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Evolving the Drive: Integrating Electric Vehicle Technologies with AI in Automotive Engineering Courses

Dr. Zahra Pournorouz, Stevens Institute of Technology

”Zahra Pournorouz received her Bachelor of Science degree in Aerospace Engineering from Amirkabir University of Technology (Tehran Polytechnic) in Tehran in the Fall of 2014. After finishing her bachelor's studies, she got admitted directly to the Ph.D. program in Mechanical Engineering at the University of Texas at Arlington and graduated in August 2018. Her research interests mainly focus on oil-based nanofluids and enhancing the thermophysical properties of synthetic oils. This was the first demonstration of the work ever done in this field and resulted in broad environmental and cost benefits, especially in energy storage and heat transfer applications. She has more than three years of experience teaching thermofluidic, mechanical design, and solid and structure courses and supervising senior capstone projects collaborating with industries such as Saint-Gobain, Klein Tools, and Parker. She also has served in leadership roles at the Society of Women Engineers and STEM advisory task force to represent diversity and inclusion and improve student success and retention for underrepresented students.”

Evolving the Drive: Integrating Electric Vehicle Technologies with AI in Automotive Engineering Course

Abstract:
This paper aims on a transformative journey through the evolution of Automotive Engineering course. This course is traditionally taught for Internal Combustion (IC) engines, however, with fast growing industry of Electric Vehicles (EV), it is necessary that we educate our student before they enter the vehicle industry. This reimagined course navigates beyond the conventional boundaries, embracing the dynamic landscape of EV technologies, all while integrating the prowess of Artificial Intelligence (AI).

The course will begin with a solid foundation in traditional automotive engineering principles, delving into the intricacies of internal combustion engines and mastering the nuances of vehicle dynamics. Transitioning seamlessly, the course unfolds into the realm of EVs, where AI becomes the orchestrator of electric powertrains and the autonomy of vehicles. Each topic, from steering systems to braking systems, and from engines to gears, transmissions, aerodynamics, suspension, and overall vehicle performance, is approached with a dual perspective. This approach bridges the gap between time-tested principles and the cutting-edge technologies that define the automotive landscape of tomorrow.

The course, inherently project-based, pioneers a pedagogical approach that introduces each subject through the lens of software incorporation and collaborative teamwork among students. A detailed exploration will be presented for each outlines subject, shedding light on its intricacies and unveiling unique assignments. What sets this course apart is its continuous thread of connection to AI, illuminating the relevance of advanced technology at every step.

Automotive Engineering stands as an elective course, drawing an annual cohort of approximately 25-30 students during the spring semester, comprising both undergraduate and graduate-level enthusiasts of automotive engineering. The course attracts individuals genuinely passionate about delving into automotive engineering concentrations. With a focus on the intersection of theoretical knowledge and practical industry applications, each assignment within the course serves as a narrative thread, illustrating the profound impact of AI on the dynamic canvas of the automotive landscape. Through this immersive experience, the aim is to equip students with the skills and insights necessary to navigate and excel in their future careers within the automotive realm.

Introduction:

The automotive industry is undergoing a transformative revolution, driven by the rapid advancements in EV technologies coupled with the ever-growing influence of AI. These disruptive forces are fundamentally reshaping the landscape of vehicle design, manufacturing, and operation, presenting both exciting opportunities and significant challenges for the next generation of automotive engineers.

In line with these industry trends, there is a critical need to reimagine and update traditional automotive engineering education to equip students with the necessary knowledge, skills, and perspectives to thrive in this dynamic environment. This paper proposes a novel approach to an Automotive Engineering course, seamlessly integrating EV technologies with AI while maintaining a strong foundation in core automotive principles.

This reimagined course aims to address the following key objectives:

First, to bridge the gap between traditional automotive engineering principles and cutting-edge EV technologies: By infusing each subject area with the latest advancements in AI technology, it is necessary to provide students with a holistic understanding of the evolving automotive landscape. The course curriculum will provide a comprehensive understanding of both time-tested fundamentals, such as internal combustion engines and vehicle dynamics, alongside the latest advancements in electric powertrains, autonomous driving systems, and AI applications in the automotive domain [1-3].

