

VR-Design Studio

Car Physics Engine

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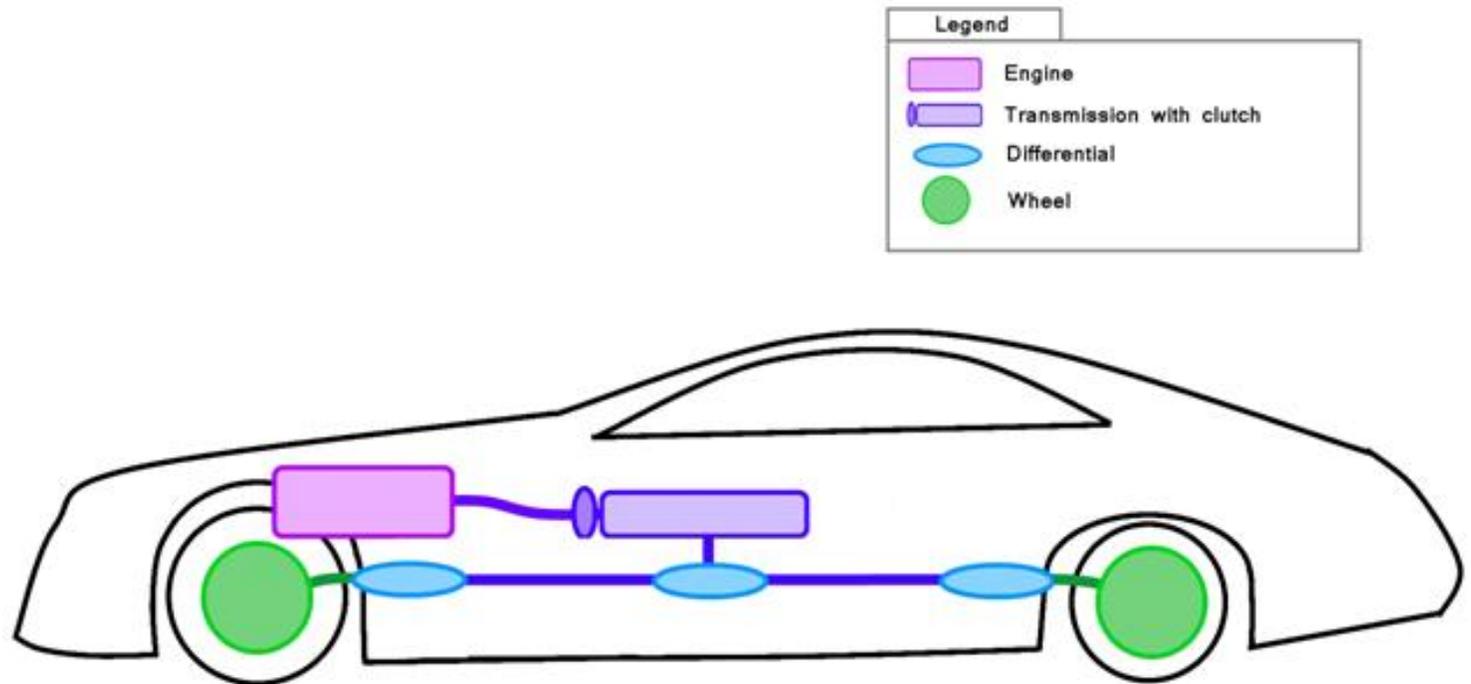
Introduction

In VR-Design Studio FORUM 8 introduces a new physics engine for cars. Our goal is to provide a more realistic comportment and a better driving experience by simulating the car from the engine down to the wheels on the road. This new model is able to simulate slipping, reverse gear and full manual transmission. This document will introduce our new physics engine for cars in VR-Design Studio.

I – General

I.1 Model

The new model is based on a manual-transmission vehicle, using a clutch to connect the engine to the transmission. When driving in automatic transmission, the gear shifting and the clutch are automatically operated.



Above: a diagram of the composition of the model used in VR-Design Studio.

The main parts of the model are:

- The engine: creates torque
- The transmission: connects the motor to the wheels and adapt the torque to the speed
- The differentials: distributes the torque from the input to its two outputs
- The wheels: transform the torque in a force that moves the car

Each of the internal parts will be detailed later in this document.

