THE CENTRIFUGAL FORCE

The concept of centrifugal force rarely comes with an instruction manual: like the Coriolis force and the inertial force, centrifugal force belongs to the category of fictitious forces, also called apparent forces or pseudo-forces.

Why are they called this way? The reason is that these forces can only exist in the context of imaginary descriptions. In effect, these forces do not really exist.

Here is a selection of various observations, experiments or demonstrations supposedly proving the existence of centrifugal force, followed by the correct interpretations.

A few definitions...

A force is any cause capable of changing the speed or trajectory of a mass. Centrifugal means '*which takes away from the center'*.

Thus, according to the definition, a force qualified as centrifugal must be able to push away a mass from any center or axis of rotation along a radial trajectory, i.e. in the direction indicated by the extension of a radius.

The object on the hood....

Let us put an object on the hood of a car (e.g. a traffic cone). The experiment consists in setting the car in motion, first in a straight line then a turn.

The so-called 'traffic cone' experiment

Seen from the inside of the car (reference frame of the car), the object effectively falls to the ground at the beginning of the bend, as if pulled away from the trajectory by an apparent force. This is the way it is described in the special reference frame [(1)] whose rules and applications have been detailed elsewhere (see ADILCA documents).

Now observe the same experiment from a window or a balcony (reference frame of Earth): as soon as the driver steers the steering wheels, the guiding force deflects the car from its original trajectory.

As the hood is a smooth area, this force cannot be transmitted to the object, which keeps its rectilinear trajectory and falls to the ground. The object in question is not subject to any force, it is simply left to itself.

Two experiments carried on a motorbike...

Let us put the traffic cone on the tank of a motorbike. Unless the driving is boorish, the object remains on top, even when the bike goes in a circle. The cone slipping and eventually falling to the ground is due to the vibrations of the engine or the air pressure, certainly not to centrifugal force.

A same kind of experiment, called ‘the water bottle experiment’, consists in using a bottle half filled with syrup instead of a traffic cone, fixed horizontally on the tank or on the handlebars: whatever the inclination of the vehicle in motion, the liquid surface remains perpendicular to the plane of symmetry of the machine. The same could be experienced aboard a plane when it banks to turn.

In fact, the interest of this experiment is to distinguish two descriptions: in *statics* (motionless motorbike), the liquid is subjected only to its weight, it falls on the side where the machine leans; in *dynamics* (motorcycle in motion), its weight is balanced by the guiding force, the liquid retains its initial position inside the bottle.

The ‘water bottle’ experiment

The rolling motion...

Observe a Citroën 2CV full turn. Because of the soft suspension, the outside wheels are compressed while the weight on the inner wheels is released. This phenomenon is called the ‘roll’.

Why does the car behave this way? To deflect the car from its initially straight path, the driver had to apply a transverse force called guiding force. This force is exerted on the steering 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 rolling motion: the car turns in on itself in a transverse plane.

It has thus nothing to do with centrifugal force! Under the effect of the guiding force, the car simply acts like a person unbalanced by the carpet being pulled under her feet. If the guiding force was exerted directly on the center of mass, there would be no roll and the car would take ‘flat’ corners.

The mascot hanging from the mirror...

Observe a mascot hanging from the mirror of the car. In a straight line at constant speed, the mascot shows the vertical.

Observe what happens when the car makes a turn: the interior of the passenger compartment (reference frame of the car), we can see that the mascot tilts to the side, as if driven by an apparent force.

Mascot hanging from the mirror

But in the reference frame of Earth, the mascot is only deflected from an initially straight line: the guiding force is exerted first on the tires of the steering wheels and is then transmitted to the chassis, to the bodywork and all the car accessories; it finally reaches the mascot through the mirror after which it hangs. Hence its inclination.

The apparent force which, from the passenger’s point of view, seems to move the mascot, is therefore only an optical illusion. In fact, this force does not exist.

The passenger's sensations...

When the car makes a turn at top speed, the passenger of a car feels pressed against the edge of the seat or against the door, as if driven by an apparent force... Why is that?

When the driver turns the wheel, the car is subject to the guiding force exerted on the tires of the steering wheels; this force is then transmitted to the chassis, the bodywork and all the accessories of the car.

The objects that are firmly attached to the body undergo this force fully and without delay, stowage consisting precisely in enabling the body to communicate this force.

But this is not the case for the passengers who, though seated on their seats, still retain some freedom of movement. When the car starts to turn, the passengers maintain a straight path, just like the mascot in the previous experiment, and they do so until the edge of the seat, the door or the body transmits the guiding force to them.

