Exam Vehicle Dynamics - 4L150

14-11-2007, 9:00-12:00

Name:
Student number:

General remarks

- exam questions must be returned!
    - Write your name and student number on the exam questions
    - Without the returned exam questions your exam is not valid!
- answers may also be given in Dutch
- the answers to the multiple choice questions should be written on the exam paper
- a calculator is allowed
- no laptop, no PDA, no mobile phone, no (lecture) notes, no books, etc. are allowed
- please note that the exam consists of 4 parts

Final note
Remember to also return the exam questions with your name and student number on it!

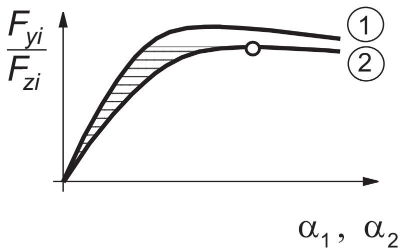
Success!
Igo Besselink

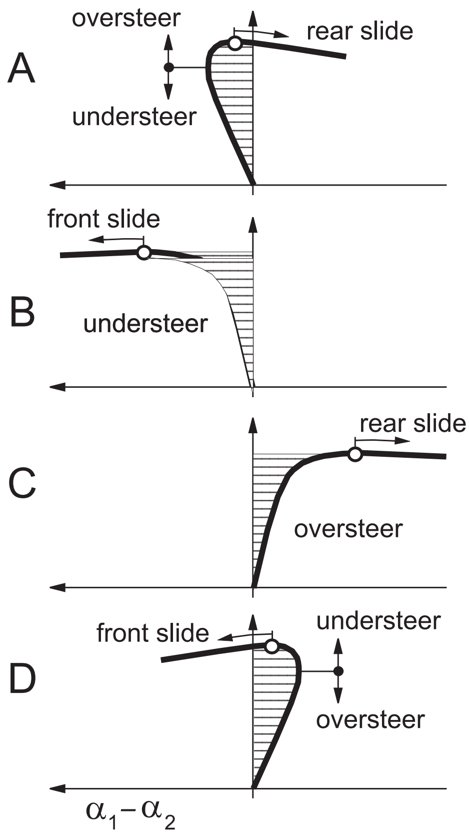
1. Multiple-choice questions

1) A VW Beetle owner is complaining that his car has too much oversteer. The Beetle has a rear mounted engine and the boot (“de kofferruimte”) is located at the front of the car. Which of the following solutions will certainly <u>not</u> work to solve the oversteer problem?

a) use a stiffer anti-roll bar at the rear
b) use wider tyres on the rear
c) put some bricks in the boot
d) add a spoiler on the rear of the car

2) Below, the normalised tyre/axle characteristics (F_{yi}/F_{zi}) of a vehicle are shown. The index i indicates the front or rear axle, 1 or 2 respectively.
Which is the corresponding handling diagram for this vehicle?

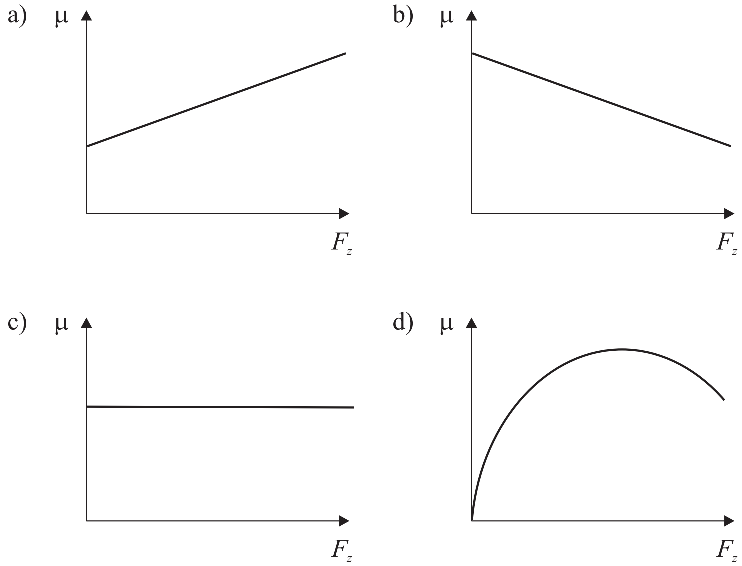




3) Which statement is <u>not</u> true?
The Magic Formula…

a) is used worldwide in the vehicle industry to analyse vehicle handling
b) was invented in the Netherlands by Egbert Bakker and prof. Pacejka
c) parameters are determined using an iterative optimisation process
d) is a computationally "slow" tyre model due to the large number of equations

4) In which figure is the relation between measured vertical tyre load F_z and peak friction coefficient μ of the tyre correctly depicted?



