

# Evaluation of handling of trucks

*Internship at Scania*

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WILFRED SCHOLTEN  
s1010964

Scania CV AB  
Department RTCD  
Södertälje, Sweden  
Supervisor Jolle IJkema

University of Twente  
Faculty of engineering technology  
Section Applied Mechanics  
Supervisor André de Boer

# 1. Preface

This report is written during my internship at Scania in Sweden. This internship took place within the department RTCD, responsible for testing of trucks on handling, ride & vibration comfort, steering and mobility. During these four months, I was part of the team and got insight in the work done by this department. My main assignments considered updating the Matlab scripts used to analyze test data. However, I also got the possibility to see the work of my colleagues and join a number of tests. I would like to thank my colleagues at RTCD. I felt really welcome and was treated as part of the team. Furthermore I would like to thank my supervisor, Jolle, for offering me this opportunity and for being a good host at work but outside the office hours as well.

## 2. Abstract

This internship is done at Scania, within the department responsible for testing of trucks regarding dynamic aspects. The main assignments during this internship consisted of updating several Matlab based tools, used to evaluate test data.

Scania uses a number of handling tests in order to judge the handling behavior of truck objectively. During these tests the vehicle is driven at  $70\text{km/h}$  and a certain steering movement varied for each test is made. The outcome of these tests is a set of metrics which describe the handling behavior.

The already in use Matlab tool used to evaluate the test data has been revised on several aspects. Test data from the random test, at which the vehicle is steered to the left and right at an increasing frequency, can now be used to approximate the results of the weave test, were the same is done but at a lower and constant frequency. Cab and axle roll gradients are calculated in a way less sensitive to influences of an inclined test track or side winds. The asymmetry of some metrics has been studied. Furthermore some practical changes have been made. This includes the establishment of a database and further automatization of storing and presenting the results.

A new script is made to analyze the steering wheel return test. In this test the steering wheel is released from a large angle while driving at slow speed. The outcomes of the test are the steering wheel angle velocity and the final steering wheel angle. The new script investigates automatically the suitability of the test data as there is a large number of faulty measurements. The new script also provides the option to compare the results with other tests.

At the end the determination of the ratio from steering wheel to steered front wheel is discussed briefly. This ratio is tested on eleven trucks, the results are used by the ESP system to quickly calculate the yaw velocity. The ESP system will brake certain wheels if the yaw velocity is considered to be too high.

*Keywords: Automotive, Trucks, Dynamics, Handling, Programming*

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# 1. Company and department

Scania is a manufacturer of trucks and buses and part of the Volkswagen group. Besides complete vehicles, Scania sells its engines to serve in many types of machinery and vessels. Nowadays services are becoming a more important product of the company as well. Scania is a global company with efficient factories all over the world. The company uses principles as lean manufacturing and house of quality, to eliminate waste, meet customer demands and keep improving its processes. These principles are not only used in production but throughout the whole company.

Scania trucks are based on a modular system in which many components are interchangeable. This enables the company to produce a large variety of trucks easily in order to meet specific customer demands. The number of different parts is kept surprisingly low, which improves efficiency in production and logistics. Furthermore new designs or technologies can be implemented quickly as a result of the modular system.

Although production is scattered around Europe and the rest of the world, almost all research and development work is done in Södertälje, Sweden. This internship took place in Södertälje at the Scania Tekniskt Centrum. Here, employees have access to many facilities. Examples are engine test cells, rigs testing the fatigue life of different components and the test track.

RTC is the department responsible for the vehicle dynamics and chassis design. It is part of a larger department developing trucks. This internship took place at the group RTCD, which is one of the subdivisions of RTC. Directly cited from the homepage [1], RTCD is responsible for complete vehicle testing for Scania truck product-development in handling, ride & vibration comfort, steering and mobility. Other groups within RTC are responsible for [1]:

- Steering design
- Basic chassis development design
- Dynamics and strength analysis
- Gear shift, cab tilt and trailer connection design
- Brake performance

## 1.1 Department RTCD

The group consist of about 20 employees, these are not only engineers but mechanics as well. Most of them have truck driving licenses and can be found on the local test track regularly. As mentioned earlier the focus of the group can roughly be separated in four fields of interests [1]:

- Handling: keeping and improving the vehicle handling which is characterized by on-course stability and quick vehicle response.
- Ride- & vibration comfort: Improving the vehicle ride- and vibration comfort by lowering the cab vibration level.
- Steering: Developing precise and responsive steering systems.

- Mobility: Increasing traction capability to allow for greater mobility on all-terrains.

The vehicle dynamic properties related to these four subjects are tested both objective and subjective. It is hard to judge the driving behavior on basis of the complex related objective measures only. That is where the experienced drivers come in. Driving properties are rated on a 1 to 10 scale by drivers opinion, the goal is to relate all objective measurements to such a scale as well.

My tasks within this department were mainly to improve Matlab scripts already in use to analyse test data. These scripts mainly referred to the steering design part of the department. Furthermore some test data has been analyzed and an internal report has been written. Besides working on these tasks I got the possibility to join on several tests and got an overall view of what kind of work was being done by this department and Scania in general. The main assignments will be elaborated in chapter 3 to chapter 5 after an introduction to the subject of vehicle dynamics in chapter 2.

## 2. Vehicle dynamics

In the beginning of this chapter some basics of vehicle dynamics, with the focus on heavy vehicles, will be discussed. Thereafter the methods used by RTCD to generate an objective description of the vehicle handling will be elaborated. Scania uses the ISO standard direction definition shown in figure 2.1. This report focuses on the handling behaviour, which refers to the lateral and longitudinal direction.



Figure 2.1: ISO direction definition[3]

In this report the following symbols will be used to describe the movement of the vehicles:

$$\begin{aligned} SWA/\delta_{st} &= \textit{Steering wheel angle} \\ \delta &= \textit{Angle of steered wheels compared to centerline of vehicle} \\ SWT &= \textit{Steering wheel torque} \\ V_x &= \textit{Velocity in longitudinal direction} \\ V_y &= \textit{Velocity in lateral direction} \\ \omega_w &= \textit{Yaw rate (angular velocity)} \\ A_y &= \textit{Lateral acceleration} \end{aligned} \tag{2.1}$$

### 2.1 Truck versus car

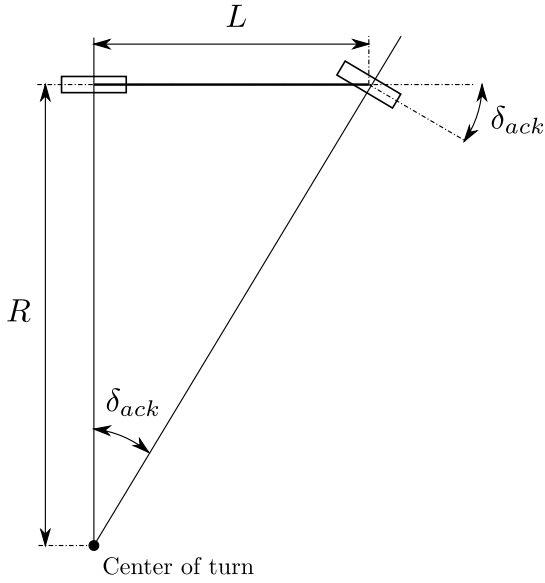
The dynamics of trucks are different of that of cars for many reasons [3]. Obviously truck are very heavy compared to cars and have a high centre of gravity. Trucks often have multiple axles, which can be steered or not. The difference between loaded and unloaded vehicle or a vehicle with or without a trailer is large.

Furthermore the design of trucks results in differences. Trucks have a front axle instead of the common independent front suspension systems in a passenger car. The cabin of the truck is suspended with respect to the chassis. The chassis is relatively compliant since it is long and does not get stiffness from the roof of the car.