It is not therefore the centrifugal force that the passenger's experience, but simply the guiding force exerted on the car and transmitted by the seat, seatbelt or part of the body of the car.

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 the car turns, the movement of luggage placed in the trunk or objects on the rear shelf is only apparent in relation to the car.

In fact, objects that are not perfectly secured maintain a straight path as long as no part of the body can transmit a guiding force to them.

Action and reaction: don't mix them up!

Could centrifugal force be regarded as the reaction associated with guiding force? The answer is no, and here's why.

Consider Newton's laws, more precisely the law known as the action-reaction law: *'When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction to that of the first body.'*(2)

The previous experiments clearly demonstrate that the circular motion of the car is due to the action of a single force, the guiding force.

We observed that the guiding force is exerted on the tires in contact with the ground. Logically, the reaction associated with this force can only occur at ground level, too.

In fact, when a driver activates the guiding force, the car performs a horizontal thrust at ground level, and this thrust should logically affect the Earth's rotational movement.

Fortunately, the effect is purely theoretical because the mass of the car is considerably lower than that of Earth [(3)], so that the car has no choice but to slide or register obediently on a circular path!

In addition, should the effect be noticeable, it would be negated by the divergent trajectories of the large number of vehicles on the road. This famous reaction, in the Newtonian sense, therefore exists, but it has nothing to do with the concept of centrifugal force!

So what is the correct formula?

Does the famous formula **$F = MV^2/R$** prove the existence of centrifugal force?

Let us first make sure it truly is a force.

According to the *International System of Units* (symbol: **SI**) – compulsory in most countries around the world, for instance in United States since 1964, in United Kingdom since 2004 – force is measured and expressed in kilograms-meters per second squared (symbol: **$kg.m.s^{-2}$**). That is a derived quantity obtained by combining three fundamental quantities: mass and length and time.

The measurement obtained is the very definition of a *newton* (symbol: **N**), the international unit of force.

To check the consistency of this formula, consider how the different quantities introduced in this equation are combined: mass is expressed in kilograms (symbol: **kg**), speed is expressed in meters per second (symbol: **$m.s^{-1}$**) and the radius of the path is expressed in meters (symbol: **m**).

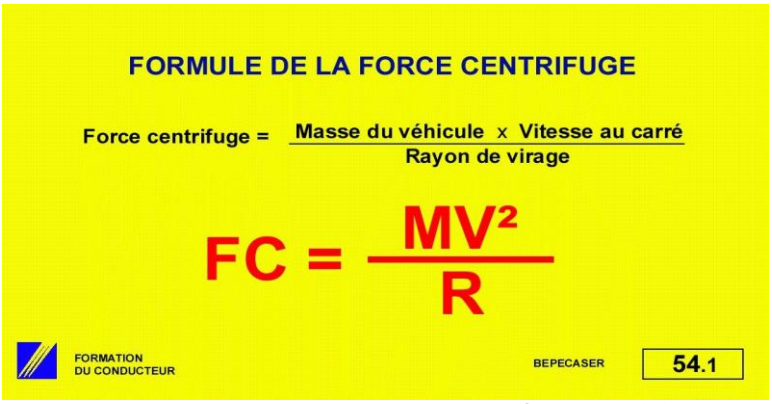
Let us combine these different quantities:

$$\mathbf{F = MV^2/R}$$

$$\mathbf{F} = kg \,.\, (m.s^{-1})^2 \,.\, m^{-1} = kg \,.\, m^{+2}.s^{-2} \,.\, m^{-1} = \mathbf{kg.m.s^{-2}} = \mathbf{N}$$

There is no possible doubt, this formula is perfectly consistent, and therefore it expresses the measurement of a force.

A force indeed, but which one? Centrifugal or guiding? That is the question!



Correct formula, but not correct force!
(French Ministry of Transport official document)

What force is it?

What force are we dealing with? We have already shown elsewhere that there were only two possibilities and two only:

- from the reference frame of the car, the centrifugal force is an apparent force and, obviously, can only be exercised on passengers and luggage but certainly not on the car;

- from the reference frame of Earth, the guiding force is a real force which is exerted on both the car and everything it contains.

How can we tell? How to distinguish the two? How to settle the debate?

The answer comes naturally by examining the various quantities introduced in the equation of the mass of the car, its speed and the radius of its trajectory. Isn't it obvious?! These variables exist only in the reference frame of Earth; they have absolutely no existence in the reference frame of the car!

To understand this significant nuance, try to imagine for a moment what the speed of the car or the radius of its path could be by reasoning exclusively in the reference frame of the car... Good luck to you!

