THE COLLISION PHENOMENON BETWEEN CARS

What is the role of the mass in a head-on collision between two vehicles? What is the role of speed? What is the force produced by each of the two vehicles?

Here are some answers to better understand how the collisions take place.

Preamble: vehicle collisions student from linear momentum. This specific physical quantity is the product of mass and speed, it is expressed in kilogram-meters per second ($kg.m.s^{-1}$ symbol). Linear momentums take refuge in case of frontal impact, they add in the event of front-rear shock.

The linear momentums are used to calculate the residual speed, that is the speed just after the collision. This speed is identical for the both vehicles when one considers that they have melted into one another so as form a single mass(*).

The comparison between the residual speed and the initial speed is then used to calculate the rate of change to clean each of the two vehicles.

The rate of change combined with the length of the collision is used to calculate the deceleration of both vehicles in the event of a frontal impact, or acceleration of the vehicle hit from behind by impact front-rear. This quantity tells the violence of the collision and helps to assess the consequences for passengers.

The length of the collision is defined as the time during which the car bodies are deformed, this duration being obviously the same for each of the vehicles involved. The length of the collision depends on many parameters such as the structure of the vehicle, its speed or the nature of the obstacle. Grandeur of course impossible to measure directly, it can be estimated from data collected during crash tests. Here, the value used for calculations is 0.1 second.

Finally, by combining the mass and the deceleration, it is possible to calculate the force that is exerted on the vehicle during the collision.

Note: This force is always of equal intensity for each of the two vehicles involved, this is a concrete verification of the principle of action-reaction of Isaac Newton(**).

Take this opportunity to recall that, whatever the circumstances, the weight and mass of vehicles, passengers and luggage in a collision remain constant and unchanging quantities.

To estimate the possible consequences of these collisions on passengers, remember these generally accepted values(***):

- Up to 100 $m.s^{-2}$, the deceleration is bearable for young passengers, healthy and belted.

- From 150 $m.s^{-2}$, risk of injury to the face and limbs, high risk of internal bleeding.

- Above 200 $m.s^{-2}$, no chance of survival.

Last precision: the collision mechanism is independent of the considered repository. In other words, all other conditions being equal, a collision on the moon would proceed in the same manner and produce the same effects on the Earth. We point out here that the results calculated based on six assumptions. Readers interested in the different modes of calculations and detailed explanations should refer to Chapter 21 of the 'GUIDE DES LOIS PHYSIQUES DE L'AUTOMOBILE'.

1st hypothesis: a **head-on collision between two identical cars of mass 2,850 lb (1,300 kg) traveling at 30 mph (14 $m.s^{-1}$).**

a) residual speed: 0

b) speed variation: 30 mph

c) deceleration: This value is identical for each of the both cars: 139 ms^{-2}

d) force: 181,000 N

Appraisal: Contrary to popular belief, the initial velocities do not add up. The degree of deceleration is a function of the initial velocity.

2nd hypothesis: a head-on collision between a 2,850 lb (1,300 kg) mass car and a 5,700 lb (2,600 kg) mass 4x4, the both cars traveling at 30 mph (14 $m.s^{-1}$).

a) residual speed: 10.6 mph in the flow direction of the 4x4.

b) speed variations:

speed of 4x4 from +30 to +10.6 mph, speed of the car from +30 to –10.6 mph

c) deceleration:

∗ 4x4: 93 $m.s^{-2}$
∗ car: 185 $m.s^{-2}$

d) force: 240,000 N

Appraisal:

The mass difference determines the intensity of the deceleration at the expense of the lightest car.

3rd hypothesis: a head-on collision between two identical cars of mass 2,850 lb (1,300 kg), one traveling at 30 mph (14 $m.s^{-1}$), the other traveling at 45 mph (20 $m.s^{-1}$).

a) residual speed: 6.25 mph in the direction of movement of the fastest car.

b) speed variations:

speed of the first car from +30 to –6.25 mph, that of the second car from +45 to +6.25 mph

c) deceleration:

this value is identical for each of the two cars: 167 $m.s^{-2}$

d) force: 220,000 N

Appraisal:

Two vehicles of the same mass always undergo the same deceleration, their initial velocities are equal or not, which demonstrates that the difference in weight is an inequality factor.

The degree of deceleration is a function of the higher initial speed (in this example, probable injury in both cars).

4th hypothesis: a head-on collision between a 2,850 lb (1,300 kg) mass car traveling at 30 mph (14 $m.s^{-1}$) and a 5,700 lb (2,600 kg) 4x4 mass traveling at 45 mph (20 $m.s^{-1}$).

a) residual speed: 18 mph in the flow direction of the 4x4.

b) speed variations:

speed 4x4 from +45 to +18 mph, that of the car from +30 to –18 mph

c) deceleration:

∗ 4x4: 111 $m.s^{-2}$
∗ car: 222 $m.s^{-2}$

d) force: 290,000 N

Appraisal:

The mass difference determines the intensity of the deceleration at the expense of the lightest car.

The speed difference does not change the ratio of deceleration.

