RECTILINEAR PERFORMANCE MODEL FOR AN ELECTRIC INDYCAR

by

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This thesis on the electrification of an IndyCar is a culmination of the collective support and guidance from family, mentors, professors, colleagues, and individuals who have been pivotal in shaping my academic and professional journey.

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ABSTRACT

This motorsport thesis explores the complete electrification of an IndyCar by simulations. Initial research was conducted on stock IndyCar specifications, and concurrently, a sequential approach was developed for MATLAB-based simulations to generate comprehensive results. The study aims to integrate extensive insights gained from courses such as Vehicle Dynamics, Aerodynamics, Data Acquisition, and Electric Powertrains, alongside practical experience from racing internships. The goal is to comprehend the impact of this conversion on engineering parameters. The analysis specifically emphasizes the engineering aspects, with a particular focus on the longitudinal dynamics of the vehicle through quarter-mile simulations.

1. INTRODUCTION

1.1 About the IndyCar series

The IndyCar, born in 1909, has become a global motorsport icon captivating audience worldwide. Fueled by the prestigious Indianapolis 500, the series offers dynamic racing on diverse tracks, showcasing driver skill and adaptability. A commitment to open competition in chassis and engine design propels IndyCar to the forefront of technological innovation, emphasizing cutting-edge engineering.

What makes IndyCar even more enticing is its international driver lineup, creating a diverse and thrilling competition that resonates with fans globally. The series transcends borders, uniting enthusiasts in their shared passion for high-speed racing. In essence, the IndyCar's enduring popularity is a result of its rich history, versatile challenges, commitment to innovation, and a global platform that unites fans from all corners of the world.

Figure 1: 1953 IndyCar [1]

Over the last decade, IndyCars have been powered by a 2.2-liter twin-turbocharged V-6 engine, and a pivotal shift is anticipated with the series embracing hybrid technology post the 108th running of the Indy 500 in May 2024. Notable features include an additional 150 horsepower from

the hybrid system, strategically deployable throughout the race. In a departure from Formula 1's DRS, IndyCar's hybrid boost lacks a time limit, relying instead on teams effectively managing the system's recharge, with the specifics of this regeneration process still being fine-tuned.

To accommodate the added weight of the hybrid system, IndyCar has implemented lighter chassis components, including the aero screen, gearbox, and bellhousing. This upcoming evolution promises to bring a heightened level of strategic complexity and potentially faster races to the IndyCar series. However, amid the gradual global shift towards electric vehicles, speculation arises about the possibility of IndyCars transitioning to full electrification in the coming years. The success of electric racing series such as FIA Formula E, MotoE, and eTouring Car World Cup underscores the global acceptance of electric motorsports. However, the prospect of IndyCars transitioning entirely to electric propulsion poses a multifaceted question without a definitive answer at present.

1.2 Arguments for Electrification

The push for electrification in IndyCar racing rests on several compelling arguments that collectively advocate for a more sustainable and technologically advanced future for the sport. One of the primary rationales is rooted in sustainability, with electric vehicles offering substantial environmental benefits that contribute significantly to the reduction of emissions and broader efforts to mitigate climate change. By embracing electrification, IndyCar has the potential to make a meaningful impact in fostering a more environmentally conscious approach to motorsports.

Another key argument centers around technological advancement, particularly the continuous improvements witnessed in battery technology. These advancements hold great promise in addressing crucial limitations related to range and charging times. As battery technology evolves, the potential to overcome these challenges becomes increasingly tangible, paving the way for electric vehicles to compete at the highest levels of performance and endurance in the world of IndyCar racing.

Furthermore, the argument for electrification is reinforced by the shifting landscape of public interest. The increasing global popularity of electric cars reflects a broader societal trend towards cleaner and more sustainable modes of transportation. This growing interest in electric vehicles may exert influence on the sport itself, compelling IndyCar to align with evolving preferences and address mounting environmental concerns.

By embracing electric power, IndyCar can position itself at the forefront of this global shift towards more sustainable and eco-friendly transportation solutions. In essence, the arguments for electrification in IndyCar converge on sustainability, technological advancement, and public interest. Embracing these principles positions the sport to be not only competitive and cutting-edge but also aligned with the evolving values and preferences of a global audience increasingly attuned to environmental consciousness and technological innovation.

1.3 Challenges to Electrification

The pursuit of electrification within the domain of IndyCar racing is met with a set of challenges that warrant careful consideration. Foremost among these challenges is the existing state of battery technology, which may not presently align with the rigorous demands in terms of endurance and speed characteristic of IndyCar events, particularly the iconic Indy 500. Addressing this challenge necessitates a sustained focus on advancements in battery technology to ensure that electric vehicles can meet and exceed the high-performance standards traditionally associated with combustion engines in motorsports.

A considerable challenge lies in the establishment and maintenance of fast-charging infrastructure at racetracks. The development of a comprehensive and efficient charging network demands a significant investment, prompting critical inquiries into the feasibility and scalability of such infrastructure within the current racing landscape. Effectively tackling this challenge is vital to ensure that electric vehicles in IndyCar possess the requisite infrastructure support to compete at the highest levels and navigate the demands of an entire racing season.

Figure 2:USA's first level 3 motorsport fast charging facility at Atlanta Motorsports Park [2]

A further substantial obstacle is rooted in the traditional appeal of IndyCar racing, where the distinct sound and performance characteristics of gasoline-powered engines are considered integral components of the overall racing experience by specific segments of fans and stakeholders. The transition towards electrification necessitates a nuanced approach that acknowledges and respects these cherished aspects of the sport while simultaneously embracing the innovations associated with electric power. Striking this delicate balance is imperative to garner widespread acceptance and support for the transition to electric-powered IndyCars.

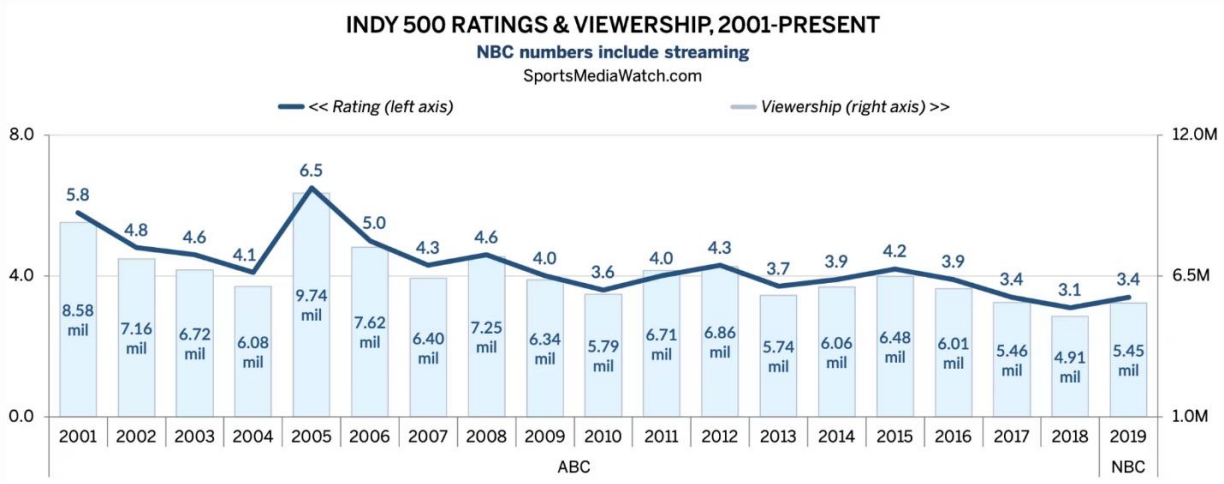

Figure 3: Indy 500 ratings and viewership [3]

In summary, the challenges inherent in the electrification of IndyCar encompass technology limitations within the current state of battery technology, the considerable investment required for charging infrastructure, and the resistance from individuals who hold a deep appreciation for the traditional appeal of combustion engines. Overcoming these challenges is essential to ensure a seamless transition to electric-powered racing while preserving the essence of IndyCar's esteemed heritage and meeting the expectations of fans and stakeholders in a formal and respectful manner.

1.4 Current Steps

IndyCar is in the process of transitioning to hybrid powertrains in 2024, combining gasoline engines with electric motors, offering a middle ground that explores the benefits of electrification while retaining traditional elements.

The series actively engages in research and development to further integrate electric technologies. To address the challenges associated with this transition, there are viable solutions. Firstly, investing in research and development to enhance battery technology specifically tailored for IndyCar's demanding requirements can overcome current limitations.
Collaborations with leading tech companies can expedite progress in this area. Secondly, addressing the charging infrastructure challenge requires a strategic partnership between IndyCar and relevant stakeholders, including government bodies and private investors, to share the financial burden and ensure the widespread availability of fast-charging stations at racetracks.

Lastly, preserving the traditional appeal of racing with the roar of engines can be achieved through innovative sound engineering solutions that replicate the visceral experience of combustion engines, ensuring the continuation of the unique atmosphere loved by fans and stakeholders.

Finding a balance between sustainability, technology, and tradition will be key to successfully navigating the electrification of the IndyCar Series. Regardless of these aspects, this research focuses exclusively on the core engineering of the vehicle during this transition.

2. LITERATURE REVIEW

2.1 Current IndyCar Setup

The IndyCar chassis is currently represented by the Dallara DW12, originally known as the Dallara IR12. Its dimensions include a length of 5012.3 mm, width of 2011 mm, and height of 1127.9 mm, with a maximum track width of 1940 mm. The wheelbase ranges from 2997.2 mm to 3073.4 mm, depending on the use of original or weight distribution correction a-arms. The chassis minimum weight is 1565 lbs, with a weight distribution of approximately 43% front and 57% rear. Fuel capacity is 18.5 gallons, reduced from the original 19 gallons in 2011 and further decreased from the 2011 fuel capacity of 22 gallons.[4]

Figure 4: Dallara DW12 Chassis [5]

IndyCar's engine lineup offers a mix of single- and twin-turbocharged configurations, adhering to a four-cycle, four-valves-per-cylinder setup. The designated engines include the Chevy IndyCar V6 by Chevrolet, the HI12R by Honda, and the DC00 by Lotus. All engines share a 2200 cubic cm displacement, a notable decrease from the 2011 value of 3500 cubic cm. With a maximum of six cylinders, these engines can reach up to 12,000 RPM, generating an estimated horsepower ranging from 550 to 700.

