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BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

Exhaust Driven Turbine
25% Final Report

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Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Brian Gleason, Angel Fernandez, and Efrain Rivero and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Abstract

There is a desire worldwide to increase the efficiency of gasoline internal combustion engines in order to decrease emissions and to counter the increasing prices of gasoline. One main challenge in all designs is the decrease of wasted energy or wasted material. In the case of engines, there is wasted energy in the form of heat and exhaust gases. Our project will focus on capturing the energy from wasted exhaust gas without creating inefficiencies in the engine.

A system will be designed to be implemented in existing gasoline exhaust pipes to capture wasted energy. A turbine with its axis of rotation along the direction of exhaust gas flow will be placed near the exit of the exhaust pipe and connected to an alternator. Electricity generated from the alternator will be stored in a battery and can be used in addition to electrical loads currently generated from gasoline engines.

Introduction

Problem Statement

Design a system to capture energy from engine exhaust gases to be used in conjunction with existing gasoline-electric hybrid engine systems. The system should introduce a minimal amount of exhaust back pressure to avoid decreasing efficiency and power output of the gasoline engine.

Waste is a major concern in any type of production whether it be in manufacturing, engines, or even a business process. Waste elimination is a process undergone while designing systems, but waste can only be reduced to a certain point until it is not cost effective to proceed. Introducing a new system to capture this excess waste would not necessarily reduce the waste from the original system, but would make better use of the waste and create an overall more efficient system.

Design Objectives

The objective is to design an axial turbine to be placed in the exhaust pipe of an engine. The rotation of axis of the turbine is to be along the direction of flow of exhaust gases allowing the design to introduce as little pressure as possible. Increasing the amount of pressure in the exhaust pipe by a negligible amount will allow the engine to perform as expected and without a decrease in efficiency.

The axis of the turbine will be connected to an alternator to generate electricity. A gear reduction between the turbine and the alternator will allow the turbine to rotate at higher speeds with low torque while the shaft connected to the alternator can rotate at lower speeds with higher torque. The low torque on the turbine axis will allow it to rotate with little resistance, and therefore accelerate faster with the increase in air flow velocity.

Motivation

Waste reduction is the main inspiration behind this design. With limited capabilities behind the reduction of waste from a gasoline engine, creating a new system to utilize the wasted energy is the next step to further increase efficiency.

This year, The Obama Administration finalized groundbreaking standards that will increase fuel economy to the equivalent of 54.5 mpg for cars and light-duty trucks by 2025 [2]. Gasoline-Electric Hybrid engines have proven to be a large step towards greatly increasing the mileage of cars. The exhaust-driven turbine will provide assistance in charging the battery used to power the electric motor, further increasing fuel efficiency.

Literature Survey

Market Analysis

The market our product is intended for is the automobile industry and more specifically vehicles utilizing hybrid engines. The use of the different power sources such as the electric motor and the internal combustion engine make the design very unique and provide the consumers with higher mileage than a conventional vehicle. The intention is to use the designed turbine to gather the energy from the exhaust gases flowing out of the car in the exhaust pipe. This energy will ultimately charge the batteries for the electric motor.

The Environmental Protection Agency's regulatory announcement in August of 2012 states that between 2017 and 2025, cars manufactured will have to meet the 54.5 mpg standards [3]. Since these regulations will exists, car manufacturers will have to make fuel economy improvements in order to meet the standards. This will be a great opportunity for our exhaust turbine to be used in the improvements of the fuel efficiency. Figure 1 it shows the trend of sales in hybrid-electric vehicles in the United States and as well as the involvement of many auto manufacturers [4]. It also shows the most popular selling car is the Toyota Prius since its release, but our design is targeted to give U.S. car manufactures an increased share into the market.

