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Review Article

Working of an Compressed Air Vehicle by Tadpole Design: A Review

Pokala Saiprasanna Kumar†*, Revu Siva Kumar† , Veerapaneni Suresh Chandra† and Yelle Rahul†

†Department of Mechanical Engineering, Joginpally B.R. Engineering College, Hyderabad, T.S., India

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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 crises. The Compressed Air Vehicle is an eco-friendly vehicle which works on compressed air. An Compressed Air vehicle uses air as a fuel. An Air Powered Vehicle uses the expansion of compressed air to drive the pistons of an engine. An Air Driven Engine is a pneumatic actuator that creates useful work by expanding compressed air. There is no mixing of fuel with air as there is no combustion. Developing a whole vehicle to run on pneumatic systems will prove an outright tedious and without doubt a costly affair, modification of current internal combustion engines to run on compressed air by an tadpole design this paper explores.

Keywords: *Chassis, Compressed air engine, compressed air, compressor*

1. Introduction

One of the major problems most developing countries facing now a days is pollution and the major source of which is automobiles running on the roads. Concerning resource availability there has been a strong warning that petroleum resources may be depleted in the relative near future. Gasoline which has been the main source of fuel for the history of cars, produces carbon monoxide, nitrogen oxides and unburned hydrocarbons which are the main pollutants and are responsible for bad effect of pollution. There comes need to think about alternatives such as Biodiesel and Natural gas, electric cars, hybrid cars, hydrogen fuel cells but these alternative fuels also have some drawbacks. One possible alternative fuel is the compressed air. Fossil fuels (i.e., petroleum, diesel, natural gas and coal) which meet most of the world's energy demand are being depleted rapidly. Also, their combustion products are causing global problems, such as the greenhouse effect, ozone layer depletion, acid rains and pollution which are posing great danger for environment and eventually for the total life on planet. These factors are leading automobile manufactures to develop cars fueled by alternatives energies. Hybrid cars, Fuel cell powered cars, Hydrogen fueled cars will be soon in the market as a result of it. One possible alternative is the air powered car. Air, which is abundantly available and is free from pollution, can be compressed to higher pressure at a very low cost, is one of the prime option since atmospheric pollution can be permanently eradicated. Whereas so far all the attempts made to eliminate the pollution has however to reduce it, but complete eradication is still rigorously pursued. Compressed air utilization in the pneumatic application has been long proven. Air motors, pneumatic actuators and others various such pneumatic equipments are in use. Compressed air was also used in some of vehicle for boosting the initial torque. Turbo charging has become one of the popular techniques to enhance power and improve the efficiencies of the automotive engine that completely runs on compressed air. There are two ongoing projects (in France, by MDI and in S. Korea) that are developing a new type of car that will run only on compressed air. Similar attempt has been made but to modify the existing engine and to test on compressed air. The Compressed Air Powered Vehicle works on the principle of the Compressed Air Technology (CAT).

Principle: Compressed normal air in a cylinder the air would hold some energy within it. This energy can be utilized for useful purposes. When this compressed air expands, the energy is released to do work.

A pneumatic motor (Air motor) or compressed air engine is a type of motor which does mechanical work by expanding compressed air Linear motion can come from either a diaphragm or piston actuator, while rotary motion is supplied by(Adder *et al* 2011) either a vane type air motor, piston air motor, air turbine or gear type motor.

*Corresponding author: **Pokala Saiprasanna Kumar**

2. History

The first air powered vehicles were actually trains. The Mekarski air engine, the Robert Hardie air engine and the Hoadley-Knight pneumatic system were used in the 1800's to power locomotives From 1896 onward Charles B. Hodges invented air powered engines and made a profit selling hundreds(MDI *et al 2012)* of locomotives through the H. K. Porter Company. The inventor of the first air car, however, has been debated for years.

In 1925, an article appeared in the Decatur Review about a man named Louis C. Kiser who converted his gasoline powered car to run on air. Lee Barton Williams in 1926 claimed to have invented the first air car. Williams was from Pittsburg and claimed the car started on gasoline but after 10 mph it switched to compressed air only.

In 1931, the Hope Star of Hope, Arkansas ran an article about Roy J. Meyers of Los Angeles inventing the first air car.