Second, to develop a deep understanding of the pivotal role of AI in modern automotive engineering: AI is rapidly transforming every aspect of the automotive industry, from design and manufacturing to performance optimization and autonomous driving. This course will emphasize the practical applications of AI in various automotive sub-systems and equip students with the ability to leverage its power for innovative solutions [4-6].

Lastly, to foster a project-based learning environment that encourages collaboration and real-world problem-solving: By incorporating projects that simulate real-world industry challenges, the course will allow students to apply their theoretical knowledge to practical scenarios and develop essential teamwork and problem-solving skills [7-9].

This paper outlines the proposed course structure, learning objectives, and assessment methods, highlighting the unique features that set it apart from traditional approaches. The curriculum will be presented in detail, showcasing how each topic is integrated with EV and AI concepts through engaging lectures, discussions, and project-based activities.

Course Design:

This section explains the changes outlined in the course description that involve a strategic blend of curriculum modification, textbook selection, grading policy refinement, an interactive implementation structure, and a meticulously crafted week-by-week schedule. This comprehensive approach ensures alignment with the overarching goal of equipping students with a complete understanding of automotive engineering principles, encompassing both traditional and emerging technologies.

The first step in reshaping the Automotive Engineering course involves a modification of the course description to reflect the expanded scope and objectives of the revamped curriculum. This modification is guided by the recognition that the automotive industry is undergoing a profound transformation with the emergence of EVs and AI integration into vehicle systems. As such, the updated course description emphasizes the integration of internal combustion engines, electric powertrains, and autonomous vehicle technologies. Key topics such as steering systems, braking systems, vehicle performance analysis, and suspension designs are reframed to encompass both traditional and modern perspectives, providing students with a comprehensive understanding of automotive design principles across diverse technological landscapes.

The selection of textbooks plays a pivotal role in providing students with the necessary resources to delve into the intricacies of automotive engineering. In this regard, careful consideration is given to two foundational texts: "Automotive Engineering: Powertrain, Chassis System and Vehicle Body" by D.A. Crolla and "Electric Vehicle Technology Explained" by J. Larminie and J. Lowry. The former is a comprehensive guide to traditional automotive engineering principles, offering detailed insights into powertrain dynamics, chassis systems, and vehicle body design. Meanwhile, the latter provides a comprehensive overview of the cutting-edge technologies driving the EV revolution, covering topics such as electric powertrains, energy storage systems, and charging infrastructure. By incorporating these complementary texts into the curriculum, students are provided with a well-rounded understanding of both conventional and emerging automotive technologies, laying the foundation for a holistic exploration of the field.

The learning objectives of this course were:

1. Applying and analyzing loads and load transfer in various vehicle systems
2. Fundamental vehicle dynamics & modeling
3. Theory of mechanisms applied to automotive systems
4. Applied aerodynamics and engine modeling
5. Analysis of overall vehicle performance

Now, the modified Learning Objectives are:

1. Apply and analyze loads and load transfer in various vehicle systems, encompassing both internal combustion engines and *electric powertrains in the context of autonomous and electric vehicles.*
2. Explore fundamental vehicle dynamics and modeling, incorporating the unique characteristics of both traditional internal combustion engines and *the advanced dynamics of electric and autonomous vehicle systems.*
3. Examine the theory of mechanisms applied to automotive systems, considering the *integration of artificial intelligence algorithms in the control and operation of both conventional and cutting-edge vehicle technologies.*
4. Investigate applied aerodynamics and engine modeling, delving into the intricacies of combustion engines and the *aerodynamic considerations specific to electric and autonomous vehicles, emphasizing AI-driven optimizations*.
5. Conduct a comprehensive analysis of overall vehicle performance, evaluating the combined impact of internal combustion engines, *electric powertrains, and autonomous systems on the holistic performance of modern vehicles, leveraging artificial intelligence for advanced performance assessments.*

