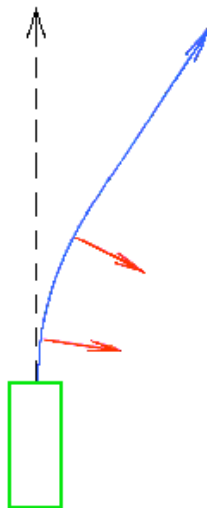


## THE GUIDING FORCE

In another ADILCA document ('*centrifugal force*'), we have shown that the centrifugal force was only an imaginary force, the only force to be considered when the car describes a circular path being the guiding force. Some specifications are now necessary as new questions arise. For example: what is a force, in the physical sense of the term? How to visualize a transverse force? Where does the guiding force come from and how to represent it? What is the true nature of the guiding force? With what formula can we express it? And what does it change, concretely? These are all the questions we shall answer here.

### A fundamental principle!

Three centuries ago, a genius physicist by the name of Isaac Newton decided to reconsider physics and formulated the universal laws of motion. Among other fundamental rules, Newton stated the following law: the natural trajectory of a moving body is rectilinear. To deflect the trajectory there must be a cause, that is to say a force. The precise definition of this term therefore follows from the previous law: a force is any cause capable of deflecting the trajectory of a mass.



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Newton's law: to deflect a mass from its rectilinear path, one must apply a transverse force, represented here by a red arrow.

### How to visualize a force?

Let us observe a child pulling a toy along with a string. The tension of the string and the movement of the toy perfectly illustrate the concept of force. In this case, there is a

tensile force, but the reasoning is also true for a circular path because according to Newton's law of motion, such a path results from the action of a transverse force.

To visualize this type of force, one only needs first to imagine the toy moving along a straight path, then to suppose that an invisible hand pulls on the string transversely to deflect the path.

### **Automotive applications**

Does this concept apply to cars? We all know from experience that the normal trajectory of a car is a straight line, it is a practical verification of Newton's law. Taking a turn is not all that obvious. If the driver wants to steer the car properly, he must apply a transverse force which deflects the initially straight trajectory. Obviously, there is no invisible hand or string, the driver simply turns the steering wheel. So what is the phenomenon involved in this operation?

### **The wheels of the caddie® trolley**

The rotation of the steering wheel causes pivoting of the steering wheels, so it is through these that this mysterious force manifests itself. How? A trivial observation will help us understand the principle. Have you ever noticed how difficult it is to push a shopping trolley if one of the wheels is not perfectly aligned? The erratic path of the trolley is due to the unexpected force the misaligned wheel exercises in contact with the floor.

### **...and those of the car...**

The same principle enables the driver to steer the car. The rotation of the steering wheel causes pivoting of the steering wheels, and, with it a transverse force exerted by the tire in contact with the road. This force is called the guiding force. It is through this principle that the driver can deflect the path of the car, there is no other force into play on this occasion. The enigma of the circular path is resolved. We must now identify the characteristics of this force.

### **How to draw a force?**

In order to draw a force, the best solution is to draw an arrow, preferably a red one, because this colour symbolizes well the concept of force. But make sure you isolate the different phenomena. You need to make a little effort to picture the situation mentally. The speed of the car, for example, is a quantity that is supposed to remain constant throughout the turn, it can only vary with the force of traction or braking, so it had better be forgotten!

And most importantly, no mixing of concepts! Remember that adding two vectors representing quantities of different natures is strictly prohibited!