In 1934, Bob Neal north of Hope, Arkansas filed a patent application for a pneumatic engine. Also in 1934, the Netherlands native Johannes Wardenier claimed to have invented the first air car. There is a whole conspiracy theory about how Wardenier was imprisoned, sent to a mental institution and then a concentration camp with his designs stolen.

In the 1970's the Troyan air mobile was said to be the first air car. Inventor Joseph P. Troyan designed the air powered flywheel in a closed system. Also in the 1970's Willard Truitt presented his air car invention. But, because he(mdi *et al* 2013) didn't have the financial means to pursue its development he sold the design to the U. S. Army and NASA in 1982.

In 1974, Russel R. Brown of Texas claimed to have invented the first air car. And, in 1975, Sorgato in Italy invented an experimental air car that used nine 2840 psi air bottles. In 1976 in Vacaville, California, Ray Starbard invented a compressed air truck.

In 1979, Terry Miller invented Air Car One which only cost him $1,500 to build. He patented his car that ran on compressed air. In the 1980's, inventors Claud Mead, Des Hill, Ricardo Perez-Pomar and George Miller said that they had invented an air car

In 2007, Tata Motors introduced the MDI CityCat developed by Guy Nègre as the first commercial air car. As of 2009, two more models of MDI air cars have been showcased.

3. 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 drive train. 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 uni body 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.

There are two types of design which is based on three type:

Delta: One wheel in front, two in back

Tadpole: Two wheels in front, one in back.

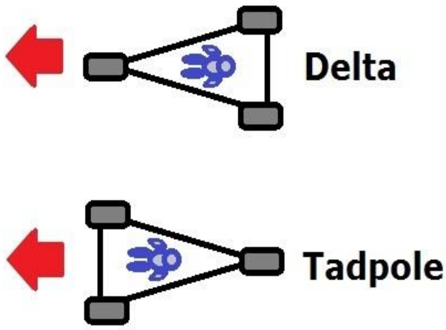

Figure 1: Types of three wheeler

3.1 Why Tadpole on Delta

Dynamic Stability: When a vehicle is said to be dynamically stable it is meant that it reacts safely and predictably under various driving conditions.When designing a chassis, we can choose how the car will react when turning too fast. One of two things will *always* happen: either the car wheels will slip relative to the ground,(kang,h *et al* 2008) or the vehicle will tip over. Obviously, slipping is the preferred outcome. Keep this in mind for the moment.

If the front wheels slip first (understeer), you won't spin out and it is easier to regain control. Understeer is considered a safe dynamic response to slipping in a turn and is designed into all commercial cars. Which wheels will slip first is a function of weight distribution and weight transfer during turns.

The problem for delta vehicles is how to When the car does slip out of control on a fast turn, we can design it in such a way that we know whether the front or rear wheels will slip *first*. This is important because if the rear wheels slip first, the vehicle runs the risk of spinning out of control (oversteer).

If you design the weight distribution for a heavy front bias to achieve understeer, you increase the risk of tipping over. Alternatively, if you increase the weight distribution on the rear tires, the vehicle will oversteer in hard turns, also bad.

We also need to consider 'nose diving'. That is, when you slam on the brakes as hard as possible, the vehicle will either skid to a halt or the rear wheels will lift off the ground. This is also a function of weight distribution and weight transfer.(Schehter *et al* 1999) It would seem that the delta design has an advantage here because it naturally lends itself to having a rear biased weight distribution.

But in the real world, a hard stop doesn't always occur when traveling in a straight line.If you stop hard enough while while turning with a delta vehicle, the weight will transfer to the front wheel .

Braking: Because your weight transfers to the front when you decelerate, the front wheels on any vehicle provide the majority of your stopping power (something like 60-70%). The delta is at a disadvantage considering the weight distribution issues discussed above and the fact that it has one less front tire to brake on.

Simplicity of Design: Steering is definitely easier to design for the delta. No special considerations need to be taken into account to avoid lateral wheel slipping on turns, while the tadpole design has to incorporate extra linkages to approximate 'Ackermann' steering geometry to prevent wheel slippage.