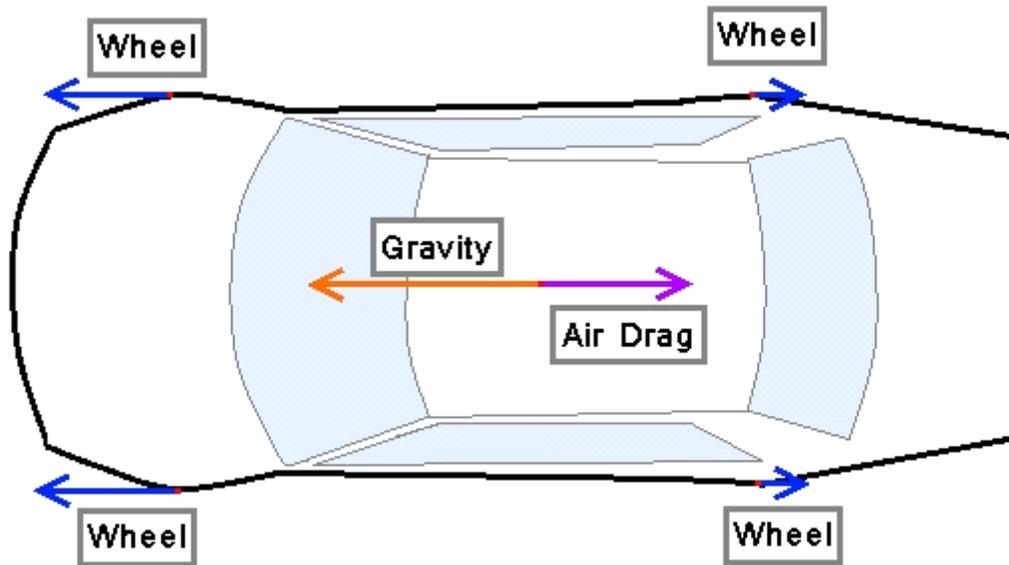
I.2 General physics

In this part we will present the general physics for a vehicle in VR-Design Studio. There are 4 forces acting on a vehicle:

- Gravity
- The force generated by the wheels
- Ground reaction
- Air Drag

In VR-Design Studio we consider only the forces that are in the road's plane so only components of the gravity force and of the ground reaction in the road plane are actually used.

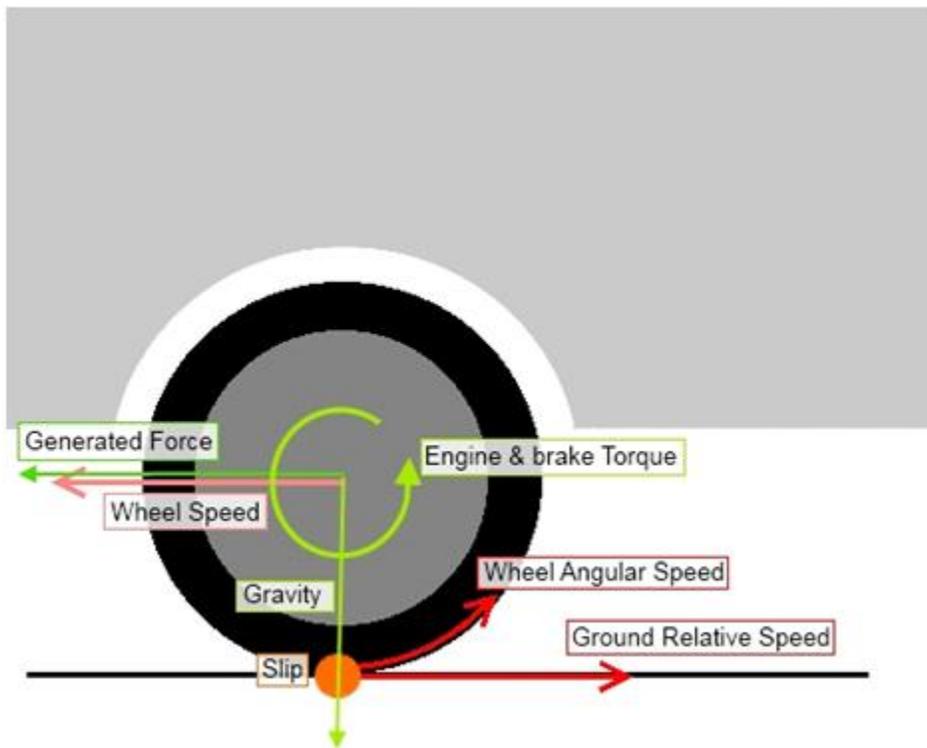
This diagram presents the car and the forces.



