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University of Wales Trinity Saint David - School of Engineering.

Development and Validation of RS660 Model in VI Grade

Advanced Motorcycle Performance (ACEA7001)

2023 - 2024



Figure 1: Aprilia RS660 on Track. (Iatrakis, 2024)

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2 Introduction

The following paper presents the method of measuring an Aprilia RS660 in order to develop a vehicle dynamics simulation model in the Dynamics modelling package "VI-BikeRealTime". Real life recorded data is used for modelling the track and validating the simulated model in VI-Grade.

The project utilizes data recorded by Brody Crockford, a former world championship R3 cup rider, around the Castle Combe Circuit. This real-world data was crucial for validating the VI-Grade model of the Aprilia RS660, ensuring the simulation accurately reflects actual performance characteristics. By creating a virtual track based on this data, the simulation could follow the exact path and conditions experienced during the recorded laps.

Motorcycle simulations like those conducted in VI-Grade are invaluable for a range of applications, from engineering design and testing to racer training and performance optimization. These simulations enable engineers to test multiple configurations in a virtual environment, significantly reducing the need for expensive and time-consuming physical testing. By adjusting parameters such as suspension settings, weight distribution, and tire characteristics, developers can predict the impacts on motorcycle behaviour, which is critical for both safety and performance enhancements.

Simulations can also extend to the development of active safety systems, where dynamic responses to various road conditions and scenarios can be tested thoroughly before being implemented in real-world models. Moreover, the ability to simulate different racing conditions helps teams and riders prepare more effectively for events, optimizing performance while minimizing risks.

3 Methodical Measurement of Physical Motorcycle Parameters

The following part describes the measurement of the physical parameters required for accurate modelling in VI-Grade. Limitations are in place as not all required values in VI-Grade are able to be measured. The measurement of physical moment of inertia and weights for rotating engine components was not feasible, as access to individual parts or entire engines was unavailable at the time. Additionally, given the relatively recent introduction of the motorcycle model, this specific data could not be sourced from any available resources.

3.1 Centre of Gravity

Centre of gravity measurement were conducted by measuring the change in mass distribution with a change in elevation on one of the wheels. [1] Measurements have been conducted at different heights of elevation to asses accuracy of the measurement method. The centre of gravity of the motorcycle on it's own, with rider tucked and rider sat upright has been measured and calculated. Table 1 shows some of the base parameters required for centre of gravity calculation.



Figure 2: Motorcycle Only Measurement (Iatrakis, 2023)



Figure 3: Rider tucked (Left) & Rider Upright (Right) CoG Measurement (Iatrakis, 2023)

Table 1: CoG Measurement Parameters (Iatrakis, 2024)

RS660 CoG Measurement Parameters		
Scale height	75.00	mm
Wheelbase	1455.00	mm
Radius AV	302.00	mm
Bike Weight	158.70	kg
Rider Weight	87.88	kg
Combined	246.58	kg

Table 2: Calculated CoG Bike only (Iatrakis, 2024)

Measurements Unloaded		
Rear Lift (mm)	Front (kg)	Rear (kg)
0	83	75.7
256	88.7	70
365	91.05	67.65
460	93.15	65.55
466	93.4	65.3

Unloaded CoG (from front)			
Rear Lift (mm)	X	Y	Precision Error
0	694.036		
256		594.385	
365		586.799	1.28%
460		581.248	2.21%
466		584.030	0.47%

Table 2 shows the measurements and calculated centre of gravity of the motorcycle. Some variation between the results is present, which is to be expected with manual measurements. This variation is often referred to as the precision error, which describes how close different measurements of the same parameter are to each other. [2] Ideally, a precision error below 10% is deemed acceptable, and the measurements obtained conform comfortably to this standard. [3]

The horizontal value of the centre of gravity is measured from the front contact patch.

Table 3: Calculated CoG Bike + Rider (Iatrakis, 2024)

Measurements with Rider				
Rear Lift (mm)	Upright		Tucked	
	Front (kg)	Rear (kg)	Front (kg)	Rear (kg)
0	113.95	132.9	115.65	130.65
255	128.175	118.4	129.125	117.45
360	135.575	111	137.575	109
455	138.975	107.6	140.225	106.35

Loaded CoG from front					
Rear Lift (mm)	Upright			Tucked	
	X	Y	Precision Error	X	Y
0	784.222			770.945	
255		782.652			739.559
360		808.059	3.14%		802.282
455		755.461	6.51%		737.537

Table 3 presents the measurements and the calculated Centre of Gravity for the motorcycle with a rider in both tucked and upright positions. The precision error remains under 10%, although it's slightly greater compared to the measurements taken with just the motorcycle. This increased error is likely attributable to variations in the rider's body position. Nevertheless, the precision error is within acceptable limits.

This shows that no significant variance is present between Centre of Gravity measurements at different raised heights. Table 4 shows an average of the different calculated results to be used in the simulations.

Table 4: CoG used for VI-Grade (Iatrakis, 2024)

CoG (mm)	X	Y
Unloaded	694.036	586.616
Upright	784.222	782.057
Tucked	770.945	759.793

3.2 Suspension Damper Dyno

To quantify the damping characteristics of the suspension system on the RS660 Trofeo, both the front and rear suspensions were tested on a damper dynamometer. The RS660 facilitates a Ohlins AP660 rear shock and a Andreani EVO Front fork Cartridge kit.



Figure 4: Andreani Fork on Damper Dyno & Spring/ shock disassembled for the Damper Dyno. (Iatrakis, 2023)

The full range of damper adjustment on the rear has been measured, which consists of 22 clicks on compression adjustment and 23 clicks of rebound adjustment. "2.5 turns" of adjustment is available for rebound and "3.5 turns" is available for compression, each 0.25 turns has been tested. The left front fork controls rebound damping, with the right front fork controlling compression damping. The acquired damping measurements have been exported as CSV files and were used to produce the damping files for use in VI-Grade.

Figure 5 displays a selection of the shock's damping measurements. It is clear that there is more rebound adjustment in actual damping compared to compression. This is likely because the manufacturer chose to stick with a proven baseline for damping of this shock, and has not provided extensive adjustment for compression adjustment. The presence of adjusters is often more for marketing purposes and to create a placebo effect. [4]

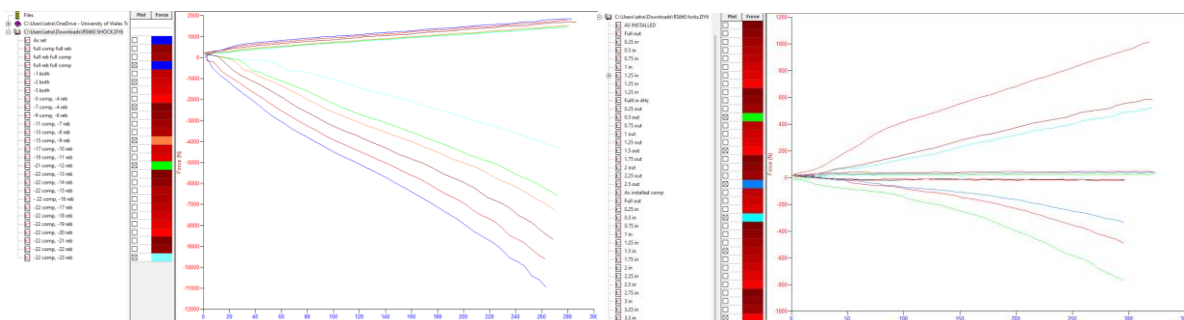


Figure 5: RS660 damping measurement. (Iatrakis, 2023)

The right hand side of Figure 5 shows a selection of damping settings on both the front forks. For the simulation, the damping settings were retained as initially installed, with the rebound set at 1.25 turns from fully closed and the compression adjusted to 2.25 turns from the completely closed position.

3.3 Spring Rate measurement

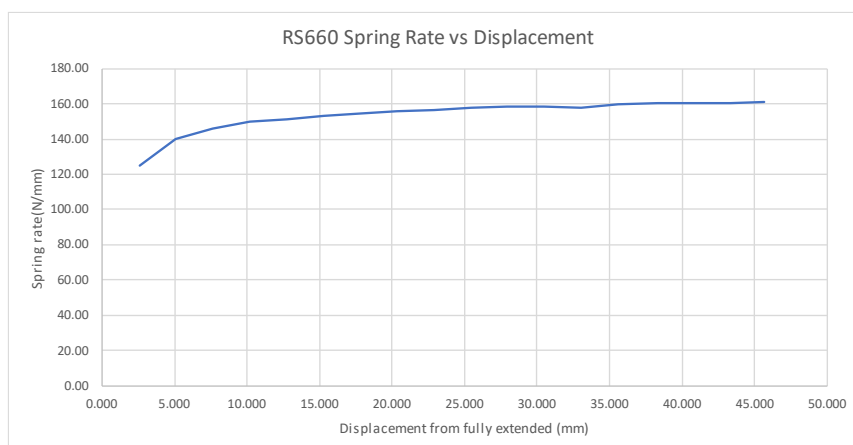
The front spring rate was marked as 9.5N/mm on the springs. The rear spring rate was measured as an investigation of non-linearity of spring rate. A Spring rate measurement tool was used in to measure the force required to compress the spring in 2.5mm steps. Non-Linearity in spring rate was found. Subsequently, Excel's LINEST function was utilized to establish a correlation between spring rate and displacement. The measurements are detailed in Table 5, while Graph 1 provides a graphical depiction of the spring rate as it varies with displacement. Additionally, Table 6 outlines the derived function for this relationship.

Table 5: Spring Rate Measurements (Iatrakis, 2023)

Spring rate Measurement						
lbs	N	0.001 inch	INCH	mm	lbs/inch	N/mm
73	324.71	102	0.102	2.591	715.69	125.25
161	716.14	201	0.201	5.105	801.00	140.17
251	1116.47	300.5	0.301	7.633	835.27	146.17
342	1521.25	400	0.400	10.160	855.00	149.63
433	1926.03	502	0.502	12.751	862.55	150.95
527	2344.15	601	0.601	15.265	876.87	153.45
619	2753.37	700	0.700	17.780	884.29	154.75
714	3175.94	802	0.802	20.371	890.27	155.80
805	3580.72	900	0.900	22.860	894.44	156.53
903	4016.63	1003	1.003	25.476	900.30	157.55
997	4434.76	1101	1.101	27.965	905.54	158.47
1050	4670.51	1200	1.200	30.480	875.00	153.13
1165	5182.04	1302	1.302	33.071	894.78	156.59
1281	5698.02	1403	1.403	35.636	913.04	159.78
1381	6142.83	1508	1.508	38.303	915.78	160.26
1467	6525.36	1600	1.600	40.640	916.88	160.45
1566	6965.72	1707	1.707	43.358	917.40	160.54
1653	7352.71	1798	1.798	45.669	919.35	160.89

Table 6: LINEST Function Spring rate vs displacement (Iatrakis, 2024)

LINEST For force calc from travel			
	X^2	x	constant
Force (N)	0.165246	155.1367	-72.8210529



Graph 1: Spring rate vs Displacement (Iatrakis, 2024)

3.4 Tire Deflection & Contact patch Area Measurement

Tire deflection stiffness and the size of the contact patch in an upright position were assessed under various pressures, primarily to facilitate future analysis aimed at accurately modelling dynamic contact patches, tire deflection, and consequently, the behaviour of the suspension/bike system. A specialized rig was constructed to secure the wheels in a press that exerted force onto a scale, recording the deflection at varying forces and pressures. To visualize the contact patch, coffee was used to mark the tire, which then imprinted on graph paper positioned atop the scale. The imprinted paper was scanned, and SolidWorks was employed to calculate the contact area. All measurements were conducted at 18.5°C. The RS660 is equipped with Pirelli Diablo Rosso 4 road tires, noting that deflection characteristics can vary with different tires based on their compound and carcass construction. The relationship between tire deflection and vertical force was established, allowing for the measurement of the contact patch at varying levels of deflection. Subsequently, the contact patch was correlated with vertical force to aid in further calculations or simulations.