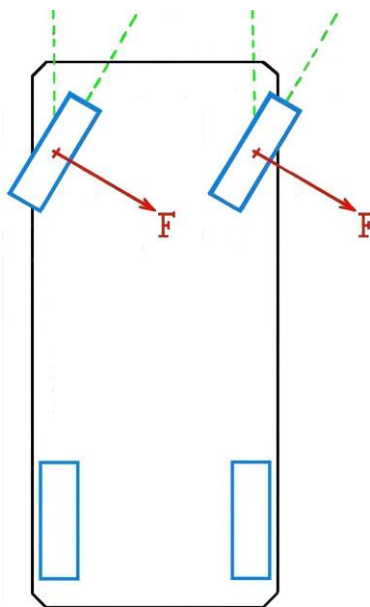
You cannot mix apples and oranges, forces and paths! In other words, on a drawing meant to represent a force, it is not advisable to include anything else, such as a path, for example, except as a dotted line or using a different colour. In any case, there is no need to add or overload the drawing as only one force is needed to make the car run! Just choose the right one and orientate it correctly.

### **Make a clean sweep of the past...**

That is not all! Brainwashing is essential! You must throw overboard everything that has been said on the subject for so many years, especially those famous wacky descriptions that clutter our minds and which everyone tries to hang onto out of habit, laziness or ignorance. You must make a clean sweep of the past, it is absolutely necessary... Too bad for the sorcerer's apprentice who juggled forces, concepts and reference frames the way one plays with a grenade without pin. Indeed, if descriptions are not lacking, they all have one thing in common: they conceal the only force that really exists!

### **Here is the guiding force at last!**

Time for a drawing now! The force that deflects the trajectory of the car originates at the ground contact point of the two steering wheels. It is represented by an arrow perpendicular to the plane of rotation of the wheels, orientated towards the inside of the bend, i.e. to the side where the car is deflected.



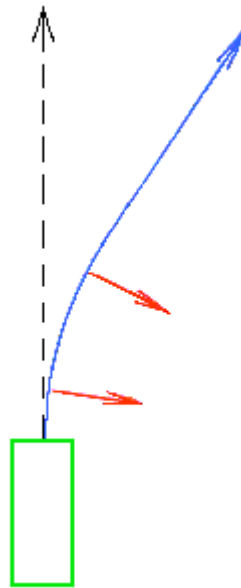
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The guiding force originates on the steering wheels upon contact with the ground.

There is nothing else to add, except for the role of the rear wheels: as they prevent the car from turning on itself, they participate in the lateral acceleration of the center of mass...

### A little tip to make sure...

No real scientific description without verification! How to check the validity of a drawing? It is very simple, and only requires a little common sense and a stretch of the imagination by replacing mentally the arrow supposed to represent a force with a string on which an invisible hand pulls.



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To visualize a force, replace the red arrow with a string on which one pulls!

If the drawing is correct, the imaginary movement reflects a path deflection as we could observe in the field! And while you are at it, you may also use this tip to test the drawings that pass through your hands. You will be surprised! No need for heavy scientific demonstration, you will tell immediately whether the description makes sense...

### The action-reaction law

Does Newton's third law <sup>(1)</sup> – also known as 'action-reaction law' – apply to the guiding force?

Of course it does, precisely because the guiding force is a real force, unlike fictitious forces (all of them!) for which this law does not apply, cannot apply and never does!

Let us resume our reasoning. As pointed out above, the guiding force is exerted on the tires in contact with the ground. The reaction associated with this force therefore also occurs at ground level.

Indeed, when a driver activates the guiding force, the car performs a thrust against Earth<sup>(2)</sup>, and this thrust should logically affect its rotational movement.

Fortunately, this effect is purely theoretical because the mass of the car is considerably lower than that of Earth<sup>(3)</sup>, so that the car can only slide or register obediently on a circular path!

Let us note that the divergent trajectories of the large number of vehicles in circulation would negate this effect, should it be noticeable...

### **The true nature of the guiding force**

One last question needs to be answered: what is the true nature of the guiding force? Is it centripetal, as some argue here and there?

Guiding force is a contact force of same nature as that which is activated when you press an object between your fingers. Just like the pressure exerted on the object, the weight which bears on the wheels is an important factor which determines the intensity of the force, but it is not the only one.

Indeed, contact affinities derived from tiny electrical loads acting at the level of atoms can occur between the tire and the road surface. These affinities allow the tread rubber to exploit the roughness of the road surface (see ADILCA files).