The fuel system operates on E85 Ethanol, facilitating direct injection with a maximum of two injectors per cylinder. This diverse engine roster underscores IndyCar's commitment to both performance and technological innovation. [6]

Figure 5: Chevrolet’s 2024 IndyCar Engine [7]

IndyCar's transmission system, supplied by Xtrac, showcases precision and performance in every detail. The clutch system, incorporating a three-plate carbon design with a robust steel housing, is sourced from AP Racing, identified by the model number CP8153-DE03. This advanced clutch configuration ensures efficient power transfer and reliability under the demanding conditions of IndyCar racing.

Complementing the clutch, the transmission itself is a testament to engineering excellence. Manufactured by Xtrac and labeled with the model number 1011, it operates as a sequential type with six gears. The cutting-edge transmission system incorporates a paddle-shifting actuation mechanism, skillfully provided by MegaLine. This seamless integration of components not only contributes to the overall performance but also reflects IndyCar's commitment to utilizing top-tier technology for a competitive edge on the track. [8]

Figure 6: Xtrac’s P1011 IndyCar Series Gearbox [8]

The suspension system stands as a pinnacle of engineering sophistication, offering a meticulous balance between responsiveness and control. Employing the double A-Arm type with pushrod mechanisms for both the front and rear suspensions, this setup epitomizes precision and adaptability on the racetrack.

A distinctive feature of the suspension system is the inclusion of a third spring and anti-roll bar, adding an extra layer of fine-tuning capabilities. This design not only enhances the car's stability during high-speed maneuvers but also allows teams to tailor the setup to specific track conditions and driving preferences. In a testament to the pursuit of optimal performance, the damper vendors are unrestricted, providing teams with the flexibility to choose the most suitable dampers for their setups. Moreover, the allowance for inerters within the damper housing adds an extra dimension to the range of tuning possibilities, enabling teams to fine-tune the suspension's response to varying track surfaces and dynamic race conditions.

The aerodynamic kit combines precision and adaptability to enhance performance on the racetrack. The front wing assembly is a masterpiece of aerodynamic design, featuring a fixed main element alongside second and third adjustable elements per side.

This intricate setup allows for dynamic adjustments, enabling teams to fine-tune the aerodynamics based on specific track conditions and driving preferences. Complementing the front wing, the rear wing assembly consists of a fixed main element coupled with a single adjustable upper element. This configuration optimizes downforce and stability while providing teams with a degree of customization to suit various racing scenarios.

At a blistering speed of 200 mph, the aerodynamics generate approximately 4600 pounds of downforce, ensuring optimal traction and handling on the track. Simultaneously, drag is effectively managed at 1500 pounds, striking a delicate balance between speed and stability. Notably, this performance is achieved with one stroke per tunnel, emphasizing the efficiency and precision of the aerodynamic package.

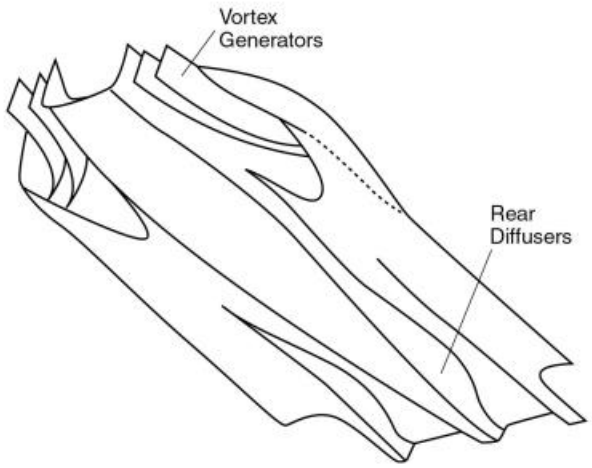

Figure 7: Underbody panel for an IndyCar [9]

The system utilizes carbon discs and pads, a testament to the series' commitment to cutting-edge materials and technology. Supplied by the renowned manufacturer Brembo [10], the monobloc aluminum calipers represent the epitome of braking efficiency. Both front and rear calipers feature a six-piston design, providing consistent and powerful braking performance under the demanding conditions of IndyCar racing.

The brake disc dimensions further underscore the meticulous engineering behind the braking system, with a diameter of 328 mm and a minimum thickness of 30 mm. This configuration ensures effective heat dissipation and durability, crucial elements for maintaining braking performance throughout the rigors of a race. The carbon brake pads, with a thickness of 24 mm, contribute to the system's overall efficiency and responsiveness.

Figure 8: IndyCar’s braking system. [11]

The Electronic Control Unit (ECU) is supplied by McLaren, designated as the 400i. Cosworth Electronics serves as the vendor for the dash, data logging system, and chassis wiring loom. The drive-by-wire system and hand clutch vendors are chosen by each manufacturer.
The wheels are of the single-lug type, supplied by vendors such as BBS, OZ, and Avus. Front dimensions are 10 inches wide by 15 inches in diameter, while rear dimensions are 14 inches wide by 15 inches in diameter. The wheel nut torque is specified at 430 lbs.

IndyCar's tire specifications underscore the critical role of tire technology in achieving peak performance on diverse racetracks. Supplied by Firestone, the slick-type tires are tailored for precision and grip, emphasizing the series' commitment to cutting-edge materials and performance. For road and street courses, the front tire dimensions are 10.0/25.8R15, weighing 18 lbs.

In contrast, the rear tires boast dimensions of 14.5/28.0R15, with a weight of 23 lbs. [12] This carefully calibrated combination ensures optimal traction and handling, crucial elements for navigating the dynamic challenges presented by IndyCar circuits.

3. METHODOLOGY

3.1 Parameter Modification

Now since we know the engineering specifications of the current IndyCar, let us analyze the potential impact on these parameters if the vehicle would go electric. The transformation of an IndyCar into an electric vehicle involves comprehensive modifications across various subsystems. With the integration of heavy battery packs, the suspension system becomes a focal point for adjustment. The weight distribution of the car undergoes a substantial change, prompting the need for a recalibration of suspension components and setup to accommodate this new distribution and enhance overall handling.

3.1.1 Motor

The Tesla Model S Performance motor emerges as an exceptionally promising candidate for propelling an electric IndyCar, tailored to meet the exacting demands of high-performance motorsports. With a commanding power output of up to 615 kW (825 bhp) and an impressive torque of 1,300 N·m, the Tesla motor surpasses the capabilities of the current IndyCar engine. This not only promises an increase in straight-line speed but also introduces enhanced acceleration, a critical factor in optimizing racing performance.

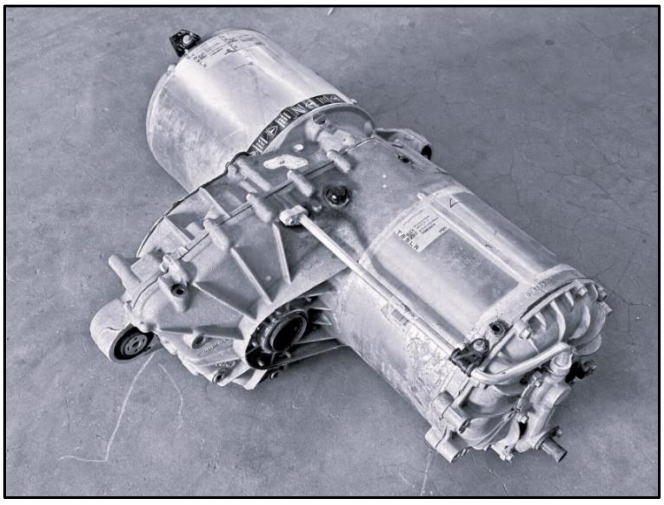

Figure 9: Tesla Model S Performance Motor [13]

One of the standout advantages lies in weight efficiency, as the Tesla motor weighs a mere 70 lbs, significantly reducing the overall weight burden compared to the existing IndyCar engine's 248 lbs. This weight reduction directly translates into improved handling, heightened agility, and increased responsiveness on the track.

The dual-motor configuration, featuring distinct drive ratios for the front and rear units, introduces a sophisticated approach to power distribution. This adaptability allows for meticulous fine-tuning of the car's handling characteristics, addressing the nuanced demands of diverse tracks in the IndyCar circuit.

The Tesla motor's high RPM capability, reaching up to 18,000 RPM in certain configurations, aligns seamlessly with the dynamic nature of IndyCar racing. This expansive RPM range offers unparalleled versatility, enabling precise tuning for optimal performance across a spectrum of racetracks. Constructed primarily from durable materials like steel and copper, the Tesla motor not only ensures robust power transmission but also withstands the demanding conditions of motorsports. The integration of regenerative braking capabilities enhances overall energy efficiency, contributing to extended race distances without the need for frequent recharging.

The motor's characteristic of delivering instant torque provides an immediate response to driver inputs, contributing significantly to a more responsive and agile racing experience. This attribute proves particularly advantageous in tightly contested racing scenarios and during acceleration phases. Moreover, the Tesla motor's variable power output, ranging from 335 kW to 475 kW, showcases a remarkable adaptability to different racing conditions. This flexibility becomes a pivotal asset, allowing teams to optimize performance based on the specific demands of each track within the IndyCar circuit. The streamlined and simplified mechanical structure of electric powertrains, characterized by fewer moving parts compared to internal combustion engines, not only reduces maintenance requirements but also enhances overall reliability over the course of a racing season.