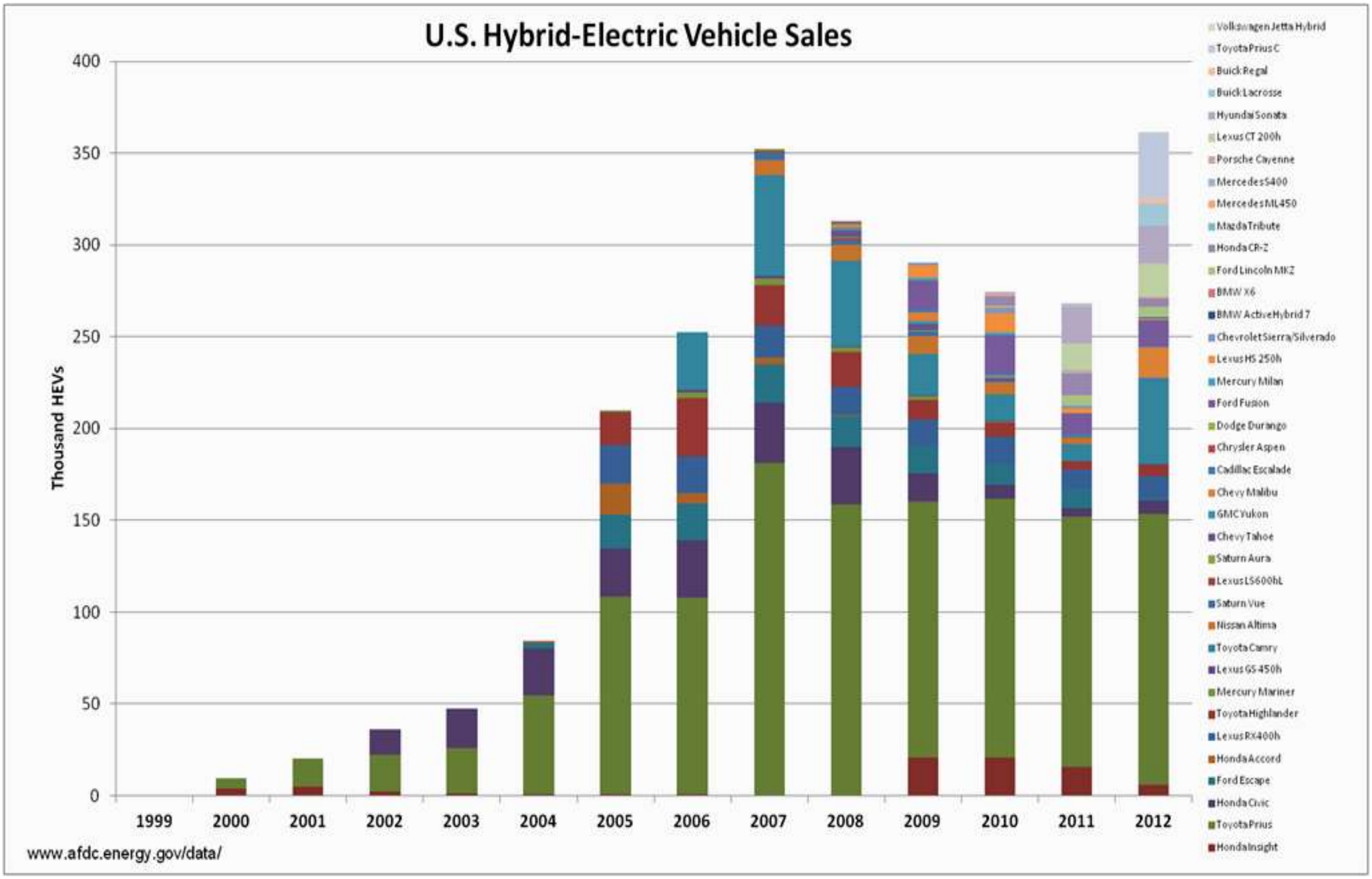

Figure 1- Hybrid-Electric Vehicle Sales in the U.S. [4]

Similar Research

As our team did an initial investigation on finding other research and product developments that were similar to our initial proposal, we came across a company named Aeristech. This company, hosted in the UK, created a comparable concept through the use of a turbocharger. For many years, this company has been developing a new approach to utilize a turbocharger more efficiently in order to boost the performance of automobile engines. Through their research, they have developed a product called the Full Electric

Hybrid Turbocharger, which utilizes state-of-the-art fast accelerating permanent magnet motors to generate electric power from the turbo turbine through a split design. The electricity generated is stored onto a hydrogen fuel-cell battery in order for the turbo compressor to be driven separately from the turbo turbine through the battery directly [8]. In this manner, turbo lag, which is a typical initial throttle response problem in most turbochargers, can be avoided by controlling the compressor separately and powering it at the right amount when it's needed.

The concept of capturing the exhaust energies through Aristech's split design turbocharger is similar to our concept in the notion that the turbocharger turbine is driving directly the generation of electric power. For our proposed design of using helical blades, we will take the similar approach of generating electric power from the velocity of the exhaust gas. The design will also include a factor of developing an optimal blade design that can produce the least amount of back pressure for maximum efficiency. Our design will route the turbine's angular power to a small electric generator through a bevel gear mesh connection that can transfer the power output outside of the pipe flow. The difference in our design as compared to Aristech's turbocharger design is based on the usage of electric power being generated. The Full Electric Hybrid Turbocharger is designed convert the turbocharger spinning speed into electric energy to then power directly an electric air compressor to boost intake of the engine. The purpose of our helical design would to store the electric energy generated onto a battery that can later be used to give additional power to an electric system such as in the case of a hybrid powertrain.