To incentivize student engagement and ensure alignment with the course objectives, the grading policy undergoes a careful refinement process. The revised grading policy allocates weightage to various components of the course, with a focus on project-based learning and active participation. Specifically, 60% of the overall grade is assigned to term project, which serve as a cornerstone of experiential learning and hands-on application of theoretical concepts. An additional 20% is allocated to pre-class assignments, which are designed to prime students for in-depth discussions and activities during class sessions. Homework assignments account for 15% of the grade, providing students with opportunities to reinforce their understanding of course material through independent study and practice. Lastly, attendance is a 5% weightage, underscoring the importance of active participation in class discussions and activities.

Regarding implementation structure, ME 515 adopts a flipped classroom paradigm, which capitalizes on the benefits of asynchronous learning and active engagement during in-person class sessions. Instructional videos, serving as content delivery mechanisms, are posted on the Canvas learning management system before each class. Students are expected to review these videos before class meetings, thereby laying the groundwork for interactive discussions and activities during in-person sessions. In-class time is then dedicated to content-specific assignments and discussions, fostering a collaborative learning environment where students can apply theoretical concepts to real-world scenarios under the guidance of the instructor. This interactive implementation structure not only promotes active engagement and critical thinking but also encourages collaboration and knowledge sharing among students, enriching the learning experience and fostering a sense of community within the classroom.

The week-by-week schedule is crafted to cover a wide range of topics, with a balanced mix of theoretical concepts and practical applications across traditional and modern automotive engineering domains. The class meets only once a week, for two and a half hours on Mondays.

The schedule from last year is presented below followed by the new modified schedule that incorporates the new objectives:

Table 1: Week-by-week schedule for ME515 for Spring 2023

Week	Date	Activities
1	**No Class. The week started on a Wednesday.**	
2	01/23	Syllabus / Introductions / course objectives / Team formation / Center of Gravity
3	01/30	Vehicle Dynamics
4	02/06	Vehicle on a Slope
5	02/13	Braking Systems
6	**02/22**	**No class on Monday 02/20** **Wednesday, 02/22: Monday class schedule** Steering Systems
7	02/27	The Engine

8	03/06	Engine Modeling I
9	**Spring Recess**	
10	03/20	Engine Modeling II
11	03/27	Gears and Transmission I
12	04/03	Gears and Transmission II
13	04/10	Aerodynamics
14	04/17	Suspension
15	04/24	Vehicle Performance I
16	05/01	Vehicle Performance II

The new updated and detailed schedule for spring 2024 is outlined below:

Week 1: No Class. The semester started on a Wednesday.

Week 2: The second week of the semester sets the foundation for the course with an overview of the syllabus, introductions, and an exploration of the course objectives. Additionally, students delve into the rich history of automotive vehicles, tracing the evolution of automotive engineering from its inception to the present day.

Week 3: *Vehicle Dynamics*
This week focuses on Vehicle Dynamics, specifically exploring the principles governing vehicle behavior on slopes. Students engage in statics and dynamics fundamentals assignment in class to understand the factors influencing vehicle dynamics and performance in sloped environments, such as load transfer, with a particular emphasis on internal combustion engines.

Week 4: *Braking Systems: Traditional and Electric Approaches*
The topic shifts to Braking Systems, where students delve into both traditional and ***electric approaches to braking***. Through theoretical discussions and practical demonstrations, students gain insights into the design, operation, and optimization of braking systems, considering the unique challenges posed by electric vehicles such as *regenerative braking in EVs.* The students complete a pre-class assignment on the Anti-lock Braking System (ABS) and *regenerative brakes*. Then an in-class homework assignment to determine the load transfer between the front/rear axles during braking and plot their results as a function of the deceleration experienced by the car using MATLAB. Many students learn how to write a plot code in MATLAB by completing this week's assignment.