The so-called 'grip' is the result of this combination of factors. It explains many phenomena that may be a priori incomprehensible: with the same mass on rough ground, wide tires stick better than narrow tires; the grip is better if the wheels roll than if they slide; the braking force can be greater than the weight, etc.. All these phenomena are denied or ignored in official literature on 'road safety'...

Is guiding force centripetal? 'Centripetal' means 'which brings closer to the center'. This center is that of the circle described by the car. But one thing is obvious: the car never takes the lead, it never gets close to it, it is only deflected from an initially straight path! Guiding force is thus not centripetal. In fact, logically, only a force acting at a distance can be called centripetal, and only two forces meet this criterion: electromagnetic force and gravitational force (see ADILCA file '*centripetal force*').

### **Guiding force: the true definition!**

The foregoing leads us to this new and original definition of the guiding force:

'Guiding force refers to any pressing force, contact or friction force capable of deflecting the trajectory of a mass'.

Is it a completely new definition? It is indeed, because we must remember once again that this force, important as it is, activated as it is daily by millions of drivers, is named or described nowhere in the usual works of reference... One would think that physicists did not know that it existed or acted as if it did not!

### **Guiding force: the correct formula!**

How to express the guiding force? Of course, everyone knows the famous formula that is used everywhere, and often indiscriminately:

$$F = M V^2 / R \quad (4)$$

However, not many know that this formula does not express, never expressed and will never express the centrifugal force, but only the guiding force<sup>(5)</sup>! Can we demonstrate it mathematically? Yes we can!

And here is how: centrifugal force is a fictitious force which appears only in the context of imaginary descriptions, as is a static description or one which takes the vehicle as a reference frame (see ADILCA documents). But what characterizes this type of description is the total lack of movement. It is as if nothing moved, as if the mobile was immobile! Under such conditions, the speed is always zero, of course. If you try to apply the formula, the result is surprising:

$$\forall M, \forall R \neq 0, \text{ for } V = 0, F = MV^2/R = 0 / R = 0!...$$

Not to mention the radius of the path which no longer exists either, but is still considered, for want of anything better, as a real non-zero real number! In short, in this kind of description, the formula is strictly inapplicable. Q.E.D.!

In reality, of course, there is no path radius without speed, and speed exists only in the context of an actual description of the movement. Then it works! The formula thus applies if, and only if, one considers a mass (**M**) driven with a speed (**V**) and describing a circular path of radius (**R**).

In other words, the famous formula **F = MV<sup>2</sup>/R** refers indeed solely to the dynamics, and therefore to the guiding force, but to it alone! Everything is now perfectly clear!

### **How to calculate the guiding force...**

Let us study the limits of the function **F = MV<sup>2</sup>/R** in relation to **R**.

If we consider that a u-turn is a curve with a zero radius, we can, on the basis of the preceding relation, write:

$$F = MV^2/R = MV^2/0 = \infty$$

We can deduce that a u-turn on the spot is impossible because it would require a guiding force of infinite intensity.

Conversely, if we consider that a straight line is a curve of infinite radius, we can, on the basis of the preceding relation, write:

$$F = MV^2/R = MV^2/\infty = 0$$

We can deduce that the rectilinear trajectory results from a lack of guiding. It is exactly what happens when a car swerves off the road: if the guiding force is insufficient or absent, the car describes or goes back into a straight path.

Let us now take the example of a car, 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<sup>-1</sup>).

Let us calculate the intensity of the guiding force that is exerted on the tires of the car in contact with the ground:

$$F = MV^2/R$$

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

Let us study now the limits of the function  $F = MV^2/R$  in relation to  $V$ .

All quantities being equal, we can see that the guiding force must vary in proportion to *the square of the speed*. In other words, the intensity of the guiding force must be doubled when the cornering speed is multiplied only by value  $2^{1/2}$  ( $2^{1/2} = 1.414$ ).

