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Research Proposal

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Abstract

This is the proposal for a Master's level dissertation that aims to develop an accurate model of a motorbike racer for lap time simulation purposes. An extensive literature review of the development of rider models for simulation was conducted. Many of the rider models were designed for simulating road riders with very few models applicable to lap time simulations of motorbike racers as they did not consider events of rapid acceleration and deceleration or large lean angles from the bike or rider. This lack of racer models is the gap in the research that this project is targeting. A critical evaluation of simulation software was conducted, and it was found that VI-Grade was the most suitable software for lap time simulations for bike racers. A methodology was suggested, justified and critically assessed. Data and video footage was collected from an Aprilia RS660 and the rider during a track day at Pembrey circuit. This data is to be analysed and used to validate the racer model made. Finally, an evaluation of the project in its entirety was undertaken. This project represents a novel addition to the research of motorcycle racer modelling. The project's greatest weakness is the limited time in which it must be completed.

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1.0 Introduction

Motorcycle simulation is an important part of motorcycle design, safety and a useful tool in development whether it is for the road or for racing. Research into vehicle simulation is extensive while rider simulation is lacking. Furthermore, research into motorcycle racer modelling is extremely limited. Thus, this project aims to build a rider model that accurately simulates a real motorbike racer. To achieve this aim, the key objectives required to achieve this are as follows:

Aim

- To build a rider model that accurately simulates a motorbike racer.

Objectives

- Data collection from riders. This was completed on 20th March 2026 at Pembrey circuit.
- Use of MATLAB to analyse video footage of the rider to validate the motorbike and rider data collected.
- Develop a racer model in VI-Grade.
- Test the developed racer model at an alternative track and critically evaluate the accuracy of the model.



Figure 1: Photograph of Aprilia RS660 used for this Study

2.0 Literature Review

2.1 Motorbike Rider Model Developments

Motorbike models for simulation are well understood and have been heavily researched, while rider models are basic and largely focus on road riders, not motorbike racers.

2.1.1 Rigid Rider Model

The study reported in Gani, Limebeer and Sharp (1997) was a simulation of a motorbike to assess weave and wobble at a range of velocities using AUTOSIM; a software which allowed for linear and nonlinear equations. This study was validated by Sharp's earlier analytical models. While this study proved that motorbike simulations (opposed to manual calculations) were accurate, the study contained one significant weakness; 'The rider was modelled as a rigid extension to the rear frame' (Gani, Limebeer and Sharp, 1997, p 228). This was not an accurate model of a human rider for the road or race.

2.1.2 Passive Rider Model

In Sharp and Limebeer (2001) the rider was modelled as two controllers, a proportional-integral (PI) controller to determine the torque that was transferred to the rear wheel from the chassis and a proportional-integral-derivative (PID) controller which produced a steering torque. Additionally, the riders' upper body was able to rotate with respect to the rear frame, Figure 2 shows how the riders' upper body feeds into the simulation. The rider is a passive system, a product of the motorcycle's behaviour, thus not a realistic model of human behaviour.

