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Evaluating the Engine's Efficiency after Converting an Internal Combustion Engine into an Advanced High-Performance Serial/Parallel Hybrid Powertrain

Eng. Vajidullah Molvizadah
International Graduate Student in Industrial Technology
Jordan College of Agricultural Sciences and Technology
California State University, Fresno (CSUF)
Fresno, California, United States of America
vajidullah@mail.fresnostate.edu

Dr. Athanasios Alexandro
Project Supervisor
Professor, Department of Industrial Technology
Jordan College of Agricultural Sciences and Technology
California State University, Fresno (CSUF)
Fresno, California, United States of America
aalexandrou@mail.fresnostate.edu

Prof. Matthew Crowder
Project Mentor
Professor, Department of Industrial Technology
Jordan College of Agricultural Sciences and Technology
California State University, Fresno (CSUF)
Fresno, California, United States of America
crowder@mail.fresnostate.edu

Abstract

This project will explore the theory and application of converting a traditional 4-stroke Otto cycle internal combustion engine into an advanced high-performance Serial / Parallel hybrid powertrain. A commercial off-the-shelf Permanent Magnet electric motor will be coupled directly to the front of the engine. This design will allow the electric motor to act as an electric supercharger to aid in vehicle acceleration during high loads, charge the HV (High Voltage) battery under deceleration (battery regen) and will provide advanced "Stop - Start" technology that will conserve fuel while the vehicle is at rest (stoplights). Along with mechanical knowledge, this project will also require electrical knowledge - safe practices around High-voltage (300v) battery packs, deep understanding of "Serial" and "Parallel" battery module orientation and their effect of voltage and amperage flow, high amperage connection requirements, low-voltage circuit wiring to monitor electricity usage. The innovative part about this project is that we are attempting to make a 600+ horsepower "Prius" engine using parts from eBay and the local automotive dismantling yard. Outside of multi-million-dollar hyper cars such as the McLaren "P1", Ferrari "LaFerrari", Koenigsegg "Regera" this type of hybrid powertrain has never been attempted. Primary components for the system:

- Air-cooled, 150kW three-phase PM brushless synchronous motor and matching motor controller from Danfoss ("UQM-Danfoss PPHD 250(+) Motor & Controller". EV Source, 2022).
- Battery pack consists of 84 Panasonic lithium ion "prismatic" cells totaling 7.6kW/h (Energy.Gov, 2022).
- 5.3 Liter "LM7" V8 engine from a 2003 Chevy Silverado 1500 - engine is a Gen3 small block and part of the legendary "LS" engine family

- First of its kind Motor / Engine coupler mounting system
- Orion BMS based charge control and monitoring system
- Raspberry Pi (RPi) can be used as an engine / motor system monitor via CANbus

Keywords
Integrated Motor Assist (IMA), regen, BMS, and Electric Motor.

1. Introduction
This design/idea draws inspiration from the 1999-2006 Honda Insight - the first hybrid powertrain ever commercially sold in the United States and one of the most fuel-efficient passenger cars ever produced (70 mpg highway) as shown in the Figure 1 below ("Autoblog Is Part Of The Yahoo Family Of Brands". Autoblog.Com, 2022).

Figure 1. 1999-2006 Honda Insight

The Honda Insight used a system called IMA or "Integrated Motor Assist", that consists of a 67 hp (50 kW), 1.0-liter, 3-cylinder gasoline engine and a 10kW (13 hp) Brushless - Permanent Magnet motor mounted to the rear of the engine block as shown in the Figure 2 below ("Autoblog Is Part Of The Yahoo Family Of Brands". Autoblog.Com, 2022).

Figure 2. Honda "IMA" powertrain

IMA uses regenerative braking system to capture the lost energy during braking or deceleration which creates heat, it reuses the power which was converted from kinetic energy into electric energy and is later used to accelerate the vehicle. The process leads to three effects: increased acceleration rate, reduced pressure on the engine, and frequency of brake hardware replacement. It is vital to enhance the acceleration rate, which allows the engine to scale down to fuel-efficient variant without making the vehicle slow or weak hence resulting in a better highway mileage as compared to their counterparts ("How Does An Integrated Motor Assist Operate?". Carfromjapan.Com, 2022). According to a journal article, a Figure 3 represented below gives a clear idea of IMA and the target to reduce

the fuel consumption on Civic 1.5-liter engine ("Development of Integrated Motor Assist Hybrid System: Development of the 'Insight', a Personal Hybrid Coupe, 2022").