5) In vehicle models the tyre relaxation length is included to get a better correspondence with measurement results. This is because:

a) the driver cannot steer infinitely fast
b) it takes some time to develop a side force
c) the tyre needs to roll some distance to develop a side force
d) a mathematical trick is needed to get the phase shift right

6) Statement: an ESP system will correct excessive understeer by applying a brake force at:

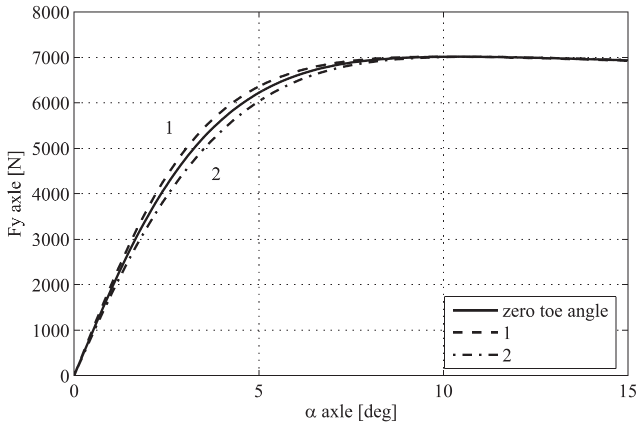
a) the outer rear wheel
b) the inner rear wheel
c) the outer front wheel
d) the inner front wheel

7) The linear single track vehicle model is valid up to about 4 m/s^2. Which of the following model extensions will be most effective in order to increasing the validity range?

a) extension to four wheels (two track model, body roll, linear tyre characteristics)
b) including nonlinear effective axle characteristics
c) including tyre relaxation length
d) including steering compliance

8) Which statement is <u>not</u> true? **(not a valid question for generation 2012/2013)**
   a) the anti-dive percentage is dependent on the fore/aft brake force distribution
   b) too much anti-dive leads to an uncomfortable vehicle on an uneven road
   c) anti-dive results in a much shorter stopping distance
   d) anti-dive helps to reduce the pitch motion of the vehicle during braking

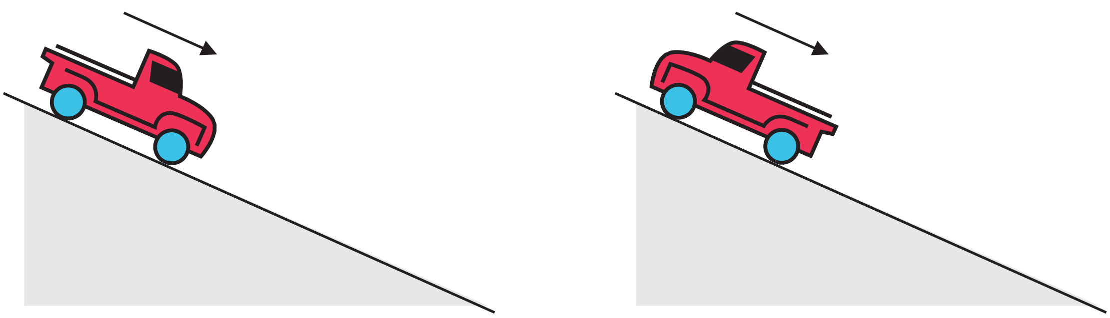
9) The figure below shows the effective axle characteristic of a vehicle. If or how does this characteristic change if both wheels of the axle have toe out?



   a) line does not change
   b) line 1 is correct
   c) line 2 is correct
   d) the correct answer is not shown

10) Some experiments are done with a toy car, the wheels on the rear axle of the vehicle are blocked with an elastic band. In the first experiment the car rolls of a slope with the nose downwards. In the second experiment the car rolls of the slope backwards.

