LAB REPORT: HANDLING TEST

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Group 2

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1. INTRODUCTION

Handling testing is a type of vehicle evaluation focused on assessing how well a vehicle responds to driver inputs and maintains stability under various driving conditions. These tests aim to measure the vehicle's maneuverability, responsiveness, and overall controllability.

Typically conducted in a controlled environment, such as a test track or closed course, handling tests involve executing specific maneuvers like lane changes, emergency braking, and cornering. Key parameters such as steering effort, lateral acceleration, yaw rate, and tire slip angle are measured during these tests. The results help determine if the vehicle meets the required handling performance standards.

Key Handling Tests

1. **Lane Change Maneuvers:** These tests evaluate the vehicle's ability to change lanes safely and effectively. They focus on measuring the vehicle's responsiveness, body roll, and lateral stability during lane-change actions.
2. **Emergency Braking Tests:** These tests assess the vehicle's braking performance in critical situations. They involve measuring stopping distance, yaw control, and overall stability during intense braking maneuvers.
3. **Cornering Maneuvers:** Cornering tests examine the vehicle's handling behavior while navigating turns at different speeds. Parameters like understeer, oversteer, lateral acceleration, and tire slip angle are analyzed to determine the vehicle's cornering limits and stability.
4. **Slalom Tests:** Designed to measure the vehicle's agility and maneuverability, slalom tests involve driving through a series of cones or obstacles at varying speeds. They assess responsiveness, steering precision, and the ability to maintain control during quick maneuvers.
5. **Double Lane Change Tests:** These tests measure the vehicle's stability and control during rapid double-lane-change maneuvers. Key factors include responsiveness, body roll, and lateral stability throughout the maneuver.
6. **J-Turn Test:** The J-turn test evaluates turning maneuverability and responsiveness in tight spaces. It involves executing a sudden 180-degree turn while monitoring the turn radius, yaw control, and stability.
7. **Fishhook Test:** This test assesses the vehicle's stability and control during sudden swerves. It involves an abrupt lane change followed by a quick counter-swerve, measuring factors such as responsiveness, body roll, and overall control.
8. **Steering Step Input:** This test evaluates how well the vehicle responds to sudden steering wheel inputs while maintaining stability. It is conducted by rapidly turning the steering wheel to a specific angle and monitoring the resulting lateral acceleration, yaw rate, and tire slip angle.

Bicycle Model Theorem

To understand the vehicle behavior during various scenarios such as turning, braking, or accelerating we use a simplified effective framework called bicycle model.

The dynamic bicycle model typically includes several key components:

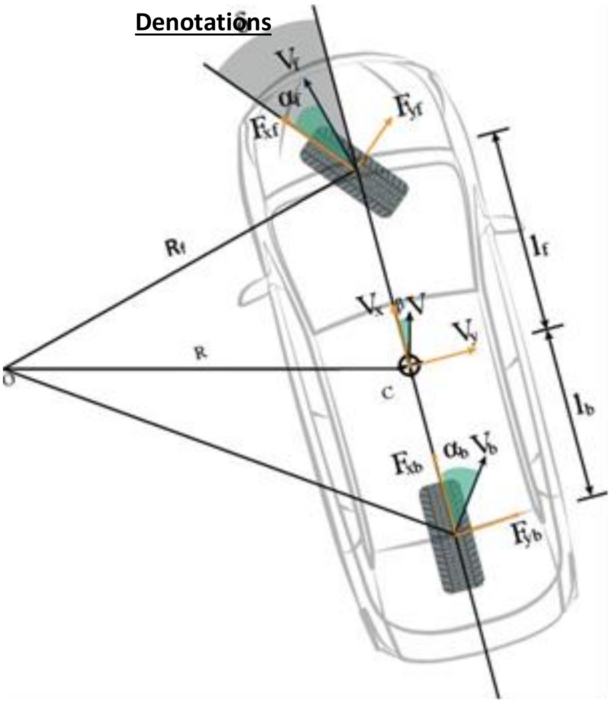
Longitudinal Dynamics: This deals with the vehicle's motion along its direction of travel. It considers forces such as propulsion, braking, and resistance.

Lateral Dynamics: This aspect focuses on side-to-side motion, including the vehicle's steering dynamics and lateral forces during turns.

Yaw Dynamics: Yaw refers to the rotation around the vertical axis (or z-axis). Yaw dynamics consider how the vehicle's body rotates, especially during cornering or sudden maneuvers.

In handling test we are interested in the lateral dynamics of bicycle model:

Denotations



O : Instantaneous Centre of Rotation

δ : Steer Angle

R : Radius of curvature (At centre of mass)

R_f : Radius of curvature (At Front Axle)

V : Velocity (at Centre of mass)

V_x & V_y : Component of Longitudinal and Lateral velocity at o

β : Slip Angle

α_f & α_b : Front and Rear Slip Angles

F_{yf} & F_{yb} : Front and Rear Lateral Force

C_f & C_b : Front and Rear Tyre Cornering Stiffness

a_y : Lateral Acceleration

From trigonometric relations we get:

$$\frac{\sin(\alpha_b + \delta - \alpha_f)}{l} = \frac{sin(90 - \alpha_b)}{R_f}$$

On Linearizing the above equation, we get:

$$\frac{\alpha_b + \delta - \alpha_f}{l} = \frac{1}{R} \Rightarrow \frac{\delta - \alpha_f}{l} = \frac{l}{R} + \frac{F_{yf}}{C_f} - \frac{F_{yb}}{C_b}$$

$$F_{yf} = \frac{l_b}{l} \times m.a_y$$

$$F_{yb} = \frac{l_f}{l} \times m.a_y$$

Thus, we get:

The steering angle,

$$\delta = \frac{l}{R} + \left(\frac{l_b}{l \times C_f} - \frac{l_f}{l \times C_b}\right) m.a_y$$

Also, we know that **vehicle slip angle**,

$$\beta = tan^{-1}\left(\frac{V_y}{V_y}\right) = \frac{l_b}{R} - \alpha_\mathrm{b}$$

Condition for oversteer: $l_b > l_f \; or \; \alpha_\mathrm{f} > \alpha_\mathrm{b}$

Condition for understeer: $l_f > l_b \; or \; \alpha_\mathrm{b} > \alpha_f$

2. MEASURING TECHNOLOGY

In handling test for measurement of lateral acceleration, slip angle, steering angle, yaw rate, vehicle velocity or covered distance we used different types of sensors and equipment to get the results.

Measurement of Steering Angle

Draw-wire sensors (also called pull-wire potentiometers) can measures distances with an accuracy of up to 0.01 mm. They detect the position and movement of an object using a flexible steel cable pulled from a spring-loaded coil. The draw wire has a length of 500 mm and a potentiometric output between 0–10 V with range of 12-30 VDC input. The sensors is mounted on the vehicle and the clip of the cable pull is attached to the other end.

- Select a suitable draw-wire sensor.
- Mount the sensor securely on the vehicle.
- Connect the sensor to the data acquisition system.
- Set a reference position (zero point) for the sensor.
- Detect wire displacement as the steering wheel turns.
- Convert sensor output to a steering angle measurement.
- Show or log steering angle information.
- Validate measurements under various conditions.
- Refine system for accuracy.
- Integrate steering angle data with vehicle systems.

