A PROJECT REPORT [06ME85]

ON

# DESIGN AND FABRICATION OF A BOUNDARY LAYER TURBINE AS A POTENTIAL AUTOMOTIVE ENGINE

Submitted in partial fulfillment of the requirement for award of degree in
Bachelor of Engineering
(Mechanical Engineering)

Of

**VISVESVARAYA TECHNOLOGICAL UNIVERSITY**, Belgaum

By


| | |
|---|---|
| CHETHAN R REDDY | 1NH07ME010 |
| D HARISH KUNAL | 1NH07ME011 |
| H J JOHAN PEREIRA | 1NH07ME016 |
| PUNEETH V | 1NH07ME025 |

Under the Guidance of

**Mr. Iranna M.Biradar**
**Lecturer,**
**Mechanical Engg. Department, NHCE**

**Department of Mechanical Engineering**

**NEW HORIZON COLLEGE OF ENGINEERING**

(**Accredited by NBA, Permanently Affiliated to VTU)**

Ring Road, Kadubisanahalli, Bellandur Post, Near Marathalli, Bangalore -560 103
Tel.: +91-80-6629 7777. Fax: +91-80- 28440770
Web: www.newhorizonindia.edu


**2010-2011**

# NEW HORIZON COLLEGE OF ENGINEERING

**(Accredited by NBA, Permanently Affiliated to VTU)**

Ring Road, Kadubisanahalli, Bellandur Post, Near Marathalli, Bangalore -560103

Tel.: +91-80-6629 7777. Fax: +91-80- 28440770

Web: www.newhorizonindia.edu


## *Certificate*

*This is to certify that the Project entitled*

Design and Fabrication of a Boundary Layer Turbine as a Potential Automotive Engine

**[06ME85]**

Is a bonafied work carried out by

| | |
|---|---|
| **Chethan R Reddy** | (1NH07ME010) |
| **D Harish Kunal** | (1NH07ME011) |
| **H J Johan Pereira** | (1NH07ME016) |
| **Puneeth V** | (1NH07ME025) |

In partial fulfillment for the award of degree of Bachelor of Engineering in Mechanical of the Visvesvaraya Technological University, Belgaum during the year 2010 - 2011. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the Report deposited in the departmental library. The project report has been approved as it is satisfies the academic requirements in respect of Project work prescribed for the Bachelor of Engineering degree.

***Signature of the Guide*** ***Signature of HOD*** ***Signature of Principal***

**External Viva**

**Name of the Examiners** **Signature with date.**

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# ABSTRACT

Our project deals with the design and fabrication of a Boundary Layer through which we could assess and analyse its performance and operation and also measure its power as well when powered by compressed air.

The aim of this project is to present the various aspects, the benefits and disadvantages of a Boundary Layer Turbine as an automotive engine. The main objective of this project is to implement alternatives such as the Boundary Layer Turbine for improvements concerning the energy utilization.The Boundary Layer Turbine offers some exciting possibilities to overturn the use conventional fossil fuels and the poor efficiency of IC engines.

This report examines the various roles Boundary Layer Turbine plays in field of future automotive industries. This has a lot of potential and much more new advances can be achieved in this field. Some techniques are practical, while others are at various stages of testing, or actually being used today.

## ACKNOWLEDGEMENT

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Chethan R Reddy

D Harish Kunal

H J Johan Pereira

Puneeth V

# CONTENTS

# LIST OF FIGURES

**FIGURE** **PAGE NO.**

**FIGURE** **PAGE NO.**

**CHAPTER 4**



**CHAPTER 6**

# LIST OF TABLES

# CHAPTER 1: INTRODUCTION

# CHAPTER 1

# INTRODUCTION

## 1.1 NEED FOR ALTERNATIVE ENERGY

Fossil fuels have been the world's best source for energy production. There are many reasons why the world is so dependent on fossils fuels. It has so far been relatively cost-effective in the short run to burn fossil fuels to generate electricity. Liquid fuels are particularly **easy to transport**. Fossil fuels have been **abundant** and **easily procured**. The basic technology for extracting and burning fossil fuels is already in place. Moreover fossil fuels were **relatively cheap**. Perhaps the simplest reason why the world continues to depend on fossil fuels is that to do anything else requires physical and economical change.

If there are so many reasons to use fossil fuels, why should we even consider alternatives? The most obvious reason of all would be that fossil fuels are, for all practical purposes, **not renewable**. At current rates, the world uses fossil fuels **100,000** times faster than they can form. The demand for them will far outstrip their availability in the near future.

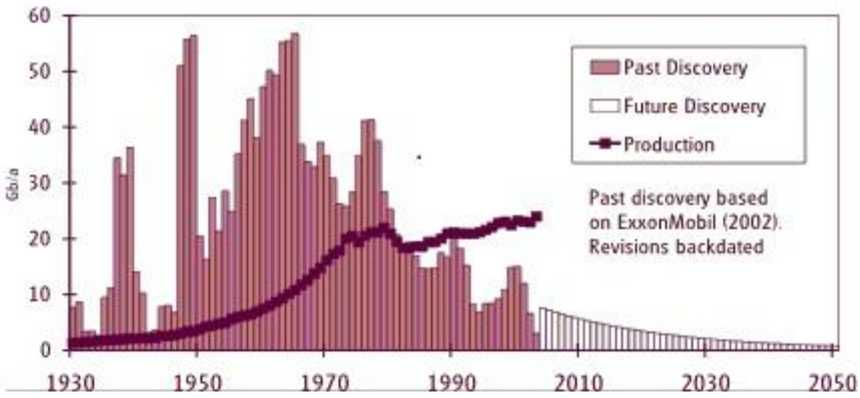


Fig 1.1: Discovery and Production of Oil

The above chart shows the production of oil over the past century. This shows that the in next **50 years** the world demand for fossil fuels will be **so high** that it **cannot be supplied**. According to an article in Wikipedia the fossil fuels would last another **50-60 years** at the current demand. This is an alarming issue at the moment as man is heavily dependent on these fossil fuels. Thus there is a need to search for an alternative to these fossil fuels.

Even though technology has made extracting fossil fuels easier and more cost effective over the years, such is not always the case. As we deplete the more easily accessible oil reserves, new ones must be found and tapped into. This means **locating oil rigs much farther offshore** or in less accessible regions; burrowing deeper and deeper into the earth to reach coal seams or **scraping off ever more layers of precious topsoil**.

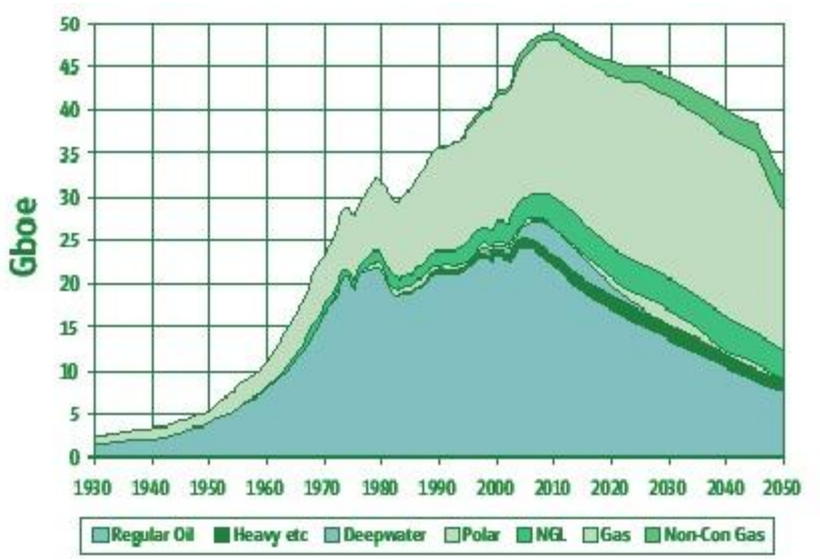


Fig 1.2: Oil and Gas Depletion profiles

The above chart shows the rapid depletion rate of oil reserves. As it can be seen, increasing demand of fossil fuels has lead man to use these resources exhaustibly and leaving nothing for the future generation. The future is not far when all of the oil reserves are finished and there is nothing left to use.

Finally, there are human and environmental costs involved in the extraction of fossil fuels. Drilling for oil, tunnelling into coalmines, transporting volatile liquids and explosive gases-all these can and have led to tragic accidents resulting in the **destruction of acres of ocean, shoreline and land, killing humans as well as flora and fauna**. During extraction fossil fuels take a toll on the atmosphere, as the combustion processes release many pollutants, including sulphur dioxide-a major component in acid rain. When another common emission, carbon dioxide, is released into the atmosphere, it contributes to the **Greenhouse Effect**.

What we need now is change. An energy source which can substitute the ever effective fossil fuels. As with many complex problems, however, the solution to supplying the world's ever-growing hunger for more energy will not be as simple as abandoning all the old methods and beliefs and adopting new ones overnight. Moreover this is a matter of practicality-the substitute processes would take considerable investments of money, education and, most of all, time. The main reason, however, is that there is **no perfect alternative energy source**.

The change can be done by supplementing the energy produced at existing power plants with alternative energy means, and converting some of those plants to operate on different fuels. Learning ways in which we can use less energy now (reduce, reuse, recycle) using advances in technology as well as simple changes in human behaviour to reduce consumption without requiring people to make major compromises or sacrifices.

The solution for the above problems can be resolved by renewable energy. Our beautiful planet gives us the opportunity to make proper us of sunlight, flowing water, strong winds, and hot springs and convert these into energy. These energy sources are abundant and free to use. We must be sure that we convert the energy the right way, without causing other problems that can again hurt our environment. Luckily the many efforts by individuals and companies show that this can be done.

## 1.2 TYPES OF ALTERNATIVE ENERGY AVAILABLE

Alternative energy is a term that refers to any source of usable energy intended to **replace fuel sources** without the undesired consequences of the replaced fuels. In a general sense alternative energy is that which is produced without the undesirable consequences of the burning of fossil fuels, such as high carbon dioxide emissions, which is considered to be the major contributing factor of global warming. Sometimes, this less comprehensive meaning of "alternative energy" excludes nuclear energy.

Renewable energy is generated from natural resources such as sunlight, wind, rain, tides etc. which are renewable i.e., naturally replenished. When comparing the processes for producing energy, there remain several fundamental differences between renewable energy and fossil fuels. The process of producing oil, coal, or natural gas fuel is a difficult and demanding process that requires a great deal of complex equipment, physical and chemical processes. On the other hand, alternative energy can be widely produced with basic equipment and naturally basic processes. Wood, the most renewable and available alternative energy, burns the same amount of carbon it would emit if it degraded naturally.

### Types of alternative energy sources

- Solar energy
- Wind energy
- Hydro-power energy
- Biomass energy
- Geothermal energy

**Hydrogen alternative energy** and **nuclear energy** are also frequently mentioned as the alternative sources of energy; however, they are surrounded by growing disputes on their safety for the environment, so it is still unclear how long those energy sources will remain marked as alternative and environment friendly energy sources. Solar energy directly or indirectly causes all the renewable sources of energy.

## SOLAR ENERGY

Solar energy is abundant renewable energy in nature known to mankind. Solar energy is the energy derived from sun. The major source from the sun is the **electromagnetic radiation**. Many of the non-conventional energy sources are originated by sun. At present solar energy is not being used as a primary source.