Upon further investigating the topic of recovering energy from the exhaust gas, our team came across U.S. and European patents [10]. The patents described an exhaust energy recovery device which utilizes a turbine rotatable by the exhaust gas in order to drive an electric magnet motor to generate electric power. This design is similar to our proposed method of capturing the kinetic energy from the exhaust gas as the rotating speed of the blade is being used to power an alternator. One key difference in comparison to our design is the type of blade that is being used. The patent schematic displays a rotary blade in resemblance to a turbocharger blade that directs the flow of the gases from entering tangentially to exiting the blade axially. In their particular design, the flow of the exhaust gas goes through a change in direction, producing a higher level of back pressure. For our proposed design, the blades will be formed in a shape that will allow for the flow of gas to enter and exit through the same axis, causing less back pressure onto the system and allowing for an increase in the overall efficiency.

Conceptual Design

Proposed Design

The proposed design entails a helical axial turbine with the axis of rotation along the direction of the flow of exhaust gases. This design will allow for minimal pressure to be introduced into the system. Figure 2 shows a three dimensional model of the proposed design in a three inch diameter pipe. Two structural columns will be used to support each end of the helical blade's central shaft. Miniature bearings will be placed at each of these joints to minimize friction. In order to transfer the angular velocity of the blades to electrical power, our design will include a bevel gear connection to one side of the blade axis that can redirect the torque of the center shaft downward where it can be connected to an electric generator from outside of the pipe area.

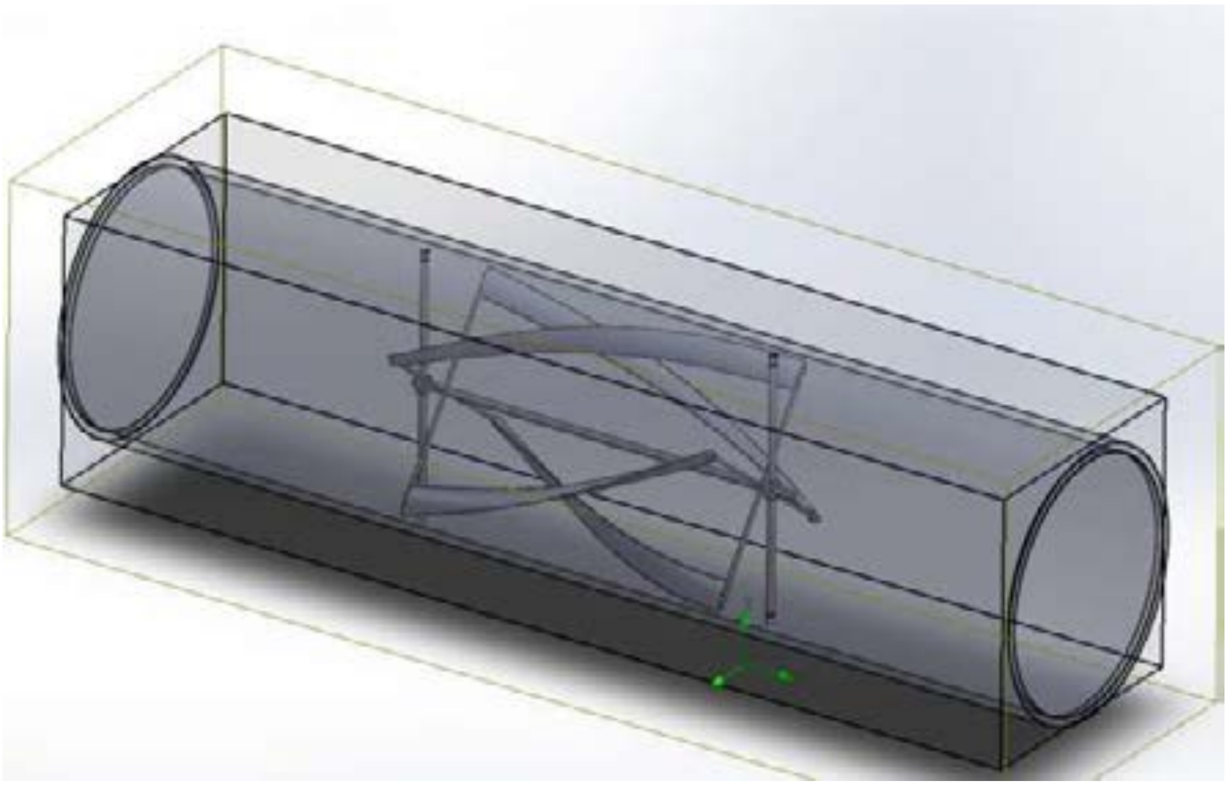

Figure 2: Axial Exhaust Turbine

The proposed turbine design has four blades which each cover a ninety degree rotation along the length of the axis of rotation. The blades have been designed to cover the full three inch diameter pipe to allow for the greatest torque to be applied by the exhaust gases.

