Optimization of an Air-Intake System on a Formula SAE Car

Analysis of the Development and Production of the 2011 Ford Focus Electric: Ford's Path to Electrification

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
In Partial Fulfillment of the Requirements of the Degree
Bachelor of Science in Mechanical Engineering

By
Pallavi Kulkarni

October 27, 2022

On my honor as a university student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISORS

Benjamin Laugelli, Department of Engineering and Society
Michael Momot, Department of Mechanical and Aerospace Engineering

Introduction:

In 1981, the Society of Automotive Engineers (SAE) developed a racing series for student engineers, the Formula SAE Competition (FSAE) (*About - formula SAE California*, n.d.). The competition tests the students' abilities to excel in design, manufacturing, testing, analysis, performance, financial management, and business tactics. Virginia Motorsports, a (501) c3 non-profit CIO, has an FSAE Team that competed in the internal-combustion engine (ICE) division for the previous two years. The competition offers an electric division as well, reflecting the up-and-coming electric vehicle market from powerhouses, such as Tesla. To keep up with the automotive industry, the team will begin the development of an electric formula car which is anticipated to compete in the 2024 FSAE Electric division. Therefore, it is imperative to understand the technical and social aspects needed to undertake a seamless transition.

The design side of the FSAE Competition is an important aspect of the competition. In the previous year, the team was awarded very few points for design, due to a lack of complex engineering understanding and higher-level simulation. As the team continues to evolve into electric, it is important to establish favorable design practices that should be emulated in all aspects of the vehicle. I will propose the optimization of the air-intake system on the current ICE drivetrain to increase the performance of the engine and gain points in the design division of the competition. These methods will be set as a standard for optimal design practices for the following year.

While the development of established design practices is crucial, social and economic factors are important to consider when transitioning from an ICE to an electric vehicle (EV). Gaining sponsorships through media publicity and understanding the economic and political aspects of the EV climate are important when presenting the final design to judges at a competition. The judges are treating the developed car as a prototype for large-scale development, as those are the standards that any automotive manufacturer is judged on for their products. A lack of understanding of the social and economical factors will lead to a poor transition between the ICE to electric competition, as the performance of the vehicle in the competition should not be hindered by this change.

To effectively transition from the ICE to the electric division of the FSAE Competition, both technical and socioeconomic factors much be considered concurrently. In this proposal, I outline the technical framework that will be developed and followed to optimize the air-intake system, which will aid in the design competition for the 2023 FSAE competition and be utilized in the following transition year. I apply actor-network theory to the case of the 2011 Ford Focus Electric to understand what human and non-human actors are important to consider when transitioning a vehicle from ICE to electric.

Technical Project Proposal:

The four-stroke ICE is the most widely used combustion engine in commercial automobiles today, producing torque from a piston assembly combined with fuel ignition (see figure 1; *Internal Combustion Engine*, 2022). The air-intake system provides the means to supply important molecules, such as oxygen, to ensure an optimal combustion mixture. Proper design of the air-intake system determines the achievable volumetric efficiency (VE) of the engine, without compromising the fuel efficiency of the vehicle (Winterbone et al., 2001). The desired function of the engine is dependent on the set-up in which it is run; as an example, for vehicles developed in motorsports, maximizing horsepower is of higher concern than minimizing fuel efficiency in many cases. However, for the concern of this proposal and for achieving optimal results at FSAE Competition, the primary focus will be on maximizing power output, while minimizing the effect of fuel efficiency.

The components of the air-intake system are established by the FSAE Competition. These rules are designed to ensure that the various systems within the vehicle can safely operate during the dynamic events (Course Hero, n.d.). The current sequence of the air-intake system is demonstrated as beginning with the air filter, which eliminates unwanted debris from the air that is being drawn, the throttle body, a mechanical valve that allows for air to flow in, a restrictor, which restricts the mass flow rate of air to ensure safe engine operation, a plenum, the air chamber, and the runners, which evenly distribute air from the plenum into the four pistons. The general layout of the air-intake system can be visualized in figure 2 (Bin Salim, 2012).