Week 5: *Steering Systems: Traditional and AI-Enhanced Design*
Steering Systems take center stage this week with a comprehensive examination of both traditional and AI-enhanced designs. Students explore the intricacies of steering system architectures, control mechanisms, and integration with advanced driver-assistance systems (ADAS), gaining insights into the role of AI in enhancing vehicle maneuverability and safety. The students complete a pre-class assignment on Ackermann Steering and the steering systems of Tesla and Bosch. Then, they complete an in-class assignment outlined below:

A summary of the assignment is as follows:

Designing a responsive and energy-efficient steering system for a compact electric city car that involves balancing multiple factors to meet the vehicle's urban commuter needs. The steering system must offer precise control and feedback to navigate crowded streets effectively while minimizing energy consumption to enhance the car's overall efficiency and range. It should also be compact, lightweight, and reliable, meeting stringent safety standards and withstanding daily use in urban driving conditions. Additionally, the system should be cost-effective to manufacture and maintain, ensuring affordability for customers while delivering optimal performance.

Then students have to answer these questions by facilitate discussions on trade-offs between performance, cost, complexity, and manufacturability.

1. What type of a steering system (EPAS, ECU, Drive-by-wire, Steer-by-wire, Integrated steering and driver assistance, and etc.) would you implement and why?

2. What is your weight assumption for the car and why?

3. What is the minimum turning radius for the steering system and why?

Week 6: *Suspension: Traditional and Modern Designs*
The focus shifts to Suspension Systems, encompassing both traditional and modern designs. Students delve into the principles governing suspension geometry, damping characteristics, and performance optimization, Double-Wishbone suspension systems, exploring the evolution of suspension technologies and their impact on vehicle dynamics and ride comfort. The students complete a pre-class assignment on mechanically controlled suspensions vs. *electronically controlled suspension systems*. Then, they complete an in-class assignment to derive the equations for a double A-arm suspension system and design a 3D thin shell with stress, fatigue, and thermal analysis on SolidWorks.

Weeks 7 and 8: *Engine Modeling I: IC Engines*
During weeks 7 and 8, students will have a deep dive into internal combustion engines, with a focus on modeling and simulation techniques. Students learn to analyze engine performance, efficiency, and emissions characteristics, laying the groundwork for advanced studies in engine design and optimization. The students complete a pre-class assignment on engine dynamics and analyzing the behavior of IC engines under varying operating conditions. Then, they complete an in-class assignment to model an IC engine in Simulink and produce a P-V diagram for it. Once they have completed their mode, they need to modify it in MATLAB to improve the accuracy or to perform an investigation and comparison of different engine types, designs, or similar and

discuss how these modifications affect the P-V diagram and, therefore, the work produced by the engine.

Week 9: Spring Recess

Weeks 10 and 11: *Engine Modeling II: EV and AI Integration*
This week marks a transition to the realm of electric vehicles and the integration of AI into engine modeling. Students explore the unique challenges and opportunities posed by electric powertrains, analyzing the role of AI algorithms in optimizing energy efficiency, range, and performance. The students complete a pre-class assignment into the complexities of electric vehicle propulsion systems, exploring advanced modeling techniques and AI-driven optimizations to enhance vehicle performance and efficiency in real-world scenarios. Then, they have an in-class assignment to analyze the performance characteristics of an electric vehicle and identify opportunities for optimization using AI-driven techniques. They will utilize engine modeling techniques to analyze the performance of the electric powertrain under various operating conditions and explore the effectiveness of the AI-driven optimization approach in enhancing EV performance.

A summary of the assignment is as follows:

This individual assignment focuses on conducting thermal analysis and optimizing the design of an Electric Vehicle (EV) battery pack using CAD software. The task involves developing a detailed 3D model of the battery pack and simulating its thermal behavior. The report submission requires several components: researching and selecting appropriate battery cells and configurations based on performance requirements, designing a detailed 3D model of the battery pack including components like casing, cooling channels, thermal insulation, and heat sinks, assigning thermal properties to these components such as thermal conductivity and heat capacity, setting up thermal simulations in the CAD software to analyze temperature distribution, heat flux, and thermal gradients under steady-state and transient conditions, and finally running these simulations to identify areas of high temperature, thermal hotspots, and potential overheating risks within the battery pack. The deliverables include both the report and CAD files detailing these processes and outcomes.