Figure 6 illustrates the setup for measuring tire deflection, Figure 7 displays the contact patch impressions on the papers in SolidWorks, and the right of Figure 6 captures the process of measuring the contact patch.

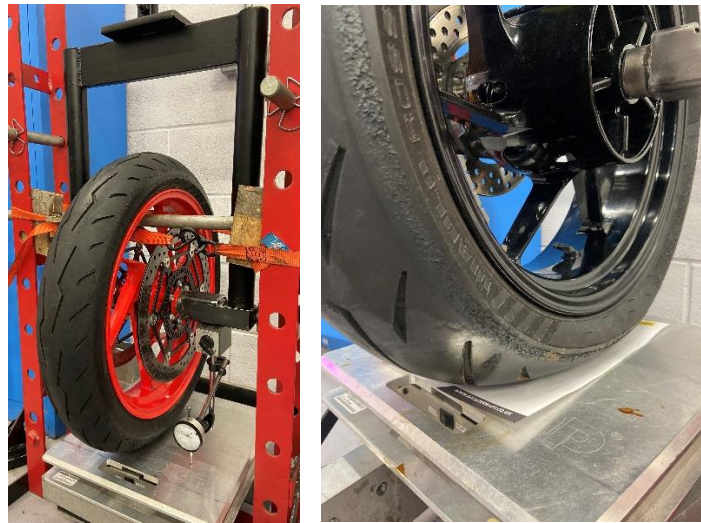


Figure 6: Tire Deflection Measurement rig (left) & Contact Patch Measurement (Right) (Iatrakis, 2024)

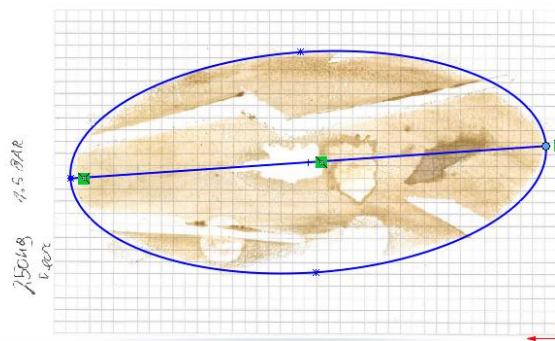


Figure 7: Scanned Contact Patch in SolidWorks for measurement (Iatrakis, 2024)

Table 7: Front Tire Deflection Measurements (Iatrakis, 2024)

RAW Deflection Measurements FRONT												
P tire (bar)	2.6	2.5	2.4	2.3	2.2	2.1	2	1.5	1	0.5	0	
P tire end (bar)	2.26	2.14	2.04	1.95	1.86	1.7	1.6	1.5	1.4	1.3	1.2	
Deflection (mm)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	
4	59	57	56	55	53	50	42	27	33	24	30	
6	88	82	81	80	78	74	67	45	44	36	46	
8	116	112	108	106	104	100	94	68	66	50	56	
10	148	142	138	135	131	126	121	90	85	64	78	
12	181	174	168	166	161	155	148	113	104	78	90	
14	218	208	203	196	193	187	178	138	125	94	100	
15	236	227	219.5	214	209	203.5	194	152	135.5	102	108	
16	252	246	236	232	225	220	210	166	146	110	116	
17				250	244	236	227	180.5	158	118.5	119.5	
18							244	195	170	123	123	
20								224	195	150	150	
22									218	172	172	
24										184	184	

Table 8: Rear Tire Deflection Measurements (Iatrakis, 2024)

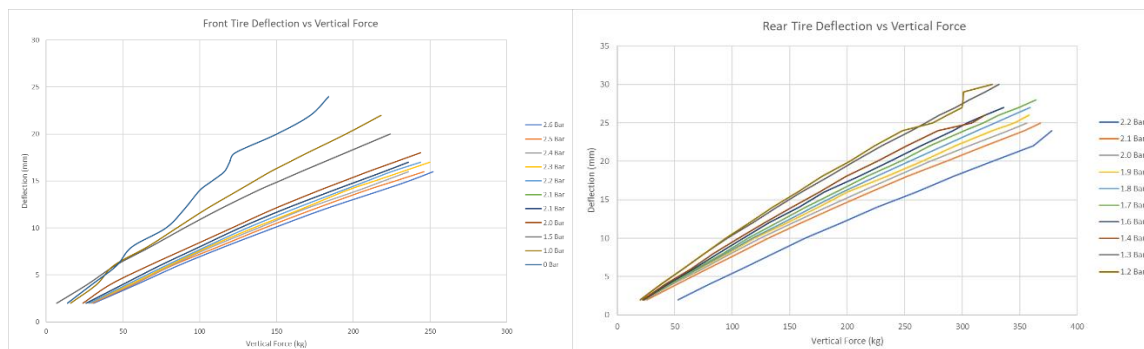
RAW Deflection Measurements REAR											
P tire end (bar)	2.2	2.1	2	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2
Deflection (mm)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)	Force (kg)
2	26	25	24	22	21	24	23	22	22	20	20
4	51	52	48	46	46	46	45	43	42	38	38
6	80	78	74	71	70	68	66	65	64	57	57
8	108	105	99	96	94	92	88	86	84	76	76
10	136	132	125	120	118	114	110	108	106	96	96
12	164	160	153	148	144	139	132	130	128	118	115
14	195	190	182	175	170	164	158	154	152	139	135
16	226	220	211	200	196	190	180	178	176	160	157
18	280	252	242	234	225	217	210	204	199	184	178
20	292	286	272	265	254	246	237	230	226	202	202
22	326	320	306	294	284	272	264	256	252	230	224
24	362	354	340	328	313	302	292	280	279	258	248
25	378	368	356	345	328	318	304	302	308	268	274
26				358	344	332	320	308	320	280	287
27					359	349	340	316	320	294	300
28						364		322		306	300.5
29								340		320	301
30										332	326

Following Table 9 shows the functions established from the measurements in order to describe contact patch related to vertical force. The surface pressure related to that force, at that contact patch is also calculated. Further work would require contact patch measurement at least over positions.

Table 9: LINEST Contact Patch Function (Iatrakis, 2024)

FRONT						REAR					
Pressure (psi)	Pressure (bar)	Force (kg)	Deflection (mm)	CP (mm ²)	Surface P (N/mm ²)	Pressure (bar)	Force (kg)	Deflection (mm)	CP (mm ²)	Surface P (N/mm ²)	
34	2.3442184	230	16.07114655	7794.55	0.28947149	1.5	300	23.51587794	17662.09	0.166628072	
28	1.9305328	200	15.37100432	8182.94	0.239767125	1.5	250	20.0614865	14462.22	0.169579774	
34	2.3442184	200	14.04047798	7565.05	0.259350566	1.5	200	16.42269979	10846.23	0.180892347	
34	2.3442184	145	10.31758559	5340.6	0.266346478	1.5	150	12.59951781	8798.53	0.167243846	
34	2.3442184	104	7.542338536	4264.19	0.239257632	1.5	105	9.000996055	6220.51	0.165589317	
34	2.3442184	62	4.699402531	2061.55	0.295030438	1.5	50	4.399967999	4398.62	0.111512247	
X^2		x	Const			x^2		x	Const		
LINEST		-18.5510751	913.790857		-1782.655584	LINEST		18.25400938	186.5002499		3209.137868

Graphs 2 depicted below illustrate the correlation between deflection and vertical force. There appears to be a linear trend that correlates with tire pressure; as pressure decreases, the relationship becomes more inconsistent, likely due to an increased impact from the tire carcass. Additional research is needed to explore the variations across different types of tire carcasses.



Graph 2: Tire Deflection vs Vertical Force (Iatrakis, 2024)

3.5 Frame Point Locations Measurement

For integration in VI-Grade, the location of different frame points compared to the Swingarm Pivot needs to be determined in a coordinate style (X, Y). The location of the top of the steering stem, bottom of the steering stem, top shock mount, bottom shock mount, rear axle, front axle in natural position of the motorcycle is required. Through use of a laser, the horizontal position of these points was determined by projecting and marking onto the floor, to then measure. The Vertical position was determined using the laser beam with a large try square. Ideally a 'Faro-Arm' would be used for more accurate measurement. The results were close to the renowned chassis program 'MotoSpec' thus satisfactory for use in VI-Grade.

Figure 8 shows the process of measuring. Table 10 shows the resulted coordinates. Figure 9 shows a simple depiction of the frame/ swingarm, shock, fork locations.



Figure 8: Frame Points Location Measurement (Iatrakis, 2024)

Table 10: Measured Frame Point locations (Iatrakis, 2024)

	X coordinate (mm)	Y coordinate (mm)
	Pivot = 0	Pivot = 0
Top of Stem	-534	523
Bottom of Stem	-613	298
Front Axle	-853	-117
Rear Axle	533	-76
Swingarm Pivot	0	0
Top Shock	-42	286
Bottom Shock	212	105

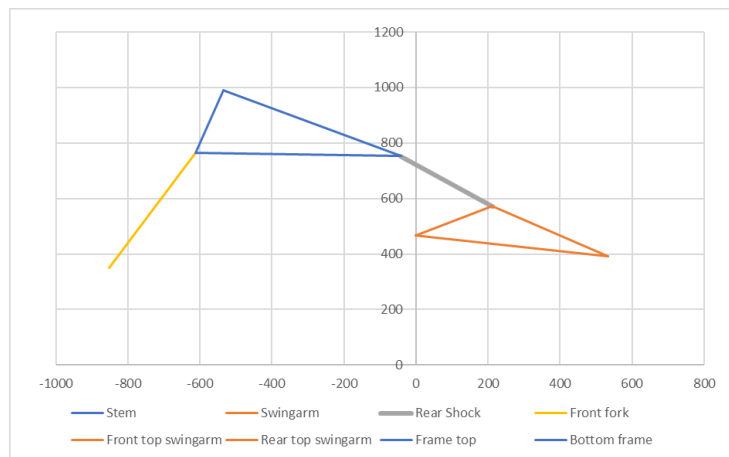


Figure 9: Graphical depiction Frame measurements (Iatrakis, 2024)

3.6 Wheel Inertia Measurement

In order to measure the Spin inertias of the wheels, three known methods have been used as an investigation into the accuracy of each. The three being ; the use of a wheel balancer with a weight attached to the wheel to introduce a fixed amount of force, the time taken for the weight to fall a set distance can be used to calculate the MOI.; Another method used was to roll the wheel down a slope and timing the time to roll a certain distance. Finally a Trifilar pendulum was used to measure the MOI, a data logger was attached to the bottom of the pendulum in order to accurately measure the decaying oscillations from a given angle input. Table 11 shows the results, the trifilar acquired numbers were used in the VI-Grade model as this is the most accurate measurement method without manual measurement error, and also a industry standard. [5] Jacob Quarry has conducted further confidence analysis between these methods.