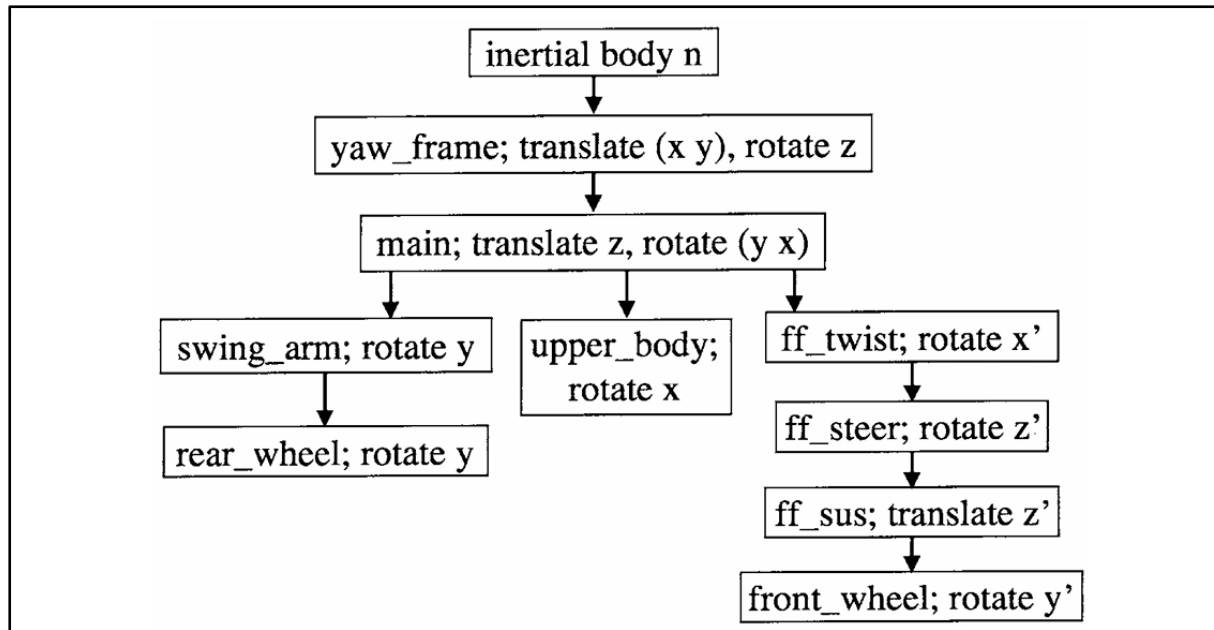


Figure 2: The Body Structure Diagram from 'A Motorcycle Model for Stability and Control Analysis', Showing How the Riders Upper Body Roll in x Feeds into the Simulation (Sharp and Limebeer, 2001)

A more recent rider model that includes feedback loops is the model used in Zhu, Murakami and Nishimura (2012). While this paper aimed to analyse motorcycle motion (a vehicle study) it took rider effects into consideration. These effects included leaning via motion of the upper body which inputted a lean torque into the simulation, the arms connection to the handlebars by modelling the arms as a spring and damper system. The stiffness coefficient was manually altered to assess the effect it had on the vehicle's stability. While this model is an improvement on Sharp and Limebeer (2001) model it still does not accurately model a human rider, furthermore this model was for a stability study not a lap time simulation.

2.1.3 Dynamic Rider Model

A more developed rider model was used in Sharp (2001) as the rider is no longer modelled as a part of the bike as in Gani, Limebeer and Sharp (1997) but as their own entity where the bike and rider interact with one another; this emulates a more realistic relationship between the rider and the bike. Steering angle, steering torque and body lean were the inputs from the rider into the simulation. Furthermore, the rider model was highlighted by Sharp as being 'especially significant' to the simulation due to their influence over the bike's handling characteristics in addition to altering the structural properties of the vehicle. Sharp also discusses areas of uncertainty and error in this study such as rider capabilities and

preferences, along with the ever-present discrepancies between simulation and practice (Sharp, 2001, pp 292-293). Lastly, Sharp's paper is intended to represent a road rider, not a racer.

The rider model in Kooijman and Schwab (2013) was focused largely on bicycle riders but has a relatively well-developed model that is worthy of note. The rider had two main roles in the simulation, to apply a steering torque and lean angle. This is a common feature among rider models and must be considered for an accurate model. The rider also has a closed loop controller which emulates the decision-making of the rider. It was responsible for deciding what path to follow around corners. In addition the controller had a delay which acted as the time it takes for a rider to make a decision.

2.1.4 Predictive Rider Model

The predictive model in Massaro, Lot and Cossalter (2012) is a further improvement from the models that use PI and PID controllers as the rider model uses the available information (vehicle speed, desired lean angle) to predict the actions required for the upcoming manoeuvre in addition the model was validated against human riders. This study gave the rider a target speed and lean angle for a manoeuvre then assessed the dynamics of the rider and motorcycle under the conditions. These conditions included lean angles of 50°, this is the lean angle which would be expected of motorbikes when racing thus this model could be used for racing applications. Furthermore, the rider model has more inputs (rear wheel torque, front and rear brake pressure) into the simulation compared to other models which were limited to body lean and steering torque. A weakness of this model was the lack of path planning by the rider.

