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***Track-Based Vehicle Dynamics Analysis and
Performance Evaluation of the Aprilia RS660
Motorcycle Dynamics and Data Acquisition ACHA7020***

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Abstract

This report covers the testing of a race bike, data collection, key parameter selection, analysis of results and the evaluation of key performance metrics and suggests possible adjustments that may provide greater performance. An Aprilia RS660 was taken to the Pembrey race circuit in Wales, it was taken out on 2 sessions and several data sets were collected by the AV200 logging feature, the data was then retrieved in files compatible with the 2D analyzer software. A critical appraisal of the gathered data was then carried out and final conclusions were discussed.

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1.0 Introduction

The handling and stability of a motorcycle are governed by the complex interaction between rider input, vehicle dynamics, tyre behaviour, and suspension characteristics. Understanding this interaction is critical for evaluating performance, particularly in high-demand environments where traction limits, transient responses, and rider control strategies strongly influence lap consistency and stability. The increasing use of ride-by-wire systems and advanced chassis configurations further emphasises the need to assess how rider inputs are translated into vehicle response under real-world conditions.

This report presents an analysis of logged dynamic data from an instrumented motorcycle to evaluate longitudinal, braking, and cornering behaviour. Key parameters including throttle position, torque delivery, wheel speed, longitudinal acceleration, brake pressure, suspension travel, lean angle, and lean rate are examined to assess traction utilisation, load transfer, pitch and roll dynamics, and rider-vehicle coupling. Attention is given to transient events such as throttle tip-in, braking initiation, and turn-in, where stability margins are most sensitive to setup and rider input.

Testing was conducted in wet track conditions, introducing additional variability due to reduced and inconsistent tyre-road friction. While this limits absolute performance assessment, it provides valuable insight into stability and control under reduced grip. The analysis aims to identify dominant performance factors, evaluate chassis behaviour, and propose evidence-based recommendations to improve handling consistency and rider confidence.

2.0 Literature Review

2.1 Fundamental Motorcycle Dynamics

(Cossalter et. al, 2014:1) discuss that a bike can be considered as a system with 6 primary bodies, these being:

1. Front wheel
2. Front Unsprung Mass
3. Handlebar
4. Chassis
5. Swing Arm
6. Rear Wheel

They also note some several geometrical parameters that play crucial roles in the bikes handling and stability.

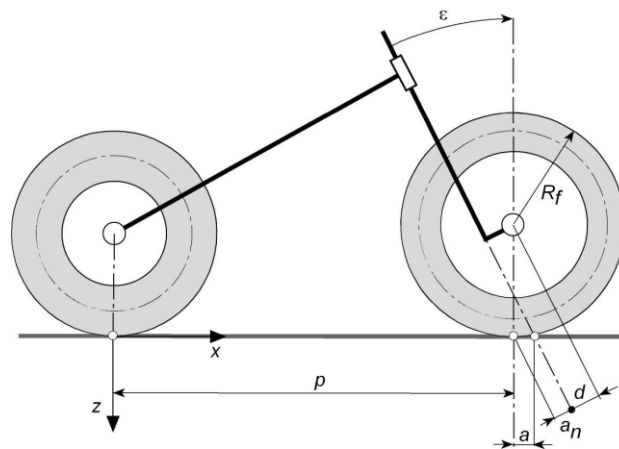


Figure 1 - Geometrical Parameters (Source: Cossalter et. al, 2014:3)

From Figure 1, The base geometrical parameters are detailed in Table 1.

Table 1 - Geometrical Parameters

Geometry	Definition	Behavioural Influence
Wheelbase (p)	Centre to centre distance between the front & rear wheel	Increased wheelbase provides more stability however reduces handling and agility

Front Wheel Radius (R_f)	Radius of front wheel	Increased radius causes an increase in rake and trail, improving stability but reducing agility
Caster/Rake Angle (ϵ)	Angle of the forks relative to the vertical axis about the front wheel (Typical range for race bikes is between 23-25°)	Increased caster angle increases trail, self-centring, and so stability, however, it increases steering effort and reduces agility
Fork Offset (d)	The distance between the steering axis and the parallel axis through the wheel centre (Typical range for race bikes is between 30-45mm)	Greater offset reduces trail and so stability, however, it reduces steering effort, and so provides increased agility
Mechanical Trail (a)	The distance between the centre of the tyre contact patch and the point the steering axis intersects the road	Increased trail provides greater stability and front tyre grip, however, reduces agility due to increased lighter steering effort

2.2 Suspension Influence

Suspension setup is a critical determinant of motorcycle handling, performance, and stability, this is particularly true in racing applications where the influence on lap time and rider confidence small changes to setup chieve can be disproportionate.

Suspension parameters such as spring preload and damping characteristics govern load transfer and tyre contact patch under braking, acceleration and cornering, and so directly affects both transient and steady-state dynamics.

Several studies have demonstrated that suspension behaviour influences overall performance through its interaction with vehicle kinematics and tyre forces, not only through comfort and vibration control. Marconi and Massaro (2020) investigated the influence of suspension modelling on the minimum achievable lap time of a racing motorcycle using an optimal-control framework. Their results showed that suspension characteristics significantly affect predicted lap time, particularly through their impact on load transfer and vehicle attitude over three-dimensional track features. This highlights that decoupling suspension setup from performance optimisation cannot be done, as it alters the forces available at the tyre–road interface.

suspension stiffness and damping have been shown to play a key role in governing high-speed dynamic modes from a stability perspective, such as weave and wobble.

Passigato et al. (2020) demonstrated that front suspension and chassis changes in effective stiffness and damping significantly modify the stability boundaries of these modes. Their eigenvalue-based analysis showed that inadequate damping or excessive compliance can increase susceptibility to oscillatory behaviour at racing speeds from reduced stability margins. This is particularly relevant for race motorcycles, where lightweight structures and aggressive geometry amplify sensitivity to setup changes.

Research into semi-active suspension systems, in addition to passive setup choices further reinforces the importance of damping characteristics. Khadr et al. (2017) showed that optimised damping control strategies can improve contact patch retention and stability without compromising dynamic performance. Although their study was not exclusively race-focused, the findings underline the sensitivity of motorcycle dynamics to damping variation and support the relevance of precise suspension tuning in high-performance applications.

2.2 Rider Influence

It is impossible to separate rider behaviour from race-bike performance because the rider provides the primary control inputs (throttle and brake modulation, steering input, and body movement) while simultaneously acting as a dynamic component coupled to the chassis.