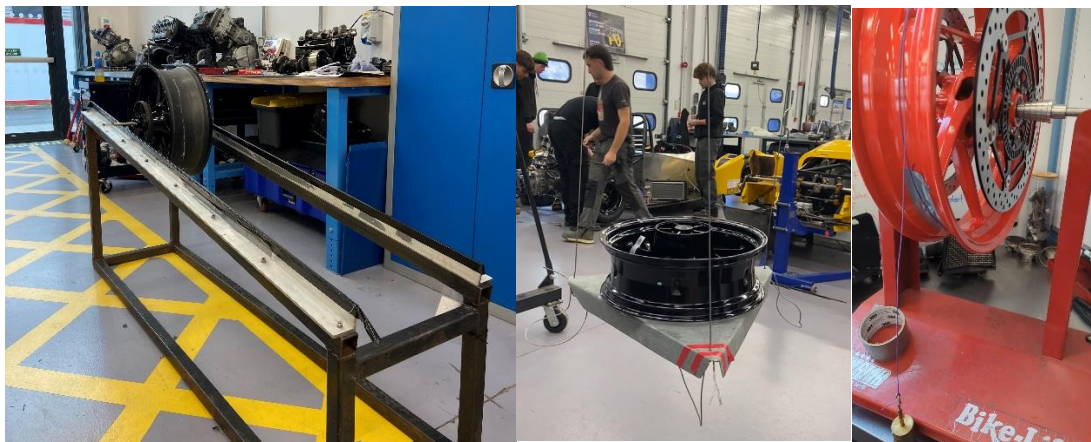


Figure 10: MOI Measurement Techniques (Iatrakis, 2024)

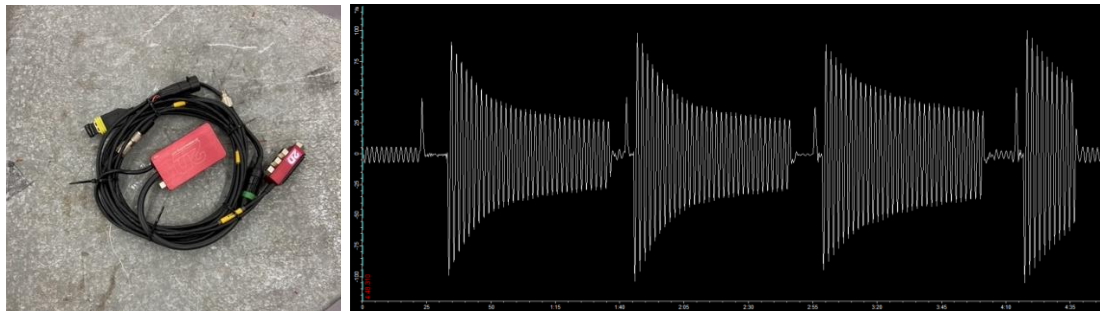


Figure 11: 2D Logger & Trifilar Pendulum Measurements result. (Iatrakis, 2024)

Table 11: MOI Results (Quarry, 2024)

	Average MOI					
	Front Wheel w/Tyre	Rear Wheel w/Tyre	Front Wheel w/o Tyre	Rear Wheel w/o Tyre	BMW carbon rim	Verification weight
Balancer	0.386	0.581	0.161	0.153	0.069	0.095
Ramp	0.325	0.627	0.108	0.074	0.054	0.068
Pendulum	0.483	0.689	0.166	0.169	0.095	0.115

3.7 Frontal Area

The frontal area was calculated using a front-facing photograph, with SolidWorks employed to establish a scale based on the front tire width of 120mm. Measurements were taken for both the tucked and braking positions to determine the frontal area. A drag coefficient was not able to be determined since this data wasn't readily available and a coast down was not feasible. Table 12 shows the acquired frontal Areas. Figures 12 & 13 show the initial photograph to outline sketch, and frontal area indicated by SolidWorks.

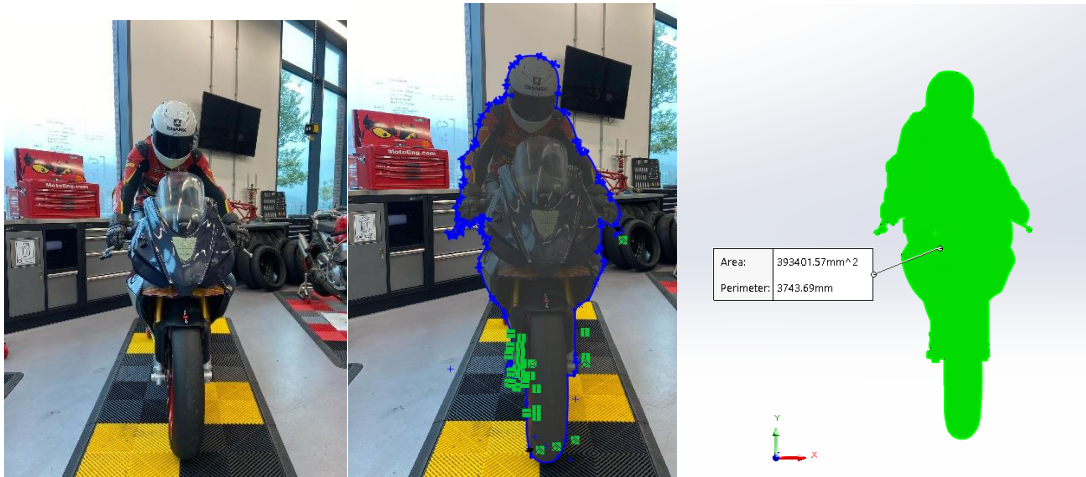


Figure 12: Upright Braking SolidWorks Frontal Area Determination. (Iatrakis, 2024)

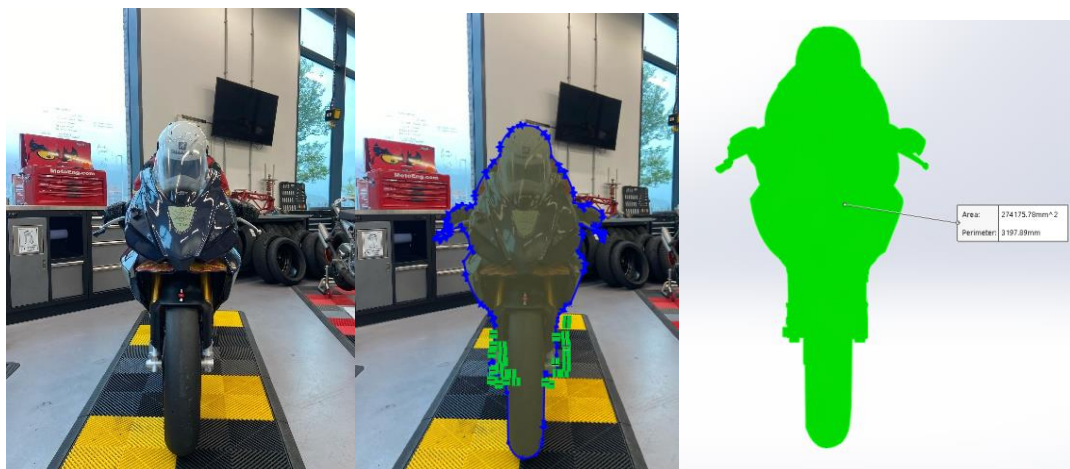


Figure 13: Tucked position SolidWorks Frontal Area Determination. (Iatrakis, 2024)

Table 12: Calculated Frontal Areas (Iatrakis, 2024)

Frontal Area RS660			
	Area (mm ²)	Area (m ²)	Diff
Full Tuck	274175.78	0.2742	
Upright Braking	393401.57	0.3934	30.31%

3.8 Engine Power Measurement

Engine power measurement has been performed on a dynamometer in house at UWTSD. A power-run in 4th gear was performed, the power and torque results were exported as CSV to be used in VI-Grade. Drag of the powertrain has been measured with the clutch pulled in. Further work requires engine brake torque measurement for increased accuracy of the model.



Figure 14: Aprilia RS660 on the UWTSD Dyno. (Iatrakis, 2024)



Graph 3: RS660 Trofeo Dyno run results (Harrison, 2023)

3.9 Data Acquisition System

In order to record real-life data, a Data acquisition system has been installed on the RS660. An Data Logger from 2D Debus & Diebold Meßsysteme GmbH has been used, this system allows connection and integration with the Aprilia RS660's Controller Area Network (CAN). This allows data streams from inbuilt sensors of the motorcycle to be read, allowing analysis of RPM, Wheel speeds, Throttle position, Gear Position, Coolant temperature, GPS, Inertial movement, etc. External suspension potentiometers are installed using bespoke designed and then 3D printed mounts.

The recorded data can then be used in order to validate the created VI-Grade Model.

Figures 15 & 16 shows the CAD Models of the bespoke made mounts and mounted suspension potentiometers.

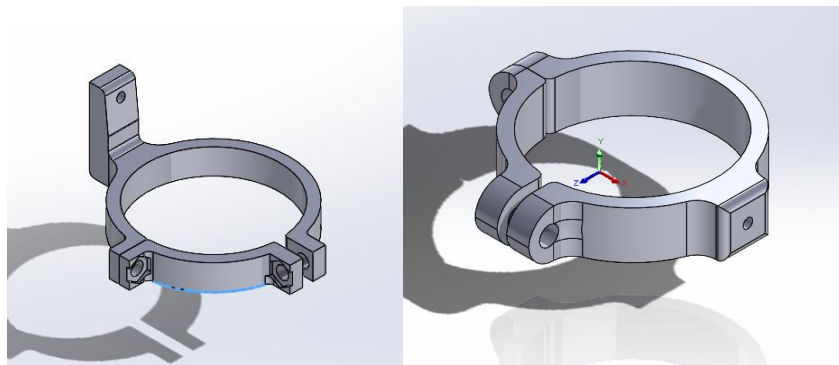


Figure 15: Suspension Potentiometer mounts CAD Models. (Iatrakis, 2024)

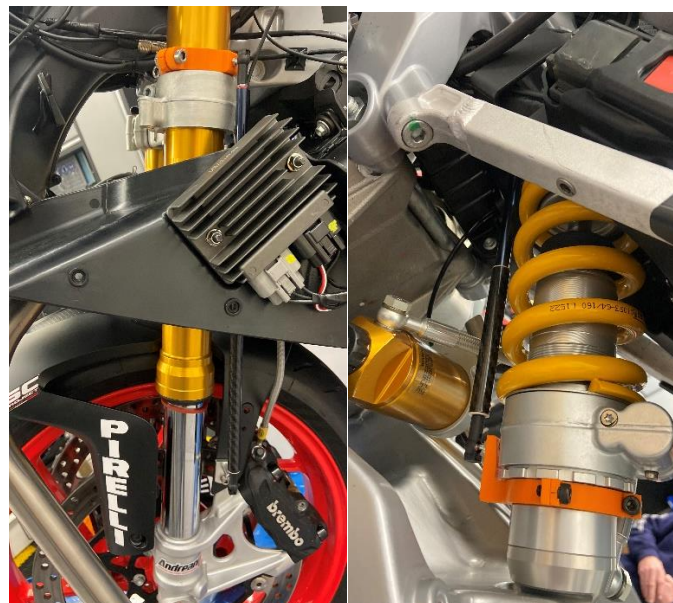


Figure 16: Bespoke Suspension potentiometers Mounts (Iatrakis, 2024)

3.10 Measurement Absences

Due to time limitations, certain parameters have not been measured which would have been required to complete the VI-BikeRealTime model completely.

