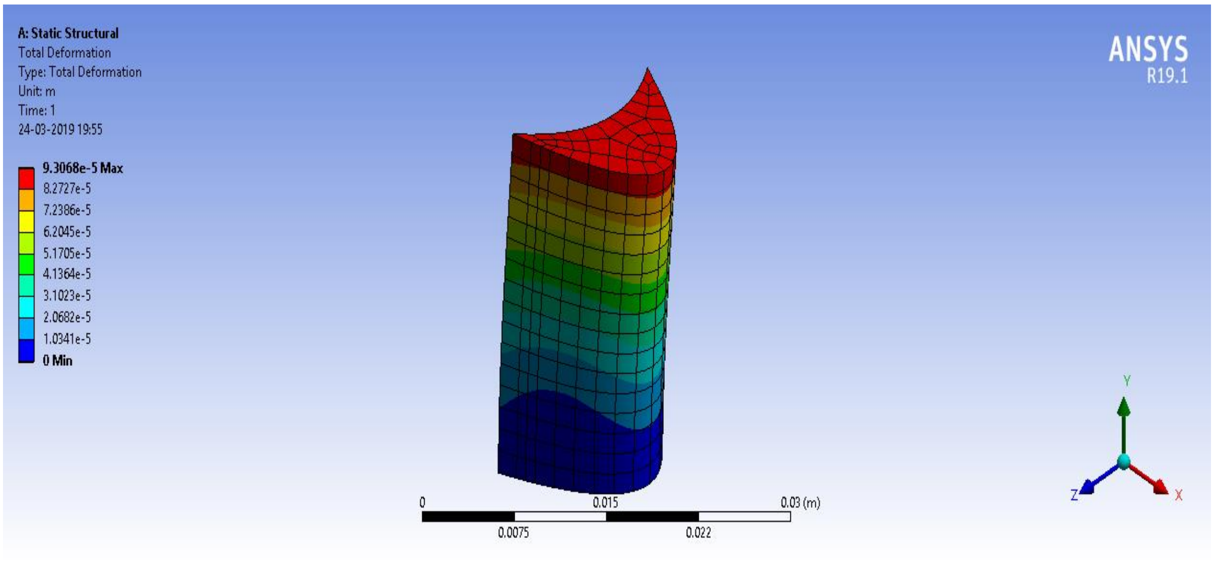

Figure 6.6 Deformation of Blade

Minimum Deformation – 0 m Maximum Deformation – 9.3068e-5 m

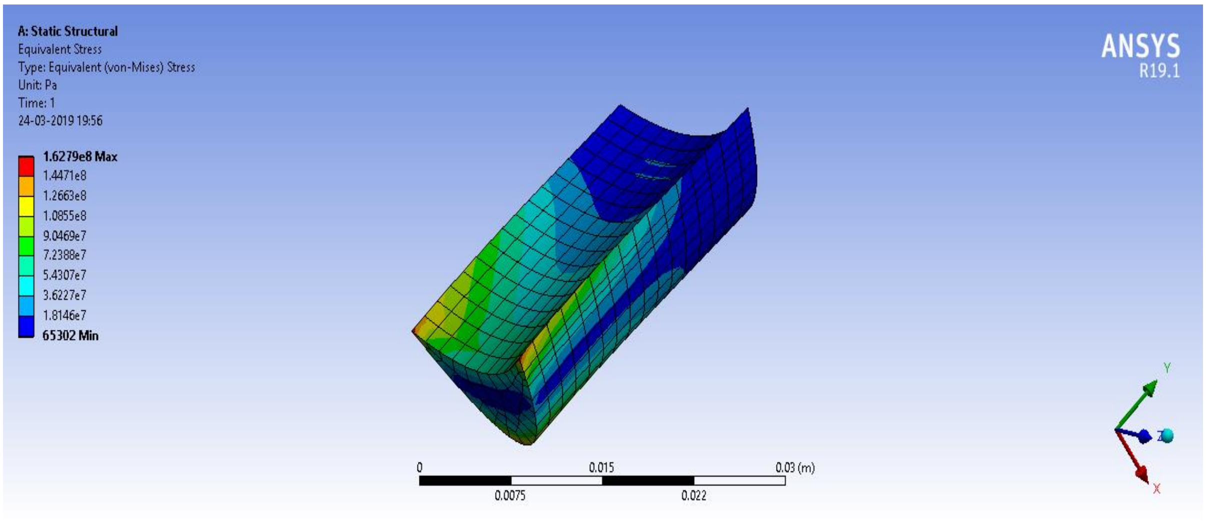

Figure 6.7 Equivalent Von Mises Stress

Minimum Stress – 65302 Pa Maximum Stress – 1.6279e8 Pa

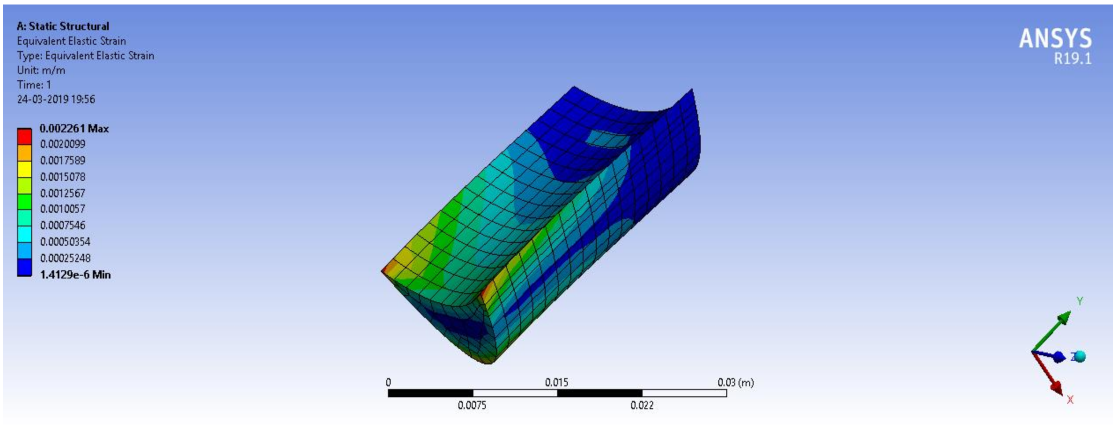

Figure 6.8 Equivalent Elastic Strain

Minimum – 1.4129e-6 m/m Maximum – 0.002261 m/m

If the yield strength is checked the maximum stress is within limits, which implies that blade can withstand the pressure of compressed air. And deformation of blade is also within limits.

6.3 CFD Analysis of Turbine

For CFD Analysis of Turbine, only middle cover and turbine wheel are considered since meshing of the entire casing is difficult. Turbine is subtracted from fluid mass and then again fluid mass is subtracted from the casing. Inlet and outlet conditions are same as designed for middle cover. The main motive of CFD Analysis of Turbine is to know the force on turbine and flow passage in the turbine.