Weeks 12 and 13: *Vehicle Performance I: IC Engines and EVs*
During weeks 12 and 13, the course shifts the focus to overall vehicle performance analysis, with an emphasis on the contributions of IC engines. Students examine the factors influencing vehicle acceleration, top speed, and fuel economy, applying their knowledge of engine dynamics to assess vehicle performance metrics. Building upon that, students explore the implications of electric powertrains and AI integration on vehicle performance. Through the pre-class assignment, students analyze the dynamic interactions between electric propulsion systems, AI algorithms, and vehicle dynamics, gaining insights into the holistic performance of electric vehicles. For an in-class assignment, they pick a car of their own research its technical specifications and the performance of its engine and transmission in particular. They utilize MATLAB script to show Engine performance data such as Torque, Power, and Gearbox data and plot the Tractive force v. vehicle speed (mph), Coefficient of dynamic performance v. vehicle speed (mph), Power v. vehicle speed (mph), Acceleration v. vehicle speed (mph), Speed v. time (i.e., 0.-60, 0-100, etc), and Distance v. time. They also have to utilize Ansys Fluent to simulate

an external flow analysis to study air flow around high-speed trains, aiding in understanding aerodynamic forces like drag. This knowledge has driven innovative designs to reduce induced drag, enhancing train efficiency. The simulation compares an old train to a streamlined bullet train, employing Ansys Fluent to model flow around scale models. Key learning includes simulating flow around trains, analyzing pressure and wall shear stress contours, and studying flow fields using velocity vectors and path lines.

Weeks 14 and 15: *Project Work Time*
During weeks 14 and 15, students start working on their term project.

The Term project details are:

Objective:

To design and simulate key components of an EV using CAD software and simulation tools by focusing on integrating AI algorithms into the design process to optimize the performance, efficiency, and safety of the selected components.

Scope:

To design and simulate choosing two of the following components:

- Electric Powertrain: Design the motor, battery pack, and power electronics system for the electric vehicle, focusing on efficiency and performance.
- Autonomous Driving System: Develop AI algorithms for autonomous driving features, such as lane-keeping assist, adaptive cruise control, and parking assistance.
- Vehicle Dynamics: Simulate the vehicle's dynamic behavior, including acceleration, braking, and cornering, to optimize handling and stability.
- Chassis and Body: Design the chassis and body structure to ensure safety, crashworthiness, and aerodynamic efficiency.

Key Features:

- CAD Modeling: Use CAD software to create detailed 3D models of the components.
- Simulation: Utilize simulation tools to analyze and optimize the performance of the components, considering factors such as stress, strain, displacements, and heat dissipation.
- AI Integration: Incorporate AI algorithms into the design process to improve the functionality and adaptability of the components, enhancing the overall vehicle performance.

Deliverables:

a. CAD Models: Detailed 3D CAD models of the designed components, including annotations and specifications.
b. Simulation Results: Analysis and optimization results from simulation tools, demonstrating the performance and efficiency of the components.

c. Design Documentation: Technical reports detailing the design process, methodology, and outcomes, including AI integration strategies and simulation methodologies. (A report template was provided on Canvas)

Week 16: *Project Due Date*
Students will create a professional presentation summarizing the project objectives, methodology, findings, and recommendations, highlighting the innovative features and performance enhancements achieved through their project.

Results:
The integration of EVs and AI has significantly transformed the course on Automotive Engineering. Students engaged in designing responsive and energy-efficient steering systems for compact electric city cars experienced a paradigm shift in their learning outcomes and project achievements.

Enhanced Understanding of Advanced Technologies: The incorporation of EVs and AI in the course curriculum deepened students' understanding of advanced automotive technologies. They gained insights into the principles governing electric powertrains, autonomous driving systems, and AI algorithms' integration for enhanced vehicle performance and efficiency.