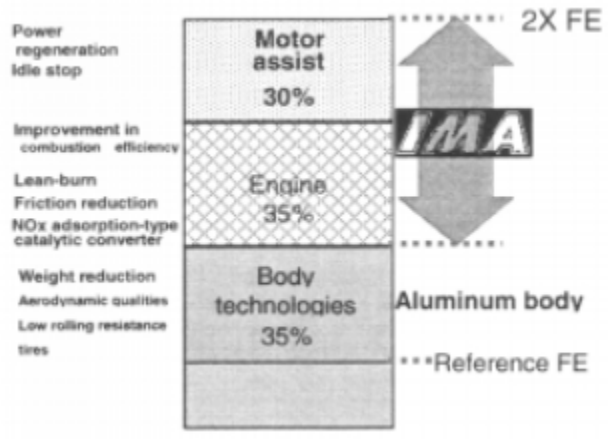

Figure 3. IMA

In this project, the synchronous permanent magnet electric motor is used because of its high torque and power density ("Predictive speed control of a synchronous permanent magnet motor, 2009") which will be placed in front of the 5.3 Liter "LM7" V8 engine and will be connected using a shaft from both ends, joining them using a grid coupler. According to the Altra Motion, "Grid couplings consist of two grooved flanged hubs connected by a tapered steel spring in the form of a grid. Like gear couplings, they require lubrication, but allow for flexibility and efficiency at high speeds or at low speeds with high torque. Grid couplings can operate up to 400 hp/100 rpm" ("Coupling Types For Different Applications". Altramotion.Com, 2022). Moreover, the grid coupling is torsionally soft, which means increase in shock absorption and damp vibration and it is beneficial for detuning a rotor system as this reduces noise and increases operator comfort ("An introduction to flexible couplings, 1996").

Batteries are the most important component in this project and there are different types of it such as Lithium, Alkaline, Carbon Zinc, Silver Oxide and many more but Lithium by far the most used with higher energy density ("Performance of batteries for electric vehicles on short and longer term, 2012"). Lithium based batteries consists of different cathodes such as Lithium Cobalt (LCO), Lithium Iron Phosphate (LFP), Lithium Nickel Manganese Cobalt Oxide (NMC), lithium nickel cobalt aluminum oxide (NCA), and spinal lithium manganese oxide (LMO) have become dominant battery materials for automotive applications compared with LCO because of their abundant resources, stable crystal structures, and low price. However, all these cathodes are evaluated for best fit to use based on costs, safety, performance, and such and Lithium-Ion is the most efficient battery with high energy density ("On the Current and Future Outlook of Battery Chemistries for Electric Vehicles—Mini Review, 2022").

Hence, Panasonic lithium ion "prismatic" cells will be used to power the electric motor and that battery will be controlled by Orion Battery Management system (BMS) to alter the electrical power flow to the motor by taking in functions like temperature of the battery, cell-voltage balance, and such as it is important to prevent any issues that may cause to the electric motor. Along with all these components, wiring them in a proper way is important, so for this project the wiring is divided into 3 types; low current wiring such as for controllers and sensors, high current wiring for BMS and controller and lastly engine compartment wiring such as spark plugs and battery ("Development And Installation Of Battery-Powered Electric Vehicle Wiring System, 2014"). So, the design of this project is similar to the Figure 5 (Bmw (2022)), however electric motor placement is in front of the engine instead and also excluding the Plug-in system. As seen from Figure 4 ("Evaluation of fuel consumption potential of medium and heavy duty vehicles through modeling and simulation, 2010"), it shows the definition of Serial/Parallel powertrain, where an engine can either solely supply power or just by the electric or the power can be divided into both and in this manner both electric and engine will be used equally.

