THE KINETIC ENERGY

All the experts agree that one of the greatest difficulties of driving is to properly estimate the speed, but also and above all to evaluate the speed differences.

Where does this difficulty come from?

The sensory organs or perceptive sensors that are the eyes and skin are not measuring instruments per se, they can inform us in a rather subjective manner on movement and speed.

That is why all cars are equipped with a tachometer so that the driver can have at any time a crucial objective data for driving.

However, being informed of the exact speed is one thing, being able to grasp the speed differences is another. Indeed, automotive phenomena such as the fuel consumption, the length of the braking distance or the consequences of possible collisions are always associated with variations of kinetic energy rather than simple speed differences.

In other words, only the calculation allows a sound and accurate assessment of these differences, the tachometer will then be useless. Here are the details of this reasoning with unexpected consequences.

Defining kinetic energy

Energy refers to any manifestation of momentum, heat or radiation. The energy that appears as motion is called kinetic energy.

There are three more precise definitions of the kinetic energy, all three completely equivalent under the general law of conservation of energy discovered and formulated by the English physicist James Joule(*).

First definition: the kinetic energy is the amount of energy used to " make " the movement. Indeed, in the absence of energy, a mass remains motionless or maintains a constant speed. The kinetic energy is a clear indication of the energy used to accelerate a mass, minus any loss due to heat, friction and various resistances.

Second definition: the kinetic energy is the amount of energy that must be entirely dissipated for complete immobilization of a moving mass. Kinetic energy is therefore a clear indication of the difficulty to decelerate a mass.

Third definition: the kinetic energy is the amount of energy dissipated in a collision. The kinetic energy is a clear indication of the violence of an impact.

Expressing the kinetic energy

The kinetic energy is expressed by the equation:

$$\mathbf{E = \frac{1}{2} M V^2}$$

According to the International System of Units (**SI**) whose use is, let us recall, mandatory everywhere in the world regardless of the areas concerned (industry, trade, education), the mass is expressed in kilograms (symbol **kg**), speed in meters per second (symbol $\mathbf{m.s^{-1}}$) and kinetic energy in joules (symbol **J**) in tribute to the work of James Joule.

The consistency check of the units is written as:

$$\textbf{Kinetic energy} = kg \cdot (m.s^{-1})^2 = kg.m^2.s^{-2} = \textbf{joule}$$

Example: let us calculate the kinetic energy of a car of mass 3,300 lb (1,500 kg) traveling at a speed of 65 mph (30 meters per second):

$$\mathbf{E} = \frac{1}{2} M V^2$$

$$\mathbf{E} = \frac{1}{2} \times 1{,}500 \times 30^2$$

$$\mathbf{E} = 750 \times 900 = 675{,}000 \ \mathbf{J}$$

Creating or removing energy

It is nothing miraculous about energy: creating, reducing or removing kinetic energy requires physical forces.

In the case of the car and under normal circumstances, these forces act on the tires in contact with the ground. In a collision, the force is applied by the barrier and it acts on the car body.

The work done by these forces matches exactly the amount of kinetic energy stored or dissipated.

Relationships between parameters

Let us look at relationships between physical parameters. What does the formula of the kinetic energy tell us? The mass is obviously a constant, while the variable is the squared speed.

In practical terms, this means that the kinetic energy is not proportional to the speed but to the square of the speed.

In other words, if the speed is doubled, the kinetic energy is multiplied by four; if the speed is multiplied by three, the kinetic energy is nine times; if the speed is multiplied by four, the kinetic energy is multiplied by sixteen, etc.

It can also be concluded that the kinetic energy is doubled when the speed is only multiplied by a factor of 1.414 as $2^{1/2} = 1.414$.