Both electromagnetic and thermal energy of the sun can be used. The **electromagnetic energy** is used to **generate electricity** while the **thermal energy** is used for **cooling and heating of buildings**, **heating purposes** (solar cookers and solar water heaters). Technology is present to convert solar energy into electricity. Solar panels (solar cells), which use the **photoelectric effect**, are used to generate electricity.

Many of the multi-storied buildings are equipped with **roof top solar panels** to generate part of the building's electricity requirements. There is an on-going plan to equip future satellites with solar panels and transmitting the energy through radio waves. Also solar energy is used to power vehicles.

## WIND ENERGY

Wind energy is one of the **promising alternatives** to fossil fuels. Though it is not successful in large scale, it does play a vital role. Roughly **10MW** of energy are continuously available from winds.

Wind energy is generated by the motion of air on earth's surface caused due to the **unequal heating** of the land and water by the sun. Wind flows from high pressure to low pressure region. Energy exists in the winds in the form of **kinetic energy**. This kinetic energy is transferred to **rotating mechanical devices** to produce electricity. Windmills are used for this purpose.

Countries like USA, Netherlands and Denmark, where strong and steady wind flow is present, produce majority of the world's wind energy.

## HYDRO-POWER ENERGY

About **75%** of the earth's surface is covered with water. It is in the form of oceans, rivers, lakes etc. Most of this can be utilized for generation of electricity. Even rainwater can be utilized.

The ocean water in the form of **tidal energy** is used to produce electricity. **Dams** are constructed across rivers to generate electricity by directing water onto a **turbine** which generate electricity. The rainwater has lot of potential energy in them. This energy of rain water is utilized to drive **hydraulic turbines**, and in turn to run electric generators.

Hydro-electric power plants contribute a lot to power generation. Most of the **world's electricity** is generated hydro-electric power plants. Research is going on to power automobiles with water.

## BIOMASS ENERGY

All organic matter contains some energy in them. Biomass is the organic matter produced by the photosynthesis process in nature. The main source of energy is again from **solar radiation**. Biomass is generated both on land and water.

Biomass refers to all plant life (agricultural products, trees, grass, algae, etc.) which undergo photosynthesis utilizing solar energy. These biomass products can be used to generate electricity by processes like pyrolysis, liquefaction, gasification, anaerobic digestion or fermentation to produce biogas.

In India biogas is popular by the name **Gobar Gas**, produced with the use of cow dung. It is used as a substitute for LPG for cooking. Biogas can be used as a source of light and also for **powering vehicles**.

## GEOTHERMAL ENERGY

Geothermal energy is the **thermal energy** stored in underground deposits as **steam, hot water** and **hot dry rock**. Geothermal is available in large quantities and in continuous form under the earth's crust.

The inner core of earth is **highly radioactive** and as a consequence a natural flow of heat occurs from the core to the surface of the earth, which can be harnessed into useful energy. It is available in two forms, namely, in **subterranean hot water** or **hot dry rock**. The extraction of this energy and subsequent conversion to electrical energy is not cost free and not without certain operating problems.

The geothermal plants are capable of **continuous operation** as it is not subjected to interruptions. Utilization of this energy is being investigated through a number of research and development programs.

## 1.3 VEHICLES POWERED BY ALTERNATIVE ENERGY SOURCES

An alternative fuel vehicle is defined as a vehicle which is **powered by a fuel other than traditional fossil fuel** or petroleum fuels such as **petrol, diesel or CNG**. It is also sometime referred to any technology of powering an engine that does not involve solely petroleum (e.g. electric car, hybrid electric vehicles, solar powered).

The development of cleaner alternative fuels and alternative fuel systems for vehicles has become a high priority for many governments and vehicle manufacturers around the world because of factors like high oil prices and environmental concerns. The current alternative fuel vehicles are powered by batteries, air, bio fuels, solar and many more.

### SOLAR VEHICLE

A solar vehicle is an electric vehicle powered by solar energy obtained from solar panels which are present on the car. Solar panels cannot currently be used to directly supply a car with a suitable amount of power at this time, but they can be used to extend the range of electric vehicles.

Fig 1.3: Nuna solar powered car

**BATTERY ELECTRIC VEHICLE**

Battery electric vehicles or all-electric vehicles are electric vehicles whose main energy is the **chemical energy of batteries**. Battery electric vehicles are **zero emission automobiles** because they do not produce any emissions while being driven. The electrical energy required to power the motors is obtained from a variety of batteries arranged into battery packs. Batteries used in electric vehicles include lead-acid, absorbed glass mat, Ni-Cd, nickel metal hydride, Li-ion and zinc-air batteries.

Fig 1.4: Nissan Leaf battery electric car

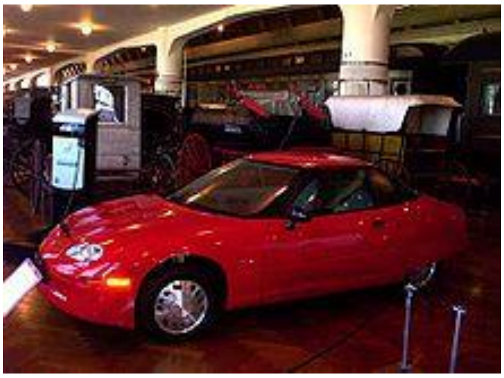

Fig 1.5: General Motors EV1 electric car

## AIR ENGINE

The air engine is an emission-free piston engine that uses compressed air as a source of energy. The expansion of compressed air may be used to drive the pistons in a modified piston engine. The first compressed air car was invented by a French engineer named Guy Nègre, of MDI. The only exhaust is cold air which could also be used to air condition the car. The source for air is a pressurized carbon-fiber tank. Air is delivered to the engine via a rather conventional injection system.

(a)

(b)

(c)


(d)

Fig 1.6: MDI air cars

(a) Multi Flow Air (b) Mini Flow Air (c) Flow Air (d) Air Pod

**BIO FUEL VEHICLE**

Bio fuel vehicles are vehicles which are powered by bio fuels such as bio alcohols like ethanol & methanol, bio diesel like fatty acid methyl ester, vegetable oils and biogas. Sometimes bio fuels are mixed with petroleum to power the vehicles. The vehicle is fitted with a carburettor with adjustable jetting which allows the use of gasoline or ethanol, or a combination of both.

Fig 1.7: Ford Taurus capable of running with either ethanol (E85) or methanol (M85) blended with gasoline.


Fig 1.8: Bus running on soybean Biodiesel

## HYDROGEN FUEL VEHICLE

A hydrogen fuel vehicle is a vehicle which uses hydrogen as its primary source of power for operation. These vehicles generally use the hydrogen in one of two methods: combustion or fuel-cell conversion. In combustion, the hydrogen is burned in engines in fundamentally the same method as traditional gasoline cars. In fuel-cell conversion, the hydrogen is turned into electricity through fuel cells which then powers electric motors. With either method, the only by-product from the spent hydrogen is water.

Fig 1.9: Honda FCX Clarity is a hydrogen fuel cell automobile


Fig 1.10: General Motors Sequel, a hydrogen fuel cell-powered vehicle

## HYBRID FUEL VEHICLES

A hybrid fuel vehicle is a vehicle which uses multiple propulsion systems to provide motive power. The most common type of hybrid vehicle is the gasoline-electric hybrid vehicles, which use gasoline (petrol) and electric batteries for the energy used to power internal-combustion engines and electric motors respectively. These motors are usually relatively small but they can provide a normal driving experience when used in combination during acceleration and other manoeuvres that require greater power.

Fig 1.11: Ford Model T – First hybrid vehicle

Fig 1.12: The Toyota Prius Hybrid

Fig 1.13: The Chevrolet Volt Hybrid

# CHAPTER 2: BOUNDARY LAYER TURBINE

# CHAPTER 2

# BOUNDARY LAYER TURBINE

## 2.1 BOUNDARY LAYER

Boundary layer is a part of fluid dynamics which deals with the flow of fluid over a flat surface. In fluid mechanics, a boundary layer is that layer of fluid in the **immediate vicinity** of a bounding surface where **effects of viscosity** of the fluid are considered in detail.

Boundary layer was first defined by **Ludwig Prandtl** in a paper presented on **August 12, 1904** at the third **International Congress of Mathematicians** in **Heidelberg, Germany**. He theorized that an effect of friction was to cause the fluid immediately adjacent to the surface to stick to the surface and that the **frictional effects** were experienced only in the boundary layer. Outside the boundary layer the flow was inviscid flow.

Consider a fluid flow over a flat plate with velocity $u_\infty$ parallel to the plate. The fluid moving along the x-direction that is in contact with the plate has no velocity. The component of velocity retards along the x-direction. Hence at the plate surface at y=0 velocity u becomes zero. This retardation effect reduces considerably on the fluid moving at a sufficiently higher level (along y-direction). At one point the retardation effect is completely negligible and the velocity u=0.99 $u_\infty$ .the locus of such points is known as **velocity boundary layer**.

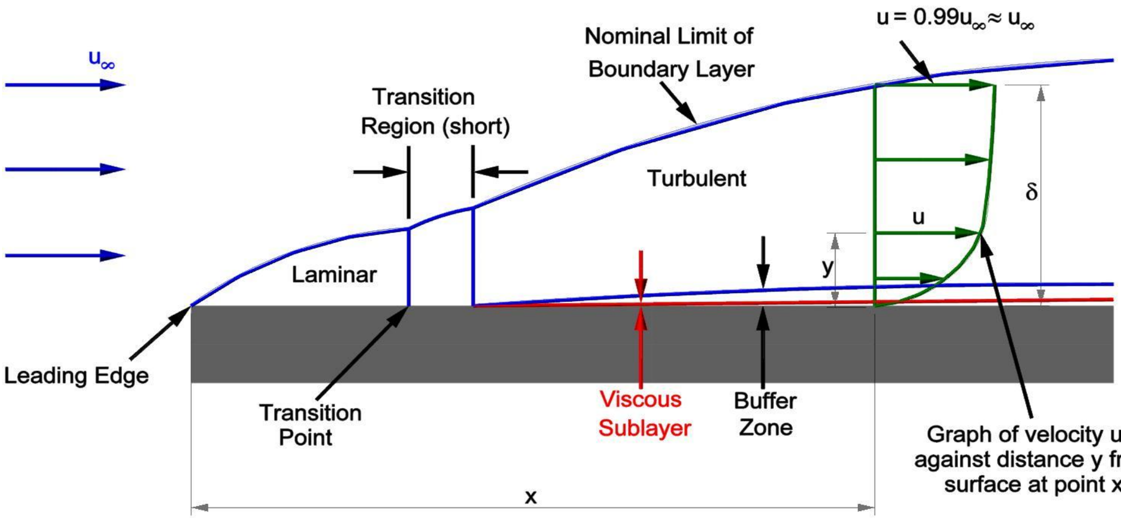


Fig 2.1: Velocity Boundary Layer Profile

The flow over the plate results in separation of flow field into two distinct regions.

- **Boundary layer region**

  In this region the velocity gradients and shear stress are large due to the rapid variation of the axial velocity component with the distance y from the plate.

- **Potential flow region**

  In this region the velocity gradient and shear stress are negligible. This region is the region outside the boundary layer.

Initially, the boundary layer development is **laminar**, where the fluids are in the form of layers but at some critical distance from the leading edge of the plate, small disturbances in the flow begin to become amplified and a transition process takes place until the flow becomes completely **turbulent**.