Evidently, this formula does not express the centrifugal force, but only the guiding force. The latter and the latter only is what it is all about.

Choosing the right reference frame! ...

These various considerations take us back to the theory of reference frames and the previous experiments can be summarized as follows:

- one is observed in an absolute reference frame (here, Earth) and describes a real movement;

- the other is observed in a relative reference frame (here, the car) and describes apparent movement.

Obviously, these two reference frames are quite distinct, so there is no question of confusing or mixing them. It is, however, a common mistake!

Choosing the correct description! ...

To be exhaustive, let us finally point out that, in an absolute reference frame (here, Earth), the description may be 'dynamic' or 'static':

- a 'dynamic' description means that the car is in motion, it follows a circular path through the guiding force that is exerted on the outskirts of the tires of the steering wheels;

- a 'static' description means that the car is stationary; we imagine a fictitious force capable of compressing the tires and suspensions as when the car turns, this pseudo-force is supposed to be exerted on the center of mass of the car.

Obviously, these two descriptions are completely contradictory, so there is no question of mixing, or superimposing them. Unfortunately, this is a very common blunder!

Centrifugal force: the true definition!

We have examined the main sources of error the evil consequences of which are so prevalent, including in some physics textbooks.

All these observations, all this reasoning, all these deductions lead us to two original and unpublished definitions of centrifugal force:

'In the reference frame of the car, centrifugal 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 subject to the guiding force'.

'In the reference frame of Earth, centrifugal 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 subject to the guiding force'.

There are 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. It is technically impossible to exert any force directly on the center of mass of any mass... This requirement alone would suffice to prove the unreality of centrifugal force!

These are sufficient reasons to assert that centrifugal force does not exist!

The inventor of centrifugal force...

History has not remembered his name!

The concept of centrifugal force is an application of the general principle of inertia (see '*inertial force*' ADILCA document) to the particular case of circular motion, an imaginary mode of reasoning initiated by Jean Le Rond d'Alembert, a French mathematician and physicist (1717-1783).

How to measure centrifugal force...

Can the intensity of centrifugal 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 centrifugal 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.

In other words, to get to centrifugal force, which is an imaginary force, it is necessary to start from the guiding force, which is a real force. Indeed, there is no imaginary force without a real force.

But the reverse is not true: the guiding force may well be considered independently, in a series of experiments and measurements, for instance, while the centrifugal force is always necessarily dependent on the guiding force!

It is therefore strictly forbidden to mention the centrifugal 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 guiding force alone, however it is absolutely forbidden to talk about centrifugal force without mentioning the guiding force!

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) which describes a circular path of radius 330 ft (100 m) at a speed of 45 mph (20 $m.s^{-1}$).

The famous formula, which is often used indiscriminately and of which we have detailed the applications, calculates the intensity of the guiding force **F** that is exerted on the tires of the car in contact with the ground:

$$F = M V^2 / R$$

$$F = 1,500 \times 20^2 / 100 = 6,000 \text{ N}$$

The corresponding transverse acceleration is:

$$\Upsilon = V^2 / R$$

$$\Upsilon = 20^2 / 100 = 4 \text{ m.s}^{-2}$$

It is only from this result that we can deduce the intensity of the centrifugal 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 when the car is subjected to the guiding force.

But what formula should be used? The following one, and no other:

$$F' = - M \Upsilon = - F$$

The calculation is easy: to produce an effect comparable to what is observed in reality, a force of **– 6,000 N** would be required!

In other words, to a guiding force of **6,000 N** in a real description, there is a centrifugal force of **– 6,000 N** in an imaginary description!

In effect, the 'guiding force' and the 'centrifugal force' have the same modulus but yet, everything divides them:

- the formula used to calculate the intensity;

- the point of application (one of these two vectors has its origin at the periphery of the tire and the other at the center of mass);

- the direction (here, the often forgotten [–] sign is crucial, it shows that the spatial orientation of the centrifugal force, if such force existed, should be strictly opposite to that of the guiding force);

- last but not least: one of these two vectors is applied to a moving car and the other to a stationary car!

In short, these two vectors do not belong to the same description at all! Thus: the intensity of the centrifugal force is deduced from that of the guiding force, and it is never the other way round!

And the quantity supposed to prove the existence of centrifugal force results in fact in confusion with the guiding force!

The inertial sensor...

Can a simple inertial sensor (also called lateral accelerometer) directly measure the intensity of centrifugal 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 lateral acceleration of the car. The device is securely attached to the car body

Let us get back to the example of a car in a circle of radius 330 ft (100 m) at a speed of 45 mph (20 $m.s^{-1}$).

