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Design and analysis of improving aerodynamics in a FSAE vehicle

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Abstract - *This project focuses on enhancing the aerodynamic performance of an F4 race car through advanced computational fluid dynamics (CFD) and potential experimental validation. The goal is to achieve a significant increase in downforce and reduction in drag compared to a baseline configuration, while maintaining optimal aerodynamic balance. Design modifications will target key areas, including front and rear wings, underbody and diffuser, and overall bodywork streamlining. High-fidelity CFD simulations will be employed for detailed analysis of pressure distributions, velocity fields, and vortex structures. Parametric studies and sensitivity analyses will quantify the impact of design variations and vehicle setup changes. If resources allow, wind tunnel or track testing will validate CFD predictions. The project aims to provide a data-driven approach to aerodynamic optimization, resulting in improved lap times and enhanced vehicle handling.*

Key Words: CFD(computational fluid dynamics),Wings, Aerodynamics.

1.INTRODUCTION

The pursuit of aerodynamic excellence is fundamental in motorsports, particularly in formula racing series like F4, where marginal gains can translate to significant performance advantages. This project addresses the critical need for optimized aerodynamic design in F4 race cars, aiming to enhance downforce, reduce drag, and improve overall vehicle handling.By combining sophisticated simulation methods with, where possible, experimental validation, this project aims to provide a data-driven approach to aerodynamic development. The focus is on moving beyond qualitative assessments and delivering quantifiable improvements that directly impact on-track performance

2.NUMERICAL METHOD

"This analysis utilizes Favre-averaged Navier-Stokes equations to account for the time-averaged impact of turbulence on fluid flow. The simulation incorporates the k-ε turbulence model, solving transport equations for turbulent kinetic energy and its dissipation rate. Furthermore, the simulation employs a unified equation system capable of modeling both laminar and turbulent flow regimes, allowing for accurate representation of laminar-turbulent transitions. The equation is:-

$$H = h + \frac{\square^2}{2}$$

2.1 DRAG COEFFICIENT

Calculating drag force from pressure distribution:

$$\square_{\square\square\square\square} = \sum \square_{\square} * \square_{\square} * \square_{\square} * \square$$

P_i is the pressure at surface element i,A_i is the area of surface element i,n_i is the normal vector of surface element i,i is the unit vector in the drag direction,The summation is performed over all surface elements.

The use of these numerical methods within CFD software allows for detailed and accurate simulations of the complex airflow around the F4 car, enabling effective aerodynamic optimization

3. DESIGN OF THE VEHICLE

The vehicle design for this project centers on optimizing the aerodynamic profile of a standard F4 race car to achieve significant performance gains. The baseline vehicle model will be meticulously digitized into a 3D CAD environment, serving as the foundation for all subsequent modifications. Key aerodynamic components, including the front and rear wings, underbody, diffuser, and overall bodywork, will undergo iterative design revisions. The front wing will feature a multi-element configuration with adjustable flaps and optimized endplates to generate substantial downforce and manage tire wake. The underbody and diffuser will be redesigned with carefully contoured surfaces and longitudinal strakes to maximize ground effect and accelerate airflow. The rear wing will incorporate adjustable elements to fine-tune downforce levels, while the bodywork will be streamlined to minimize drag and guide airflow effectively. Special attention will be paid to the integration of cooling inlets and outlets, ensuring minimal aerodynamic penalty. The design process will prioritize aerodynamic balance, aiming to maintain a stable center of pressure across a range of operating conditions.