5th hypothesis: a head-on collision between a 3,300 lb (1,500 kg) mass car traveling at 55 mph (25 $m.s^{-1}$) and a 88,000 lb (40,000 kg) truck traveling at 37.5 mph (16.7 $m.s^{-1}$).

a) residual speed: 34 mph in the direction of movement of the truck.

b) speed variations:

The car speed from +55 to –34mph, the truck one from +37.5 to +34 mph

c) deceleration:

∗ car: 400 $m.s^{-2}$
∗ truck: 15 $m.s^{-2}$

d) force: 600,000 N

6th hypothesis: a rear-front collision between a 88,000 lb (40,000 kg) mass truck travelling at 37.5 mph (16.7 $m.s^{-1}$) and a 3,300 lb (1,500 kg) mass car traveling at 55 mph (25 $m.s^{-1}$).

a) residual speed: 38 mph

b) speed variations:

the speed of the truck from +37.5 to +38 mph, that of the car from +56 mph to +38 mph

c) acceleration or deceleration:

∗ truck: acceleration 3 $m.s^{-2}$
∗ car: deceleration 80 $m.s^{-2}$

d) force: 120,000 N

Appraisal:

The shock is front or not, the mass difference determines the intensity of the deceleration to the detriment of the lightest vehicle.

Conclusion

During a collision, the deceleration intensity is still a function of the initial speed or, in the case of two vehicles having different initial velocities of the higher initial speed.

In other words, the speed is still an aggravating factor.

Moreover, whatever the parameters and configuration of the collision, the ratio of deceleration experienced by both vehicles is always exactly equal to the ratio of their masses.

In other words, the heavy vehicle still dictates its law to lighter.

(*) *A collision of this type, sometimes referred to as soft or inelastic, is characterized by a deformation of the sheets and the structure, in other words by a work which corresponds to the variation of kinetic energy of the car. In the absence of deformation, a collision is called hard or elastic, it is characterized by a rebound and obeys other laws.*

(**) *Third Newton's principle or principle of action-reaction: any force acting on a body causes an intensity equal and opposite reaction. See other applications of this principle in ADILCA the folders devoted to different forces.*

(***) *The values shown here are average decelerations but not maximum ones. Moreover, in case of collision, the belted occupants of a car undergo a deceleration lower than that of the car, provided to benefit from the deformation of the structure (sheet metal engine compartment or trunk).*

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SOME RELATIONSHIPS BETWEEN QUANTITIES ...

Linear Momentum:

$Q = M . V$

Q: linear momentum, expressed in **$kg.m.s^{-1}$**
M: mass, expressed in **kg**
V: speed, expressed in **$m.s^{-1}$**

consistency of units: $Q = kg . m.s^{-1} = kg.m.s^{-1}$

Example: calculate the linear momentum of a 1,500 kg (3,300 lb) mass traveling at a speed of 20 $m.s^{-1}$ (45 mph):

$$Q = 1,500 \times 20 = 30,000\ kg.m.s^{-1}$$

Residual speed after a head-on collision:

$V = (Q1 - Q2) / (M1 + M2)$

V: residual velocity, expressed in **$m.s^{-1}$**
Q1: 1st vehicle linear momentum, expressed in **$kg.m.s^{-1}$**
Q2: 2nd vehicle linear momentum, expressed in **$kg.m.s^{-1}$**
M1: 1st vehicle mass, expressed in **kg**
M2: 2nd vehicle mass, expressed in **kg**

consistency of units $V = kg.m.s^{-1} . kg^{-1} = m.s^{-1}$

Example: calculate the residual velocity after a head-on collision between two cars, one is a 1,500 kg (3,300 lb) mass car traveling at 20 $m.s^{-1}$ (45 mph), the other is a 1,000 kg (2,200 lb) mass car traveling at 15 $m.s^{-1}$ (30 mph):

$$V = (30,000 – 15,000) / (1,500 + 1,000) = 15,000 / 2,500 = 6\ m.s^{-1}$$

Residual velocity after a collision of two vehicles traveling in the same direction:

$V = (Q1 + Q2) / (M1 + M2)$

V: residual velocity, expressed in **$m.s^{-1}$**
Q1: amount of movement of the vehicle 1, expressed in **$kg.m.s^{-1}$**
Q2: amount of movement of the vehicle 2, expressed in **$kg.m.s^{-1}$**
M1: 1st vehicle mass, expressed in **kg**
M2: 2nd vehicle mass, expressed in **kg**

consistency of units $V = kg.m.s^{-1} . kg^{-1} = m.s^{-1}$

Example: calculate the residual velocity after a collision between two cars traveling in the same direction, one is a 1,000 kg (2,200 lb) mass traveling at 15 ms^{-1} (30 mph), the other is a 1,500 kg (3,300 lb) mass traveling at 20 $m.s^{-1}$ (45 mph):

$$V = (15,000 + 30,000) / (1,000 + 1,500) = 45,000 / 2,500 = 18\ m.s^{-1}$$

Deceleration:

$Y = \Delta V / T$

Y: deceleration, expressed in **$m.s^{-2}$**
ΔV: rate of change, expressed in **$m.s^{-1}$**
T: length of the collision, expressed in **s**

consistency of units: $Y = m.s^{-1} . s^{-1} = m.s^{-2}$

Example: calculate the deceleration of a car having undergone a speed variation of 15 $m.s^{-1}$ during 0.1 s:

$$Y = 15 / 0.1 = 150\ m.s^{-2}$$

Force:

F = M . Y

F: force, expressed in **N**
M: mass, expressed in **kg**
Y: deceleration, expressed in **m.s^{-2}**

consistency of units: F = kg . m.s^{-2} = N

Example: calculate the force that is exerted on a 1,000 kg (2,200 lb) mass car undergoing a deceleration of 150 m.s^{-2}:

Y = 1,000 x 150 = 150,000 N

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