The gravity is created by the inclination of the road while the air drag depends of the speed of the car. Usually the main force moving the car is the cumulative force of the 4 wheels that will be the subject of this document.

I.3 Introduction to the force created by the wheels

The difference between the wheel angular speed and the ground relative speed creates a slip between the tyre and the ground, which will then create a force proportional to the load supported by the tyre.



While the ground relative speed is related to the car speed, the wheel angular speed is related to the torque created by the engine, the brake torque and the ground reaction force.

In the other parts, we will see in detail every part from the engine to the wheels to see how we determine the force generated by the wheels.

II – The Engine

In this part we will describe the engine.

To calculate the force created by the wheels, we need to know the torque created by the engine.

In an engine, the output torque is a function of the RPM and the throttle. We need to calculate the RPM of the engine and then we can calculate the torque.

II.1 Engine RPM

There are two sources of RPM for an engine : The RPM created by the engine itself, and the RPM of the wheels coming through the transmission.

When the clutch is disengaged the RPM depends only of the RPM created by the engine itself, when the clutch is fully engaged the RPM of the system engine-transmission-wheels determines the engine's RPM. Finally between those two states, when the clutch is partially engaged the RPM is a mix of both.

If we consider the engine alone (clutch disengaged), the engine angular speed depends of the engine output torque and it's inertia alone.

Then if we consider the engine and the wheels (clutch engaged), the rotating system includes all from the engine to the wheels. To calculate the angular speed, we use the total torque applied on the system on the wheels and the total inertia viewed from the wheels.

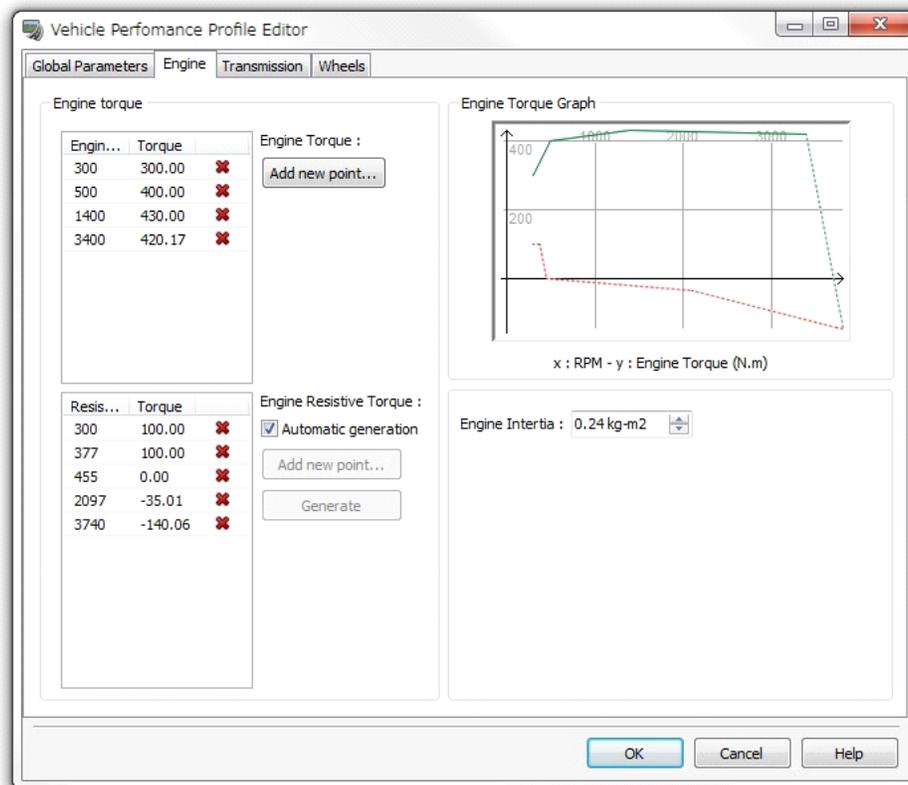
Then the RPM goes back to the engine through the transmission.