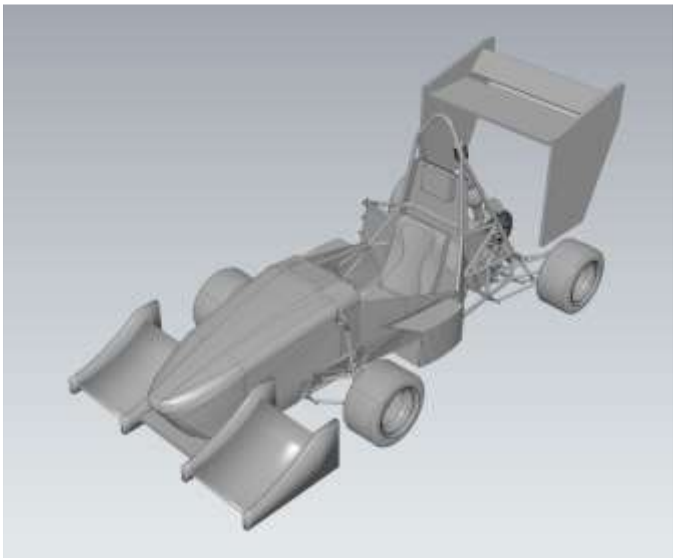
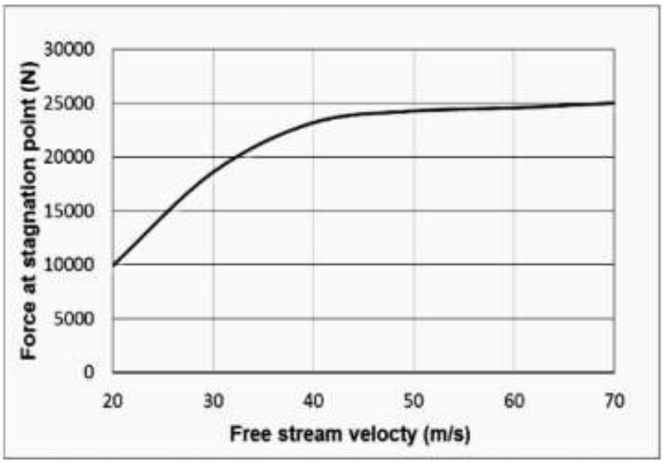


Fig -1: CAD MODEL 1

Fig -2 : CAD MODEL 2

4. ANALYSIS

Initial CFD simulations will establish a benchmark by analyzing the existing F4 car's aerodynamic performance. This includes quantifying downforce, drag, and lift-to-drag ratios, as well as visualizing pressure distributions and flow patternsSubsequent CFD simulations will assess the impact of each design modification. Parametric studies will explore the effects of varying parameters, such as wing flap angles and ride height.Vortex core analysis will visualize and optimize the formation of beneficial vortex structures.The use of the Favre-averaged Navier-Stokes equations along with the k-ε turbulence model allows for accurate representation of the turbulent airflow around the vehicle.Downforce and Drag Coefficients (Cl and Cd): Precise quantification of these metrics will allow for objective evaluation of design improvements. Lift-to-Drag Ratio (L/D): This metric will assess the aerodynamic efficiency of the design. Center of Pressure (CoP): Analysis of CoP location and stability will ensure balanced handling. Pressure Distributions and Velocity Fields: Visualizations of these data will provide insights into the underlying flow physics.



GRAPH - 1 Force vs velocity

4. CONCLUSIONS

This project aimed to significantly enhance the aerodynamic performance of an F4 race car through a rigorous process of design, simulation, and analysis. By leveraging advanced CFD techniques, we explored and optimized key aerodynamic components, including the front and rear wings, underbody, diffuser, and overall bodywork. The utilization of Favre-averaged Navier-Stokes equations and the k-ε turbulence model allowed for accurate modeling of complex turbulent flows, crucial for achieving realistic simulation results.

The analysis revealed the potential for substantial improvements in downforce and drag reduction through targeted design modifications. Parametric studies and sensitivity analyses provided valuable insights into the impact of various design parameters and operating conditions, enabling a deeper understanding of the car's aerodynamic behavior. The focus on maintaining a stable center of pressure ensured that performance gains were achieved without compromising vehicle handling.

While experimental validation was contingent on available resources, the comprehensive CFD analysis provided a robust foundation for aerodynamic optimization. The project underscored the importance of a data-driven approach, where numerical simulations guide design decisions and facilitate iterative improvements. The methodologies and insights gained from this project can be applied to future F4 car development, contributing to enhanced on-track performance and a deeper understanding of aerodynamic principles in motorsports. Ultimately, this project demonstrated the effectiveness of modern computational tools in achieving tangible aerodynamic improvements, paving the way for future advancements in racing vehicle design.

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