A coastdown test was unable to be conducted before the time of hand in of this paper, this means the coefficient of drag and rolling resistance were unable to be measured and have had to be assumed as default at a 0.02 rolling resistance. The drag acceleration application and drag brake acceleration coefficient were not determined.

A measured negative Engine Brake Torque has not been able to have been determined as this test was not conducted on the dyno I order to accurately measure this.

The moments of inertias of all the individual engine parts, swingarm, frame, front forks, centre of gravities of these individual parts have not been measured due to time constraints and lacking a method to measure these accurately at the time of this paper. An engine has now been made available to be stripped at the University of Wales TSD MotoEng department, meaning that for further work this is possible.

4 RS660 Trofeo VI-Grade Model Inputs

The following part will discuss the inputs used to create a model of the previously acquired parameters of the Aprilia RS660 Trofeo.

4.1 Front Suspension

Figure 17 shows the VI-Grade interface in which the front suspension setup settings are input. A Non Linear spring of 9.5N/mm in order to limit at a 120mm travel is used with 6mm preload. This matches with the setup used when the real-life data was recorded.

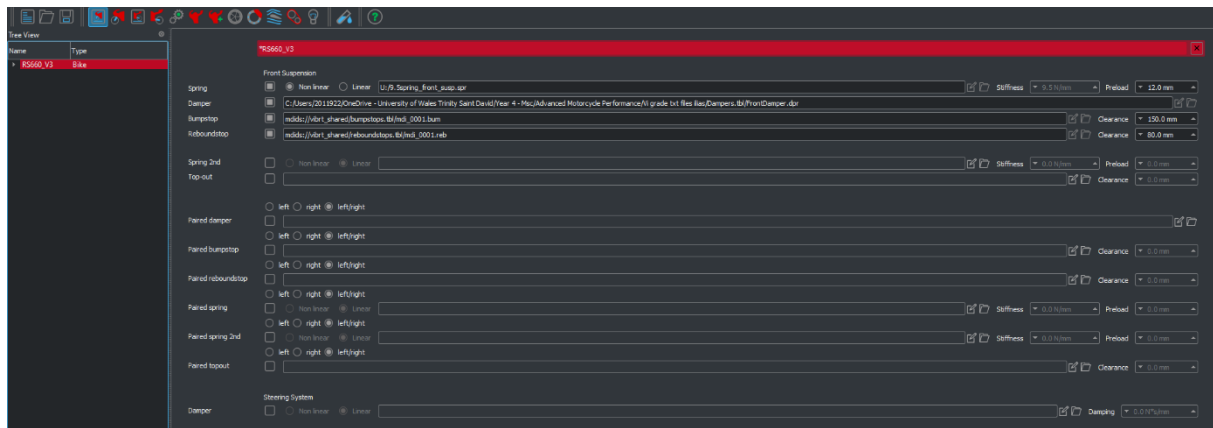


Figure 17: Front Suspension Setup Settings (Iatrakis, 2024)

Figure 18 shows the physical suspension settings. The lengths of the upper and lower part of the fork are configured. The Head angle, Fork angle, Offset, upper fork length and Max fork length are set. Remaining values are kept as default since these data were not available at the time, further work would require measurement of these values.

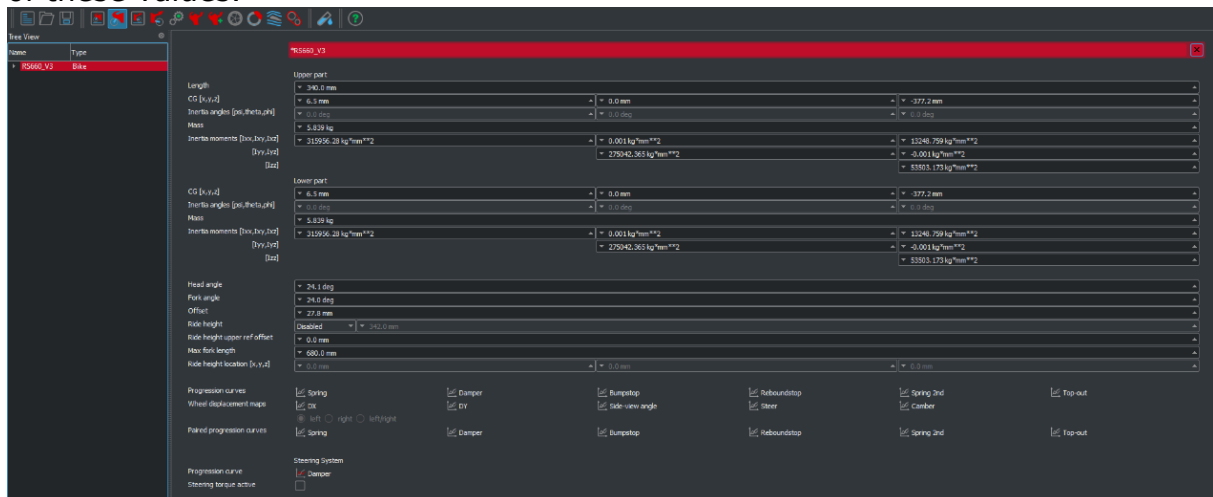


Figure 18: Front Suspension physical settings (Iatrakis, 2024)

4.2 Rear Suspension

Figure 19 shows the settings used for the rear suspension setup. A Non Linear spring with a 120N/mm rate in order to limit at 51mm suspension stroke with 8.5mm preload is used. As used during the real-life test. Damping settings used are middle The remaining values are kept as default.



Figure 19: Rear Suspension Setup settings (Iatrakis, 2024)

Figure 20 shows the physical settings of the rear suspension. The swingarm length, Pivot Point set as 0,0 coordinate and the measured locations of the suspension mount, swingarm, rear axle has been input. The mass is left as default since it comes close to usual values of swingarm weights (From previous measured motorcycles), inertia moments were unavailable at the time of simulation and require measurement.

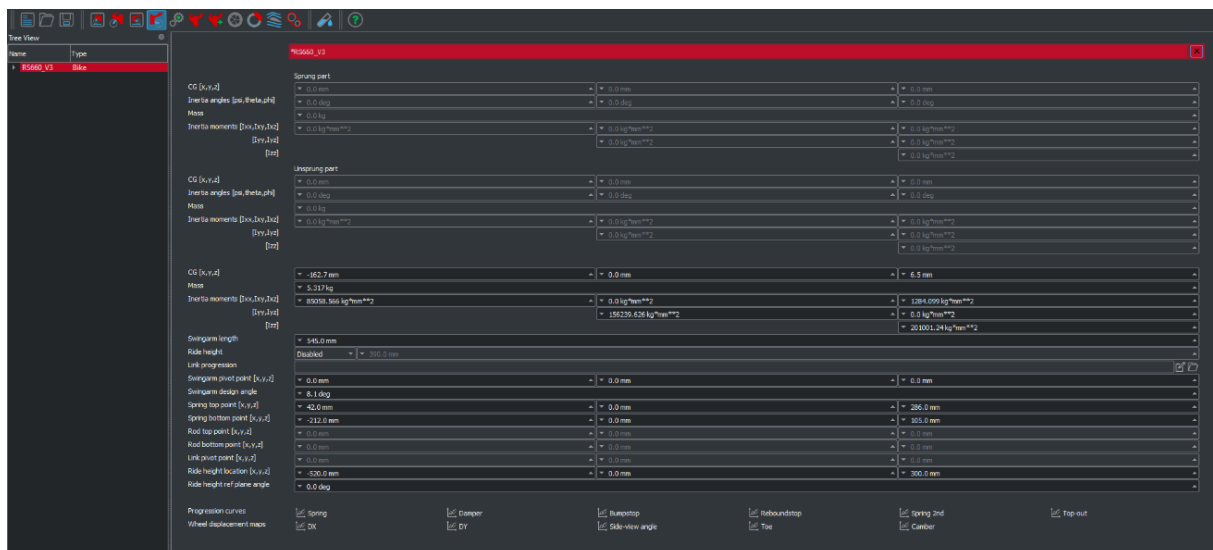


Figure 20: Rear Suspension Physical Settings (Iatrakis, 2024)

4.3 Powertrain

The window below (Figure 21) displays the powertrain settings used for the RS660. Gearbox ratios were sourced from the Aprilia Workshop Manual. The final gear ratio reflects real-life testing configurations, utilizing sprockets with 16 and 43 teeth. The rev limit is set at 11,500 RPM, and the power map is derived from a dyno test conducted on the actual Aprilia RS660.

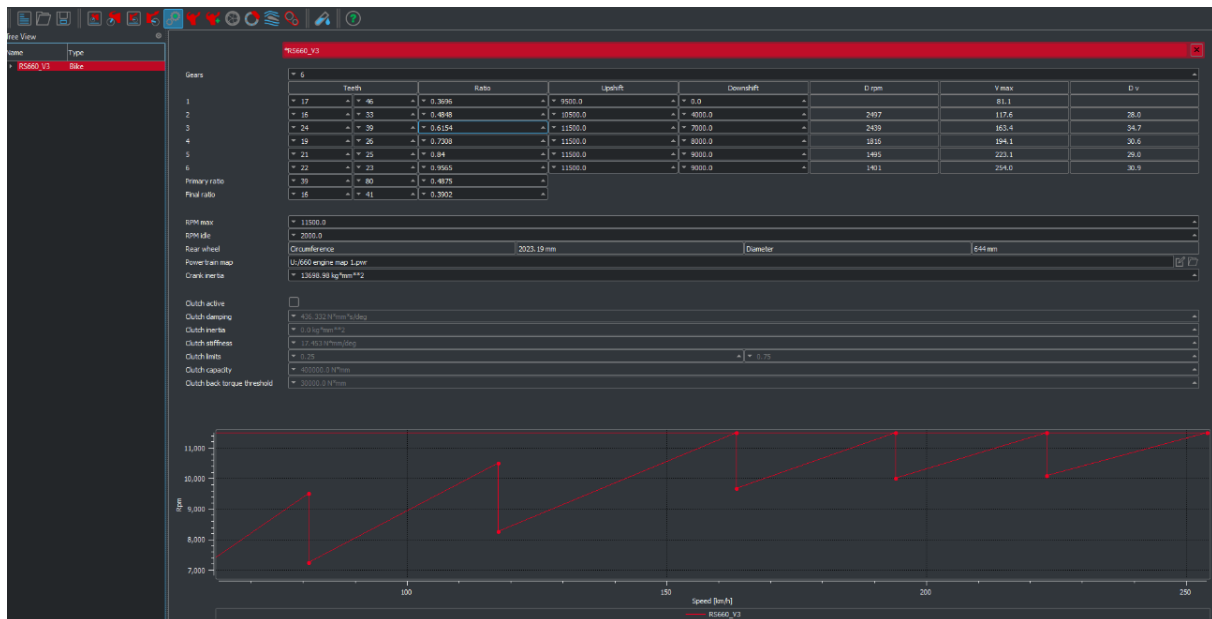


Figure 21: Powertrain Settings (Iatrakis, 2024)

4.4 Frame

The window below outlines the settings for the "Frame." The centre of gravity is positioned as tucked and is defined relative to the swingarm pivot (see Figure 23). The combined weight of the bike and rider reflects the specifications used during real-life data collection tests, which included rider Brody Crockford. Steer joint position is set as the bottom of the steering stem. Inertia moments are kept as default since this data was unavailable at the time of measurement.