Front suspension design is definitely easier on the delta. The best choice is a 'telescopic fork' positioned with some degree of caster angle to ensure that the car drives straight when you let go of the wheel (Setup like a motorcycle). The rear suspension design can be any number of options.

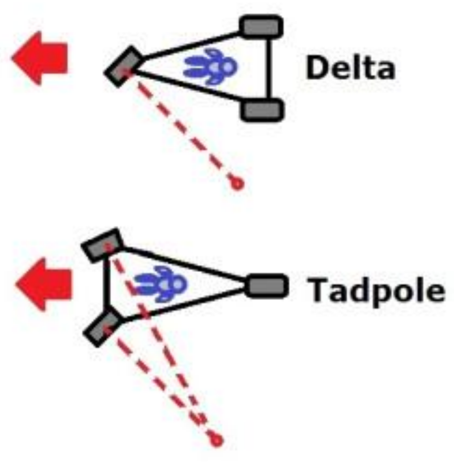

Figure 2: Comparison of delta and tadpole

The reverse is true of the tadpole.

Aerodynamics: The tadpole design lends itself better to the aerodynamic tear drop with the correct length/width ratio (.255) more easily than the delta. The image below shows how poorly the correct shape fits the delta design. Plus, you have to encase more empty space with the delta.

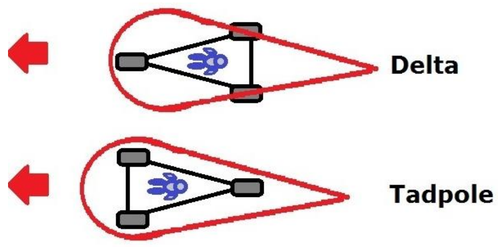

Figure 3: Aerodynamic comparison of delta and tadpole

Powertrain: The delta design has more disadvantages when selecting your drive wheel. If you go with front wheel drive, you have to fight against the dynamic stability disincentive of putting too much weight on the front of a delta. You also have to make sure that your steering system doesn't conflict with your method of driving that wheel.

If you power a back wheel on a delta you need to add a differential gear to the rear wheels or else risk stability issues caused by the off center driving wheel force.

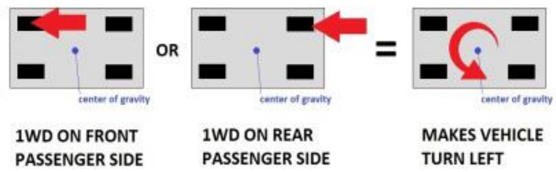

Figure 4: Powertrain of 4 stroke engine

On the other hand a tadpole with rear wheel drive gets the best of both worlds. No differential is necessary and you can keep a good 30% of the vehicle weight on the drive wheel to maintain traction.

Conclusion: For most vehicles the tadpole is clearly the best option on three wheels. However, the delta will always have value for niche applications.

Working

At the beginning of the intake process, the intake valve opens immediately, and the exhaust valve stays closed while the piston moves from the top dead center (TDC) toward the bottom dead center (BDC). During this process, the incoming compressed air pushes the piston downward, producing the power stroke. The intake valve closes before the piston reaches the BDC to reduce the air consumption, and thus changing the process from a constant pressure expansion to an isentropic expansion. The downward movement of piston produces work while the compressed air feeds into the cylinder during the intake process, and even after the intake valve closes during the isentropic expansion process. At the start of the exhaust process, the exhaust valve opens immediately while the intake valve remains closed. The piston moves from the BDC toward the TDC to discharge the compressed air from inside the cylinder. The simplicity in design, durability and compact size of pneumatic systems make them well suited for mobile applications. Pneumatic control system plays very important role in industrial system owing to the advantages of low cost, easy maintenance, cleanliness, readily available, and cheap source, etc.