If the mass of the block is 10^{-2} kg, if the device is accurately calibrated, the cursor indicates a force of 4×10^{-2} N, this is the force necessary to curve the trajectory of the block.

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

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

$$\mathbf{\Upsilon = 4 \times 10^{-2} / 10^{-2} = 4\ m.s^{-2}}$$

Note that this transverse acceleration is strictly identical to that of the car, which is not surprising since the sensor is a part of the car body and describes a circular path of the same radius.

As there is no motion without cause, it is deduced that the transverse acceleration of the block comes from the guiding force exerted on the car to impose a circular trajectory.

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

The true meaning of the word ‘exist’...

The centrifugal force does not exist, as we have just been demonstrating at length. However, you can still come across contrary opinions here and there, especially on the web. A true dialogue of the deaf! Who is to be believed?

Let us first remember that '*physics*' refers to the science of natural things [4], it is focused on the observation and knowledge of real things, and this is precisely what makes it a concrete and rigorous hard science.

The misunderstanding about centrifugal force rests on the true meaning of the verb 'exist'. According to the dictionary, the word applies to everything that is part of reality, as opposed to what is only fiction.

But for some, the only trace of the concept of centrifugal force in a physics book would suffice to prove its existence: since it is written in the book, it really exists!

However, the fact that some physics books make mention of centrifugal force does not prove its *existence*, in the physical and literal sense of the word...

Indeed, many abstractions may be conceived on paper, but in science and especially in physics, only reality matters... Is not fact stranger than fiction, as the saying goes!

The example of literature...

To understand this significant nuance, let us look at literature and ask ourselves this question: do the characters found in novels really exist?

Let us take an easy example: Father Christmas!

Of course, there are children's stories dealing with Father Christmas and in this case, Father Christmas exists for good, both in the tale and on paper... But it does not prove his *existence* in the physical and literal sense of the word!

And there is a good reason for this: Father Christmas is not a historical figure, he has never been and will never be part of reality. In other words, nobody has ever met nor will ever meet him or come across him in the street.

Father Christmas does not *exist*, therefore, in the physical and literal sense of the word, he has never *existed* and never will!

In short, there definitely are two meanings to the word 'exist', and these meanings are by no means equivalent!

But that is not all! Literature also teaches us a second lesson!

The second lesson is that mixing genres is prohibited. Indeed, in literature, the distinction between reality and fiction is always perfectly clear.

That is to say, combining within the same tale two characters, a historical one and an imaginary one, is strictly prohibited, as it would be an unholy combination.

The combination would be devoid of interest, grotesque, absurd, even downright stupid!

Indeed, no one has ever thought of doing so!

So? If literature clearly distinguishes between reality and fiction, what about science in general and physics in particular?

Is the boundary between real and imaginary descriptions perfectly well defined in textbooks? Is the distinction between real forces and fictitious forces neat? Is the application of fictitious forces clearly detailed?

Carefully read everything that has been written here and there about fictitious forces, and more particularly about centrifugal force, including what has been endorsed, signed and validated by emeritus professors, you will have the answer!

We maintain that Father Christmas does not exist, nor does centrifugal force.

Various reactions...

How did the teaching community react to this amazing discovery?

As usual, when it comes to something new: '*We already knew that!*' '*You haven't discovered anything!*' '*It's useless!*'

As far as the first two reactions are concerned, one just needs to consider the eagerness with which the champions of orthodoxy stood up to save the moribund dogma, and especially the value of the arguments used, to understand that it is far from being useless.

How useful is the discovery? It is for those who have had it all wrong with the idea of centrifugal force to prove the value of an imaginary concept. Scientific truth, precision, accuracy need not be justified.

A gigantic brainwashing...

How do we explain such infatuation, such fervour, such blind faith in such a questionable, such a hazy, useless concept?

Ambiguous contents that are poorly put designed or misinterpreted, have been exposed in full or developed at length across most modern scientific literature (see the '*Cessac & Treherne*' ADILCA document, especially the paragraph on 'Saison, Allain, Blumeau, Duboc, Herchen, Mérat and Niard') and misused for propaganda on road safety, just to look good, scientific... and it unacceptably hijacks physics.

Intended to champion a laudable policy, these convoluted contents have never been able to avoid any accident and never will.

But promoted by teachers without qualifications or expertise, they have had the effect of a massive brainwashing, which young people willingly withstood every year.

As a result, everyone has heard of centrifugal force at one time or another, but hardly anyone has ever heard of guiding force!