Measurement of Speed of Vehicle

The vehicle velocity or covered distance is recorded by a non-contact optical CORREVIT sensor (Kistler). Correvit S-Motion sensors use the proven Correvit technology for non-contact measurement of speed and slip angle. The sensor is basically an displacement transducer. The basic idea of how we can measure the speed of vehicle with this optical sensor:

- Mount the CORREVIT sensor securely with a clear view of the road.
- Provide power and connect the sensor to a data system.
- Follow the manufacturer's calibration procedure for accurate measurements.
- Understand how the sensor uses laser or infrared to measure vehicle velocity.
- Use sensor data to calculate vehicle velocity and covered distance.
- Apply filtering to improve measurement accuracy.
- Integrate data into the vehicle's systems.
- Test and validate measurements under various conditions.
- Periodically check and maintain the sensor for optimal performance.

Measurement of Lateral Acceleration

The 3DM-GX3-25 is a high performance, Miniature Attitude Heading Reference System(AHRS) utilizing MEMS sensors technology. It combines a triaxial accelerometer, triaxial gyro, triaxial magnetometer, temperature sensors and an on-board processor running a sophisticated sensor fusion algorithm to provide static and dynamic orientation and inertial measurements.

- Securely mount the AHRS on the object.
- Provide power according to guidelines. Connect AHRS to the data system.
- Calibrate MEMS sensors for accuracy.
- Identify lateral acceleration axis (X or Y).
- Retrieve data from the AHRS.
- Convert raw data to acceleration units. Use filters for noise reduction.

Measurement Data Acquisition System

For the measurement data acquisition in the driving test, the laboratory area of the entire vehicle is provided with various mobile measuring systems of different design

Integrated measuring system (e.g. B+S Integra): Robust PC for measuring purposes:

- Robust PC optimized for vehicle use.
- Integrated data interfaces and measurement hardware.
- Mounted with a signal preparation module on a base plate.
- Operation and display via monitor and keyboard.
- Space and weight-intensive.
- Suitable for self-sufficient operation.

USB measurement system (e.g. DeweSoft SIRIUS): robust and cheap measurement system:

- Robust and cost-effective.
- Similar setup to integrated systems but lacks an integrated PC.
- Control via notebook, PC.
- USB (or EtherCAT) used as the interface.
- Expandable channel number by coupling multiple systems.
- Limited data rate due to USB.
- No self-sufficient operation.
- Online data display only on the operating PC.

Modular peripheral measurement system: small, light measurement collector

- Dissolved components connected via fieldbus (e.g., CAN).
- Modules optimized for specific variables near sensors.
- Reduced wiring effort; often provides sensor power.
- Data stored on a logger or transmitted to a PC.
- Integration with vehicle data buses (CAN, MOST) possible.
- Enables self-sufficient operation based on configurable triggers.
  1. **Pros**: Small, light, robust modules; inconspicuous installation; easy self-sufficient operation.
  2. **Cons**: Limited measurement and data rates (5 kHz/channel).

DSP-measurement system (e.g. IMC µMUSYCS): device for measuring and regulating

- Compact device with a digital signal processor (DSP).
- Records analog/digital data, generates/export values for control.
- No full PC; runs autonomously with loaded program.
- Can control test benches; multiple systems can be networked.
  1. **Pros**: Robust; closed operation practical; regulations possible with DSP.
  2. **Cons**: Online data display requires additional hardware; space requirements vary.

3. HANDLING TESTS

3.1 STEADY-STATE SKID PAD TEST

Test Objectives

This experiment utilizes three distinct measurement techniques: constant steering wheel angle, constant radius, and constant velocity. These methods categorize driver behavior into two classifications: Closed Loop (constant radius) and Open Loop (constant steering wheel angle and constant velocity). The constant radius method requires the driver to be part of the signal feedback loop, where they must maintain a steady radius path while adjusting to variations in the vehicle's longitudinal velocity (Vx). The experiment's primary objective is to sustain a constant radius trajectory while gradually increasing the vehicle's speed. During the initial phase of acceleration, a linear relationship is observed between the steering wheel angle and lateral acceleration. However, as acceleration increases further, the vehicle eventually exhibits understeer characteristics, marking the point of maximum lateral acceleration. Additionally, as acceleration continues to rise, the relationship between lateral acceleration and steering wheel angle transitions into a non-linear pattern.

Test Procedure:

The vehicle is driven along a circular path with a fixed radius (or alternatively, with a fixed steering wheel angle). The driving speed is incrementally increased from a low velocity until either the constant radius can no longer be maintained through steering adjustments or the vehicle becomes unstable. The resulting steady-state characteristics can be utilized, for example, to parameterize the vehicle's characteristic velocity (bicycle model) or to analyze its static steering behavior. This includes evaluating metrics such as the understeer gradient for comparing different vehicles or component variations.

Analysis of the results:

a) MATLAB command for displaying the steering angle over the lateral acceleration.

```
plot(ay, lw);

xlabel('Lateral Acceleration(ay)');

ylabel('Steering Angle (lw)');

title('Steering Angle vs Lateral Acceleration');

grid on;
```

For the Steady-State Skid Pad test, apart from analyzing the graphs from the measurement data, we also find the steering angle and slip angle using the linear Bicycle model shown in the previous section.

BICYCLE MODEL WORKING AND EXPLANATION

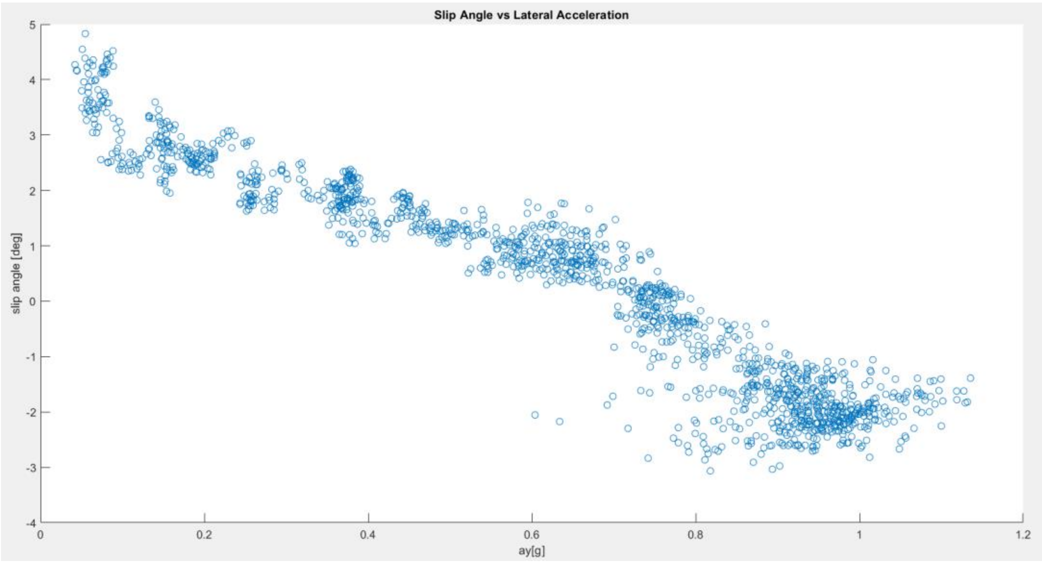
Procedure:

From the data recorded by the sensors on the vehicle, we get the values for longitudinal and lateral velocities. These values are recorded at the Correvit sensor and must be shifted to the COG of the vehicle using the following equation:

$$v_{CG} = v_{sensor} + yaw\ rate \times (L_r + L_c)$$

$L_r = Distance\ of\ rear\ axle\ from\ CG$
$L_c = Distance\ of\ Correvit\ sensor\ from\ rear\ axle$

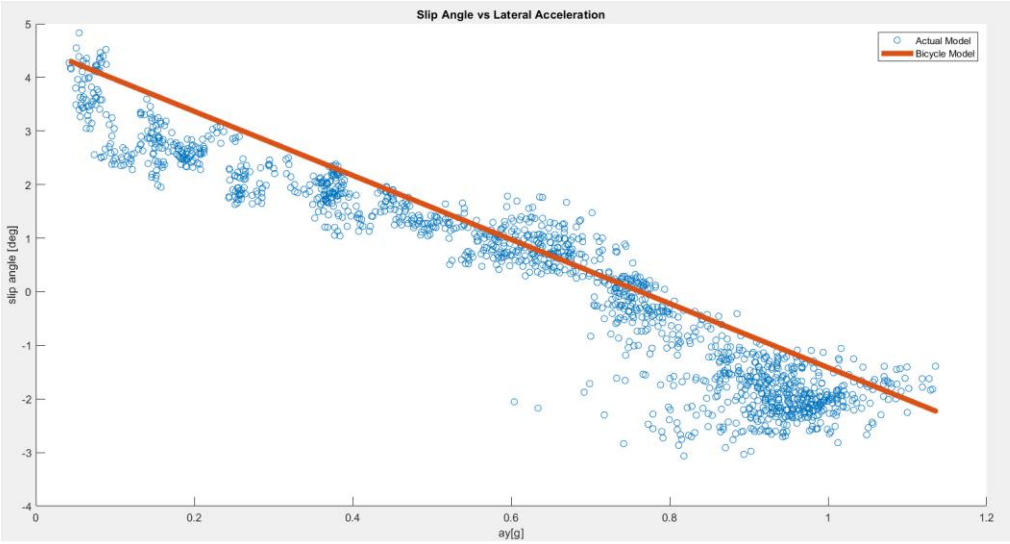
From the test, we get a scattered plot of the slip angle as shown below.



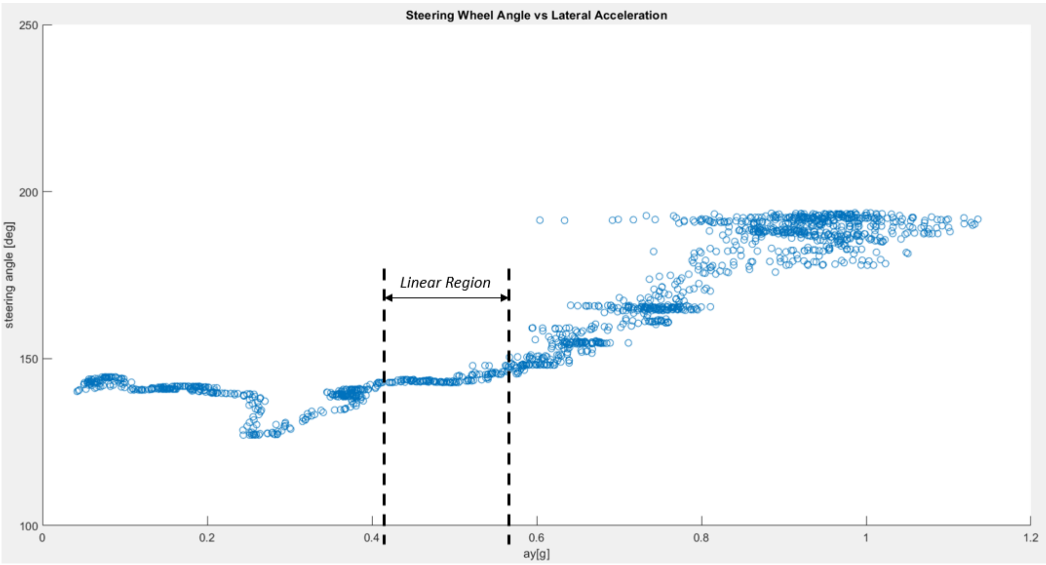
Using the **"polyfit"** command in MATLAB, we obtain a regression line for this plot. With the slop of this regression line, we calculate the value for rear axle cornering stiffness (C_b) using the following equation:

$$\beta = \frac{l_b}{R} - \left(\frac{1}{C_b} \times \frac{L_r}{L} \times m\right) a_y$$

Using these values, we can plot the linear line for slip angle vs lateral acceleration graph for the linearized Bicycle Model.



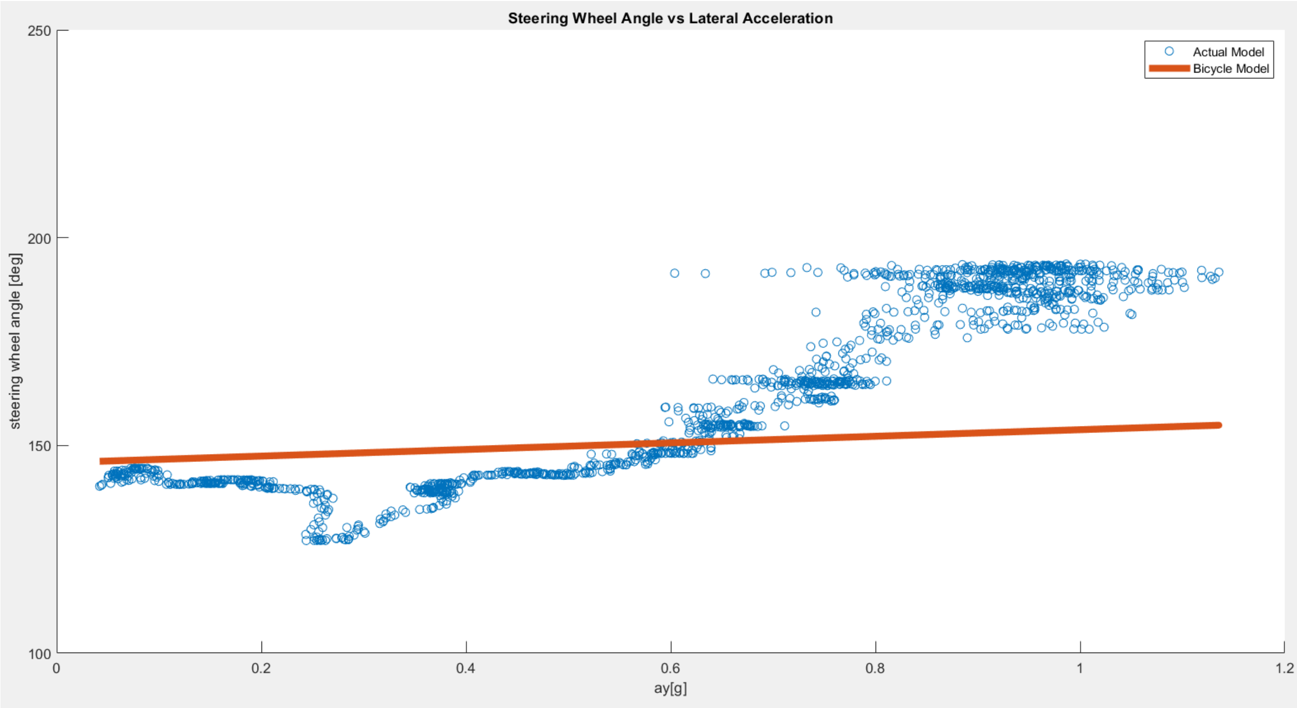
The graph for the steering angle against lateral acceleration is linear at the beginning but becomes non-linear at higher lateral acceleration. For the bicycle model, we limit our calculations only in the linear region of the graph (We ignore the sudden dip in steering angle at the beginning).