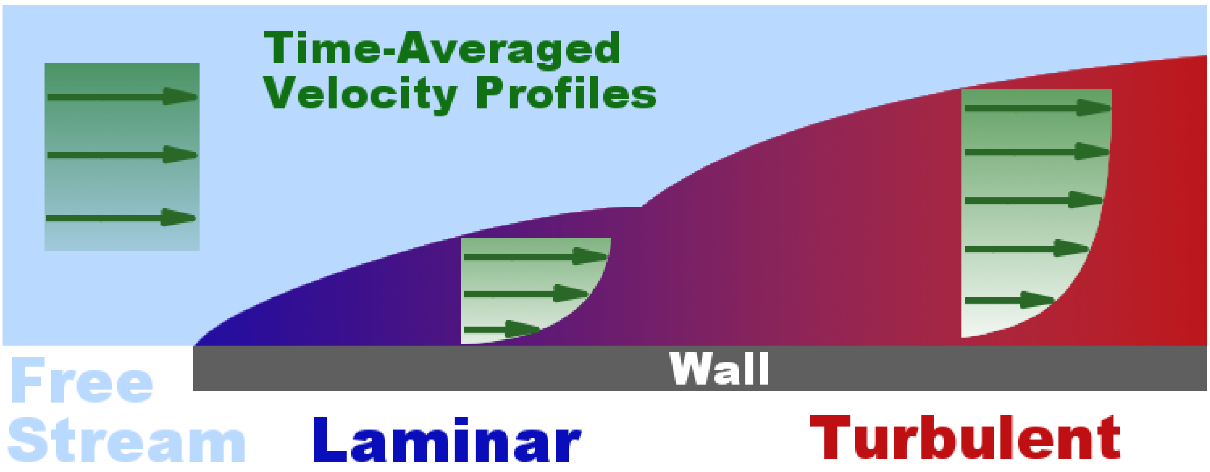


Fig 2.2: Different Regions in Boundary Layer

The flow characteristics are governed by **Reynolds's number**. It is expressed as

$$\mathbf{Re} = \frac{\mathbf{u_{\infty}\ x}}{\boldsymbol{\nu}} \qquad 1.1$$

For flow along a flat plate, the critical **Reynolds number** at which the transition from laminar to turbulent flow takes place is approximately $\mathbf{5\times10^{5}}$. The value depends on the **surface roughness** and the **turbulence level** of free stream.

In the turbulent region there is a very thin layer called **viscous sub-layer** in which the viscous flow character is retained by the flow. In the **buffer layer**, the region adjacent to viscous sub-layer, the mean axial velocity increases rapidly with the distance from the wall.

## 2.2 HISTORY OF BOUNDARY LAYER TURBINE

Boundary layer turbine is a **bladeless centripetal flow** turbine. As in a conventional turbine, where a fluid is impinging on the blades, the boundary layer turbine uses the boundary layer effect for its functioning. Hence it is called bladeless turbine. Boundary layer turbine is also known as **Tesla turbine** (after Nikola Tesla), cohesion-type turbine, and Prandtl layer turbine (after Ludwig Prandtl).

**Nikola Tesla**, born 10$^{th}$ July 1856, can be called the **pioneer of the boundary layer turbine**. Most people know Tesla as the **Father of Alternating Current** but Tesla was also a prodigious inventor who applied his genius to various practical problems. Tesla took the basic concept of a turbine, first patented in Europe in 1832, and made several improvements. He refined the idea over the span of almost a decade and actually received three patents related to the machine. In **1913** Tesla patented his unique turbine which he described as his most important invention.

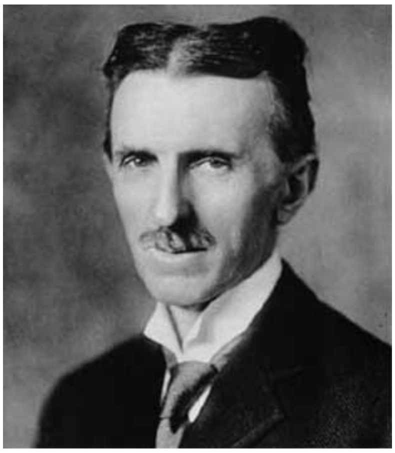

Fig 2.3: Nikola Tesla

The turbine has a series of **closely packed parallel** and **smooth discs** attached to a shaft and arranged within a sealed chamber. When a fluid is allowed to enter the chamber and pass between the discs, the discs turn, which in turn rotates the shaft. This rotary motion can be used in a variety of ways, from powering pumps, blowers and compressors to running cars and airplanes. In fact, Tesla claimed that the turbine was the most efficient and the most simply designed rotary engine ever designed.

Tesla constructed and used the turbines for generation mostly. The first, built in 1906, featured eight disks**, 15.2 cm** in diameter. The machine weighed less than **4.5 kg** and developed **30 hp.** The rotor attained high speeds of **35,000 rpm** and the metal disks stretched considerably, hampering efficiency.

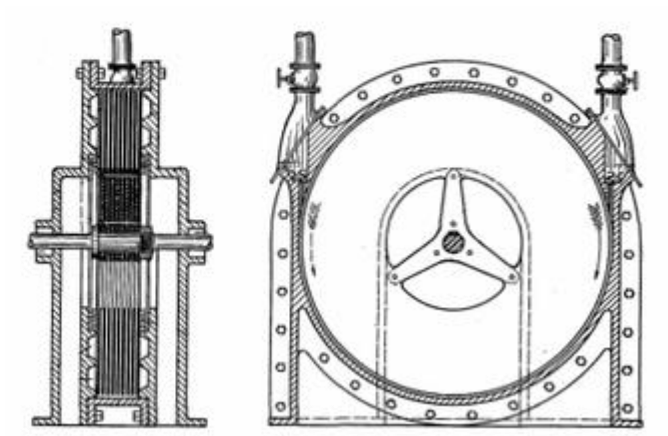

Fig 2.4: Tesla's Design of a Boundary Layer Turbine

In 1910, **Juilus C. Czito**, the son of Tesla's long-time machinist and Tesla built a larger model with disks **30.5 cm** in diameter. It rotated at **10,000 rpm** and developed **100 hp.** Then, in 1911, the pair built a model with disks **24.8 cm** in diameter. This reduced the speed to **9,000 rpm** but increased the power output to **110 hp**.

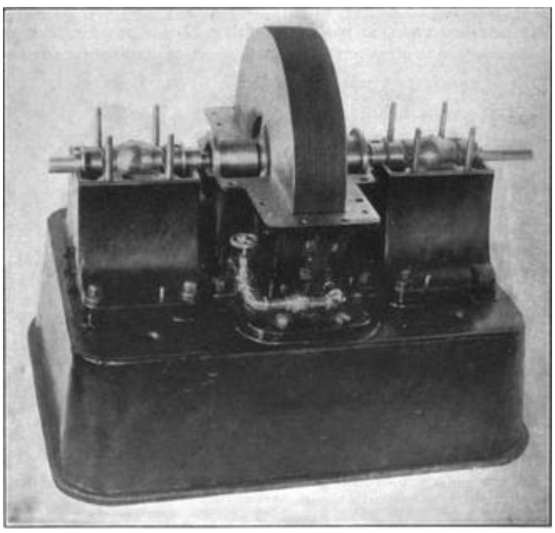

Fig 2.5: Tesla's Turbine with top off

Tesla built a double unit turbine which was larger and each turbine had a rotor bearing disks **45.7 cm** in diameter. The two turbines were placed in a line on a single base. During the test, Tesla was able to achieve **9,000 rpm** and generate **200 hp**.

In Tesla's final attempt to commercialize his invention, he persuaded the Allis-Chalmers Manufacturing Company in Milwaukee to build three turbines. Two had **20 disks** of **45.7 cm** in diameter and developed speeds of **12,000 and 10,000 rpm** respectively. The third had **15 disks 1.5 m** in diameter and was designed to operate at **3,600 rpm,** generating **675 hp**.

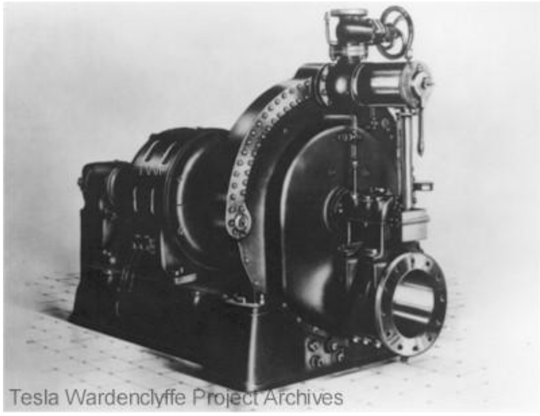


Fig 2.6: The third turbine built by Allis-Chalmers Manufacturing Company

Tesla tested his double unit turbine in **New York Edison Company**. Some engineers present at the test, loyal to Edison, claimed that the turbine was a failure based on a misunderstanding of how to measure torque in the new machine. This bad press, combined with the fact that the major electric companies had already invested heavily in bladed turbines, made it difficult for Tesla to attract investors.

Also due to the **lack of material development** during Tesla’s period, he could not use better materials for the discs to sustain the yielding and distortion of the discs which were one of the reasons for the failure of his turbine.

## 2.3 PARTS OF A BOUNDARY LAYER TURBINE

The Boundary layer turbine is very simple and easy to construct as compared to the conventional piston engine or steam engine. The fundamental design of the machine is the same, regardless of its configuration. The turbine consists of two basic parts, **the rotor** and **the stator**.

### ROTOR

The rotor is the prime mover of the turbine. The rotor assembly consists of multiple discs which are keyed to the shaft. The size and number of the disks can vary based on factors related to a particular application. The rotor assembly consists of the **discs**, **shaft**, **key**, **washers** and a **threaded nut**.

Each disc is made with openings surrounding the shaft. These openings act as exhaust ports through which the fluid exits. To make sure the fluid can pass freely between the discs, metal washers are used as dividers. Again, the thickness of a washer is not rigidly set, although the intervening spaces typically don't exceed 2 to 3 mm.

A threaded nut holds the discs in position on the shaft, the final piece of the rotor assembly. Because the discs are keyed to the shaft, their rotation is transferred to the shaft.