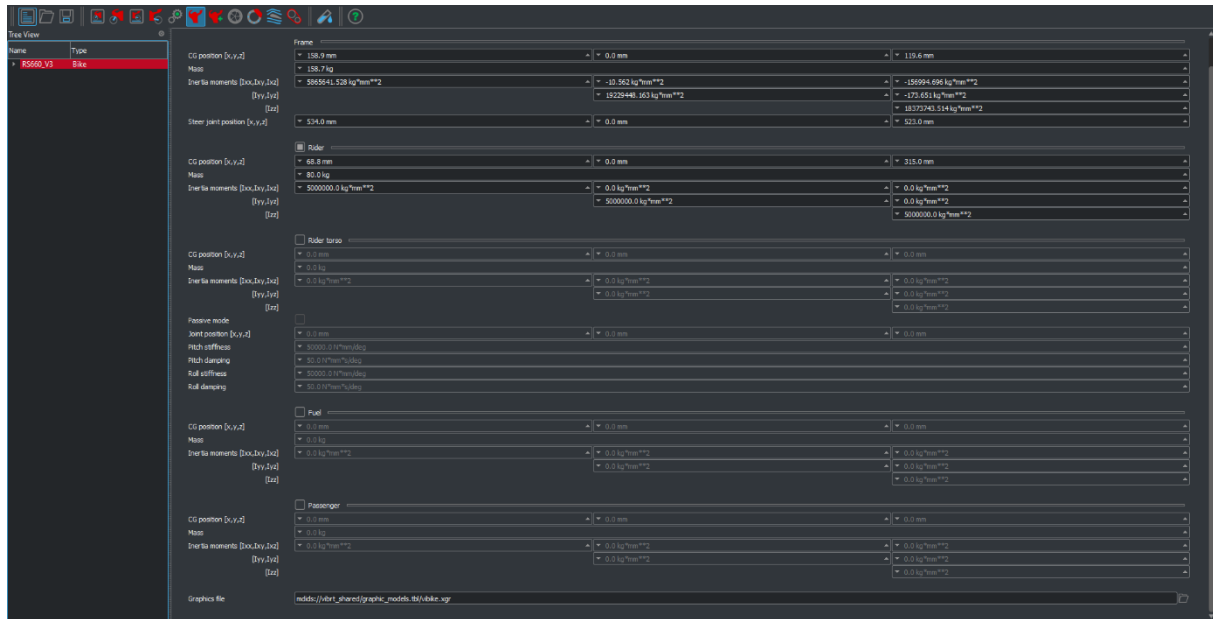


Figure 22: VI-Grade RS660 Frame settings. (Iatrakis, 2024)

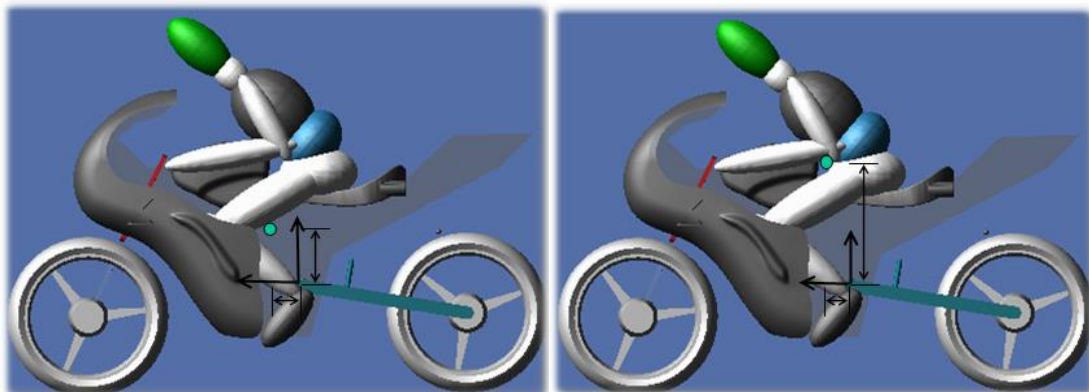


Figure 23: VI-Grade CoG position Bike Illustration (Left) & VI-Grade Rider CoG Illustration (Right) (VI-Grade, 2024)

4.5 Wheels

The following window shows the used settings for the wheels of the VI-Grade RS660 model. The Initial Spin Inertias were the Pendulum Measured numbers. As setting up the Spin Inertias in VI-BikeRealTime was not possible, altering the Spin Inertias in the .XBK Text File was required (Figure 26) in Line 18, the front wheel settings can be changed, Line 52 is used to alter the rear wheel settings. The front wheel weight is set at 11.5kg, and the rear wheel weight set at 15.39kg, as measured on the RS660 Trofeo. (Figure 25)



Figure 24: RS660 Wheels setup window VI-Grade (Iatrakis, 2024)



Figure 25: RS660 Wheel weight measuring (Iatrakis, 2024)



Figure 26: Altering XBK Files for Spin inertias (Iatrakis, 2024)

4.6 Brakes

The following window shows the used brake settings in VI-Grade. The maximum brake pressure is set to 20Bar. The friction coefficient is set to 0.61 as an average from the published specification of the SBS DS-1 Racing Brake pads (Figure 28)[6]. The effective piston radius is set to 160mm as 320mm brake discs are used. The Piston Area equals to one side of the calliper [7], calculated by the spec of the 32mm diameter pistons used in the 4 piston Brembo callipers on the RS660 [8].

The rear friction coefficient is also set to 0.6, the effective piston radius is set to 110mm as a 220mm diameter brake disc is used. The piston area is calculated through the 34mm diameter brake pistons used in the 2 piston Brembo calliper on the RS660.

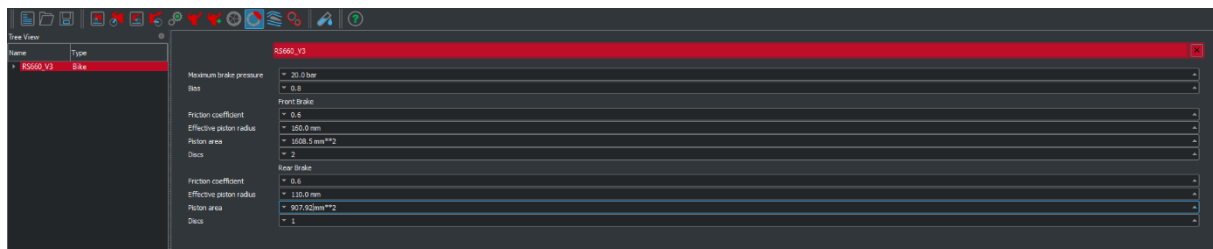


Figure 27: VI-Grade RS660 Brake Settings (Iatrakis, 2024)

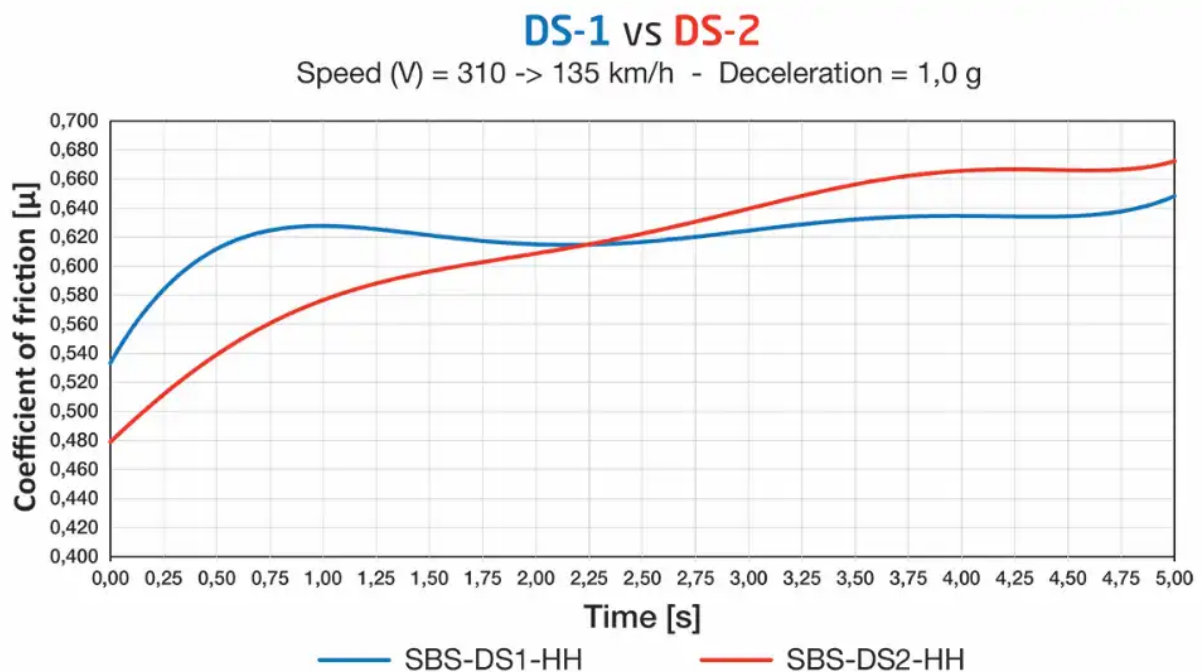


Figure 28: Coefficient of Friction Graph SBS Brake Racing Brake pads (SBS, 2024)

4.7 Aerodynamic Settings

Following window (figure 29) shows the aerodynamic settings set for the VI-Grade simulation. The air density was set to 1.167kg/m^3 for 15°C English weather, as the test was held at castle combe. The measured frontal area at full tuck is used. The remaining settings were set as default since these parameters were unavailable at the time. Further work is required to perform coast down tests in order to acquire aerodynamic drag.

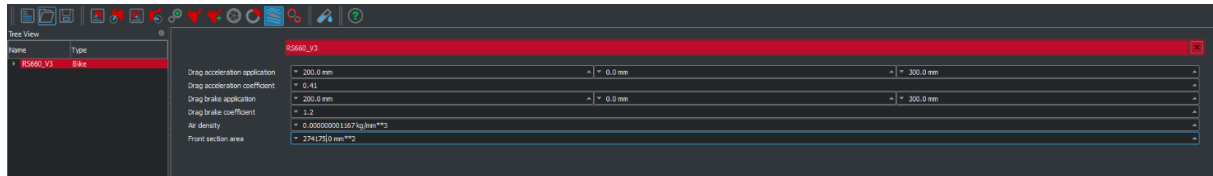


Figure 29: VI-Grade RS660 Model Aerodynamic Settings (Iatrakis, 2024)

4.8 Chain Settings

The following window shows the chain settings used for the VI-Grade Simulation, the slack has been set to 30mm, the pitch for the DID ER520 chain is 15.8mm.