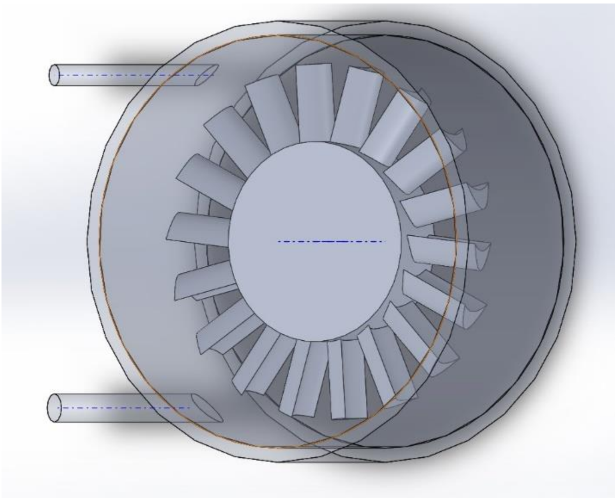

Figure 6.9 CAD Model for CFD Analysis

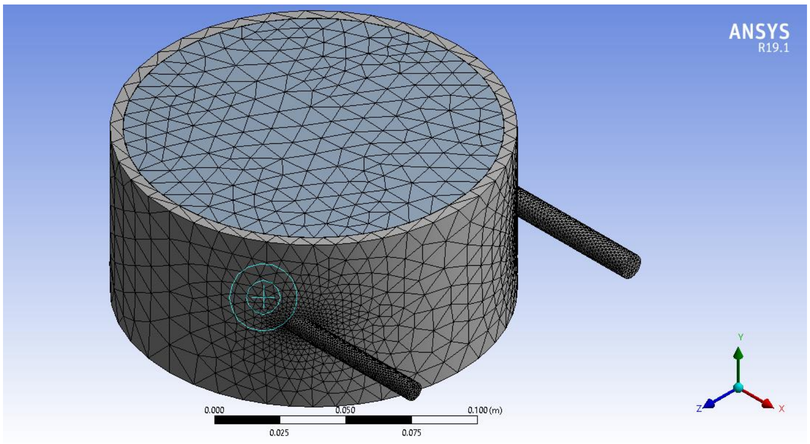

Figure 6.10 Meshed Model of Turbine and Casing

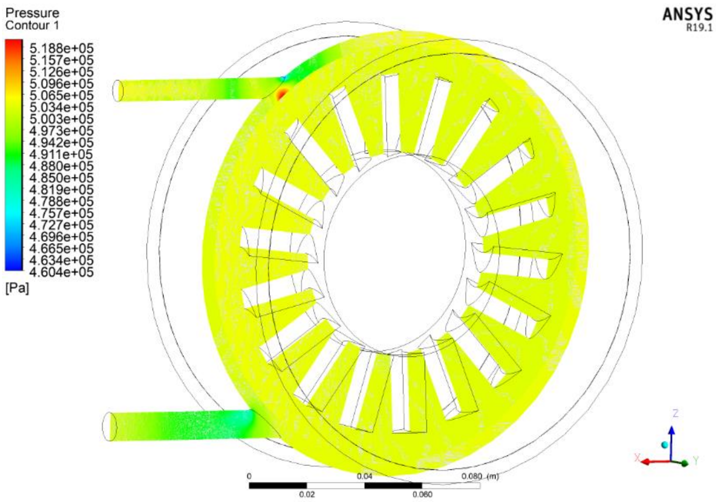

Figure 6.11 Pressure Contour of Turbine and Casing

Minimum – 4.8e5 Pa Maximum – 15e5 Pa

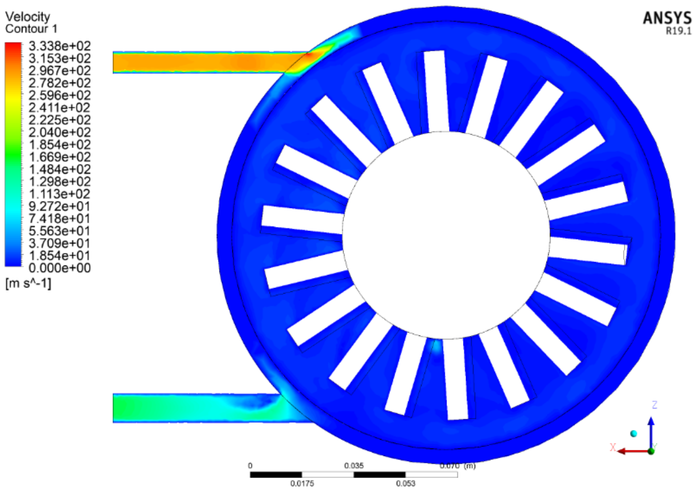

Figure 6.12 Velocity Contour of Turbine and Casing

Minimum – 0m/s Maximum 333.8m/s

6.4 Static Analysis of Chassis

In the static analysis of chassis, various impacts are considered to make sure that the chassis withstands and doesn't break in any type of circumstances and to check if bending stress is within limits. Following impact conditions are considered and analyzed.

i. Front Impact Condition
ii. Side Impact Condition
iii. Impact on Chassis due to Driver's weight
iv. Impact on Chassis due to the parts weight

Since chassis weights 24kg, driver's weight is 100kg

The parts weight almost 10kg

Total weight is 135kg

Total force considered is 5500N with a factor of safety 4.

6.4.1 Front Impact Condition

In front impact a load of 5500N is applied at the front bumper and the connections where wheels connect with chassis are fixed.