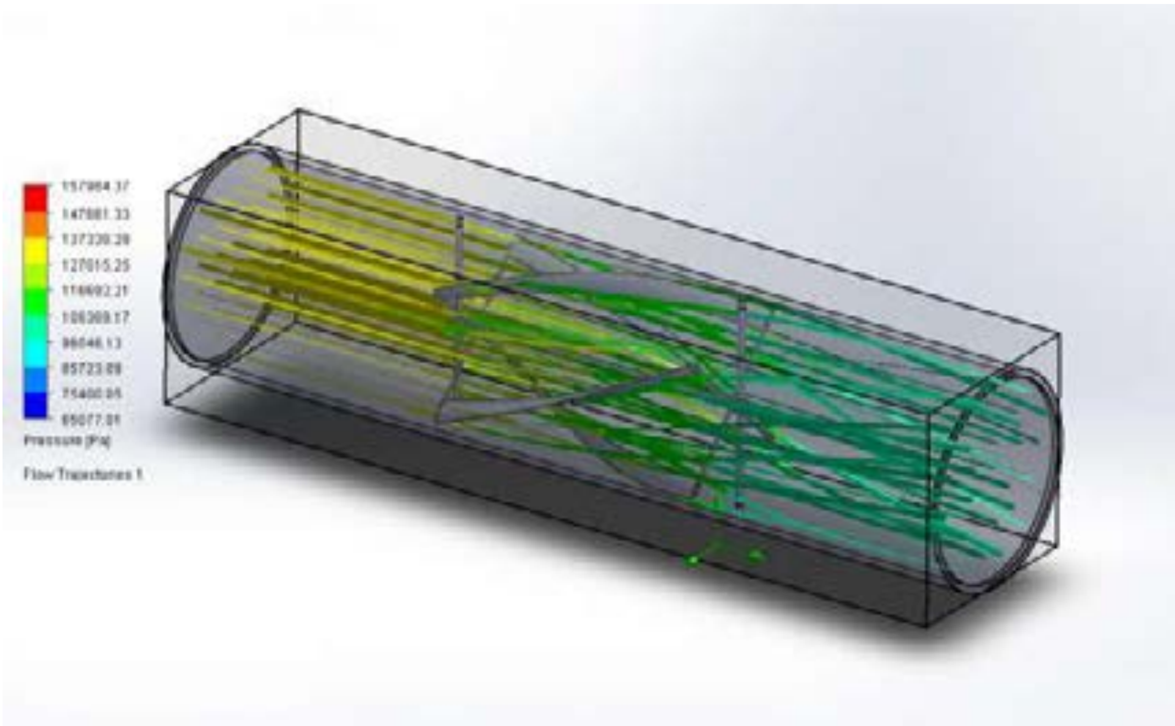

Figure 3: Constant Volume Flow Analysis

Figure 3 shows a fluid analysis of the proposed design in a static setting. This simulation represents initial air flow or sudden increases in flow in which the turbine is spinning at a slow speed relative to the expected speed at steady state.

Alternate designs such as a turbine with a perpendicular axis of rotation or one with different blade patterns were considered.

Design Alternative 1

The first design alternative includes a similar configuration to the proposed design. The model featured two blades which covered a 180 degree rotation along the length of the axis of rotation. This design required steeper blade profiles to cover the degree of rotation, which increases resistance as they are further from parallel to the direction of air flow.

