

# Brake performance and stability for bicycles

*by Gunnar Olsson*

SAFER & SVEA seminar "Vehicle Dynamics Challenges"  
May 15, 2013, Göteborg

LeanNOVA



TRAFIKVERKET

# Brake performance and stability for bicycles

## Background

- More and more people are living in cities, which promotes small vehicles
- Number of people driving bicycles are increasing
- Number of accidents with cars are decreasing. This is not the case with bicycles
- Accidents with bicycles often have severe consequences.

## Objective

- To investigate brake performance and stability behaviour for bicycles
- to propose measures to mitigate stability problems while maintaining/enhancing brake performance.

## Project team

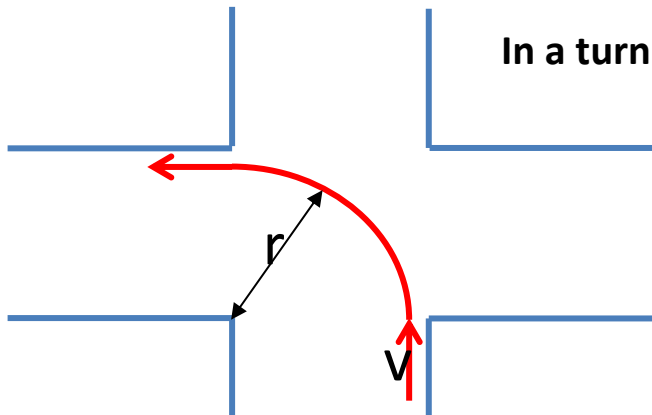
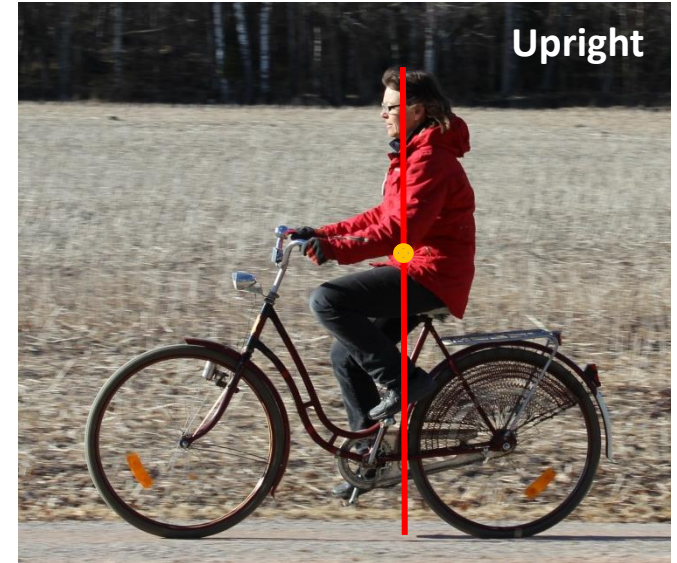
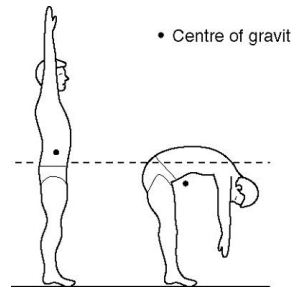
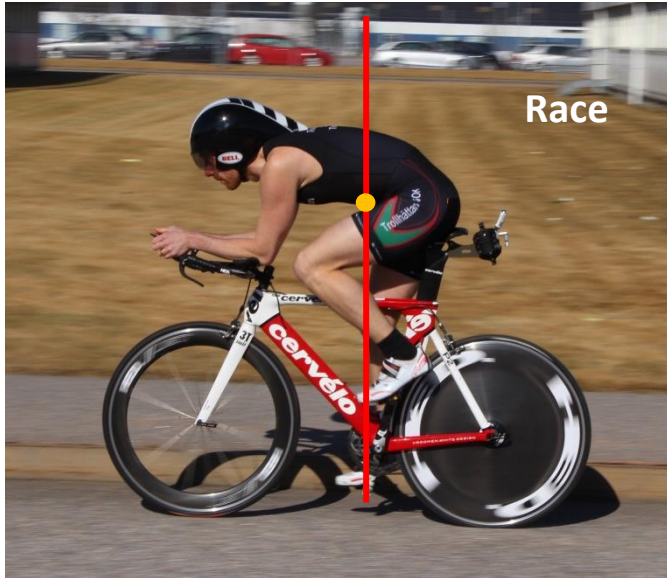
Gunnar Olsson, Petter Hedström at LeanNova and CAE-Value (simulation)