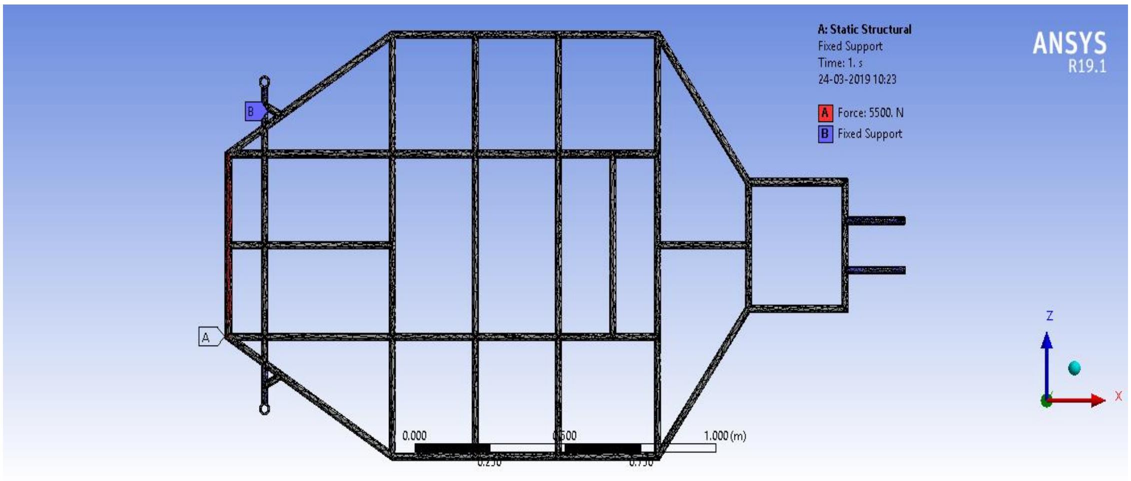

Figure 6.13 Front Load Boundary Conditions

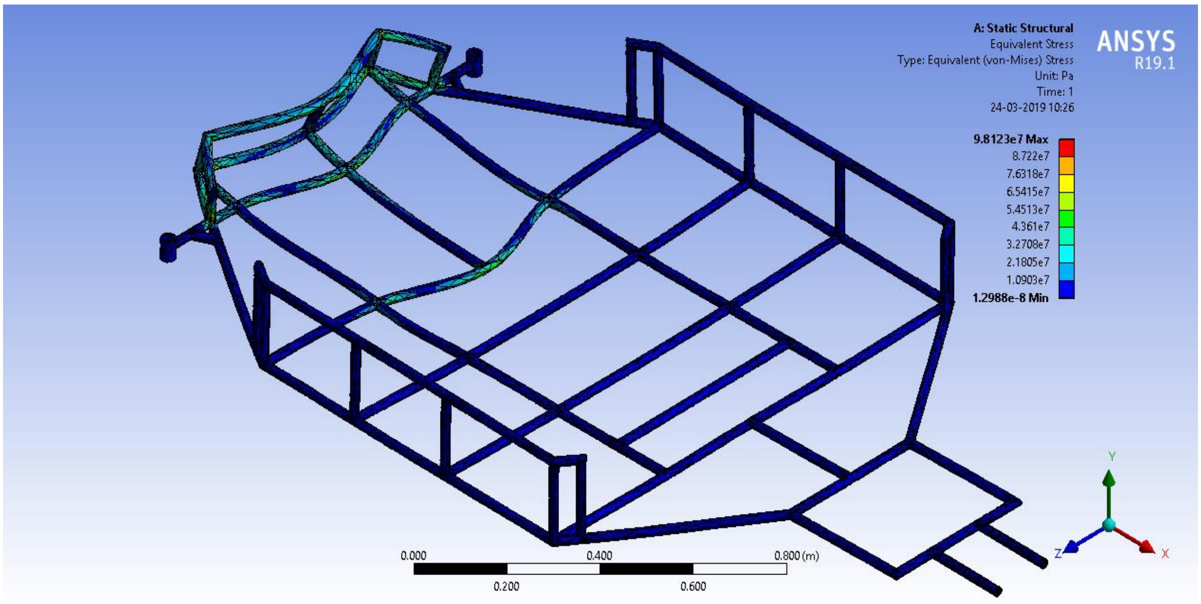

Figure 6.14 Front Impact Von Mises Stress – Isometric View

Minimum Stress – 1.3e-8 Pa Maximum Stress – 9.812e7 Pa

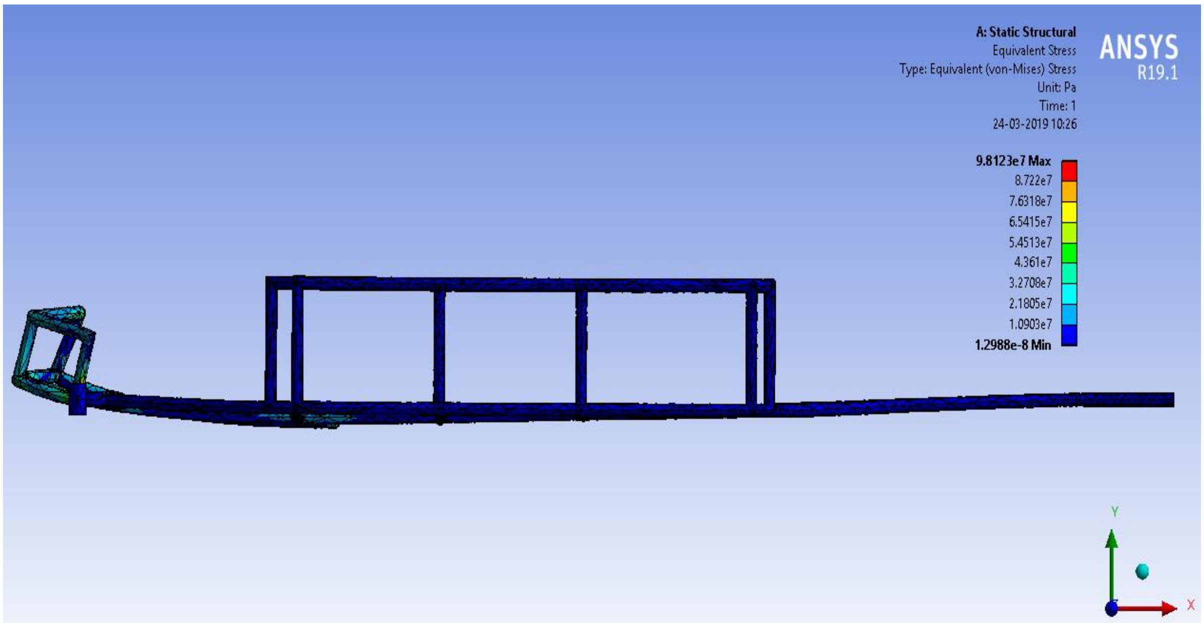

Figure 6.15 Front Impact Von Mises Stress – Side View

Minimum Stress – 1.3e-8 Pa Maximum Stress – 9.812e7 Pa

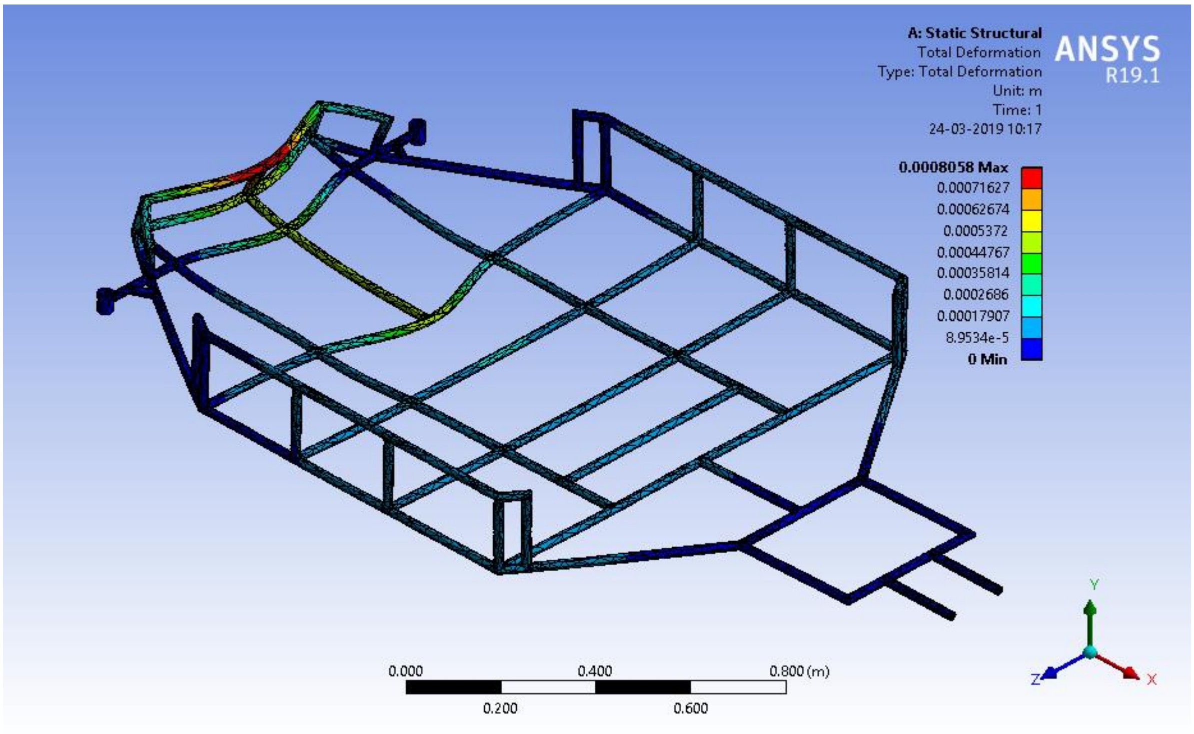

Figure 6.16 Front Impact Total Deformation – Isometric View