In practice, rider technique shapes the transient phases that dominate lap time—corner entry and exit—where small differences in braking release rate, initial steering torque, and body positioning alter tyre utilisation and vehicle attitude.

From a stability standpoint, the rider does not simply “command” the motorcycle; they can also modify the system’s natural modes through passive and active coupling. SAE International work by H. Uchiyama et al. (2018) modelled weave behaviour while explicitly accounting for the rider’s whole-body vibration characteristics, showing that predicted weave response is measurably influenced by rider dynamics and therefore the stability margin at speed. This supports the common motorsport observation that oscillatory behaviour can either be damped or excited by grip stiffness, “hands-on” posture, and upper-body compliance depending on how the rider interacts with the bars and seat.

When modelling race conditions, rider influence becomes even more pronounced, where manoeuvres are rapid and strongly non-linear. M. Nishimura et al. (2020) developed a rider model aimed at motorcycle racing simulation and highlighted that rider-control representations built for steady, linear riding are often insufficient when aggressive acceleration/braking and fast direction changes are present. This is important for data-driven track analysis: identical hardware setup can produce different outcomes if the rider’s control strategy changes (e.g., later brake release, higher steering torque rate, or altered body position), so any setup conclusion must be conditioned on repeatability of rider inputs.

Recent “rider-in-the-loop” simulator research reinforces that capturing human acceptability and control behaviour is vital to replicating realistic dynamics; rider generated inputs are influenced by the fidelity of sensory cues, which then feeds back into observed handling metrics. P. Michel et al. (2022) emphasises this human-in-the-loop dependency, highlighting why when interpreting performance and stability from logged data, rider effects must be considered explicitly.

3.0 Methodology

The Aprilia RS660 has an “ultra lightweight” 403lbs, Euro 5+ forward facing twin-cylinder engine capable of outputting 105hp and reaching a top speed of 149mph, with winglets inspired by that of a MotoGP bike and a Ride-by-Wire electronic throttle. Fitted with Öhlins suspension, it features STX 46 shock absorbers and an NIX 30 fork (Aprilia.com, 2026).



Figure 2 - UWTSDD Aprilia RS660

3.1 Background & Sensor Setup

The bike was fitted with an AV200 IMU (Inertial Measurement Unit) and an array of CAN-bus sensors for data collection and analysis purposes. These sensors include:

Table 2 - Aprilia RS660 Sensor Setup

Sensor Type	Sensor Use	Measurements
-------------	------------	--------------

GPS Speed	Data shows bike speed based on GPS tracking	Based on dual antenna data with backup systems like GNSS (Global Navigation Satellite System)
Front & Rear Wheel Speed	Data can show overall bike speed as well as traction losses	Magnetic field changes as a tone ring on each wheel passes the sensor, disruptions are converted to a digital signal
Throttle Position	Data highlights rider behaviours, errors, and preferences as well as hinting at available traction levels	Measures throttle plate angle to send real-time information to the ECU
Steering Position	Data shows steering inputs, and can display moments of instability where spikes appear	Hall effect sensors or Giant Magnetoresistance (GMR) is used to measure
Brake Pressure	Data shows where, when, and how the rider was applying the brakes	Measures the hydraulic pressure within the bikes brake lines, data is then sent to ECU
Gear Position	Data shows gear position over a lap, useful when analysing rider timing	Hall effect sensor produces and sends specific voltage signal to the ECU based on changes in the magnetic field as the drum rotates

Front & Rear Suspension travel	Data shows the distance travelled by the suspension, useful for analysing damping rates and load transfer	Voltage values change as the measured length of the potentiometer varies
X, Y, Z Accelerometers	Data shows longitudinal, lateral and vertical acceleration, useful for analysing cornering performance and load transfer	Micro-Electro-Mechanical Systems (MEMS) accelerometers that detect forces caused by movement and convert to electrical signals
X, Y, Z Gyroscopic	Data shows the roll, yaw and pitch values, useful for analysing dive, squat, and rider lean angle	3-axis gyroscopes measure angular velocity, this data is compared to acceleration values
Handlebar & Footpeg Strain Gauges (X & Y)	Data shows forces exerted by the rider on the handle bars and footpegs, useful when analysing bike vs rider position and load transfer	As the strain gauges stretch and compress based on the loads experienced, resistance values change and so affect voltage

3.2.2 Data Channel Selection Justification

The data channels selected and compared in the results section of this report were chosen based upon well-established principles of motorcycle dynamics. Through the analysis of values in wheel speed, throttle position, brake pressure, suspension travel, acceleration and lean angle/rate, it is possible to identify stability and handling influences such as traction loss, rider input and throttle lag.

The data channels selected and compared in the results section of this report were chosen based upon well-established principles of motorcycle dynamics and common

measurement practice in high-performance two-wheeled vehicle studies. In particular, signals such as wheel speed, throttle position, brake pressure and suspension travel provide direct insight into rider control inputs and vehicle response, supporting interpretation of handling/stability behaviours including traction loss (via slip-related wheel speed behaviour), braking & acceleration transients, and effects of chassis attitude Lot, R., et al. (2016).

3.2.3 Testing Specifications

The Aprilia was taken to the Pembrey circuit where it was run in 2 outings, no changes to geometry or physical adjustables were carried out, and the marginal changes made in the ECU software were found to have a negligible effect. On the day of testing, the track conditions were poor, with rain intensity varying meaning track surface was damp, this must be considered when analysing and discussing data reliability. The Pembrey circuit has an emphasis on right handers with 6 typically tighter corners compared to the 2 more high speed lefts, the circuit is approximately 2.4km in length and the data collected was logged in 2D for later analysis.