II.2 Engine Torque

The engine torque is a function of the RPM and of the throttle. In the Vehicle Performance Profile the user defines a torque curve and a resistive torque curve. The output torque is calculated from those curves with $x = \text{RPM}$ and y depending of the throttle and both curves for this RPM.

The point (x,y) is the output torque of the Engine. This Torque is then transmitted to the transmission.

II.3 Engine settings in VR-Design Studio



Here is the Vehicle Performance Profile where the user can set the torque, the resistive torque and the engine inertia:

III - The Transmission

III.1 Transmission modes

In VR-Design Studio, when using the new car physics model, you can choose between 3 different modes for the transmission :

- Automatic : The clutch and the gear shifting are automatically operated
- Sequential Manual : The clutch is automated but the driver shifts the gears
- Manual : complete manual transmission, the driver has the control of both the clutch and the gear shifting

III.2 General functioning

The transmission consists of two parts : the clutch and the gearbox.

The clutch is here to allow a disconnection between the wheels and the engine. An engine needs to have a minimum RPM to keep functioning, but when a car starts, the RPM of the wheels is usually 0 so there is a need to disconnect them and then progressively add speed to the wheels until we can lock them system as a whole.

The clutch is also used to disconnect the engine from the transmission while shifting gears.

The gear box adapts the torque and RPM of the engine with speed of the vehicle by multiplying the torque and dividing the RPM by a ratio. High ratios allow high torque but the limit in RPM is lower while low ratios allow high RPM but low torque. Usually the first gear has the highest ratio while the higher gear has the lowest ratio.

The transmission also has an overall ratio it is always applying, the final drive ratio, and as all physical systems loses some energy by converting it into heat.

Finally the formula of the Transmission is (engine → wheels):

III.3 Automatic gear box

In VR-Design Studio we implemented an automatic gear box algorithm operating the clutch and shifting the gears.

III.3.1 Clutch

The clutch operation is divided in phases, the more important ones being the start phase and the shift phase.

- Start phase : the clutch is progressively engaged while the car is gaining speed
- Shift phase : the clutch is disengaged, the gear is shifted and then the clutch is re-engaged.

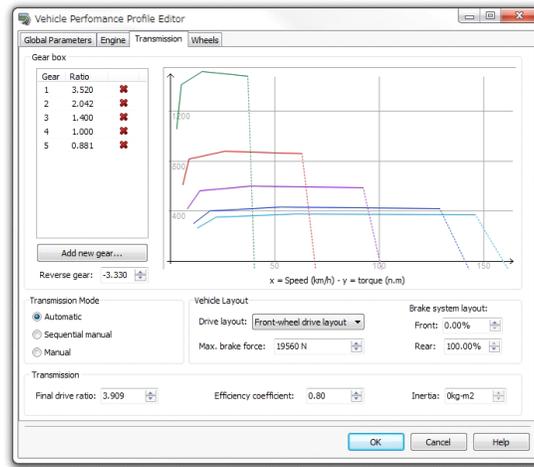
In sequential mode, the clutch is operated in the same way.

III.3.2 Gear Shifting

The transmissions tries to always be on the gear allowing the maximum torque at the current speed. When the car stops, it goes to neutral.

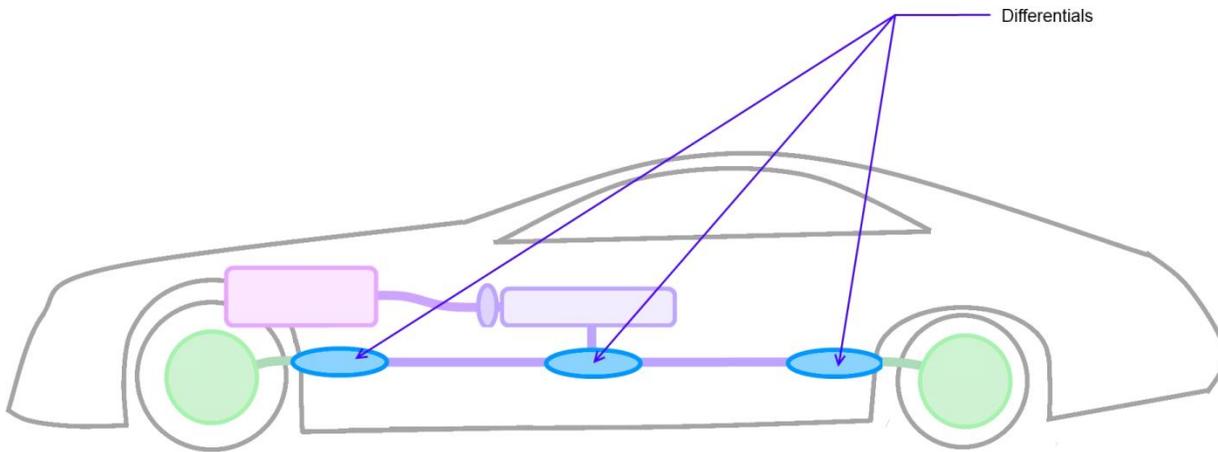
III.4 Transmission Settings in VR-Design Studio