Minimum Deformation – 0 m Maximum Deformation – 0.0008058 m

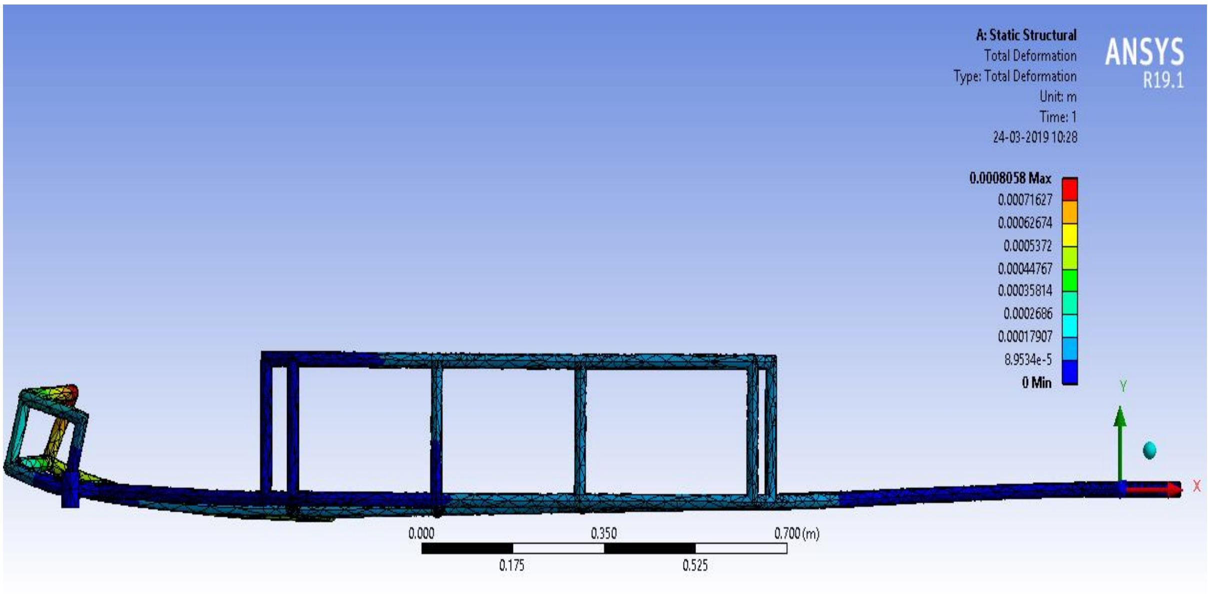

Figure 6.17 Front Impact Total Deformation – Side View

Minimum Deformation – 0 m Maximum Deformation – 0.0008058 m

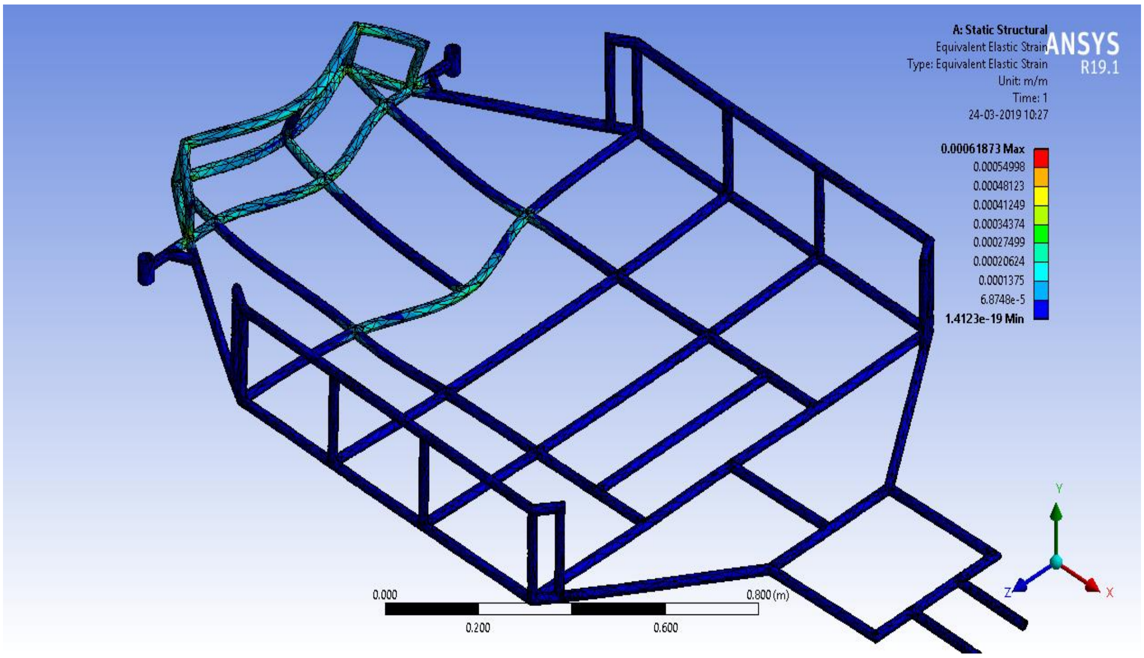

Figure 6.18 Front Impact Equivalent Strain– Isometric View

Minimum – 1.4123e-19 m/m Maximum – 0.00061873 m/m

6.4.2 Side Impact Condition

In side impact a load of 5500N is applied on the side bumper and the connections where wheels connect with chassis are fixed.