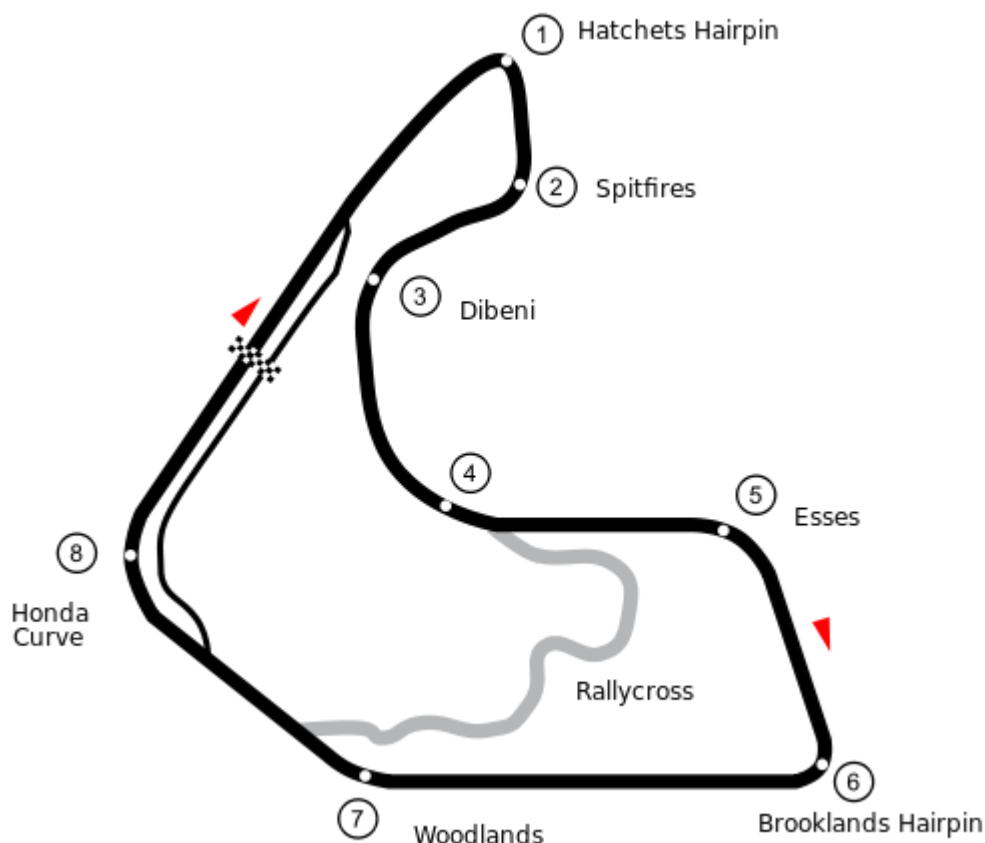


Figure 3 - Pembrey Circuit Map

4.0 Results

4.1 Bike Data

4.1.1 Rear Wheel Speed Against Throttle Position

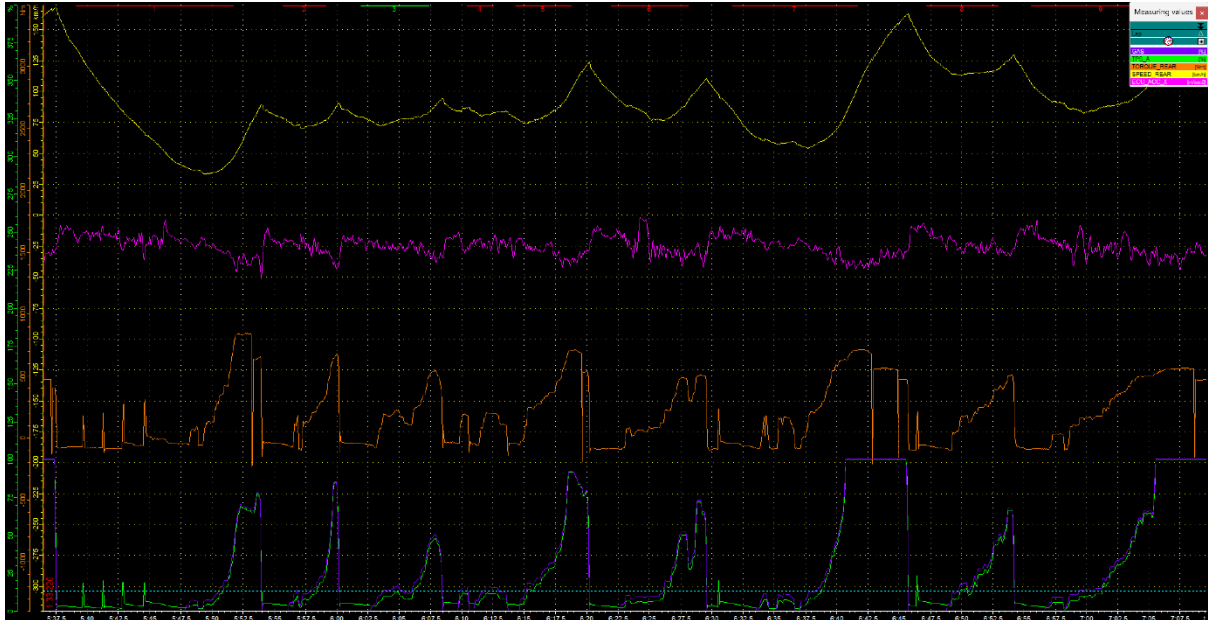


Figure 4 - Rear Wheel Speed & Torque, Throttle Position Channels

Figure 4 shows:

- ❖ Yellow → Rear wheel speed (km/hr)
- ❖ Pink → Longitudinal acceleration (m/s^2)
- ❖ Orange → Rear torque (Nm)
- ❖ Green → Throttle Position (%)