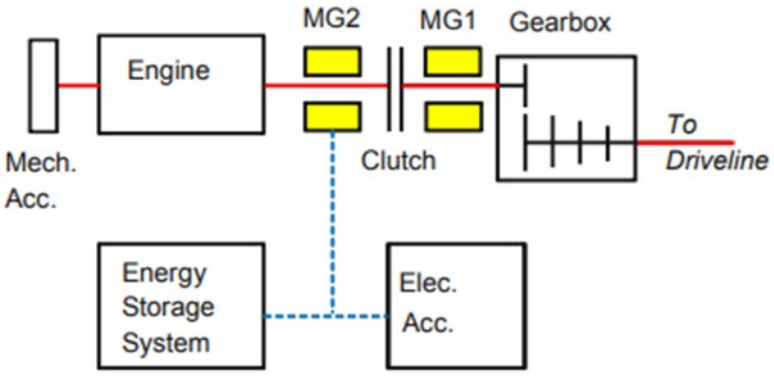

Figure 4. Serial/Parallel Powertrain

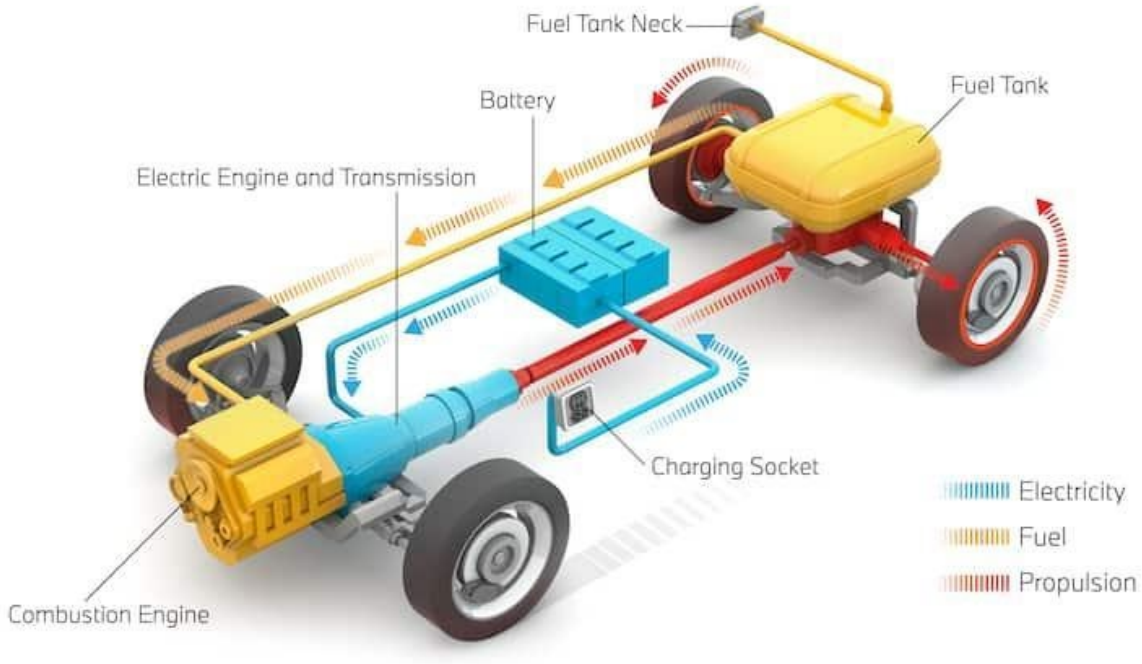

Figure 5. Plug-In Hybrid

1.1 Objectives

The objective of this project is to experiment and observe the recorded results as it will mimic much of the operational aspects of the Honda IMA but at a much higher performance level. After project's objective is achieved, it will be placed in the altered body of Miata, where the hood is extended to fit in the engine and electric motor.

2. Literature Review

The concept of using electric motors is to enhance the power efficiency of the engine is almost in every car nowadays, where placing it next to the engine, with the help of electric power to start the engine, reduces the amount of fuel consumption and pressure on the engine, this method is widely used. It all began in 1899, Ferdinand Porsche was the first one to create a hybrid car, and it was known as Lohner-Porsche Mixte, where it used the gasoline engine to supply the electric motors with power and was placed in the front wheels. At the beginning, the car manufactured over 300 cars, but it started to decline due to its high price and less power compared to the gasoline-powered cars. After a few

decades, in the 1960s, the US Congress introduced a legislation to support the use of electric vehicles to reduce the air pollution caused by gasoline cars. Also, Arab oil embargo caused an unrest in the US with high price and drastic reduction on oil supply rate and currently with war in Ukraine caused the gas prices to rise, many are focusing on the electrical, hybrid, or plug-in hybrid vehicles. First mass-production HEV in the US was in 1999, the Honda Insight, its futuristic look attracted many and after Prius came in the market which became a stiff competitor, then Chevrolet introduced the Volt. The number of automobile industries are building HEV to meet the current demands, this will increase the demand for batteries and electric motors, and this will reduce the dependence on the fossil fuel (A brief history of hybrid cars – carsdirect, 2022). Hence, shifting to EV there will be further improvement which in result may reduce the impact on environment caused by excessive air pollution ("Performance of batteries for electric vehicles on short and longer term, 2012").