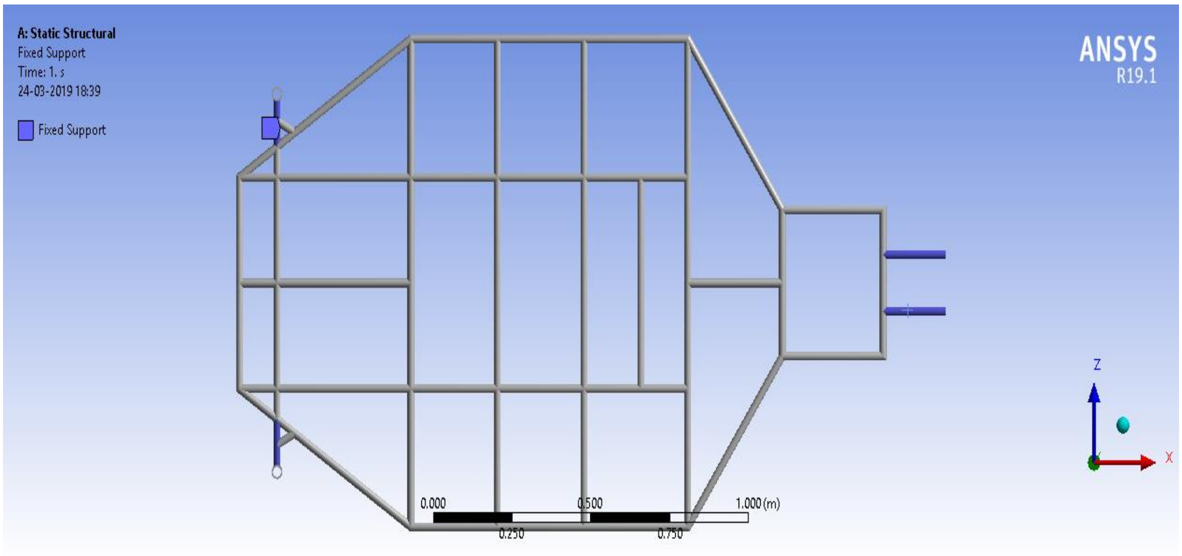

Figure 6.19 Side Impact Boundary Conditions

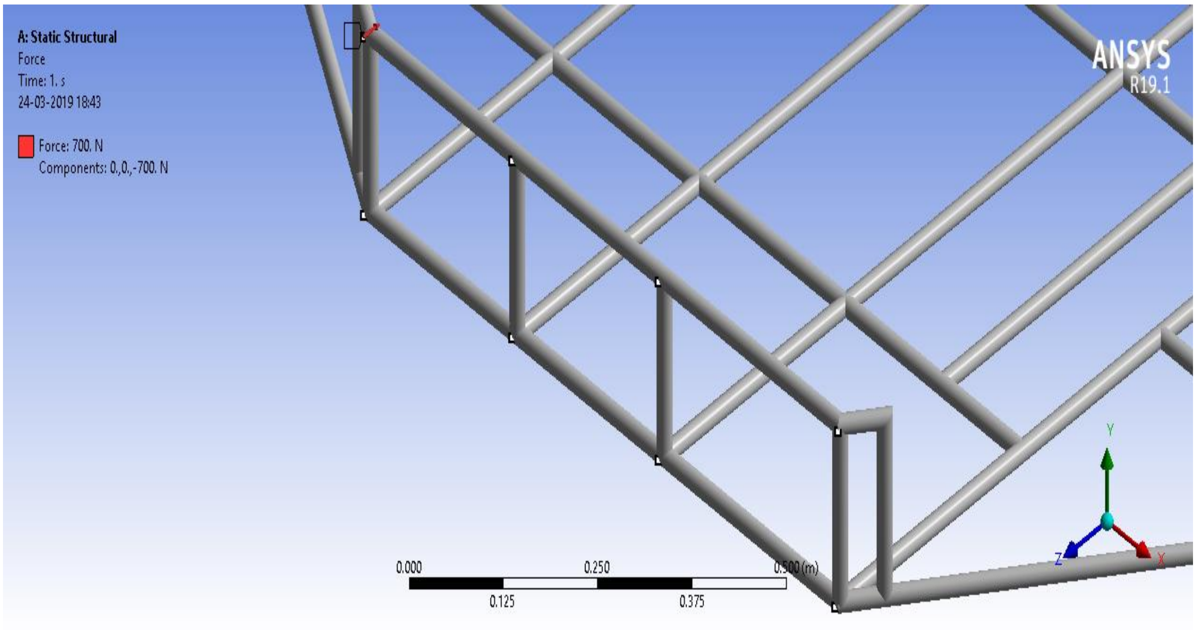

Figure 6.20 Side Impact Force Conditions – Isometric View

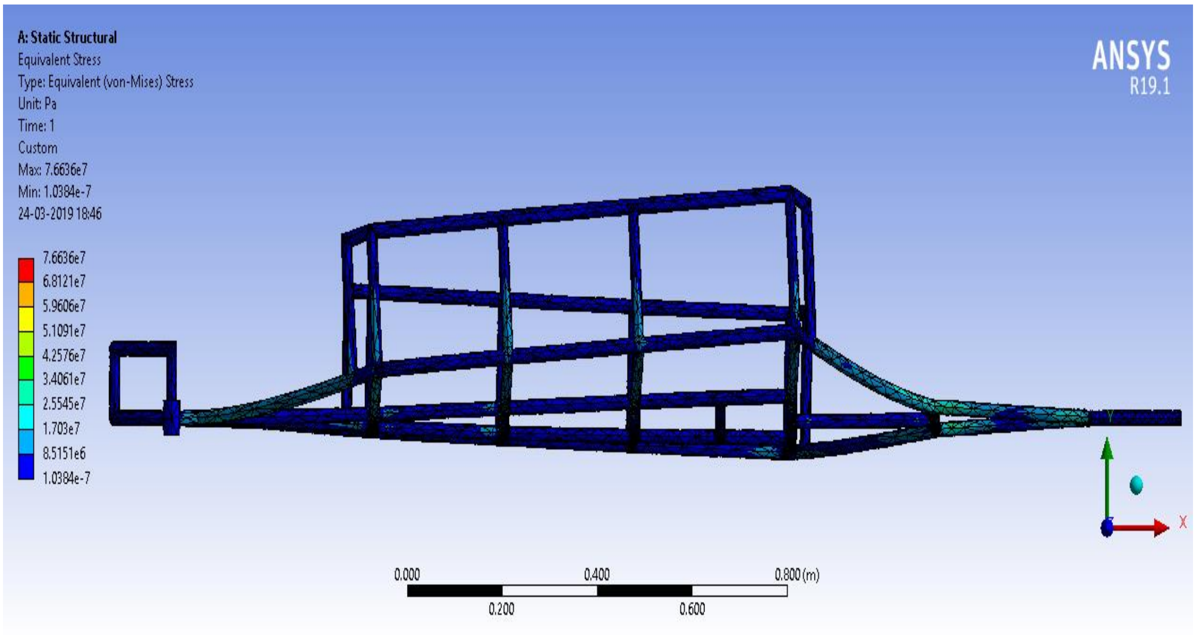

Figure 6.21 Side Impact Equivalent Von Mises Stress – Side View

Minimum Stress – 1.03e-7 Pa Maximum Stress – 7.663e7 Pa

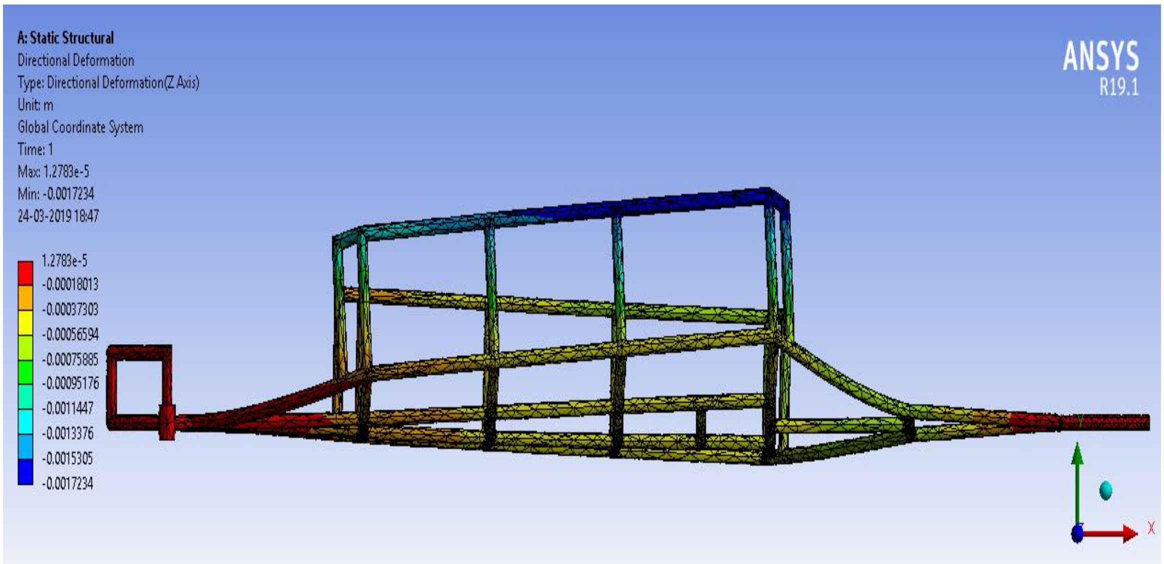

Figure 6.22 Side Impact Directional Deformation (Z axis) – Side View

Minimum Deformation – -0.0017 m Maximum Deformation – 1.2783e-5 m

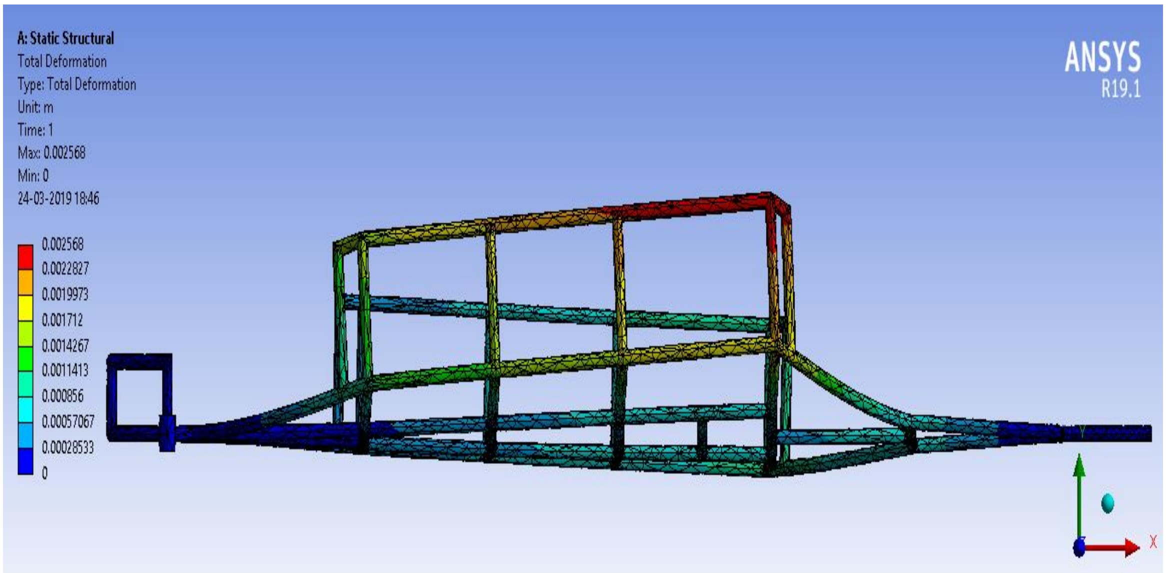

Figure 6.23 Side Impact Total Deformation – Side View

Minimum Deformation – 0 m Maximum Deformation – 0.002568 m

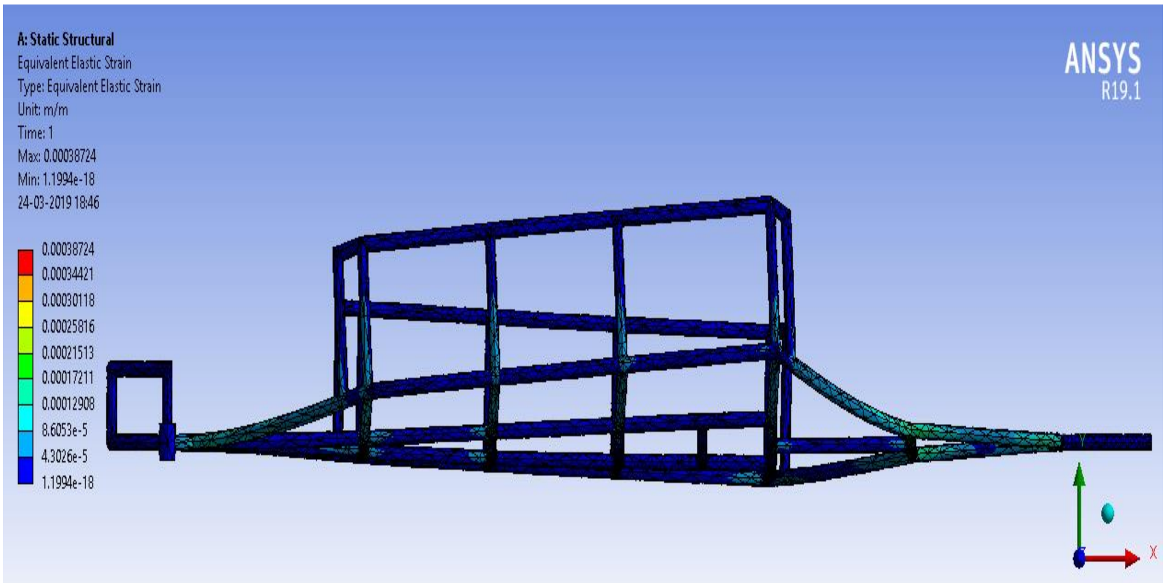

Figure 6.24 Side Impact Equivalent Elastic Strain – Side View

Minimum– 1.2e-18 m/m Maximum – 0.00038724 m/m

6.4.3 Effect of Driver's weight

In driver impact a load of 5500N is applied on the chassis and the connections where wheels connect with chassis are fixed.