4.1.2 Longitudinal Acceleration Against Throttle Position

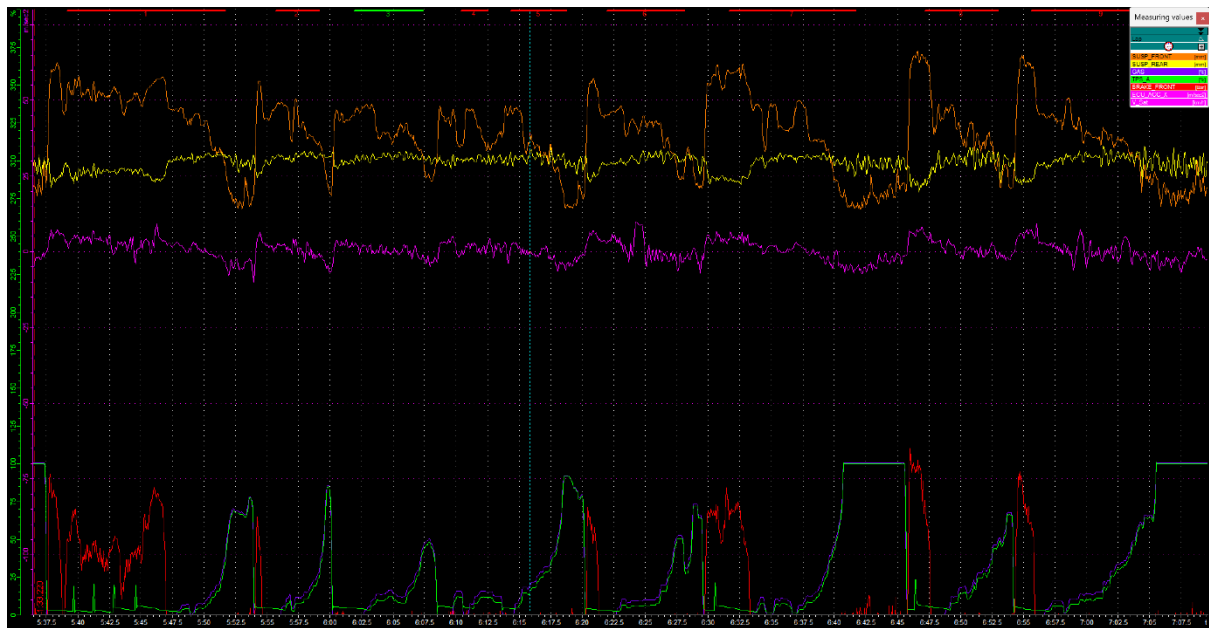


Figure 5 - Longitudinal Acceleration & Throttle Position Channels

Figure 5 shows:

- ❖ Orange → Front suspension travel (mm)
- ❖ Yellow → Rear suspension travel (mm)
- ❖ Pink → Longitudinal acceleration (m/s^2)
- ❖ Green → Throttle Position (%)
- ❖ Red → Brake Pressure (Bar)

4.1.3 Suspension Travel Against Brake Pressure

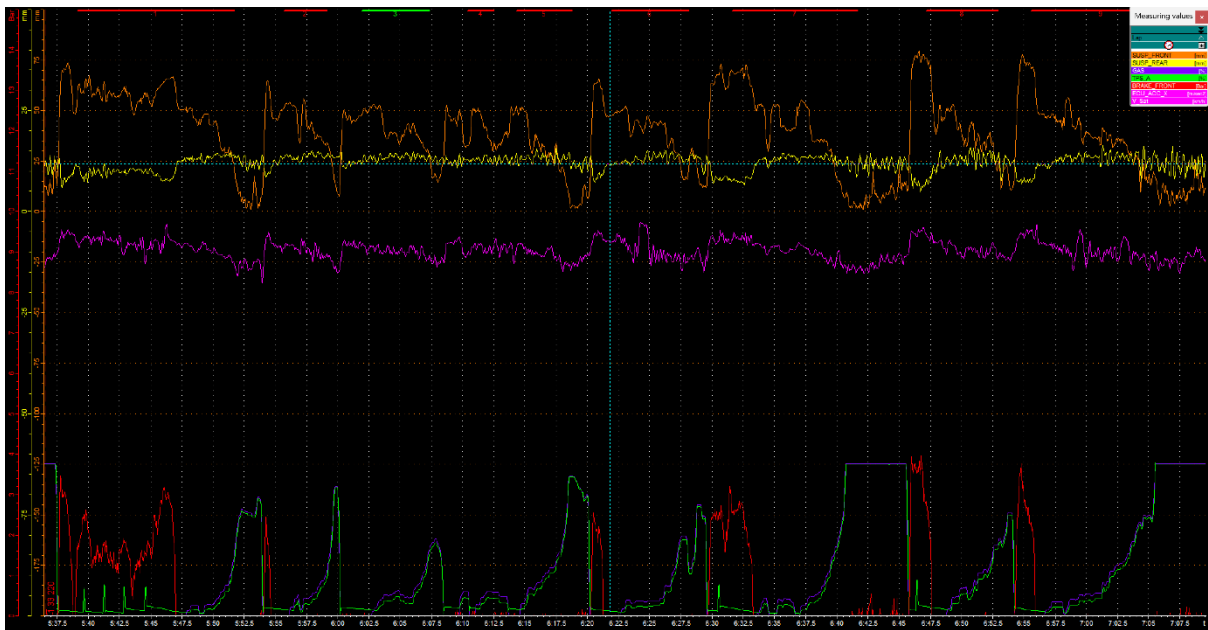


Figure 6 - Suspension Travel & Brake Pressure Channels

Figure 6 shows:

- ❖ Orange → Front suspension travel (mm)
- ❖ Yellow → Rear suspension travel (mm)
- ❖ Pink → Longitudinal acceleration (m/s^2)
- ❖ Green → Throttle Position (%)
- ❖ Red → Brake Pressure (Bar)

Rear suspension travel displayed at 2:1 ratio of front for ease of visual analysis.