Practical Application of CAD and Simulation Tools: Students effectively applied CAD software and simulation tools to design and analyze steering systems for electric city cars. They developed detailed 3D models, conducted simulations to optimize responsiveness and energy efficiency, and analyzed results to validate design improvements.

Optimization of Steering System Performance: Through the integration of AI algorithms, students optimized steering system performance by balancing responsiveness, precision, and energy consumption. They explored innovative design solutions that enhanced vehicle maneuverability and driver confidence in urban environments.

Impact on Course Dynamics: The introduction of EVs and AI integration shifted the course dynamics towards a more hands-on, industry-relevant approach. Students were challenged to apply theoretical concepts to real-world design scenarios, fostering critical thinking, problem-solving skills, and creativity.

Here is one examples of students’ work for term project:

Team A2 chose the Tesla Model S body for their design. They modeled the body and chassis and performed a drop test in SolidWorks to show how the vehicle chassis will react to a collision as shown in figures 1 and 2. The impact velocity was set at 130 m/s to show the extremes that the chassis would undergo while hitting a vehicle or obstruction head on at high speeds. They performed the simulation for front, side and rear impacts.
They also performed an aerodynamics study with speed that was set was 40 mph as a baseline and results are shown in figure 3.
For integrating AI, the team chose Obstacle Avoidance and Automated Parking. Then, the team referenced MathWorks’ Obstacle Avoidance Using Adaptive Model Predictive Control to program a vehicle to follow a reference velocity and avoid obstacles using adaptive model

predictive control (MPC). Their assumptions include but not limited to a rectangular shape for the car, three lanes straight street, constraint on throttling range to avoid unpredicted acceleration or deacceleration, and etc.
They also referenced MathWorks' Automated Parking Valet to plan a feasible path in a parking lot environment. Their goal was to find an optimized local trajectory or smooth the path using splines and generate a speed profile along the smoothed path. Their steps for simulation included the "Motion Planning to reference the path using the goal positions (utilizes MathWorks' plannerHybridAStar algorithm in the Navigation Toolbox).", "Local Path Optimization to optimize the local path by maintaining a smooth curvature and safe distance from obstacles (utilizes MathWorks' controllerTEB in the Navigation Toolbox), "Vehicle Control to utilize MathWorks' HelperPathAnalyzer which calculates the reference position and velocity based on the current position and velocity of the vehicle (utilizes MathWorks' lateralControllerStanley and HelperLongitudinalController functions which compute the steering angle to control the head of the vehicle and the acceleration/deceleration to maintain vehicle velocity, respectively), and "Goal Checking to check if the vehicle has reached the final position of the segment using the helperGoalChecker function provided by MathWorks."