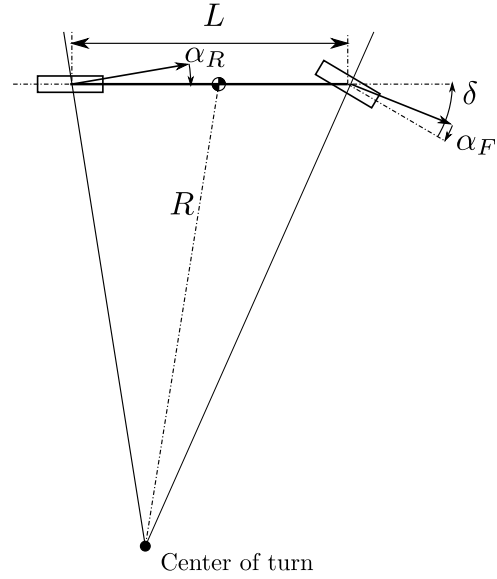
## 2.2 Handling diagram

The simplest vehicle model to describe yaw response[4][5] is the so-called bicycle model in which the vehicle is simplified to two wheels of which the one in front is steered. The following section is based on steady state cornering, so cornering with constant velocity and lateral acceleration. At very low speed the direction of movement of the wheel lies in the plane of the wheel, see figure 2.2. The vehicle drives a perfect circle with the centre of the turn at the intersection of lines through both wheels axis. The angle between these lines is the so-called Ackerman angle and is approximated by equation 2.2. This approximation is valid since this angle will be small.

$$\delta_{ack} = \frac{L}{R} \quad (2.2)$$



**Figure 2.2:** *Corner at low speed*



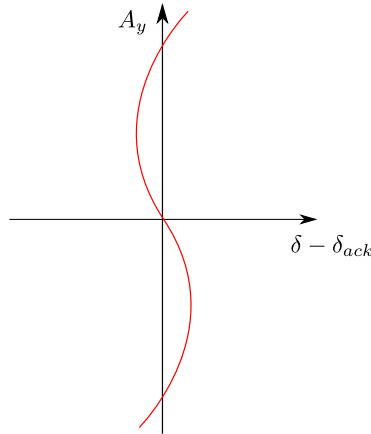
**Figure 2.3:** *Corner at high speed*

At high velocities the tires provide the force to realise the centripetal or lateral acceleration. As the tires are not infinitely stiff they will deform and therefore the direction, in which the wheels move, will not be parallel to the wheels itself. The front and rear wheels will have a slip angle,  $\alpha_F$  and  $\alpha_R$  respectively, see figure 2.3. The centre of turn lies at the intersection of the lines perpendicular to the actual wheel movement, which is not in line with the rear axle. As these angles are small during stable operation, maximal 10 degrees [5], and  $R \gg L$ , the following relation could be derived.

$$\delta_{ack} - \delta = \alpha_R - \alpha_F \quad (2.3)$$

In which  $\delta$  is the steer angle, the angle between the front wheel and the centreline of the vehicle. In case this steer angle exceeds the Ackerman angle the vehicle is said to be understeered. The slip angle of the front tires will exceed those of the back tires and the vehicle will turn at a larger corner than when it would drive slowly. The vehicle is oversteered if this is the opposite way around. In general understeer is preferred as this represents stability, however this should not be too much as this would cause the feeling that the car does not respond to the driver. Figure 2.4 shows the typical handling diagram for a heavy vehicle. For high lateral accelerations the vehicle might be oversteered, however most heavy vehicles will rollover before that.





**Figure 2.4:** *Typical handling diagram for heavy vehicle*

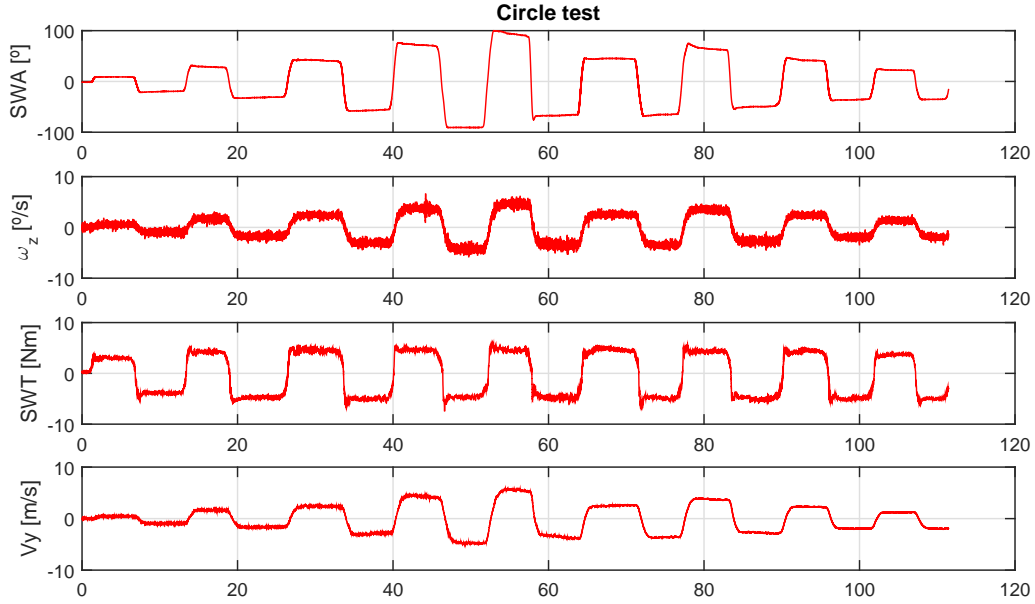
In this section a lot of simplifications had been made. The actual steering behaviour is heavily influenced by the suspension system. Wheels tend to steer as result of movement in the suspension. For trucks with over two axles the tag axles can alter the handling diagram. At low speeds and small radii a rigid tag axle will make the vehicle more understeered, however a large corners it might give more oversteer.

## 2.3 Metrics and test methods

RTCD uses a number of standardized tests in order to determine the handling behaviour of trucks. This internship had a lot to do with the Matlab script which is used to evaluate the testdata, calculate a large set of parameters and determine a small set of leading metrics. In this section these tests and the determination of some important metrics will be discussed.

### 2.3.1 Circle test

In the circle test the vehicle will be driven at a constant velocity of  $v = 70km/h$ . The steering wheel is turned and kept at a constant angle for a certain amount of time. The vehicle reaches the state of steady state cornering and measuring data is gathered. This is done at several steering wheel angles in order to generate different lateral accelerations.



**Figure 2.5:** *Time history circle test*

This test is performed on a runway. The truck actually does not make full circles as that would require an enormous area of asphalt and steady state is reached earlier on in the corner. The truck makes left and right handed corners alternately at an increasing steering wheel angle. The time histories of such a test can be seen in figure 2.5. Measured during the test are: Steering wheel angle, steering wheel torque, suspension compression, longitudinal and lateral velocity, yaw rate.

### Metrics

The handling curve consist of  $(\delta - \delta_{ack})$  on the x-axis and lateral acceleration  $a_y$ , which is measured directly, on the y-axis, see figure 2.4. The ackerman angle is calculated with the use of equation 2.2 in which the turning radius is approximated by:

$$R = \frac{v_x}{\omega_z} \quad (2.4)$$

The steer angle  $\delta$  is calculated with the use of the known ratio between steering wheel and front wheels. The gradient of the handling curve at zero lateral acceleration is calculated and set to be the understeer gradient.

The slip angle of the rear wheel is calculated by using the velocities in lateral and longitudinal direction, see equation 2.5.

$$\alpha_R = \arctan\left(\frac{v_{y,rear}}{v_x}\right) = \arctan\left(\frac{-v_y + \omega_z L_r}{v_x}\right) \quad (2.5)$$

The relation between this rear slip angle and the lateral acceleration is determined. The gradient of this relation at zero lateral acceleration is set to be the side slip angle gradient.

Other important metrics determined during this test are:

- Cab roll: gradient of roll angle of the cab versus lateral acceleration.
- Yaw rate gain: gradient of yaw rate versus steering wheel angle function.
- Effort: torque required for maintaining a certain steady state corner.

### 2.3.2 Random test

In the random test the vehicle also drives at  $70\text{km/h}$ . The steering wheel is turned left and right alternately as the driver performs a sine input on the steering wheel. The frequency is increased slowly, starting under  $0.1\text{Hz}$  and slowly increasing to about  $2\text{Hz}$ . The amplitude of the lateral acceleration in the beginning of the test should be around  $2\text{m/s}^2$ .