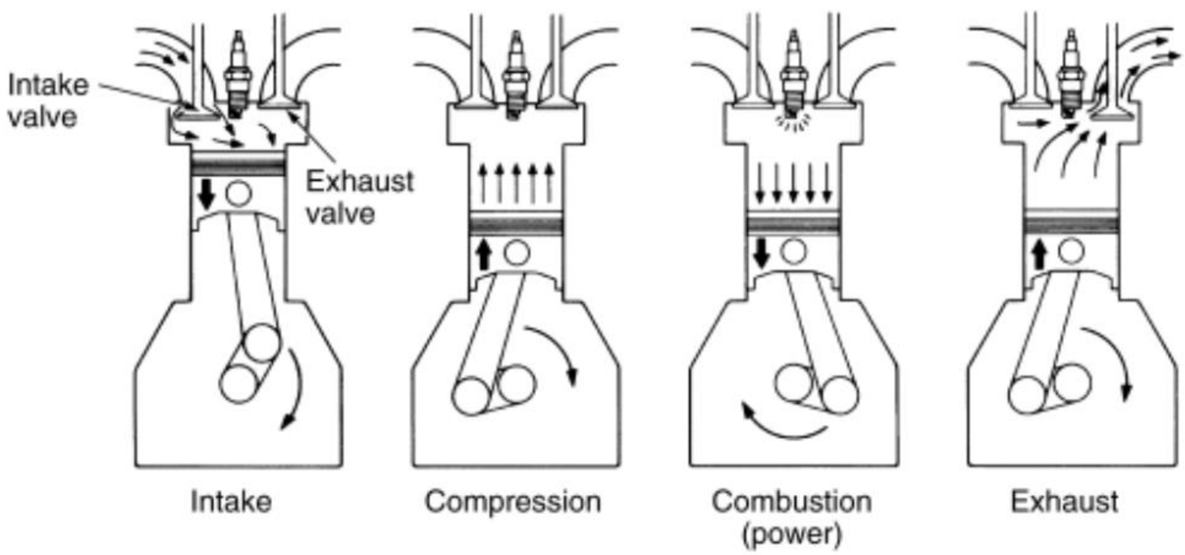

Fig.1. Four Stroke Combustion Schematic (Brady, 2004).

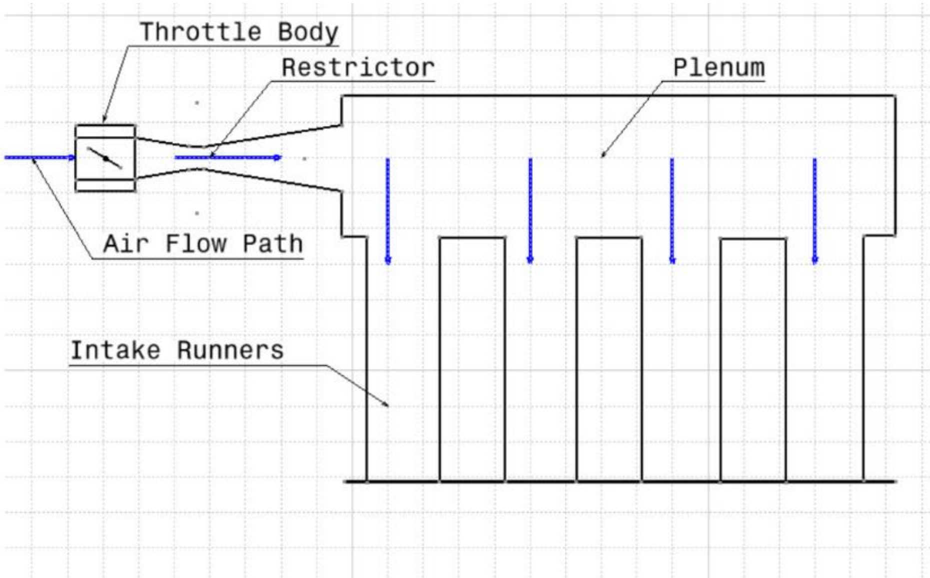

Fig.2. General Air-Intake Structure (Bin Salim, 2012).