In the Vehicle Performance profile, the Transmission Tab allows you to set the gear and final drive ratios, the efficiency and the inertia of the transmission. You can also choose which mode you want to use.



IV – The Differentials

The differentials distribute the torque from the engine to it's two outputs.
In VR-Design Studio one car has 3 differentials :



The first one, connected to the transmission passes the power to the front differential or the back differential or both, depending on the car setting. For a traction car, all the power goes to the front differential, for a propulsion car all the power goes to the rear differential and for a four-wheel drive car the torque is distributed between front and rear. When connected to the drive wheels, the rear and front differentials distribute the power to the left and right wheels depending of the resistance they oppose. The wheel having the less resistance will receive the bigger torque. When not connected to drive wheels they don't transmit any torque to the wheels or between the wheels. You can choose the type of the vehicle in the transmission tab of the Vehicle performance profile. Front Drive Car, Rear Drive Car and Four Drive Wheels Car are available.

V – Brakes

In VR-Design Studio the brakes are a torque applied to the wheels when the user presses the brake pedal. The torque on each wheel depends of the front/rear repartition of the brakes, the maximum brake torque defined by the user and how much the brake pedal is pressed.

The front/rear repartition and the maximum brake torque can be edited in the transmission panel of the Vehicle Performance Profile Editor.

VI – Wheels

As we saw in (1.3) the wheels create a force depending on the “slip” the difference between their angular speed and the relative speed of the ground. We will now see in detail the physics of the wheels.

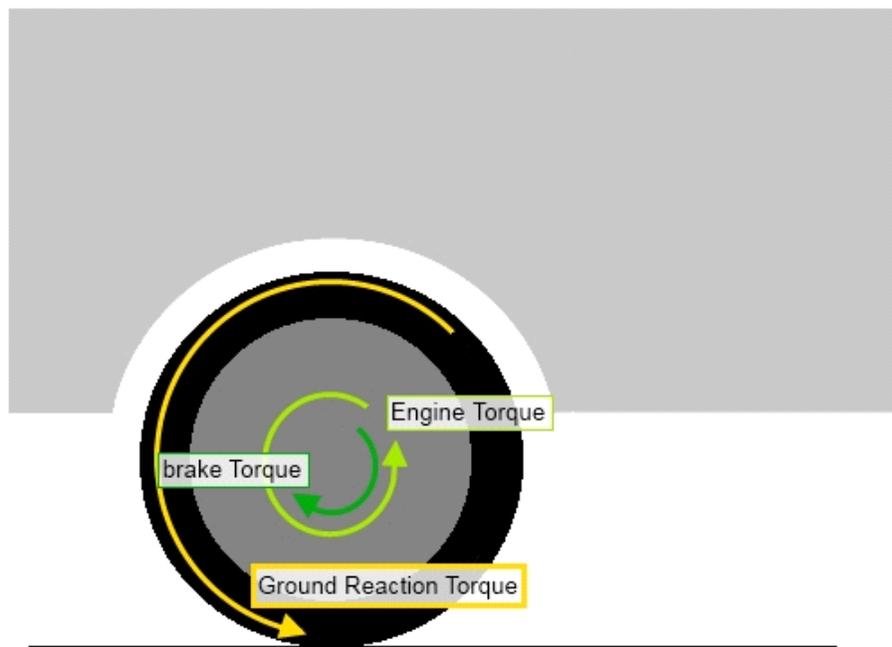
VI.1 Longitudinal Force

VI.1.1 Torque and angular speed

To calculate the slip we need the angular speed of the wheel. The angular speed is determined by the torque acting on the wheel :

