Virtual Racing: Building a Formula Student Race Car Simulator

MECH5080M Contract Performance Plan

MECH5080M – Team Project
Virtual Racing: Building a Formula Student Race Car Simulator

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Industrial Mentor: University of Leeds – Formula Student 'Gryphons Racing'

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Introduction and Background

Formula Student (FS) is an annual engineering competition run by student teams from over 100 universities all over the world, in which the aim is for students to create a fully functional racecar using their engineering expertise. This car is then raced against other teams as a competitve way to demonstrate the practical engineering and project management skills that the students have learned [1].

Just like with professional racing teams in competitions like Formula One, an accurate driving simulator is an invaluable tool for FS teams to help train their drivers, especially when the real vehicle is undergoing work, damaged, or unavailable to be driven on a real track (i.e. track unavailability). Simulators can also be used as a safe enviornment to perform both training and research, and, when implemented correctly, can be easily configured to different settings to simulate different road conditions, different vehicle configurations, vibration, noise, and plenty of other variables [2]. A further use is as an outreach tool to demonstrate what the FS team does and recruit more members to join the team and share their engineering expertise. This is important to improve the overall competency of the team.

One key area in simulator creation is the inclusion of data acquisition systems built into the device [3]. These not only allow the device to more accurately portray real motion to the driver, but also allow for real-time driving data to be collected (for example how a particular driver slows down before an upcoming turn), which can be useful for strategy analysis. This data can also be compared to data from the real vehicle if available, which can aid in iterative improvement of the simulator over time.

Other notable areas of importance for the simulator are realistic emulations of steering wheel resistance, visual and auditory cues, vibration, and pedal resistance. These systems work in tandem to create a more natural and immersive experience, with the steering wheel and pedals being the most important, since they are the primary ways that the driver interacts with both simulator and vehicle [4].

Previous projects have aimed to create a similar device for the University of Leeds' Formula Student team, but currently there is no functioning device that the team can use for training or data acquisition. This project aims to build upon the previous work carried out by these students, resulting in a fully realised simulator.

Aim

To design and manufacture a portable and cost-effective simulator of the Formula Student Race Car for driver training and outreach activities.

Objectives

1. Determine a suitable approach for the simulation encompassing both hardware and software aspects.
2. Design and develop an actuated cockpit environment to simulate the dynamics of vehicle including functional feedback system.
3. Adapt pedal and steering arrangements to mimic functionality of the real formula student car.
4. Implement a virtual environment containing an immersive graphical representation of the formula student car and external surroundings.
5. Implement auditory and haptic feedback systems to deliver a highly immersive driving experience to the user.
6. Ensure a feasible level of portability to aid with outreach events such as university open days and formula student events.
7. Minimise simulator discomfort and ensure ergonomic experience for a wide range of users.
8. Deliver the aforementioned objectives alongside a critical assessment of safety with adequate mitigation in place.
9. **Stretch Objective:** Improve the immersive experience by enhancing the actuation system, implementing a virtual-reality headset, and replicating racing-condition features.

Activities and Deliverables

For Objective 1:

a) Literature review of existing software to determine a suitable package for the application.

b) Detailed analysis of existing hardware with research into additional appropriate hardware.

For Objective 2:

2a) Suitable actuators found and purchased capable of producing the required forces.

2b) A lightweight chassis mounted upon a 2 DoF actuated rig capable of simulating pitch and roll.

2c) An accurate dynamic model to mimic the real life feel of a race car.

For Objective 3:

3a) A steering system capable of providing realistic force feedback.

3b) A communications network for transferring information from both the steering and peddles into the game engine.

For Objective 4:

4a) An in-simulation representation of the formula student car within the simulation software that can be tweaked through the use of software modification.

4b) A custom racetrack that can be loaded into the simulation software.

4c) A stream of data output from the game engine to the simulator hardware to enable seamless communication between the hardware and software components.

For Objective 5:

5a) A sound system that can accurately portray engine and ambient noise.

5b) A vibration system with game engine synchronization

For Objective 6:

6a) A relatively lightweight and compact device, that can fit in the school’s lift.

6b) An aesthetically pleasing design that upholds engineering quality.

For Objective 7:

7a) A suitable choice of hardware and software to reduce motion sickness.

7b) An adjustable design that can accommodate a wide range of users.

For Objective 8:

8a) An electrically and mechanically safe simulator with an emergency stop and other risk mitigation.

For Objective 9 (Stretch):

9a) An integrated virtual reality system and lower latency actuators for a more immersive experience.

Resources and Expenditure

Table 1 contains the expected expenditure based upon required components. Note that most of these values are estimates as market fluctuations results in price variability.