In summary, the Tesla Model S Performance motor stands out as a technologically advanced and competitive solution for an electric IndyCar. With its potent combination of power, weight

efficiency, adaptability, and advanced materials, it holds significant promise for meeting the high-performance demands of IndyCar racing. While further refinement and integration efforts are necessary, the Tesla motor presents a compelling foundation for ushering in the electric era of IndyCar, seamlessly fitting into the existing chassis and regulations with precision.

3.1.2 Battery

The choice and specification of the battery pack play a crucial role in the success of the project. The requirements for such a battery pack are multifaceted and must balance several key considerations. Firstly, the energy capacity of the battery pack must be calculated to support the peak power output of the Tesla motor, which stands at an impressive 615 kW (825 bhp). This calculation involves estimating the energy requirement for typical race durations, ensuring that the pack can sustain high power delivery throughout the entirety of the race. In addition to energy capacity, the battery pack must also meet the voltage and current requirements of the Tesla motor to facilitate efficient power delivery. Compatibility with the motor's voltage range and the ability to supply high currents during acceleration are essential for maximizing performance on the track.

Weight considerations are paramount in motorsport, and the battery pack must strike a delicate balance between energy capacity and weight to meet the minimum weight requirement of the IndyCar chassis while still providing sufficient power. Furthermore, the packaging of the battery pack within the confines of the IndyCar chassis must be carefully engineered to ensure optimal aerodynamics and weight distribution. Safety features are of utmost importance to prevent thermal runaway, overcharging, and over-discharging of the battery pack. Advanced monitoring systems, temperature sensors, and fail-safe mechanisms are essential to maintain the integrity of the pack under the demanding conditions of racing. Effective thermal management is critical to regulate battery temperature and prevent overheating during high-performance driving. The battery pack should incorporate advanced cooling systems, such as liquid cooling or active air cooling, to maintain optimal operating temperatures and extend battery life.

Modularity and scalability are desirable attributes that allow for flexibility in configuring the battery pack to meet specific race requirements and accommodate future upgrades. Additionally, integration of regenerative braking technology enables the battery pack to capture and store energy

during deceleration, improving overall energy efficiency and extending the car's range during the race.

By carefully considering these factors and requirements, the selected battery pack will serve as a reliable and high-performance power source for the electrified IndyCar, unleashing the full potential of the Tesla Model S performance motor on the racetrack. The lithium-ion battery packs used in Formula E are potentially the most suitable and proven type of battery pack for motorsports application. This can be justified through the following factors.

Energy Capacity and Performance:
The energy capacity of a Formula E battery pack, typically around 54 kWh, aligns closely with the energy requirement calculated for the Tesla Model S performance motor. This ensures sufficient power delivery to support the high-performance characteristics of the IndyCar, including its peak power output of 615 kW and torque of 1,300 N·m.

Voltage and Current Rating:
Formula E battery packs operate at a high voltage of around 800 volts, which matches the requirements of the Tesla motor. This compatibility ensures efficient power delivery and performance optimization, as both components are designed to work within similar voltage ranges.

Weight Consideration:
The weight of a Formula E battery pack, approximately 385 kg, is relatively lightweight considering its energy capacity. This is crucial for the IndyCar conversion, as maintaining a low overall weight is essential for achieving optimal handling and performance characteristics on the track.

Safety and Reliability:
Formula E battery packs are engineered with robust safety features and undergo rigorous testing to ensure reliability and durability under extreme racing conditions. These safety standards and

performance benchmarks make them well-suited for the demanding environment of motorsport, providing peace of mind for drivers and teams.

Cooling Systems and Thermal Management:
Both Formula E and IndyCar applications require effective thermal management systems to regulate battery temperature and ensure optimal performance during races. The advanced cooling systems employed in Formula E battery packs, such as liquid cooling, can be adapted for use in the electrified IndyCar to maintain ideal operating temperatures and extend battery longevity.

Modularity and Scalability:
The modular design of Formula E battery packs allows for easy integration and scalability, enabling teams to customize the energy capacity based on specific race requirements or technological advancements. This flexibility is advantageous for the electrified IndyCar project, as it allows for future upgrades and optimizations as battery technology evolves.

Regenerative Braking:
The regenerative braking technology utilized in Formula E cars, which captures kinetic energy during deceleration and braking to recharge the battery pack, enhances energy efficiency and extends the car's range. Integrating this feature into the electrified IndyCar further enhances its performance and sustainability on the track.

Overall, leveraging a Formula E battery pack for the electrification of an IndyCar using a Tesla Model S performance motor offers a synergistic combination of performance, reliability, safety, and efficiency, making it an ideal choice for high-performance electric racing applications.

3.1.3 Chassis

Transitioning an IndyCar to a fully electric configuration utilizing the Tesla Model S Performance motor within the Stock Dallara DW12 chassis represents a feasible and innovative prospect. The electric motor's robust specifications, boasting a power output of up to 615 kW (825 bhp) and a torque of 1,300 N·m, align well with the performance demands of IndyCar racing. The immediate

torque delivery characteristic of electric motors could significantly enhance acceleration and responsiveness on the track, contributing to an exciting and dynamic racing experience.

One of the notable advantages of adopting the Tesla electric motor is the substantial reduction in weight. Weighing only 70 lbs, the electric motor is significantly lighter than the existing IndyCar engine, which weighs 248 lbs. This reduction not only contributes to improved energy efficiency but also allows for more favorable weight distribution within the car. The Dallara DW12 chassis, known for its adaptability and versatility, provides an excellent platform for accommodating the unique requirements of the electric powertrain. The chassis' adjustable components, such as a-arms, allow for fine-tuning and optimizing weight distribution based on the characteristics of the electric motor.

The compact size of electric motors facilitates easier integration within the existing Dallara DW12 chassis. This, coupled with the weight reduction, could lead to a more favorable center of gravity, positively influencing the car's handling characteristics. Furthermore, the electric motor's high maximum rpm of 18,000 aligns with the high-revving nature of IndyCar racing, contributing to maintaining the excitement and dynamic performance associated with traditional IndyCar engines.

The Dallara DW12 chassis, with its existing weight distribution of approximately 43% front and 57% rear, complements the dynamics of electric vehicles, where battery placement often influences a rear-weight bias. This could aid in achieving an optimal weight distribution for enhanced performance and stability on the track. Additionally, the transition to an all-electric configuration aligns with the global push for sustainability and technological innovation in motorsports. It positions IndyCar at the forefront of the industry's evolution, showcasing a commitment to environmentally friendly practices and staying relevant in the rapidly advancing automotive landscape.

In conclusion, the integration of the Tesla Model S Performance motor into the Stock Dallara DW12 chassis offers a promising avenue for the future of electric IndyCar racing. The combination of power, torque, weight advantages, and the adaptability of the chassis positions the proposal as a compelling exploration of high-performance electric motorsport, demonstrating a commitment to both innovation and sustainability.

3.1.4 Aerodynamics

The powerful and lightweight characteristics of the electric motor demand a nuanced reassessment of the existing aerodynamics. With the Tesla motor's immediate torque delivery and reduced weight, aerodynamicists must optimize the car's traction and stability while adjusting for the absence of a traditional exhaust system. The adaptability of the Dallara chassis becomes pivotal, allowing for seamless integration of the electric powertrain and a redefined aerodynamic balance.

The current aerodynamic setup, finely tuned for conventional engines, undergoes a transformative iteration. Both the front and rear wing assemblies require meticulous adjustments to align with the immediate torque delivery of the electric motor and maintain downforce and stability at speeds of 200 mph.

3.1.5 Brakes

The adaptability of the Dallara chassis allows for modifications to key braking components, ensuring alignment with the new weight dynamics introduced by the electric powertrain. Considerations include adjustments to brake bias, distribution, and heat management. The redesign extends to the carbon brake pads, which may undergo changes to optimize friction characteristics while accommodating regenerative braking demands. In essence, aerodynamicists face the challenge of balancing efficiency and responsiveness in the evolving landscape of electric motorsport.

3.1.6 ECU

Electronic components experience significant changes in an electric IndyCar. The Electronic Control Unit (ECU) supplied by McLaren must be adapted or replaced with a unit specifically designed for electric powertrains. Additionally, the drive-by-wire system and other electronic elements require reconfiguration to align with the distinct requirements of an electric motor, ensuring seamless integration and optimal performance.

3.1.7 Weight distribution

The shift to a fully electric IndyCar, integrating the Tesla Model S Performance motor into the Stock Dallara DW12 chassis, prompts a significant reevaluation of weight distribution. With the Tesla motor boasting 615 kW and a reduced weight of 70 lbs, compared to the conventional 248 lbs, aerodynamicists face the challenge of recalibrating the traditional 43% front and 57% rear weight bias. The Dallara DW12 chassis' adaptability, offering options for adjusting the wheelbase and fine-tuning distribution, becomes crucial in leveraging the advantages of the electric powertrain. Meticulous adjustments are imperative to harmonize the weight dynamics, considering variables like regenerative braking and torque delivery nuances. Navigating these intricacies, aerodynamicists aim to optimize the revised weight distribution, ensuring it enhances the electric powertrain's advantages while maintaining the agility, responsiveness, and aerodynamic efficiency synonymous with top-tier IndyCar racing. The evolution toward electric propulsion demands a sophisticated approach, emphasizing the pivotal role of aerodynamicists in reshaping the balance and optimizing overall performance in the dynamic landscape of electric motorsport.

3.1.8 Tires and wheels

While the wheels may retain their single-lug type, adjustments to dimensions become likely to accommodate the altered weight distribution and handling characteristics of an electric IndyCar. Tires also come under scrutiny, with optimization needed to account for the unique torque characteristics and weight distribution of an electric vehicle. The reduction in heat generated by the absence of an internal combustion engine may impact tire temperature management, prompting adjustments in tire design and specifications.