3. Methods

The methodology to complete such project is to first design on SolidWorks to observe the complete look of the project and measure the length so that the body of Miata can be altered accordingly. It includes a V8 engine, a Grid Coupler, and an Electric Motor.

After designing a model on SolidWorks, V8 engine was cleaned thoroughly to prevent any foreign material affecting the experiment, it was cleaned using brush, tissues, microfiber cloth, WD-40, and a scraper, where WD-40 was used to loosen the rust and scraper to remove any silicon or glue on the engine. There are many ways to clean an engine such as for this project, only outside part was cleaned but wasn't disassembled as seen in the Figure 6 below, the proper way of cleaning an engine is shown in the schematic ("Selection of a cleaning system for engine maintenance based on the analytic hierarchy process, 2009").

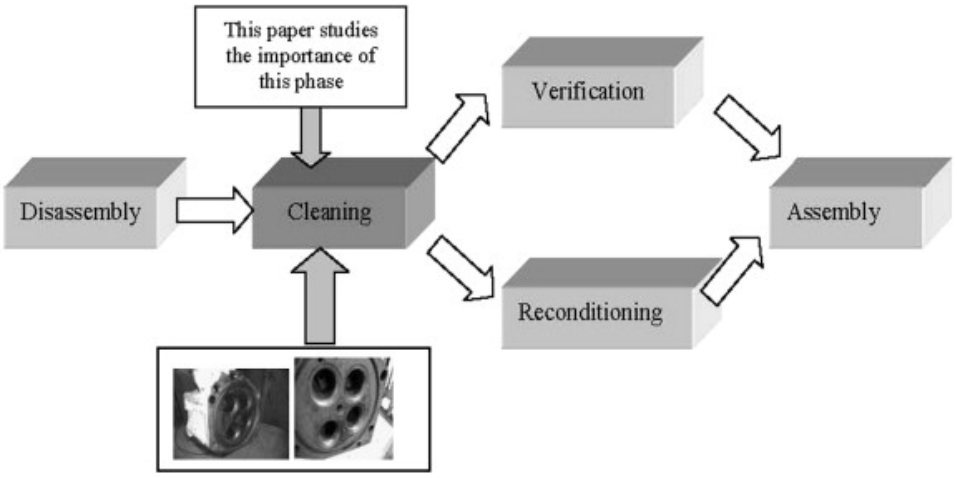

Figure 6. Cleaning Engine Method

Multiple studies were carried out to understand the BMS and it functions. A battery removal study was done as the battery pack available for this experiment was large and only a small part was needed to supply power to electric motor. A general self-study was carried out to understand the concept of EVs and Hybrid vehicles and its benefit in terms of economically and environmentally.

4. Data Collection

- Drawing of V8 Engine on SolidWorks application:

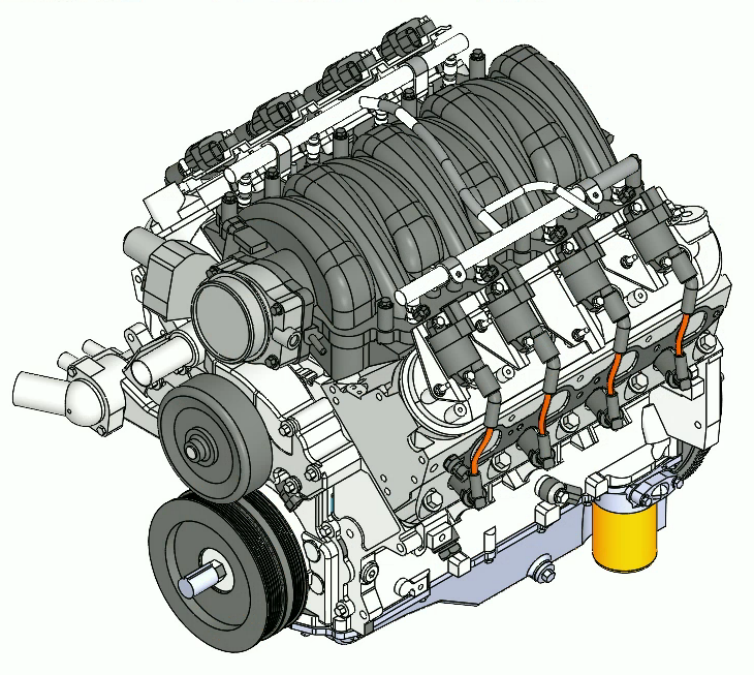

Figure 7. V8 Engine - Isometric View

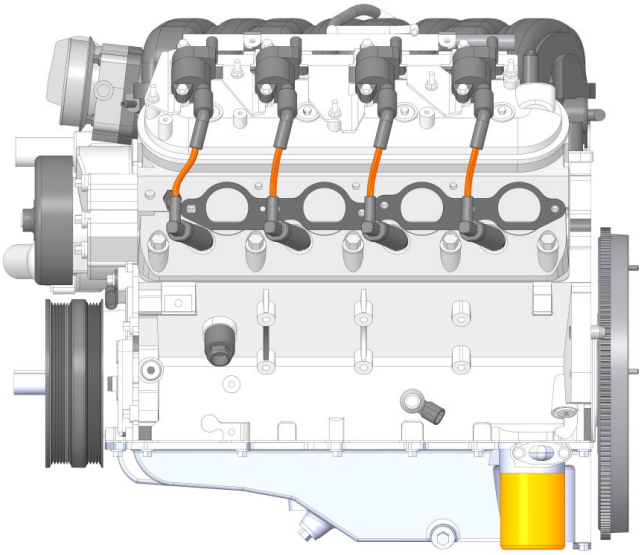

Figure 8. V8 Engine - Side View

This is V8 engine 5.3 Liter "LM7" V8 engine from side view and isometric view to give and a shaft was added in front of the engine which then it will be connected to a grid coupler and this V8 engine file was downloaded from GrabCAD (“The Grabcad Community Library". Grabcad.Com, 2022”).

- Drawing of Grid Coupler on SolidWorks application:

Figure 9. Grid Coupler - Isometric View

This is a grid coupler used for connecting the shafts of electric motor and the engine's shaft, while also absorbing shock and reduce vibration and this part was made in the SolidWorks application.

- Drawing of Electric Motor on SolidWorks application:

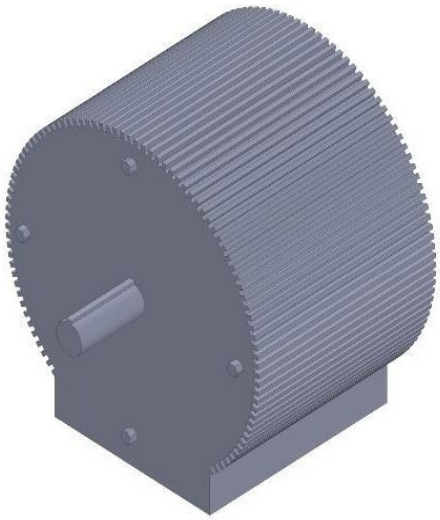

Figure 10. Electric Motor - Isometric View

This is a Synchronous Permanent Magnet Electric Motor, where its shaft will join the grid coupler and will be used to power the engine.

- Assembly view of all the parts on SolidWorks:

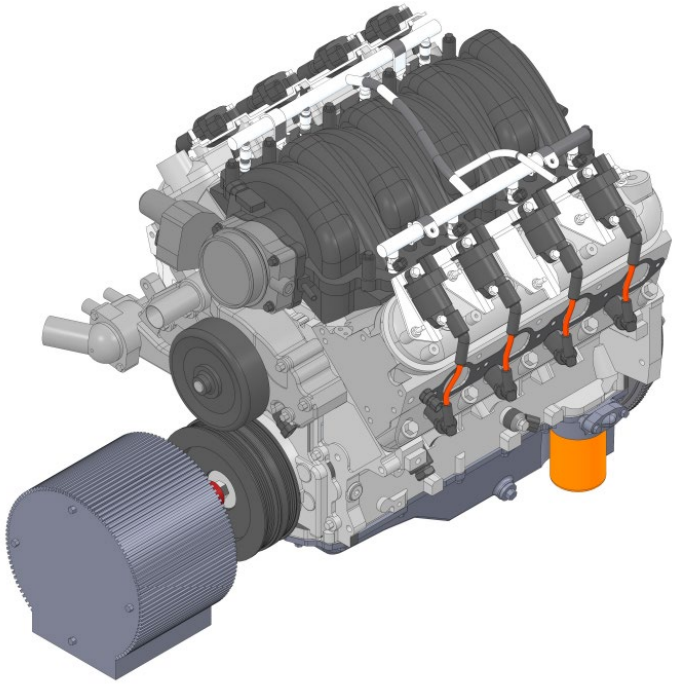

Figure 11. Assembly - Isometric View

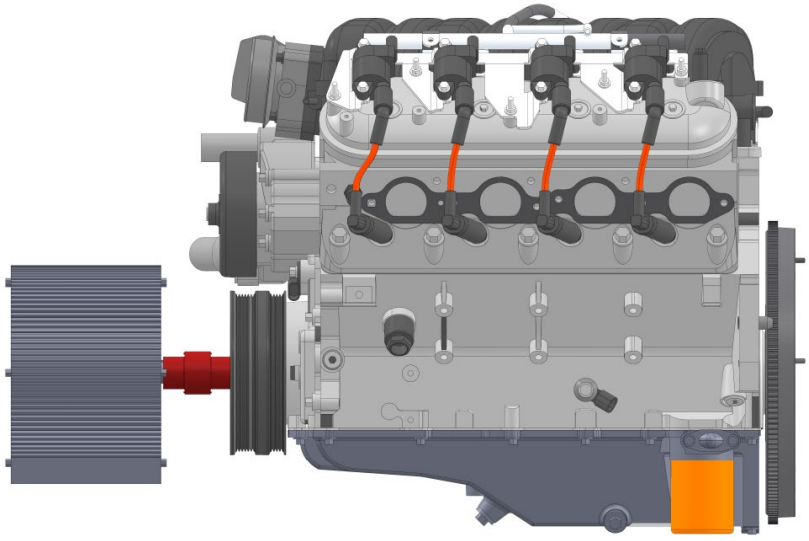

Figure 12. Assembly - Side View

These two are the assembled view of the electric motor, grid coupler, and the V8 engine, there are other parts of this project such as Battery, BMS, Transmission, and Electrical wiring weren't completed due to lack of time and displaying electric motor and engine helps to visualize the idea of this project.

- After the SolidWorks design, cleaning of V8 engine was carried out:

Figure 13. V8 Engine - Before Cleaning

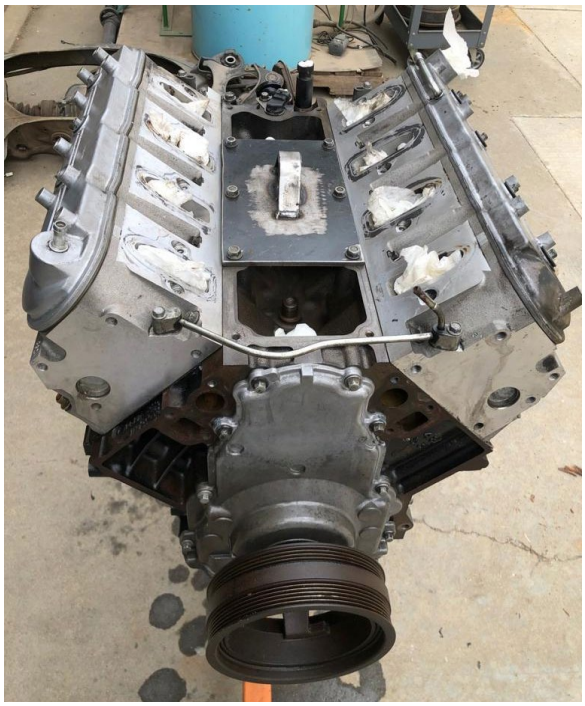

Figure 14. V8 Engine - After Cleaning

As seen from the Figure 13 and 14 above, exterior part of the engine was cleaned using WD40, microfiber cloth, tissues, and scraper, where Figure 13 is before and Figure 14 is after the engine was cleaned.

