THE INERTIAL FORCE

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I. THE LAWS OF NEWTON

The general laws of movement were discovered and formulated by the English mathematician and physicist Isaac Newton (1642 - 1727).

These laws are universal and allow you to describe any form of movement.

These laws read as follows:

Principle of inertia

'*A mass on which no force is acting, remains motionless if motionless, or keeps a constant speed if in motion.'*

The concept of force stems from this principle.

Force concept

'*A force refers at any cause acting on the speed of a mass.*'

Principle of reciprocity

'*Any mass subjected to a force, responds by a reciprocal action of equal intensity, but of opposite direction*.'

How do these laws apply in the case of a land vehicle, and how can we define the concept of inertial force?

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II. INERTIAL FORCE: THE TRUE DEFINITION

Along with the Coriolis and centrifugal forces, inertial force is one of the three fictitious forces physicists refer to in the context of imaginary descriptions.

What is a fictitious force? What is an imaginary description? What is meant by inertial force? Where does it come from and how does it work? Why doesn't this force really exist? Here are some answers...

Reminder...

A *reference frame* refers to a coordinate system from which the characteristics of the motion of a mass can be measured [(1)].

According to the *principle of inertia* of Isaac Newton, a mass on which no force is acting remains motionless or keeps a constant speed. Hence this definition: a *force* refers to any cause of acceleration or deceleration a mass.

The correct meaning...

Inertial comes from 'inert'. Inertial force means a force delivered by an inert object. How could an inert object deliver any force? This definition sounds paradoxical... In fact, everything is explained when one knows that the inertial force belongs to the category of fictitious forces, as we shall see...

A curious phenomenon...

Imagine a stationary truck parked on level ground, with a ball placed in the middle of the bed. Get the truck moving and watch the scene from a window or a balcony, for example: as soon as the truck starts, the ball seems to roll towards the rear of the bed, as if driven by an apparent force.

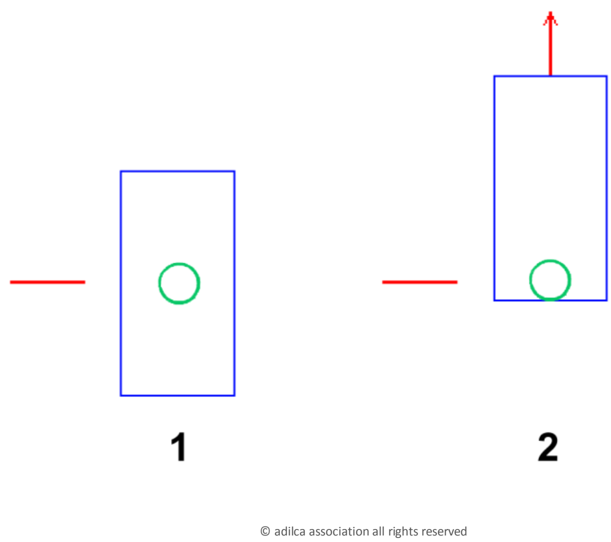
This apparent force is the inertial force. But beware! The movement of the ball is an optical illusion. Indeed, a ground reference can verify that in fact the ball has not moved, it has only been caught up and then hit by the tailgate of the truck.

Explanation: The only force requested in this experiment is the traction force created by the truck engine. This force is exerted on the tires of the driving wheels in contact with the ground. It then transmits to the wheels, the chassis, the body and the bed as well as everything it contains, including the ball.

The point of contact between the truck bed and the ball is too small a surface to communicate the force required to accelerate the ball, so that the latter remains stationary in relation to the Earth while the truck starts [(2)].

And it is precisely because the ball remains motionless, completely insensitive to the movement of the truck, and thus completely inert, that it gives the illusion of movement, hence the name given to this force.

In fact, in this experiment, the one and only force exerted, the one and only force that really exists is the traction force that applies on the driving wheels of the truck as they touch the ground. There has been no other force brought into play in this description. The inertial force is an imaginary force indeed.



Experiment top view:
1. A ball is placed in the middle of the bed of a stationary truck.
2. When the truck starts, it seems that the ball moves to the back of the bed.
A ground reference (red line) shows that in fact the ball has not moved.

Two reference frames

These two observations are contradictory and incompatible because it is important to distinguish between two reference frames [3]:

1. The Earth is the reference frame to describe the trajectory of the ball, observed from a window or a balcony, so the description takes place in an absolute reference frame.