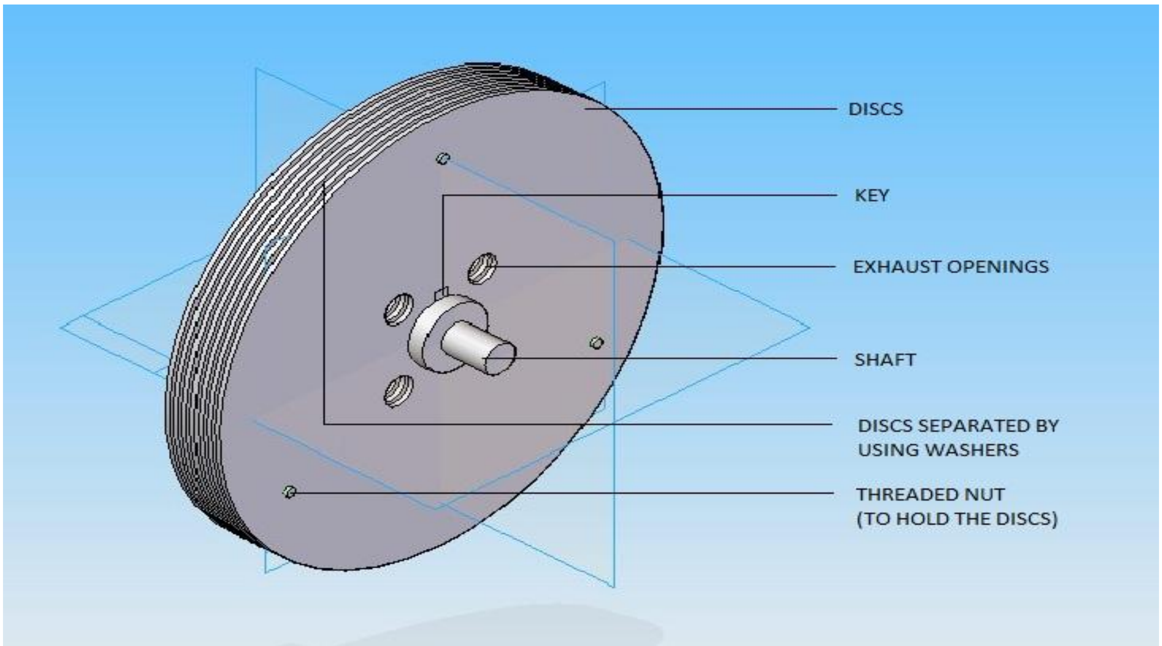


Fig 2.7: Rotor Assembly

## STATOR

The rotor assembly is housed within a cylindrical stator, or the stationary part of the turbine. The stator assembly consists of a **housing**, **external cover**, **inlet nozzle**, **dispenser** and **bearings**.

To accommodate the rotor, the diameter of the cylinder's interior chamber must be slightly larger than the rotor disks themselves. Each end of the stator contains a bearing for the shaft. The stator also contains one or two inlets, into which nozzles are inserted. Tesla's original design called for two inlets, which allowed the turbine to run either clockwise or counter-clockwise. The housing also contains a dispenser which allows the inlet fluid to pass through the dividers.

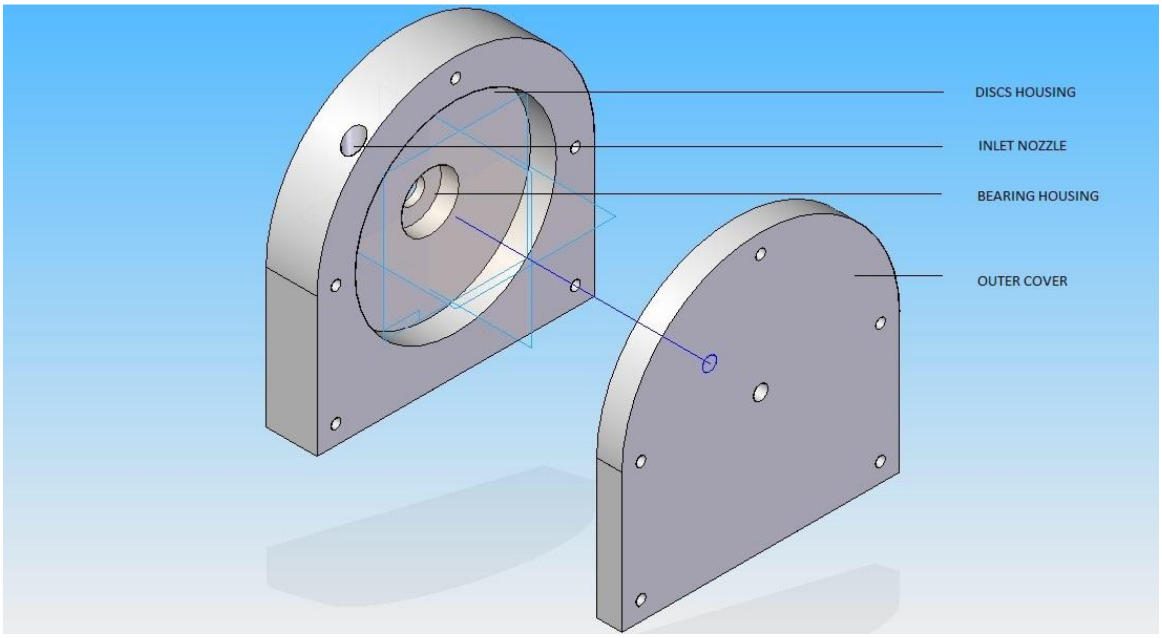


Fig 2.8: Stator Assembly

## 2.4 WORKING OF A BOUNDARY LAYER TURBINE

As said earlier the turbine runs when a **high-pressure fluid** enters the nozzles at the stator inlets. The fluid passes between the rotor disks and causes the rotor to spin. Eventually, the fluid exits through the exhaust ports in the centre of the turbine. The turbine runs at almost **90%** of the velocity of the inlet fluid.

But one may wonder how the energy of a fluid can cause a metal disk to spin which is perfectly smooth and has **no blades, vanes or buckets** to **catch** the fluid. The fluid should simply flow over the discs, leaving the discs motionless. But this is not what happens. Instead not only does it spin, it spins **rapidly**!

The boundary layer turbine works on two basic properties of a fluid - **Adhesion** and **Viscosity**. Adhesion is the tendency of dissimilar molecules to cling together due to attractive forces. Viscosity is the resistance of a substance to flow. These two properties work together in the boundary layer turbine to transfer energy from the fluid to the rotor or vice versa.

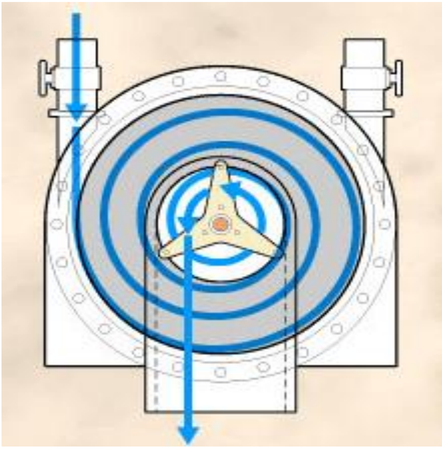

Fig 2.9: Fluid Path in Turbine

The above figure shows the fluid flow within the boundary layer turbine. The fluid enters the turbine at the inlet, sticks to disc surface after which it follows a spiral path and exits through the centre of the disc. The detail working of the turbine is explained in the next section.

The turbine functions in the following steps:

- The fluid enters the turbine through **the inlet nozzle** present in the stator.
- As the fluid moves past each disk, **adhesive forces** cause the fluid molecules just above the metal surface to slow down and stick.
- The molecules just above those at the surface slow down when they **collide** with the molecules sticking to the surface.
- These molecules in turn slow down the flow just above them.
- The farther one moves away from the surface, the fewer the collisions affected by the object surface.
- At the same time, **viscous forces** cause the molecules of the fluid to resist separation.
- This generates a **pulling force** that is transmitted to the disk, causing the disk to **move in the direction of the fluid**.
- Finally the fluid exits through the **centre of the shaft**.

The thin layer of fluid that interacts with the disk surface in this way is called the **boundary layer**, and the interaction of the fluid with the solid surface is called the **boundary layer effect**. As a result of this effect, the propelling fluid follows a rapidly accelerated spiral path along the disk faces until it reaches a suitable exit. Because the fluid moves in natural paths of least resistance, free from the constraints and disruptive forces caused by vanes or blades, it experiences **gradual changes in velocity** and direction. This means more energy is delivered to the turbine.

The working fluid for the boundary layer turbine can be air, water, steam or even fossil fuels. Tesla claimed an efficiency of **over 90%** for his turbines which were far greater than the conventional rotary turbines. The factors which influence the efficiency, speed and power of the turbine are discussed in the next section.

## 2.5 FACTORS AFFECTING THE EFFICIENCY OF THE TURBINE

The factors which influence the efficiency, speed and power generated by the turbine are:

- Disc Geometry
- The Exit Nozzle
- The Inlet Nozzle

**DISC GEOMETRY**

Disc geometry is a simple matter of using the right material with the right **spacing** and the right **number of discs**, **position of spacers**, or sandwiched elements.

- Discs should be made of high strength material like stainless steel of a good grade with as bright a polish as possible. Even materials like FRP'S, Kevlar and carbon fibre can also be used.
- Space the discs anywhere from 0.8mm - 3mm, with the narrow spacing developing higher torque, lower horsepower and vice-versa.
- Spacers should be at the periphery as much as possible and should not block the central exits.

Disc spacing is given by,

$$\mathbf{D} = \boldsymbol{\pi}\sqrt{\frac{\boldsymbol{\gamma}}{\boldsymbol{\omega}}} \qquad 2.1$$

where,

D = disc spacing length (m)

$\gamma$ = kinematic viscosity ($m^2/s$)

$\omega$ = angular velocity (rad/s)

**EXIT NOZZLE**

The exit nozzle is located at the centre of the engine and controls key elements such as **backpressure**, **horsepower**, and **overall efficiency**. Generally speaking, the larger the exhaust opening, the higher the horsepower and torque, but efficiency suffers. And also the exit openings should be as close as possible to the **centre of the discs**.

**THE INLET NOZZLE**

The inlet nozzle is by far the most important element in achieving and fine tuning the efficiency of the turbine. A properly designed nozzle has a complex shape that determines the efficiency of converting gas pressure to shaft horsepower.

The inlet nozzle is responsible for two important functions:

- It converts gas pressure to gas kinetic energy.
- It directs the gas kinetic energy, in parallel streams, into the turbine disc pack (or rotor).

A traditional Convergent-Divergent Nozzle would be suitable as an inlet nozzle as it is efficient in **converting gas pressure, or potential energy, into gas kinetic energy**.

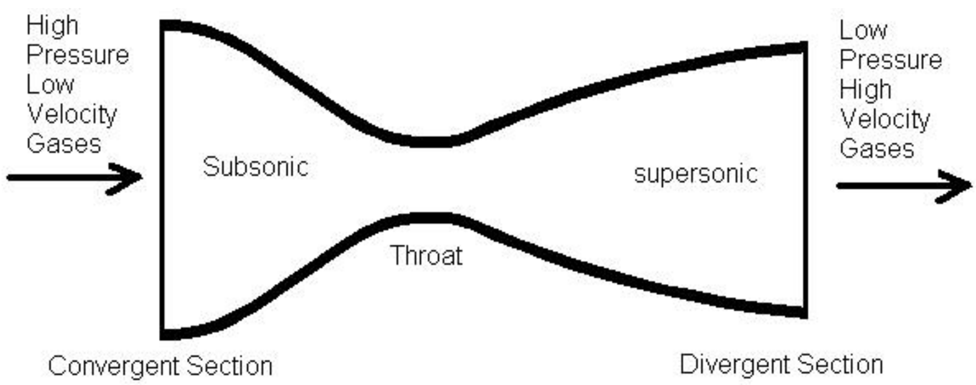


Fig 2.10: A convergent-divergent nozzle

The fluid enters the nozzle and increases the velocity initially. After a certain point the increase in volume causes a rapid expansion of the gas, which in turn increases the velocity enormously and simultaneously cools the gas. After passing through the divergent portion of the nozzle, it is important to straighten out the flow with a parallel section on the end.

**Properties of the inlet nozzle:**

- Should increase the velocity of the fluid.
- The nozzle exit point must match the width of the disc pack.
- Should effectively transmit the fluid into the disc gaps.

The diameter d of the nozzle is based on:

- The working pressure.
- The flow rate for a given turbine horsepower
- Maintaining the highest velocity

The various parameters which influence the various aspects of the turbine are discussed in the table below. These parameters directly influence the speed, power and efficiency of the turbine. These parameters are adjusted accordingly based on the required factor of performance.