### **The reactions of the car**

It is clear and final: the guiding force is definitely the only force to be considered in the study of circular motion.

What difference does it make in practice? Lots of things! For example, it is now possible to describe in a logical and precise manner the nature and intensity of the reactive movements of the mass of the car phenomena that had been ignored, or unexplained or considered as unexplainable by those who were stuck with the concept of centrifugal force. It is one of the great successes of the new concept.

What is it all about? The guiding force has two components, one is transverse and the other is longitudinal. These two components are not exerted on the center of mass of the car but on the steering wheels in contact with the ground.

That is why, when the driver operates the steering control, the mass of the car responds with a triple rotational movement which is decomposed along three orthogonal axes.

Those three movements are pitch, roll and yaw. They cannot be studied here; interested readers may refer to '*GUIDE DES LOIS PHYSIQUES DE L'AUTOMOBILE*'.

The new concept thus responds to questions that had haunted automotive specialists for ages and had as yet not been answered satisfactorily, among which are the following ones:

- how to explain the rotation of the car in a horizontal plane when the driver makes a turn to change course<sup>(6)</sup>?
- where does the induced braking process come from?
- why is the pivoting angle of the steering wheels limited to 45°?
- what is the role of the rear wheels?
- what are the consequences of acceleration or braking in a turn?
- how to account for the action of the ESP (Electronic Stability Program)? Etc.

Try explanations based on the concept of centrifugal force: the contradictions, inconsistencies and absurdities will multiply, and you will soon come to a dead end.

## Conclusion

Physics is a noble science which admits only one truth. The natural path of a vehicle is straight. To deflect this path, one needs to apply a transverse force called guiding force: it is a contact force exerted on the tires of the steering wheels in contact with the ground when the driver activates the steering control.

This force is expressed by the formula  $F = MV^2/R$ . Its intensity is inversely proportional to the radius of the path, it depends on the mass of the car and the square of its speed. There is no other force into play on this occasion.

(1) *Newton's third law goes: '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) *This reaction can 'work' the coating, as can be seen for example on car racing circuits, where drivers operate a transverse acceleration.*

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



(4) According to the International System of Units (symbol: **SI**) – compulsory in most countries around the world, e.g. in United States since 1964, in United Kingdom since 2004 – the mass is expressed in kilograms (symbol **kg**), the speed is expressed in meters/second (symbol  $\mathbf{m.s^{-1}}$ ) and the radius of a trajectory is expressed in meters (symbol **m**). The dimension obtained is kilogram-meter per square second (symbol  $\mathbf{kg.m.s^{-2}}$ ) which characterizes the force unit, the newton (symbol **N**). This quantity is named in tribute to the work of Sir Isaac Newton, English physicist and mathematician (1642-1727), one of the forerunners of modern science.

(5) It is more precisely the net force causing the lateral acceleration of the center of mass of the car, which must be distinguished from the yaw moment exerted by the steering axle (see 'GUIDE DES LOIS PHYSIQUES DE L'AUTOMOBILE').

(6) One could perfectly imagine a transverse acceleration without such a rotation, so without a change of course, which would happen if the car was equipped with four wheel steering that could pivot at the same angular value.

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## SOME RELATIONS BETWEEN QUANTITIES...

### Transverse acceleration

$$Y = V^2 / R$$

**Y**: transverse acceleration expressed in **m.s<sup>-2</sup>**

**V**: speed, expressed in **m.s<sup>-1</sup>**

**R**: radius of trajectory, expressed in **m**

consistency of the units:  $Y = (m^{+1} \cdot s^{-1})^2 \cdot m^{-1} = m^{+2} \cdot s^{-2} \cdot m^{-1} = m \cdot s^{-2}$

Example: calculate the transverse acceleration of a car describing a circular path of radius 100 m at a speed of 20 m.s<sup>-1</sup> :

$$Y = 20^2 / 100 = 400 / 100 = 4 \text{ m.s}^{-2}$$

### Transverse acceleration coefficient

$$\mu = Y / g$$

**μ**: transverse acceleration coefficient, dimensionless quantity;

**Y**: transverse acceleration in **m.s<sup>-2</sup>**

**g**: reference acceleration, expressed in **m.s<sup>-2</sup>**

(Earth's gravitational acceleration  $g = 9.8 \text{ m.s}^{-2}$ )

consistency of the units:  $\mu = (m^{+1} \cdot s^{-2}) \cdot (m^{-1} \cdot s^{+2}) = \text{dimensionless quantity}$ .