1. The vehicle is the reference frame to describe the trajectory of the ball, observed from the bed, so the description takes place in is a relative reference frame.

Why is the vehicle reference frame qualified as relative?

The motion of a land vehicle only exists in relation to the Earth, it does not exist in the reference frame of the vehicle. So, in this reference frame, the vehicle must be considered as motionless [4]. Of course, it is forbidden to mix the two descriptions.

Now we can analyze all the other experiments supposed to prove the existence of the inertial force.

The mascot hanging from the mirror...

Here is another experiment which is easily achieved and often misinterpreted as proving the existence of inertial force.

Just hang any kind of mascot or pendulum from a car interior mirror. In a straight line at a constant speed, the mascot is subject solely to gravitational force, so it remains completely still and indicates perfect verticality.

But during speed or trajectory variations, the mascot tilts. Where does this movement come from? Here is the correct explanation...

Let us describe what happens when the car starts: from inside the car, we can see the mascot tilt back, it seems that it is driven by an apparent force, and the term makes it clear that the observation is only valid in the reference frame of the car.

But in reality, in the Earth reference frame, there is no reason why the mascot would move without a force being exerted on it. It therefore remains motionless, completely inert, like the ball in the truck bed, and it remains so until the acceleration of the car is transmitted to it. Where does this acceleration come from and how is it transmitted?

The acceleration of the car comes from the traction force exerted on the tires of the steered wheels in contact with the ground. This force is then transmitted to the rest of the car and everything in it through the wheels, the chassis and the bodywork. It finally reaches the mascot through the mirror and the string after which it hangs. Hence its inclination.

This apparent force is the inertial force! It seems to move the mascot, but this observation is nothing but an optical illusion. In reality, this force does not exist and a ground reference would show that, when the mascot tilts, there is no movement in relation to the Earth. It is only when the inclination is stabilized that the mascot really moves and picks up speed thanks to the traction force transmitted to it by the string...

The same phenomenon occurs during braking, and these explanations enable us to better understand what the passengers may feel…

The ‘seatbelt’ effect...

When heavy braking or a collision occur, car passengers have the feeling they are pressed against the seatbelt, as if driven by an apparent force...

This apparent force is inertial force, of course, but here again it is only a feeling!

In reality, this force does not exist in this experiment any more than it did in the previous ones. So where does the feeling come from? Here is the correct explanation...

When the driver presses the brake pedal, the car is driven by the braking force exerted on the tires in contact with the ground. This force is then transmitted to the wheels, the chassis, the bodywork and all its accessories. Objects firmly attached to the body are entirely and immediately driven by this force, as stowage precisely consists in enabling the bodywork to communicate this famous force.

But it is not the case with the passengers who, though seated on their seats, still retain some freedom of movement. When the car starts to slow down, the passengers therefore retain their original speed, just like the mascot in the previous experiment, and they do so until their seatbelts communicate the famous braking force to them.

In this example, the seatbelts play the same role for the passengers as the string did for the mascot.

The passengers of a car are therefore never thrown forward, they are simply held back by the bodywork and the seat belts... or by the dashboard and the windshield, if they have forgotten to fasten their seatbelts!

The feelings they experience therefore only come from the braking force that is communicated to them by the car... As inertial force is an imaginary force, it is of course impossible to observe or feel its effects.

The movement of luggage...

What about luggage placed in the trunk or objects on the rear shelf?

The explanation is the same as for passengers: when braking or a collision occurs, the movement of luggage placed in the trunk or objects on the rear shelf is only apparent.

In reality, these objects are never thrown forward, they simply retain their original speed if they have not been firmly anchored to the bodywork, and as long as no part of the body can communicate any braking force to them.

Inertial force: the true definition

The foregoing leads us to these two original and unpublished definitions of inertial force:

'In the reference frame of the car, inertial force is the imaginary force that would have to be exerted on the center of mass of the passengers and luggage of a stationary car to see them driven by a motion identical to that observed in reality when the car is driven by traction or braking forces.'

Let us insist on the three fundamental requirements to these definitions:

1. The car must be stationary;

2. This force is hypothetical, as clearly stated by the conditional: *'the force that <u>would</u> have to be exerted'*...