Again, using the "polyfit" command of MATLAB, we find the slope of the graph in this linear region. With this slope value, we now find the value of the front axle cornering stiffness (C_f) by the formula shown below:

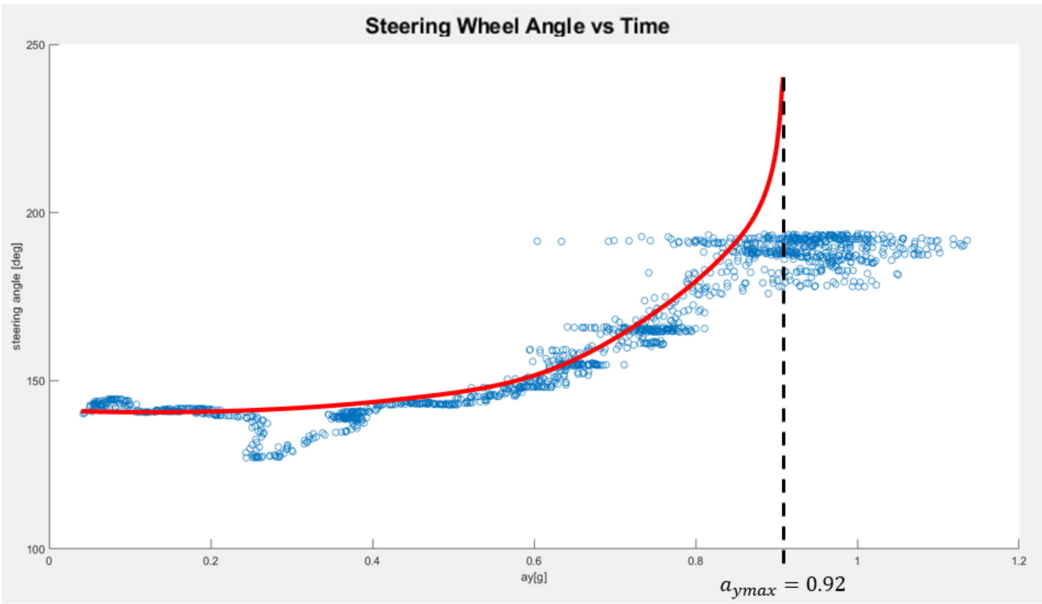
$$\delta = \frac{l}{R} + \left(\frac{l_b}{l \times C_f} - \frac{l_f}{l \times C_b}\right) m.a_y$$

For the bicycle model, we now plot the graph of "Steering Wheel Angle vs Lateral Acceleration" with the help of the calculations shown above.

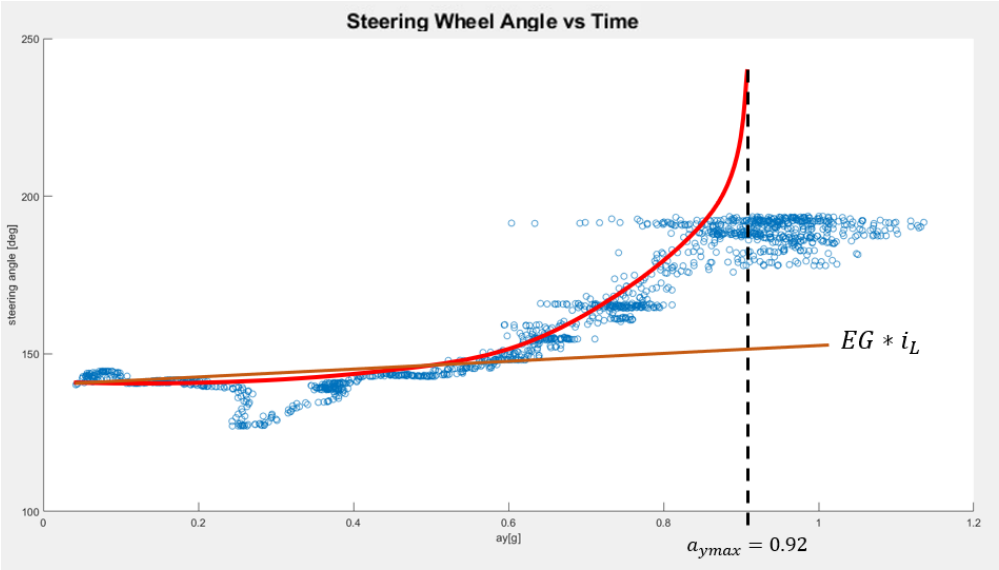


b) **Approximate maximum lateral acceleration from diagram.**

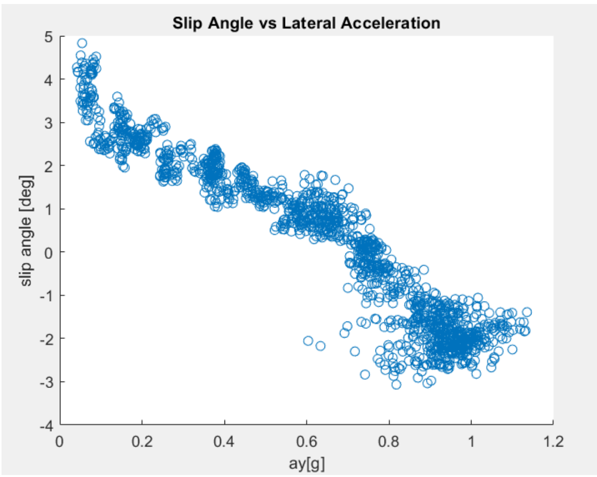
a_y = 0.92 m/s^2

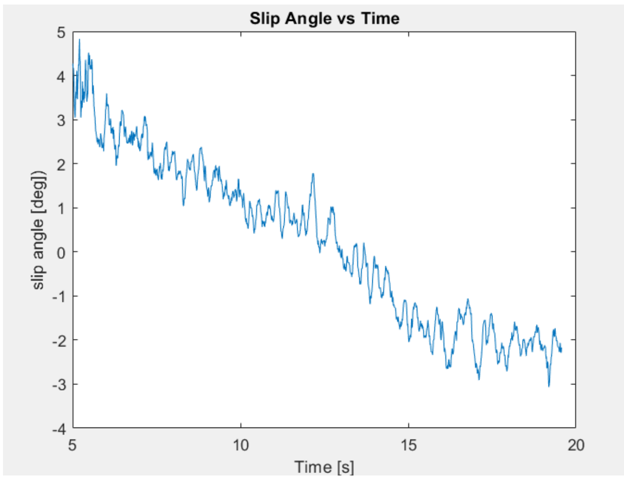


c) **Value of the steering wheel angle related self-steering gradient EG_L=$EG * i_L$ by drawing and evaluating the corresponding straight line.**