Figure 4: Alternate Design 1 - Two 180° blades

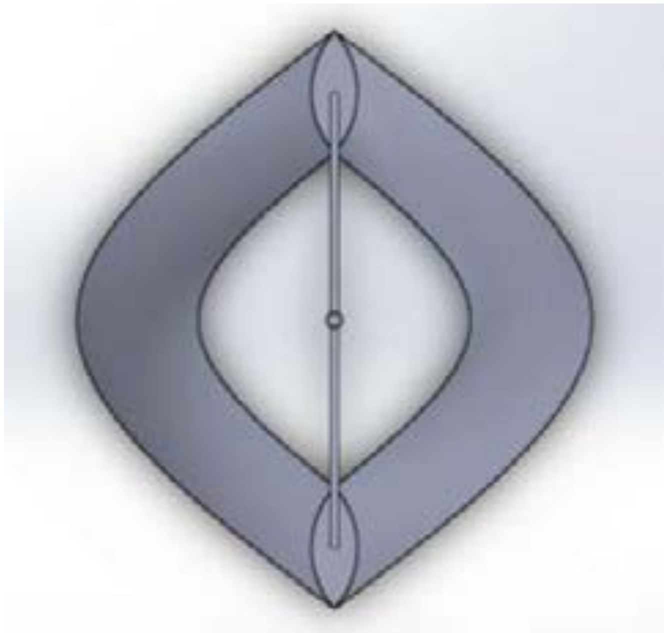

Figure 5: Alternate Design 1 - Axial View

The model of this alternate design can be seen in Figure 4 and Figure 5. The axial view of the turbine shows the full 360° coverage necessary to capture as much energy as possible.

Design Alternative 2

The second alternate design is a turbine with the axis of rotation perpendicular to the direction of air flow. This design was decided against due to the resistance while the gas hits the rear of the blades. Although the turbine can be optimized to be more effective on one particular side of the turbine, there will still be resistance on the returning side. Figure 6 shows the design utilizing a vertical axis turbine.

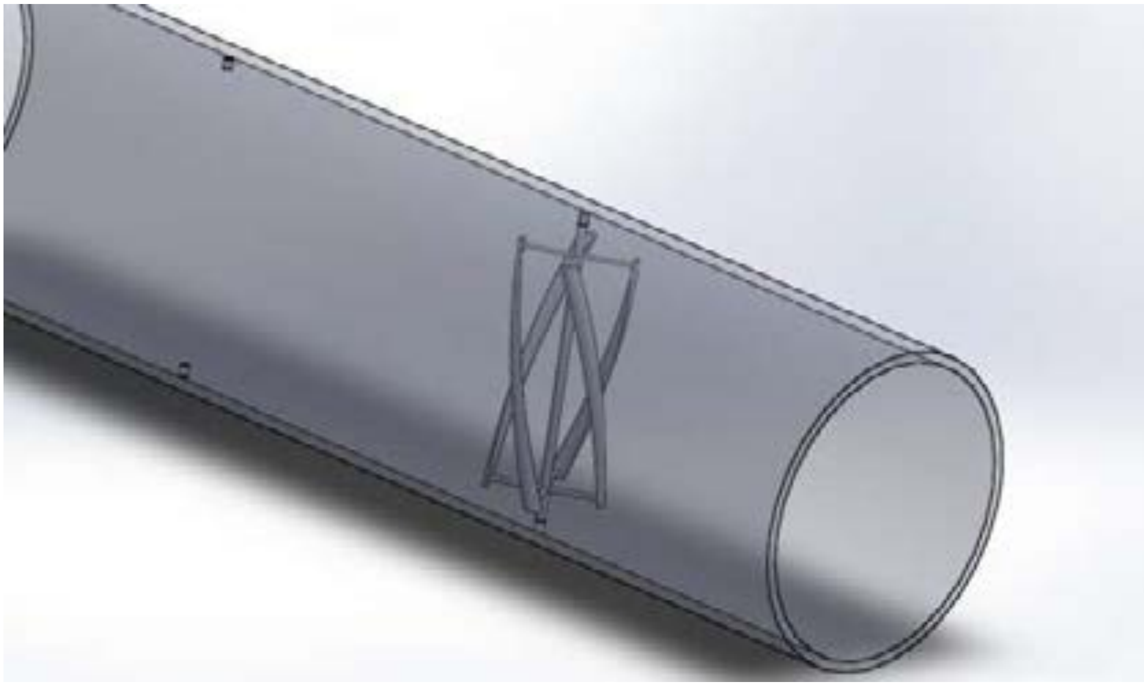

Figure 6: Alternate Design 2 - Perpendicular axis of rotation

Design Alternative 3

A vertical axis turbine with vertical blades was considered. This design featured twelve blades perpendicular to the direction of air flow. The blade profile was set as an arc in order to capture the air flow on one side of the turbine and not introduce resistance on the other side. This design was decided against because the vertical axis turbine introduced large pressure drops across the system due to the direction of rotation. Figure 7 is a model of this design.

