Modalities

It is requested to solve the following exercises, which are related to the lecture of vehicle dynamics in steady state cornering.

The exercises will be solved **individually** (no group).

Reports have to be in **pdf format** and should be entitled **Name_Firstname_HW2.pdf**. Reports can be written using word processor (e.g. Word, Latex…) or they can be manuscript, provided they are clearly written, and they are easy to read, and then scanned in pdf (photos using mobile phones are not accepted). They have to be posted by emails to Pierre Duysinx (p.duysinx@uliege.be) and to Simon Bauduin (S.Bauduin@uliege.be) by **May 1st 2020** at 12:00.

Questions and discussions should be preferably formulated using Discussion Forum on e-Campus to share the information with your classmates.

**Question n°1**

We consider the vehicle investigated in Ref ¹ whose total weight is 1702 kg. The centre of gravity is located at $b=1170.8$ mm behind the front axle and $c=1397.2$ mm in front the rear axle. The inertia moment about vertical axis is measured as $J_z=3377.33$ kg/m².

The cornering stiffnesses of the front and rear tires are given by:

- Front: $C_{af} = 1608.5$ N/deg
- Rear: $C_{ar} = 1391.4$ N/deg

For a turn with a radius $R=200$ m and a vehicle speed of 100km/h, we ask to calculate:

1. The Ackerman angle (deg)
2. The cornering stiffness of the front and rear axles (N/deg)
3. The slip angle under front and rear axles (deg)
4. The drift angle at the centre of gravity (deg)
5. The actual steering angle at front wheels (deg)
6. The vehicle understeer gradient (deg/g)

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7. Depending on the case, the characteristic speed or the critical speed (m/s and km/h)
8. The vehicle static margin (in cm and in %)

It is also requested to plot a figure showing the evolution of:
9. The gain in lateral acceleration (g/deg) per degree of steer angle
10. The yaw velocity gain under the same conditions (/sec)
For a speed varying from 0 to 500 km/h² per step of 25 km/h.

Question n°2

Let’s consider a new Shell eco marathon prototype (see Fig. 1) equipped with torque vectoring control system able to control independently the e-motor torques applied at the two front wheels (See Fig. 2). Applying different tractive/ braking forces enables to take a turn while keeping steering wheels in straight position. The new facility is available in addition to the classic steering mechanics of the vehicle.

The wheelbase L of the vehicle is 1,58 m and the distance between the rear axle and the center of mass of the vehicle with its driver is estimated as c = 0,88 m. The front track is measured as t=0,50 m. The effective rolling radius of the wheels is Re=0,24 m.

The total mass of the vehicle including the driver is estimated by m=100 kg.

The cornering stiffness of the race tires is given by $C_\alpha = 20 000$ N / rad.

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2 It is a virtual computation since the top speed of the car is much below 500 km/h!
It is asked:

1. To develop an augmented theory of the steady state cornering of the vehicle equipped with steering system and electronic torque vectoring system:
   a. Draw the sketch of the equivalent bicycle / single track model of the vehicle with all its features and define the appropriate parameters
   b. Write the equilibrium equations of the vehicle
   c. Write the behavior equations of the tires and axles
   d. Give the expression of the slip angles under the wheels in terms of the geometrical parameters and of the velocity components
   e. Give the expression of the applied torque (and the related tractive forces) to be developed as a function of the turn radius and of the vehicle velocity
   f. Define the equation of the understeer gradient for this new kind of vehicle.

2. For the following numerical data and a speed $V=10 \text{ m/s}$ and turn radius of $R=50 \text{ m}$, calculate the numerical value of
   a. The understeer gradient,
   b. The steering angle to take the turn if it is applied alone,
   c. The torque to be applied to take the turn using torque vectoring alone,
   d. The sideslip angles under the wheels and the float angle at the center of mass of the vehicle for the steering input,
   e. The sideslip angles under the wheels and the float angle at the center of mass of the vehicle for the torque input,
   f. The yaw and acceleration gain for the torque vectoring alone,
   g. The yaw and acceleration for the steering input alone.

3. Since the friction coefficient between the tire and the road is bounded by $\mu=0.8$ and the tractive torque is developed by a small e-motor, comment and discuss the feasibility of using a steering system based solely on the torque vectoring compared to a pure steering mechanism. Discuss additional features to improve the situation.