3.2 Calculations

3.2.1 Powertrain Model

Depending on the voltage capability, electric motors can run at peak power or at continuous power. Operating at peak power allows the motor to deliver best highest possible torque for a short period of time, whereas continuous power can provide moderate performance for prolonged distance.

Since the quarter mile run is expected to be completed in less than 15 seconds, it is feasible to assume that the motor can be operated at peak power.

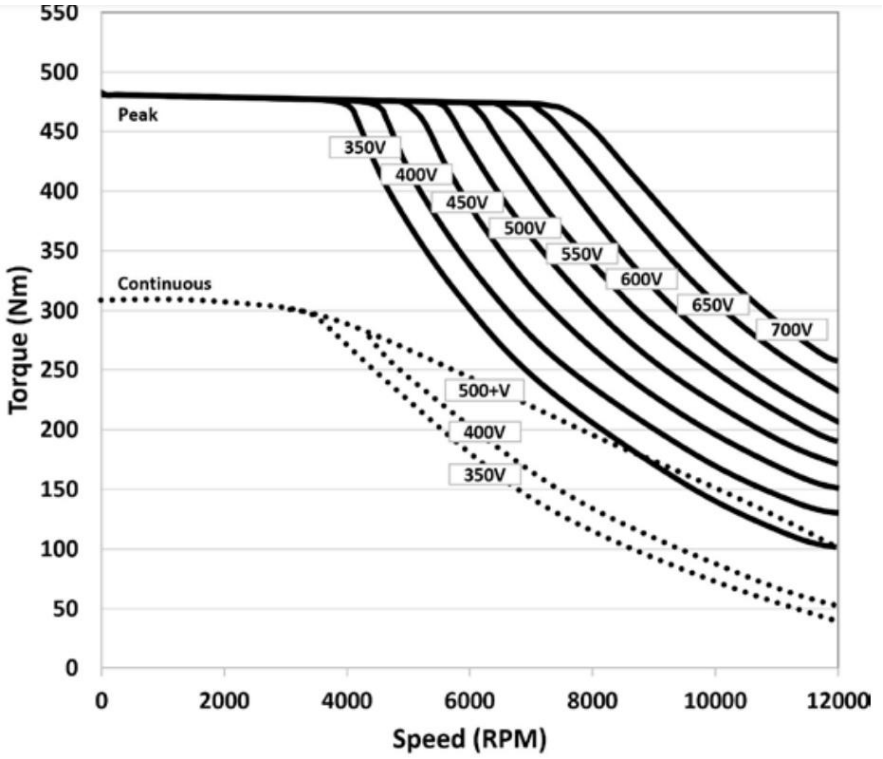

Figure 10: Peak Power vs Continuous power characteristics for electric motors. [14]

The observed behavior of electric motors in the image above can be justified by the dyno test results for Tesla Model S performance motor. The torque is nearly constant until a certain rpm before dropping. The image below shows the power and torque curves for three variants of the Tesla Model S electric motor.

The red curve showcases a high peak power output of approximately 320 kW at around 40 mph speed, accompanied by substantial peak torque of about 600 Nm within a similar speed range. However, the power curve sharply declines beyond 75 mph, indicating a limitation in sustaining high power output at higher speeds. Additionally, the torque curve exhibits a gradual decline after reaching its peak, suggesting a relatively linear decrease in torque as speed increases.

In contrast, the blue curve exhibits a slightly lower peak power output of around 225 kW at approximately 42 mph, with peak torque reaching around 425 Nm within a similar speed range. Notably, this powertrain demonstrates a more favorable characteristic of maintaining higher power output over a wider RPM range compared to the red curve. Furthermore, the torque curve of the blue curve declines more gradually after reaching its peak, indicating a more sustained torque delivery across various speeds.

The green curve shares similarities with the blue curve in terms of peak power output and torque characteristics. It also peaks at around 275 kW and 440 Nm, respectively, but at a slightly higher speed of approximately 50 mph. However, what sets the green curve apart is its ability to maintain higher power and torque outputs over an even wider RPM range compared to both the red and blue curves.

Overall, the curves highlight a trade-off between peak power output and the ability to maintain higher power and torque over a broader RPM range. The red curve excels in peak power but struggles to sustain it at higher speeds, while the blue and green curves offer a more balanced approach with the ability to maintain relatively high outputs over a wider range of speeds. The green curve demonstrates superior performance in this regard, indicating a more versatile powertrain design.

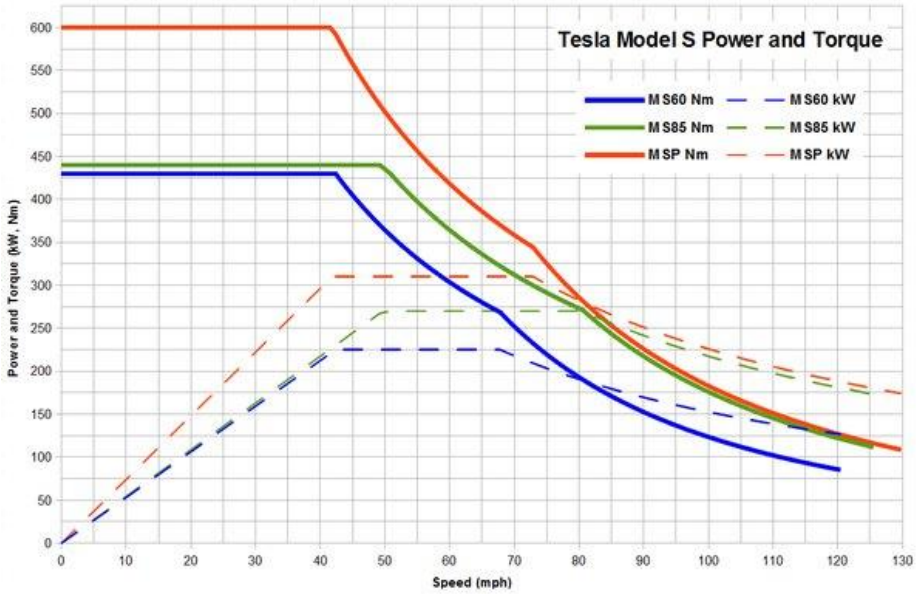

Figure 11: Dyno Test Results for Tesla Model S motor. [14]

In electric vehicle motors, the centrifugal clutch plays a crucial role in optimizing power transfer to the drivetrain. This component engages based on centrifugal force, smoothly connecting the motor to the wheels. A constant reduction in clutch slippage with respect to motor rpm is assumed in this study, emphasizing the need for precision in engineering.

This mechanism allows the motor to operate efficiently across a range of speeds, balancing torque and speed for optimal performance. The gradual reduction in slippage enhances energy efficiency, contributing to improved range and overall operational capabilities of the electric vehicle. In summary, the centrifugal clutch is a sophisticated solution that refines power delivery in EV motors, showcasing the ongoing advancements in electric vehicle technology.

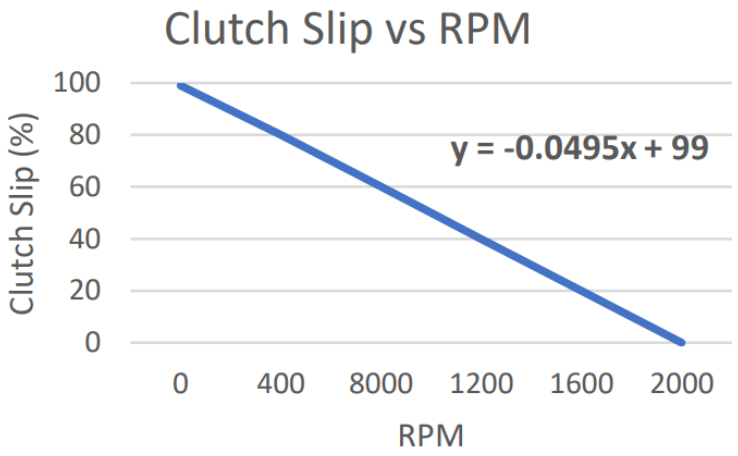

Figure 12: Centrifugal Clutch slip vs RPM

Four research papers were studied, and the following formulas were learned to calculate various important parameters, including angular acceleration, tire slip, coefficient of friction, and kinematic properties such as distance, vehicle velocity, and vehicle acceleration. The papers include works by John M. Starkey, Scott Gray, David Watts (SAE 881733)[15], P. D. Spanos, D. Hernandez, R. Tapia (SAE 2008-01-2961)[16], Michael R. Petersen, John M. Starkey (SAE 960521)[17], and Louis J. Faix (SAE 983076)[18].

The angular acceleration of the motor will be calculated using the following described below. This formula essentially equates the product of the rear wheel traction and the radius of the tires to the sum of various factors influencing the motor torque and acceleration, including the motor torque itself, the inertia of the powertrain, and the heat dissipation function.

$$F_r \times r_t = \zeta_a \times \eta_a \times \left[T_e - \left(\frac{\pi}{30}\right) \times \dot{n}_e \times I_{eq} + H_c\right] \quad (1)$$

F_r is Rear Wheel Traction. r_t is the radius of the rear tires. η_a is a coefficient representing the efficiency of the axle. It accounts for additional losses and inefficiencies in power transmission. T_e is Motor Torque. $\dot{n}_e$is Motor Angular Acceleration. I_{eq} is the equivalent inertia with clutch slip.

It represents the combined inertia of the motor and axle system, accounting for the effects of clutch slip. H_c is a Heat Dissipation function.