- The engine torque
- The break torque
- The ground reaction torque
- The rolling resistance (a turning tyre creates a resistance to this movement)

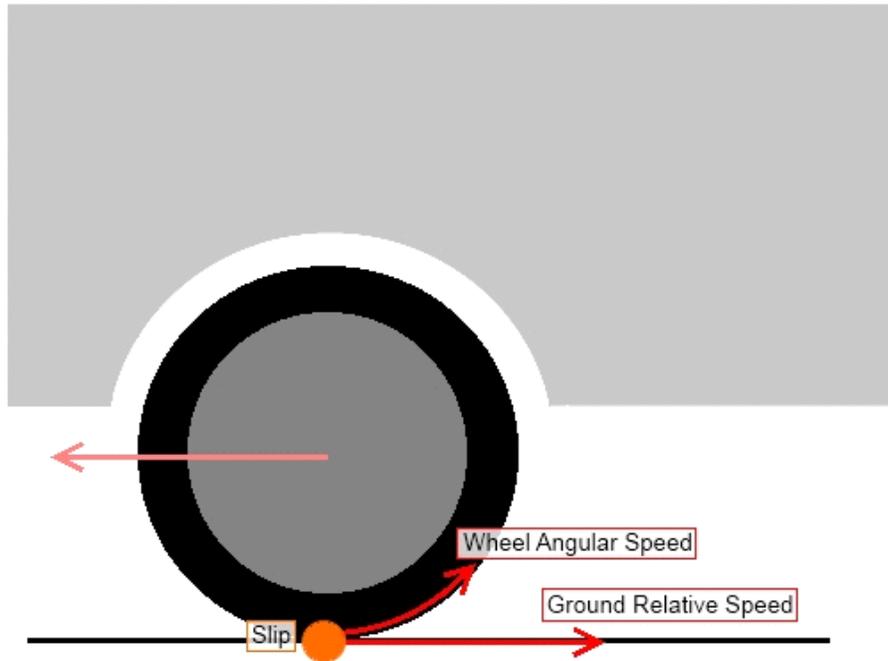
One other thing to take in account is the inertia : what turns is not only the wheel but the whole wheel-transmission-engine system so the inertia is not the wheel inertia alone but the inertia of the whole system.



VI.1.2 Speed and Slip

The total torque creates an acceleration which in turn modifies the angular speed of the wheel.

Then the difference between the relative speed of the ground and the speed of the surface of the tyre at the contact point with the ground (angular velocity) will create a slip.

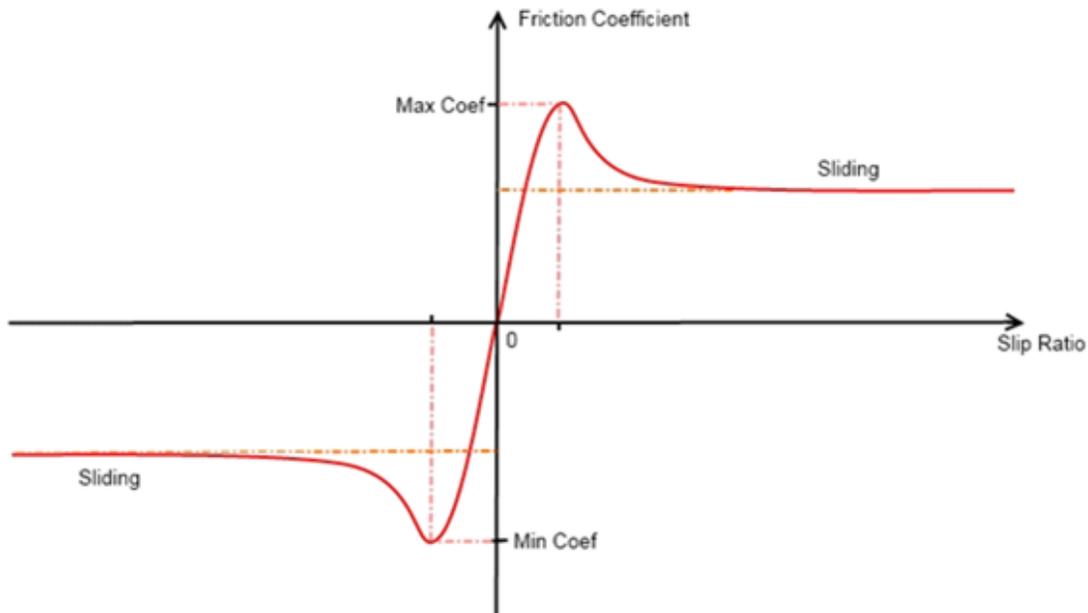


VI.1.3 Slip and forces

Finally the slip will determine the friction coefficient of the tyre which in turn will determine the force generated by the tyre. The value used to quantify the slip is a ratio of the two speeds called slip ratio.