Table 2.1: Various parameters which influence the speed, power and efficiency of the turbine

| **PARAMETER** | **SPEED** | **POWER** | **EFFICIENCY** |
|---|---|---|---|
| DISC GEOMETRY | Closely packed | Narrow | Narrow |
| MATERIAL | High Strength,<br>Low Density | High Density | High Strength,<br>Low Density |
| FLOW RATE | High | Low | High |
| INLET NOZZLE | Should cover the disc pack,<br>Should increase fluid velocity | High Discharge | NA |
| EXIT NOZZLE | Big | Big | Small |

## 2.6 ADVANTAGES OF BOUNDARY LAYER TURBINE

- The boundary layer turbine is **simple in design** and **easy to construct** and **manufacture.**
- As the design is simple the **design** and **production costs** of the boundary layer turbine are **lesser** compared to the conventional turbines.
- The boundary layer turbine has **lower part complexity** than conventional machinery as it does not involve complicated parts.
- The size of the boundary layer turbine is **very compact** as it uses minimum space for its operation.
- The boundary layer turbine can **easily made to adapt** to compressed air, steam or any viscous flue gases for its operation.
- This turbine can be **easily reversed** at any point of time hence making it **regenerative**.
- The turbine is a high speed turbine as it can achieve **high speeds**, greater than **30000 rpm**.
- The turbine has high **power to weight ratio**.
- The turbine has **great stability** and **durability** at high speeds.
- The boundary layer turbine has **better efficiency** than conventional machinery.
- The turbine is **quieter** in operation when compared to conventional engines.
- **Easy to maintain** as the damaged parts can be easily replaced with new parts.

## DISADVANTAGES OF BOUNDARY LAYER TURBINE

- The boundary layer turbine is a high speed turbine, but it **produces low rotor torque**.
- When the turbine runs at high speeds, the **discs stretch** considerably which **reduced the efficiency**.
- There is **concern over prolonged** use of the turbine as it would eventually fail cause of the **distortion of discs**.
- The turbine **cannot be easily adapted for mass production**.
- The turbine **cannot be easily replaced** in place of conventional machinery without necessary changes made.
- The boundary layer turbine has not been able to **fully replace** the mass produced I C Engines, steam turbines and rotary turbines as companies have already invested in conventional machinery.

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# CHAPTER 3: DESIGN OF BOUNDARY LAYER TURBINE AS AN AUTOMOTIVE ENGINE

**3.1 INTRODUCTION**

**3.2 PROTOYPES**

**3.3 DESIGN SPECIFICATIONS**

**3.4 FABRICATION OF BOUNDARY LAYER TURBINE**

# CHAPTER 3

# DESIGN OF BOUNDARY LAYER TURBINE AS AN AUTOMOTIVE ENGINE

## 3.1 INTRODUCTION

An **engine** is a machine designed to convert energy into useful mechanical motion. It is the heart of an automobile. The engine basically converts the energy generated by the fuel into useful mechanical work. The purpose of an automobile engine is to convert fuel into motion so that your car can move.

The job of any engine is to convert energy from a **fuel source** into **mechanical energy.** Whether the natural source is air, moving water, coal or petroleum, the input energy is a fluid. All engines used today for vehicles, power generation, compressors etc., need some kind of energy to run. This energy can be renewable or non-renewable sources of energy.

At the beginning of the 20th century, two types of engines were common, **rotary engines** and **reciprocating engines**. The rotary engines were the bladed turbines which were driven by either moving water or steam generated from heated water. Reciprocating engines were the piston engines which were driven by gases produced during the combustion of gasoline. Both types of engines were complicated machines that were difficult and time-consuming to build.

The bladed turbines mainly consisted of **Impulse Turbines** and **Reaction Turbines**. Impulse turbines included Pelton Wheel, Kaplan Turbine, Axial Flow Compressors etc. Reaction turbines included Francis Turbine and most Steam Turbines.

The piston engines were of two types **Internal combustion engines** and **External combustion engines**. Currently it is the easiest way to create motion from gasoline by burning the gasoline.

## 3.2 PROTOTYPES

For a successful project one has to have the theoretical knowledge as well as practical experience of the concept. The research and literature survey helps us in gaining theoretical knowledge whereas prototypes give us practical experience. Prototypes also help us in improvising our designs. So we did build few prototypes.

The three prototypes we did were:-

- Prototype I: Modified 4-stroke engine
- Prototype II: Boundary layer turbine made of compact disc
- Prototype III: Boundary layer turbine made of SS-304

These prototypes gave us practical hands on experience on the necessary concepts and helped us make progress step by step. To know more about the subject of using alternative energy as a fuel source we had made running prototypes. To understand the concept of boundary layer turbine we had built two turbines which gave satisfactory results.

These prototypes are discussed individually in detail in the next section.

## PROTOTYPE I: MODIFIED 4-STROKE ENGINE

This was our first prototype. It was a 4-stroke **Hero Honda Splendor** engine. A lot of changes had to be made to the engine to make it adaptable for compressed air. We used high pressure compressed air of about **300 bar** to run the engine.

Fig 3.1: Prototype I – Modified 4-stroke engine

The changes we made were:-

- Changed the **sprocket and timing gear**.
- Made it a **2-stroke engine**.
- Loosened the **cam springs on rocker arm**.
- **Welded Mild Steel rod** to add load as well as **crank start** the engine.

Fig 3.2: 4-stroke engine with modified timing gear

Fig 3.3: Welded Mild Steel rod

This engine ran successfully at pressure over **200 bar** and gave maximum performance at **300 bar**. The torque produced was very low compared to the input pressure. So the efficiency we achieved was about **12%** only. Also there was undesirable **cooling effect** and **icing** of the engine due to the rapid pressure drop inside the cylinder.

Table 3.1: Cost Analysis of Prototype I

| **PRODUCT** | **QUANTITY** | **COST** |
|---|---|---|
| Engine | 1 | 3500 |
| Sprocket | 2 | 150 |
| Chain | 1 | 150 |
| Iron rods | 2 | 300 |
| Mild Steel | 1 kg | 100 |
| Fabrication | NA | 1000 |
| | **TOTAL** | **5200** |

## PROTOTYPE II: BOUNDARY LAYER TURBINE MADE OF COMPACT DISCS

To overcome the ill effects of piston-cylinder engines we shifted our interest to rotary engines because they had **fewer moving parts** compared to the piston-cylinder engines. As the boundary layer turbine was simple and also had many advantages compared to other conventional turbines, we started researching more about these turbines. So we built a prototype made of hard disc platters.

This prototype was a very basic design of the turbine. The turbine had **8 compact discs**. This turbine rotated at about **15000 rpm** at **6 bar** pressure.


Fig 3.4: Tesla CD turbine

Though it ran at high speed it produced a relatively low torque to use it as an automotive engine. Also the discs could not sustain high pressure air inlet and due to high distortion the discs failed. So this turbine could not be used in further experiments.

Table 3.2: Cost analysis of Prototype II

| PRODUCT | QUANTITY | COST |
|---|---|---|
| Compact Discs | 8 | NA |
| Magnets | 2 | 50 |
| Pin | 6 | 100 |
| Fabrication | NA | 300 |
| | **TOTAL** | **450** |

**PROTOTYPE III: BOUNDARY LAYER TURBINE MADE OF SS-304**

As our previous design failed due to a few factors we built a new turbine by improving the factor due to which the previous prototype failed. We made the turbine discs out of stainless steel 304 grade (SS-304) as this has a better yield strength. Also SS-304 has more weight density as compared to compact discs which is made of acrylic fibre.

This prototype consisted of 4 discs in which each disc was of 150 mm diameter and 3 mm thickness. The discs were separated by central washers of 3mm thickness.

Fig 3.5: Rotor assembly

Fig 3.6: Outer cover

Initially this turbine was tested with water. When given high pressure air as inlet, this turbine ran at an initial pressure of 100 bar. It ran at 5000-6000 rpm at a pressure range of 130-150 bar.

Table 3.3: Cost analysis of Prototype III

| PRODUCT | QUANTITY | COST |
|---|---|---|
| Mild steel | 2.5 kg | 225 |
| Stainless Steel 304 grade | 5 kg | 1250 |
| Fabrication (SS-304) | NA | 2500 |
| Fabrication (Mild Steel) | NA | 1000 |
| Rubber gasket | 1 | 150 |
| Bearings | 2 | 500 |
| | **TOTAL** | **5625** |

Even though this turbine ran at low speed it generated a good amount of torque and power. It could also sustain the high pressure and not yield. But due to air leaks from the outer cover and also due to offset of bearings the efficiency of the turbine was largely affected.

## 3.3 DESIGN SPECIFICATIONS

As our previous designs failed to provide the desired results, we made our final design with extreme care and perfection. We made sure that there were minimal faults in the design. With the help and consultation of the fabricators we were able to make this turbine as a powerful unit.

The design is based on Tesla's patent design but with a lot of changes made on our own. These changes were made according to our specifications and expectations. Let us look into the design aspects in detail of every part.

**KEY**

**Purpose**

The key connects the discs to the shaft.

**Dimensions**

18.4 mm x 4 mm x 4.2 mm

**Material**

SS-304

**Quantity**

1 key

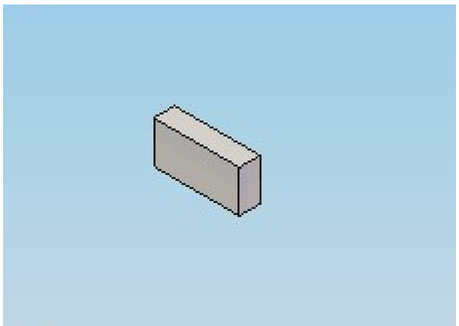


Fig 3.7: Key

**DISC**

**Purpose**

This is the prime mover. It converts the fluid energy into useful mechanical energy.

**Dimension**

150 mm diameter

1.6 mm thickness

**Material**

SS-304

**Quantity**

7 discs

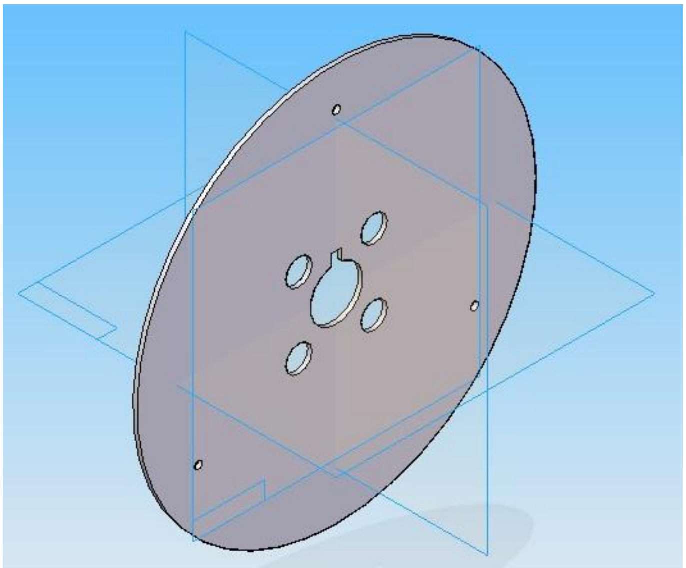


Fig 3.8: Disc

**SHAFT**

**Purpose**

The shaft houses the discs and holds the discs with the help of the key. It is made in two parts.