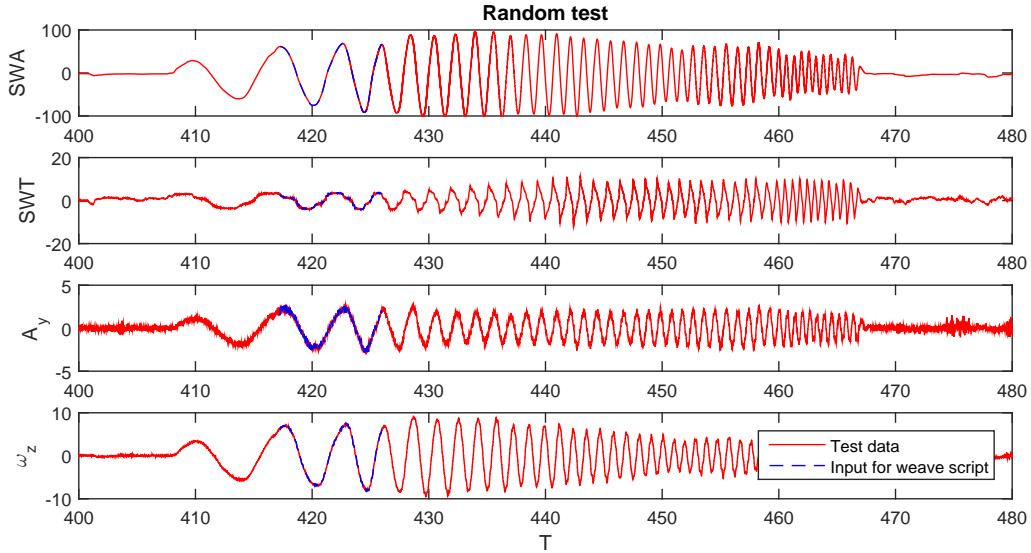


Figure 2.6: Time history random test

The time histories of a random test can be seen in figure 2.6. During the test the steering wheel angle, yaw rate, lateral acceleration, longitudinal velocity and suspension compression are being measured. Transfer functions are calculated between input and response signals and plotted as bodeplots.

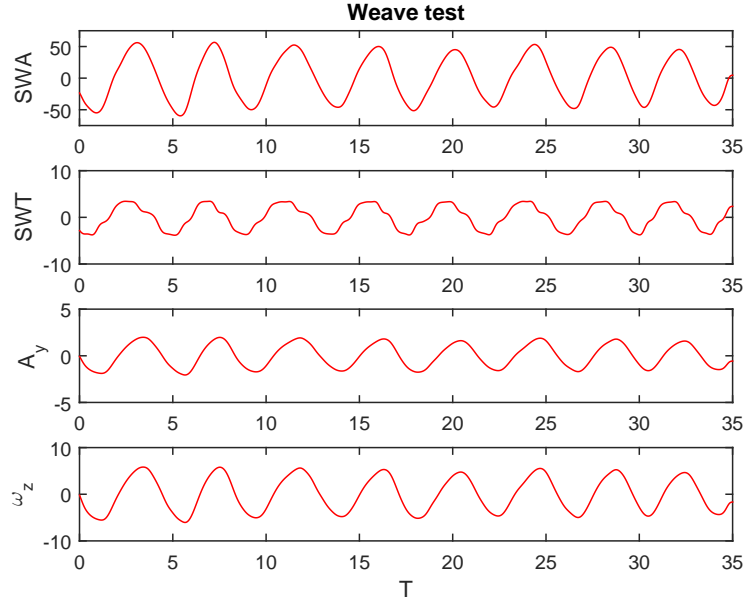
#### Metrics

The metrics calculated from this test are called yaw rate response time and cab roll damping. To do so frequency response models are generated with the use of the signal analysis toolbox in Matlab. Linear transfer functions are calculated for steering wheel angle to yaw rate and steering wheel angle to cab roll.

The yaw rate response time is calculated from the phase delay at  $f = 0.5\text{Hz}$  for the steering wheel angle to yaw rate model. The cab roll damping refers to the resonance peak around  $1\text{Hz}$  is the steering wheel angle to cab roll gain.

### 2.3.3 Weave test

In the weave test the steering wheel is again rotated to the left and right while the vehicle is moving at  $70\text{km/h}$ . The frequency of the sine shaped input should be  $0.2\text{Hz}$ , with an amplitude that results in a lateral acceleration of about  $2\text{m/s}^2$ .



**Figure 2.7:** *Time histories weave test*

Time histories of the test can be seen in figure 2.7. During the test steering wheel angle and torque, yaw rate and longitudinal velocity are measured. Evaluation of the test data is done by plotting vehicle response against steering wheel angle and steering wheel torque. This typically results in hysteresis loops.

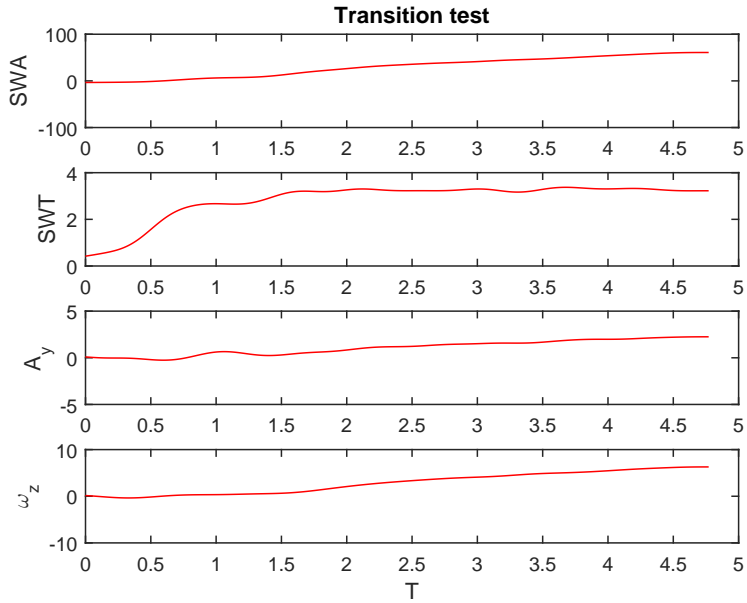
### Metrics

Metrics of this test describe the several hysteresis loops and are:

- Friction: The torque deadband at  $0^\circ/s$  in the steering wheel torque vs yaw rate plot.
- Play: The steering wheel angle deadband at  $0m/s^2$  in the steering wheel angle vs lateral acceleration plot.
- Road feel on-centre: The steering wheel torque gradient at  $0m/s^2$  in the steering wheel torque vs lateral acceleration plot.
- Steering sensitivity: The steering wheel angle gradient around  $0m/s^2$  in the steering wheel angle vs lateral acceleration plot.
- Returnability: Lateral acceleration deadband at  $0Nm$  steering wheel torque in the steering wheel torque vs lateral acceleration plot.

### 2.3.4 Transition test

The transition test is also performed while driving  $70km/h$ . The vehicle is driven in a straight line without holding the steering wheel. Thereafter the driver turns the steering wheel to the left or the right at a constant rate until the vehicle reaches a lateral acceleration of  $2.5m/s^2$ .



**Figure 2.8:** *Time histories transition test*

Time histories of a test can be found in figure 2.8. Several test to the left and to the right are being done. With these tests it can be evaluated at which steering wheel angle and torque the vehicle starts to react.

### Metrics

The most important metric determined with this test is the breakaway torque. This is the sum of the absolute steering wheel torques in a left- and a righthand corner at a yaw rate of  $\pm 1.1^\circ/s$ .

## 3. Update of handling script

At RTCD a Matlab script is used to analyse testdata from the handling tests discussed in the previous chapter. My tasks was to update this script on several points and make the script even more functional. The calculation and simulation group within RTC as well as a group working on buses want to use the script as well. Some adjustments needed to be made in order to run their simulation data generated with multibody dynamics program Adams.

In this chapter the major changes regarding the calculations done by the script will be discussed. At the end a list of more practical adjustments is presented.

### 3.1 Roll gradients

#### 3.1.1 Assignment

The circle test script calculates a number of roll gradients from the steady state test; front axle roll gradient, rear axle roll gradient, gyro roll gradient and if available cab roll gradient. The method for gradient calculation depends on the test track. On a flat test track the data is subjected to a linear fit. For a roof-top shaped test track like Eskilstuna the data is separated into left-hand and right-hand turns and curve fitted separately. In principle it should be possible to apply the roof-top fit to any test track. The effect of an inclined track on the roll gradient can be seen in figure 3.1.