5. Results and Discussion

Numerical and Graphical results are the expected or referenced figures, where the actual or measured data is much higher in terms of efficiency than the reference values.

5.1 Numerical Results

A study was carried out to observe the difference of technological improvements done on both conventional and hybrid vehicles and according to the study both had significant enhancements in terms of reduction in fuel consumption and hybrid made the highest upgrade with 5.1% fuel saved according to the Figure 15 ("Evaluation of fuel consumption potential of medium and heavy duty vehicles through modeling and simulation, 2010").

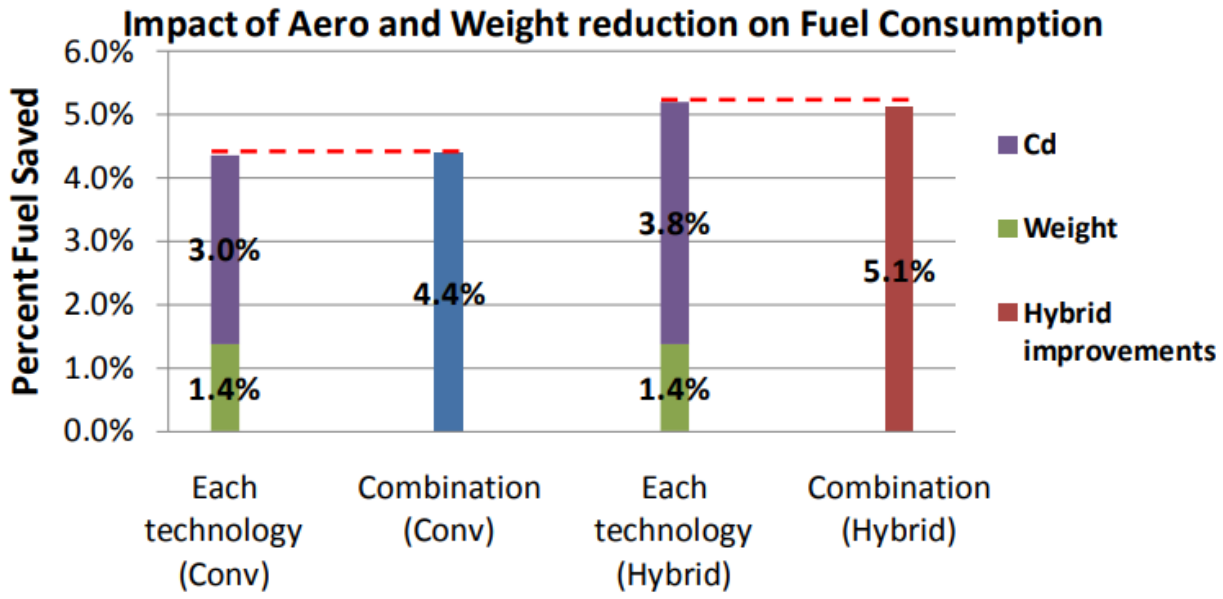

Figure 15. Percentage Fuel Saved

The average expected time for 0-30 mph could be in between 3.8 – 4 seconds for this project whereas in the Table 1, the average time taken to travel from 0-30 mph is 4.2 seconds.

Table 1. Honda Insight Acceleration Test

Sequence	Direction	0 – 30 mph (s)	0 – 60 mph (s)	30 – 55 mph (s)
1	S	3.67	12.58	-
2	N	3.94	11.56	7.15
3	S	4.16	12.38	7.37
4	N	4.18	12.20	7.06
5	S	4.60	13.40	-
6	N	4.64	13.79	-
	Average (s)	4.20	12.65	7.19