**Dimensions**

20 mm in diameter

22 mm diameter (collar)

**Material**

SS-304

**Quantity**

1 shaft (made in two parts)

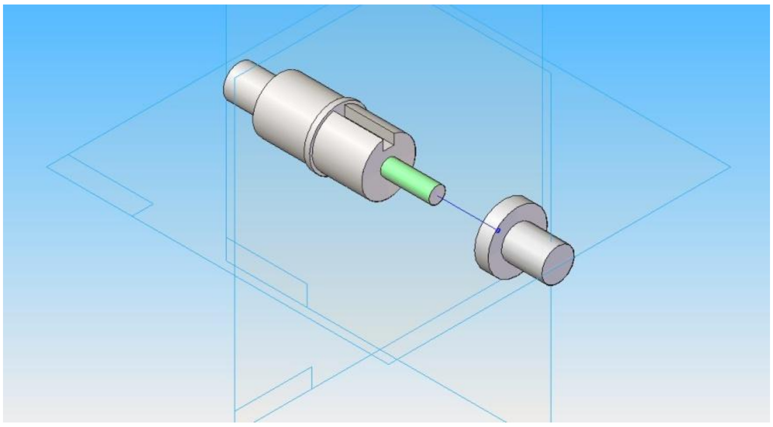


Fig 3.9: Shaft

## SPACER SHAFT

**Purpose**

The spacer shafts are used to hold the peripheral washers. It also holds the discs intact with the help of the lock nut.

**Dimensions**

3 mm diameter

19.5 mm length

**Material**

SS-304

**Quantity**

3 spacer shafts placed 120$^{\circ}$ apart.

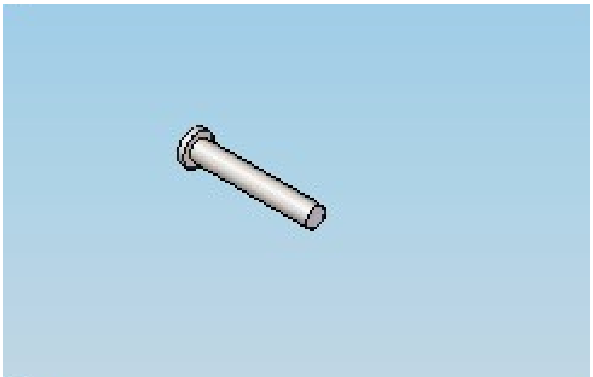


Fig 3.10: Spacer Shaft

**PERIPHERAL SPACERS**

**Purpose**

The peripheral spacers are used to space the discs. The spacers are placed on the periphery because they cannot be placed at the centre as the fluid exits through the centre.

**Dimension**

3mm diameter

1.2 mm thickness

**Material**

SS-304

**Quantity**

18 spacers

6 spacers on each spacer shaft

The washers are of 6 mm diameter. The washers are made of SS-304.

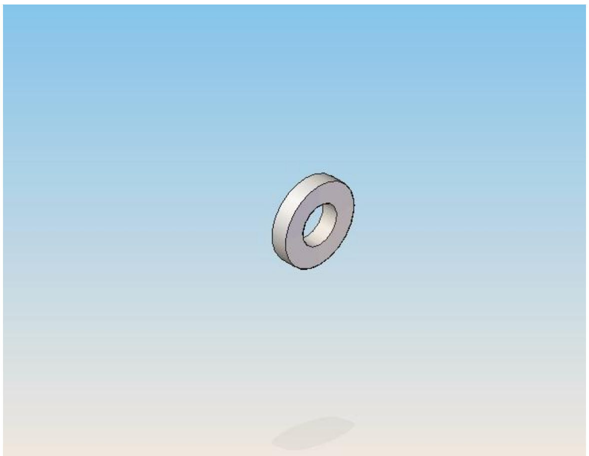


Fig 3.11: Peripheral Washers

**STATOR HOUSING**

**Purpose**

The stator housing is used to house the rotor assembly. It is also used to house the bearing. The inlet nozzle is also placed into the stator housing.

**Dimensions**

220 mm x 220 mm x 40.4 mm

Arch diameter 220 mm

**Material**

Acrylic

**Quantity**

1 stator housing

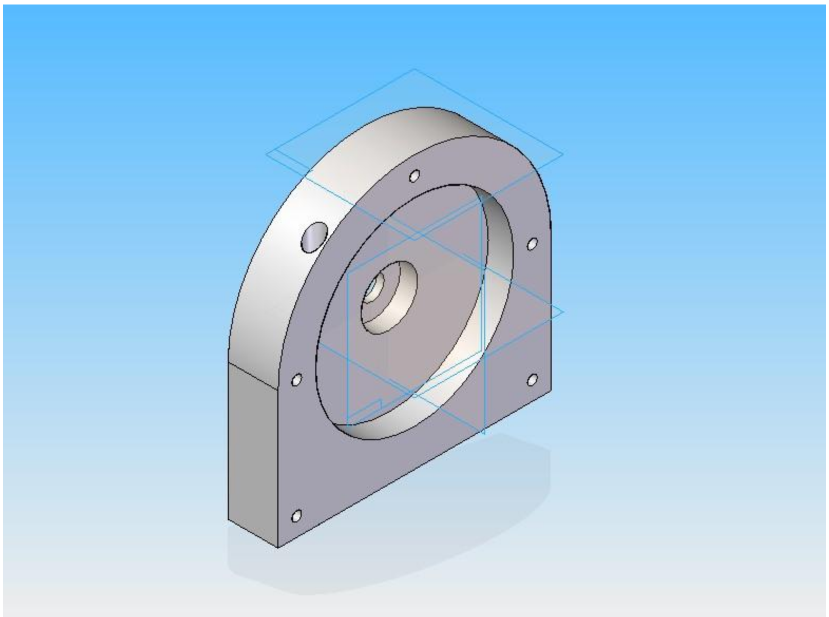


Fig 3.12: Stator Housing

## EXTERNAL COVER

### Purpose

The external cover is used to seal the rotor assembly and prevent any air leaks. It also provides path for easy flow of air through the exhaust holes.

### Dimensions

220 mm x 220 mm x 20 mm

Arch diameter 220 mm

### Material

Acrylic

### Quantity

1 external cover

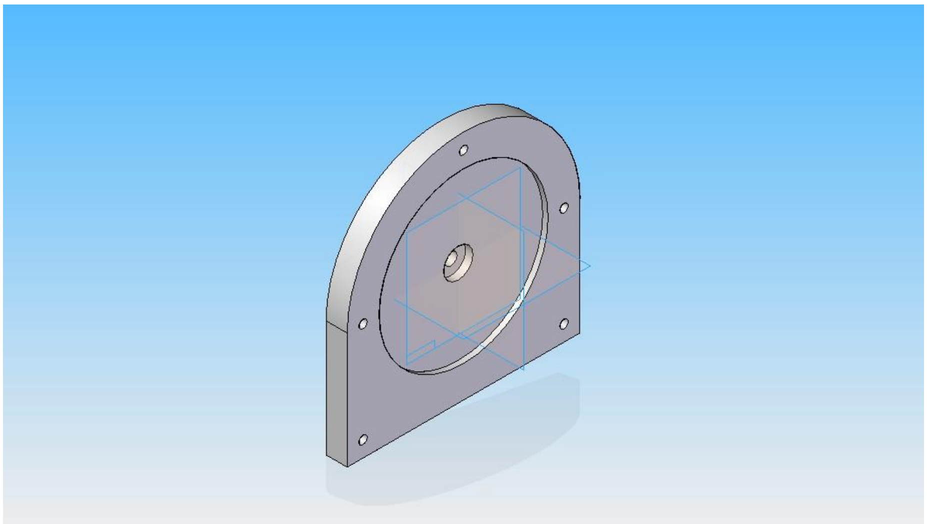
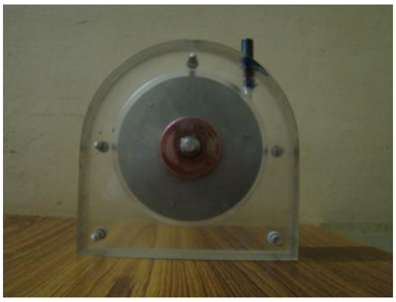


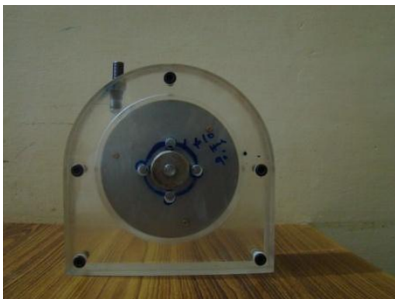
Fig 3.13: External cover

## 3.4 FABRICATION OF BOUNDARY LAYER TURBINE

After completion of our design we had to fabricate our design. We fabricated our turbine in Ashwini Enterprises and Sai Kunal Industries, Bommasandra Industrial Area, Bangalore. The fabrication was completed within 25 days.



(a)



(b)

(c)

(d)

(e)

Fig 3.14: Different views of the turbine

(a) Front view (b) Back view (c) Exploded view (d) Rotor front view (e) Rotor side view

Majority of the stainless steel fabrication was done on a lathe whereas the acrylic fabrication was done on a milling machine. Our design was improvised with feedback from the fabricators and their constant guidance on the changes required to our design.

Table 3.4: Cost Analysis of turbine as automotive engine

| PRODUCT | QUANTITY | COST |
|---|---|---|
| STAINLESS STEEL- 304 | 5 kg | 1250 |
| MILD STEEL | 500 gm | 50 |
| ACRYLIC | 3 kg | 1800 |
| FABRICATION | NA | 7000 |
| SPROCKET | 2 | 150 |
| CHAIN | 1 | 120 |
| DYNAMO | 1 | 510 |
| MULTIMETER | 1 | 150 |
| SERVICING | NA | 100 |
| | **TOTAL** | **11130** |

# CHAPTER 4: TESTING OF BOUNDARY LAYER TURBINE AS AN AUTOMOTIVE ENGINE

**4.1 EXPERIMENTAL SETUP**

**4.2 TESTING OF BOUNDARY LAYER TURBINE WITH CYCLE**

# CHAPTER 4

# TESTING OF BOUNDARY LAYER TURBINE AS AN AUTOMOTIVE ENGINE

## 4.1 EXPERIMENTAL SETUP

Our experimental setup consisted of a compressor which ran the engine. The engine was connected to a cycle by means of a chain drive. A dynamo was fixed to the cycle wheel. This dynamo was used to measure the power output through a multimeter. The system of dynamo and multimeter together functioned as a dynamometer.

The experiment setup consisted of many individual components. The experiment consisted of a compressor, engine, cycle, dynamo nozzle and a multimeter. We have described in detail the various components of our experiment below.

Fig 4.1: Experimental Setup

**COMPRESSOR**

The compressor used was an MAC Micromax Indian made compressor. The compressor has a tank capacity of 160 litres. The compressor has a discharge of 7 cubic feet per minute. The compressor has a working pressure of 4 bar. The compressor powers the engine by providing high pressure compressed air.