In the above formula, the following part represents the equivalent inertia with clutch slip:

$$I_{eq} = \left(\mathrm{I}_e + \left(\frac{\mathrm{I}_a}{\eta_a * \zeta_a^2} \right) \times \left(1 - \frac{\mathrm{i}_c}{100} \right) \right) \quad (2)$$

Where, I_e is the inertia of the motor. This inertia accounts for the rotational mass and inertia of components such as shafts, gears, and wheels in the drivetrain. I_a is the inertia of the axle. Clutch slip occurs when there's a difference in rotational speeds between the input and output shafts of the clutch system. i_c is the clutch slip ratio, expressed as a percentage.

Additionally, the following part represents Heat Dissipation function:

$$H_c = \left(\frac{\pi}{30} \right) \times \left(\frac{\mathrm{I}_a}{\eta_a \times \zeta_a^2} \right) \times \left(\frac{\frac{\mathrm{di}_c}{\mathrm{dt}}}{100} \right) \times \mathrm{n}_e \quad (3)$$

Where $\frac{\mathrm{di}_c}{\mathrm{dt}}$ reflects the rate at which the centrifugal clutch slip changes over time. This change in slip directly affects the power distribution and mechanical interactions within the powertrain, leading to heat generation. The overall expression is scaled by $\frac{\pi}{30}$, which is a conversion factor to convert rotational units to time-based units.

3.2.2 Tire Model

Tire slip is a measure of the difference between the speed of the tire's contact patch and the speed of the vehicle. Calculation of tire slip is crucial for analyzing vehicle handling, traction, and overall performance.

The tire slip will be calculated using the following formula:

$$\dot{x} = \frac{\pi}{30} \times \frac{r_t}{\zeta_a} \times \left(1 - \frac{i}{100} \right) \times \left(1 - \frac{\mathrm{i}_c}{100} \right) \times \mathrm{n}_e \quad (4)$$

The Burkhardt Longitudinal Tire Model is a mathematical model used in vehicle dynamics to describe the relationship between the coefficient of friction and the slip ratio. Slip ratio is a measure of the difference between the actual speed of the wheel and the speed of the vehicle. The formula for estimating the coefficient of friction using this model is given by:

$$u_i = u_t \times \left(1.35 \times \left(1 - e^{-0.175 \times i}\right) - (0.008 \times i)\right) \quad (5)$$

The peak coefficient of friction, which represents the maximum achievable coefficient of friction between the tire and the road surface, is denoted by u_t. The estimated coefficient of friction is denoted by u_i. Lastly, the slip ratio is denoted by i.

Tractive force

This is the force that propels the vehicle forward or backward. It's influenced by various factors such as the coefficient of traction, weight distribution, road surface conditions, and powertrain characteristics. The coefficient of traction represents the grip between the tires and the road surface. It's influenced by factors such as tire type, tire condition, road surface condition, and slip ratio. The slip ratio is the ratio of the difference between the speed of the tire and the speed of the vehicle to the speed of the vehicle. In a rear-wheel-drive vehicle, a significant portion of the vehicle's weight is typically distributed over the rear wheels due to the location of the engine and drivetrain components. This weight provides the necessary normal force for the tires to generate traction.

By multiplying the coefficient of traction by the weight supported by the rear wheels, this formula provides an estimation of the traction force available at the rear wheels of a rear-wheel-drive vehicle. This traction force is essential for determining the vehicle's acceleration, braking, and cornering capabilities. Understanding and optimizing this traction force is crucial for vehicle dynamics engineers to enhance vehicle performance, stability, and control.

$$F_r = u_i \times W_r \quad (6)$$

Rolling Resistance

This force is caused by the deformation of the tire as it rolls over the road surface and other factors such as tire construction, tire pressure, road surface condition, and vehicle speed. This coefficient quantifies the level of resistance encountered by the tires as they roll over a surface. It is a measure of how efficiently the tire rolls over the road surface. In this case, C_{rr} is given as 0.015, which is a typical value for many vehicles and road conditions. The rolling resistance of the tires ($R_{f,r}$) can be calculated as:

$$R_{f,r} = C_{rr} \times W_{f,r} \tag{7}$$

Tire Growth Model

Since aerodynamic lift is proportional to square of vehicle velocity, it creates an increase in the radius of tire. This can be studied through the following equation:

$$r = (0.00717 \times x) + r_s \tag{8}$$

Where r is the instantaneous radius of tire. x is vehicle velocity in Ft/lbs. r_s is tire radius when the vehicle is stationary.

3.2.3 Dynamic rigid body mode

The free body diagram serves as a simplified representation of the vehicle, isolating it from its environment and illustrating the external forces at play. From this diagram, we derive three fundamental equations based on Newton's laws:

Firstly, the sum of forces along the horizontal axis accounts for all external forces acting on the vehicle in the horizontal direction. These forces include propulsion, frictional forces, and aerodynamic effects. By equating the sum of these forces to the mass of the vehicle times its acceleration, we can analyze its linear motion along the horizontal plane.

Secondly, we consider the sum of moments about the front tires. This equation focuses on the torques or rotational forces acting on the vehicle about the front tire contact patches. It encompasses factors such as steering inputs, weight transfer, and lateral forces. Balancing these moments allows us to assess the vehicle's rotation and stability characteristics, particularly during cornering maneuvers.

Thirdly, we examine the sum of moments about the rear tires. Similar to the previous equation, this one focuses on the torques acting about the rear tire contact patches. It accounts for factors such as traction distribution, longitudinal weight transfer during acceleration and braking, and rear-wheel drive dynamics. Balancing these moments provides insights into the vehicle's acceleration, braking, and overall longitudinal stability.

By systematically applying these equations, we gain a comprehensive understanding of how external forces and torques influence the vehicle's motion and stability. This analysis is crucial for optimizing vehicle design, performance, and handling characteristics to meet desired specifications and safety standards. It forms the basis for the development of advanced vehicle control systems and the refinement of automotive engineering practices.

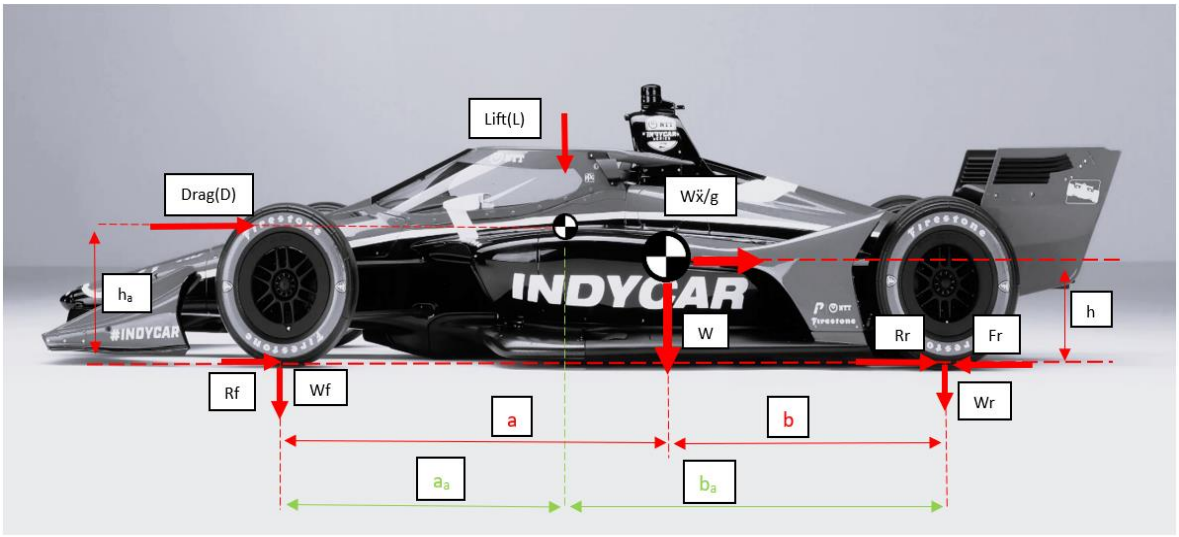

Figure 13: Free body diagram for the vehicle.

In the above image, W represents the total weight of the vehicle. W_f and W_r represent the divided weights on front and rear tires respectively. R_f and R_r represent the coefficient of rolling resistance on front and rear tires respectively. F_r represents traction force. The aerodynamic forces, drag and lift, are represented by D and L respectively. Talking about the dimensions, h and h_a represents the height of center of gravity and center of pressure respectively. a and b represent the distance of the front and rear tires from the center of gravity location respectively.

By summing forces along the horizontal axis (F_x) = 0

$$\ddot{x} = \left(\frac{g}{W}\right) \times \{F_r - R_f - R_r - D - [W \times \sin(\theta)]\} \tag{9}$$

Equation 9: By summing moments about the front tires (M_a) = 0.

$$\frac{W_r}{W} = \left(\frac{a}{l} \times cos\theta\right) + \left(\frac{h}{l} \times sin\theta\right) + \left(\frac{L \times a_a}{W \times l}\right) + \left(\frac{D \times h_a}{W \times l}\right) + \left(\frac{x \times h}{g \times l}\right) \tag{10}$$

Summing moments about the front tires (M_b) = 0.

$$\frac{W_f}{W} = \left(\frac{b}{l} \times cos\theta\right) - \left(\frac{h}{l} \times sin\theta\right) + \left(\frac{L \times b_a}{W \times l}\right) - \left(\frac{D \times h_a}{W \times l}\right) - \left(\frac{x \times h}{g \times l}\right) \tag{11}$$

Additionally, the increments in motor rpm, and vehicle's velocity, displacement can be calculated on the principles of Euler Forward Difference method, as a function of step time and their respective acceleration.

$$n_e = n_{eo} + (\dot{n_e} \times \Delta t) \tag{12}$$

Where, n_e represents new motor rpm. n_{eo} represents motor rpm from previous iteration (In the simulation loop), $\dot{n_e}$ represents motor angular acceleration.

$$x = x_o + (\ddot{x} \times t) \tag{13}$$

Where, x represents new vehicle velocity. x_o represents vehicle velocity from previous iteration(In the simulation loop), $\ddot{x}$ represents vehicle acceleration.

$$s = s_o + (x \times t) + \left(\frac{1}{2} \times \ddot{x} \times t^2\right) \tag{14}$$

Where, s represents new position of the vehicle. s_o represents vehicle position from previous iteration (In the simulation loop).