3. The point at which to exert this force: it is technically impossible to exert any force directly on the center of mass of any mass... (try to make the experiment, and you will have to admit that this requirement alone would suffice to prove the unreality of inertial force!)

These are sufficient reasons to assert in a clear and final way that inertial force does not exist.

Which brings another question: could inertial force appear in the Earth reference system?

The pitching motion...

Observe a Citroën 2CV braking suddenly. Because of the soft suspension, the front wheels are compressed while the weight on the rear wheels is released. This phenomenon is called the pitching motion.

Why does the car behave this way? To brake the car, the driver had to apply a force called braking force which is exerted on the wheels in contact with the ground, but not on the center of mass.

It is therefore the height of the center of mass that explains the pitching motion: the car rotates from back to front.

Under the effect of the braking force, the car simply acts like a person unbalanced by the carpet being pulled under her feet.

If the braking force was exerted directly on the center of mass, there would be no pitching motion and the car would brake 'flat'.

So, the pitching motion has nothing to do with the inertial force.

Both descriptions

However, the observation of the pitching motion allows two possible descriptions of the same phenomenon:

1. A real description, called 'dynamic', which describes all the movements of the car and their cause.

2. An imaginary description, called 'static' which considers that the car is immobile. In which case it would be necessary to imagine a force capable of creating a movement of artificial pitching.

Now the concept of inertial force comes in:

'In the reference frame of Earth, inertial force is the imaginary force that would have to be exerted on the center of mass of a stationary car to create on the tires and suspensions an effect identical to that observed in reality when the car is driven by traction or braking forces'.

Let us insist again on the three fundamental requirements to these definitions:

1. The car must be stationary;

2. This force is hypothetical, as clearly stated by the conditional: *'the force that would have to be exerted'*...

3. The point at which to exert this force: it is technically impossible to exert any force directly on the center of mass of a car... (this requirement would suffice to prove that inertial force is not real!)

Reciprocity: the Newton's third law

Could inertial force be regarded as the reciprocal action to traction or braking force?

Consider Newton's law[5]:

'*Any mass on which a force is acting, responds by a reciprocal action equal in magnitude but opposite in direction.'*

This law is probably the most misunderstood of all those ever enunciated by Newton.

Indeed, the reciprocal action associated with any force can occur only in a single description from a common reference frame. Again, mixing genres is strictly prohibited!

Logically, since the traction or braking forces are exerted in contact with the ground, the reciprocal action associated with these forces can only occur at ground level too, and not elsewhere

In fact, this famous reciprocal action exists for good! Indeed, when a land vehicle accelerates or brakes, the tires rest on the ground, thus exerting a horizontal thrust which would be perfectly capable of disrupting the rotation of the Earth, were it not for the mass of the Earth itself, much too large, compared to that of the vehicle, for the movement of the Earth to be affected[6]!

This thrust is the reciprocal action associated with the traction or braking forces.

In other words, the notion of reciprocal action has nothing to do whatsoever with the concept of inertial force.

The feelings of the passengers

The misuse of the concept of inertial force led motorists to believe that they could feel the effects of an imaginary force, thus proving its existence.

Let us detail the mechanism of the motion: the traction or braking force is exerted on the tires in contact with the ground, it is then transmitted to the passengers via the wheels, the frame, the bodywork and the seats.

The principle of reciprocity then applies: the passengers are driven by the force transmitted by the bodywork and the seats, they thus exert a reciprocal action on the seats and the bodywork, of equal intensity but of opposite direction.

Therefore, the passengers feel this reciprocal action, which is not the inertial force.

All this is very logical because it is obviously impossible to observe or feel the effects of an imaginary force.

How to measure inertial force

Can the intensity of inertial force be measured? It is indeed quite possible to measure the intensity of an imaginary force, i.e. the intensity of a force that does not exist, but that would have to be resorted to if... Physicists love this kind of exercise!

However, with regard to inertial force, the usual approach is not correct, and here's why...

First things first: in science, as a rule, one should always check the origin of the quantity one is faced with, what it represents, and how it was obtained. This is what you may call a principle of traceability.

Before any calculation is carried out, a physicist must perform experiments, define benchmarks and make measurements. The process is what matters most. Calculations only come next, but they are necessarily based on concrete measures, numerical values whose origin and meaning are certified – in short, quantities that really exist...