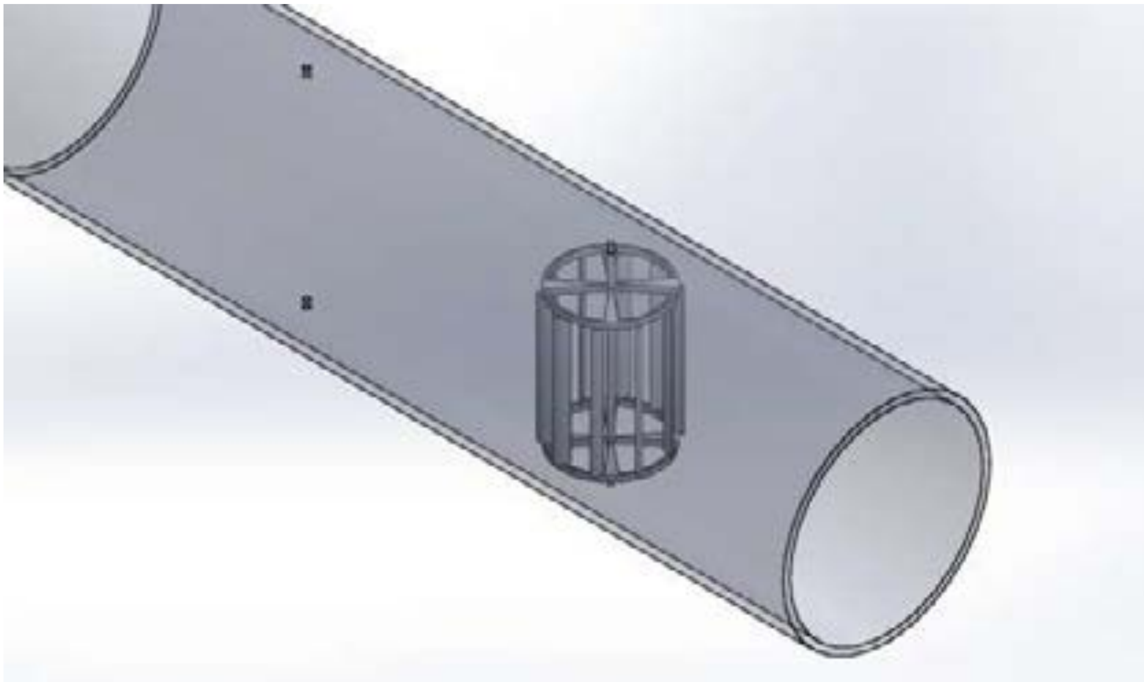

Figure 7: Alternate Design 3

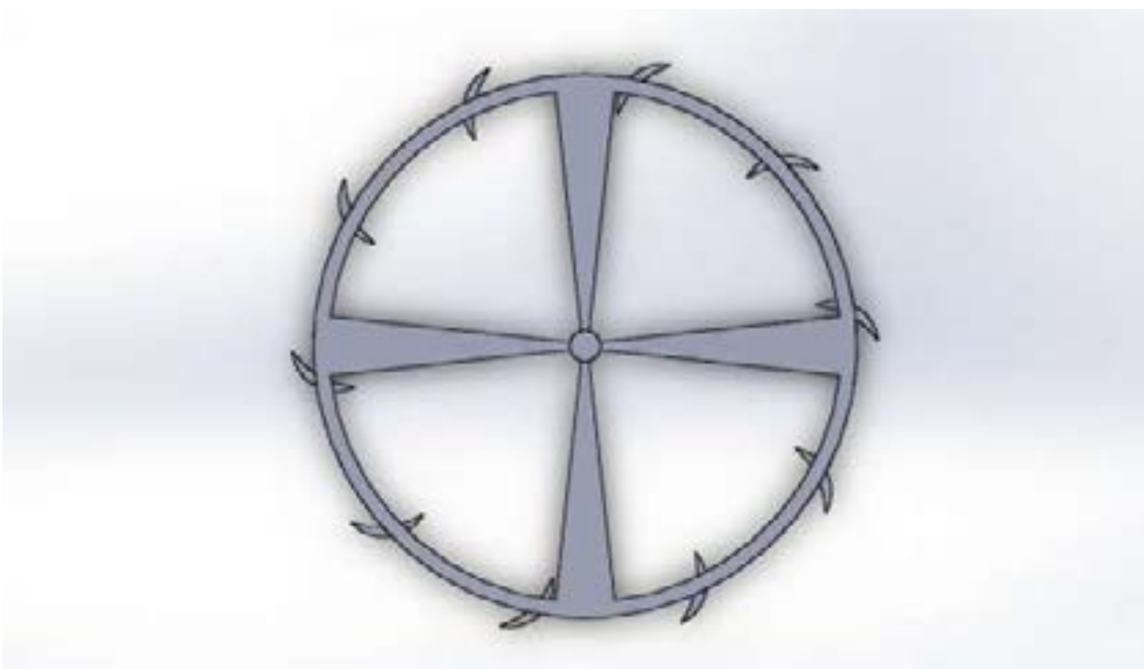

Figure 8: Alternate Design 3 - Top View

Figure 8 shows a top view of the design. The blades have been installed at an angle to increase the force applied by the air flow. However, as the blades rotate around, the back side of the blades move against the air flow, creating unnecessary restrictions.