The air-intake design for the 2022 Virginia Motorsports FSAE car consisted of a purchased air filter, a butterfly valve throttle body, a nylon-printed restrictor with chopped carbon fiber as structural reinforcement, a plenum 3D-printed from Acrylonitrile Butadiene Styrene (ABS), and Billet Aluminum Runners with a tapered-angle fitting for the fuel injectors. The runner length and angle of taper for the fuel injectors were determined using Engine Analyzer-Pro, an Engine Simulation Software, to simulate which geometry would optimize the power output of the engine. Although this design passed technical inspection at the 2022 FSAE Competition, there were several limitations in this design. Optimizing the airflow of an intake system requires the analysis of unsteady gas dynamics to ensure smooth flow with minimal losses, while also utilizing physical concepts, such as resonance, to maximize the VE of the engine (Winterbone et al., 2001). As a primary example, the lack of attention to computational-fluid dynamics (CFD) analysis of restrictor and plenum geometry hindered the previous design from grasping a complete quantitative understanding of how to optimize the airflow and pressure distribution throughout the system.

This technical project aims to design an air-intake system through viable CFD and engine simulation to maximize achievable horsepower while increasing fuel efficiency. The technical team members will use ANSYS, a CFD software, to understand how the mass air flow rate and pressure are affected by geometric constraints of the intake design and friction. We will also utilize GT-Suite, an engine simulation software provided by SAE, to determine the optimal length of the runners and the volume of the plenum to maximize horsepower and improve fuel efficiency. We will generate horsepower and torque versus RPM graphs, VE versus RPM graphs, and tabulated data tables with control parameters, such as pressure, volume, length, etc., and how these effects the VE and fuel efficiency of the engine. The design methods used during the scope of this technical project will be documented and used as a reference when designing the electric counterpart. The design techniques and CFD software can be used for mirrored systems, such as the liquid cooling of a battery pack, on the electric powertrain.

STS Project Proposal:

The Ford Focus Electric was unveiled at the 2011 Consumer Electronics Show (CES) in Las Vegas, as Ford's first EV for a compact car design (Cunningham, 2011). The 5-door hatchback was made in response to the 2010 Nissan Leaf, which introduced similar vehicle infrastructure (Harrison, 2021). The Ford Focus Electric implemented a completely electric powertrain unit into the existing chassis of its ICE counterpart and was produced on the same production line as ICE and Diesel vehicles (Harrison, 2021). Ford's first iteration boasted a 23-kilowatt-hour lithium-cooled battery pack with a 76-mile range, as calculated by the United States Environmental Protection Agency (Harrison 2021). The production of the Ford Focus

Electric began in the United States in 2011 and was released in Europe following the 16-million-pound investment by Ford in their production facility in Saarlouis, Germany (Eis, V. & Thomasen, F, 2013). In 2017, the EV implemented a 33-kilowatt-hour battery pack, which was able to sustain a driving range of 115 miles (Harrison, 2021). After a total of close to 9,000 sales within the United States, the production of the all-electric Ford Focus was terminated in 2018 (Harrison, 2021).

The demise of the Ford Focus Electric is currently attributed to factors involving design issues, performance issues, and the unestablished electric infrastructure at the time (Harrison, 2021). As an example, since the design involved packaging an electric drivetrain unit in the chassis of the ICE car, the Ford Focus Electric was never truly intended to be an electric car (Harrison, 2021). The compact size of the car left minimal room for consumer storage, placing the electric car at a disadvantage to its ICE equivalent (Harrison, 2021). The sudden retrofit of an ICE drivetrain into an electric powerhouse was not the standalone oversight. The aforementioned interpretation fails to evaluate external pressure from competitors, the influence of the political agenda, and poor marketing strategies as a contribution to the dissolution of the Ford Focus Electric. Ford did not build their production infrastructure, business strategies, and marketing tactics around the EV. Ford began as a manufacturer of predominantly ICE and Diesel vehicles and procured this reputation over the past century. Apart from the lack of technical understanding, socioeconomic factors influenced the development of the Ford Focus Electric and are important in gaining a complete understanding of the semi-failure of providing a seamless transition from ICE to electric-vehicle production. I retain the use of semi, as the insights learned from the Ford Focus Electric served as lessons learned for current success stories in the electric-vehicle arena for Ford.