2.1.5 Motorbike Racer Model

A rider model that has trajectory planning was made by Lot, Massaro and Sartori (2008). The model was then further developed in a paper written by Massaro (2011). This study included roll angles up to 50° and longitudinal acceleration of 0.8g much like the study in the previous chapter (Massaro, Lot and Cossalter, 2012), Massaro (2011) aimed to accurately simulate

manoeuvres and behaviours of skilled motorbike racers. To achieve this, parameters were put in place, examples of these targets were roll angles (e.g. 50°), entering the curve with an average deceleration of 5ms^{-2} and a maximum of 7.9ms^{-2} , exiting the curve with an average acceleration of 5ms^{-2} and a maximum of 7.9ms^{-2} . These are behaviours of a rider that is racing a motorbike. This model was not validated against a real motorbike racer thus is less reliable than the Massaro, Lot and Cossalter (2012) model.

2.2 Human Errors of Motorcyclists

Bartolozzi *et al.* (2023) discuss the effects that rider experience has on their riding style. They found that more experienced riders made fewer errors however, all the riders in the study made errors. All riders in the Bartolozzi's study repeated the motorbike handling exercise multiple times and all improved with the increase in attempts. This is pertinent to this study as regardless of the skill level of the racer modelled some errors or discrepancies between simulations should be expected, and to some extent be considered in the modelling of the racer. Furthermore, the data used as the target behaviour for the racer model should be taken once the human rider has completed multiple laps of the circuit such that the discrepancies of behaviour between the laps are minimal.

2.3 Lap Time Simulation

Cossalter *et al.* (2011) demonstrated that high-fidelity motorcycle simulators (Figure 3) can effectively reproduce real riding conditions for road riding and racing. However, while the simulator improved environmental realism, the study placed less emphasis on accurately modelling elite rider behaviour, particularly under racing conditions where rider input becomes the dominant performance factor. Cossalter highlighted that rider inputs become more significant in racing situations compared to road riding. Thus, it is critical that the racer model for this Masters' project encompasses as many racer behaviours as possible, to improve the accuracy of the lap time simulations.



Figure 3: Photograph of Motorbike Simulator (Cossalter et al., 2011)

2.4 Conclusion for Motorbike Rider Models, Human Behaviour and Lap Time Simulation

Existing research demonstrates a strong understanding of dynamic vehicle modelling and sufficient rider models for stability studies. These stability studies are for road riding application and would not be an accurate model for a racer in performance focused simulations. There is limited research into accurately modelling motorcycle racer behaviour using real-world data. This study aims to reduce the errors in lap time simulation caused by poor racer models by developing an accurate racer model.

To generate a racer model the following rider behaviours should be modelled. These rider behaviours have been selected and informed by the papers cited in the previous chapters.

Table 1: Racer Model Inputs to Simulation and their Rationale for Inclusion in the Lap Time Simulations

Racer Model Inputs to Simulation	Rationale
Body movement and load transfer	Racers lean their body (rider lean angle) to the inside of the turn to improve cornering. They also use 'knee down' strategies to improve cornering
Torque inputs for handlebars and foot pegs	Knowing the load transfer of the riders' weight alters the bikes dynamics. Additionally, racers implement counter steer by applying a pushing force on the inner handlebar when cornering
Throttle usage	Racers aim to accelerate at the maximum rate allowable by the bikes dynamics
Braking strategies	Racers aim to decelerate at the maximum rate allowable by the bikes dynamics
Path Planning	Racers use the fastest path (the racing line) around the circuit

2.5 Motorbike Modelling Software

Several software were identified as appropriate motorbike and rider modelling. This chapter covers a brief outline of the different software, their strengths, weaknesses and the justification for the selection of VI-Grade for this project.

2.5.1 MotorcycleMaker

MotorcycleMaker is a software by IPG Automotive, a company widely used in vehicle and driver simulation. It is a well-developed software with high fidelity in terms of the simulation physics. However, this software focuses on simulations for on-road vehicles for dynamics development thus, was not the most suitable software to conduct a racing simulation in.

2.5.2 BikeSim

BikeSim is a software that specialises in motorcycle and sidecar simulation with excellent physics modelling frequently used by engineers and researchers. However, this software was not designed for simulating the aggressive riding style used by racers.