It is only later, thanks to a purely theoretical reasoning, that the physicist can transpose his reasoning to the study of an imaginary phenomenon.

Indeed, there is no imaginary force without a real force. But the reverse is not true: the traction or braking forces may well be considered independently, in a series of experiments and measurements, for instance, while the inertial force is always necessarily dependent on a traction force or a braking one.

It is therefore strictly forbidden to mention the inertial force without explaining where it comes from, what it represents and how it was obtained.

In short, though it is quite possible to talk about the traction force or the braking force alone, however it is absolutely forbidden to talk about inertial force without mentioning traction or braking forces. In other words, to come to the inertial force, which is an imaginary force, one needs to start from the traction force or the braking force, which are real forces.

These details of what is in fact a very logical approach are often ignored or overlooked. To illustrate this, here is a concrete example.

A concrete example

Take the example of a car with a mass of 3,300 lb (1,500 kg) accelerating from 0 to 45 mph (20 $m.s^{-1}$) in 10 seconds. Let us first calculate the intensity of the supposedly constant acceleration:

$$\boldsymbol{\Upsilon = V / T}$$

$$\boldsymbol{\Upsilon} = 20 / 10 = 2 \ \mathbf{m.s^{-2}}$$

The fundamental relation of dynamics enables one to calculate the intensity of the traction force **F** exerted on the tires of the steered wheels in contact with the ground:

$$\mathbf{F = M \Upsilon}$$

$$\mathbf{F} = 1{,}500 \times 2 = 3{,}000 \ \mathbf{N}$$

It is only from this result that we can deduce the intensity of the inertial force **F’**, the famous force that would have to be exerted on the center of mass of the car, if it was stationary, in order to produce an effect comparable to that observed in reality when the car is driven by the traction force or the braking force. The following formula, and no other, is then used:

$$\mathbf{F' = - M \Upsilon = - F}$$

The calculation is easy: to a real force of **3,000 N** in a dynamic description corresponds an imaginary force of **– 3,000 N** in a static description! Hence the confusion!

Indeed, the ‘real force’ and ‘imaginary force’ vectors have the same modulus! But beware, everything divides them:

- their point of application (one of these two vectors originates at the periphery of the tire and the other at the center of mass);

- their direction (here, the sign [–], which is often forgotten, is determining; it shows that, if the inertial force existed, inertial force, its spatial orientation should be rigorously opposed to that of the traction force or of the braking force.

- and one of these two vectors applies to a moving car while the other applies to a stationary one.

In short, these two vectors do not all belong at all to the same description. Be careful not to mix genres!

Thus, the intensity of the inertial force results from that of the traction force or of the braking force, it never works the other way. And the quantity supposed to prove the existence of the inertial force results in fact from a confusion with the traction or braking forces.

The inertial sensor...

Can a simple inertial sensor (also called accelerometer) directly measure the intensity of inertial force?

Let us detail the principle of operation of this device: a block capable of sliding in a tube, is maintained at rest by two springs, but can nevertheless move along a slider in case of acceleration or deceleration. The device is securely attached to the car body.

Let's get back to the example of a car that accelerates from 0 to 45 mph in 10 seconds. If the mass of the block is 10^{-2} kg, if the device is accurately calibrated, the cursor indicates a force of 2×10^{-2} N, this is the force necessary to accelerate the block.

The fundamental relation of dynamics enables one to calculate the intensity of the acceleration communicated to the block by the car:

$$\boldsymbol{\Upsilon = F / M}$$

$$\boldsymbol{\Upsilon} = 2 \times 10^{-2} / 10^{-2} = 2\ \mathbf{m.s^{-2}}$$

Note that this acceleration is strictly identical to that of the car, which is not surprising since the sensor is a part of the car body and accelerates at the same rate.

As there is no motion without cause, it is deduced that the acceleration of the block comes from the traction force exerted on the car.

In other words, the inertia sensor measures the intensity of the traction force, and its operating principle has nothing to do with the concept of inertial force.

Newton and the inertia

It is an open-and-shut case: inertial forces do not exist. But then, where does the mistake come from? In fact, the mechanisms of the confusion are old, complex and cultural.

Let us go back to the beginning and remember Isaac Newton's writings published in London in 1687 ('*Philosophiæ Naturalis Principia Mathematica*')[7]:

'*Materiæ vis insita est potentia resistendi, qua corpus unumquodque, quantum in se est, perseverat in statu suo vel quiescendi vel movendi uniformiter in directum*.'