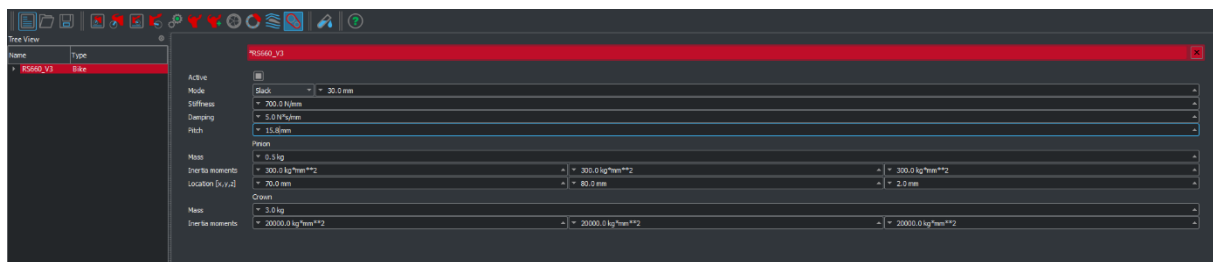


Figure 30: VI-Grade RS660 Chain Settings. (Iatrakis, 2024)

5 Track Setup

Recorded data around Castle Combe Circuit on the RS660 has been recorded in order to simulate and validate the RS660 model. GPS data of the fastest lap recorded in 2D has been exported to Google Earth pro, using the 'GoogleEarth Link' function (Figure 31). Using Google Earth Pro, The track can then be exported as a 'KMZ' format to be used in VI-Grade Road to create a path for the simulation to follow.

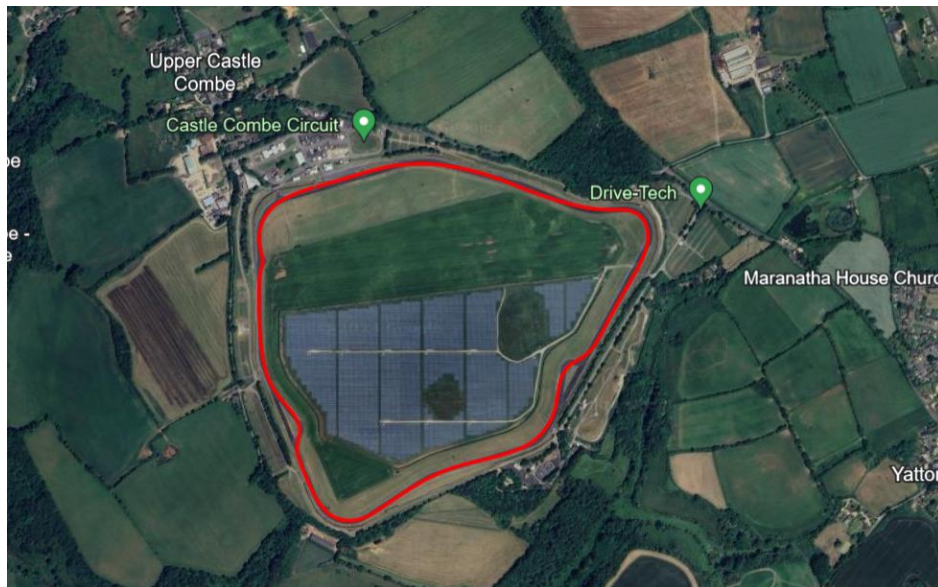


Figure 31: 2D Imported GPS Data to Google Earth. (Iatrakis, 2024)

Using 'VI-Road' The KMZ file can be opened in order to create a path (Figure 32).

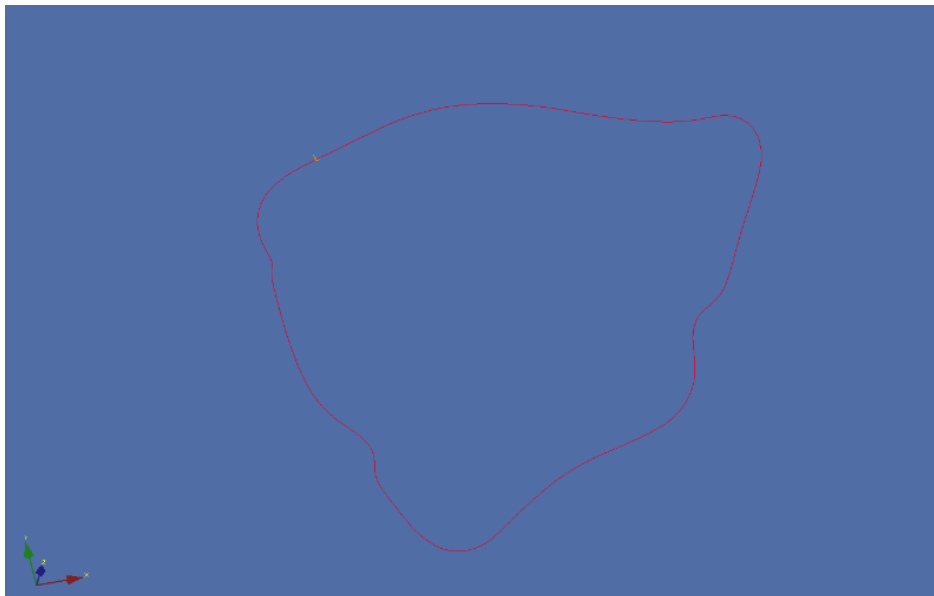


Figure 32: Initial Path Creation in VI-Road (Iatrakis, 2024)

In order to match the direction of travel of the real-life data, the path is required to be mirrored around the YZ plane and aligned in the X- axis using the transform function in VI-Road (Figure 33).

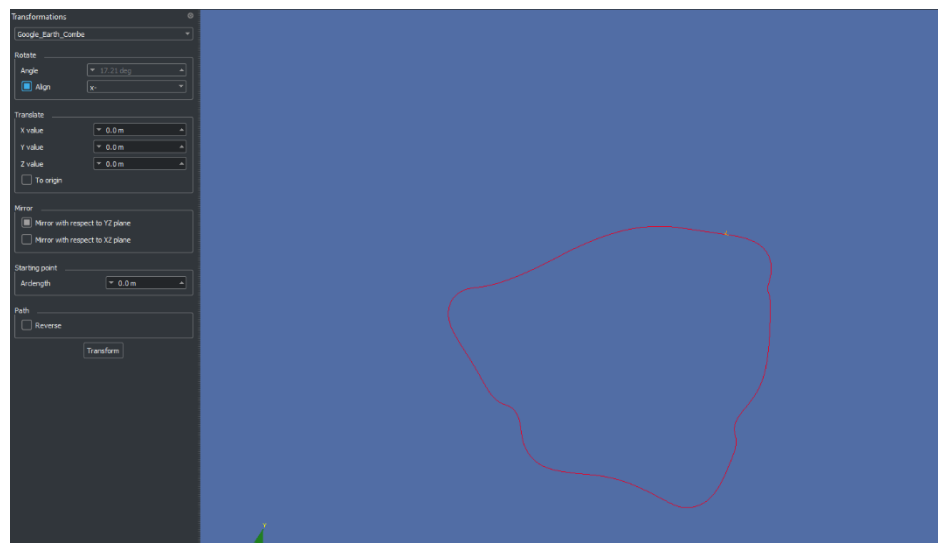


Figure 33: Track Dirrection Transformation in VI-Road (Iatrakis, 2024)

6 Simulation Settings

Using VI-Grade BikeRealTime, the previously constructed RS660 Model and Reconstructed Castle Combe track is used for simulation. The SpeedGenMoto Analysis Simulation is used to generate a speed profile around the track using a static lap-time solver. [7] The data can then be exported as a CSV and compared to the recorded data. The Performance Map function can be used to change Longitudinal Acceleration, Longitudinal Brake, and Lateral performance factors to alter the speed profile and match it to the recorded data.

The MaxPerfMoto Simulation in VI-BikeRealTime is used to automatically calculate the dynamic limit speed profile on a given track. [7]

Using the generated speed profile in SpeedGenMoto, MaxPerfMoto verifies its feasibility through a dynamic solver. If the speed profile is found unfeasible, the initial optimiser is able to modify the velocity profile accordingly until a feasible velocity profile is found.

The window below shows the initial MaxPerfMoto simulation settings, with the previously configured .DRD, .RDF, .OBJ track files for Castle combe. All the performance settings were left as default. Initial conditions of the simulation were matched to the start of the real lap. 4th gear and 158.8km/h has been used.

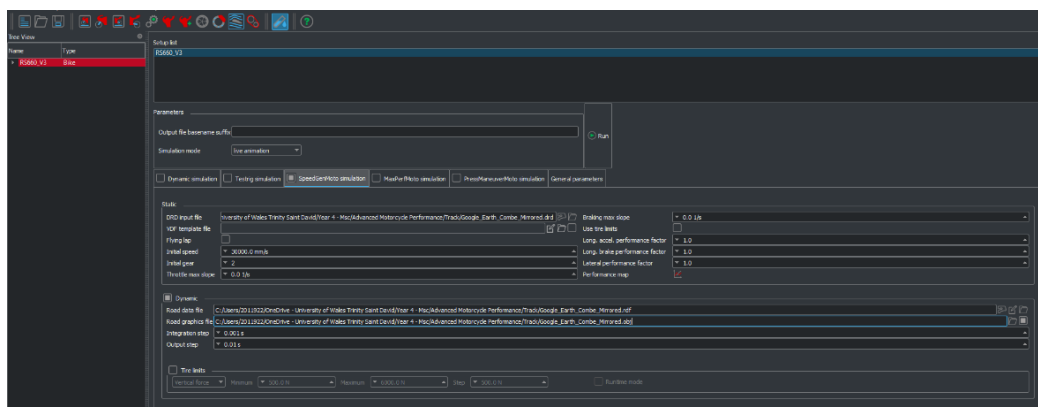


Figure 34: RS660 SpeedGenMoto Simulation (Iatrakis, 2024)

The graph below shows the initial simulation results, with a simulated lap time of 89.16s compared to the measured 76.96s. The initial speed profile looks correct with acceleration, deceleration for the corners etc. The main thing that shows is inconsistent acceleration. In an attempt to alter the individual areas, performing a SpeedGenMoto simulation, the solver kept crashing. As visible in figure 36, a sudden high driver demanded steering angle is executing, explaining the crash.

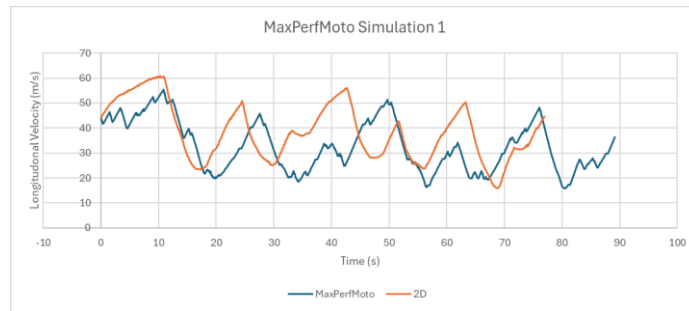


Figure 35: Initial MaxPerfMoto vs Recorded data Speed Comparison (Iatrakis, 2024)

SpeedGenMoto Simulation

On initial Speed profile Generation, starting at 44111/s and 4th gear, such as the starting parameters of Brody's lap. A lap time of 86.633 seconds has been calculated, although the model could not complete a lap. Before Quarry corner the driver demands a high steering angle, causing the bike to crash. Figure 36 shows this sudden peak in driver demand. When lowering all the performance factors to 0.8 the model was able to compete a lap of 97.112s without crashing. Anything above 0.8 performance factor would make it crash.