5. Design of engine (Modified)

The main objective of this study is to run an engine (in this case a petrol engine) by compressed air without any fuels such as diesel, petrol or natural gas. In this research, the opening and closure of both the inlet and exhaust valves are controlled by the revolution of the lobe as well as the camshaft. The camshaft gear is messed with crankshaft gear and is driven by crankshaft gear. As crankshaft gear's total revolution is 720 degrees, and the intake and exhaust valves open once, the camshaft gear must revolve 360 degrees while the crankshaft gear revolves 720 degrees. Therefore the camshaft gear must be larger than the camshaft gear, and the number of teeth of the camshaft gear must be twice the number of teeth of the crankshaft gear. For this reason, the camshaft rotates 360 degrees while the crankshaft rotates 720 degrees, and this is the method of opening the intake and exhaust valves once while the crankshaft rotates through two revolutions. Suction and power and Exhaust stroke. In the power stroke, the compressed air is supplied from the (schehter *et al* 2000)compressed air tank through the intake manifold with a very high velocity and force (pressure) because when the air is compressed, its volume decreases but its pressure and temperature increases. For a continuous running operation and fast response, air flow is simply controlled by a proper cam design mechanism in many response CAE systems (Yu, Shi, & Cai, 2014). Here, compressed air comes through a narrow pipe (intake manifold) to a bigger space (engine cylinder), resulting in a big thrust force on the piston. In other words, it pushes the piston with a high velocity and as a result, the piston moves downwards (TDC to BDC). As the piston begins to move downwards and reaches the BDC, a power stroke is produced. With this power stroke engine, the flywheel absorbs some energy. When the piston moves upwards due to the release of absorbed energy from the flywheel and kinematic momentum of the flywheel, the exhaust valve opens and air exits the engine cylinder. This is the exhaust stroke. From the above discussion, it is seen at the beginning that the inlet valve opens and compressed air enters the engine cylinder, pushing the piston downwards (TDC to BDC) and causing the cranks to begin revolving. When the piston is at BDC, the crank completes its 180 degree revolution. Subsequently, the piston begins to move upwards (BDC to TDC), causing the exhaust valve to open and the compressed air to exit from the cylinder. The crank then finishes another 180 degree revolution and so completes one total revolution (360). Hence in this case, both the intake and exhaust valves open and close once while cranks and crank shaft revolve 360°. The opening and closing of the valve is controlled by the lobe, which is attached to the camshaft. The camshaft gear is driven by the crank shaft gear. In the case of the conventional engine, the crankshaft gear is smaller than the camshaft gear. Let the teeth of crankshaft gear be T1, and teeth of camshaft gear be T2. As discussed earlier, the relation T2 = 2T1 is derived, so that 2N1 = N2. Therefore, when crank shaft gear revolves 720°, the camshaft gear revolves 360° and from every 720° of rotation of the crankshaft, a single power stroke is obtained. However, when the engine is run by compressed air, one power stroke occurs every 360° of rotation of the crankshaft. An arrangement was made to get a single power stroke every 360° of rotation of the crankshaft by changing the camshaft lobe shape. The normal lobe shape is an oval or egg shape but the lobe shape was changed to an eye shape.

A conventional, non-tilting three wheel car can equal the rollover resistance of a four wheel car, provided the location of the center-of-gravity (cg) is low and near the side-by-side wheels. Like a four wheel vehicle, a three-wheeler's(braun *et al* 1875) margin of safety against rollover is determined by its L/H ratio, or the half-tread (L) in relation to the cg height (H). Unlike a four-wheeler, however, a three-wheeler's half-tread is determined by the relationship between the actual tread (distance between the side-by-side wheels) and the longitudinal location of the cg, which translates into an effective half-tread. The effective half-tread can be increased by placing the side-by-side wheels farther apart, by locating the cg closer to the side-by-side wheels, and to a lesser degree by increasing the wheelbase. Rollover resistance increases when the effective half-tread is increased and when the cg lowered, both of which increase the L/H ratio.

The single front wheel layout naturally oversteers and the single rear wheel layout naturally understeers. Because some degree of understeer is preferred in consumer vehicles, the single rear wheel layout has the advantage with the lay driver. Another consideration is the effect of braking and accelerating turns. A braking turn tends to destabilize(kalpesh chavda *et al* 2014) a single front wheel vehicle, whereas an accelerating turn tends to destabilize a single rear wheel vehicle. Because braking forces can reach greater magnitudes than acceleration forces (maximum braking force is determined by the adhesion limit of all three wheels, rather than two or one wheel in the case of acceleration), the single rear wheel design has the advantage on this count. Consequently, the single rear wheel layout is usually considered the preferred platform for a high-performance consumer vehicle in the hands of the non-professional driver. But racecar drivers often prefer slight oversteer to understeer. Oversteer gives the skilled driver the ability to perform extreme maneuvers that an understeering vehicle would simply mush through and refuse to perform. Moreover, by varying tire size and pressure, a single front wheel vehicle can be designed for neutral steer with oversteer present only at the limit of adhesion. Much depends on the details of the design, as well as driver preferences and skills.