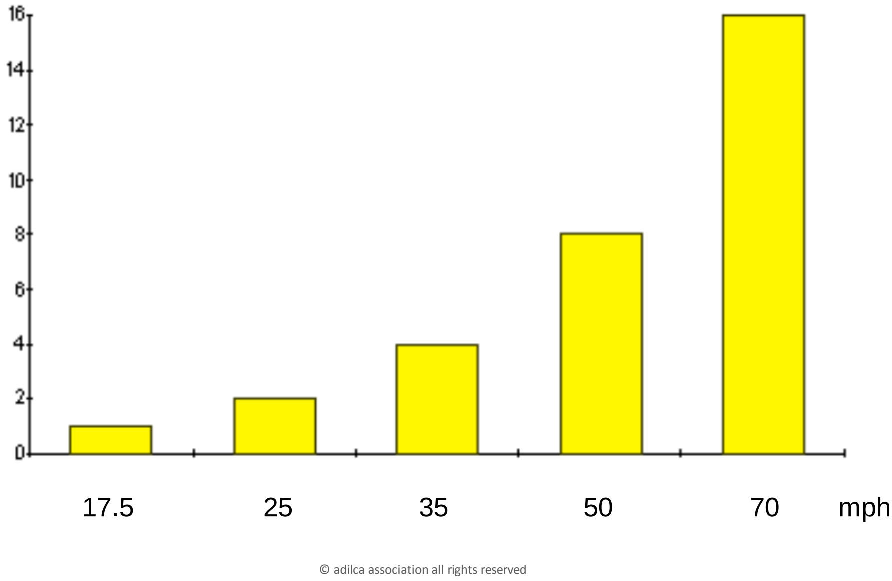

Diagram of the kinetic energy as a function of speed.

The role of the speed

The relationship between energy and speed shows us that:

- to double the speed of a car, you need to consume four times more fuel(**); the braking distance is then four times longer and, in case of collision, the impact is four times more violent!

- to triple the speed of a car, you need to consume nine times more fuel(**); the braking distance is then nine times longer and, in case of collision, the impact is nine times more violent!

- to quadruple the speed of a car, you need to consume sixteen times more fuel(**); the braking distance is sixteen times longer and, in case of collision, the impact is sixteen times more violent! etc.

Therefore, now we sense the interest of more accurately calculate what actually represent these speed differences, especially since they seem insignificant to us. How to do it?

A simplified formula ...

The mass being constant, the variation of kinetic energy only depends on the square of the speed. We can test it by considering a two-kilogram mass.

And since this is not about calculating an amount, but about evaluating a difference impacting the variable speed, it is then possible to calculate the difference with the speed in miles per hour (symbol mph).

In other words, the simple calculation of the square root of the difference of squares of speed in miles per hour tells us correctly and precisely about the variation of kinetic energy, and thus the corresponding difference in speed!

The simplified relationship is then:

$$V = (Vb^2 - Va^2)^{½}$$

In this relationship, V is the variation of kinetic energy between the speed Vb and the speed Va, all three magnitudes expressed in miles per hour. The power ½ means the square root of this difference.

The relationship fulfills the consistency requirement of the units, which is proved by the following:

$$\text{variation of kinetic energy} = [(\text{mph})^2]^{1/2} = \text{mph}$$

Not only the calculation is faster, but more importantly the result is particularly meaningful, as we shall see in the following examples.

Some practical examples ...

Readers familiar with calculations can, using the complete formula expressing the kinetic energy, calculate it for each example provided and thus check the results indicated.

First example: what is the difference of kinetic energy between 30 and 40 mph?

$$V = (40^2 – 30^2)^{1/2} = (1{,}600 – 900)^{1/2} = (700)^{1/2} = 26.5 \text{ mph}$$

It can be inferred the following: to accelerate from 30 to 40 mph, you must consume as much fuel(**) as to accelerate from 0 to 26.5 mph; to brake from 40 to 30 mph, it is necessary to dissipate as much energy as for braking from 26.5 to 0.

On the level of energy, running at 40 mph is therefore 26.5 mph faster than 30 mph!

