Assignment 3 – Crashworthiness
INSTRUCTIONS

Course	TME 121 – Engineering of Automotive Systems Chalmers University of Technology Academic year 2018/19
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Introduction

This assignment illustrates the basic principles of crash safety by solution of a few simplified examples. The learning outcome is general knowledge of how crash testing in the laboratory influences real life safety. Furthermore, the effect of optimization of the protective systems in a car is to be demonstrated.

Reporting (5 points)

The assignment is performed in groups of two or three students. You should be already assigned to a group. If not, please, contact the teaching assistants immediately.

To solve the assignment, you are required to write a brief report that contains the solution of each task. The report must comply with the given template. If you would prefer to use LaTeX, you can use the basic Article document class, and modify it to match the given template.

For all the computations and graphs, MATLAB should be used. You are given two MATLAB files that need to be completed: a template script for solving the assignment (*TME121_Assignment3.m*) and the function to solve the equations of motion (*solveEquationsOfMotion.m*).

Use International System of Units (SI) as primary units. Define abbreviations and acronyms the first time they are used in the text. Include all values and equations (including derivations). Insert labels and legend in each graph. Make sure the font size of the graph is large enough. Proofread spelling and grammar. (5 points are assigned based on the quality of the report)

In the appendix of your report, state the contribution of each student in the group.

> A zip folder that includes (1) the report (in PDF format) and the MATLAB source code (*TME121_Assignment3.m* and *solveEquationsOfMotion.m*) should be sent by email to: **alberto.morando@chalmers.se** no later than **Sunday, November 4th (23:59)**. The subject of the email and the folder name should be *"TME121_Assignment_3_group_XX"*, where XX is your group number. Please, make sure the naming is correct. We will filter the incoming emails based on this subject. If the subject is different, your email may pass unread. Please, include the names of the students in your group in the body of the email and in the script. If corrections are required, please, submit the second version no later than 1 week after you have received feedback.

Task 1 (7 points)

The old US frontal impact regulation includes a full width frontal impact into a rigid wall at an impact speed, v_0, of 48 km/h, Figure 1. Figure 2 illustrates a typical force-deformation characteristic of an older car in a full-frontal impact test. For this task, F_0 is the maximum force allowed, and d_0 is the distance from the foremost point of the car to the passenger compartment.

To protect an occupant in a frontal crash, the force and accelerations acting on the occupant should be kept low to avoid injury, while at the same time large deformations leading to intrusions into the passenger compartment should be avoided. Ideally, the passenger compartment should be infinitely stiff, while the front structure consumes a maximum amount of energy without exceeding d_0.

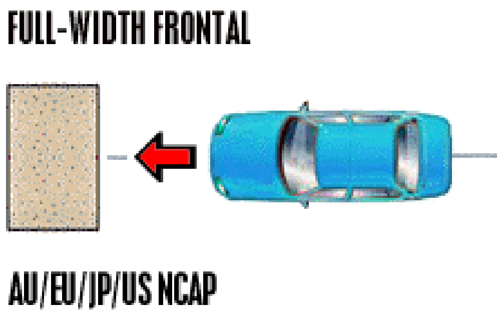


Figure 1. Scenario for the full-frontal impact test.

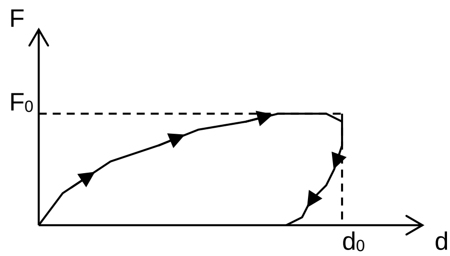


Figure 2. Typical force-deflection curve for the full-frontal impact test.

a) Assume that your vehicle front deforms as an ideal linear elastic-plastic structure, with the maximum force F_0 reached at 40% of the maximal deformation d_0. Draw (using Matlab) a simplified graph of the force-displacement curve of the vehicle front. Assume that after deformation *no elastic restitution* of the material occurs. Include this graph in your report. (0.5 point)

b) Complement the ideal force-deflection curve for deformations at and above d_0 in order to keep the deformation of the passenger compartment equal to zero. Include this graph in your report. (0.5 point)

c) Which design parameters for a vehicle structures could influence the shape of the force-deflection curve such as drawn here? (0.5 point)

Optimize the maximum front structure forces F_A and F_B in the test condition for the two vehicles A and B. The data for vehicle A and B are as follow:

Vehicle	m [kg]	d [m]
A	1700	0.73
B	1050	0.53

where *d* is the length of the vehicle deformation zone and *m* is the mass of the vehicle. As above, assume that your front structure deforms as an ideal elastic-plastic structure with maximum force reached at 40% of max deformation *d*. As before, assume that after deformation no elastic restitution of the material occurs.

d) Calculate the maximum crash forces and the acceleration levels of each of the two vehicles in the full-frontal rigid wall impact test. Tabulate the results as shown in the table below. (4 points)

Vehicle	F_{max} [kN]	$\|a_{max}\|$ [m/s^2]
A		
B		

e) Which one of the cars has the best safety potential? Why? (1 point)

f) Plot the force-displacement curves for vehicle A and B in the same figure and include it in your report. (0.5 point)

Task 2 (8 points)

For this task, you will consider a driver sitting in **vehicle A**, optimized for the 48 km/h rigid wall impact in Task 1 (Use vehicle data and force-deflection characteristics that you used and computed in Task 1). Model the driver by a mass of m_d=35 kg and the seat belt to be active over a ride-down distance of d_d=0.35m, as shown in Figure 3. For this task, assume that the driver does not affect the dynamics of the vehicle in the crash (which can be justified by that $m_d << m_A$).