Table 1: Details of required components and anticipated expenditure to meet base and stretch objectives.

To Meet Base Objectives			
Item	**Description**	**Expenditure**	**Comment**
Chassis	Formula Student 2017 Chassis.	N/A	Existing from previous project.
High-Performance Computer	Re-configuration of existing workstation (GPU/SSD upgrade).	£200 (est)	For running the simulation software.
Chassis Actuation Motors	Output speed: 80rpm, Output torque: 7nm, 24v DC, Quantity: 2.	N/A	Existing from previous project.
Chassis Motor Controllers	Used to control motors that actuate the chassis.	£150 (est)	Including Limit Switches
Steering wheel	Formula Student steering wheel.	N/A	Provided by FS team.
Steering Wheel Electronics	Arduino & Electrical Components (buttons, resistors, transistors etc)	£40 (est)	Available from the University.
Pedal box – Mechanical	Existing pedal box from previous project with appropriate upgrades.	£20 (est)	Provisions for replacement springs..
Pedal box – Electrical	2 x Rotary Encoders, Arduino, Cables, etc.	£40 (est)	
Simulation Software	rFactor 2.	£10 (est)	From re-seller.
Existing engines/ packages/ modules	Open Source tools to interface with rFactor 2.	N/A	Open Source, freely available.
3D printing	3D Printed Components.	£40 (est)	
	Total	**£500**	
To Meet Stretch Objectives			
Item	**Description**	**Expenditure**	**Comment**
VR Headset	Oculus Quest 2 or similar.	£299.99 [7]	Personal item available for testing.
Upgraded actuators	Fast-response linear actuators or DC Motors.	£1600 (est)	
Vibration system	Motor with eccentric weight and motor controller.	£100 (est)	
	Total	**£1999.99**	

Project Management

Team Structure

The team is made up of 5 students with Andrew Jackson as the main supervisor. The team has opted for an Agile Flat Hierarchy management approach, with Curtis as lead and is the main go between with the module leader. The competencies of the group members are below:

Curtis Lovett

Curtis is a L4 Mechanical Engineering at the University of Leeds. Having just returned from a year in industry working as a Design Engineer at Eaton Corporation, Curtis' knowledge of design and the surrounding areas is profound. Curtis has a keen interest in the automotive industry, having briefly worked as a part of the Formula Student team before and studying modules based around 'Vehicle Design', 'Automotive Chassis' and 'Electrical and Hybrid Drivetrain'.

Alex Bury

Alex is a L4 Mechanical Engineering student at the University of Leeds who has a wealth of experience within the formula student team, previously leading the drivetrain development of both internal combustion and electric vehicles. With a strong interest in manufacturing and automation, Alex also has a part-time job at PepsiCo following his placement year and continues to leverage his programming skills to develop digital applications for manufacturing facilities.

Jordan Partridge

Jordan is a L4 Mechatronics and Robotics student at the University of Leeds. He recently completed a year-long placement at Solid Solutions and is therefore an expert in using the SOLIDWORKS suite of software, including mechanical design, simulation, animations and rendering. He has also undertaken modules in circuit design, programming in C++, MATLAB, and Python, and has a wealth of knowledge about Embedded Systems and signal processing.

Mathew Fuller

Mathew is a Level 4 Mechatronics & Robotics student at the University of Leeds. He has gained experience during extracurricular activities such as the Leeds University Rocketry Association where he built a rocket as a member of the avionics team, as well as personal projects such as a voice-controlled prosthetic arm. He has experience in multiple coding languages (C++, Python, R, Rust etc.), SOLIDWORKS, and several other pieces of software, as well as experience in manufacturing and simulation.

Albert (Qianli Liang)

Albert is a Level 4 Mechanical Engineering student at the University of Leeds. His recent internship in China gives him experience in developing the control system of autonomous vehicles and the remote sensing system. He has developed his skills in MATLAB, Python, SOLIDWORKS and computer vision. He has also taken modules in automotive propulsion systems, vehicle design, automotive chassis and Electrical & hybrid drivetrain.