5. Compressed air(fuel)

Pneumatic motors generally convert the compressed **air** orgastomechanical **work** through either linear or rotary motion. Linear motion can come from either a diaphragm or piston actuator, while rotary motion is supplied by either a vane type **air motor** or piston **air motor.**

Compressed air energy storage (CAES) is a way to store **energy** generated at one time for use at another time using **compressed air**. At utility scale, **energy**generated during periods of low **energy** demand (off-peak) can be released to meet higher demand (peak load) periods. **Compressed air** is air kept under a pressure that is greater than atmospheric pressure. It serves many domestic and industrial purposes.

In Europe, 10 percent of all industrial electricity consumption is to produce compressed air.

Compressed air has a low energy density. In 300 bar containers, about 0.1 MJ/L and 0.1 MJ/kg is achievable, comparable to the values of electrochemical lead-acid batteries. While batteries can somewhat maintain their voltage throughout their discharge and chemical fuel tanks provide the same power densities from the first to the last litre, the pressure of compressed air tanks falls as air is drawn off. A consumer-automobile of conventional size and shape typically consumes 0.3–0.5 kWh (1.1–1.8 MJ) at the drive shaft[4] per mile of use, though unconventional sizes may perform with significantly less.

Compressed air energy storage (CAES) is a way to store energy generated at one time for use at another time using compressed air. At utility scale, energy generated during periods of low energy demand (off-peak) can be released to meet higher demand (peak load) periods.[1] Small scale systems have long been used in such applications as propulsion of mine locomotives.(ss verma *et al* 2013) Large scale applications must conserve the heat energy associated with compressing air; dissipating heat lowers the energy efficiency of the storage system.

The laws of physics dictate that uncontained gases will fill any given space. The easiest way to see this in action is to inflate a balloon. The elastic skin of the balloon holds the air tightly inside, but the moment you use a pin to create a hole in the balloon's surface, the air expands outward with so much energy that the balloon explodes. Compressing a gas into a small space is a way to store energy. When the gas expands again, that energy is released to do work. That's the basic principle behind what makes an air car go.

6. Working of Tadpole vehicle

Tadpole designs are much more stable than the delta setup because the back wheel drives the vehicle while the two wheels up front are responsible for steering. There's also an aerodynamic benefit, since the vehicle is shaped almost like a teardrop -- wide and round up front and tapering off in(embadi koushik varma *et al* 2016) the rear. This allows air to flow easily over the vehicle's bodywork

The tadpole design is becoming more and more favored among auto designers for its stability, aerodynamics and ability to house a fuel-efficient engine (Jeripotula Sandeep Kumar *et al* 2016) In fact, a number of current hybrid and electric concept vehicles use a three-wheel setup along these lines. As cars get more eco-friendly, you may be seeing more and more three-wheelers on the road than ever before.

Figure 5 Tadpole vehicle which runs on compressed air

6. Advantages

This thesis evaluated the lateral dynamics, roll stability, handling, and ride dynamics of a threewheeled vehicle with tadpole design. The primary objective was to study the effects of adding active camber system on the vehicle dynamic performance. In addition to evaluating the performance of the suspension in regards to the ride quality of the vehicle, load case studies were also performed to evaluate both the static and dynamic forces on the suspension parts under different operating scenario.

Compressed-air vehicles are comparable in many ways to electric vehicles, but use compressed air to store the energy instead of batteries. Their potential advantages over other vehicles include:

- Much like electrical vehicles, air powered vehicles would ultimately be powered through the electrical grid. Which makes it easier to focus on reducing pollution from one source, as opposed to the millions of vehicles on the road.
- Transportation of the fuel would not be required due to drawing power off the electrical grid. This presents significant cost benefits. Pollution created during fuel transportation would be eliminated.
- Compressed-air technology reduces the cost of vehicle production by about 20%, because there is

no need to build a cooling system, fuel tank, Ignition Systems or silencers.