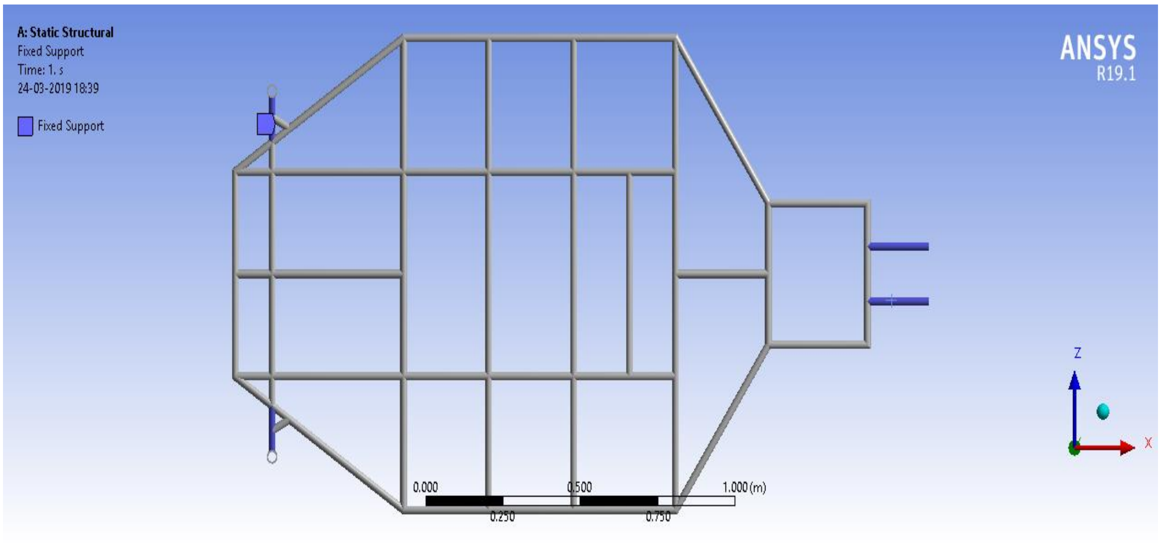

Figure 6.25 Impact due to Drivers weight - Boundary Conditions

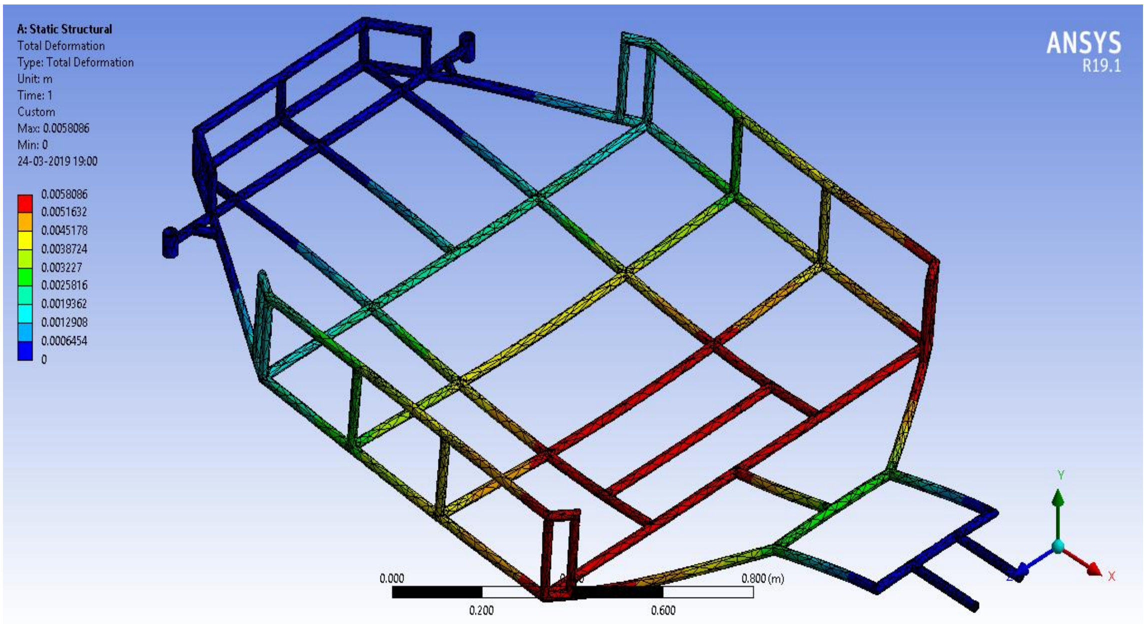

Figure 6.26 Impact due to Drivers weight - Total Deformation – Isometric View

Minimum Deformation – 0 m Maximum Deformation – 0.0058086 m

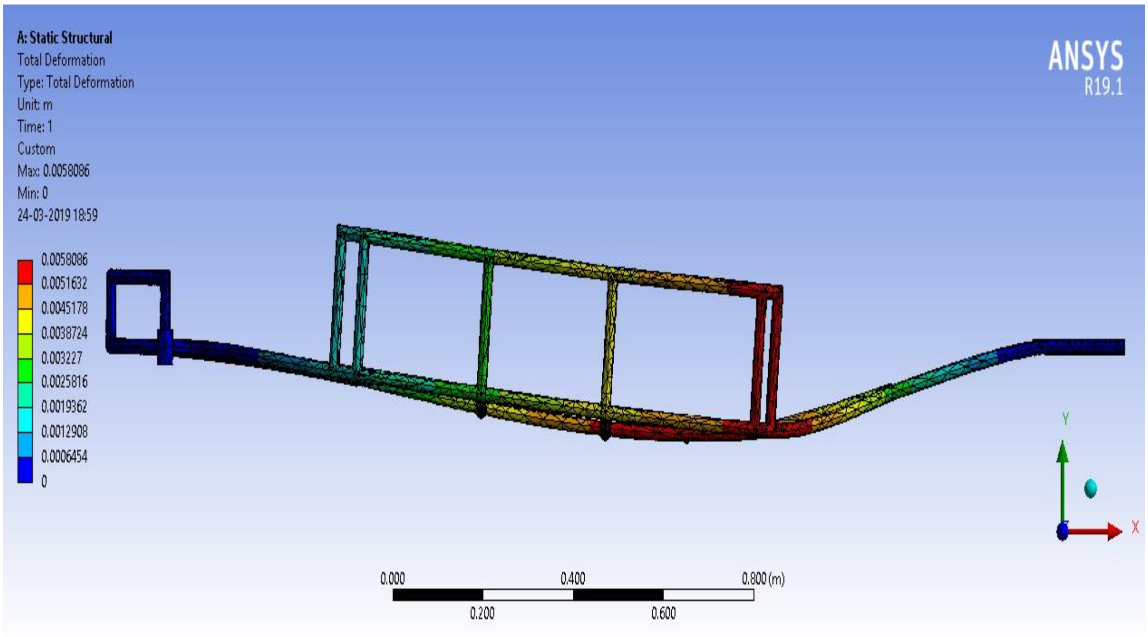

Figure 6.27 Impact due to Drivers weight - Total Deformation – Side View

Minimum Deformation – 0 m Maximum Deformation – 0.0058086 m

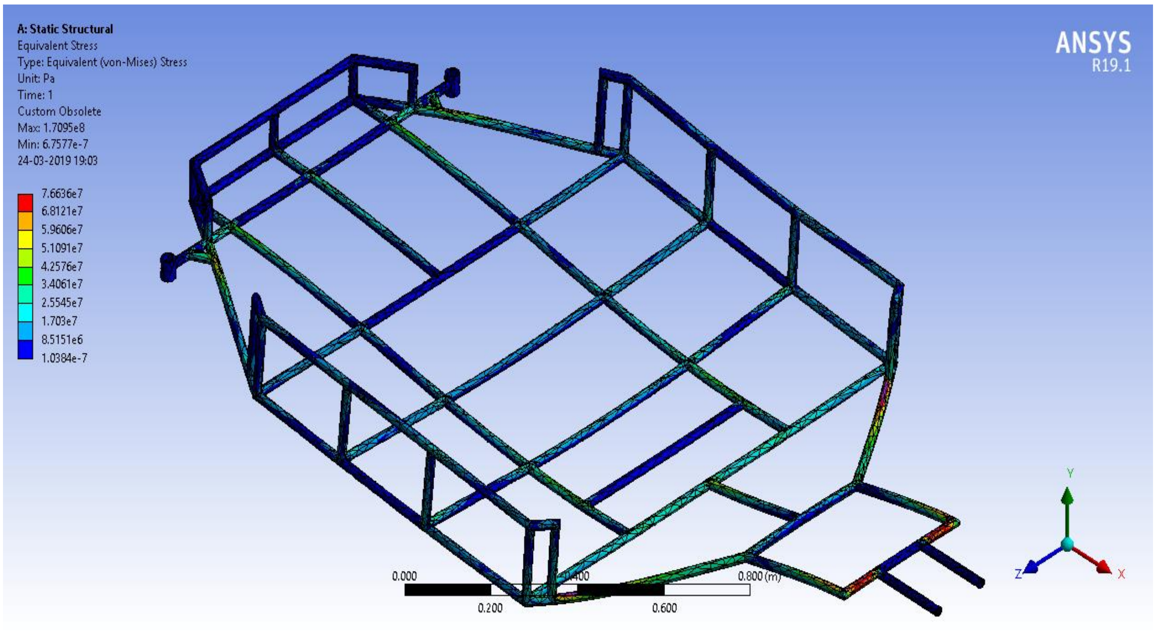

Figure 6.28 Impact due to Drivers weight - Equivalent Von Mises stress – Isometric View