I argue that in tandem with the technical aspects lacking from the model, the external pressures from the success of competitors, the political climate about EVs at present, and the failed marketing strategies led to the ultimate termination of the 2011 Ford Focus Electric. I will draw on the science, technology, and society (STS) framework of Actor-Network Theory (ANT) to analyze the human and non-human actors at play. ANT prescribes and analyzes a network builder who recruits human and non-human actors to accomplish a particular goal. The generation and stabilization of the developed network are known as translation (Callon, 1986). I will evaluate advertisements and marketing tactics put forth by Ford, state legislature surrounding EVs and electric infrastructure at the time, and accounts from Ford and its competitors' executives via press releases and interviews to gain an understanding of the actor-network built and the important social factors that influence the transition of vehicle infrastructure from ICE to electric.

Conclusion:

The technical project will deliver a design framework based on the optimization of an air-intake system through comprehensive simulation and quantitative engineering analysis. The STS research paper will deliver a complete socio-economical understanding of the transition that occurred with the 2011 Ford Focus Electric, to establish the important non-technical aspects to consider to enable a smooth transition between ICE and EV. ANT will be applied to this case study to further understand the development of the network and which human and non-human actors were at play. The combined analysis of the technical and STS framework will serve as a proving ground for how to ensure a successful transition for the Virginia Motorsports FSAE team from ICE to electric.

Total Word Count: 1,799

References

About - formula SAE California. SAE International. (n.d.). Retrieved October 17, 2022, from https://www.sae.org/attend/student-events/formula-sae-california/about

Bin Salim, M. (2012). *Development of variable intake system for spark ignition engine*. Faculty of Mechanical Engineering, Universiti Malaysia Pahang. UMP Institutional Repository.

Brady, R. N. (2004). Internal combustion (gasoline and diesel) engines. *Encyclopedia of Energy*, 515–528. https://doi.org/10.1016/b0-12-176480-x/00089-9

Callon, M. (1986). *Some* elements *of a sociology of translation: Domestication of the scallops and the fishermen of St. Brieuc Bay*. J. Law.

Cunningham, W. (2011, January 7). *Ford unveils the All-Electric Focus*. CNET. Retrieved October 17, 2022, from https://www.cnet.com/tech/tech-industry/ford-unveils-the-all-electric-focus/

Eis, V., & Thomasen, F. (2013, June 10). *Ford Focus Electric*. Ford Media Center. Retrieved December 7, 2022, from https://media.ford.com/content/fordmedia/feu/fr/en/products/cars/focus/focus-electric.html

FSAE_Rules_2023_V1.pdf - rules 2023 version 1.0 1 Sept 2022 Formula SAE® Rules 2023 version 1.0 1 Sept 2022 © 2022 SAE International Page 1 of: Course hero. FSAE_Rules_2023_V1.pdf - Rules 2023 Version 1.0 1 Sept 2022 Formula SAE® Rules 2023 Version 1.0 1 Sept 2022 © 2022 SAE International Page 1 of | Course Hero. (n.d.).

Retrieved October 17, 2022, from https://www.coursehero.com/file/169768755/FSAE-Rules-2023-V1pdf/

Harrison, T. (2021, May 20). *Forgotten Electric Cars: The Ford Focus Electric*. Top Gear. Retrieved October 17, 2022, from https://www.topgear.com/car-news/electric/forgotten-electric-cars-ford-focus-electric

Internal Combustion Engine. Internal combustion engine - Energy Education. (2022, May 10). Retrieved October 18, 2022, from https://energyeducation.ca/encyclopedia/Internal_combustion_engine

Loh, E. (2009, September 9). *2010 Nissan Leaf First Look - Motor Trend*. MotorTrend. Retrieved October 17, 2022, from https://www.motortrend.com/reviews/2010-nissan-leaf-first-look/

Winterbone, D. E., & Pearson, R. J. (2001). *Design techniques for engine manifolds: Wave action methods for IC engines*. Society of Automotive Engineers.