- The engine can be massively reduced in size.
- The engine runs on cold or warm air, so can be made of lower strength light weight material such as aluminium, plastic, low friction teflon or a combination.
- Low manufacture and maintenance costs as well as easy maintenance.
- Compressed-air tanks can be disposed of or recycled with less pollution than batteries
- Compressed-air vehicles are unconstrained by the degradation problems associated with current battery systems.
- The air tank may be refilled more often and in less time than batteries can be recharged, with re-filling rates comparable to liquid fuels.
- Lighter vehicles cause less damage to roads, resulting in lower maintenance cost.
- The price of filling air powered vehicles is significantly cheaper than petrol, diesel or biofuel. If electricity is cheap, then compressing air will also be relatively cheap.

7. Disadvantages

The principal disadvantage is the indirect use of energy. Energy is used to compress air, which – in turn – provides the energy to run the motor. Any conversion of energy between forms results in loss. For conventional combustion motor cars, the energy is lost when oil is converted to usable fuel – including drilling, refinement, labor, storage, eventually transportation to the end-user. For compressed-air cars, energy is lost when electrical energy is converted to compressed air, and when fuel, either coal, natural gas or nuclear, is burned to drive the electrical generators. Energy collectors such as dams, wind turbines and solar collectors, are expensive and have their own problems in manufacture, pollution, transport and maintenance.

- When air expands, as it would in the engine, it cools dramatically (Charles's law) and must be heated to ambient temperature using a heat exchanger similar to the Intercooler used for internal combustion engines. The heating is necessary in order to obtain a significant fraction of the theoretical energy output. The heat exchanger can be problematic. While it performs a similar task to the Intercooler, the temperature difference between the incoming air and the working gas is smaller. In heating the stored air, the device gets very cold and may ice up in cool, moist climates.
- Refueling the compressed-air container using a home or low-end conventional air compressor may take as long as 4 hours, while the specialized equipment at service stations may fill the tanks in only 3 minutes.
- Tanks get very hot when filled rapidly. SCUBA tanks are sometimes immersed in water to cool them down when they are being filled. That would not be possible with tanks in a car and thus it would either take a long time to fill the tanks, or they would have to take less than a full charge, since heat drives up the pressure. However, if well insulated, such as Dewar (vacuum) flask design, the heat would not have to be lost but put to use when the car was running.
- Early tests have demonstrated the limited storage capacity of the tanks; the only published test of a vehicle running on compressed air alone was limited to a range of 7.22 km (4 mi).
- A 2005 study demonstrated that cars running on lithium-ion batteries out-perform both compressed-air and fuel cell vehicles more than threefold at same speeds. MDI has recently claimed that an air car will be able to travel 140 km (87 mi) in urban driving, and have a range of 80 km (50 mi) with a top speed of 110 km/h (68 mph) on highways, when operating on compressed air alone.

8. Possible improvements

Compressed-air vehicles operate according to a thermodynamic process because air cools down when expanding and heats up when being compressed. Since it is not practical to use a theoretically ideal process, losses occur and improvements may involve reducing these, e.g., by using large heat exchangers in order to use heat from the ambient air and at the same time provide air cooling in the passenger compartment. At the other end, the heat produced during compression can be stored in water systems, physical or chemical systems and reused later.

It may be possible to store compressed air at lower pressure using an absorption material within the tank. Absorption materials like Activated carbon, or a metal organic framework is used for storing compressed natural gas at 500 psi instead of 4500 psi, which amounts to a large energy saving.

9. Result and conclusion

The air powered vehicle are the best options which provide most comprehensive answer to the present urban pollution problems in simple, economic and inoffensive manner. This is clean, easy to drive, comparatively low cost and does not take a life time to pay off. Thus these vehicles are safe to manufacture, safe to use, safe to users and also Environment friendly. We were able to successfully complete the design and fabrication of the air driven engine. The air driven engine provides an effective method for power production and transmission. Even though its applications are limited currently, further research could provide wider applications. The Air Vehicle provides an effective use and applied to the transportation light vehicles. It's speed, range and the power are limited now, so further research could provide more effective results.

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