2.5.3 AUTOSIM

Frequently used by researchers such as Sharp and Limebeer AUTOSIM is a software and computer language that can be used for vehicle simulation. In the papers cited above it was used for stability studies of motorcycles. While this software has the capability to simulate complex systems it is now considered an older program hence may be less suited to modern day lap simulation.

2.5.4 VI-Grade

VI-Grade is a software purpose-built for motorcycle racing lap simulation. The software treats the rider and bike as two separate objects that interact with one another. This lends itself to more accurate simulation of motorbike racers (Figure 4). Furthermore, the geometry of Aprilia RS660 can be implemented into the bike model with ease as the geometry type (direct shock) which is an available preset within the motorcycle model (Figure 5). As a result, an accurate Aprilia RS660 will be created for the study, which reduces the overall error of the simulation.

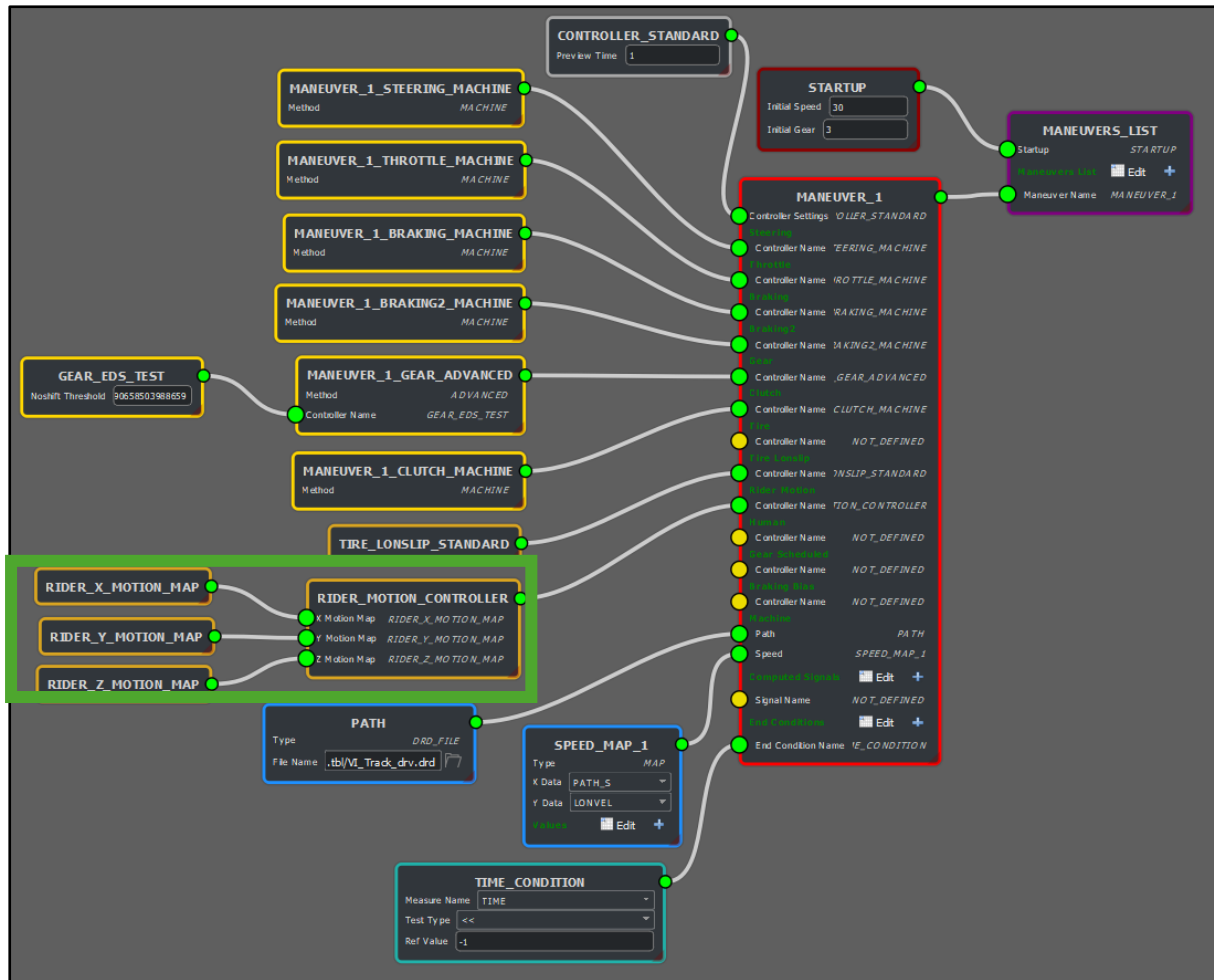


Figure 4: VI-Grade Manoeuvre Input Tree

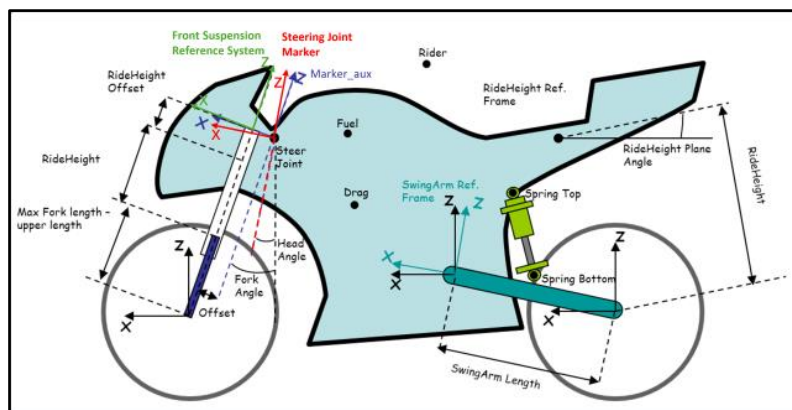


Figure 5: VI-Grade Bike Direct Shock Bike Geometry Drawing

2.6 Motorbike Modelling Software Conclusion

MotorcycleMaker and BikeSim both provide strong vehicle dynamic modelling and AUTOSIM is highly effective for stability studies, all are less suited to performance-focused rider behaviour modelling. VI-Grade was designed for motorsport applications and allows rider model modification, making it the most appropriate platform for modelling motorcycle racer behaviour.

3.0 Methodology

3.1 Data Collection

The Aprilia RS660 completed a Pembrey track day on the 20th March 2026. Data was collected from three sources during the bike time on track. Firstly, data was collected from a 2D logger (AV200) which stored the behaviour from the Aprilia RS660. Secondly, another 2D data logger was placed in the suit of the rider such that rider behaviours were measured and stored in the data logger. The final data source was from a GoPro placed on the tail of the bike. This recorded the rider's movements when on the bike. The weather was favourable on the test day at Pembrey which improved the readability of data collected. Furthermore, simulations with dry conditions are significantly simpler and allow for the focus of the simulation to be placed on the rider model, not the accuracy of the weather and track conditions.