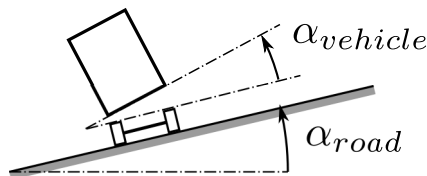


Figure 3.1: Roll gradient on inclined road

#### 3.1.2 Background information

First of all the script and method of calculating roll gradients,  $\alpha_{roll} = \frac{d\phi}{da_y}$ , is investigated. The test data contains several roll angles corresponding to different centripetal accelerations. In the existing script compensation can be switched on and off. With compensation switched off, the data will be subjected to a linear fit directly. The gradient of this fitted line is set to be the roll gradient and can be recognised as  $p_1$  in the fitted equation like below.

$$\alpha_{roll} = p_1 \cdot a_y + p_2 \quad (3.1)$$

When compensation is switched on, the data is separated in left- and right-hand turns. These datasets are fitted separately so two roll angle gradients are obtained. One corresponds to left handed turns, the other to right handed turns. The roll angles as result of the inclination of the test track are subtracted from the corresponding datasets. A single roll gradient is determined afterwards by subjecting all adapted data points to a single linear fit again.

The value  $p_2$  in equation 3.1 can be seen as the roll angle as result of an inclination of the test track. Figure 3.2 gives a representation of the fitting procedure in case compensation is turned on.

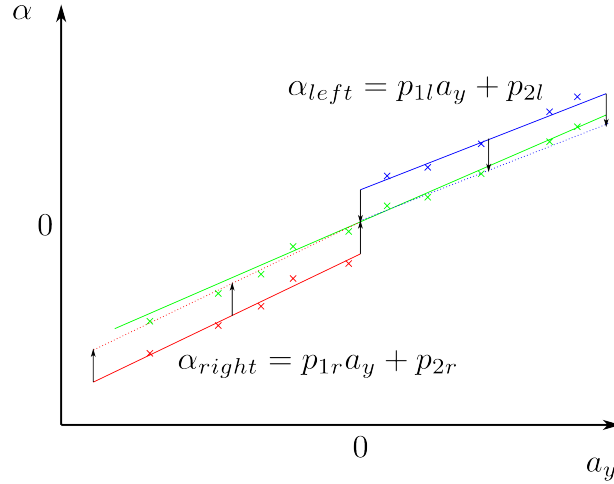


Figure 3.2: Fit procedure with compensation switched on

### 3.1.3 Procedure

Both methods are compared with data generated during multiple tests, these tests were done on several test tracks. Eskilstuna is known as a quite roof-top shaped test track, the shape of the test tracks Västerås is unknown. The MBS tests refer to simulation data generated with the use of multibody dynamic program Adams. Figure 3.3 shows different calculations for rollgradients of the gyro. Roll gradients for left and right handed turns separately are shown as well. These are expected to be equal and figure 3.3 gives no suggestion for an asymmetry. The compensated roll gradient is always somewhere in between the left and right hand values, while the non-compensated value will deviate a lot for an inclined track as can be seen for the first test.

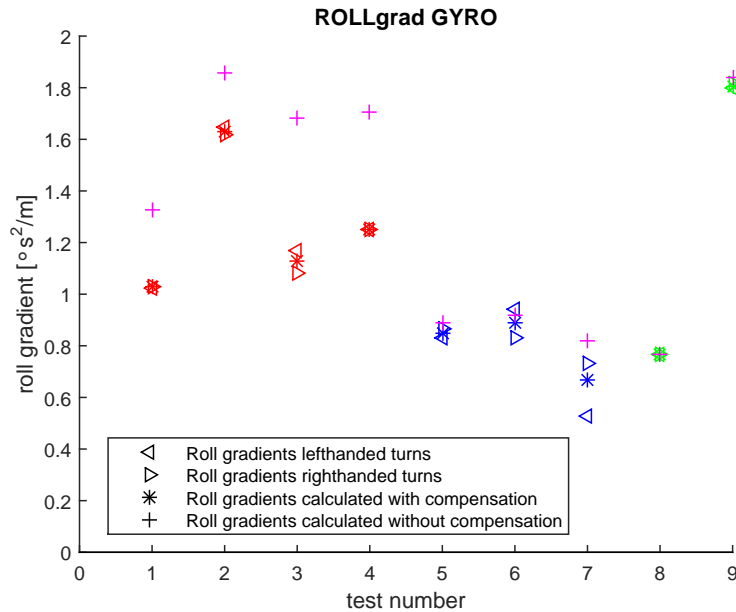


Figure 3.3: Roll gradients (Red: Eskilstuna, Blue: Västerås, Green: MBS)

Note that roll gradients should not differ for left or right handed turns. Even on inclined test tracks this should be the same for both directions, the difference will be in the roll angle itself, so the  $p_2$  values of

equation 3.1. The  $p_2$  values will differ a lot for left and right turns on a inclined track as can be seen for the first four tests in figure 3.4. However on test 7 a large difference can be recognized as well. This indicates that the Västeraås track is not flat as well, or other aspects like wind might influence the roll angle.

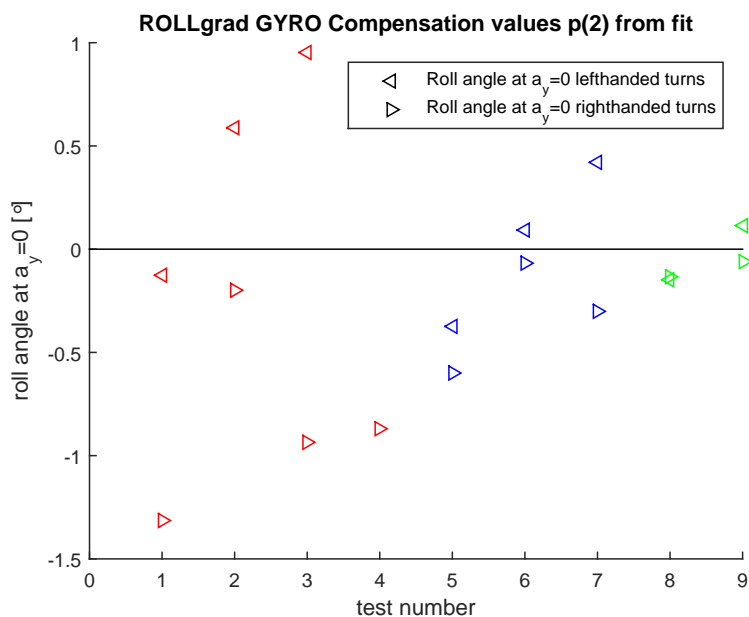


Figure 3.4: Roll angles at zero centripetal acceleration (Red: Eskilstuna, Blue: Västeraås, Green: MBS)

### 3.1.4 Conclusion

Based on the odd deviation of the values for test 7 in figure 3.4 compensation should be switched on any time. This way the uncertainty about the flatness of the test track and other external influences can be avoided.

## 3.2 Steering feel metrics from random test

### 3.2.1 Assignment

Steering feel is quantified by the weave and transition test. However, the random test is quite similar to the weave test and it is possible that some metrics can be obtained from the random test as well. VW uses a criteria that hysteresis in the steering wheel torque vs steering wheel angle plot should not become negative in a certain frequency range. The task is to investigate if there are any metrics from the weave and transition test that correlate to new metrics from the random tests. This correlation analysis can be done using data from competitor benchmark tests where the spread in metrics is large.

### 3.2.2 Background information

The random, weave and transition tests are already described in section 2. The random test is preferred above the weave test for a few reasons:

- The driver needs experience to do a proper weave test as the steering wheel is rotated manually at the right frequency. While not much experience is needed to do a random test.
- The random test could be done at the Scania test track. A wider and longer track is needed to do the weave test. This means these tests need to be performed at a runway.



- More data is already present for the random test as this test is easier to perform and therefore done more regularly.

### 3.2.3 Procedure

#### Data within frequency band

Data from the random test within a certain frequency range is inserted in the weave script directly. To gather the correct data the following procedure is used:

- The steering wheel signal is subjected to a bandpass filter which is designed to pass the part of the signal with a frequency of  $0.15Hz$  to  $0.25Hz$ . The Matlab `filtfilt` command is used, which filters the data twice, once in forward and once in reverse direction. This way the data can be filtered without phase shifting.
- The envelope of the filtered signal is calculated.
- The time intervals in which the envelope exceeds a minimum value are set to be weave-like. In figure 2.7 the blue part of the graph can be recognized as weave-like.
- The original signals at the weave-like intervals are used as input for the weave test script. So the same script is used although the number of periods in the data is smaller, the frequency can be more off and the amplitudes do not need to be in the supposed range.