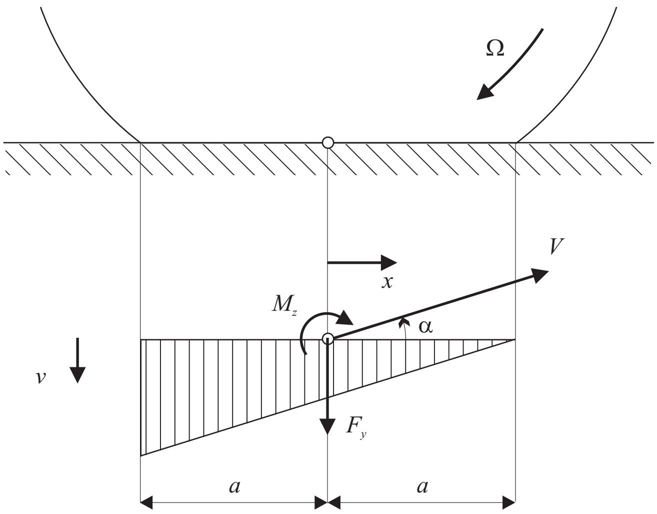
rear wheels are blocked rear wheels are blocked



Will the car rotate 180 degrees around the vertical axis or not?
a) experiment 1: yes experiment 2: no
b) experiment 1: no experiment 2: no
c) experiment 1: no experiment 2: yes
d) experiment 1: yes experiment 2: yes

2. Brush tyre model

In the figure below a side view and top view of the brush model are given. In this case we may assume that the side slip angle is small and that we have adhesion of the bristles over the entire contact area. The wheel is rolling freely (no braking or driving).



In the figure we see the following symbols:

V	forward velocity
α	side slip angle
x	longitudinal coordinate along the plane of symmetry of the tyre
a	half of the tyre contact length
v	lateral bristle deflection
F_y	lateral force
M_z	self-aligning moment
Ω	rotational velocity

The lateral stiffness of the bristles per unit of length equals c_{py}. The force per unit of length equals q_y and we get $q_y(x) = c_{py}v(x)$.

a) Derive an analytical expression for the lateral bristle deflection v as a function of the longitudinal coordinate x. (So $v(x)$=….). Check the function; for $x=a$, $v(a)$ should be zero. For $x=-a$ the lateral bristle deflection v reaches its maximum.

b) Calculate the lateral force F_y using the result of a) and by solving $F_y = \int_{-a}^{a} q_y(x)dx$.

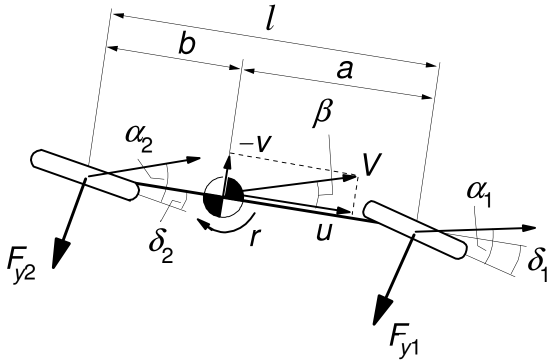
c) Calculate the self-aligning moment M_z using the result of a) and by solving $M_z = \int_{-a}^{a} q_y(x)xdx$.

d) Give an analytical expression for the magnitude of the cornering stiffness $C_{f\alpha}$ and self-aligning stiffness $C_{m\alpha}$ of the brush model.

e) Determine an expression for the magnitude of the pneumatic trail t.

3. Rear wheel steering

In this exercise we analyse the cornering behaviour of a vehicle equipped with rear wheel steering. This is done using a single track vehicle model, see figure below.



In this exercise tyre behaviour may assumed to be linear and relaxation effects are neglected.

a) Derive/give the equations of motion for the bicycle model in the lateral and yaw direction. Note: it is sufficient to use the lateral forces F_{yi}. Expressions for the tyre behaviour or side slip angles do not have to be provided here.

b) Give the expressions for the side slip angles α_1, α_2 and β as a function of motion of the centre of gravity (velocities u, v, r) and steering angles δ_1 and δ_2. You may assume small angles: $\tan(x) = x$

c) We will now consider steady-state cornering with a constant forward velocity V and fixed corner radius R. Simplify the equations obtained under a) and b).
   Assume: $u \approx V$, $F_{y1} = C_1\alpha_1$, $F_{y2} = C_2\alpha_2$ and $\dfrac{r}{u} = \dfrac{1}{R}$.