The Aprilia RS660 was selected as it is a race motorcycle owned by the university which was familiar to the proposed riders of the bike for the track day. Moreover, the Aprilia RS660 has a logger preinstalled on the bike and strain gauges on the footpegs and handlebars. The loggers in the bike and the rider suit were 2D loggers; a company and software commonly used in motorbike racing for data analysis. There was no justification for changing the loggers, it was determined that they should be used for this project.

Pembrey circuit was selected due to the university association with the track. This reduced the costs associated with taking a motorcycle on track. Additionally, the circuit never had more than two vehicles on circuit at the same time. Therefore, influence from other riders was not a factor of error in the data collection. This allowed for the rider to have a clear view of the circuit ahead and they did not have to compromise their racing line due to the other riders on circuit.

The GoPro was placed on the tail of the bike as this is a good position to see the rider lean relative to the bike lean. This is also a video technique used by other branches of motorcycle racing.

3.2 Data Validation

The data from the two loggers will be synchronised and aligned with the video footage from the GoPro. This will be used to validate the data collected from the track day.

3.3 VI-Grade

3.3.1 Aprilia RS660

The Aprilia RS660's geometry was measured and validated against other students' measurements in addition to the MotoSPEC specifications. The geometry was then implemented into the VI-Grade's Bike model such that an accurate Aprilia RS660 was built in the software. This bike will remain unchanged throughout the project's iterations as it is a control variable within the project.