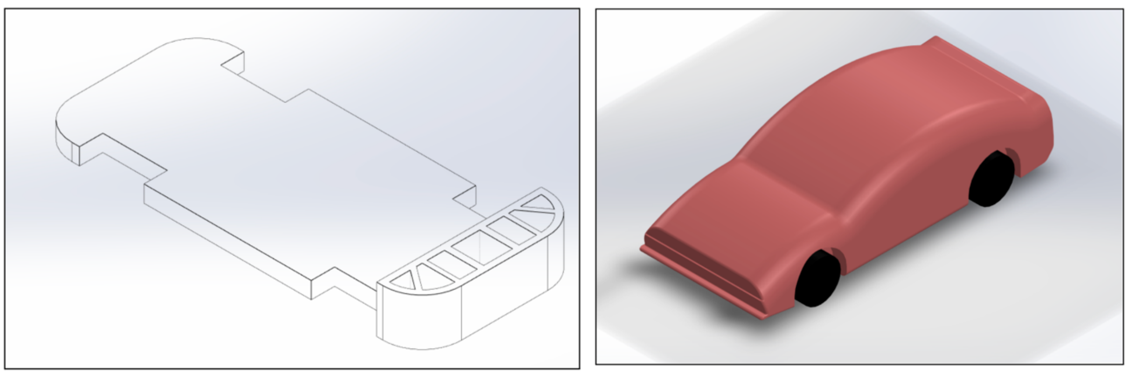

Figure 1. Team A2's design for Tesla Model S body and chassis

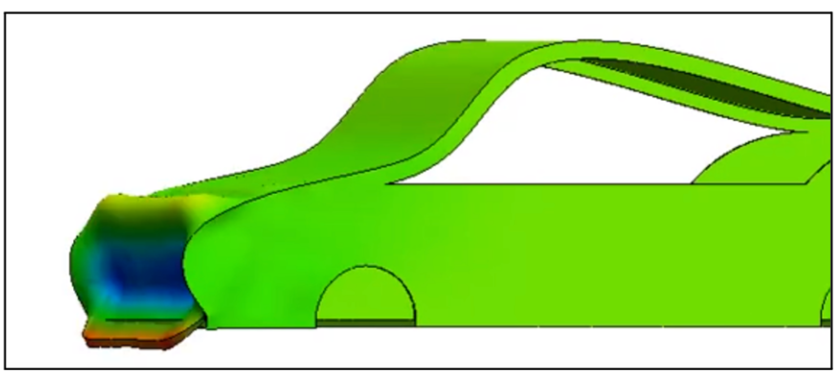

Figure 2. Team A2's work for collision impact

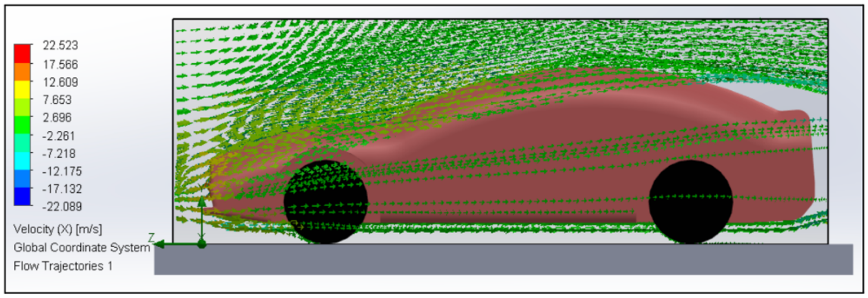

Figure 3. Team A2's aerodynamics study

Conclusion:
In conclusion, this paper has presented a transformative journey in the field of automotive engineering education, reflecting the dynamic evolution of the automotive industry towards EVs AI integration. By reimagining the traditional Automotive Engineering course and integrating cutting-edge technologies, the new curriculum aims to equip students with the knowledge, skills, and insights necessary to thrive in the rapidly changing automotive landscape.

The modifications made to the course description, learning objectives, instructional methodology, and assessment strategies were presented. By embracing a holistic approach that spans traditional internal combustion engines to the forefront of EV and AI technologies, the new curriculum ensures that students are prepared to tackle the multifaceted challenges and opportunities presented by the automotive industry of tomorrow.

The integration of AI algorithms into vehicle systems represents a pivotal aspect of the new curriculum, enabling students to explore AI-driven optimizations in areas such as powertrain efficiency, vehicle dynamics, and autonomous driving capabilities. By leveraging computational simulations, students gain practical experience in applying AI techniques to real-world automotive engineering challenges, laying the foundation for future innovation and advancement.

Furthermore, the project-based nature of this curriculum fosters a spirit of inquiry, creativity, and problem-solving among students, empowering them to develop innovative solutions to complex engineering problems. By engaging in interdisciplinary collaboration, students cultivate the critical thinking skills and technical expertise necessary to excel in the automotive industry.

The success of integrating EVs and AI in the course underscores the importance of staying abreast with technological advancements in the automotive industry. It prepares students to tackle complex engineering challenges and contributes to shaping the future of sustainable, intelligent transportation.

In summary, the reimagined Automotive Engineering course outlined in this paper represents a bold step toward preparing the next generation of automotive engineers for the challenges and opportunities of the future. By embracing emerging technologies, fostering interdisciplinary collaboration, and promoting experiential learning, the new curriculum seeks to empower students to become leaders and innovators in the ever-evolving field of automotive engineering.

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