Aerodynamic forces:

Drag force is a resistance force exerted by the fluid (air) against the motion of the object through it. It acts opposite to the direction of motion. Drag force can be calculated as:

$$D = 0.5 \times \rho \times C_d \times A \times V^2 \quad (15)$$

Equation 15: Lift is a force that acts perpendicular to the direction of motion and is typically associated with aircraft, while downforce is a force that acts in the opposite direction to lift and is commonly encountered in automotive applications, particularly in high-performance vehicles. Lift (or downforce) can be calculated as:

$$L = 0.5 \times \rho \times C_l \times A \times V^2 \quad (16)$$

Where, ρ represents density of air in slugs/ $ft^{3.}$ $C_{d,l}$ represents the coefficient of drag and lift respectively. A is the frontal area in ft^2. V is vehicle velocity in ft/sec. Following are the assumptions of the entire project, The quarter mile run was performed on a flat road with zero grade.

3.3 Simulation

Conducting a quarter-mile straight-line simulation with modifications to key engineering parameters in Vehicle Dynamics and Aerodynamics using MATLAB, offers several valuable benefits. Firstly, the quarter-mile scenario is a standard performance metric in motorsports. By simulating the electrified IndyCar's performance over this distance, we can assess its acceleration, speed, and position in a context that is widely recognized and provides a direct comparison to traditional combustion engine counterparts. The simulation allows us to specifically analyze the impact of electrification on powertrain, and tires.

This is crucial in understanding how the transition to electric power affects the acceleration, stability, and handling of the IndyCar during a short, high-intensity sprint. Furthermore, the quarter-mile simulation provides a focused evaluation of the electric powertrain's efficiency and performance in a real-world racing scenario. It allows us to quantify and compare the results against established benchmarks, helping to validate the effectiveness of the modifications made to achieve optimal electrified IndyCar performance.

In summary, the quarter-mile simulation serves as a condensed and intense testing ground, enabling a detailed examination of the modified parameters' impact on the electrified IndyCar's acceleration and dynamics. The outcomes derived from this simulation contribute valuable insights into the efficacy of the electrification process, aiding in the formulation of informed conclusions and recommendations for the integration of electric power in IndyCar racing.

3.3.1 Simulation Structure

The methodology is a sequential approach incorporating concepts discussed above. Iteration loops were generated by applying logical statements in terms of time, distance, gear shift, rpm, and tire slip. A standard step time of 0.001 seconds was considered for the iterations. After combining the knowledge extracted from the four research papers mentioned earlier, the following sequence of calculations was developed. [19]

1. Motor Torque through motor rpm
2. Powertrain inertia (Equation 2)
3. Motor angular acceleration (Equation 1)
4. Motor angular velocity (Equation 12)
5. Tire slip (Equation 4)
6. Track coefficient of friction (Equation 5)
7. Rear Wheel traction (Equation 6)
8. Vehicle Drag (Equation 15)
9. Vehicle Lift (Equation 16)
10. Vehicle Acceleration (Equation 9)
11. Vehicle Velocity (Equation 13)
12. Vehicle Position (Equation 14)
13. Weight on rear wheel (Equation 10)
14. Weight on front wheel. (Equation 11)

4. RESULTS

In the realm of professional motorsport engineering, the generation and comprehensive analysis of dynamic performance graphs play a pivotal role in thoroughly assessing the quarter-mile performance characteristics of an IndyCar starting from rest. These dynamic representations, encompassing a multitude of parameters such as position, speed, front weight, rear weight, and traction against time, serve as fundamental tools for understanding and optimizing various facets of the vehicle's performance. By delving into these detailed graphs, engineers gain invaluable insights into how the IndyCar evolves over time during the intense quarter-mile sprint.

These dynamic representations not only provide a snapshot of the IndyCar's performance at different stages of the race but also offer a holistic understanding of its overall behavior. By examining the correlations between different performance parameters depicted in these graphs, engineers can discern patterns and trends that guide the coordinated adjustment of the IndyCar's setup, aiming for maximum efficiency and performance enhancement. This holistic approach to performance optimization ensures that every aspect of the vehicle's dynamics is carefully considered and fine-tuned for optimal results on the track.

Furthermore, the utilization of advanced computational tools, such as MATLAB simulations, to generate these dynamic performance graphs further enhances their significance. By employing sophisticated simulation techniques, engineers can create virtual representations of the IndyCar's behavior under various conditions, allowing for detailed analysis and comparison with real-world performance data. This iterative and data-driven approach not only validates the accuracy of the simulation but also supports the continuous refinement of the IndyCar's quarter-mile performance characteristics.

In the ever-evolving world of motorsport engineering, where precision and performance are paramount, the generation and analysis of dynamic performance graphs represent a crucial step towards achieving the ultimate goal of optimal racing capabilities. By harnessing the power of data-driven insights and advanced simulation techniques, engineers can unlock the full potential of the IndyCar, pushing the boundaries of speed and performance on the racetrack.

4.1 Position vs Time

Position versus time graphs provide a macroscopic view of the IndyCar's trajectory, offering insights into the efficiency of its path and highlighting potential areas for improvement. The curve on the graph manifests as a seamlessly ascending line, embodying the hallmark behavior of an entity experiencing uniform acceleration.

Around the 6-second mark, the position registered on the graph stands at approximately 375 feet. This signifies that within the initial half of the quarter-mile stretch, the IndyCar adeptly amassed considerable velocity, propelled by its formidable acceleration capabilities.

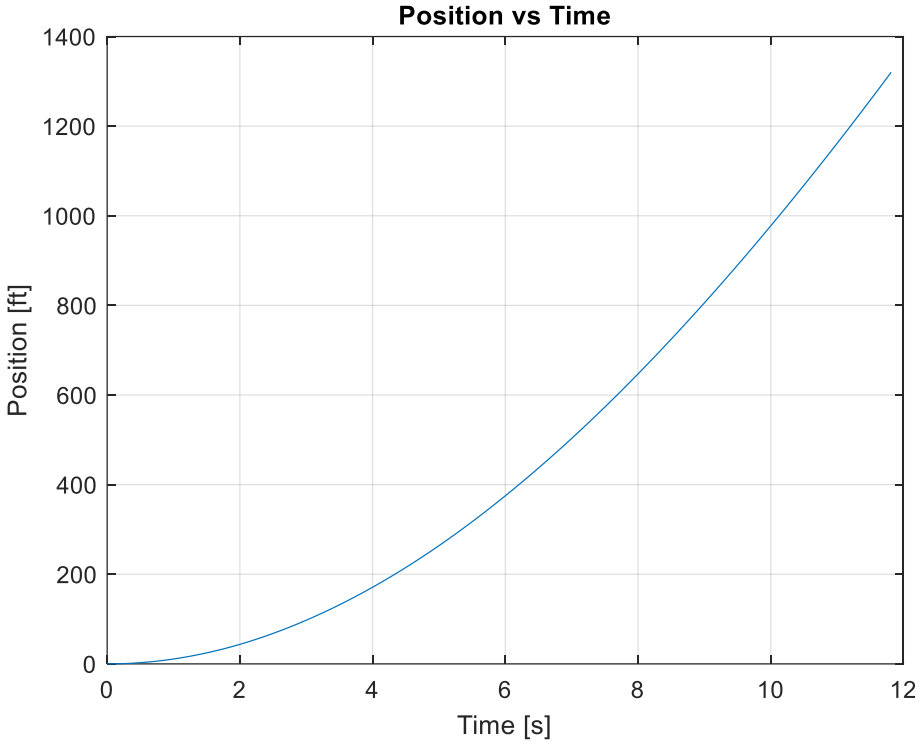

Figure 14: Position vs Time Graph

The curve's inclination continues to intensify, mirroring the escalating velocity of the car as it traverses the remaining distance. As the IndyCar reaches the quarter-mile milestone at 1320 feet at 11.81 seconds, the curve's pronounced steepness implies that the vehicle has achieved a high-top speed within that specific distance.

4.2 Velocity vs time

The graph delineates the velocity-time profile of the IndyCar, showcasing a linear progression in velocity over the quarter-mile distance. At the 6-second mark, the velocity registers at 120 ft/s, equivalent to 81.81 mph. This data point signifies that the IndyCar has achieved a substantial speed by the midpoint of the quarter-mile stretch, a testament to its remarkable acceleration capabilities.