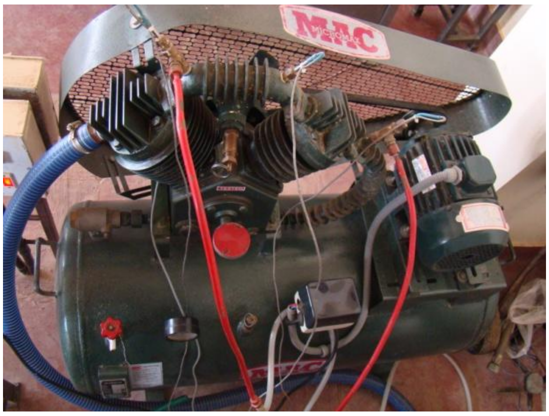



Fig 4.2: Compressor

**ENGINE**

The compressor is connected to the nozzle of the engine directly. The engine receives the input from the compressor and uses it to operate. A sprocket is housed on the engine shaft. The engine shaft output is connected to the cycle by chain drive.

Fig 4.3: Engine connected to compressor

**SPROCKETS**

Sprockets were used to connect the engine shaft to the to the cycle wheel. The sprockets used were brass sprockets. One sprocket with 18 teeth was used on the engine shaft. The other sprocket of 22 teeth was used on the cycle wheel. These sprockets were connected by a chain drive.

Fig 4.4: Chain drive with sprockets

**TACHOMETER**

The tachometer was used to check the speed of the turbine as well as the cycle wheel. The tachometer used was a non contact tachometer. The tachometer shows the speed directly on the digital display.

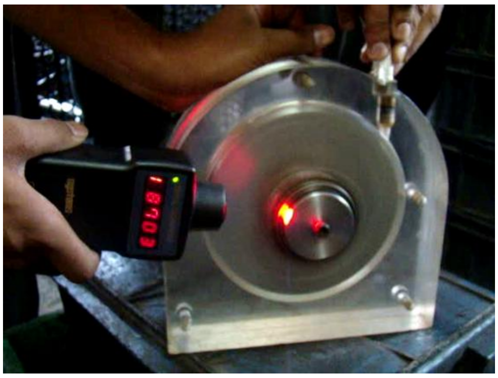


Fig 4.5: Tachometer

**CYCLE**

The cycle used was a Hero Hawk cycle. The sprocket on the cycle was changed in order to reduce the speed and increase torque.

Fig 4.6: Hero Hawk cycle

**DYNAMOMETER**

We used a custom made dynamometer which consisted of a dynamo which in turn was connected to a multimeter. The dynamo was also connected to a light bulb. The light bulb was connected to the multimeter.

Fig 4.7: Dynamometer

## 4.2 TESTING OF BOUNDARY LAYER TURBINE WITH CYCLE

The turbine was tested at New Horizon College of Engineering, Bangalore. The engine was tested by connecting the engine to the compressor and running the compressor at an optimum pressure of 58 psi. The compressor was filled to its full capacity and it was later discharged into the engine. But the compressor had continuous input supply.

As there was no access to conventional dynamometer, we made our own dynamometer by connecting a dynamo to a multimeter. The dynamo absorbs the power from the shaft and converts it into electrical energy. The multimeter shows the value of voltage and current through which the power output of the shaft can be calculated by simply multiplying the voltage and current values.

The observation was made and the values were noted down. The data and calculations are given below.

**OBSERVATION**

The subscript $_1$ is used for engine

The subscript $_2$ is used for wheel

**Compressor data**

| | | | |
|---|---|---|---|
| Compressor pressure, | $P$ | = | 58 psi |
| Discharge of compressor, | $Q$ | = | 1 cfm |
| Compressor capacity, | $C$ | = | 160 litres |

**Wheel data**

| | | | |
|---|---|---|---|
| Diameter of wheel, | $d_2$ | = | 100 mm |
| Speed of cycle wheel, | $N_2$ | = | 98 rpm |
| Number of teeth on wheel sprocket, | $Z_2$ | = | 22 |

**Engine data**

| | | | |
|---|---|---|---|
| Diameter of rotor, | $d_1$ | = | 150 mm |
| Mass of rotor, | m | = | 3.6 kg |
| Speed of turbine, | $N_1$ | = | 120 rpm |
| Number of teeth on engine sprocket, | $Z_1$ | = | 18 |
| Diameter of nozzle, | d | = | 6 mm |

**Multimeter data**

| | | | |
|---|---|---|---|
| Current produced, | I | = | 19.65 mA |
| Voltage produced, | V | = | 5.67 V |

## CALCULATIONS

As some readings are not in SI units, it has to be converted into SI units. They can be converted into SI units by multiplying them with the conversion factor.

**Pressure**

1 psi = 6.89 kPa

Therefore,

58 psi = $58 \times 6.89$

**58 psi = 399.899 kPa**

**Discharge**

1 cfm = $4.72 \times 10^{-4}$ $m^3/s$

Therefore,

1 cfm = $1 \times 4.72 \times 10^{-4}$

**1 cfm = $4.72 \times 10^{-4}$ $m^3/s$**

**Compressor tank capacity**

1 litre = $1 \times 10^{-3}$ $m^3$

Therefore,

160 litres = $160 \times 10^{-3}$

**160 litres = 0.16 $m^3$**

**RESULTS**

**Gear ratio**

$$G = \text{Teeth on wheel} \div \text{Teeth on engine}$$

$$G = Z_2 \div Z_1 \qquad 4.1$$

$$G = 22 \div 18$$

$$\mathbf{G = 1:1.22}$$

**Linear velocity of engine**

$$v_1 = (2\pi \times \text{Speed of engine}) \div 60$$

$$v_1 = (2\pi \times N_1) \div 60 \qquad 4.2$$

$$v_1 = (2\pi \times 120) \div 60$$

$$\mathbf{v_1 = 12.57\ m/s}$$

**Linear velocity of wheel**

$$V_2 = (2\pi \times \text{Speed of wheel}) \div 60$$

$$v_2 = (2\pi \times N_2) \div 60 \qquad 4.3$$

$$v_2 = (2\pi \times 98) \div 60$$

$$\mathbf{v_2 = 10.26\ m/s}$$

**Velocity ratio**

VR = Velocity of wheel ÷ Velocity of engine

$$VR = v_2 \div v_1 \quad (4.4)$$

$$VR = 10.26 \div 12.57$$

$$\mathbf{VR = 0.8162}$$

**Power generated on engine**

$OP_1$ = Voltage × Current

$$OP_1 = V \times I \quad (4.5)$$

$$OP_1 = 5.67 \times 19.65 \times 10^{-3}$$

$$\mathbf{OP_1 = 1.114 \times 10^{-4}\ kW}$$

**Torque generated on engine**

Output power is also given by,

$OP_1$ = (2π × Speed of engine× Torque of engine) ÷ 60

$$OP_1 = (2\pi \times N_1 \times T_1) \div 60 \quad (4.6)$$

Therefore,

Torque generated, $T_1 = (OP_1 \times 60) \div (2\pi \times N_1)$

$$T_1 = (1.114 \times 10^{-4} \times 60) \div (2\pi \times 120)$$

$$\mathbf{T_1 = 8.865 \times 10^{-3}\ N\text{-}m}$$

**Torque generated on wheel**

As the speed is reduced to increase torque, the amount of speed reduced is equal to torque increased.

$$N_1 \div N_2 = T_2 \div T_1 \qquad 4.7$$

$$T_2 = (N_1 \div N_2) \times T_1$$

$$T_2 = (120 \div 98) \times 8.865 \times 10^{-3}$$

$$\mathbf{T_2 = 0.011\ N\text{-}m}$$

**Power generated by wheel**

$$OP_2 = (2\pi \times \text{Speed of wheel} \times \text{Torque of wheel}) \div 60$$

$$OP_2 = (2\pi \times N_2 \times T_2) \div 60 \qquad 4.8$$

$$OP_2 = (2\pi \times 98 \times 0.011) \div 60$$

$$\mathbf{OP_2 = 1.129 \times {}^{10\text{-}4}\ kW}$$

**Inlet fluid velocity**

$$v_f = \text{Discharge} \div \text{Area}$$

$$v_f = Q \div A \qquad 4.9$$

$$v_f = 4.72 \times 10^{-4} \div (\pi \times 0.006^2 \div 4)$$

$$\mathbf{v_f = 16.69\ m/s}$$

**Tangential force on discs**

Torque on discs is given by,

$T_1 = \text{Tangential force} \times \text{Radius of disc}$

$$T_1 = F_1 \times r_1 \tag{4.10}$$

Therefore,

$F_1 = T_1 \div r_1$

$F_1 = 8.865 \times 10^{-3} \div 0.075$

$\mathbf{F_1 = 0.1182\ N}$

**Tangential force on wheel**

Torque on wheel is given by,

$T_2 = \text{Tangential force} \times \text{Radius of wheel}$

$$T_2 = F_2 \times r_2 \tag{4.11}$$

Therefore,

$F_2 = T_2 \div r_2$

$F_2 = 0.011 \div 0.2$

$\mathbf{F_2 = 0.055\ N}$

**Density of inlet air**

$\rho$ = Pressure ÷ (Gas constant × Temperature)

$\rho = P \div (R \times T)$ 4.12

$\rho = (400 \times 10^3) \div (287 \times 305)$

$\boldsymbol{\rho}$ = **4.5696 kg/m$^3$**

**Mass flow rate**

$\dot{m}$ = Density × Discharge

$\dot{m} = \rho \times D$ 4.13

$\dot{m} = 4.5696 \times 4.72 \times 10^{-4}$

$\dot{m}$ = **2.157 × 10$^{-3}$ kg/s**

**Kinetic energy of inlet air**

$KE_a$ = ½ × mass flow rate × (Input fluid velocity)$^2$

$KE_a = \frac{1}{2} \times \dot{m} \times v^2$ 4.14

$KE_a = \frac{1}{2} \times 2.157 \times 10^{-3} \times (16.69)^2$

**$KE_a$** = **3 × 10$^{-4}$ kW**

**Efficiency of engine**

$\eta_e$ = Output power of engine ÷ Input power to engine

$\eta_e$ = $OP_1 \div KE_a$ 4.15

$\eta_e$ = $1.114 \times 10^{-4} \div 3 \times 10^{-4}$

$\boldsymbol{\eta_e}$ = **37.13 %**

**Range of engine (w.r.t time)**

Range on full capacity of compressor tank is given by,

t = Tank capacity ÷ Discharge

t = $C \div Q$ 4.16

t = $0.16 \div 4.72 \times 10^{-4}$

**t** = **339 s**

**Range of engine (w.r.t distance)**

Range on full capacity of compressor tank is given by,

D = Linear velocity of wheel × Time

D = $v_2 \times t$ 4.17

D = $10.26 \times 339$

**D** = **3478.14 m**

## 4.3 TESTING OF ENGINE WITH HIGH PRESSURE COMPRESSOR

We tested our turbine in Sai Kunal Industries, Bommasandra Industrial Area.