Risk Assessment

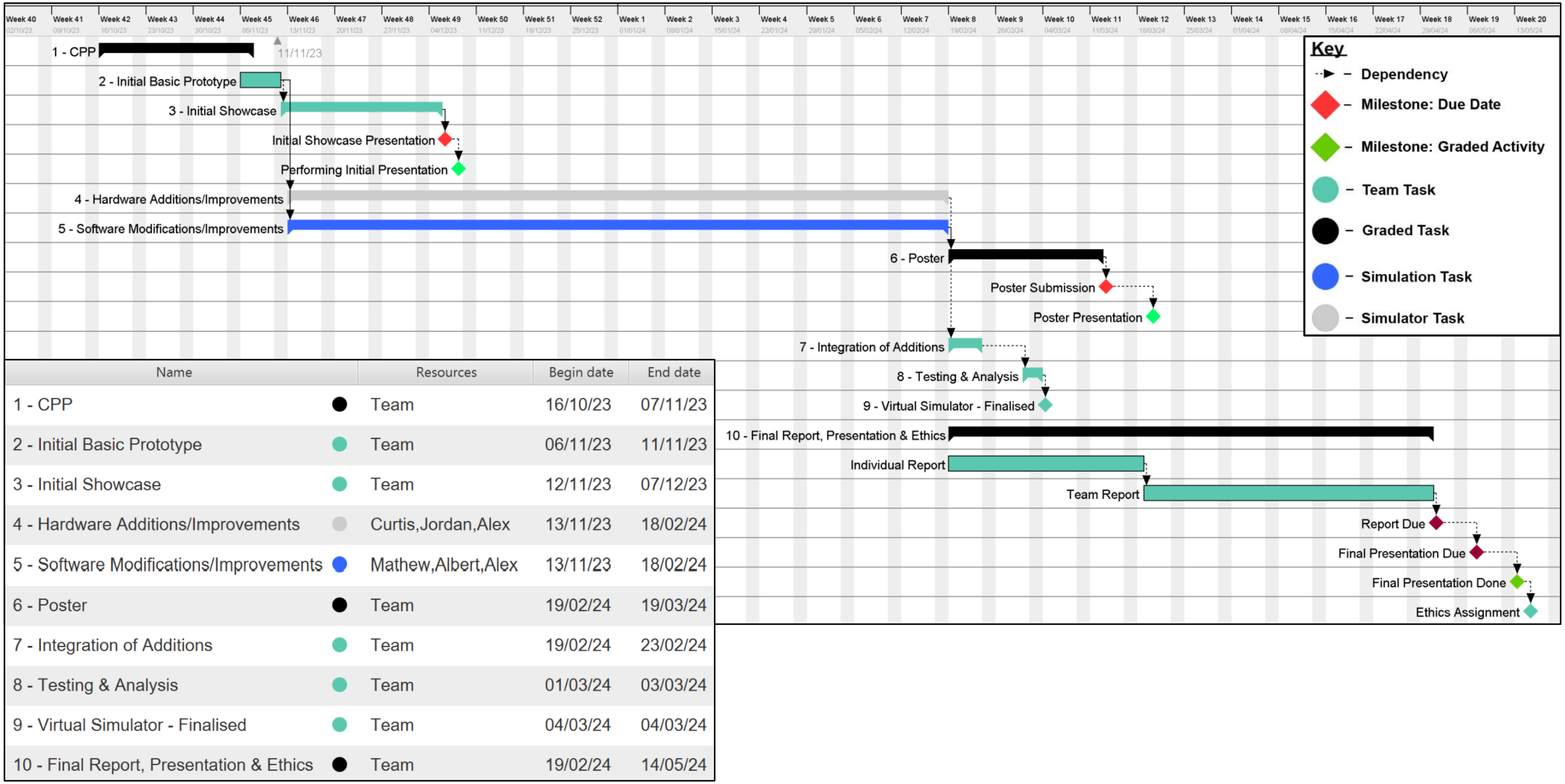
Table 2 details the identified risk, mitigations, and contingencies specified.

Table 2: Risk Management Table.

Risk	(Before Mitg.)		Mitigation	Contingency	(After Mitg.)
	Proba-bility	Impact			Severity
Damage of key components such as the chassis or steering wheel during assembly	Low	High	Resources are available to repair components in workshop	Repair parts	Low
Delay in arrival of purchased components/good	Med	High	Order all parts with a 20% buffer on lead time	Use alternative suppliers	Med
Final simulator is unsafe for testing	Low	High	Consider all aspects of safety throughout the design process	Redesign unsafe components	Med
Unavailability of team member (Illness or health problem)	Low	High	Add safety margins into the plan	Contact the module leader and supervisor to discuss further actions	Low
Inadequate budget	Low	Med	Use resources readily available at the university	Contact the formula student team to discuss further budget	Low

Unavailability of workshop	Low	Med	Complete lab induction in the early stages of the project and book time in, in advance	Use alternative design where less time in the workshop is required	Low
Documentation loss	Low	High	Store all key documents in shared online databases e.g., OneDrive	Recover most recent back up	Low
Limited access to software due to licensing issues	Low	High	Use software in which the university already has a shared license or that does not require a license	Use other available software	Low
Poor time management leading to incomplete objectives	Med	High	Objectives split into primary and stretch, hence prioritise the primary objectives	Agree a new scope with formula student team	Med
Rejection of ethical approval for testing	Low	High	Apply for approval in the early stages in the project	Do not include testing in final report	Med