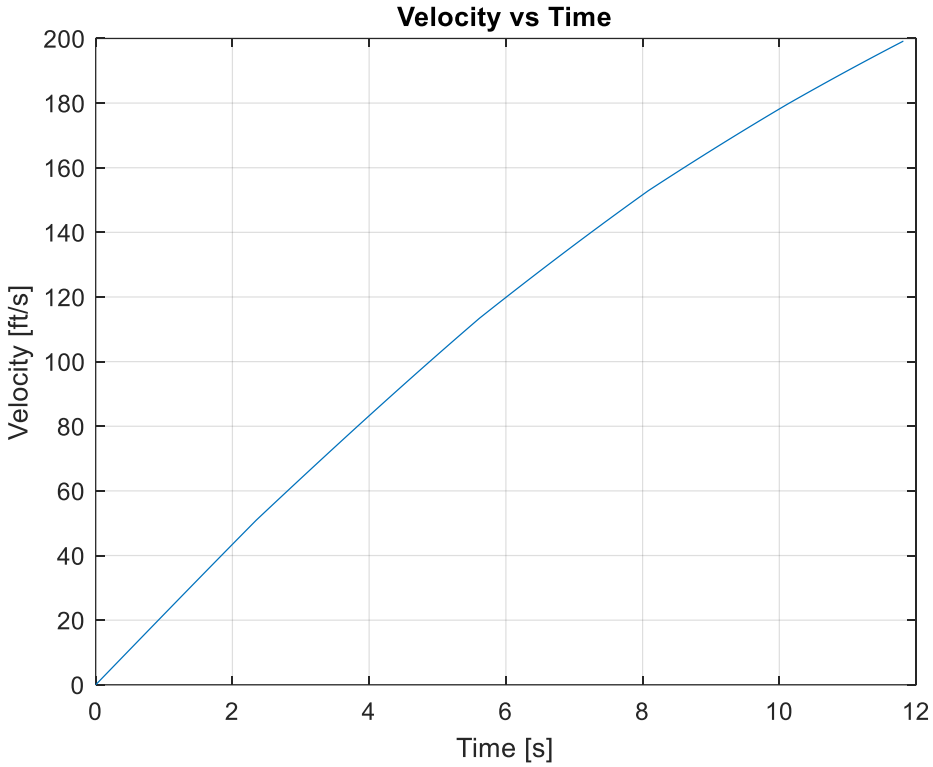

Figure 15: Velocity vs Time Graph

The steady ascent of the nearly straight line reflects a consistent rate of acceleration, showcasing the IndyCar's sustained performance as it covers the remaining distance. Upon nearing the quarter-mile mark, the velocity approaches 199.18ft/s, translating to around 135.8 mph. The linear nature of the curve underscores the vehicle's ability to sustain high and constant acceleration, underscoring the advanced engineering and formidable power of the Tesla Model S performance motor.

4.3 Acceleration vs Time

By examining acceleration profiles through speed versus time analyses, engineers gain valuable insights into the efficiency of power delivery and the car's acceleration capabilities. The curve follows a diminishing trend, signifying that the acceleration is not constant but gradually decreases over the course of the run. In the initial 0-2 seconds, the acceleration peaks at approximately 0.6g or 0.6 times the acceleration due to gravity (32.2 ft/s²). This peak acceleration phase facilitates a rapid build-up of speed from a standstill, showcasing the car's impressive initial burst of acceleration.

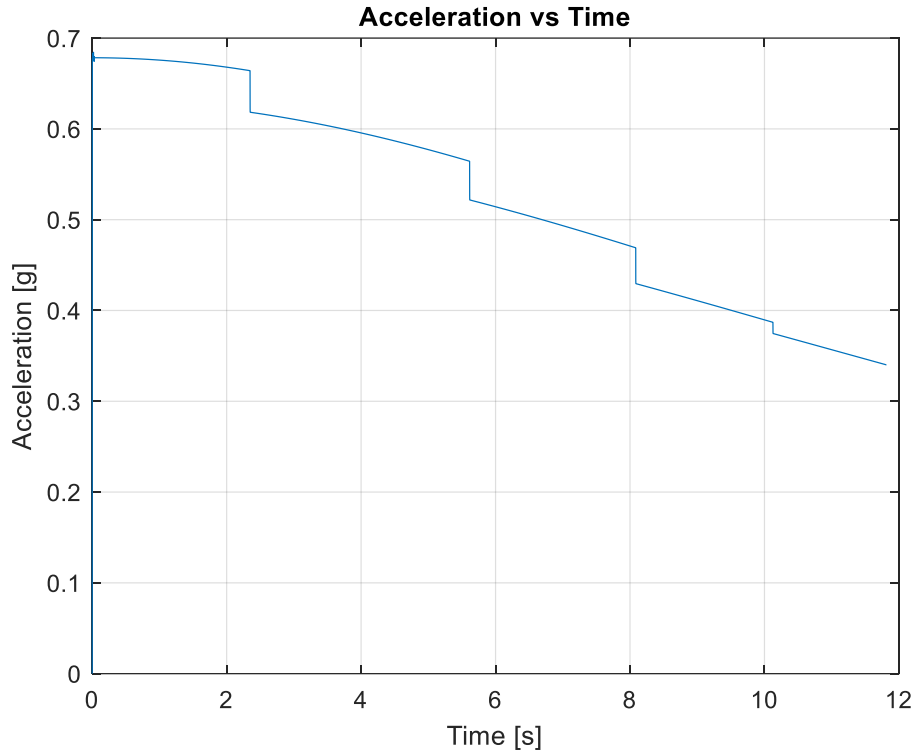

Figure 16: Acceleration vs Time Graph

However, as the run unfolds, the acceleration undergoes a steady decline. By the 8-second mark, the acceleration has diminished to approximately 0.43g’s. This reduction is likely influenced by factors such as increasing aerodynamic drag and limitations within the car's powertrain, particularly at higher speeds.

The descending curve persists, with acceleration tapering off further as the car approaches the quarter-mile mark. At this juncture, the acceleration seems minimal, suggesting that the car has essentially reached its terminal velocity for the given distance.

4.4 Rear Tractive Force vs time

Traction versus time analyses contribute to the evaluation of tire grip during acceleration, guiding decisions related to tire management and ensuring optimal traction for enhanced performance. The graph delineates the fluctuation in rear tractive force. In the initial 0-2 seconds, the rear tractive force peaks at approximately 1500 lbs. This formidable force serves as a catalyst, overcoming static inertia and propelling the car into rapid acceleration during the launch phase.

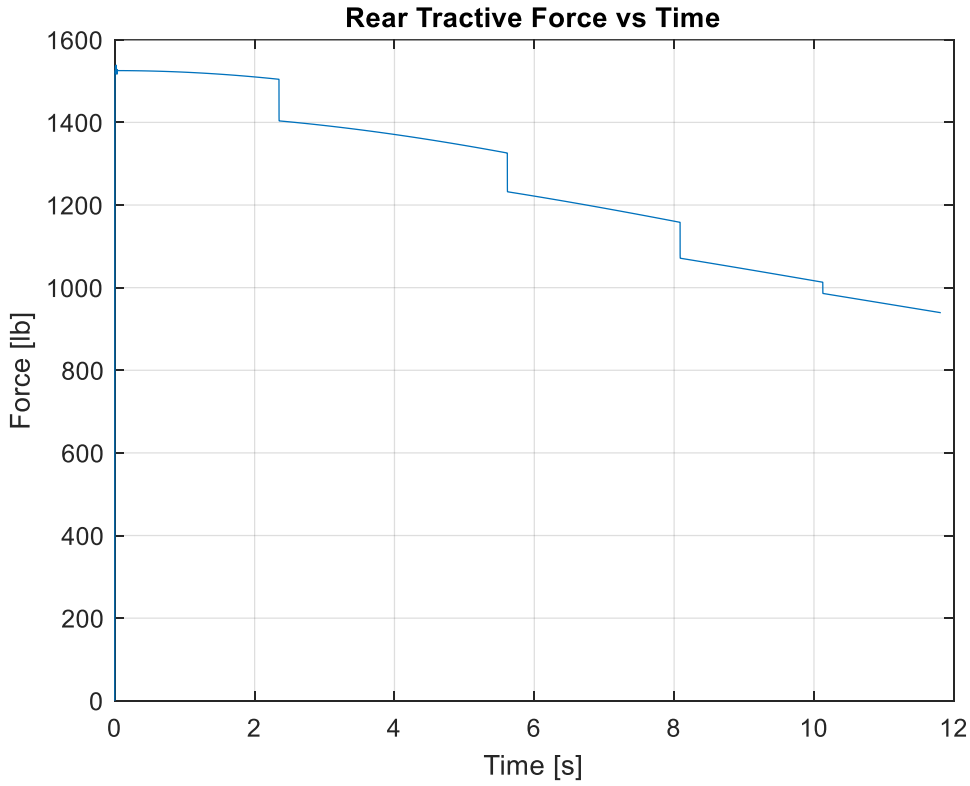

Figure 17: Traction vs Time Graph

However, as the run progresses and the car gains speed, the rear tractive force experiences a decline. By the 6-second mark, it diminishes to around 1220 lbs, indicating that while still substantial, the force requirement has lessened as the car continues to build momentum.

The tractive force gradually tapers off as the car approaches its terminal velocity for the quarter-mile distance. At the finish line, the force appears to have decreased to approximately 940 lbs. This rear tractive force profile sheds light on the evolving force demands on an IndyCar's drivetrain during a quarter-mile drag run. The initial surge of exceptionally high tractive force is imperative for the rapid launch, while the force steadily diminishes as the car accelerates, influenced by the changing dynamics of acceleration, aerodynamic drag, and rolling resistance.

4.5 Front weight vs tire

The assessment of weight distribution dynamics, represented by front and rear weight graphs, is crucial for achieving an optimal balance that enhances stability and overall handling performance. At the commencement of the run, at the end of the initial 2 seconds, the front weight attains a value of 1080 lbs. However, as the car progresses and gains speed, the front weight gradually diminishes. By the 6-second mark, the front load has decreased to approximately 1020 lbs. This decline in front weight is a consequence of the aerodynamic forces and the effects of longitudinal load transfer that come into play as the car accelerates.

The descent in front weight persists as the car approaches its terminal velocity for the quarter-mile distance. At 11.81 seconds, the front load seems to have further reduced to approximately 875 lbs. This fluctuation in front tire load brings attention to the dynamic weight transfer characteristics of the IndyCar during its acceleration run.

The initial emphasis on high front weight optimizes traction during the launch, but as speed increases, the load redistributes rearward to counteract growing aerodynamic forces and uphold an optimal grip balance between the front and rear tires.

