Instructions for Assignment 2 (25 points)
Lateral Dynamics

Introduction

Engineering task: ***You shall propose roll stiffness distribution and brake force distribution*** *for a passenger vehicle. The vehicle is studied under 3 load cases, which differ in longitudinal position of centre of gravity.*

This assignment introduces some fundamental parameters used in analysing vehicle cornering performance. The assignment consists of five tasks:

- Task 1: You should set up and use a steady state model for some steady state diagrams.
- Task 2: You should verify steady state model by means of a simple (time domain) simulation model and generate the first diagrams of transients.
- Task 3: Improve simulation model with lateral load transfer and propose roll stiffness distribution.
- Task 4: Improve simulation model with combined slip tyre models and propose brake force distribution.
- Task 5: Driving experience of variation of design parameters and of models in the simulator. Brief analysis of logged data.

Note that you should have a **clear proposal for the engineering task** in your report, i.e. a quantitative proposal of roll stiffness distribution and brake force distribution.

General vehicle data:

- 4-wheel passenger vehicle
- Mass = 1675 kg
- Wheelbase = 2.675 m
- Steering ratio = 15.9
- Cornering stiffness **(for one wheel and not for one axle)**: $C = c_0 F_z + c_1 F_z^2$, where $c_0 = 30.7 \frac{1}{rad}$, $c_1 = -0.00235 \frac{1}{N \cdot rad}$ and F_z is normal force (**for one wheel**).

Useful commands/tips:

- In Matlab, after a simulation if you need to store data so that you can compare it with the results of another simulation, you can use the 'save' command. The command is used as follows: 'save <filename> <variable 1> <variable 2> <variable 3>…'
- In some cases, it might be of help to write a short Matlab script that loops through the simulation for different cases. The simulation can be started from a Matlab script using the 'sim(<path to model>)' command. Also, in your Simulink model, modify 'File ->Model Properties->Model Properties-> Callbacks->InitFcn' by removing the command 'run ./InitModel.m;', and instead, adding 'InitModel;'

in your script, before ‘`sim(<path to model>)`’. Then you will be able to change the necessary parameters in the loop.

Task 1: Steady State Cornering Characteristics (5 points)

In this task, use the following load cases:

- Load case 1: $l_f = 0.37*L$
- Load case 2: $l_f = 0.63*L$
- Load case 3: $l_f = 0.47*L$

Task 1.1: Steady state cornering equations (2 points)

Derive the steady state cornering equations for a single-track vehicle model at high speeds. Assume small steering and slip angles and linear tyres.

Task 1.2: Understeer gradient (0.5 point)

For all load cases above, determine the understeer gradient in rad/(m/s^2) units and express its relation to the vehicle body mass distribution between front and rear axles.

Task 1.3: Critical/Characteristic speed (0.5 point)

For all load cases above, determine the critical and characteristic speeds

Task 1.4: Steering wheel angle for one certain operating point (1 point)

For all load cases above, determine the steering wheel angle required to get 4 m/s^2 of lateral acceleration at 100 km/h.

Task 1.5 Steering wheel angle for varying operating point (1 point)

Plot the steering wheel angle required vs speed curves for the three cases for a curve radius of 200 m. Which of the load cases is understeer, oversteer and (relatively) neutral steer?

Task 2: Simulation with single track model (without load transfer and without combined tyre slip) (5 points)

In this task, you will complete a transient single-track model in Simulink and run simulation. A skeleton model is provided.

Task 2.1: Implement model (2 points)

Write the lateral slip equations and equations of motion (dynamic equilibrium equation) in the x-y plane for the single-track vehicle model at high speed (3 degrees of freedom; Translation – X, Y and Rotation – Z). Ignore aerodynamic drag and rolling resistance. Do not assume small steering angles or small slip angles. Fill in these equations in the space provided in the Simulink file. The slip equations should be added in the 'Lateral slip'-block, the cornering axle stiffness equations should be added in the 'LatForce'-block inside the 'Tyre model'-block and the equations of motion should be added in the 'Chassis'-block. Double click the blocks to open the code editor for writing the equations. In all further simulations, unless otherwise specified, use an initial speed of 100 km/h.

The Simulink file also runs the 'InitModel.m' and the 'DrawPath.m' scripts at the beginning and the end of the simulation respectively. If you want to change this behaviour of the Simulink file, you can do so by changing the 'InitFcn' and 'StopFcn' callbacks under File>Model properties>Callbacks. The 'InitModel.m' script sets the vehicle parameters which will be used during the simulation. The 'DrawPath.m' script is used for drawing the path of the vehicle. Additional plots, if required, can be added in this file.