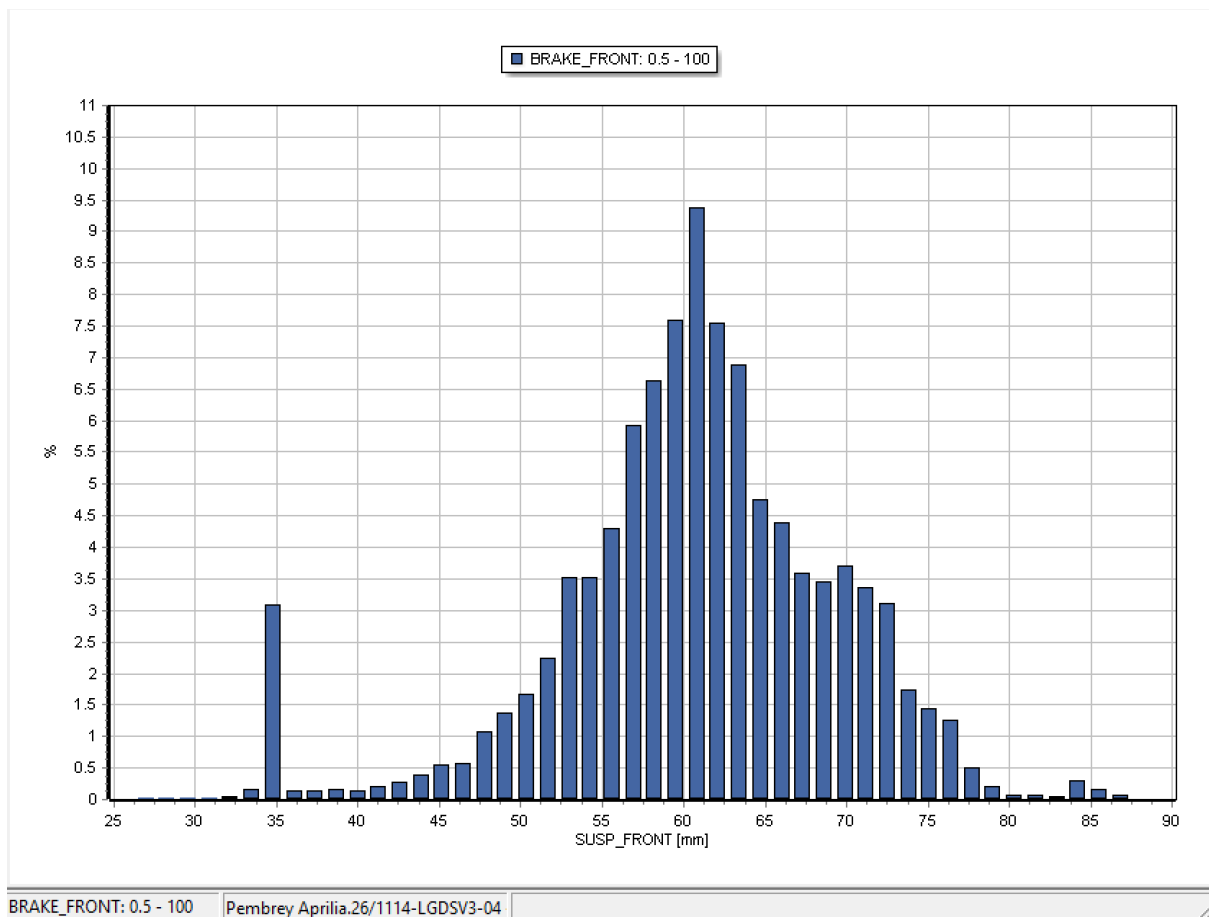


Figure 7 – Histogram of Front Suspension Travel in Braking (>0.5 Bar)

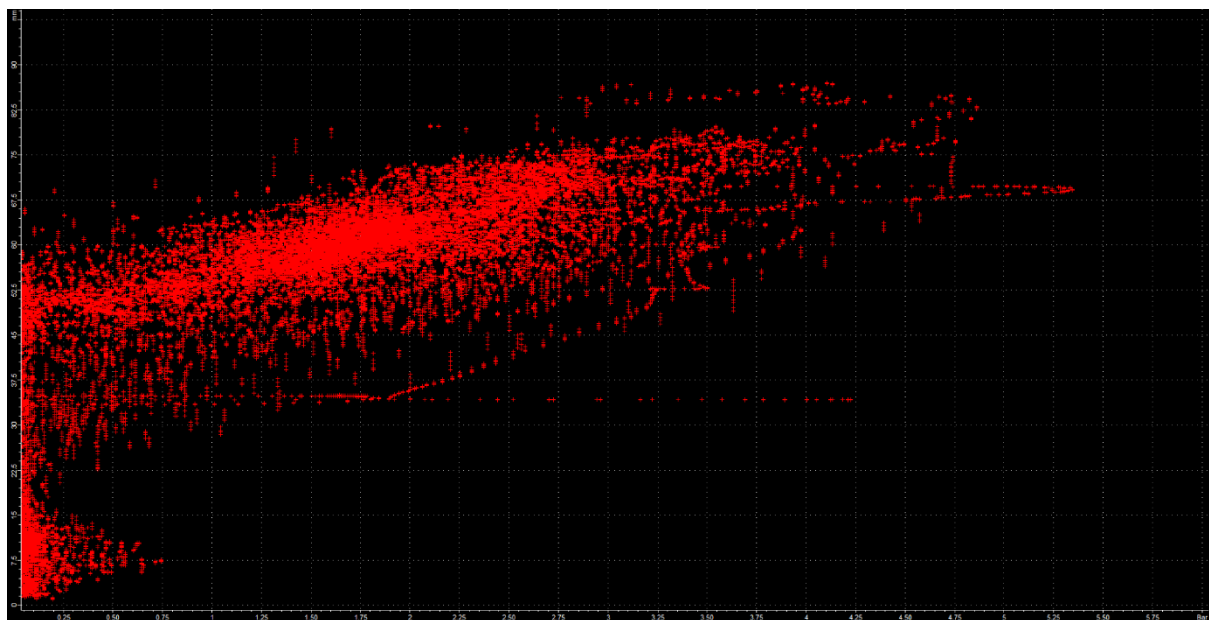


Figure 8 – Scatter of
Front Suspension Travel Against Brake Pressure

4.1.4 Lean Angle Against Throttle Position

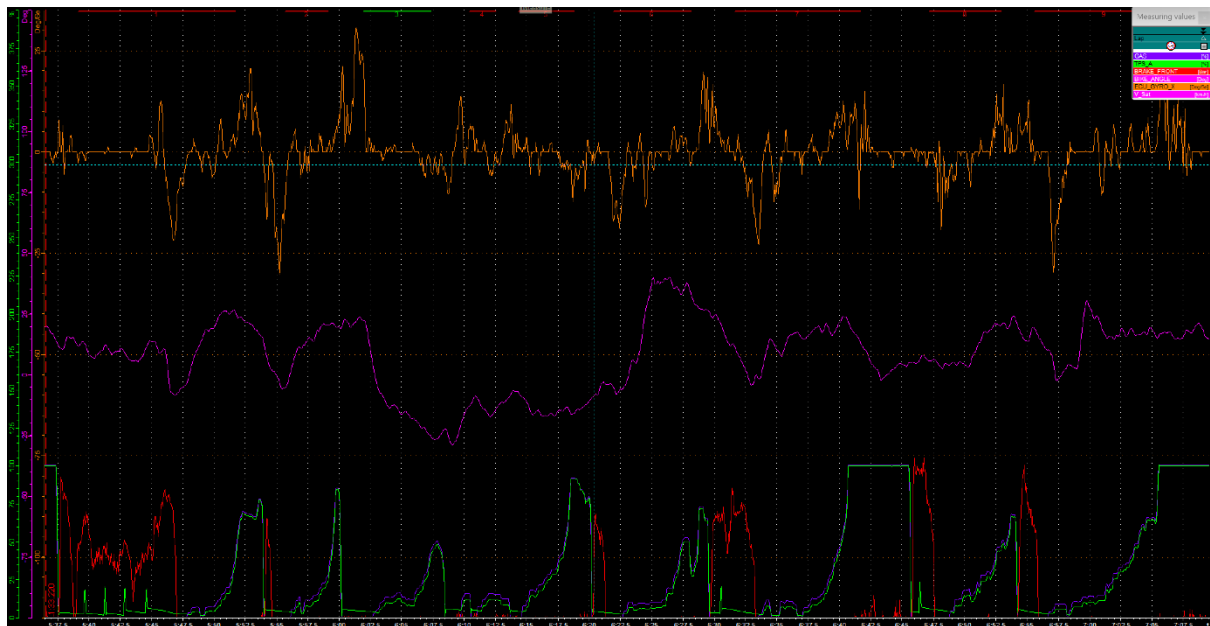


Figure 9 - Bike Lean angle & rate, Throttle Position Channels

Figure 9 shows:

- ❖ Orange → Bike lean rate (Deg/s)
- ❖ Pink → Bike lean angle (Deg)
- ❖ Green → Throttle Position (%)
- ❖ Red → Brake Pressure (Bar)

4.2 Rider Data

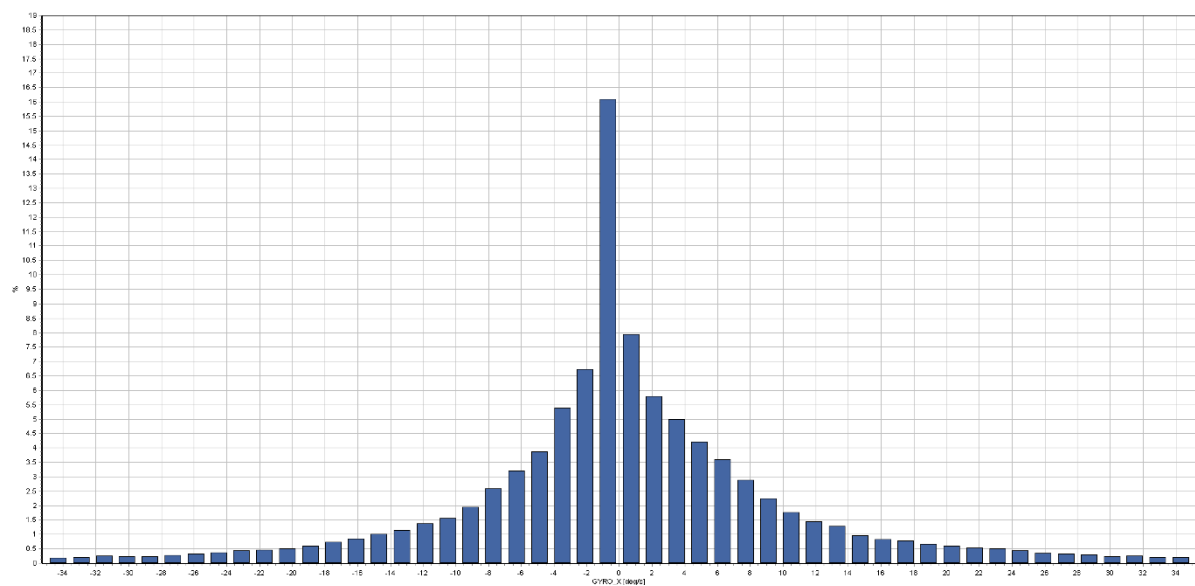


Figure 10 - Histogram of Rider Lean Rate

4.3 Combined

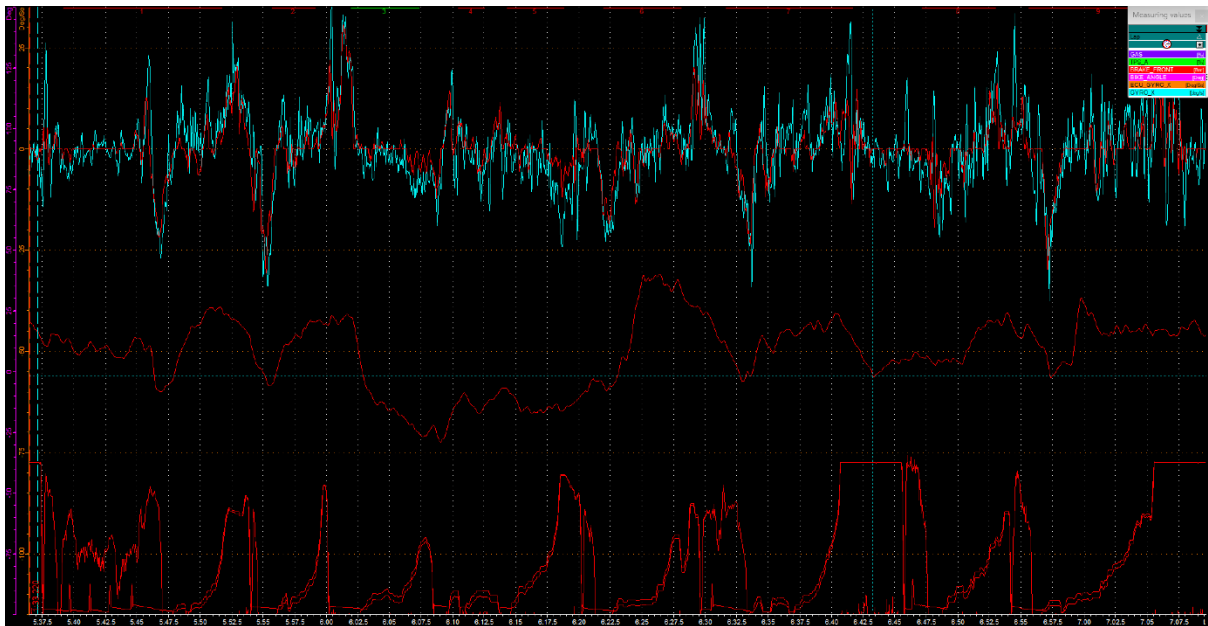


Figure 11 - Bike & Rider Lean Rate

Figure 11 shows:

- ❖ Top Red → Bike lean rate (Deg/s)
- ❖ Cyan → Rider lean rate (Deg/s)
- ❖ Centre Red → Bike lean angle (Deg)
- ❖ Bottom Red → Throttle position (%) & Brake pressure (Bar)

5.0 Analysis

5.1 Bike

5.1.1 Rear Wheel Speed Against Throttle Position

Firstly, looking at torque, when compared to TPS an initial quick step in torque is observed at low TPS values, this could suggest low end throttle sensitivity. This sensitivity could be explained by throttle dead-zone commonly found in ride-by-wire systems, while custom torque mapping could also produce these artifacts as some maps attempt to improve “tip-in” response by delivering an initial bump to fuel injection and combustion timing Reddy et al. (2023).