The Force equals the friction coefficient multiplied by the load on the tyre (weight of the tyre and more or less a quarter of the weight of the car).

The Friction coefficient is determined by the friction curve : Friction Coefficient = $f(\text{Slip Ratio})$



When the car is accelerating, the wheel speed is greater than the ground relative speed so the slip ratio is positive, whereas when the car is braking, the wheel speed will be slower than the ground relative speed and the slip ratio will be negative.

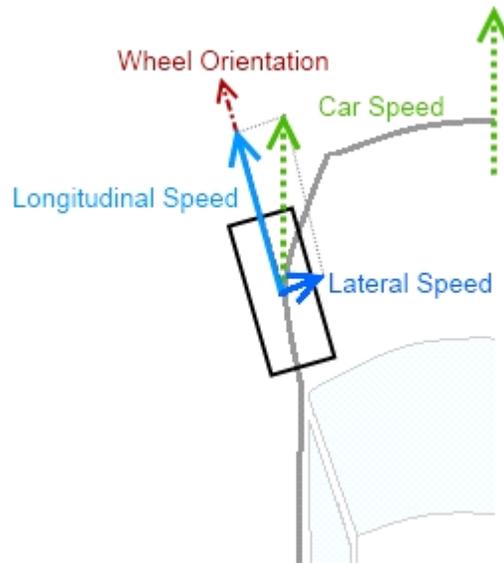
The Friction coefficient has a maximum (Slip Ratio ~ 0.1) and when the slip ratio is greater than the value of the maximum friction coefficient, the car is sliding.

VI.2 Lateral force

For the lateral force the principles are the same than for the longitudinal force, the only differences being the definition of the slip and the curve that while having the same shape, as different values.

The lateral slip is the difference between the longitudinal and lateral speeds of the tyre. When the wheel is aligned with the movement of the car, it's lateral speed is nonexistent and it's longitudinal speed equals the car's speed. But if the

wheel and the car movements are not aligned, as when steering in a car going straight, a lateral speed appears on the tyre and a force is generated.



VI.3 Wheels settings in VR-Design Studio

In the Wheels tab of the Vehicle Performance Profile Editor you can edit the settings of the wheels. The following values can be edited :

- Longitudinal and lateral friction coefficient curves
- Rolling Resistance
- Wheel Radius
- Wheel Inertia

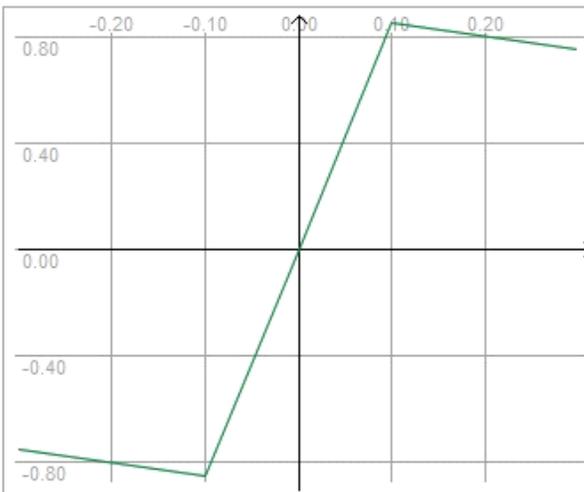
Enable Tyre Dynamics

Friction Coefficient

Type:

- Longitudinal
- Lateral

Slip ratio	Coefficient	
-0.30	-0.750	✘
-0.10	-0.850	✘
0.00	0.000	✘
0.10	0.850	✘
0.30	0.750	✘



Add new point...

Rolling Resistance

Rolling resistance coefficient: 0.004

Rolling resistance speed coefficient: 0.090 s/km

Geometry

Wheel radius: 0.393 m

Spin inertia: 0.90 kg-m²

OK Cancel Help