Example: calculate the transverse acceleration coefficient enabling a transverse acceleration of 4 m.s<sup>-2</sup>:

$$\mu = 4 / 9.8 = 0.4$$

### 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<sup>-1</sup>**

**R**: radius of path, expressed in **m**

consistency of the units:  $F = \text{kg} \cdot (m \cdot s^{-1})^2 \cdot m^{-1} = \text{kg} \cdot m^{+2} \cdot s^{-2} \cdot m^{-1} = \text{kg} \cdot m \cdot s^{-2} = \text{N}$

Example: calculate the guiding force capable of maintaining a 1,500 kg car mass over a circular path of radius 100 m at a speed of 20 m.s<sup>-1</sup> :

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

### Center of mass

$$d = L \cdot M2 / (M1 + M2)$$

**d**: distance between the center of mass and the steering axle, expressed in **m**

**L**: wheelbase, expressed in **m**

**M1**: mass on the front axle, expressed in **kg**

**M2**: mass on the rear , expressed in **kg**

consistency of the units:  $d = m \cdot kg \cdot kg^{-1} = m$

Example: calculate the distance between the center of mass and the steering axle of a car with the following characteristics: wheelbase 2.5 m, 840 kg weight on the front wheels, 660 kg on the rear wheels:

$$d = 2.5 \times 660 / (840 + 660) = 1\ 650 / 1\ 500 = 1.1 \text{ m}$$

### Front wheel drive axle guidance

$$F = M \cdot Y \cdot (L - d) / L$$

**F**: guidance of front wheel drive axle, expressed in **N**

**M**: mass, expressed in **kg**

**Y**: transverse acceleration, expressed in **m.s<sup>-2</sup>**

**L**: wheelbase, expressed in **m**

**d**: distance between center of mass and steering axle, expressed in **m**

consistency of the units:  $F = kg \cdot m^{+1} \cdot s^{-2} \cdot m^{+1} \cdot m^{-1} = kg \cdot m \cdot s^{-2} = N$

Example: calculate the guiding force exerted by the front wheel drive axle of a car of mass 1,500 kg (wheelbase 2.5 m, distance between the center of mass and steering axle 1.1 m) for a transverse acceleration of 4 m.s<sup>-2</sup>:

$$F = 1,500 \times 4 \times (2.5 - 1.1) / 2.5 = 6,000 \times 1.4 / 2.5 = 3,360 \text{ N}$$

### Rear wheels guidance

$$F = M \cdot Y \cdot d / L$$

**F**: guidance of rear wheels, expressed in **N**

**M**: mass, expressed in **kg**

**Y**: transverse acceleration, expressed in **m.s<sup>-2</sup>**

**d**: distance between center of mass and steering axle, expressed in **m**

**L**: wheelbase, expressed in **m**

consistency of the units:  $F = kg \cdot m^{+1} \cdot s^{-2} \cdot m^{+1} \cdot m^{-1} = kg \cdot m \cdot s^{-2} = N$

Example: calculate the guiding force exerted by the rear wheels of a 1,500 kg car mass (distance between the center of mass and steering axle 1.1 m, wheelbase 2.5 m) for a transverse acceleration of  $4 \text{ m.s}^{-2}$ :

$$F = 1,500 \times 4 \times 1.1 / 2.5 = 6,000 \times 1.1 / 2.5 = 2,640 \text{ N}$$

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