'*Vis impressa est actio in corpus exercita, ad mutandum ejus statum vel quiescendi vel movendi uniformiter in directum*.'

The work of Newton was translated by Andrew Motte and published in London in 1729 ('*The Mathematical Principles of Natural Philosophy*'):

'*The* 'vis insita'*, or innate force of matter, is a power of resisting, by which every body, as much as in it lies, endeavours to persevere in its present state, whether it be of rest, or of moving uniformly forward in a right line.*'

'*An impressed force is an action exerted upon a body, in order to change its state, either of rest, or of moving uniformly forward in a right line.*'

Logically, this '*innate force of matter*' described by Newton is not a force, but a principle, that of inertia[8]! So, it's obvious, there is no inertial force in Newton's writings.

The advent of the statics...

As we have said, the *concept of inertial force* is inherent to the *statics*, a reasoning mode that we owe to Jean Le Rond d'Alembert, a French mathematician and physicist (1717 - 1783).

Statics is to reverse the reasoning by considering that any accelerated system could be described as being motionless, this inertia (in the real sense of the term) requiring a fictitious force to explain an apparent movement. This fictitious force is named inertial.

In a work published in Paris in 1743 ('*Traité de Dynamique*'), D'Alembert thus delivers the key to static reasoning:

'*At all times, there would be an equilibrium between the forces actually acting on a set of moving material points, and the forces of inertia at various points in the system, if these were to act.*'

The word '*equilibrium*' could have led to believe that the two forces, equal and opposite, were acting at the same time on the same mass. But if that were the case, these two forces would neutralize each other. D'Alembert would then have used the expression '*destroy themselves*', since this is the term he uses elsewhere. Therefore, in D'Alembert's reasonning, the word '*equilibrium*' should be understood as meaning '*equivalence*'.

D'Alembert's sentence is therefore perfectly clear: the two forces are equal and opposite but do not act at the same time: real forces on one side (in dynamics), fictitious forces on the other (in statics). Two perfectly separate descriptions. Besides, the use of conditional ('*there would be equivalence ... if they were to act*') clearly proves that inertial forces do not exist: they are just imaginary forces.

The role of teachers...

Around the middle of the 19th century, the concept of inertial force, legitimized by the work of Gaspard Coriolis, a French military engineer (1792-1843), the inventor of the force that bears his name (see ADILCA file '*Coriolis force*'), aroused renewed interest among teachers, anxious to update programs in times of war.

What role have teachers been playing in this hoax? While it is quite obvious that no physics teacher worthy of the name ever could mix up the origin of a phenomenon with its effects, the cause of a movement with its consequences, a real description with an imaginary description, that is still the way it goes.

And since most physics teachers remained confined in classrooms, lecture halls or laboratories, they focused their teaching on these famous imaginary concepts. Unconcerned about pragmatism, disconnected from reality, they forgot to issue the instruction manual.

In short, as time and classes went by, imaginary descriptions irresistibly supplanted real descriptions.

Physics textbooks…

What should be made of physics books?

You only need to take a look at the current production at all levels (secondary schools, higher education) to see the extent of the phenomenon. The least one can say is that these textbooks give imaginary descriptions more than their share!

Yet the honesty, the good faith and good intentions of the authors are not in question. Indeed, since most of these books were written by scholars and not by men with practical experience, the descriptions given by the former logically appear to the detriment of those proposed by the latter.

Let us also note that when it comes to writing a physics textbook, the concept of inertial force is very convenient as it is a comprehensive generic concept adaptable to a number of phenomena.

Conversely, the description of a real movement requires much more minuteness, in the etymological sense of the word, and is rather a matter for specialized books: the forces exerted on a car, for example, are not exactly the same as those exerted on a boat, an airplane or a satellite; identifying and exposing them in detail is therefore long and delicate.

...and those who read them!

How have pupils and students assimilated these differences?

Pedagogy is the art of controlling what happens in the minds of students. In this case, sophisticated knowledge, honesty and good intentions are no longer enough.

Unfortunately, the system has always worked in closed circuit the teachers have only validated through exams the knowledge they consider to be fundamental, within the limits of their skills and knowledge.