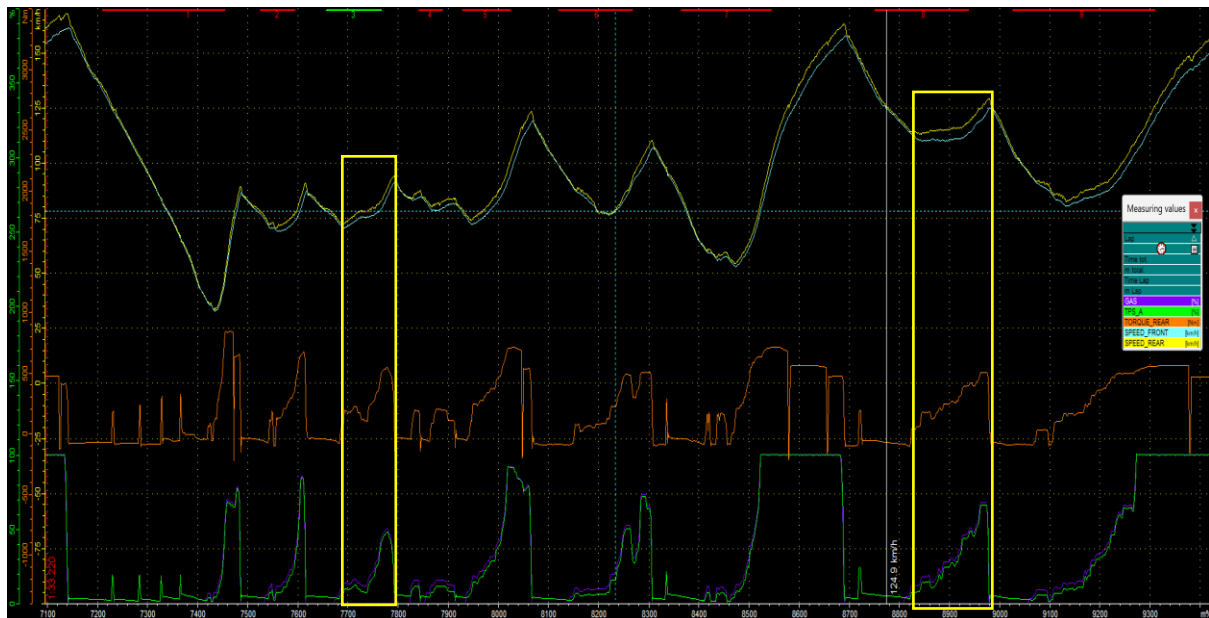


Figure 12 – Front & Rear Wheel Speed Variance

Seen in figure 12 in the yellow highlighted sections, as TPS increases, a separation of wheel speeds is observed with rear values (yellow) increasing at a faster rate. This indicates traction-limited behaviour on corner exit, correlation between throttle ramps and rapid wheel speed gain highlight high input sensitivity which increases longitudinal load transfer and rear suspension extension, reducing effective tyre load at the rear and so grip. It is also important to consider the wet track conditions present during testing, this can skew data and increase obscurity and reduce reliability of results, with tyre-

road friction coefficients showing a “decrease of approximately 26%” Wan, Y. *et al.* (2025).

5.1.2 Longitudinal Acceleration Against Throttle Position

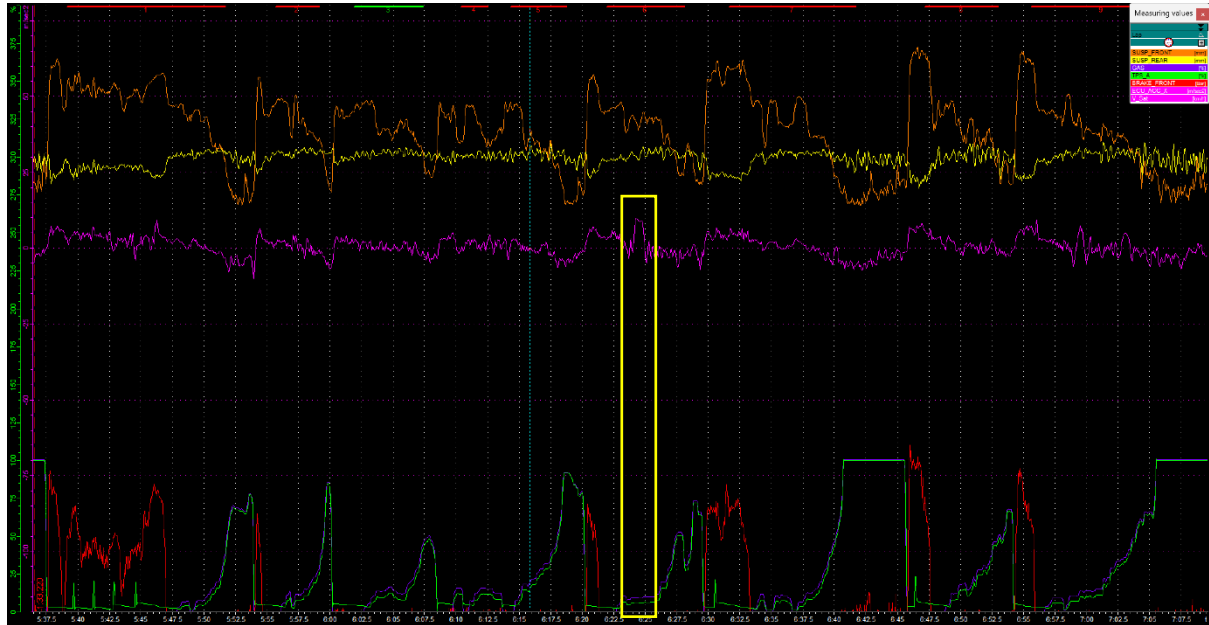


Figure 13 - Longitudinal Acceleration Artifacts

Longitudinal acceleration (Pink) responds consistently to TPS (Green), which indicates predictable drive response as it displays smooth increases during TPS ramps, and stabilises at higher openings. Small oscillations during steady TPS (seen in figure 13) indicate sensitivity to rear tyre load, particularly during corner exit where load transfer varies. Reductions align with rapid throttle roll-offs, and the overall relationship indicates stable chassis behaviour with traction largely regulated by tyre load transfer, while throttle modulation plays a key role in maintaining longitudinal stability.

5.1.3 Suspension Travel Against Brake Pressure

Brake pressure spikes overlap with pronounced compression of front suspension and corresponding rear extension; this indicates clear forward load transfer under braking. The rate and magnitude of front travel imply effective brake support, with rear extension control implying good chassis pitch stability Zhang *et al.* (2022). The 2:1 scaled rear travel highlights balanced pitch behaviour, indicating longitudinal weight transfer is effectively managed by suspension geometry and damping and overall displays a stable braking performance.