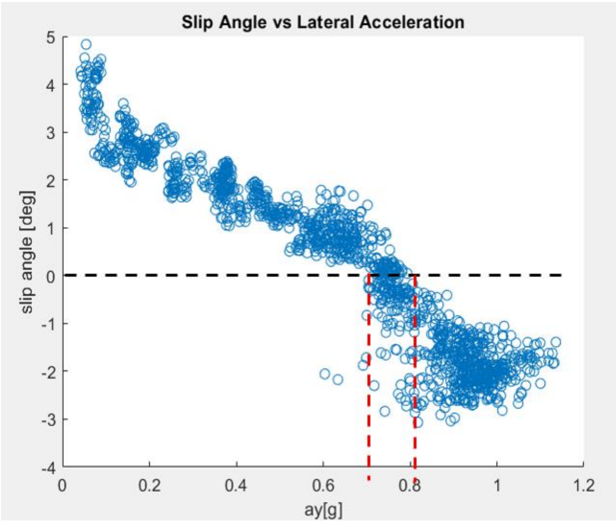


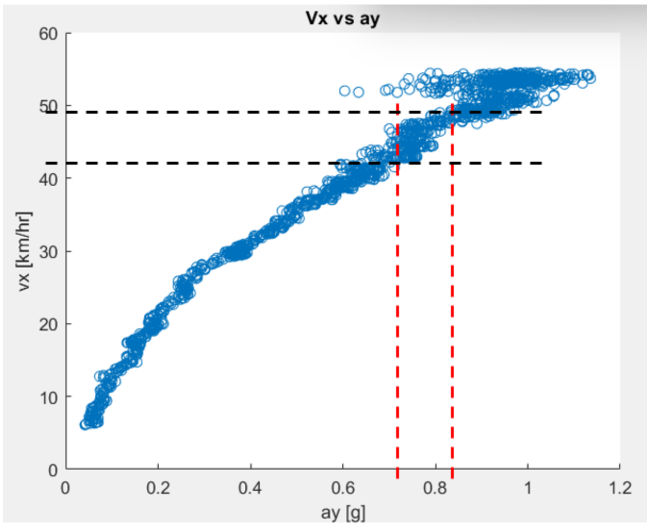
d) **Plot of angle of deviation beta with existing data vectors vx and vy of the longitudinal and lateral velocity in the center of gravity Vs Time and Lateral acceleration, ay**





e) Declare the vehicle velocity v_X at which the angle of deviation is zero.

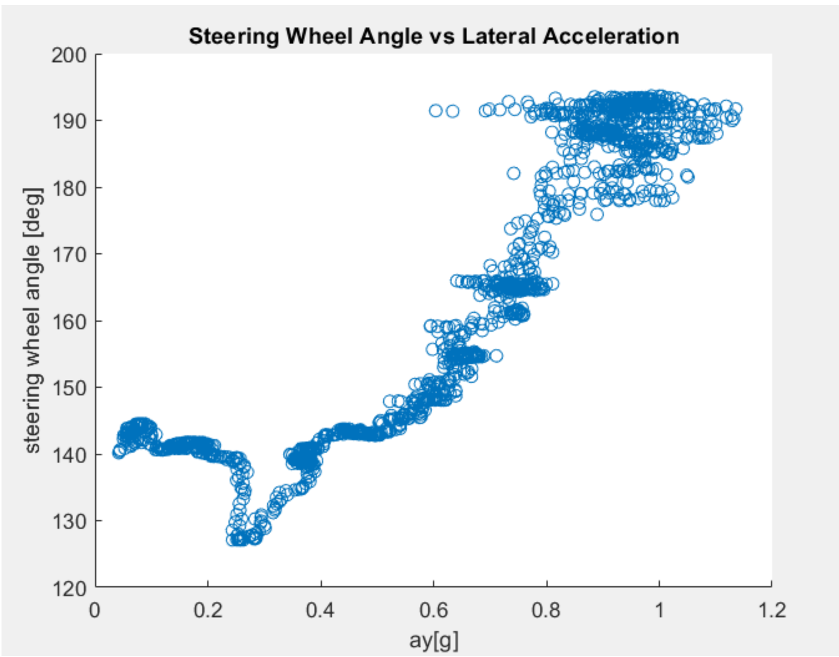




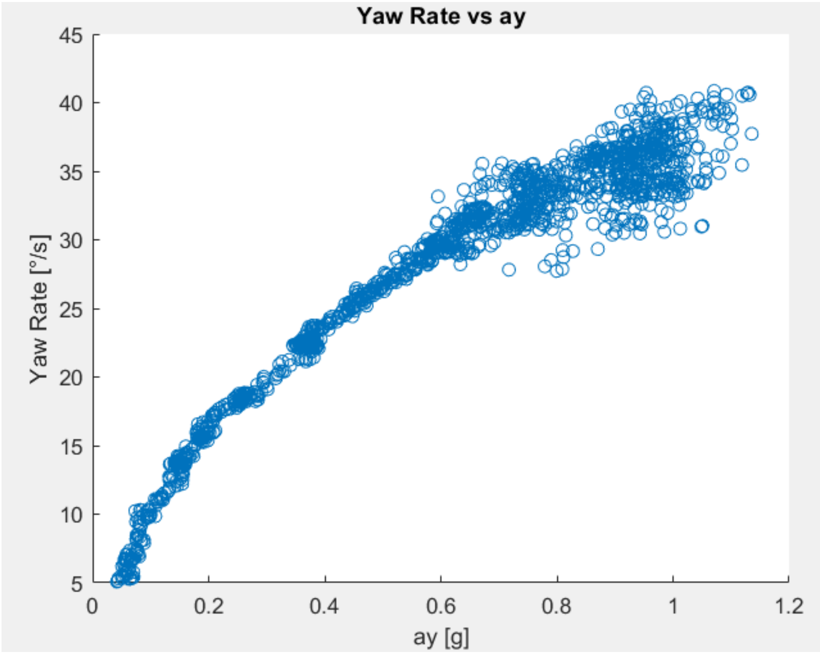
When the slip angle = 0, the lateral Acceleration ranges from 0.69 – 0.83g. The corresponding velocity Vx at which the angle of deviation or slip angle is zero is Vx = 42 – 49 km/h.

f) How can you recognize in the diagrams that the vehicle is also showing understeering behavior in the non-linear range?

Understeer is characterized by a decrease in lateral acceleration despite a specific steering input. Examining the correlation between steering angle and lateral acceleration is pivotal. Within the non-linear range, if the lateral acceleration fails to correspondingly rise with higher steering angles, this absence of anticipated increase might strongly hint at potential understeer concerns.



Understeer happens when the car doesn't respond as expected to steering input, with lateral acceleration decreasing instead of increasing. It's important to look at how the steering angle and lateral acceleration are connected. If, in the non-linear range, turning the wheel more doesn't lead to the expected increase in lateral acceleration, it's a clear sign that understeer might be a problem.