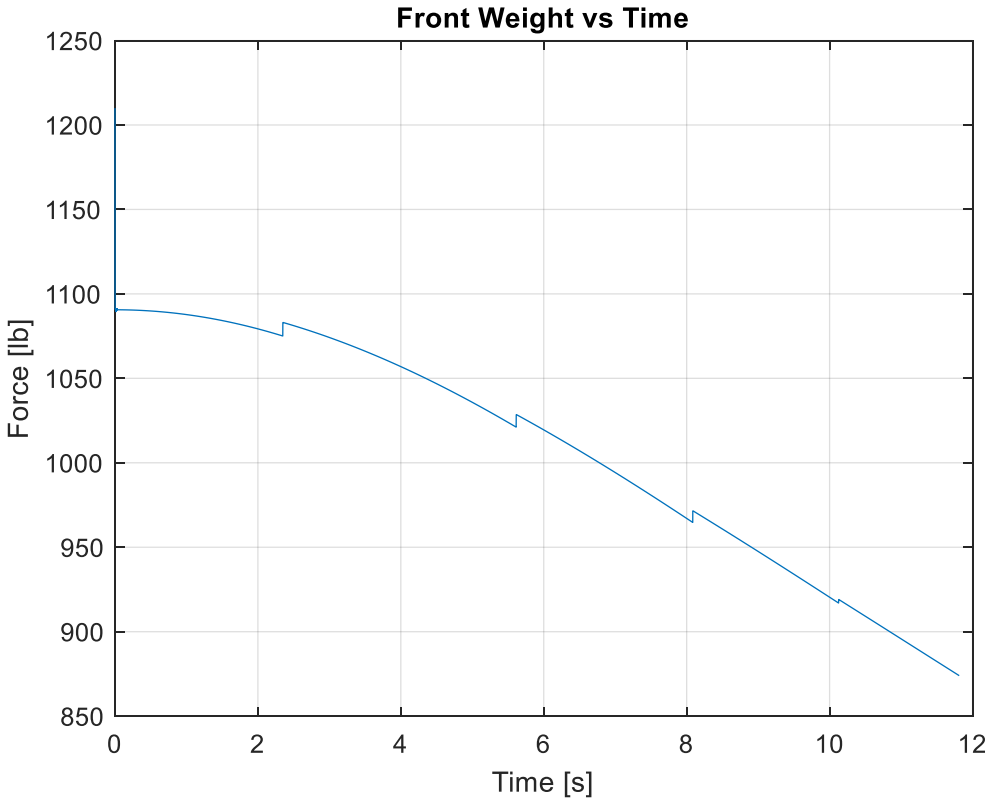

Figure 18: Front weight vs Time Graph

4.6 Rear weight vs time

At the onset (t=0 seconds), the rear weight stands at approximately 990 lbs, reflecting the static weight distribution when the car is stationary. This weight instantaneously shoots up to 1110 lbs in the initial second, indicating the initial weight transfer due to longitudinal acceleration. Within the initial seconds, the rear weight undergoes a significant drop, reaching around 1060 lbs by the 4-second mark. This pronounced shift of weight towards the front wheels is essential to optimize traction and grip during the initial acceleration phase.

Continuing the acceleration, the rear weight steadily decreases. By the 10-second mark, the rear weight has diminished to around 900 lbs., signifying a noteworthy transfer of weight to the front tires. Optimal weight distribution plays a pivotal role in maximizing traction and overall performance, making this depiction crucial for understanding the intricacies of the vehicle's behavior during acceleration.

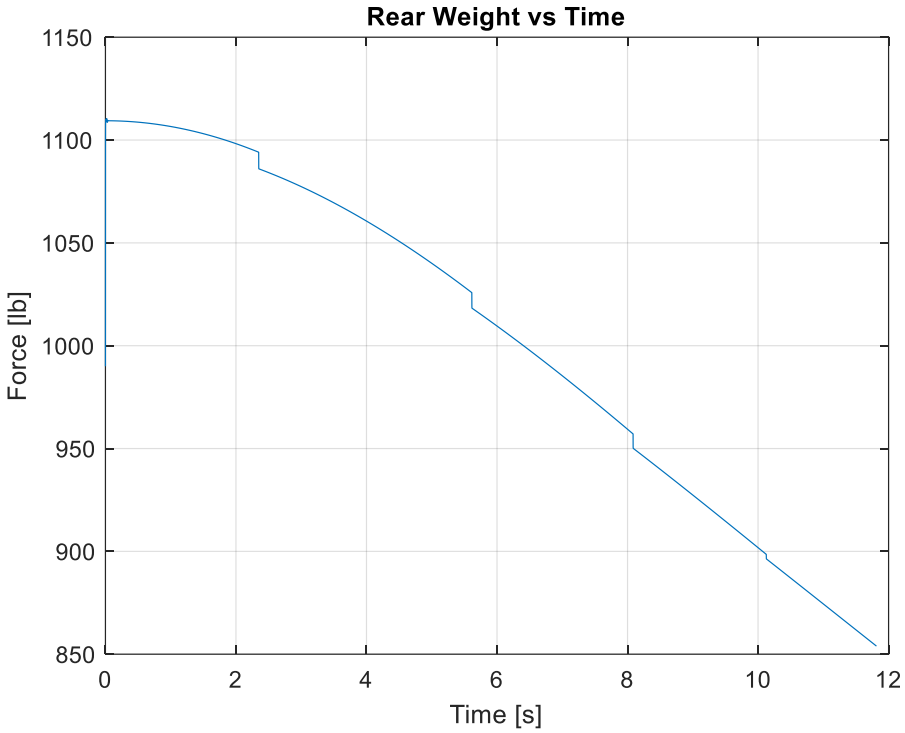

Figure 19: Rear weight vs Time Graph

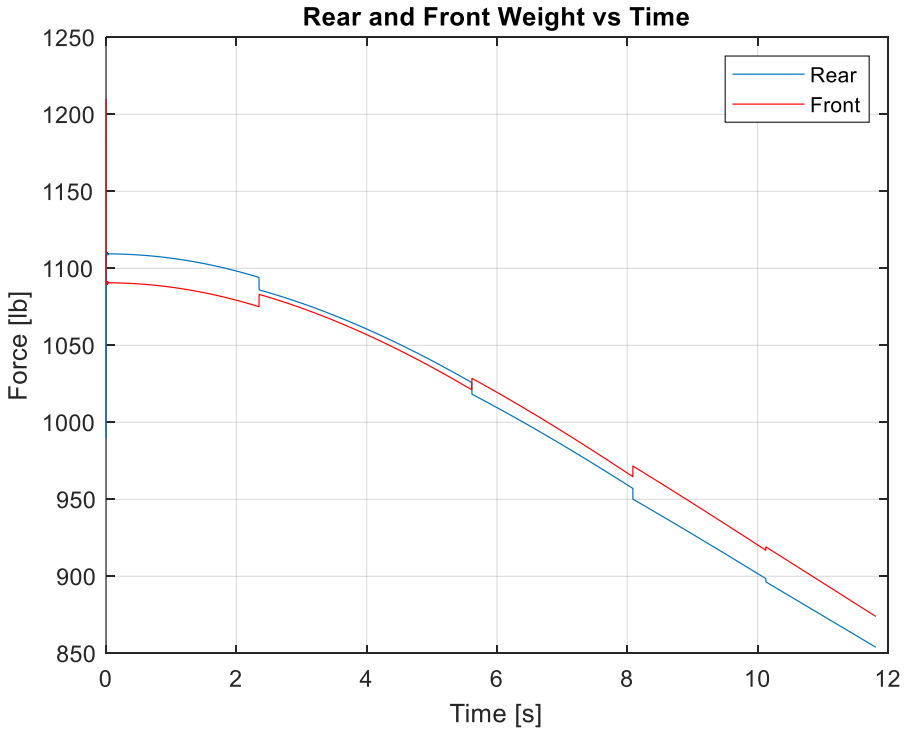

Figure 20: Combined graphs for Weight vs Time.

5. CONCLUSION AND DISCUSSION

The primary aim of this research was to explore the potential of achieving comparable, if not superior, performance results with an electrified IndyCar, specifically one outfitted with a Tesla Model S performance motor. The following section provides insights from Motortrends' investigation, delving into the quarter-mile characteristics of a conventional gasoline-powered IndyCar.

During the performance testing of the Cobb Racing G Force-Infiniti IndyCar on the Texas pit road, driven by Roberto Guerrero, the vehicle exhibited remarkable acceleration. Despite the initial wheelspin and a slow start attributed to the tall first gear, the car achieved a 0-60 mph time of 3.8 seconds. In the subsequent 3.8 seconds, the car accelerated to nearly 60 mph more, reaching a top speed of 153.7 mph during the full quarter-mile run, which concluded in a total time of 10.6 seconds. The performance not only showcased the car's acceleration capabilities but also highlighted the impact of an awkward 1-2 upshift on the overall time. [20]

In contrast, the electrified IndyCar, featuring the Tesla Model S performance motor, demonstrated a top speed of 135.8 mph, completing the quarter mile in 11.81 seconds. Despite the commendable 615 kW (825 bhp) power output and substantial torque of 1,300 N·m, the electric counterpart fell short of the traditional gasoline IndyCar's performance benchmarks. The weight distribution, slightly favoring the front at 45%, and the lighter electric motor influenced the overall dynamics of the electrified IndyCar. While the electric powertrain showcased impressive acceleration, the traditional gasoline IndyCar's superior top speed and quarter-mile time underscore the nuanced interplay of factors such as weight distribution, power delivery, and overall system efficiency.

In conclusion, this study clarifies that, in the context of quarter-mile performance starting from rest, the conventional gasoline IndyCar with its internal combustion engine outperformed the electrified IndyCar equipped with a Tesla Model S performance motor on the stock Dallara DW12 Chassis. These findings underscore the multifaceted considerations required when transitioning from traditional combustion engines to electric powertrains in the realm of motorsports, where a delicate balance between various factors determines overall performance success.

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