Project Management

The major components of the project have been divided among the members based on subject matter expertise.

Timeline

The timeline for the project spanning a seven month period is shown in Figure 9. The minor components of the project have been grouped into larger phases to generate the timeline.

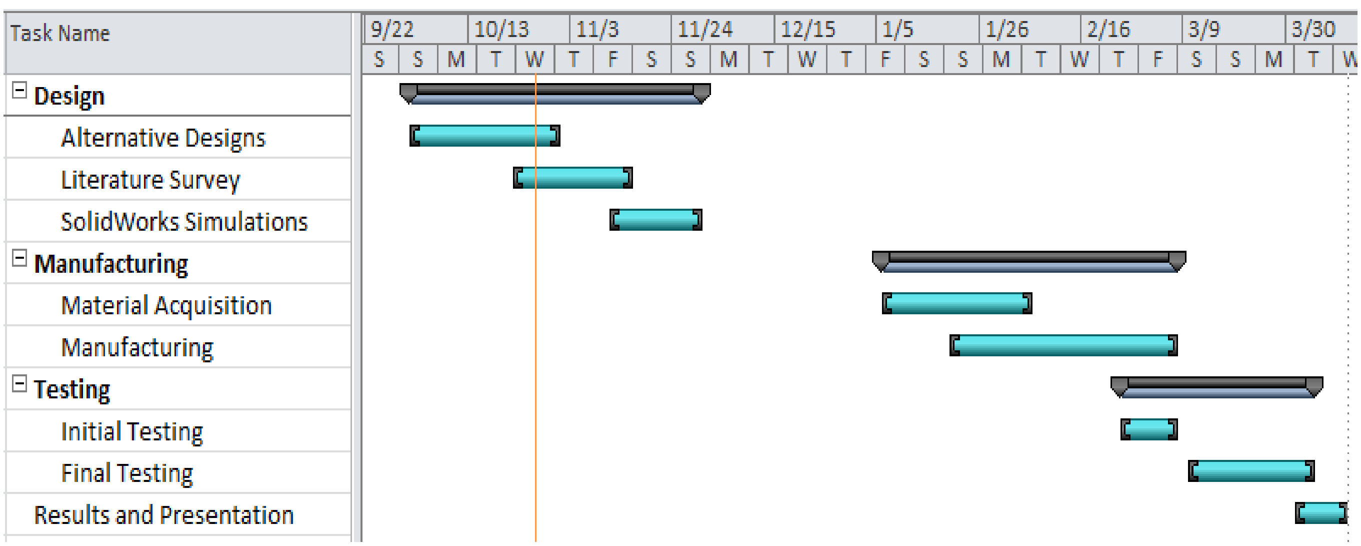

Figure 9: Project Timeline

Table 1 outlines the expected timeline for the major components of the project. The initial testing is expected to begin early in order to complete the simulations and select the most efficient design of the turbine profile.

Table 1 - Timeline

Design	**10/1/2013**	**11/29/2013**
Alternative Designs	10/1/2013	10/31/2013
Literature Survey	10/22/2013	11/15/2013
SolidWorks Simulations	11/11/2013	11/29/2013
Manufacturing	**1/6/2014**	**3/7/2014**
Material Acquisition	1/6/2014	2/5/2014
Manufacturing	1/20/2014	3/7/2014
Testing	**2/24/2014**	**4/4/2014**
Initial Testing	2/24/2014	3/7/2014
Final Testing	3/10/2014	4/4/2014
Results and Presentation	**4/1/2014**	**4/11/2014**

Major Components

Blade Material Selection

The material selection of the turbine designed had to take into consideration the temperatures that will be present in the exhaust. For the positioning of the turbine, it will be placed toward the ends of the exhaust pipe as opposed to being closer to the engine where the temperatures are highest. For conventional passenger cars the temperature at the end of the exhaust pipe is typically 200°-250°C. This provides us with a good starting point to make a material selection. Further information can gathered on the types of cars and the temperature range for the exhaust pipes for more accuracy with the analysis. Table 2 shows the different types of materials considered for the designed turbine along with the melting points [5]. The aluminum alloy meets the requirement for the temperature conditions in which the turbine will be placed in the exhaust pipe. In future designs, if the turbine is place closer to the engine, there are other material which can be used based on the temperature increase. Iron and steel can both sustain temperatures over 1000°C in case that's a design condition pursued.