Task 2.2: Verify model for moderate a_y (1 point)

Run the simulation for the 3 load cases specified with the steering angles determined in Task 1.4. Verify that the vehicle reaches 4 m/s^2 of lateral acceleration in each case.

(Simulink should be installed on student computers. The model requires that Simulink is setup with a C-compiler. A C-compiler should be installed on student computers, but might need to be setup to Simulink. Write "mex –setup" at Matlab prompt to setup.)

Task 2.3: Transient response (1 point)

Observe the transients from Task 2.2. Which vehicle setup is the quickest to respond to steering input?

Task 2.4: Try model at over-critical speed (1 point)

Run a simulation with the oversteer load case with an initial speed above the critical speed, typically 200 km/h, and a steering wheel angle of 3 degrees. Set the simulation time to 10 seconds. Do the results match with what you would expect from Task 1? Then extend the simulation time to 30 seconds. What is the difference of the results.

Task 3: Load transfer (5 points)

In this task, you will modify the single-track model to include load transfer, i.e. redistribution of vertical tyre forces. Since lateral load transfer requires that both wheels of an axle be considered, you will modify the model to make an enhanced single-track model. The load transfer will be calculated for each wheel individually, which in turn will be used to determine the individual tyre stiffness. This will then be combined to form the axle stiffness. You will do some simulations to check the steering response to tune the roll stiffness distribution.

Set the simulation time back to 10 seconds and set the initial speed back to 100 km/h.

Task 3.1: Add load transfer to model (2 points)

Write the load transfer equations (longitudinal and lateral) for a two-track vehicle. For longitudinal load transfer, assume that the vehicle travels on a flat road with no aerodynamic drag. For lateral load transfer assume a non-rigid suspension with different roll stiffness front and rear. Assume steady state in both the cases. The equations for load transfer need to be added in the 'Load transfer'-block. Consider roll stiffness distribution in the equations. Verify that the model runs and behaves reasonable.

Task 3.2: Influence from load transfer on steering response (1 points)

Keeping the default roll stiffness distribution of 0.65 (65% roll stiffness front), simulate the 3 load cases with their respective steering angles as in Task 2.2. Do they still achieve the same lateral acceleration level? Express the change in peak lateral acceleration in percentage. Can the linear 2-DOF single track model (from task 2) be used to analyse the handling characteristics of a vehicle in its linear range?

Task 3.3: Influence from roll stiffness distribution on steering response (1 points)

To see the effect of roll stiffness distribution, simulate load case 3 with a steering wheel angle of 30 degrees and a roll stiffness distribution of 0.45 and compare the trajectory and yaw rate with the default case of 0.65 roll stiffness distribution. What difference do you see and why does it happen?

Task 3.4: Propose roll stiffness distribution (1points)

Tune the roll stiffness distribution so that the vehicle with load case 3 is neutral steered for a steering wheel angle of 10 degrees at 100 km/h. Show the results. Would you recommend that the roll stiffness distribution you obtained from the tuning should be used in a production car if it has the same load case? Why (or) why not?

Task 4: Combined tyre slip (5 points)

In this task, you will implement a simplified combined slip model. Keep in mind that since this is very simplified, it may not be representative of a real situation (especially in the non-linear region of the tyres), but it is sufficient to illustrate the effect of combined slip and to perform a qualitative analysis. You will do some simulations to check the response of braking in a curve to tune the brake force distribution.

Task 4.1: Add combined slip to model (2 point)

Implement following simple combined slip tyre model. The axle lateral stiffness is corrected so that it decreases with how much longitudinal tyre force, F_x, that is used:

$$C_{corr} = \left(\frac{\sqrt{(\mu F_z)^2 - F_x^2}}{\mu F_z}\right) \cdot C;$$

The correction is inspired by the mathematical representation of the friction limit circle. The equation must be added in the 'LatForce'-block inside the 'Tyre model'-block. Add a brake demand of 4000 N and keep the default brake distribution ratio of 0.5. Simulate the same case as in task 3.4 (steering wheel angle and roll stiffness distribution). Is the vehicle still neutral steer? If not, why?

Task 4.2: Influence of brake force distribution (1 point)

To see the effect of brake distribution, simulate the same case as task 4.1 but with a brake distribution ratio of 0.2 (i.e., 20% of the braking is done on the front axle). What difference do you see and why does it happen?