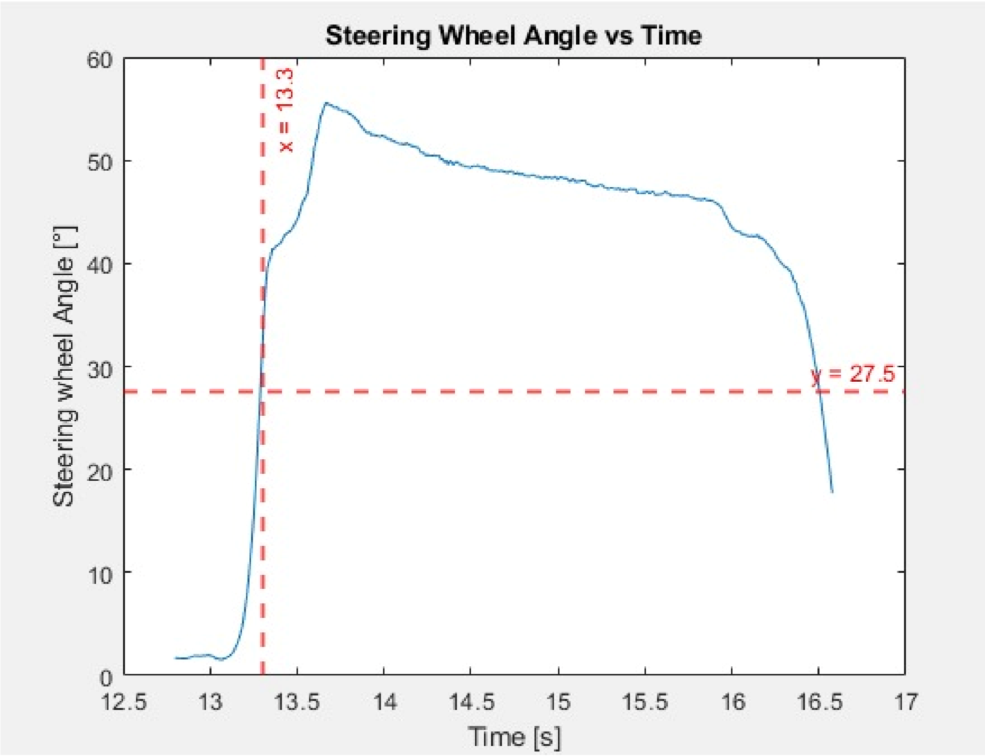


In an understeering scenario, the yaw rate is lower than expected for a given steering input. This indicates that, despite the driver turning the wheel, the vehicle doesn't rotate as much as intended and follows a path closer to its original trajectory. On a graph comparing steering angle to yaw rate, understeer is evident when the yaw rate curve falls below the expected trend, highlighting a lack of responsiveness in the vehicle's turning behavior.

3.2 STEERING STEP INPUT TEST:

Test Objectives:

This test is part of the assessments to evaluate the dynamics of a vehicle. The objectives of this test are to evaluate how fast the car stabilizes after the step input for the driver's comfort and predictability, to see the overshooting which can be unsafe when too high and the speed of vehicle's reactivity to the step input which is the feedback that the driver can feel.



For our test, we have a steering step input of approximately 55 deg [Figure 1]. We can also observe that the step is not perfect because we act in a physical environment, and it is done by hand. So we have a kind of PT2 input with a very short time constant and big damping so that we can approximate it to a step.

Test Procedure

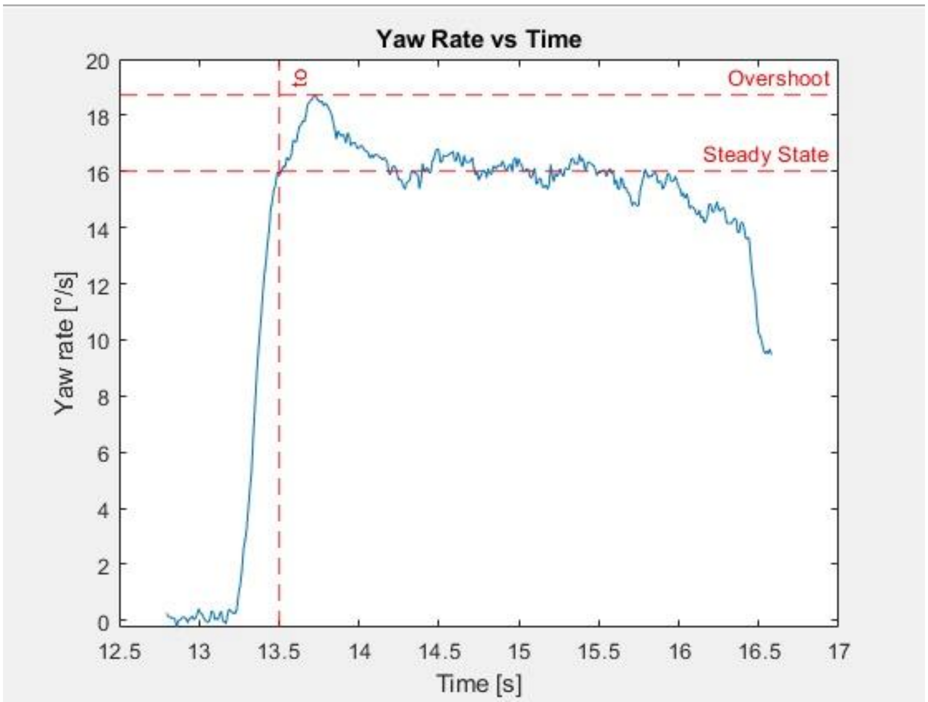
During the test we need to try to keep a constant velocity which is in this case around 80km/h. This speed can be determined if we want a certain steering angle thanks to the previous test. Or on the opposite, we can determine the steering angle that we need for a certain speed thanks to the previous test too. The test starts while driving straight then the driver applies a steering step to 55deg ([Figure 1] at 13.3s). The driver will keep this angle for a few seconds until the vehicle stabilizes to a constant yaw rate and lateral acceleration. Then we got all the output that we want and we can stop the vehicle.

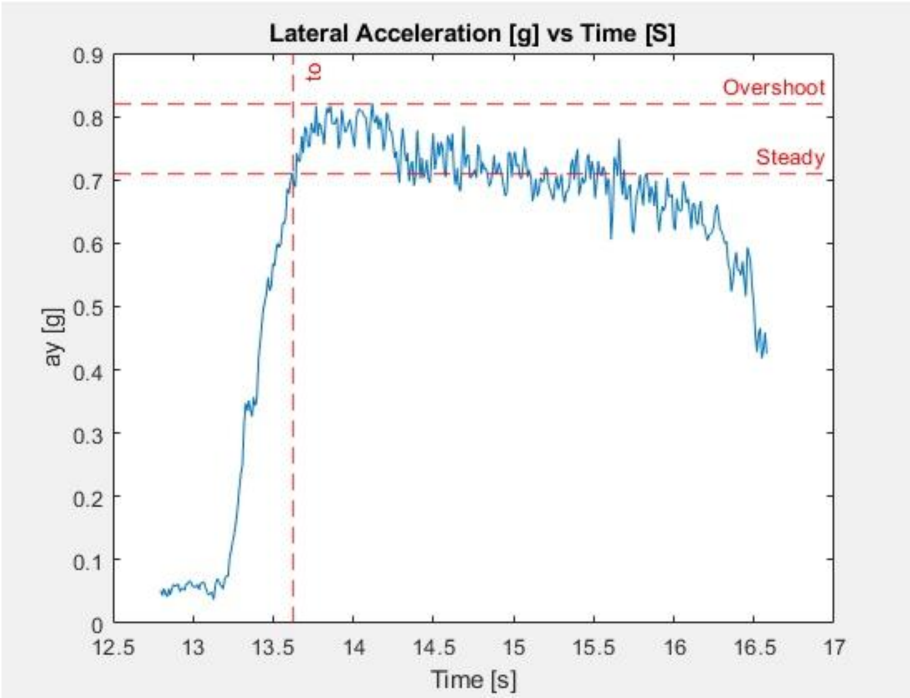
Analysis of the results:

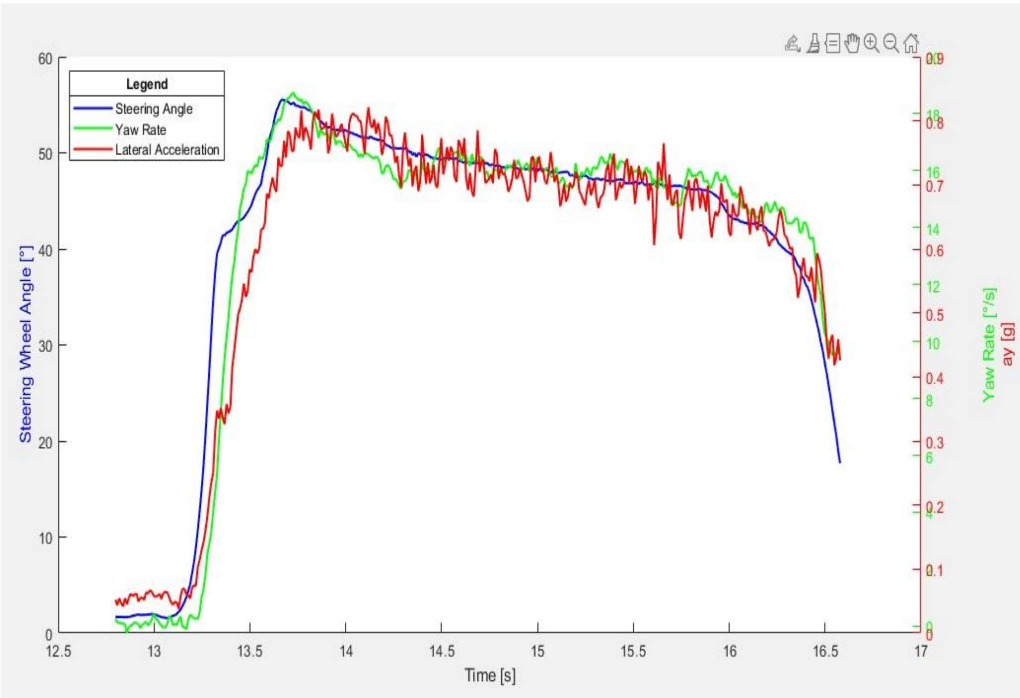
As shortly explained before, we want to observe the time response, the overshot and the steady state value of the yaw rate and the lateral acceleration with a steering step input.

First at all, we will set the starting time t_0 of the measurements at the time when the steering angle reaches 50% of the steady state value. On the Figure 1 we can read t_0 = 13.3s. Then for the time response, we will consider the time between t_0 and the time when the output value reaches 90% of the steady state value. Regarding the overshot, we will calculate the percentage corresponding to how much the maximum peak is over the steady state value. We will simply use the formula.

$$overshot = \frac{(max - steady\ state)}{steady\ state}$$







We can observe that both, the yaw rate and the lateral acceleration have a small delay. Both are also overshooting their steady state value with 10% for the yaw rate and 20% for the acceleration. The delay can be interpreted with the inertia of the vehicle, the suspensions parameters and the tires performances. To reduce the delay, the tires should have a better adherence, the suspensions to be harder and the vehicle a low gravity center point. The lower the delay is, the better the feeling for the driver is. With an instant response when the driver steers, he can act directly which is better for safety. The driver is like a controller who corrects the steering to match the desired cornering with his own sensor: visually with the yaw rate and the feeling of the lateral acceleration. The overshot is also due to the same reasons. When steering, the whole vehicle's body will move to the exterior of the corner and when the steering angle stabilizes, the body wants to stabilize to a position, but the inertia and suspension damping will make the vehicle's body oscillate.

3.3 VDA LANE CHANGE TEST:

Test Objectives

The purpose of this test is to evaluate the vehicle's lateral dynamics performance under challenging driving conditions, as outlined in ISO 3888-2. The test involves navigating through three cone-defined lanes at the highest possible speed. The entry speed, measured in the entry lane, is progressively increased, typically ranging from 60 to 75 km/h under optimal conditions. This test examines the complete system, including the driver, with the driving behavior assessed within a closed control loop.

Test Specifications:

- The accelerator pedal is released when entering the alley. The vehicle must be in the highest possible gear (engine speed at least 2000 rpm). For vehicles with an automatic transmission, gear D should be selected.
- The entry speed of the vehicle is measured at the last pylon of the approach lane.
- The test must be completed at the maximum possible entry speed. Several journeys, whereby the entry speed is gradually increased to the maximum possible.
- The test is passed when no pylon is knocked over.

Test Procedure:

- Begin by setting up a test track with clearly marked lanes and cones or similar indicators to outline the path for the double lane change maneuver.
- Accelerate the vehicle to the target velocity, which in this case is 60 to 65 km/h, then release the accelerator pedal before entering the defined path.
- Perform a rapid yet controlled steering input to execute the double lane change maneuver, involving a lane change to the left followed by a quick return to the right within a limited distance.
- The driver should carry out the maneuver smoothly and accurately, avoiding contact with any cones. A test is deemed successful if no cones are hit.
- After completing the maneuver, collect the necessary parameters for stability assessment using the various measurement sensors installed in the vehicle.

Calculation Equations:

As we get the main parameters from the graph and get the different values to evaluate the behavior of the vehicle.

S. No	MEASUREMENT	1	2	3
1.	Entry Speed [km/h] max	60	64	70
2.	Lateral Acceleration [g] max	1.04	1.065	1.17
3.	Vehicle Slip Angle [deg] max	6.23	5.97	5.55
4.	Steering wheel angle [deg] max	171	149	210
5.	Yaw Rate [°/s] max	45	37.8	51.76

Vehicle Slip Angle Equation:

The slip angle (β) is the angle between the direction a tire is pointing and the direction in which it is moving. It can be calculated by using the following equation by putting the following values from the table we can calculate the slip angle:

$$\alpha = \beta - \delta$$

Where:

- α is the slip angle,
- β is the vehicle's sideslip angle (the angle between the velocity vector and the vehicle longitudinal axis),
- δ is the steering angle.

The sideslip angle (β) can be calculated as:

$$\beta = tan^{-1}(\frac{v_y}{v_x})$$

Where:

- β is the slip angle.
- *Vy is* the lateral velocity of the vehicle.
- *Vx is* the longitudinal velocity of the vehicle.