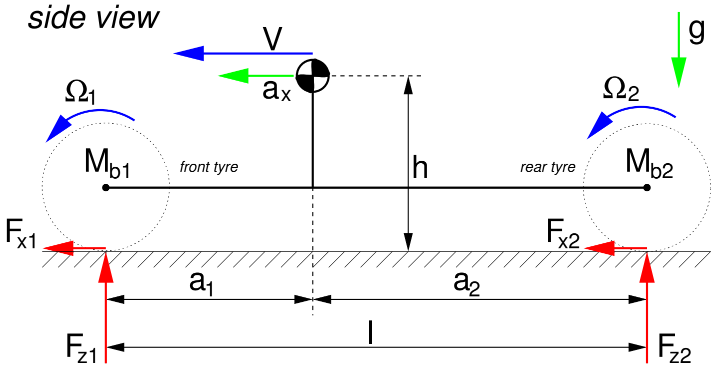
The following control law will be used: $\delta_2 = K \cdot \delta_1$, so the rear wheel steering angle is proportional to the steering angle applied to the front wheel. The gain K will be a function of the forward velocity V. Aim of the controller is to make the vehicle side slip angle β equal to zero under steady-state driving conditions. For convenience we may assume that $C_1 = C_2$ and $b=a$.

d) Make two (big!) sketches of the bicycle model to show that to make β equal to zero:
   - at zero and low forward velocity the rear wheels have to steer in opposite direction compared to the front wheels.
   - at high forward velocity the rear wheels should steer in the same direction as the front wheels.

   The sketches should include the tyre side slip angles, lateral tyre forces F_y, vehicle side slip angle and front/rear steering angle.

e) Determine an expression for the gain K as a function of forward velocity, using the results obtained under c) and the assumption that $C_1 = C_2$ and $b=a$.

4. Straight line braking



A 2-dimensional model as shown in the picture will be used to analyse the problem. Shown are the longitudinal acceleration a_x and forces acting on the tyres (F_x and F_z) according to the ISO sign conventions. Obviously during braking the longitudinal acceleration a_x and longitudinal tyre force F_x will be negative. In the revolute joint between the wheel and chassis a braking moment M_b is applied (M_{b1} and M_{b2} for the front and rear tyre respectively). The vehicle mass equals m, the moment of inertia of the wheels may be ignored and the radius R of the front and rear tyre is the same.

a) Derive analytical expressions for the vertical force on the front and rear tyre (F_{z1} and F_{z2}) as a function of the acceleration a_x. Check the result: during braking a_x will be negative and the vertical force on the front tyre will increase and the vertical force on the rear tyre will decrease with respect to the static situation.

b) The longitudinal force F_x of the tyre is a nonlinear function of the slip ratio κ and vertical load F_z. Make a sketch of the longitudinal force characteristic for three different vertical forces and a slip ratio ranging from wheel lock ($\kappa = -1$) to free rolling ($\kappa = 0$). Mark the different curves with: “low F_z”, “medium F_z” and “high F_z”.

c) Ideally both the front and rear tyres operate close to the peak in the longitudinal slip characteristic. Assume that the peak friction coefficient between tyre and road equals $\mu_{x,peak}$ and may be considered constant. What is the relation between $\mu_{x,peak}$ and acceleration a_x of the vehicle during braking?

d) Using the peak friction coefficient $\mu_{x,peak}$ for both front and rear tyres, derive an analytical expression for the optimal brake moment distribution p.

$$p = \frac{M_{b1}}{M_{b1} + M_{b2}}$$

(for example $p = 0.7$ would indicate that 70 % of the total brake moment is applied to the front brakes and 30 % to the rear brakes) Hint: use the results of a) and c).

e) Suppose that the brake moment distribution p has been determined on a dry road surface and stays fixed, what happens on a slippery road surface (low μ)? What about the brake moment to be applied? Will the front or rear wheels lock-up first? Is it possible to obtain the maximum deceleration as derived under c)? Give a short explanation.