Task 4.3: Propose brake force distribution (2 point)

Tune the brake force distribution so that the vehicle is neutral steered while braking. Does the determined brake force distribution make the vehicle neutral steer under braking irrespective of the brake demand? What kind of brake distribution would you suggest to ensure that it is optimal for all brake demands?

Task 5: Driving experience in simulator (5 points)

Purpose of Task 5:

- Driving experience of design changes in motion platform driving simulator.
- Understand how a *simulation model* (the model you have from Task 4) is integrated in a *simulator-model* (the model that executes in real time in a driving simulator, i.e. has I/O blocks).
- Briefly *analyse logged data* from driving.

General information:

- Book your slots at the Caster website: http://www.casterchalmers.se/education/vehicle-dynamics/ Two bookings are needed for your group, one for model validation and one for your driving session.
- All groups have been assigned to a folder on Chalmers box. A link to your group folder is sent to your Chalmers mail. An instruction on how to find and use your box account for the first time is available at: https://it.portal.chalmers.se/itportal/StuDATWindows/BoxCom

Task 5.1: Participate in model validation session

Simulation handout model is similar to the simulator model. The structure within the Matlab function is kept the same for easy integration. The overall purpose of model validation is to integrate your 'simulation model' into the 'simulator model' and, if needed, make some changes so you and your model is ready for driving sessions.

- Before you attend model validation, make sure the group has stored their simulation model, developed at least to Task 4.1 level, in the group folder on Box. Then run the following 3 cases as a part of model verification.

Parameter	**Case 1**	**Case 2**	**Case 3**
Steering Wheel Angle [deg]	10	0	3
Brake Force [N]	0	2000	1000
Brake Distribution Ratio [-]	0.5	0.5	0.5
Roll Stiffness Distribution [-]	0.65	0.65	0.65
Speed [kph]	80	80	80
l_f/L [-]	0.47	0.47	0.47

  Please list the maximum and minimum values for longitudinal acceleration, lateral acceleration, yaw rate and yaw acceleration (in each case). These will be checked before the driving simulator test for each group separately.

- Replace the '**Green'**-coloured blocks in the Caster simulator model with those from your handout model. Specifically, these blocks are – **Lateral Slip Equations, LatForce-block within Tyre Model (not**

the complete Tyre Model block), Chassis and Load Transfer. It is sufficient to copy and paste the code from inside your blocks to the blocks with the same name in the Caster model. Remember to also upload this version of your model on your box folder before model validation.

- During the session, the group should integrate their model into the simulator model so that it becomes driveable in the simulator without producing any fatal errors.
- **Wait until the instructor from CASTER clearly approves you before you leave**

Task 5.2: Participate in simulator drive session

Approval of Task 5.1 is mandatory before Task 5.2.

- Introduction of session and simulator
- Steady state Skid-pad
  - Do at least one constant radius test, i.e. slowly increase speed but keep on a constant radius.
  - 80/20 Weight distribution
  - 20/80 Weight distribution
  - Discussion
  - Instructor will store log-data from above tests on your personal folder at CASTER disk
- Over-speeding into curve
  - 57/43 Brake bias
  - 80/20 Brake bias
  - 20/80 Brake bias
  - Discussion
- Model comparison with Caster Vehicle Model
  - Try the Caster Vehicle Model (Porsche Cayman) on test track and Autodromo
  - Discussion
- **Wait until the instructor from CASTER clearly approves you before you leave**

Points are given individually through mandatory participation, so it is not enough for group members that group is present. It is not mandatory, but strongly encouraged, to drive. It is fun and gives some driving experience of “on-limit driving”.

Task 5.3: Documentation in assignment report

This task asks for some documentation in the project report. Add the following:

- List some additional aspects or features related to the simulator, visualization, real-time application, etc., need to be considered when integrating a *simulation model* into a *simulator-model*.
- Use the log data from steady state constant radius test above: plot lateral acceleration as function of steering wheel angle in your Assignment 2 report. So, it will be 3 curves, one for each weight distribution, in the diagram. Comment on similarities with a handling diagram. Selecting only important part of log data could be beneficial instead of the entire big log data. Try to guess the handling diagram (see 4.3.8 in compendium) [1] and comment on your findings.
- Add a plot for the trajectories of the vehicle (XY-plot).

Reference:

[1] CHRISTOPHER B. WINKLER (1998) Simplified Analysis of the Steady-State Turning of Complex Vehicles, Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, 29:3, 141-180, DOI: 10.1080/00423119808969371.