Using the individual Performance Map to turn down the performance factors around the area where the sudden steering input is asked for resulted in the same crash and a calculated lap time of 86.633s. This method to try and complete a lap was unsuccessful for the author.

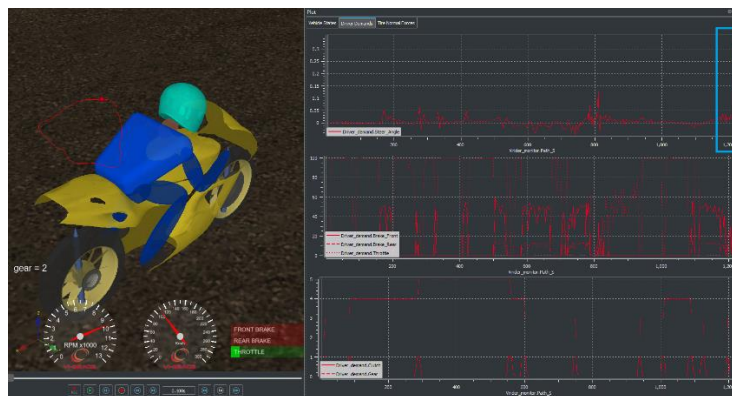


Figure 36: SpeedGenMoto Simulation High Torque Demand Crash (Iatrakis, 2024)

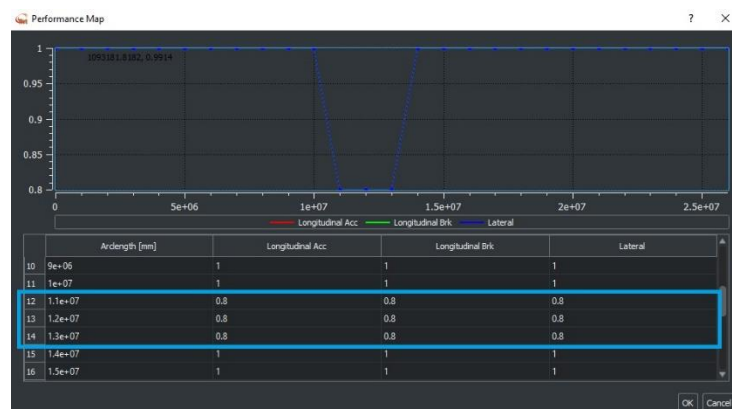


Figure 37: Altered Performance Factors place of crash SpeedGenMoto (Iatrakis, 2024)

Figures 38 show a comparison between the initial SpeedGenMoto Simulation and the Completed simulation with all the performance factors set to 0.8. It is clear that the requested steering torque is a lot lower on average than the initial run, with a maximum of 10° , with it also being able to complete the lap.

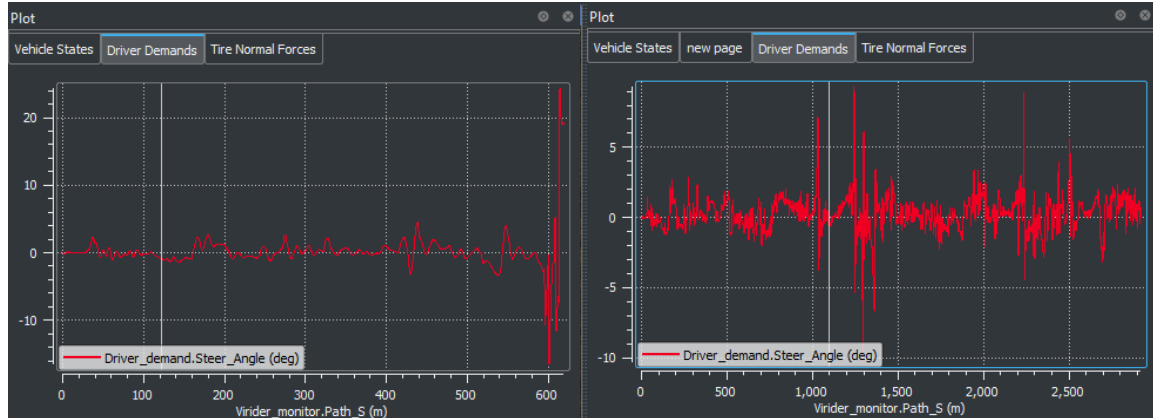


Figure 38: SpeedGenMoto Steering demand comparison (Iatrakis, 2024)

MaxPerfMoto

Following the previous SpeedGenMoto, the same setup was ran using the MaxPerfMoto Simulation, With a starting Velocity of 44.111m/s and in 4th gear. Calculating an 88.420s laptime with all performance settings set to 1.

7 VI-BikeRealTime & Recorded Data Comparison

This section presents a comparative analysis of the data recorded by championship winner Brody Crockford at the Castle Combe Circuit, alongside the RS660 model developed in VI-BikeRealTime, using the SpeedGenMoto and MaxPerfMoto simulations.

As previously noted, the SpeedGenMoto Simulation failed to successfully reproduce a complete lap using the Individual Performance Factors, as the model caused crashes that could not be resolved, an issue encountered by the entire Motorcycle MSc group. However, the speed profile generated by SpeedGenMoto was utilised successfully with the MaxPerfMoto simulation to create a simulated lap time. Table 13 displays the lap times comparing the fastest recorded lap with the initial simulated laps. While there is a noticeable difference in lap times, they can still be compared through distance plots. The total lap distances vary due to different racing lines taken, but initial comparative analysis remains feasible.

A direct and initial comparison can be observed in the vehicle speeds over the lap distance. Figure 39 illustrates the speed comparison across laps, showing that the simulated laps consistently register lower speeds throughout the lap. The overall speed patterns, such as approaching and exiting corners and during deceleration, are largely similar.

A significant issue identified between the real and simulated laps is the inconsistent throttle response in the simulations; instead of maintaining a steady acceleration, the simulated models exhibit a hesitant acceleration pattern, alternately slowing down and speeding up.

The SpeedGenMoto simulation indicates a slower starting speed, which is expected given the limited Performance Factors used. Additionally, the corner velocities in the MaxPerfMoto simulation align well with the speed limits initially set by the SpeedGenMoto.

The MaxPerfMoto simulation has clearly found good time and speed in the acceleration and deceleration. Resulting in a 10 second time gain. Altering the performance factors in the MaxPerfMoto had no influence on the smoothness of the acceleration and also hasn't altered the performance.

Consequently, the subsequent section will focus more intensively on comparing the simulated and recorded data to further analyse the dynamics/ bike behaviour.

Table 13: Recorded Lap Time vs Simulated Lap time (Iatrakis, 2024)

Lap	Laptime	Lap Distance (m)
Brody Fastest Recorded	01:16.969	2978
SGM 0.8 Performance Factor	01:37.112	2920
MPM 1.0 Performance Factor	01:26.633	2916

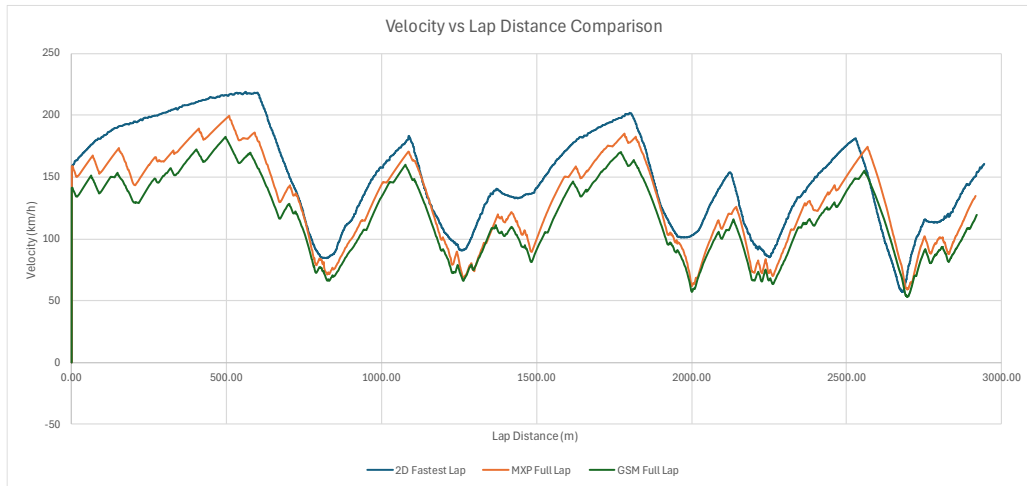


Figure 39: Velocity vs Lap Distance comparison. (Iatrakis, 2024)

Figure 40 presents a comparison of lean angles over the lap for the three different laps. It's evident that all laps exhibit similar lean angle trends through the corners. The SpeedGenMoto lap consistently displays the lowest lean angles, correlating with its slower speeds and longer lap times. Variations in lean angle during cornering are expected, as seen in the recorded lap; however, the MaxPerfMoto simulation shows abrupt peaks in lean angle, indicating its indecision and inaccuracies—such sudden changes of 20 degrees in lean angle in either direction are unrealistic during a fast, well-executed lap. The initial rates of rolling into the corners align well across the three laps, but the significant differences manifest in the cornering behaviour.

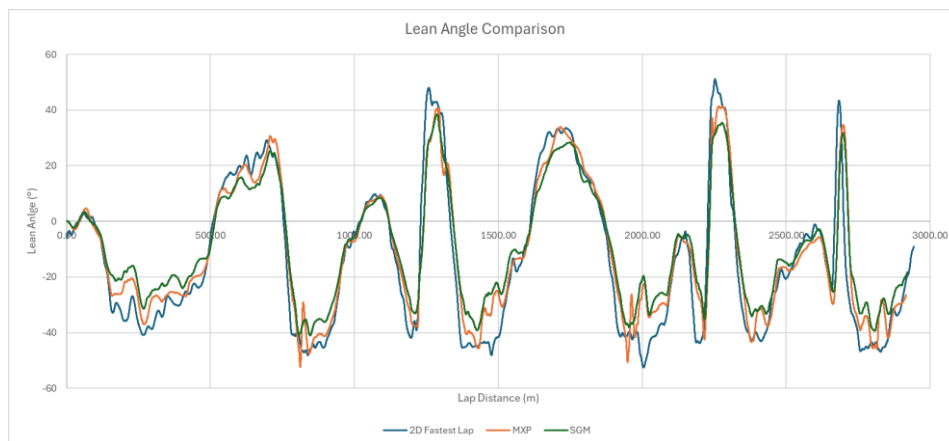


Figure 40: Lean Angle vs Lap Distance Comparison (Iatrakis, 2024)

Table 14: Max Lean Angle Comparison

Max Lean Angle Comparison			
	Recorded	SGM	MXP
MIN	-52.57	-40.9595	-52.3956
MAX	51.04	38.40679	41.2717

The subsequent figures show a comparison of engine RPM and gear selection throughout the lap. A significant issue identified in the VI Grade MXP Simulation involves overly aggressive downshifts, causing RPMs to spike up to 14,000rpm, despite the rev limit being set at 11,500RPM. Realistically, first gear is seldom used because of its harshness and the difficulty it poses in handling, yet both simulated laps shift down to first gear. This choice is likely due to the lower speeds observed in the simulations, which theoretically make using first gear feasible. There is a discrepancy in RPM at the start between the MaxPerfMoto Simulation and the recorded data, even though the starting speeds, gears, and gear ratios are identical. This discrepancy is expected to be attributed to inaccuracies in the recorded RPM resulting from its stepped recording process. Overall, the SpeedGenMoto Simulation exhibits relatively smooth and consistent behaviour throughout the lap, in contrast to the MaxPerfMoto, which displays some unexpected and excessively large spikes, tying in with the abruptness of acceleration of the models.