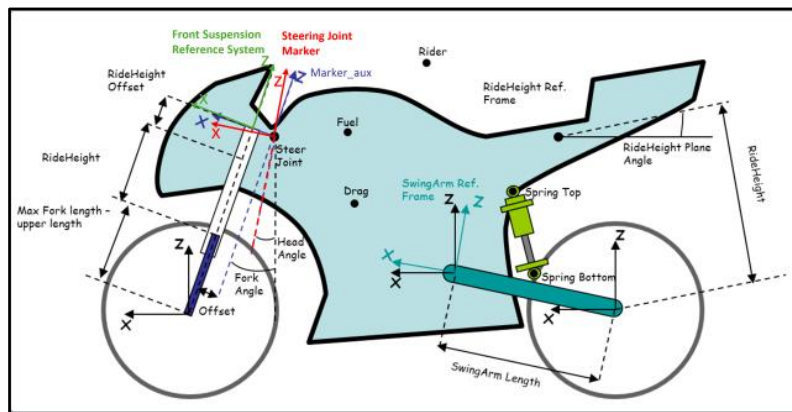


Figure 6: VI-Grade Bike Direct Shock Bike Geometry Drawing (same as Figure 5, included here for clarity)

3.3.2 Rider

The rider height and mass will be implemented into the model. Of the four available rider models within VI-Grade (Robot, Professional, Amateur and Novice) one must be selected. Thus, a simulation will be run on for all the base models as the model that displays behaviour most similar to the human rider will be selected as the starting model.

4.0 Anticipated Results

The results for this project will be quantitative data and largely continuous. The data from the logger on the Aprilia RS660 and the rider's suit displayed as graphs within the 2D software, where the x-axis represents displacement. This will then be compared to the bike and rider data generated from the VI-Grade lap time simulation. When the behaviour of the model racer aligns with the data from the human rider then the model will be a reasonable representation of the motorbike racer at Pembrey circuit. The main variables of concern are:

Table 2: Main Variables of Concern for Comparison

Rider Variables (from Suit logger)	Motorbike Variables (from Bike logger)
Lean angle	Lean angle
Roll rate	Roll rate
Rider body position (x,y and z co-ordinates)	Brake pressure front and rear
	Throttle position and gas delivery
	Steering input
	Torque on handlebars and footpegs
	Corner entry and exit speed
	Lap time

A relationship study between the human and model racer data will be conducted using the Root Mean Square Error method (Chai and Draxler, 2014; Hodson, 2022) in conjunction with Spearman Correlation due to the small sample size (de Winter, Gosling and Potter, 2016). A lower Root Mean Square Error value and stronger Spearman correlation coefficient will indicate that the model demonstrates strong agreement with the real rider data.

Further testing of the racer model would include completing lap time simulations with the model at another circuit such as Donington Park. The human racer which completed laps of Pembrey circuit would then do laps of Donington Park. If the model and the human data aligned, then the model would be validated and deemed an accurate model of a motorbike racer.

5.0 Evaluation

5.1 Strengths

This project represents a novel contribution to motorcycle simulation research as there is minimal research into the building of motorbike racer models. Much of the research (as discussed in the literature review) was focused on road rider behaviour. The data from the track day at Pembrey can be validated and then be used to validate the accuracy of the racer model created in VI-Grade.

5.2 Research Constraints

The sample size for this project is very small. Only two riders were available to complete laps of Pembrey circuit. Therefore, anomalies within their riding style may be hard to identify. However, both riders completed multiple laps; therefore, discrepancies between their behaviour lap to lap should reduce with the more laps they complete as discussed in chapter 2.2 Human Errors of Motorcyclists (Bartolozzi *et al.*, 2023).

There is limited time to complete this project. Concessions will have to be made regarding simulation accuracy. When running simulations inaccuracies due to approximations are inherent and unavoidable but may be minimised.