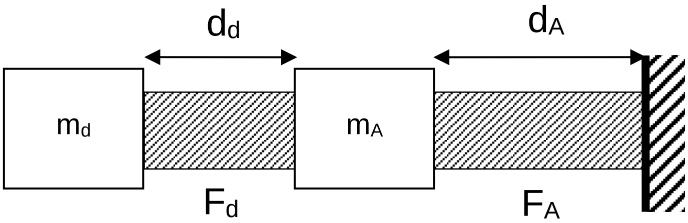


Figure 3: Schematic of vehicle and driver.

a) Calculate the optimal (minimum) belt force F_d which is needed to restrain the driver under the assumption that the seat belt force can be represented by an ideal plastic force-deformation curve. (5 points)

b) Calculate the deceleration of the driver chest and compare to that of the vehicle. Please comment on this comparison. (2 points)

c) Your design above with a constant belt force can be achieved by a device called a force-limiter in the belt retractor. Discuss possible advantages and disadvantages of such a design, for instance in relation to the scenario presented here. (1 point)

Task 3 (15 points)

Calculate what will happen with the two vehicles A and B (disregard the drivers and consider only the vehicles) if they meet in a head-on-collision (full frontal collision), each at a speed v_0 of 48 km/h, Figure 4. The force level in the contact will vary with the deformation of the vehicles. First, both vehicles will deform as linear elastic springs (Appendix A) and once the weaker structure is in plastic deformation it will dictate the force level until bottoming out. As before, assume that there is no elastic restitution of the front structures. Hence, both vehicles will have the same final velocity, v_{end}.

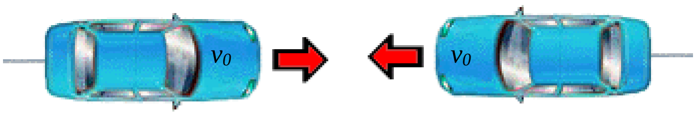


Figure 4. Vehicle-to-vehicle collision.

a) Solve the equations of motions for vehicle A and B in the impact (see Appendix B). Plot the force levels, acceleration, and velocity time histories, as shown in Figure 5. Include this graph in your report. For solving this task, complete the function *solveEquationsOfMotion.m* (5 points)

b) Tabulate the times when plastic deformation starts for each structure (t_y), the maximum force (F_{max}), and the maximum acceleration level for each vehicle ($|a_{max}|$), as shown in the table below. (5 points)

Vehicle	t_y	F_{max} [kN]	$\|a_{max}\|$ [m/s^2]
A			
B			

c) Tabulate the change of speed in the collision (ΔV), and the residual speed (v_{end}) for each vehicle, as shown in the table below. (2 points)

Vehicle	ΔV [m/s]	v_{end} [m/s]
A		
B		

d) Will both vehicle fronts be fully deformed? If not, what is the proportion of deformation for each vehicle? (2 points)

e) Discuss how the safety level of the two vehicles was affected on this head-on collision compared with the rigid wall test in Task 1. Which vehicle is safer in the head-on collision? (1 point)

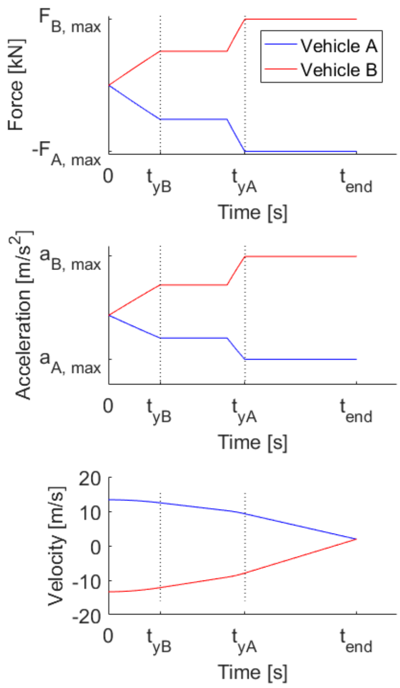


Figure 5. Force, acceleration, and velocity time history of vehicle-to-vehicle collision.

Task 4 (25 points)

Figure 6 shows the more modern test setup used in the EEVC Frontal Offset Deformable Barrier ECE R94 (Figure 6). Let us assume that this barrier engages 50% of the width of the vehicle front structure; thus it engages 50% of the full vehicle deformation force.