Table 2 - Material melting points[5]

Material	Melting Points (°C)
Aluminum Alloy	463 -671
Carbon Steel	1425 - 1540
Gray Cast Iron	1127 - 1204
Stainless Steel	1510
Titanium	1670

Structure Material Selection

In order to minimize the area occupied by the turbine support, a strong material such as steel will be considered. Many types of metal will be analyzed based on the expected air flow velocity, temperature, and likelihood of corrosion.

Structural Design

The final structural design will be based on the optimized model built and analyzed. The support of the turbine will be minimized in volume to prevent unnecessary volume flow restrictions. The support may be designed utilizing an air foil type design to assist with the redirection of air flow. The bearings selected will also be chosen based on the size of the bearing which will not restrict air flow. The shape and orientation of the blades will be closely analyzed to optimize the amount of energy conversion while minimizing the pressure drop across the system.

Based on simulations, an enclosure for the bearings and gears may be required to lubricate the joints and prevent failure. The turbine axis will be designed with a slight diameter increase over the length of the shaft to deter air flow from the gear assembly.

Cost Analysis

The consideration of the cost for the parts is based on the desired prototype that will be built in order to determine the effectiveness of turbine designed. The turbine will be 3-D printed with PrintrBot FDM printer which our group currently has, therefore introducing no additional cost associated to the printing of the turbines. The material used to print the turbine is PLA (polylactic acid) which is a polymer. The material itself costs roughly $2 for the multiple pieces so that cost is substantially small and was not accounted for. In Table 3 is the breakdown of the component that will be required to build a prototype for experimentation and comparison to SolidWorks simulation.

The clear PVC pipe is to simulate an exhaust pipe of an automobile and since it is clear, it is easy to see the turbine spinning which can help with future design considerations. Since the turbine will be spinning, the bearing will make the motion very smooth for optimal efficiency. The tool that may be required is a small drill to secure the housing for the turbine to be pipe as well as other miscellaneous parts can't be determined at this time.

Table 3: Prototype Materials

Parts	Cost
Clear PVC Pipe	$145
Turbine	$20
Bearing	$10
Tools	$50

In this group, every member contributed equally with their time and efforts. Table 4 shows the breakdown of the hour distribution per member that is expected to take place through the completion of the project. This estimate is done based on the hours already spent during the first half of the project. Our final estimation was 420 hours, which calculated at $35 per hour, gives us a total labor cost of $14,350.

Table 4: Engineering hours

	Brian Gleason	Angel Fernandez	Efrain Rivero
Task	Hours	Hours	Hours
Project Formulation	2	3	3
Prototype Design	7	8	7
Possible Designs	9	10	10
Design	8	11	13

Testing and Analysis	12	13	14
Solid Works Modeling	30	20	20
Solid Works Analysis	35	32	31
Prototype Assembly	9	10	10
Component Research	8	9	12
Cost Analysis	10	12	10
Report Writing	10	12	10
Total Hours Per Person	140	140	140
Total Project Hours		**420**	

Prototype

Cost Analysis

The prototype of the turbine will be manufactured utilizing Fused Deposition Modeling (FDM). This method will allow the cost of materials and manufacturing to be lower than that of different types of metals such as aluminum and titanium. The material commonly used by noncommercial FDM machines is Polylactic Acid (PLA), a thermoplastic polymer. This material will be used to produce the prototype blades and costs $30 per kilogram.

Testing Plan

Initial testing will consist of a computational fluid dynamic analysis of the built model. This will assist in determining which blade profiles and configurations will produce the best results. In order to properly simulate an exhaust pipe, a simulation will first be performed using an empty pipe to determine the mass air flow. This mass air flow will then be used to determine the pressure drop once the system is installed. The pressure difference between the two simulations will provide the expected outcome.

In order to test the worst case scenario, the simulations will be performed on a blade which is not rotating. This will cause the bigger restrictions, and closely simulate a large sudden increase in air flow. Simulations will also be performed with the blades in motion and with varying air flow velocities to better reproduce realistic scenarios.

Testing the prototype of the exhaust turbine will consist of measuring the drop of pressure across a three inch tube with the system towards the output of the pipe. A pressure meter will be placed between the input of the tube and the turbine system to read the pressure as the speed and flow increase. The testing will be performed at different speeds to simulate the varying speeds of the engine. A volt meter will be attached to the alternator which is on the output shaft of the turbine system.

Conclusion

There are currently few options available which can utilize wasted energy rather than reduce the amount of energy lost. This system can be implemented in existing gasoline engine exhaust pipes, and can be expanded to other areas of high air flow such as the output of a home air conditioner, the exhaust of a household drier, or building vents.

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