The results can be seen as the circles in figure 3.5. For all metrics the results of using the random data are in line with those of the weave test. The results might not exactly match, like for the lateral acceleration hysteresis for example. However one should keep in mind that the outcome of the actual weave test can change significantly with each test run. Before this uncertainty is investigated some attempts have been made to improve the method of determining the weavetest metrics with the random data.

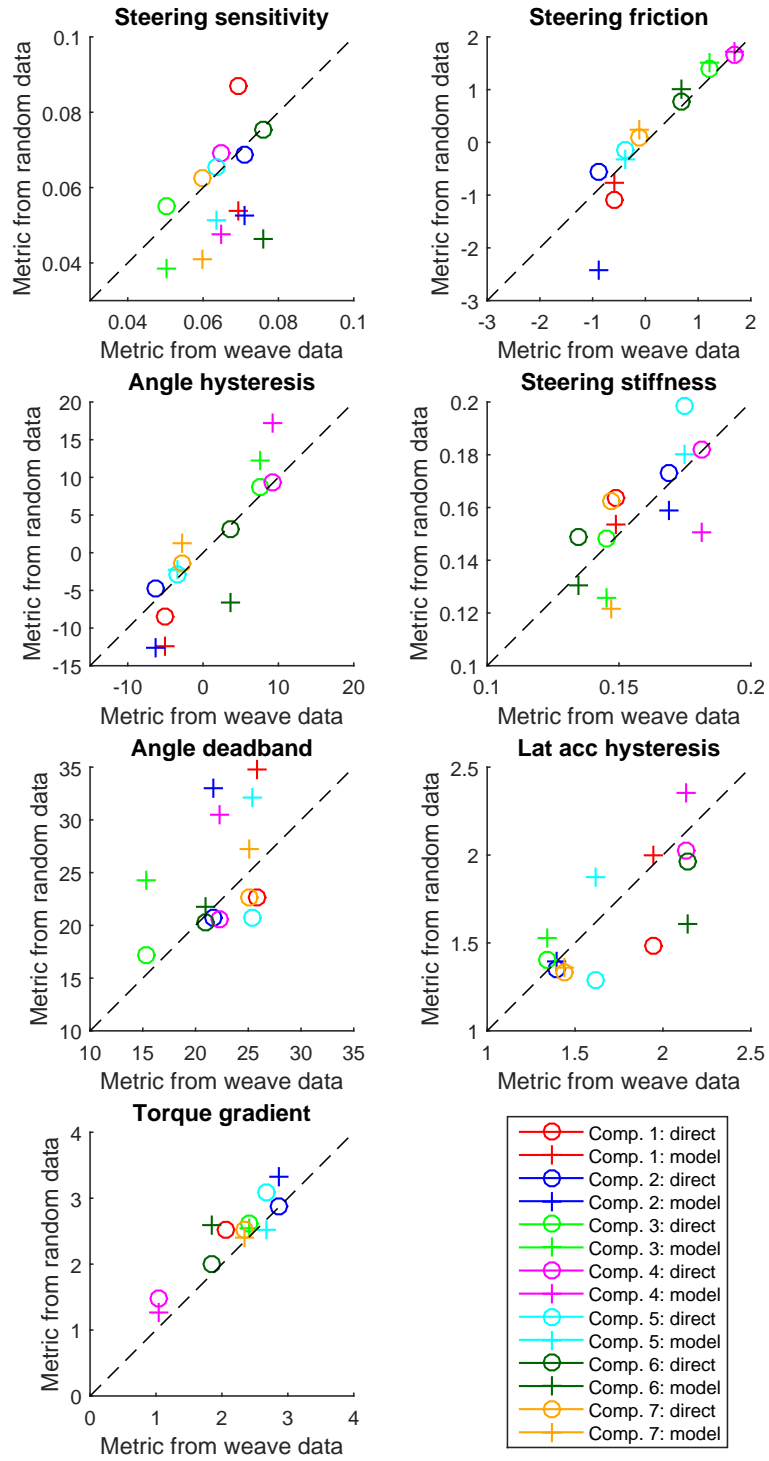


Figure 3.5: Comparison of metrics

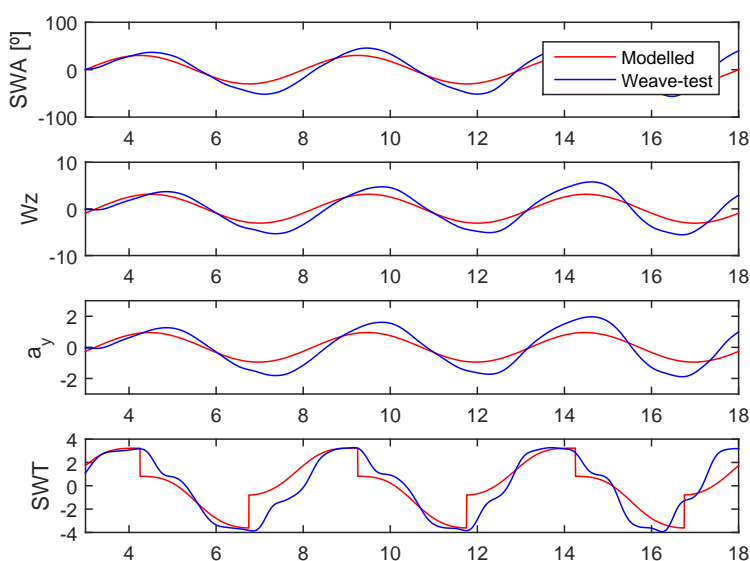
## Hysteresis area

The area of the hysteresis loops is calculated for several trucks as it was expected to be related to the width or height of the loops. Furthermore this area is in theory related to the phase shift of the transfer function, which might be easier to predict with the data form the random test.

It turned out to be hard to calculate this hysteresis area properly. Difficulties arise since each loop is a bit different, also the starting and end point of the loop are variable. The approximated hysteresis areas showed no clear correlation with the deadbands.

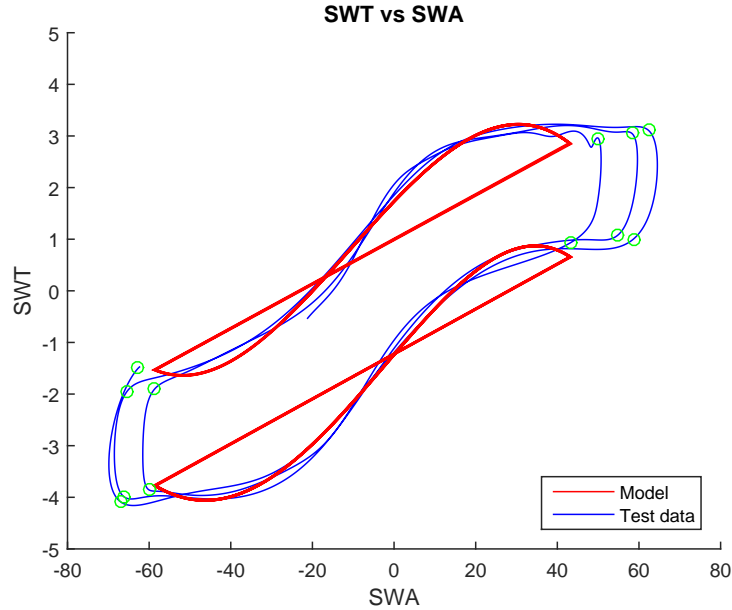
## Synthetic signal

The data of the random test is used to estimate the transfer functions for steering wheel angle to lateral acceleration and steering wheel angle to yaw rate. Hereby is assumed that these relations are linear. The relation between steering wheel angle and steering wheel torque turned out to be somewhat harder to model as it is non-linear, see the blue line in figure 3.6



**Figure 3.6:** *Synthetic signals*

The relation between steering wheel angle and steering wheel torque is not only non-linear but frequency dependent as well. The script described in the previous section is used to identify the data with a frequency of about  $0.2Hz$ . The blue curve in figure 3.7 shows the steering wheel torque versus angle for this part of the data. Functions are written for the distance between each point on the curve and the points  $(0, -4)$ ,  $(0, 0)$  and  $(0, 4)$ . The peaks of these functions represent the corners of the curve. A third order polynomial is fitted through the top part of the graph and the bottom part of the graph as well. The behaviour for maximum steering angles is not modelled as the metrics calculated from the weave test do not depend on these parts of the curves.