The consequences of this diversion are enormous and even catastrophic on a large scale, to such an extent that we can speak today of a genuine intellectual and cultural disaster.

Conclusion

Just like the inertial force and the Coriolis force, centrifugal force is a fictitious force that has no real existence: it appears only in the context of imaginary descriptions.

Let us make it clear, it is obviously impossible to observe or feel the effects of an imaginary strength. This concept was consequently used wrongly to describe the phenomena observed when driving a car.

The truth is much simpler: the normal trajectory of a moving car is straight. To deflect the trajectory a transverse force called 'guiding force' must be activated.

The guiding force is a contact force exerted on the outskirts of the tires of the steering wheels when the driver operates the steering control (see '*guiding force'* ADILCA document).

The clear, logical and rational explanations to all the other phenomena that may be observed in a car result from this truth.

(1) *A special reference frame is what some physicists call a relative, non-inertial or non-Galilean reference frame.*

(2) *Be careful! The principle of action and reaction applies only to real forces, not to fictitious forces. Indeed, in an imaginary description, interactions do not exist. Isaac Newton did not need to specify this, as fictitious forces were unknown at the time.*

(3) *If one compares a car that weighs 2 metric tons and Earth (6 x 10^{24} kg), the mass ratio is 1 to 3 x 10^{21}, that is 1 to 3,000 trillion!*

(4) *To designate this discipline, the name of 'physical science' has gradually supplanted 'natural philosophy', in use until the early eighteenth century.*

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SOME RELATIONSHIPS BETWEEN PHYSICAL QUANTITIES…

1. Guiding force

$$F = M \cdot V^2 / R$$

F: guiding force, expressed in **N**
M: mass, expressed in **kg**
V: speed, expressed in **$m.s^{-1}$**
R: trajectory radius, expressed in **m**

Consistency of the des units: **F** = kg . $(m.s^{-1})^2$. m^{-1} = kg . ($m^2.s^{-2}$. m^{-1}) = $kg.m.s^{-2}$ = **N**

Example: calculate the guiding force acting in contact with the ground and which maintains a car with a mass of 1,500 kilograms (3,300 lb) on a circular trajectory of 100 meters radius (330 ft) at a speed of 20 meters per second (45 mph):

$$F = 1{,}500 \times 20^2 / 100 = 1{,}500 \times 400 / 100 = 6{,}000 \text{ N}$$

2. Transverse acceleration

$$\Upsilon = F / M$$

Υ: transverse acceleration, expressed in **$m.s^{-2}$**
F: guiding force, expressed in **N**
M: mass, expressed in **kg**

Consistency of the units: **Υ** = $kg.m.s^{-2}$. kg^{-1} = **$m.s^{-2}$**

Example: calculate the transverse acceleration of a car with a mass of 1,500 kilograms (3,300 lb) describing a circular trajectory of 100 meters radius (330 ft) at a speed of 20 meters per second (45 mph):

$$\Upsilon = 6{,}000 / 1{,}500 = 4 \text{ } m.s^{-2}$$

3. Centrifugal force

$$F' = - M \cdot \Upsilon$$

F': centrifugal force, expressed in **N**
M: mass, expressed in **kg**
Υ: transverse acceleration, expressed in **$m.s^{-2}$**

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

Example: calculate the force that should be exerted on the center of mass of a stationary car to create, on the suspensions and the tires, an effect comparable to that observed in reality when this car describes a circular trajectory of 100 meters of radius (330 ft) at the speed of 20 meters per second (45 mph):

$$F' = \mathbf{-}\ 1{,}500 \times 4 = \mathbf{-}\ 6{,}000\ \mathbf{N}$$

Note 1: this force is commonly referred to as "*centrifugal force*" which is an incorrect name since there is neither trajectory nor center (the bicycle + cyclist set remains motionless all the time). The scientific name of this force is: imaginary force, fictional force, or pseudo-force.

Note 2: the sign [**–**] is mandatory, it specifies that the spatial orientation of the centrifugal force is contrary to the logic of the movement.

Note 3: beware to misinterpretation, the numerical equality of results does not allow the interchangeability of descriptions, concepts or reasoning.

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

Note 5: any scientific approach is based on the same principle: from experiment, observations to *measurements* (here: measuring the mass of the car, its speed and the radius of its trajectory); measurements allow *calculations* (here: calculation a force and a transverse acceleration); calculations lead to a *reasoning* (here: the concept of centrifugal force). This passage from the concrete to the abstract reasoning, from the real to the imaginary has often been short-circuited, hence the confusion or misunderstanding about the centrifugal force.

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