Figure 41: RPM Comparison (Iatrakis, 2024)

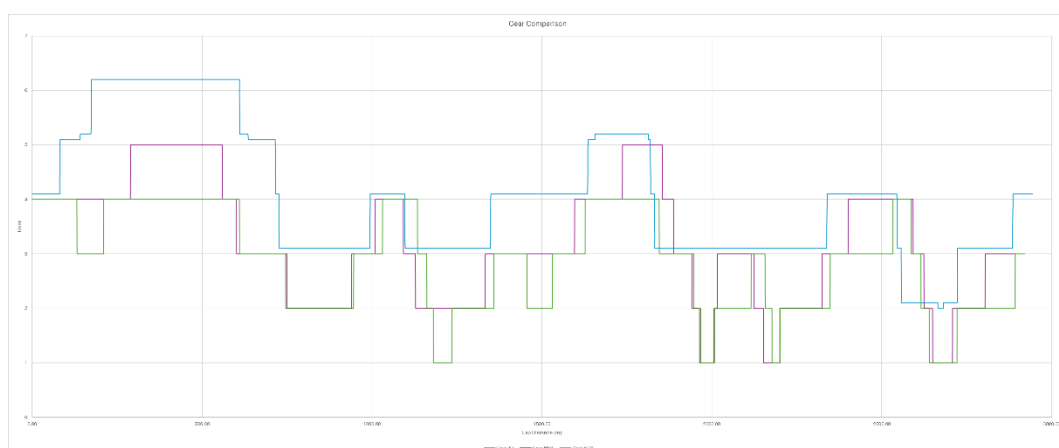


Figure 42: Gear Choice Comparison (Iatrakis, 2024)

Figure 43 and table 15 provide a comparison of rear suspension travel across the three laps. The SpeedGenMoto's general behaviour appears reasonable, with occasional peaks but nothing excessively erratic. The travel seems somewhat high, especially during acceleration where you might expect it to be closer to full extension. Conversely, the MXP simulation exhibits very abrupt behaviour, with travel peaks reaching up to 110mm, despite the rear shock having a travel limit of 51mm. In the VI Grade Spring file, the force required to exceed 51mm is set at 8000N; experimenting with a higher force might help mitigate this behaviour, though such extremes should not occur.

The recorded travel data appear low, which is likely due to limitations in the measurement technique. The potentiometer used for recording is not mounted parallel to the shock (as illustrated in Figure 45), which means it does not accurately reflect true shock travel. This angular discrepancy is not factored into the data, and the conversion ratio was unavailable at the time of analysis. Based on other recorded data from RS660s with similar spring setups, average travel is typically about 5mm higher, with a maximum of around 10mm more than what was recorded (as indicated in Table 16). Even so, there is significant discrepancy between the simulated and recorded data. A likely contributing factor to this issue is the absence of weight transfer due to the use of a non-moving rider in the simulations, even so the difference is too big.

Table 15: MinMax Values Suspension Comparison (Iatrakis, 2024)

	Suspension Travel Comparison (mm)					
	Recorded		SGM		MXP	
	Front	Rear	Front	Rear	Front	Rear
Min	6.50	0.40	3.92	11.67	0.48	-2.28
Max	116.30	25.90	94.88	61.27	110.48	110.94
Avg	46.02	10.40	46.37	39.43	48.47	40.58

Table 16: MinMax Values Rear Suspension Correct Mounting method RS660 (Iatrakis, 2024)

MIN			-0.2	21.8	11.1
MAX			0.6	35.3	13.7
AVG			0.1	29.8	12.9

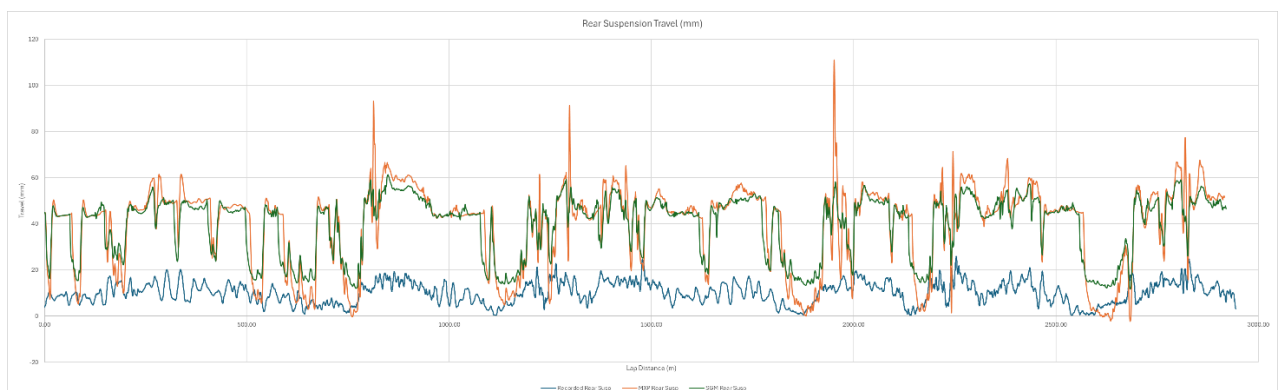


Figure 43: Rear Suspension travel vs Lap Distance Comparison (Iatrakis, 2024)

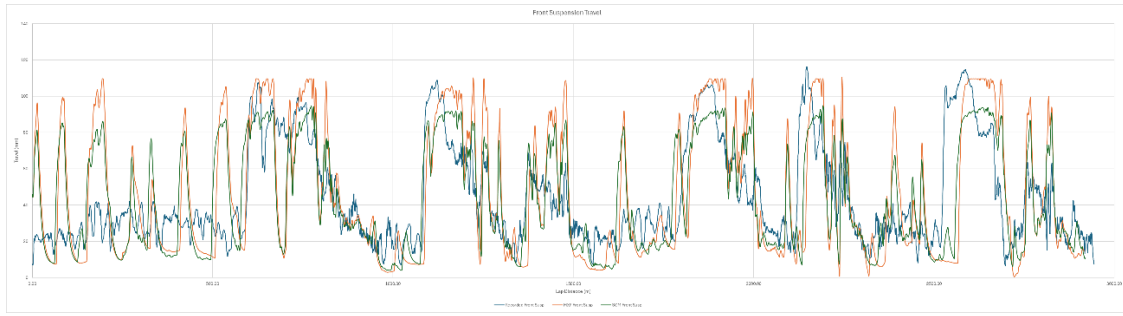


Figure 44: Front Suspension vs Lap Distance Comparison (Iatrakis, 2024)

Figure 44 presents a comparison of front suspension travel across different laps. This comparison shows a much closer alignment between the recorded and simulated data, as evidenced by the minimum, maximum, and average values detailed in Table 15. A notable discrepancy is observed at the beginning of the lap, where, as previously mentioned, hesitant acceleration and braking rather than smooth acceleration result in exaggerated weight transfers and unnecessarily high suspension travel. This behaviour is largely unrealistic. For the remainder of the lap, the data reasonably conforms, with the MaxPerfMoto simulation displaying slightly higher travel values than the SpeedGenMoto, though without the erratic peaks seen previously.

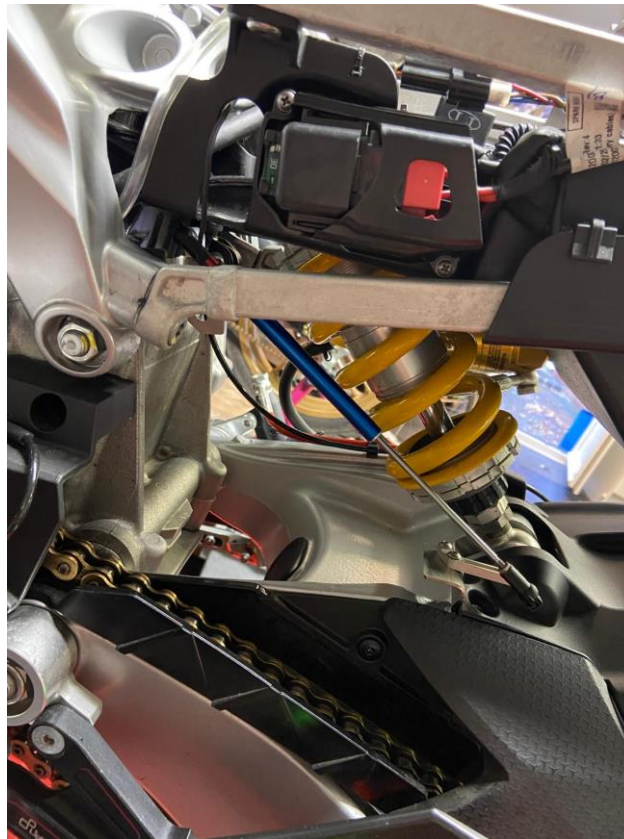


Figure 45: Rear Suspension Potentiometer Setup (Iatrakis, 2024)

Conclusion

This study successfully utilized the VI-Grade simulation software to model and analyse the dynamic behaviour of the Aprilia RS660, integrating real-world data from laps recorded at the Castle Combe Circuit by Brody Crockford.

The comparison between the simulated data and actual lap data revealed key insights into the motorcycle's performance characteristics and dynamic behaviour. While discrepancies, particularly in terms of throttle response and suspension travel, highlighted areas for further refinement, the overall alignment in trends such as lean angles and velocity profiles confirmed the effectiveness of the current model and provided a solid foundation for ongoing adjustments and improvements.

The project also emphasized the necessity of precise and thorough measurement of physical parameters like centre of gravity, moments of inertia, and tire deflection. These measurements are crucial for enhancing the fidelity of simulation models and, by extension, their usefulness in predicting real-world behaviours under varied conditions. The difficulties encountered in measuring some of these parameters pointed to the need for improved measurement techniques and equipment, which could significantly elevate the accuracy and reliability of future simulations.

Moving forward, the model's development will benefit from the newly available engine for disassembly and further testing, promising deeper insights and more refined data inputs. Additionally, exploring the dynamic changes under different racing conditions, as well as adjusting the simulation to incorporate a 'rider out of the loop' approach, will expand the model's applicability and utility in both competitive and commercial motorcycle development.

In conclusion, this project not only advanced our understanding of the Aprilia RS660's dynamics but also contributed to the broader field of motorcycle engineering by highlighting the potential and challenges of integrating simulation technology with empirical testing

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