**Figure 3.7:** *Steering wheel torque vs angle*

A sine with a  $0.2Hz$  frequency is used as input for the model. The resulting signals for the yaw rate, lateral acceleration and steering wheel torque are shown in figure 3.6. The model seems to work well for this test data. Note that the steering wheel angle in the actual weave test is not a perfect sine, so some deviation between both lines in these graphs was expected.

These synthetic signals are used as input for the weave script. The outcome is presented by the plus signs in figure 3.5. Again the results are in line with the results from the actual weave test but the similarity was larger when the data from the random test was used directly.

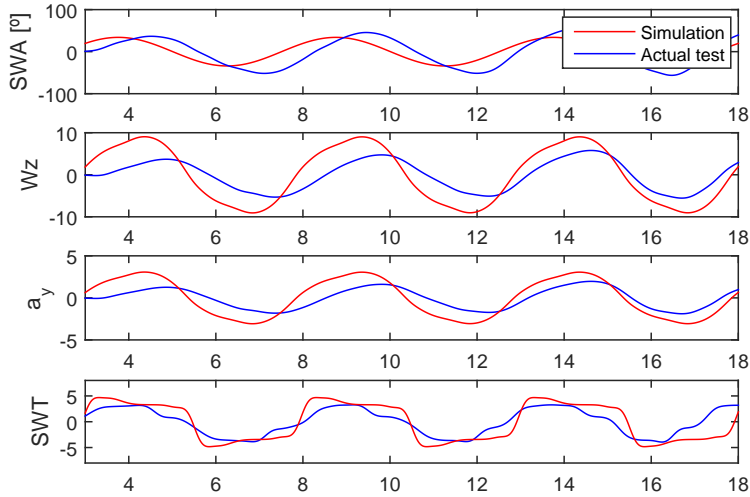
For some test data a problem occurred, the amplitude of the steering wheel angle in the random test was insufficient as it was smaller than the amplitude of the synthetic signal. The model could either be extrapolated or the amplitude of the synthetic signal could be lowered. Both options had negative effects on the results. Extrapolation of the polynomial resulted in insane relations between steering wheel angle and torque. Lowering the amplitude of the synthetic signal could cause the weave script to include the parts with maximal steering angles in the determination of metrics.

Based on these findings this method is rejected. As it turns out hard to model the behaviour properly on bases of the random data the metrics of the transition test will not be approximated with this data.

### **Multibody simulation data**

The results shown in figure 3.5 seem to be rather good. However it is hard to make conclusions because of the uncertainties in the weave test itself. These uncertainties are introduced by the fact that it is impossible to drive a perfect sine. Furthermore the metrics from the weave test could be influenced by the road and weather conditions.

Simulation data generated with the use of multibody dynamics should take away this uncertainties. The department responsible for calculation and simulation of the truck chassis provided data for a simulated weave and random test for a truck which was also tested in reality. Figure 3.8 shows the time history of the simulated and the actual weave test, as can be seen the differences are quite large.



**Figure 3.8:** *Time histories of multibody simulation and actual weave test*

The amplitude of the lateral acceleration in the simulation data is about  $3 \text{ m/s}^2$  as it is supposed to be for a weave test as mentioned in chapter 2. Clearly the actual weave test does not fulfil this criteria. The amplitude of the steering wheel angle however is almost equal, this suggests the steering wheel to wheel ratio is overestimated by the model. The shapes of the steering wheel torque curves do not match as well.

The metrics calculated with simulation data deviates a lot from the results generated with the actual test data and data of the random test as could be expected when looking at figure 3.8. Because of the inaccuracy of the model, the simulation data cannot be used to take away the doubtfulness of the metrics calculated with the actual weave test. The simulations can still be used to test the ability to reproduce the metrics calculated from weave test data with data from the random test. It turns out the simulation data of the random test is not that suitable. Normally multiple random tests are performed, resulting in data sets with fluctuating frequency contents. Data sets corresponding to a test in which the steering wheel is turned relatively slow have a larger weave-like part. This has a positive effect on the approximation of the metrics. The weave-like part in the chirp signal used in the simulation of the random test is relatively small. A different input signal could be used but note that there is no need to approximate these metrics with data from the random test for simulation models since the arguments stated in section 3.2.2 are not valid for simulations.

### 3.2.4 Conclusion

Based on figure 3.5 it is reasonable to use data from the random test as input for the weave test script. The best way is to use weave-like parts directly like described earlier. For virtual vehicles a simulation of the weave test should be done.

## 3.3 Asymmetry metrics

### 3.3.1 Assignment

Many handling properties are by design not symmetric but the standard handling script is not always considering this. The task is to investigate which metrics should be reported asymmetrically and how this should be displayed. It can be displayed by means of two absolute values or by means of an average value and an asymmetry factor. The task also includes a retroactive benchmark on data of relevant vehicles.

### 3.3.2 Background information

Asymmetries might be introduced by the steering system as this is by design not symmetric. The metrics related to the circle and weave test are investigated since this data contains a clear separation between left and right handed corners. For many of these metrics the separation in a left and right value was done easily, as these metrics consist out of an average value for the left and right side already. The separation in a left and right parameter for the understeergradient is less straightforward. The understeergradient is normally determined by fitting a third order polynomial to estimate a function like in figure 2.4. The gradient at  $a_y = 0$  is set to be the understeergradient. Fitting the left and right hand data separately would result in differently shaped functions. Therefore all data points are mirrored which means  $a_{y,mirror} = -a_y$  and  $(\delta - \delta_{ack})_{mirror} = -(\delta - \delta_{ack})$ . So the understeergradient for left handed turns is calculated from the left hand corner data and its mirrored set of data. The same procedure is used to calculate a right hand turn value.

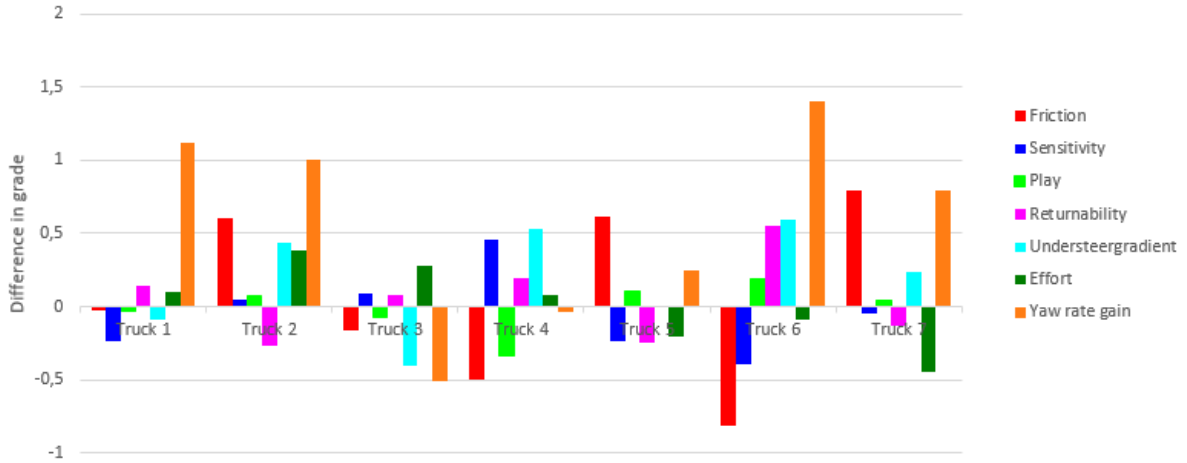


Figure 3.9: Asymmetry of metrics

All metrics show differences in left and right. The difference in left and right value is compared to the grading scale which is used to give the metric a grade between 1 and 10. This gives insight in the asymmetry of the metrics, the results can be seen in figure 3.9.

### 3.3.3 Conclusion

Based on the results in figure 3.9 there is chosen to include asymmetry for all these metrics except for play and steering sensitivity. Both these metrics are sensitive to which steering wheel angle is set to be zero. Since it is hard to determine which exact steering wheel position should be regarded as zero the outcome of these metrics would not reflect the left and right side behaviour properly.