Gantt Chart



Name	Resources	Begin date	End date
1 - CPP	Team	16/10/23	07/11/23
2 - Initial Basic Prototype	Team	06/11/23	11/11/23
3 - Initial Showcase	Team	12/11/23	07/12/23
4 - Hardware Additions/Improvements	Curtis,Jordan,Alex	13/11/23	18/02/24
5 - Software Modifications/Improvements	Mathew,Albert,Alex	13/11/23	18/02/24
6 - Poster	Team	19/02/24	19/03/24
7 - Integration of Additions	Team	19/02/24	23/02/24
8 - Testing & Analysis	Team	01/03/24	03/03/24
9 - Virtual Simulator - Finalised	Team	04/03/24	04/03/24
10 - Final Report, Presentation & Ethics	Team	19/02/24	14/05/24

Figure 1 Project Gantt Chart

Ethical Considerations

The simulator is designed to seat a human who will be subjected to stimuli in the form of video, sound, motion, and force feedback through the controls. While the aim is to replicate the feedback an individual feels when driving a vehicle, it is virtually impossible to identically replicate this due to limited motion, computational power, and modelling accuracy [5] [6]. Consequently, it is likely that some participants will feel motion sickness when using the simulator, and therefore they may become uncomfortable. It is therefore advised that any participants should be made aware of the risks associated with using the simulator, and that they can immediately and safely stop the stimuli if they desire.

In addition, to properly evaluate the efficacy of the project, it will be necessary to conduct a study with participants from the industrial sponsor, in this case the formula student team, and request them to complete a survey for feedback. As they will be reporting on their experience in an *active* environment (IE one with stimuli that respond to their input), this aspect of the project does not fall within the MECH5080M block ethical approval and therefore requires separate approval.

References

[1] IMechE, “Formula Student,” Institution of Mechanical Engineers, 2023. [Online]. Available: https://www.imeche.org/events/formula-student. [Accessed 05 November 2023].

[2] E. Blana, “Driving Simulator Validation Studies: A Literature Review,” Institute of Transport Studies, University of Leeds, Leeds, 1996.

[3] J. Campelo, A. Mart'i, J. P. Albiach and J. S. Martín, “A Real-Time Data Acquisition System for a Car Simulator to Study Disabled People Driving,” *Analysis,* vol. 2015, pp. 6-22, 03 April 2006.

[4] P. Bouchner and S. Novotný, “Development of advanced driving simulator: steering wheel and brake pedal feedback,” in *Proceedings of the 2nd international conference on Circuits, systems, control, signals*, 2011.

[5] J. Iskander, M. Attia, K. Saleh, D. Nahavandi, A. Abobakr, S. Mohamed, H. Asadi, A. Khosravi, C. P. Lim and M. Hossny, “From car sickness to autonomous car sickness: A review,” *Transportation Research Part F,* vol. 62, no. 1, pp. 716-726, 2019.

[6] H. Asadi, T. Bellmann, M. C. Qazani, S. Mohamed, C. P. Lim and S. Nahavandi, “A Novel Decoupled Model Predictive Control-Based Motion Cueing Algorithm for Driving Simulators,” *IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY,* vol. 72, no. 6, pp. 7024-7034, 2023.

[7] Currys, “META Quest 2 VR Gaming Headset - 128 GB,” Currys Group Limited, 2023. [Online]. Available: https://www.currys.co.uk/products/meta-quest-2-vr-gaming-headset-128-gb-10226485.html. [Accessed 6 November 2023].

Appendix A – Ethical Submission Form

MECH5080M ethical approval form

Don't forget to save your answers in the next screen (you can ask for it to be emailed to you) - you need to include the file as appendix of your scoping and planning document. Once completed, if more information is required, you will be contacted by the module leader

1. What is your team number? (this is the PID number given to you at allocation) *

   135

2. who is your team lead? *

   Curtis Lovett: mn19cl@leeds.ac.uk

3. Does your project involve human participants or their data (eg interviews, questionnaire, focus group, measurement) *

   - (selected) yes
   - no

4. Is it a clinical trial or an investigation of a medicinal product?

   - Yes
   - (selected) No

5. Are participants NHS patients (including deceased), or identified as participants because they are relatives of or carer of NHS patients (not including existing PPI groups)?

- ○ Yes
- ◉ No

6. Are NHS staff involved as participants, because of their role in the NHS?

- ○ Yes
- ◉ No

7. Is this project already covered by the school low risk block ethical approval?

- ○ Yes
- ◉ No

8. Confirm that you know that your project requires University ethical approval

Yes