Let us instead see things from the pupils or students' point of view: when the discourses of teachers and textbooks combine to drum the compulsory dogma into their heads, it is difficult for them to escape indoctrination.

Yes indeed, even in the field of science, this is quite possible!

It is the way it goes, and it is appalling: in people's brains, the logic is that of imaginary descriptions.

A small survey of students or young graduates is enough to convince one.

Conclusion

The concept of inertial force, often confused with Isaac Newton's principle of inertia, has been misused to describe any movement, unfortunately without any precaution as to its instructions for use.

The inertial force is an imaginary force that only appears in statics or in a relative reference frame, it has no real existence, any more than the centrifugal force and the Coriolis force (see ADILCA files '*centrifugal force*' and '*Coriolis force*').

It is therefore wrong if this concept has been used to describe the movement of cars, because it is obviously impossible to observe, feel or measure the effects of an imaginary force.

The reality: to accelerate a car, a single force is necessary, it is the traction force (see ADILCA file '*engine torque & traction force*'). To brake a car, a single force is necessary, it is the braking force (see ADILCA file '*braking force*').

The traction force and the braking force are contact forces acting on the periphery of the tires of the car, depending on whether the driver presses the accelerator or the brake control. There is nothing else to add.

All the other phenomena observed have clear, logical and rational explanations that have nothing to do with the concept of inertial force.

(1) *A coordinate system is made of three orthogonal axes (length, width, height) and a measurement of time (chronometer).*

(2) *In fact, the contact surface between the truck bed and the ball does not allow for total slip, the ball begins to spin, thus gaining kinetic energy of rotation. If the truck stops suddenly, this accumulated energy can be sufficient to cause the ball to be dragged towards the tailgate. In the context of this experiment, it is what is called an artefact.*

(3) *A reference frame can be absolute (one also says: inertial or Galilean) or relative (one also says: non-inertial or non-Galilean) according to the object of the study: thus, the Earth is an absolute reference frame to describe the movement of land vehicles, it is a relative reference frame to describe the movement of the Sun or that of the planets of the solar system.*

(4) *This manipulation is common in physics: the truck is said to be a 'non-inertial reference frame' or 'non-Galilean reference frame' or 'relative reference frame' to indicate that it is not an absolute one. Concretely, it means that describing its own movement is now strictly forbidden! In short, let us pretend the truck is stationary! The movement observed from a relative reference frame is called apparent movement, which is what an observer perceives if he is deprived of external landmarks. The Sun, for example, is animated by an apparent movement for who observes it from Earth, being convinced that the terrestrial globe is motionless.*

(5) *Beware! This principle applies only to real forces, never to fictitious forces. Indeed, in an imaginary description, interactions do not exist. Isaac Newton could not specify this, as fictitious forces were unknown at the time.*

(6) *Equality between traction force and reciprocal action does not mean that their effects are equal. Indeed, according to the dynamics principle (Newton's second law), the acceleration produced by any force is inversely proportional to the mass on which it is exerted (fundamental relation [$Y = F / M$]). In this example, the traction force is exerted on the truck, the reciprocal action is exerted on the globe. If you compare a 10-ton truck and the Earth (6×10^{24} kg), the mass ratio is of 1 to 600 trillion to the benefit of the Earth, to the detriment of the truck...*

(7) *Translation of the title: '*Mathematical Principles of Natural Philosophy' *(Latin was the language of scholars at that time). Natural philosophy refers to what nowadays is called physics*.

(8) *Do not confuse Newton's principle of inertia with the concept of inertial force. Newton's first principle, or principle of inertia, states that:* 'Any motionless mass on which no force is exerted remains motionless. Any moving mass on which no force is exerted, describes a rectilinear trajectory with a constant speed'*. The notion of force is deduced from this principle and can be defined as follows:* 'A force refers to any cause acting on the trajectory or the speed of a mass*'.*

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III. INERTIAL FORCE: THE CALCULATION MODE

1. Acceleration

$$\Upsilon = \Delta V / T$$

ϒ: acceleration, expressed in **$m.s^{-2}$**
V: speed variation, expressed in **$m.s^{-1}$**
T: duration, expressed in **s**
Consistency of the units: **ϒ** = $m.s^{-1} . s^{-1}$ = **$m.s^{-2}$**