Minimum Stress – 1.03e-7 Pa Maximum Stress – 7.6636e7 Pa

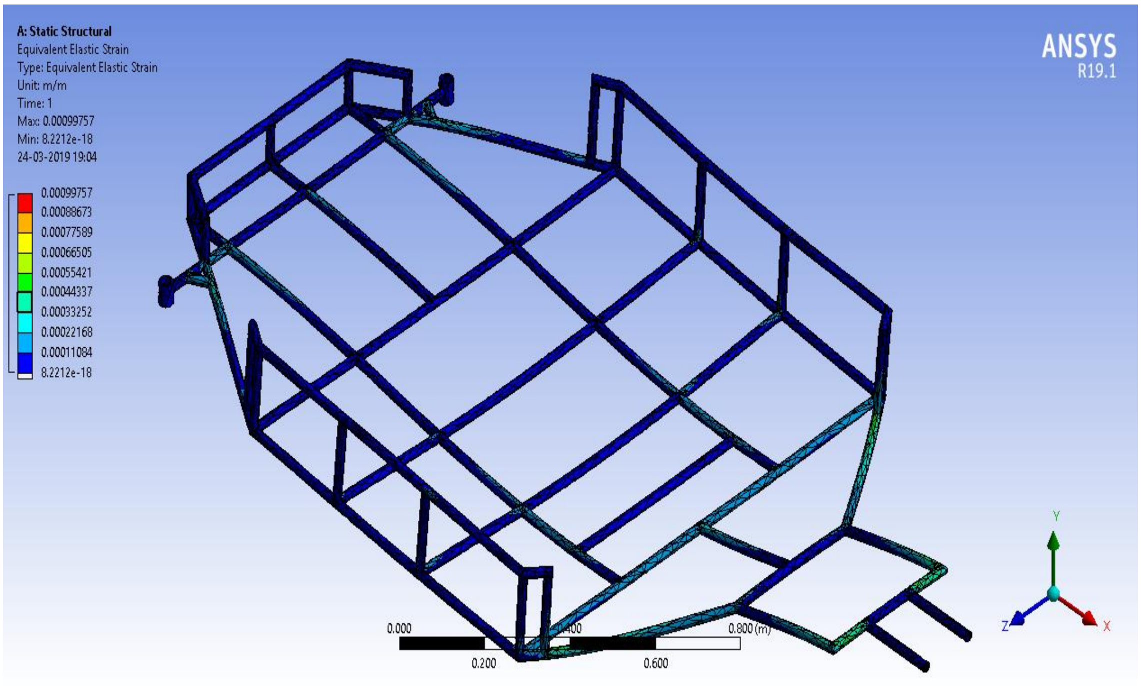

Figure 6.29 Impact due to Drivers weight - Equivalent Elastic Strain – Isometric View

Minimum –8.22e-18 m/m Maximum – 0.00099757 m/m

6.4.4 Effect of Parts weight

In part impact a load of 5500N is applied on the chassis and the connections where wheels connect with chassis are fixed.