**Compressor data**

Compressor working pressure = 160 psi

Compressor discharge = $3 \times 10^{-4}$ $m^3/s$

Compressor capacity = 270 litres

Shown below is a graph of speed of the engine v/s time

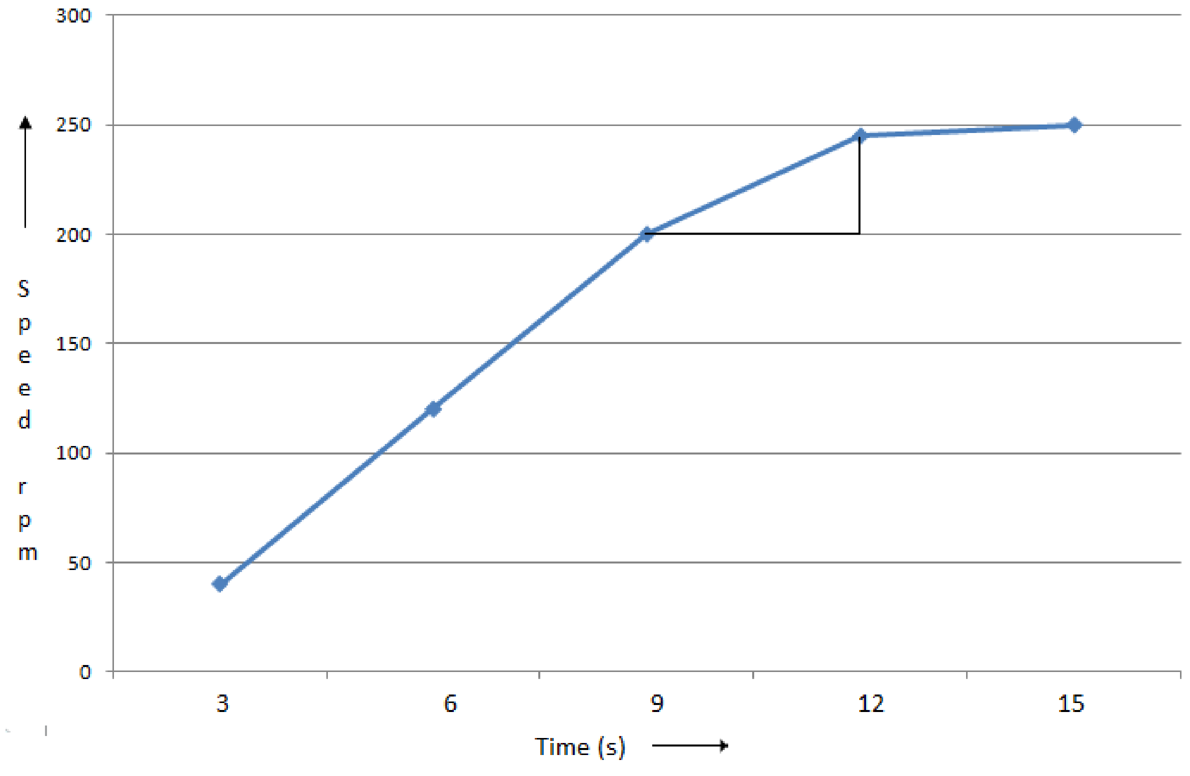



Fig 4.8: Graph of Speed v/s Time

Based on the above graph the average torque can be calculated

**Slope (Angular Acceleration)**

$\Delta = \frac{dy}{dx}$

$\Delta = (245-200) \div \{(12-9) \times 60\}$

$\mathbf{\Delta = 0.25\ rev/s^2}$

**Linear Acceleration**

$\alpha = 0.25 \times 2\pi \times r$

$\boldsymbol{\alpha} = \mathbf{0.1178\ m/s^2}$

**Torque**

$T = \alpha \times W$

$\mathbf{T = 0.7068\ Nm}$

# CHAPTER 5: CONCLUSION

# CHAPTER 5

# CONCLUSION

So far we have seen the objective, advantages, disadvantages and scope of the boundary layer turbine and also seen its use and results as an automotive engine. Let us summarize this report in a nutshell.

The clear conclusion we can draw from chapter 1 is that we must reduce our dependency on fossil fuels and move towards cleaner and greener energy sources. In this project we have taken advantage of the versatility of the boundary layer turbine to run it on compressed air. The efficiency of this turbine is high and even though energy is required to compress air, the overall efficiency is much higher for the boundary layer turbine run by compressed air when compared to the current petrol/diesel run engines. The most important advantage is that the exit air is clean green air which also cools the environment. The turbine is suited for hybrid systems as well, as touched upon in the future scope section.

The efficiency of the turbine as an automotive engine is surely higher than that of IC engines as shown in our results. Even though this engine is a low torque engine, it substitutes with very high speeds when compared to the IC engines. With the hike in fuel prices now-a-days we can say with a degree of confidence that the boundary layer turbine is the engine for the future. This is discussed in fair detail in the future scope section.

Thank You for reading our report.

# CHAPTER 6: FUTURE SCOPE

# CHAPTER 6

# FUTURE SCOPE

As we have seen the boundary layer turbine has a lot of applications ranging from an Air Motor, to completely reversible Vacuum Pump or a Compressor. Let us now examine the scope of the boundary layer turbine as an Automotive Engine.

Using the versatility of this Turbine as an Air Engine, and equip the Vehicle with a series of high pressure reservoirs, thus running the Vehicle with compressed air, with no pollution whatsoever. Such a proposal is in active consideration in France, Mexico and Australia.

Let us examine the efficiency of the boundary layer turbine and compare with conventional bladed Turbines and IC Engines.

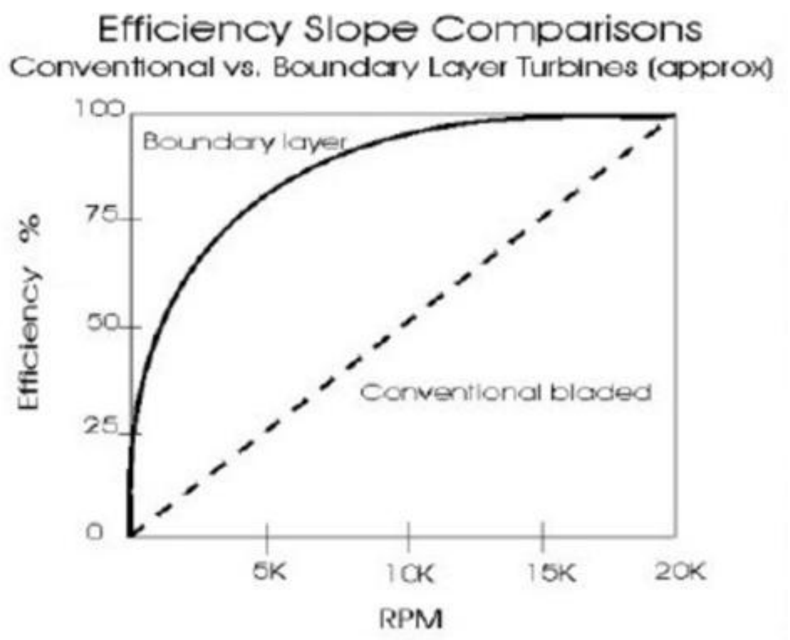



Fig 6.1: Boundary layer turbine efficiency slope

We can see that the efficiency of the boundary layer turbine is higher than the conventional bladed Turbine at every point of the shaft speed. Furthermore we know that the efficiency of an IC Engine in the useful range is never above 25%.

And now let us analyse the Torque and Power of the boundary layer turbine.

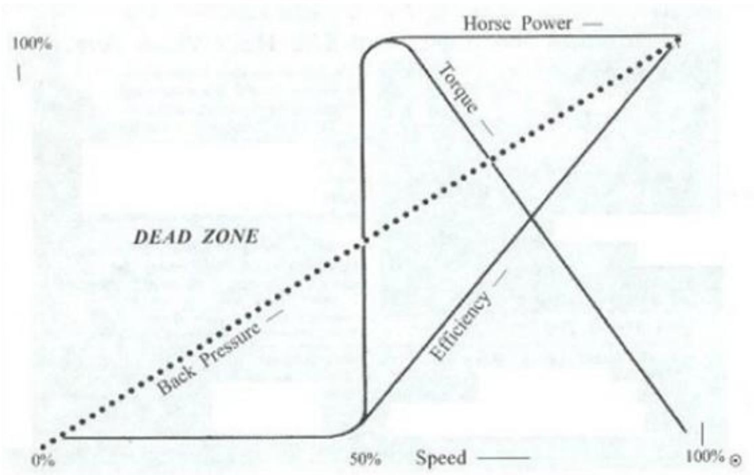



Fig 6.2: Efficiency, Torque & Power slope of boundary layer turbine

The boundary layer turbine has very negligible Torque initially till 50% of the design speed (as seen in the graph), and shoots up to 100% Torque at about 50% of the design speed and gradually reduces with increase in speed.

The conventional bladed Turbine deliver a much low end Torque but rapidly build Torque as they spool up. The IC Engines on the other hand the Torque and Power increase steadily with a much greater low end Torque.

Both the conventional bladed Turbine and IC Engine show an analog response but the boundary layer turbine shows a digital response; therefore it must toggle between idle and maximum loaded power in one quick step.

Today all the Vehicles are moving towards hybrid, electric and alternative sources, and they all exhibit digital characteristics. Here it is important to mention why not this changes earlier? It is because previously it was costlier to build the digital mode engines and a much higher low end torque was preferred. Therefore it is appropriate to say the boundary layer turbine is the Engine of the future.

A useful range and speed can be obtained from high pressure air reservoirs charged to 40 bar, and the vehicle is extremely simple, with no gearbox, fuel tank or engine, and can be of very light construction.

Let us look at the projected line diagram of the boundary layer turbine powered Vehicle run by compressed air.

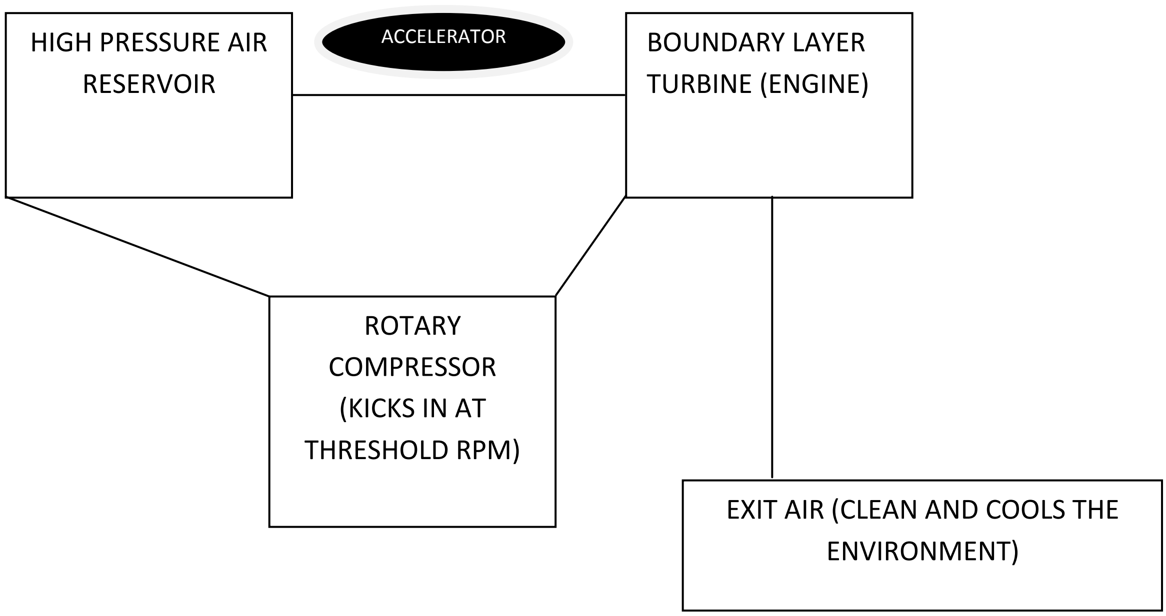



Fig 6.3: Line diagram of the boundary layer turbine powered Vehicle run by compressed air

# CHAPTER 7: BIBLIOGRAPHY

# CHAPTER 7

# BIBLIOGRAPHY

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