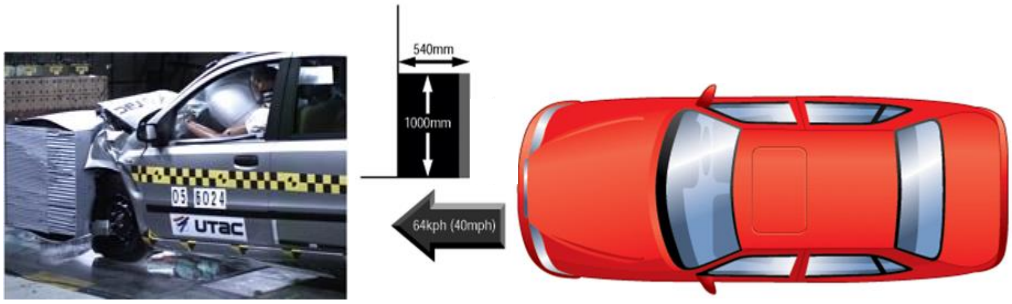


Figure 6. Deformable barrier test.

Furthermore, let the barrier represent an ideal plastic structure which deforms at 100 kN applied to 50% of the vehicle front structure (Figure 7). The available deformation length of the barrier is 540 mm and for this test the impact speed v_0=64 km/h.

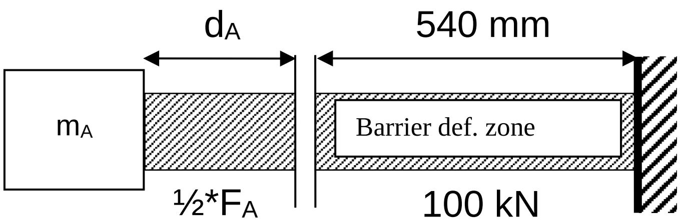


Figure 7. Schematic of deformable barrier test.

Based on this new crash setup, redesign the vehicle, that is find the new maximum front structure forces F_A and F_B (but keep the given mass, the length of the vehicle deformation zone, and the yield point):

a) Calculate the maximum crash forces and the acceleration levels of each of the two vehicles in this impact test configuration. Tabulate the results as shown in the table below. (5 points)

Vehicle	**F_{max} [kN]**	**$\|a_{max}\|$ [m/s^2]**
A		
B		

b) What are the *total* front structure force levels F for both vehicles? Tabulate the results as shown in the table below. (5 points)

Vehicle	**F_{total} [kN]**
A	
B	

Now, consider that the two cars, with this new modified stiffness, meet in a head-on collision. Both vehicles travel at 48 km/h. As in Task 3, assume that there is no elastic restitution of the front structures. Hence, both vehicles will have the same final velocity, v_{end}. Similarly to Task 3:

c) Solve the equations of motions for vehicle A and B in the impact. Plot the force levels, acceleration, and velocity time histories, as shown in Figure 5. Include this graph in your report. For solving this task, use the same function *solveEquationsOfMotion.m* that you used for Task 3a. (1 point)

d) Tabulate the times when plastic deformation starts for each structure (t_y), the maximum force (F_{max}), and the maximum acceleration level for each vehicle ($|a_{max}|$), as shown in the table below. (5 points)

Vehicle	t_y	F_{max} [kN]	$\|a_{max}\|$ [m/s^2]
A			
B			

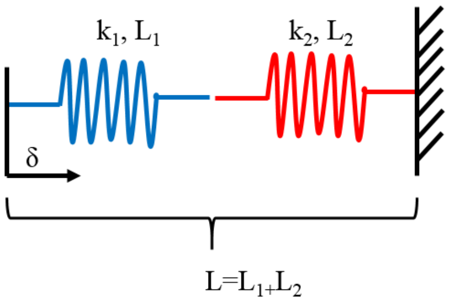
e) Tabulate the change of speed in the collision (ΔV), and the residual speed (v_{end}) for each vehicle, as shown in the table below. (5 points)

Vehicle	ΔV [m/s]	v_{end} [m/s]
A		
B		

f) Will both vehicle fronts be fully deformed? If not, what is the proportion of deformation for each vehicle? (2 points)

g) Discuss whether the new stiffness of the cars A and B have increased the crash safety, compared to what you found in Task 1. (2 point)

Appendix A: Series coupled linear elastic springs



$$F = \frac{k_1 k_2}{k_1 + k_2}\delta$$

$$\delta_1 = \frac{F}{k_1} = \frac{k_2}{k_1 + k_2}\delta$$

$$\delta_2 = \frac{F}{k_2} = \frac{k_1}{k_1 + k_2}\delta$$

where L_x is the length of the spring at rest, F is the elastic force, k_x is the elastic stiffness, and δ_x is the displacement.

Appendix B: Numerical solution of the equations of motion

The equations of motion can be discretized as follow:

$$\begin{aligned} \ddot{x}_{i+1} &= \frac{F_{i+1}}{m} \\ \dot{x}_{i+1} &= \dot{x}_i + \ddot{x}_{i+1} \cdot dt \\ x_{i+1} &= \mathrm{x}_i + \dot{\mathrm{x}}_{i+1} \cdot dt \end{aligned}$$

where *x* is the deformation, *F* is the active force, *m* is the vehicle's mass and *dt* is the time step (e.g. 1e-4)