5.1.4 Lean Angle Against Throttle Position

Lean angle indicates stable corner entry and mid-corner balance as increases are progressive with smooth throttle application. Lean rate peaks align with initial turn-in and direction changes, highlighting decisive rider input. Lean rate remains controlled as TPS increases at higher lean angles, indicating tyre grip is adequate and roll response predictable. Minor oscillations in lean-rate at steady lean align with TPS and brake inputs and imply sensitivity to surface grip, however, no abrupt spikes indicative of instability are observed. This data indicates a well-balanced chassis, where controlled roll dynamics and confident throttle application is effectively supported by suspension and tyre setup through corner exit.

5.2 Rider

The lean-rate histogram (figure 10) is strongly centred near zero, representing long periods of stable, steady-state cornering. While balanced left–right behaviour is indicated by a mostly symmetric distribution of positive and negative rates, there is a marginal skew into the negative (left lean) which could signify a slight left leaning preference and confidence of the rider Magiera et al. (2016), however, this could also be present due to specific corner characteristics. Low occurrence of extreme values implies controlled turn-in and exit. This reflects predictable roll dynamics supported by tyre grip and suspension setup.

5.3 Combined



Figure 14 - Rider-Bike Lean Rate

As seen in figure 14, bike lean rate (upper red trace) is consistently lead by rider lean rate (cyan trace), signalling the rider initiates roll input in advance of chassis response. The close tracking between the two indicates good roll coupling and predictable chassis behaviour. Small deviations during rapid direction adjustment suggest suspension roll damping and tyre compliance affecting rider inputs before the bike settles. Stable mid-corner roll balance is observed in bike lean angle (central red trace), with no continuous asymmetry. Overall, the data indicates effective suspension and geometry supporting smooth roll dynamics, while tyre characteristics regulate the rider input to chassis response transient lag Lot, R. *et al.* (2018).

6.0 Discussion & Conclusions

6.1 Result Evaluation

The results demonstrate a clear and consistent relationship between rider input and vehicle response, with the motorcycle generally exhibiting predictable and stable behaviour across braking, cornering, and acceleration phases. However, several areas were identified where rider input sensitivity, environmental conditions, and setup choices materially influence performance and data reliability.

At low TSP values, an initial step increase in torque relative to throttle position indicates heightened low-end sensitivity. On a ride-by-wire system, this behaviour is consistent with torque-based control strategies that prioritise responsiveness, particularly through tip-in enrichment and ignition advance to improve perceived throttle sharpness (Reddy et al., 2023). While beneficial in dry conditions, this sensitivity increases the likelihood of traction-limited behaviour in low-grip environments. This is supported by the observed separation between front and rear wheel speeds during throttle application, particularly in wet conditions, where reduced friction coefficients significantly lower the available traction margin (Wan et al., 2025). As a result, rider throttle input becomes a dominant factor in rear tyre load variation, with aggressive ramps promoting rear suspension extension and reduced effective tyre load.

Longitudinal acceleration data supports this interpretation, showing a generally linear and predictable response to throttle input, but with small oscillations during steady throttle application. These fluctuations are indicative of rear tyre load sensitivity rather than engine delivery instability, reinforcing the conclusion that chassis behaviour and tyre interaction govern acceleration performance more strongly than powertrain response. This highlights the importance of throttle modulation by the rider in maintaining longitudinal stability, particularly under compromised grip conditions.

Braking analysis further illustrates effective rider–vehicle interaction. Brake pressure spikes correspond closely with front suspension compression and rear extension, demonstrating expected forward load transfer and controlled pitch dynamics. The scaled suspension travel data confirms that damping and geometry are effectively

managing longitudinal weight transfer, resulting in stable braking behaviour without excessive dive or rear unloading. This aligns with established findings that appropriate suspension control is critical for maintaining braking stability and front tyre load consistency (Zhang et al., 2022).

Cornering behaviour shows similarly positive characteristics. Lean angle increases progressively with smooth throttle application, and lean rate peaks align with deliberate turn-in inputs, suggesting confident and controlled rider actions. The absence of abrupt lean-rate spikes at high lean angles indicates adequate tyre grip and predictable roll response. Minor oscillations at steady lean appear correlated with throttle and brake inputs and are likely attributable to surface grip variability rather than inherent instability.

The lean-rate histogram reinforces these observations, with a strong concentration around zero and low occurrence of extreme values, reflecting long periods of steady-state cornering. A marginal skew towards left lean may indicate a slight rider preference or confidence bias, although track layout effects cannot be excluded (Magiera et al., 2016). Importantly, this asymmetry is small and does not suggest compromised stability.

Finally, the comparison between rider and bike lean rates demonstrates that rider input consistently precedes chassis response, confirming that roll dynamics are rider-initiated and subsequently filtered by tyre compliance and suspension damping. The close coupling between the two indicates a well-matched chassis setup, with transient lag remaining small and well controlled (Lot et al., 2018).

6.2 Recommendations

To improve handling and stability, particularly in low-grip conditions, a reduction in low-TPS torque sensitivity is recommended through revised torque mapping or softened tip-in strategies. This would reduce rear tyre load fluctuations and improve traction consistency on corner exit. Additionally, minor increases in rear rebound damping to limit excessive rear extension could further stabilise longitudinal load transfer under throttle. Finally, conducting repeat testing in dry conditions or with tighter

environmental control would improve result reliability and allow clearer isolation of setup effects from surface-induced variability.

Overall, the data indicates a fundamentally stable and well-balanced machine, with performance primarily directed by rider input sensitivity and tyre-limited behaviour rather than inherent chassis deficiencies.

6.2 Future Work

In future, analysis of the strain gauges equipped on the bike would further improve understanding of the rider-bike relationship, highlight rider proficiency, confidence and skill and provide more intuitive graphs for visual aid. A proper analysis of these values would require use of the math channels present in 2D to obtain derivative values for each peg and grip as well as creating a full analysable system. This depth requires knowledge and experience in 2D that the author does not currently have, however further use of the software along with consulting of experienced users would allow for a project such as this to be completed.

6.3 Development

The author was unfamiliar with the 2D data logging and analysing software prior to carrying out this report, from this they have gained confidence in basic use of the software and plan on further developing their skills in 2D as well as carrying across transferable skills to other software such as MoTec.

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8.0 Appendices