Example 1: calculate the acceleration of a car whose speed varies from 0 to 30 meters per second (67 mph) in 15 seconds:

$$\Upsilon = 30 / 15 = 2 \ \mathbf{m.s^{-2}}$$

2. Traction or braking force

$$F = M . \Upsilon$$

F: traction or braking force, expressed in **N**
M: mass, expressed in **kg**
ϒ: acceleration or deceleration, expressed in **$m.s^{-2}$**
Consistency of the units: **F** = kg . $m.s^{-2}$ = $kg.m.s^{-2}$ = **N**

Example 1: calculate the traction force acting on the tires giving an acceleration of 2 meters per square second to a 1,500 kilograms (3,300 lb) car mass:

$$\mathbf{F} = 1{,}500 \times 2 = 3{,}000 \ \mathbf{N}$$

By virtue of the principle of reciprocity, the tires of the car exert a thrust on the ground, of equal intensity but in opposite direction.

Example 2: calculate the traction force acting on a passenger weighing 100 kilograms (220 lb) giving an acceleration of 2 meters per square second:

$$\mathbf{F} = 100 \times 2 = 200 \ \mathbf{N}$$

By virtue of the principle of reciprocity, the passenger exerts a thrust on the seat of the car, of equal intensity but in opposite direction. This thrust is perfectly felt by the passenger, it has been confused with the inertial force.

3. Reciprocal action

A = – F

A: reciprocal action, expressed in **N**
F: traction or braking force, expressed in **N**

(the [–] sign specifies the spatial orientation of this action)

Example 1: calculate the reciprocal action that the tires of the drive wheels of a car with a mass of 1,500 kilograms exert on the globe when the car is driven by a traction force of 3,000 N:

A = – 3,000 **N**

The earth globe remains insensitive to this action because of the ratio of the masses: terrestrial globe (6×10^{24} kg) *versus* car (1.5×10^{3} kg) = 4×10^{21}.

Example 2: calculate the reciprocal action that a passenger weighing 100 kilograms exerts on the seat when he is driven by a traction force of 200 N:

A = – 200 **N**

The passenger feels perfectly this action which gives him the impression of weighing on the seat. The seat must be strong enough to withstand this action.

4. Inertial force

F' = – M . Ɣ

F': inertial force, expressed in **N**
M: mass, expressed in **kg**
Ɣ: acceleration, expressed in $\mathbf{m.s^{-2}}$

Consistency of the units: **F'** = kg . $m.s^{-2}$ = **N**

(the [–] sign specifies the spatial orientation of this force)

Example 1: calculate the force, called 'inertial force' that should be exerted on the center of gravity of a stationary car with a mass of 1,500 kg to create, on the suspensions and the tires, the same effect as observed in the reality when the car is driven by an acceleration of 2 meters per square second:

F' = – 1,500 x 2 = – 3,000 **N**

Example 2: calculate the force, called 'inertial force', which should be exerted on the center of gravity of a passenger weighing 100 kg sitting in a motionless car in order to create the same feeling as in the reality when the car is driven by an acceleration of 2 meters per square second:

$$\mathbf{F'} = -100 \times 2 = -400 \ \mathbf{N}$$

Note 1: the sign [–] is required, it specifies that the spatial orientation of the inertial force conflicts the logic of the movement.

Note 2: this force is commonly referred to as '*inertial force*' which is an incorrect name. The scientific name of this force is: imaginary force, fictional force, or pseudo-force.

Note 3: be careful not to confuse the inertial force with the reciprocal action: these two forces are equal, but the resemblance stops there:

- the reciprocal action is a real force that the passenger feels perfectly, it acts by contact with the seat, in response to the traction force when the car accelerates.

- the inertial force is an imaginary force that is impossible to feel: it is the force that should be exerted on the center of gravity of the passenger, if the car was motionless.

Note 4: the different calculations must be done in the order indicated. It is indeed impossible to directly calculate the inertial force without performing the intermediate calculations detailed above.

Note 5: Every scientific approach goes through four steps:

- form observation to *experiment* (here: a car which describes a circular path);

- from experiment to *measurements* (here: measuring the mass of the car, its speed and the duration of the speed variation);

- from measurements to *calculations* (here: calculation a traction force and an acceleration);

- from calculations to *reasoning* (here: the concept of inertial force).

This transition from concrete to abstract reasoning, from the real to the imaginary, has often been short-circuited, hence the confusion or misunderstanding about inertial force.

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