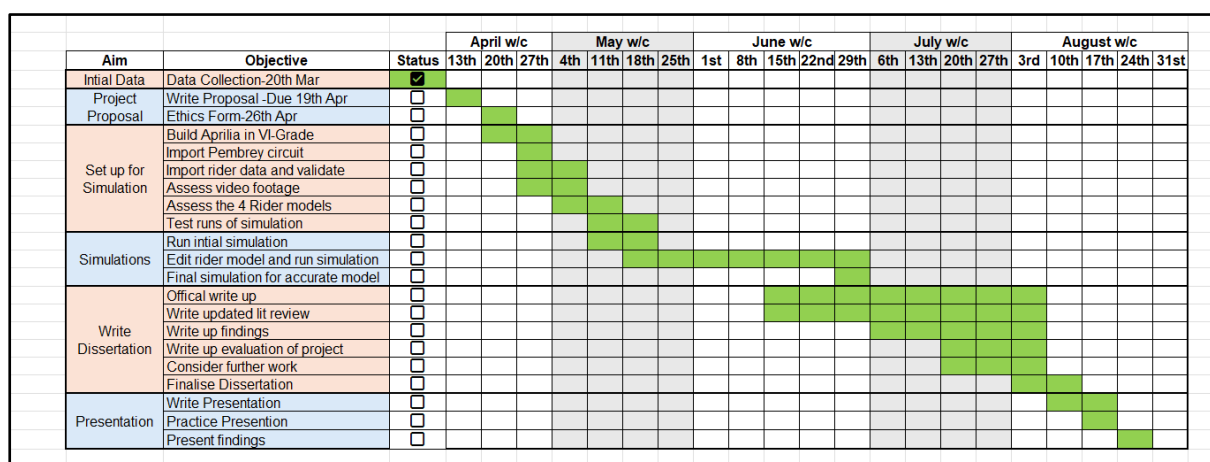


Figure 7: Gantt Chart for Project Planning

5.3 Future Work

Other factors that would improve the strength of this project would include.

Repeating the Pembrey test day with a larger sample of riders for the Aprilia RS660. With more riders, an average racer could be generated, and the VI-Grade model could be developed based on the average racer calculated. Currently the model is most likely to be a model that is strongly based on one rider's behaviour. This may be desirable in the motorsport industry as race teams may want a racer model that represents their rider's behaviour. However, this limits the general applications that the model could be used in.

As discussed in chapter 4.0 Anticipated Results the racer model is to be validated using human data from another circuit and compare it to the model's lap time simulation of the same circuit. The greater the number of circuits that the model can be validated at the greater the proof of the accuracy of the model.

Lastly, riders' behaviour changes due to weather conditions. There is potential for a further project to develop the model such that it emulates a racer's behaviour under different weather conditions.

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7.0 Appendices

Information about the sensors on the Aprilia RS660

Sensors	Measures	Reason for Sensor
OxTS AV200 (logger)	Measures motion using Inertial Measurement Unit (IMUs) and Global Navigation Satellite System (GNSS)	From the measurements many factors can be known such as: Positioning, velocity, acceleration, roll angle, yaw rate. (Oxford Technical Solutions Ltd., 2021)
Fork travel sensor	Change in voltage caused by the change on sensor length	Knowing the distance and rate that the forks compress at gives rise to the suspension behaviours.
Brake pressure sensor	Change in voltage caused by the change on sensor length	Can be used in support finding of load transfer and deceleration. In addition to rider behaviour analysis
Throttle position sensor	Change in voltage caused by the change on sensor length	Knowing the timing and throttle percentage can inform to the rider confidence in the vehicle as well as the stability and responsiveness of the bike.
Handlebar strain gauges	Change in voltage from the change in resistance caused by the extension/compression of the gauges	Knowing the force the rider is exerting on the handlebars can highlight the steering effort and indicate the level of counter steer being applied
Footpeg strain gauges	Change in voltage from the change in resistance caused by the extension/compression of the gauges	Knowing the force the rider is exerting on the footpegs can highlight the lean effort
Steering Angle	Analog measurement	Knowing the steering angle can highlight handling issues and inform to rider confidence and handling mechanics

Measurements of the Aprilia RS660

Measurement	Value Measured	Units
Wheelbase	1390	mm
Front Wheel Radius	300	mm
Rear Wheel Radius	314	mm
Fork Angle	66.45	degrees
Triple Clamp Offset	30.0	mm
Trail	87.14	mm
Swingarm Length	540	mm

Track Map of Pembrey Circuit