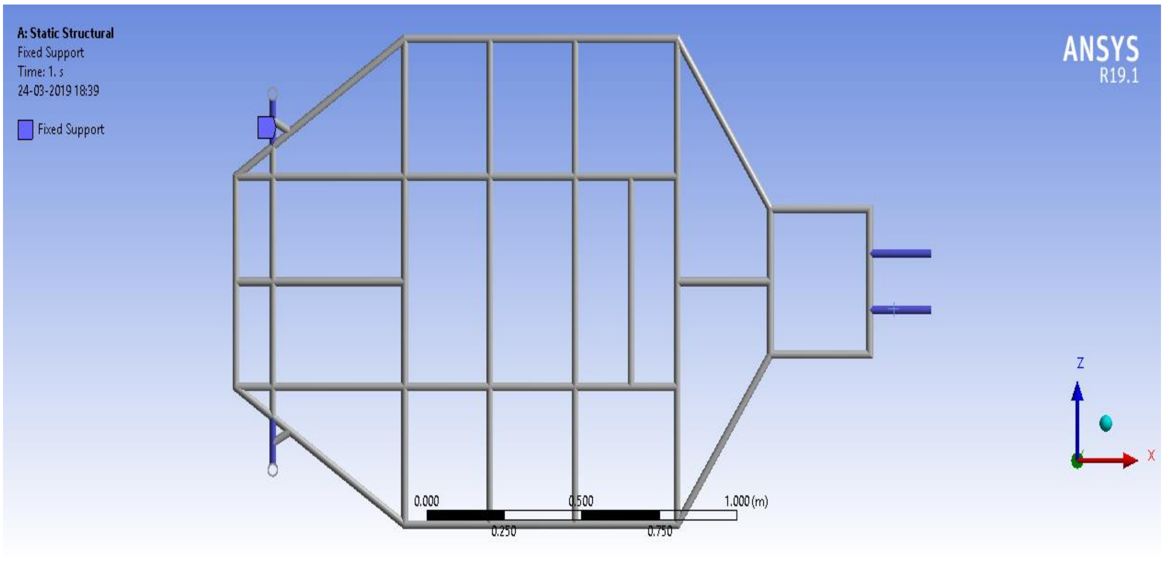

Figure 6.30 Impact due to Parts - Boundary conditions

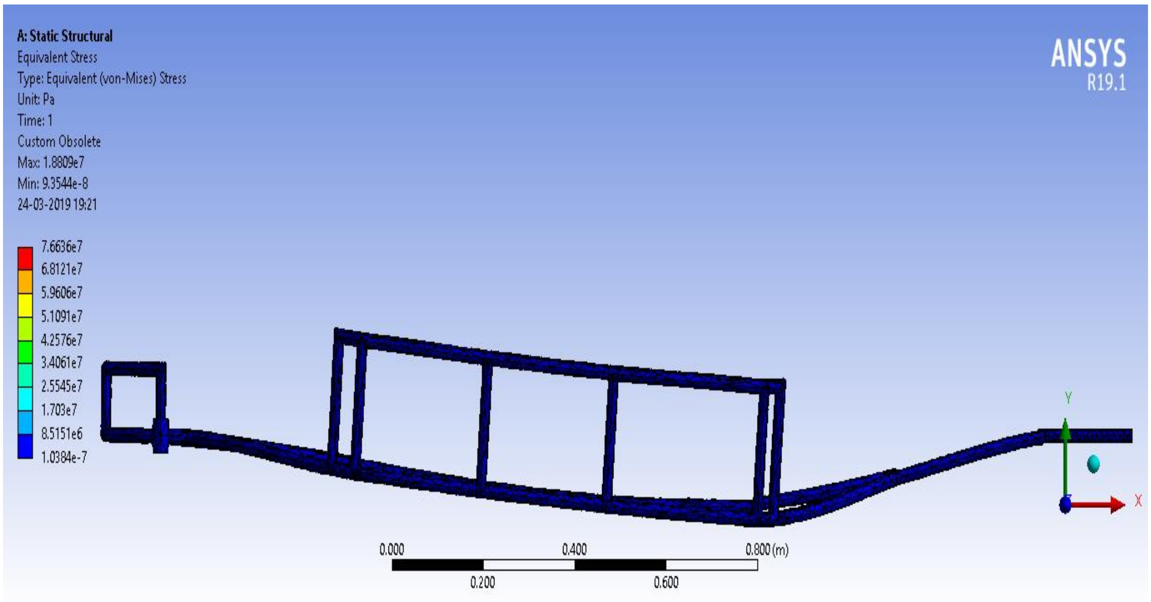

Figure 6.31 Impact due to Parts - Equivalent Von Mises Stress

Minimum Stress – 1.03e-7 Pa Maximum Stress – 7.6636e7 Pa

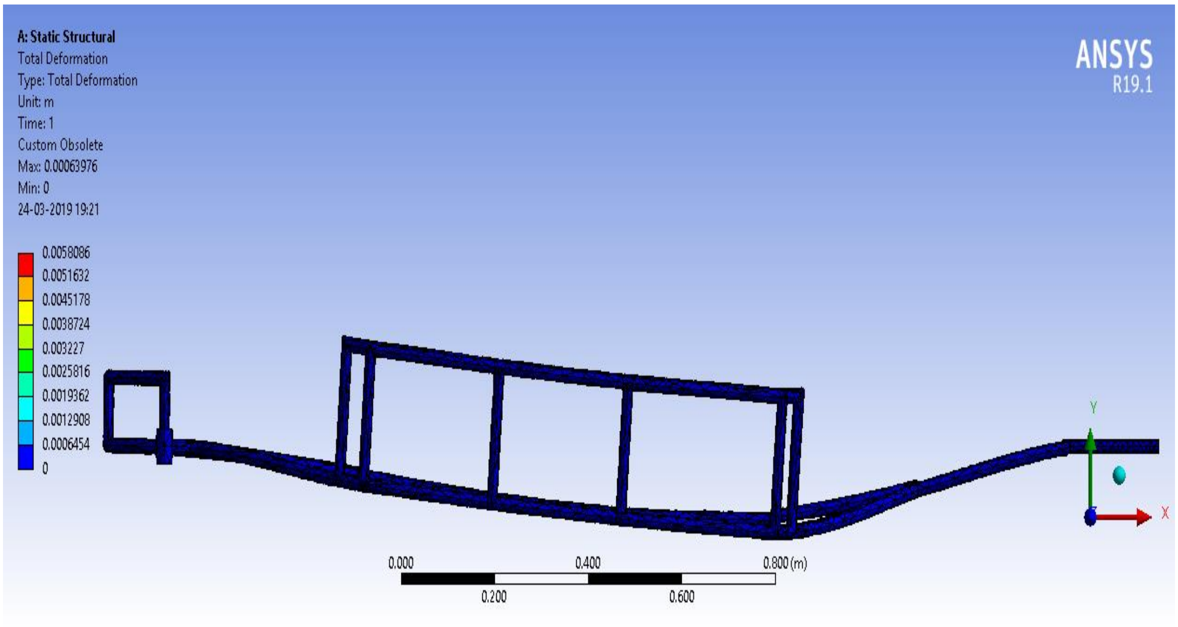

Figure 6.32 Impact due to Parts - Total Deformation

Minimum Deformation – 0 m Maximum Deformation – 0.0058086 m

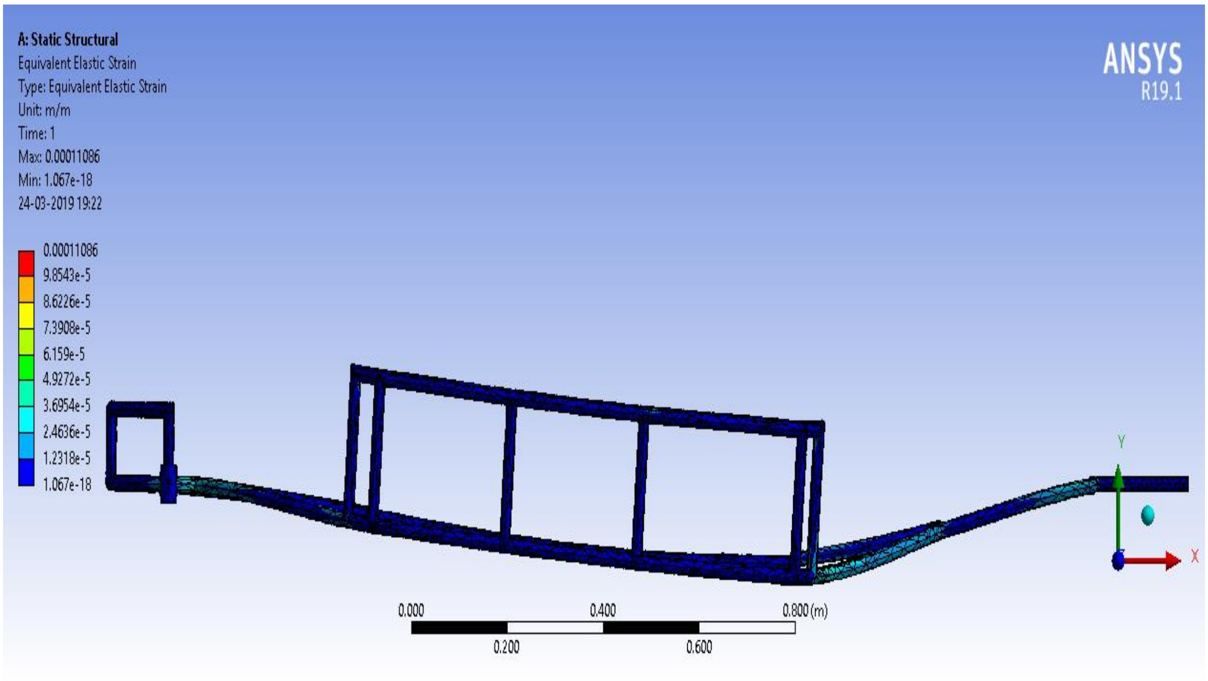

Figure 6.33 Impact due to Parts - Equivalent Elastic Strain

Minimum –1.067e-18 m/m Maximum – 0.00011086 m/m

CHAPTER 7

RESULTS AND DISCUSSIONS

Cylinder

According to the market survey and previous literature review, we have chosen the specifications of the storage tank as follows:

Table 7.1 Specifications of Cylinder

Pressure	30 MPa
Volume	65 cf
Diameter	177.8 mm
Height	609.6 mm

The material chosen will withstand the high pressure of air and is anti-corrosive in nature so as to protect from the moisture content present in the air.

Nozzle

By analyzing the characteristics and calculations, Convergent type of nozzle is preferred over convergent-divergent nozzle as there is a drastic drop in temperature which is impractical. After theoretical calculations are completed, analysis is done using CFD software where there is only 10% deviation. The outlet velocity from analytical calculations is 353.4 m/s while the value from analysis is 320 m/s. This deviation is caused since calculations are prepared for the ideal case without considering friction and other factors.

Turbine

The main aim of the project is to calculate the power generated by the turbine which is on par with the Indian light weight motor vehicle standards. The blade profile is taken from NACA standards and the hub diameter is chosen accordingly. The theoretical power obtained is 611.3 W. The variation in the power values between theoretical and analytical is 15% and this may be due to losses in energy conversion and assuming that the turbine is 100% efficient.

Chassis

A tadpole design of chassis is taken in our project which have many advantages. While considering a single wheel at the rear, the necessity of usage of differential is eliminated which has a great impact on total weight of the vehicle and cost is also reduced. Also, aerodynamic shape is obtained through this design which has impact on speed (drag forces are reduced) and stability of the vehicle. While designing the frame, the procedure followed in making a SAE frame is followed and the material is its standard. Various tests are performed such as front impact, side impact and bending to check its sustainability.

CHAPTER 8

CONCLUSIONS AND FUTURE SCOPE

8.1 Conclusion

- This equipment is very useful in reducing pollution to zero levels which are otherwise harmful to human beings. Hence this will be used for eliminating the pollutants.
- Inter - Industrial links can be established with the design of limits like compressed cylinder, convergent divergent nozzle, turbine can be directly obtained with specifications of design as detailed by author.

8.2 Future Scope

- As there is consumption of air, it expands inside the cylinder and thus there is a drop in energy stored by pressurized air. By maintaining the constant pressure inside the cylinder loss in energy can be reduced and thus efficiency is improved.
- Instead of using a storage tank, a compressor unit can be installed in the vehicle which reduces the refilling costs and the range of vehicle is increased.
- Further research can be encouraged in this direction with different sources of renewable energy like Solar Energy, Fuel cell energy etc.
- The compressor unit can be powered by solar energy where solar panels are installed on roof. Hence it gives 100% environmental friendly vehicle where no carbon footprints are formed.
- A diffuser system can be mounted above the front bumper and the air through this system will act as inlet to compressor while the vehicle is running.

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