Visualizing Fluid Dynamics Simulation in High-Performance Automotive Vehicles

Dhruv Meduri
u1471195@utah.edu

Filemon Mateus
u1419667@utah.edu

§1. Give an overview of the project.

This project is designed to delve into the complex world of fluid dynamics, particularly as it applies to high-performance automotive vehicles. By leveraging computational fluid dynamics (CFD) simulations with OpenFOAM and visualizing the results in Paraview, the aim is to elucidate how air flow interacts with the surfaces of various iconic Formula 1 racing cars and the high-performance Porsche 911. It intends to showcase the intricate interplay between air flow and vehicle surfaces, highlighting how this interaction influences vehicle drag, efficiency, and overall performance. By doing so, it seeks to bridge the gap between theoretical aerodynamics and practical automotive design, offering a vivid, detailed visualization of airflow patterns, drag coefficients, and vortex formations around these vehicles as they "move" through the air.

§2. Why is this project important and/or interesting?

Aerodynamics plays a pivotal role in the design and performance of high-speed vehicles. The way air flows around a vehicle can significantly affect its speed, acceleration, fuel efficiency, and stability. For high-performance vehicles, these effects are magnified due to the extreme speeds and the need for precise handling and efficiency. This project is therefore of great importance as it provides insights into the aerodynamic design and optimization for minimal drag and enhanced performance.

The project also has a broad appeal due to its combination of advanced simulation and visualization techniques to real-world engineering problems, providing insights into complex physics of fluid dynamics in an accessible and visually engaging way. It stands at the intersection of engineering, physics, and computer science, making it an interesting endeavor for students (like us!) in these fields. By focusing on iconic vehicles with rich histories in motor sport, the project adds an element of nostalgia and engagement for fans and historians alike.

§3. What are the objectives of the project? What are the questions you want to answer?

The primary objectives of the project are:

1. To accurately simulate the airflow around a variety of high-performance vehicles, using detailed CAD models and OpenFOAM for CFD simulations.
2. To create detailed visualizations of these simulations with Paraview, focusing on key aerodynamic factors like drag and vortex generation.
3. To animate the fluid flow data, providing a dynamic view of how air moves around the vehicles over multiple time steps, which, in turn, can help in understanding the transient nature of aerodynamic forces.

In pursuit of these objectives, the project seeks to answer the following questions:

1. How does the aerodynamic design and structural shape of different high-performance vehicles affect airflow, and what implications does this have for drag and vehicle performance?
2. What specific design features contribute to optimal airflow management, reducing drag and possibly enhancing downforce?

3. How are vortices generated around these vehicles, what are their characteristics, and how do they impact the vehicle's aerodynamics and performance?

§4. What would you like to learn by completing this project?

The project is not just a technical challenge; it is also a learning journey. Through its completion, the following are anticipated learning outcomes:

1. A deep understanding of CFD simulation techniques, particularly how to apply `OpenFOAM` to complex, real-world problems in automotive aerodynamics.
2. Advanced skills in data visualization, learning how to use `Paraview` to turn large scale, complex simulation data into understandable and visually appealing images and animations.
3. A better grasp of fluid dynamics principles, especially as they apply to aerodynamics in the context of high-performance vehicles, including the impact of different shapes and surfaces on airflow.
4. The ability to interpret CFD simulation results to draw conclusions about vehicle design and performance, potentially informing future designs or studies in automotive aerodynamics.

§5. What data will you be using for your project?

To achieve its objectives, the project will utilize CAD models of several high-performance vehicles, each chosen for its significance in automotive history and its unique design characteristics. These models include Formula 1 racing cars driven by legendary figures and a Porsche 911 race car sourced from free online repositories. These detailed models will serve as the foundation for the CFD simulations, providing a realistic basis for studying airflow dynamics. Below is a list of model sourced from the internet:

1. Ferrari 2018 F1 (driven by Sebastian Vettel & Kimmi Raikkonen)
   — `https://cdn.thingiverse.com/zipfiles/74/c9/ac/99/71/Ferrari_SF71H_F1_1-20_V5.zip`.
2. Red Bull Racing 2018 F1 (driven by Daniel Riccardo & Max Verstappen)
   — `https://cdn.thingiverse.com/zipfiles/f5/50/e6/c9/0d/Red_Bull_RB_14_F1_V1_1-20.zip`.
3. Williams F1 (1991 & 1992)
   — `https://cdn.thingiverse.com/zipfiles/52/39/ad/9b/26/Williams_FW14_1-20_F1_V2.zip`.
4. McLaren 1991 (driven Ayrton Senna)
   — `https://cdn.thingiverse.com/zipfiles/cf/3d/af/4d/64/Mclaren_MP4_6_F1_1-20_V2.zip`.
5. Lotus F1 1970
   — `https://cdn.thingiverse.com/zipfiles/bb/21/12/ed/e9/Lotus_72_F1_1-20.zip`.
6. Ferrari 1970
   — `https://cdn.thingiverse.com/zipfiles/96/82/5a/c5/49/Ferrari_312B_F1_-_1_20.zip`.
7. McLaren 1968
   — `https://cdn.thingiverse.com/zipfiles/fa/87/91/df/c7/Mclaren_M7A_F1_V2_-_1_20.zip`.
8. Honda 1965
   — `https://cdn.thingiverse.com/zipfiles/f3/35/14/d1/04/Honda_RA272_F1_1-20_v1.zip`.
9. Porsche 911
   — `https://cdn.thingiverse.com/zipfiles/8c/a4/1c/9f/be/Porsche_911_Race_Car.zip`.

§6. If you are doing a programming project, list the hardware and software you will be using.

The project will leverage specific software tools for simulation and visualization:

Software

1. OpenFOAM — for generating simulation data.
2. Paraview — for visualizing/animating data.

Hardware

1. On the hardware side, while the project initially does not require any specialized hardware, it acknowledges the potential need to leverage the School of Computing's infrastructure for more demanding simulations. This flexibility ensures that computational limitations do not hinder the project's scope and ambition/objectives in **§3**.

§7. What is your project schedule? What have you done thus far and what will you have to do to complete this project? Be as specific as possible.

The project schedule, with key milestones set to monitor and guide progress, is as follows:

- 03/07 — become proficient in using OpenFOAM for simulating fluid flow around the CAD models of the vehicles. This step is critical as it lays the foundation for all subsequent analysis. It includes setting up the simulation environment, importing vehicle models, and running preliminary simulations to ensure accuracy and reliability of the data generated.
- 03/14 — begin the visualization process with Paraview. This stage is about translating the raw simulation data into visual formats that clearly and effectively communicate the dynamics of fluid flow around the vehicles. Techniques for visualizing vector fields, pressure distributions, and vortices will be explored and applied, with the goal of developing a series of static visualizations that highlight key aerodynamic features.
- 03/18 — submit progress report, documenting the methodologies adopted, preliminary findings, challenges encountered, and resolutions. This milestone will serve as a checkpoint to assess the project's status against its schedule and objectives, allowing for adjustments and refinements to the plan as necessary.
- 04/05 — complete simulations and visualizations for multiple vehicles in **§5**. This involves running simulations under various conditions, analyzing the results, and developing a comprehensive set of visualization that compare and contrast the aerodynamic behaviors of different vehicles.
- 04/12 — if time permits, this period will be dedicated to animating the fluid flow data. Animation adds a dynamic component to the visualization, showing changes in airflow patterns over different time steps as the vehicle "moves" through the air. This step requires not only technical proficiency with Paraview's animation tools but also a deep understanding of the fluid dynamics involved to ensure the animations accurately reflect realistic behaviors.
- 04/17 — submit final project report. This comprehensive report will include detailed descriptions of the methods used, a discussion of the findings, visualizations and animations of fluid flow, and conclusions regarding the impact of vehicle design on aerodynamics. It will also reflect on the project's success in meeting its objectives in **§3** and learning goals in **§4**.

Currently, the project is in the planning phase, with initial steps focusing on acquiring the necessary CAD models and familiarizing with OpenFOAM and Paraview simulation and visualization pipelines.

§8. When the project is completed, how specifically can we evaluate how successful it is?

The success of this project can be evaluated through several criteria, focusing both on the process and the outcome.

1. The fidelity of the CFD simulations to real-world fluid dynamics principles will be a primary measure. Success in this area means that the simulations accurately model airflow around the vehicles under various conditions, providing reliable data for analysis.
2. The effectiveness of the visualizations and animations in conveying complex fluid dynamics concepts will be another key metric. High-quality visualizations should make the invisible visible, clearly showing how air flows around the vehicles, where high-pressure zones form, and where vortices are generated.

3. The depth of insight gained into the aerodynamics of high-performance vehicles and the impact of design on airflow and drag will be evaluated. Success here means that the project provides meaningful conclusions that could inform future vehicle design or further research in automotive aerodynamics industry.
4. The extent to which the project has expanded the team's knowledge and skills in CFD simulation, data visualization, and fluid dynamics will be assessed. Success here means not just technical depth but also deeper understanding of the principles underlying the project's focus areas in §4.

§9. Any other useful information?

As the project progresses, there may be opportunities to expand the scope to include more vehicles or different types of simulations.