Where:

The lateral velocity (*Vy*) can be related to the lateral acceleration (*ay*) using the equation:

$$a_y = v_y \times \omega$$

- *ay is* the lateral acceleration.
- ω is the yaw rate of the vehicle

The yaw rate (ω) is related to the steering wheel angle (δ) and the vehicle speed (*V*):

$$\omega = V.tan(\delta)/L$$

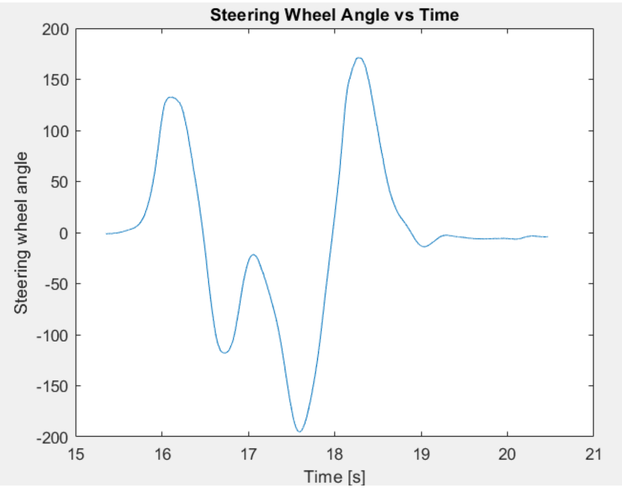
Where:

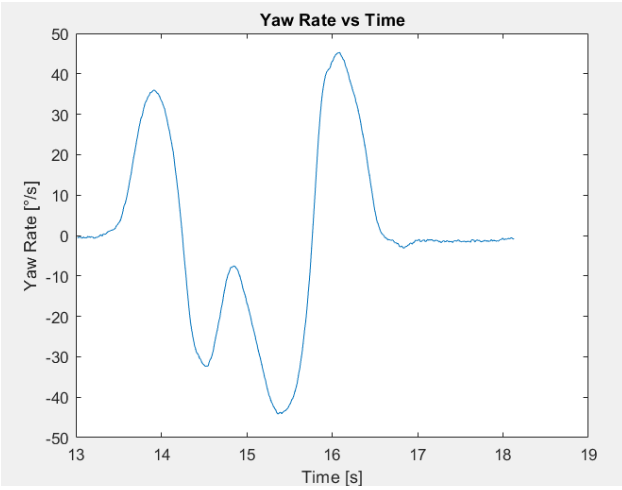
- δ is the steering wheel angle.
- *V* is the vehicle speed.
- *L* is the wheelbase of the vehicle.

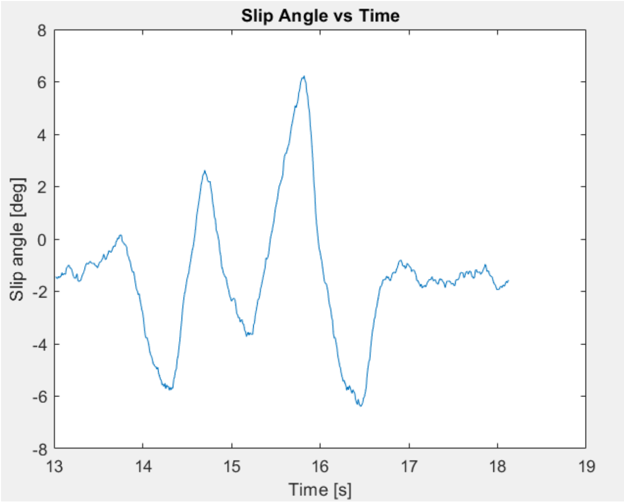
By combining these equations, you can calculate the slip angle (*β*) using the measured variables from the lane change maneuver.

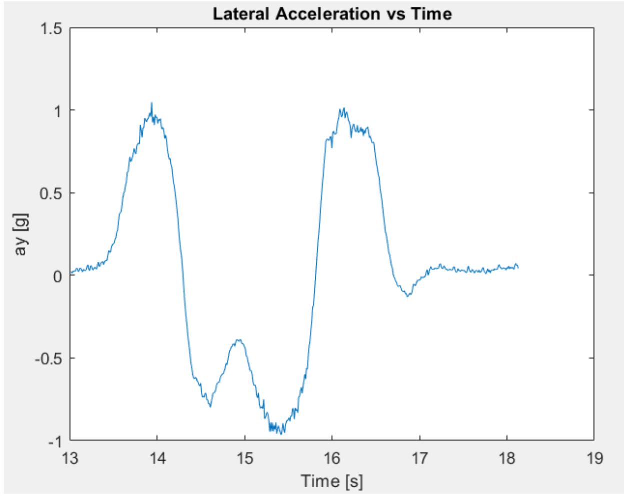
Analysis of Results:

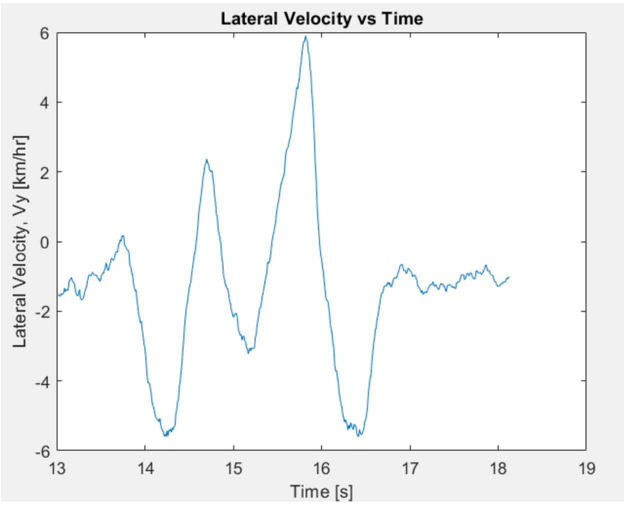
As we perform the test several times to get the maximum result at higher velocity (70 km/hr for our case), we get the following results from the different measurement sensors :

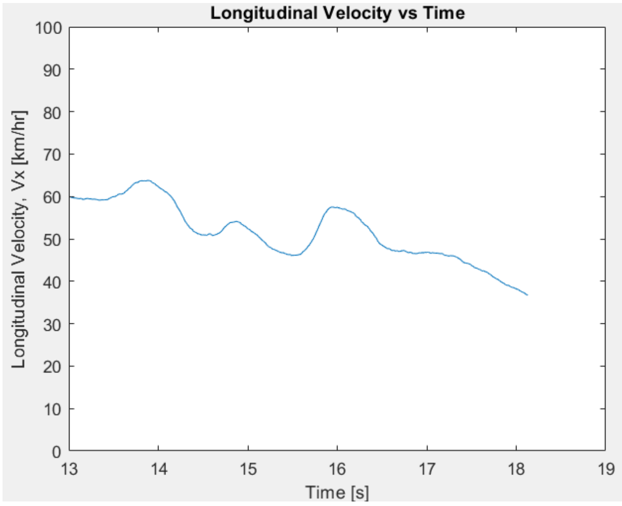












Final Inference

- The test provides insights into the vehicle's stability during rapid lateral movements. Stability is crucial for ensuring that the vehicle can maintain control and trajectory during emergency situations or extreme maneuvers.
- Handling characteristics, including responsiveness to steering inputs, slip angle Lateral acceleration, yaw rate, Longitudinal acceleration are assessed during the double lane change. This helps identify any tendencies toward oversteer or understeer, which can impact the vehicle's ability to navigate sudden turns.
- The test helps determine the vehicle's limit handling conditions, revealing how we can manage to avoid the Oversteer or understeer behavior in the vehicle. This
  information is essential for understanding the vehicle's behavior in extreme driving scenarios.