## 3.4 Other updates

Besides the aforementioned fundamental changes some more practical additions are made to the script as well. This includes:

- The option to store all metrics in a database.
- An automated update of the file which is used to keep track of which vehicles have been tested and analyzed.
- A tool which can be used to compare new results with metrics stored in the database.
- The possibility to edit settings that used to be hard coded, like filter coefficients, steady state criteria etc.

## 4. Steering wheel return script

The steering wheel return test is a simple test in which the vehicle drives slowly while the steering wheel is released from a 360 or 540 degree angle. The metrics determined with this test are the peak steering angle velocity and the final steering angle. These metrics are the average of a bunch of measurements. A time history plot of such a measurement can be seen in figure 4.1.

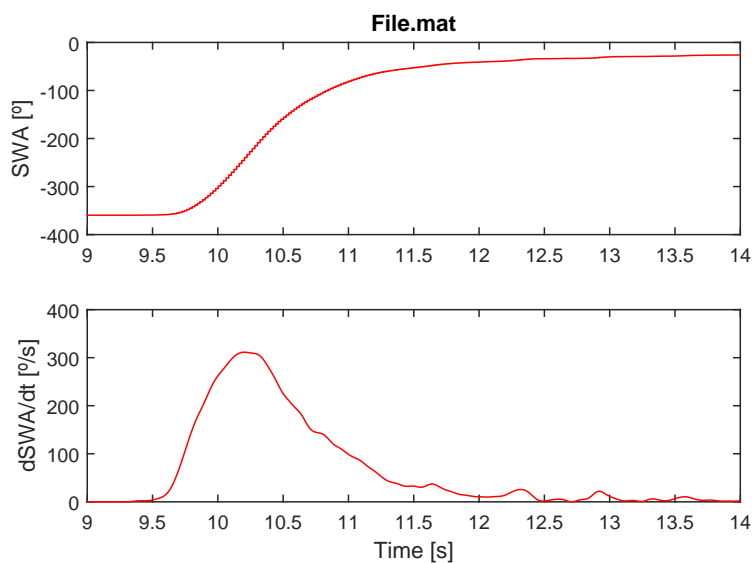


Figure 4.1: Time histories steering wheel return

### 4.1 Background information

The measurement is triggered when the steering wheel angle passes a  $-300$  or  $300$  degree angle while returning to the straight forward position. The pretrigger and posttrigger time is set to be 10 seconds. The driver makes left and right corners alternately, which causes the truck to follow a figure of 8 path while starting a new measurement in both corners. A large area is needed to perform these tests, which on the Scania test track can be quite busy. The driver needs to correct the direction on the truck regularly to stay on the track and to avoid other vehicles. As the measurements are triggered automatically, this results in a large number of faulty measurements.

### 4.2 Assignment

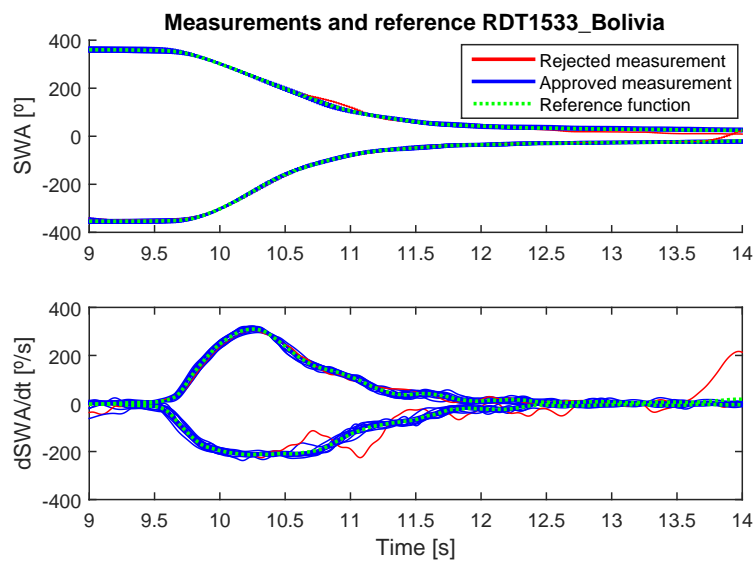
In the past a Matlab script was run twice. The first run was used to identify faulty measurements which needed to be deleted manually. The second run only uses approved measurements after which the metrics are determined. The task is to automate this procedure. Furthermore the metrics should be stored in a database and a grading system needs to be implemented.

## 4.3 New script

A new Matlab script is made which fulfils the requirements named in the previous section. The calculation section of the script is partly based on the existing scripts. The major change is the reduction of the filter order and the cutoff frequency in the lowpass filter used in the calculation of the steering wheel velocity. This is done as some data would result in aliasing.

### 4.3.1 Measurement selection

The new script determines average values for the steering wheel angle and the derivative of it at each sample point between  $t = 9s$  and  $t = 14s$  in order to create reference functions. Thereafter each measurement is compared to these reference functions. The measurement will be discarded in case the average deviation of the steering wheel angle or angular velocity is above a certain threshold. Figure 4.2 shows measurements as well as the reference function for a certain truck.



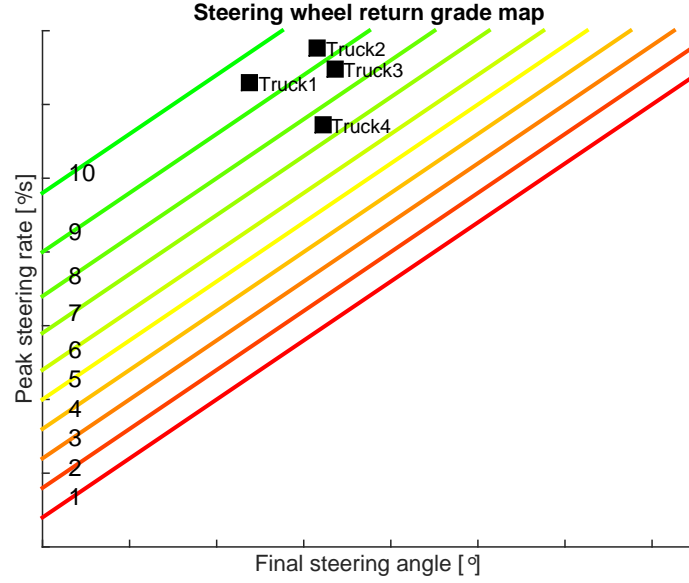
**Figure 4.2:** *Measurements and reference function*

As can be seen faulty measurements are rejected while proper measurements are approved. This script is tested on all available data of which the faulty measurements were not already deleted. The program works fine, although it can be a bit picky on which files to use. In general plenty measurements are available to calculate a proper average of the metrics.

### 4.3.2 Grading

Figure 4.3 shows the grade map created by the script. A grade is based on the peak steering wheel angle rate and the final steering wheel angle.





**Figure 4.3:** *Grade map steering wheel return*

The colored lines and corresponding grades were provided based on driver experience. A second order polynomial is fitted through the peak steering rates and corresponding grades with a final steering angle of zero. This polynomial is used to calculate the grade as a function of a reference peak steering rate,  $PSR^*$ :

$$Grade = p_1 \cdot (PSR^*)^2 + p_2 \cdot PSR^* + p_3 \quad (4.1)$$

This reference peak steering rate are determined by the actual peak steering rate and final steering angle according to:

$$PSR^* = PSR - a \cdot FSA \quad (4.2)$$

In which  $a$  represents the gradient of the lines in figure 4.3. Based on this figure, this grading system leads to a satisfactory spread in grades for different vehicles.

# 5. Steering ratio

In the new truck program the steering gear design will be partly new. Therefore some parameters for the ESP Yaw Controller need to be updated. One of these parameters is the total steering ratio from the steering wheel to front wheels. The tests needed for determination of the steering ratio were already done for a large number of trucks. The generated data needs to be processed and a report should be written which contains the new set of steering ratios.

## 5.1 Test description

The vehicle is driven on the test track at crawl velocity. After a few seconds straight driving, the steering wheel is turned at a constant rate to its maximum on one side. When the maximum is reached the wheel is turned in the other direction at the same rate until the maximum on that side is reached. After this the steering wheel is returned to the straight forward position. This is repeated several times for each truck.