Second example: what is the difference of kinetic energy between 50 and 60 mph?

$$V = (60^2 – 50^2)^{1/2} = (3{,}600 – 2{,}500)^{1/2} = (1{,}100)^{1/2} = 33.2 \text{ mph}$$

It can be inferred the following: to accelerate from 50 to 60 mph, you must consume as much fuel(**) as to accelerate from 0 to 33.2 mph; to brake from 60 to 50 mph, it is necessary to dissipate as much energy as for braking from 33.2 to 0.

On the level of energy, running at 60 mph is therefore 33.2 mph faster than 50 mph!

Third example: what is the difference of kinetic energy between 70 and 80 mph?

$$V = (80^2 – 70^2)^{½} = (6{,}400 – 4{,}900)^{1/2} = (1{,}500)^{1/2} = 38.7 \text{ mph}$$

It can be inferred the following: to accelerate from 70 to 80 mph, you must consume as much fuel(**) as to accelerate from 0 to 38.7 mph; to brake from 80 to 70 mph, it is necessary to dissipate the same energy than for braking from 38.7 to 0.

On the level of energy, running at 80 mph is therefore 38.7 mph faster than 70 mph!

A table to sum up...

The following table includes all the values calculated from 15 mph for the usually practiced speeds in United States.

75	73.5	72.3	71	68.7	66	63.4	60	56	51	45	37.4	27	0
65	63	62	60	57.7	54.8	51.2	47	41.5	34.6	25	0	26	37.4
55	53	51	49	46	42.4	37.7	31.6	23	0	24	34.6	43	51
45	42.4	40.3	37.4	33.5	28.3	20.6	0	21.8	31.6	39.7	47	53.6	60
35	31.6	28.7	24.5	18	0	19.4	28.3	35.7	42.4	48.7	54.8	60.6	66
25	20	15	0	16.6	24.5	31	37.4	43.3	49	54.5	60	65.4	71
15	0	13.2	20	26	31.6	37	42.4	47.7	53	58	63	68.4	73.5
mph	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**

How to read this chart? You just need to match the speed shown in bold in the left column and bottom line. The value shown is the difference of kinetic energy expressed in miles per hour.

Example 1: between 15 and 25 mph, the difference is 20 mph. This means that for a car to accelerate from 15 to 25 mph, it needs as much energy as to accelerate from 0 to 20 mph, the difference being the same in braking or in a collision.

Example 2: between 25 and 55 mph, the difference is 49 mph. This means that for a car to accelerate from 25 to 55 mph, it needs as much energy as to accelerate from 0 to 49 mph, the difference being the same in braking or in a collision.

Example 3: between 55 and 75 mph, the difference is 51 mph. This means that for a car to accelerate from 55 to 75 mph, it needs as much energy as to accelerate from 0 to 51 mph, the difference being the same in braking or in a collision.

Such differences are obviously impossible to estimate only from the data displayed in the tachometer, let alone the driver's perceptions or feelings...

A law of unexpected consequences ...

A consequence of this law is that the higher the speed, the greater the differences! Translated into current arithmetic language, this law could be written as:

25 mph = 15 mph + 20 mph

55 mph = 25 mph + 49 mph

75 mph = 55 mph + 51 mph

Or even:

75 mph = 15 + 20 + 49 + 51 mph!

Farfetched in appearance, this equivalence can be verified as follows:

$75^2 = 15^2 + 20^2 + 49^2 + 51^2 = 5{,}625$(***)!

Concretely, this means that only one car traveling at 75 mph has as much kinetic energy as four identical cars circulating respectively at 15, 20, 49 and 51 mph!

Therefore, we now understand the requirement for safety as for energy saving and environmental protection, to limit the speed at reasonable levels.

(*) *James Prescott Joule, English physicist (1818-1889). The law of conservation of energy states that the work, heat and energy are equivalent quantities that change in shape but are still fully conserved*.

(**) *This calculation, purely theoretical, only takes into account the energy required to accelerate a mass. Actually, this amount is greater if one takes into account the action of resisting forces (rolling resistance, air resistance) during the time that lasts this acceleration.*

(***) *The exact result is 5,627, the difference being due to approximations of exact values of square roots.*

ASSOCIATION ADILCA

www.adilca.com

*****