5.2 Graphical Results

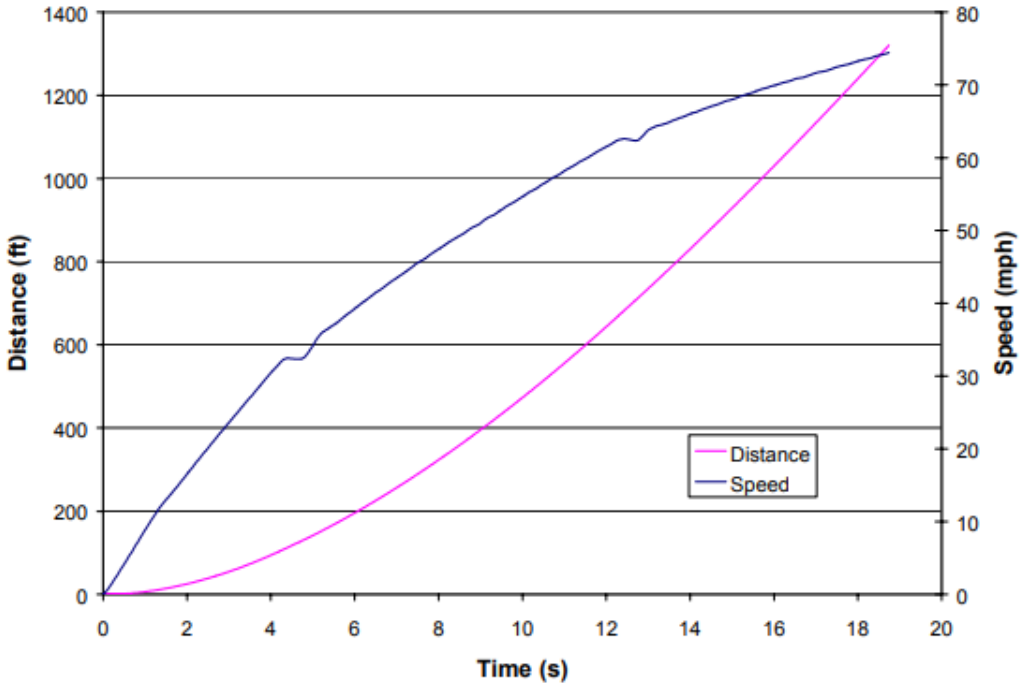

Figure 16. Honda Insight Acceleration Result

The graph in the Figure 16 above shows a logarithmic growth where after a certain speed after 70 mph, the graph indicates a sign of plateau. Meanwhile, from the graph the distance (ft.) increases exponentially and as it increases there is a logarithmic increase in the speed (mph), hence, making them rather proportionally correlated but at some distance the speed becomes plateau, and the distance keeps increasing. For this project, due to lack of funding and time, the experiment to record the actual data wasn't carried out this fall 2022, hence the reference values are presented to show the expected results (Avt.Inl.Gov, 2022).

6. Conclusion

From all the data collected and work done, it can conclude that the parts of objectives were achieved, which were to clean the V8 engine and draw a design on SolidWorks to visualize this theory. Reference values were presented to show the targeted values for this experiment, since due to the lack of funding and time, the entire project wasn't completed such as successfully assembling the parts (V8 engine, Grid Coupler, Electric Motor, Battery, and BMS) physically, from which it would've given some experimented values after diagnosis.

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MEASURE

I would also like to thank Fresno State Transportation Institute (FSTI) for sponsoring this IEOM conference.

Biographies

Eng. Vajidullah Molvizadah is an international graduate student originally from Afghanistan majoring in Industrial Technology at California State University, Fresno. Vajidullah is working for Fresno State Transportation Institute (FSTI) as a website and social media editor and involving in the K-12 Railroad Model competition. He is also a president of the Robotics Club, where he does projects based on engineering and industrial technologies and working on his senior project with Dr. Athanasios Alexandrou and Professor Matthew Crowder about converting a Gasoline car into a Hybrid car for fall 2022 final year project.

Dr. Athanasios Alexandrou is a full-time faculty at California State University, Fresno and teaches undergraduate courses in mechanized agriculture. Research focuses on mechanical weed control as part of organic farming, tractor-implement interaction, soil mechanics with particular interest in soil compaction and its assessment. Research interests

also include assistive technology for people with disabilities so that they will remain engaged in agriculture, technology into the classroom, and ancient Greek technology. Joined the department of Jordon College of Agricultural Sciences and Technology in 2006.

Prof. Matthew Crowder is a part-time faculty at California State University, Fresno and teaches undergraduate courses such as Vehicle Design and Development and other courses mainly focusing on vehicles and with his expertise in vehicle design and engineering, he mentored many students in their final year graduate and undergraduate projects.