The test was included in the rapid dynamic testing program. This is a test program in which new prototypes are subjected to a series of tests while they are only available for two days. The test program is set up efficiently but as the truck also needs to be rigged with the right equipment the actual time slot for testing is narrow.

Data is gathered from the internal CAN system. Relevant data for this test are the steering wheel angle, the velocity of the front wheels and the yaw rate. This data is analyzed with the use of an existing script which basics will be explained in the next section.

## 5.2 Background information

The calculation of the steering ratio is based on the bicycle model introduced in chapter 2. At each sample point the vehicle velocity,  $v_x$ , and yaw rate,  $\omega_z$ , are used to calculate the steering radius:

$$R = \frac{v_x}{\omega_z} \quad (5.1)$$

Combined with the wheel base,  $L$ , the Ackermann angle can be determined, see equation 5.2.

$$\delta_{ack} = \frac{L}{R} \quad (5.2)$$

The relation between steering wheel angle and Ackermann angle is not linear and therefore the steering ratio is dependent on the Ackermann angle. Figure 5.1 shows the typical shape of the Ackermann vs Steering wheel angle curve. The steering ratio can be recognized as the derivative of this curve. The ESP software however uses a slightly different determination of this ratio, see figure 5.1 and the equation below.

$$i = \frac{\Delta\delta_{st}}{\Delta\delta_{ack}} \quad (5.3)$$

Values of this ratio are required at:  $\delta_{ack} = [-0.6, -0.2, 0, 0.2, 0.6]$ .

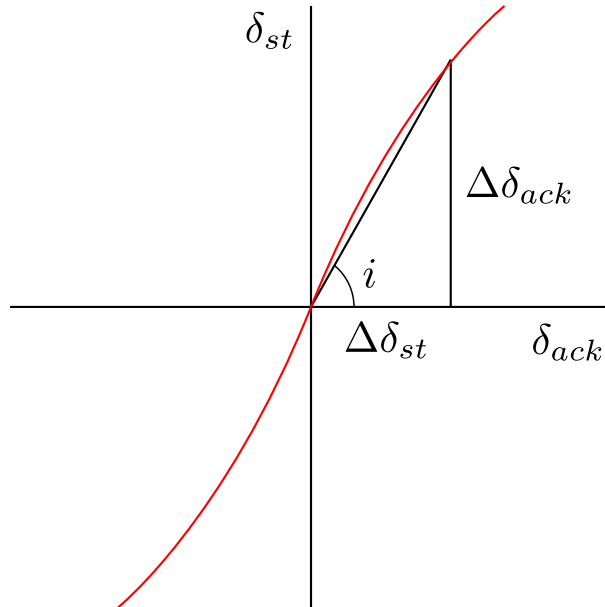


Figure 5.1: Ackerman angle versus steering wheel angle

### 5.3 Results

The existing script delivered figures like figure 5.2. Figures like this are made for all available test vehicles. These vehicles have different axle configurations, steering gears and can be left or right hand driven trucks. For vehicles with tag axles the tag axle should be lifted in case the axle is not steered.

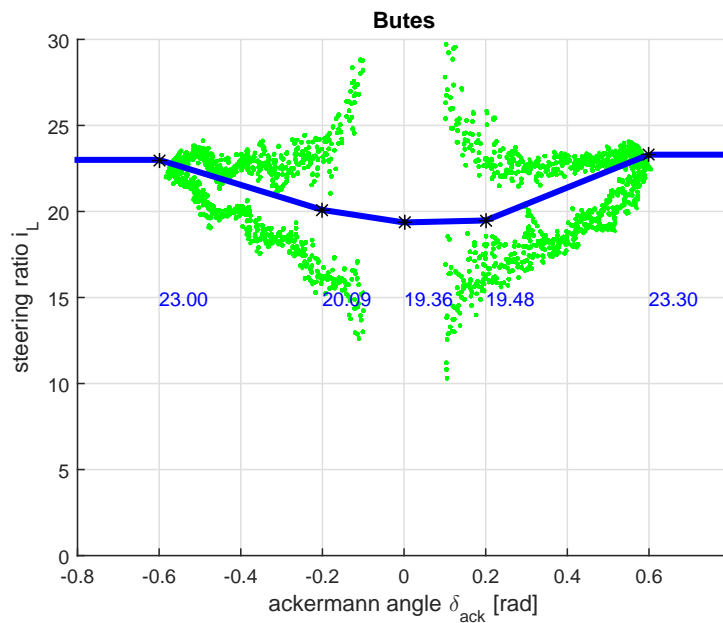


Figure 5.2: Steering ratio used for ESP

A internal report has been written in which the results are combined to a set of parameters for each steering gear. In this report also the asymmetry between left and right handed driven trucks is investigated. The influence of the dual circuit steering gear compared to the single circuit steering gear of the same manufacturer is discussed as well.

## 6. Reflection

In this chapter I will reflect on this internship and working at Scania. I will discuss things that stood out to me. This whole chapter is written from a personal point of view.

### 6.1 Company and RTCD

Every day at Scania starts with a fifteen minute morning meeting called "Daglig styrning". The agenda of this meeting will differ for each group but the general idea is to discuss accidents or problems from the previous day and the planning of the coming day. At RTCD the meetings starts with accidents and thereafter problems or "Events" from the previous day. Thereafter the progress and planning for each test is discussed. The meeting continuous with a round in which each individual states what he or she will be doing that day. The meeting ends with the workshop layout planning for that day.

Scania uses a system in which an "Event" will be written in case there is a problem with a product or a design. This system is copied from the factory. All events are registered in order to keep track of each problem. This way one could see if a problem is fixed and in addition it provides an indication of the current status of the departments and the company in general. I knew such systems were in use in the Scania factories and at other (automotive) companies, but I was a bit surprised to see these systems are being used within R&D as well.

In the company introduction was already stated that Scania always works on improving its processes. This was most apparent in the weekly Forbattringsarbete, or improvement work, meeting. In this meetings annoyances and ideas to get rid of these annoyances or improve the functionality of the team are being discussed. All ideas are labelled according to effort and benefits. Ideas which could be realized with low effort and result in high benefits are assigned as a task to someone in the group. The progress of each person on his or her tasks will be briefly discussed the next meetings until the task is finished. Clearly this meeting and associated tasks do not have the highest priority. However, I suppose it is a good way of improving the work being done by the department. And by using this regulated system all new ideas will be discussed and no good ideas will be forgotten.

The relation between company and employees was different to me than expected. I expected the working conditions in Sweden and the Netherlands to be comparable. But I was surprised by the excellent treatment of Scantias employees considering (flexible) working hours, breaks and career opportunities. However it might sound obvious I would say the safety and well-being of employees is really important at Scania.

### 6.2 Communication

The difference between working within a project group of eight people within my bachelor and at Scantias R&D department consisting of 3500 employees is, off course, huge. The implications were not known to me at forehand. I was amazed by the effort needed to plan all tests and the number of times this planning needed to be revised. Also the difficulty of distributing information and knowledge to each other was striking to me.

For my assignment I did not need to collaborate with other people that much. This was mostly limited to meetings with the simulation group that were about to use the handling script as well and informal chats with my supervisor about my progress. At these moments the communication was good according to me.

In my experience there were more difficulties in understanding conversations that were not related to my assignments. At first I was not acquainted with all terminology and abbreviations used around me. Later on these conversations were more often in Swedish. Hereby I need to mention that I did not ask to speak English again that often as many conversations were not related to me at all and I started to globally understand what these conversations were about.

### **6.3 What I learned**

I certainly improved my Matlab programming skills. I became more familiar with the dealing of large amounts of data. Also the usage of scripts with this size and this amount of functionalities was new to me. The importance of properly commenting and providing proper documentation to such a program became more clear to me.

During this internship and my time in Sweden I did not only improve my English speaking and writing skills. I also got to know the importance of speaking and writing English in a multinational team or company in general.

In this internship I learned a lot about vehicle dynamics. Although I had the required theoretical knowledge from the courses Dynamics I, Dynamics II, Advanced Dynamics and my work as teaching assistant for these courses, seeing the application of this knowledge was new to me.

In my studies performing experiments and analysis of test data did not get that much attention. At RTCD I learned about these topics and got more interested in this field as well.

There had only been very little practical experience in my studies so far. All in all I would say I learned most of just being part in this team and working in a large company.

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