# Brake performance and stability for bicycles

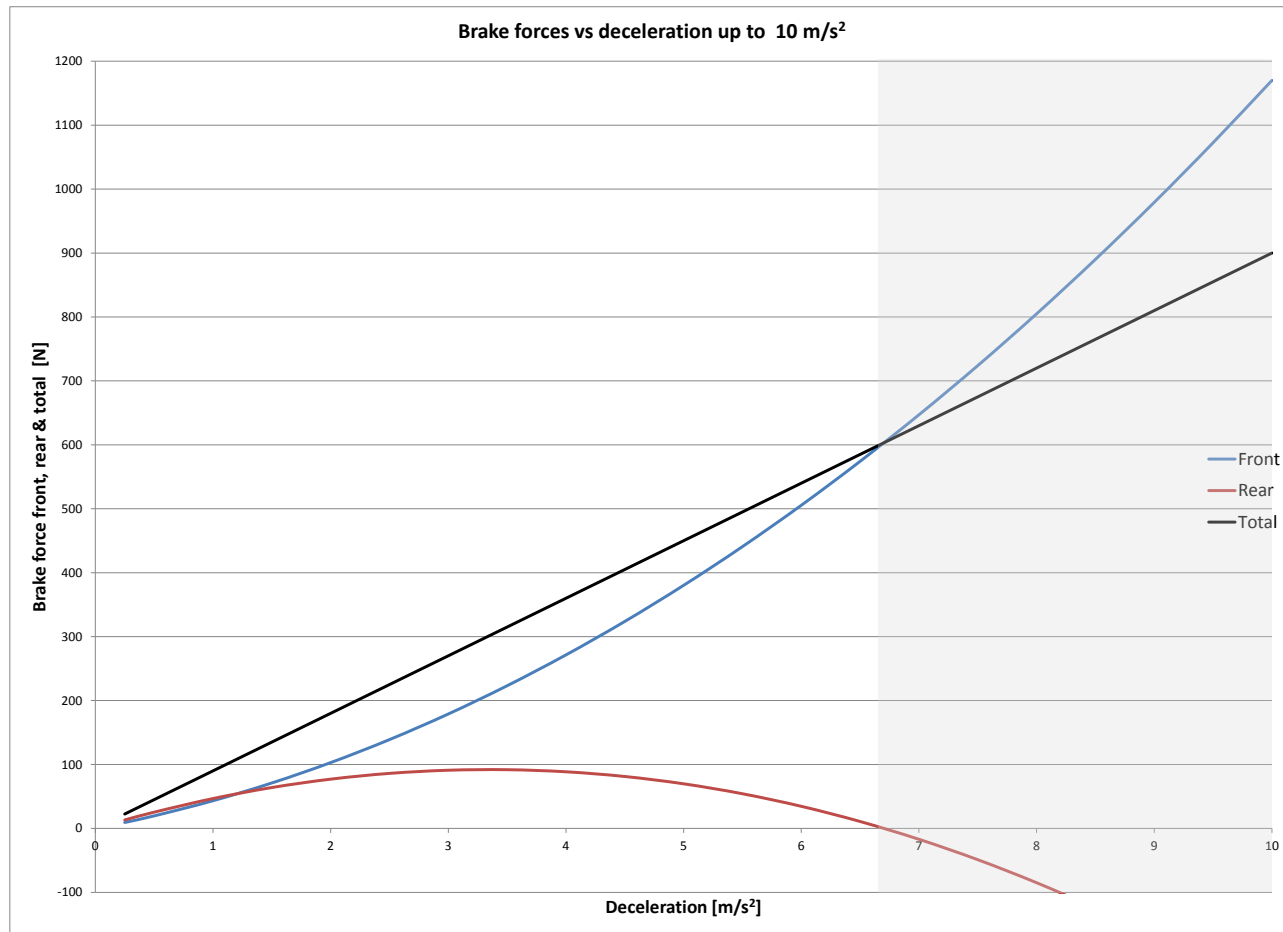
## Calculations and simulations, procedure:

- Collecting input data from bicycles regarding dimensions, mass and mass distribution
- Estimating the centre-point of gravity (CoG) for the driver
- Calculating the brake force distribution for different configurations and driving conditions using MS Excel
- For some transient manoeuvres add dynamic simulations using the “VI-Driver” software

# Bicycle configurations and driving conditions



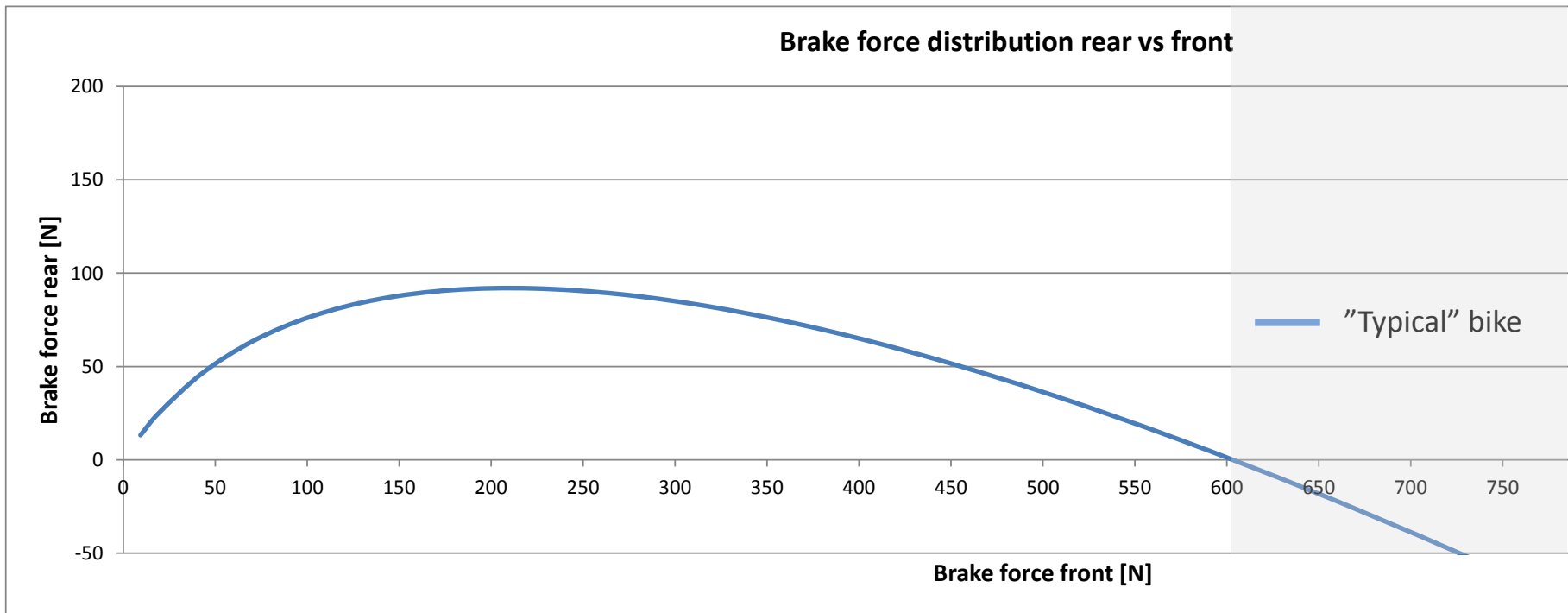
# Brake forces for a “typical” bike



The figure shows the total brake force from a “typical” bicycle with a total weight of 90 kg including driver (75 kg) and how this force need to be distributed between front and rear for maximum utilization of the tyre/road friction  $\mu$ .

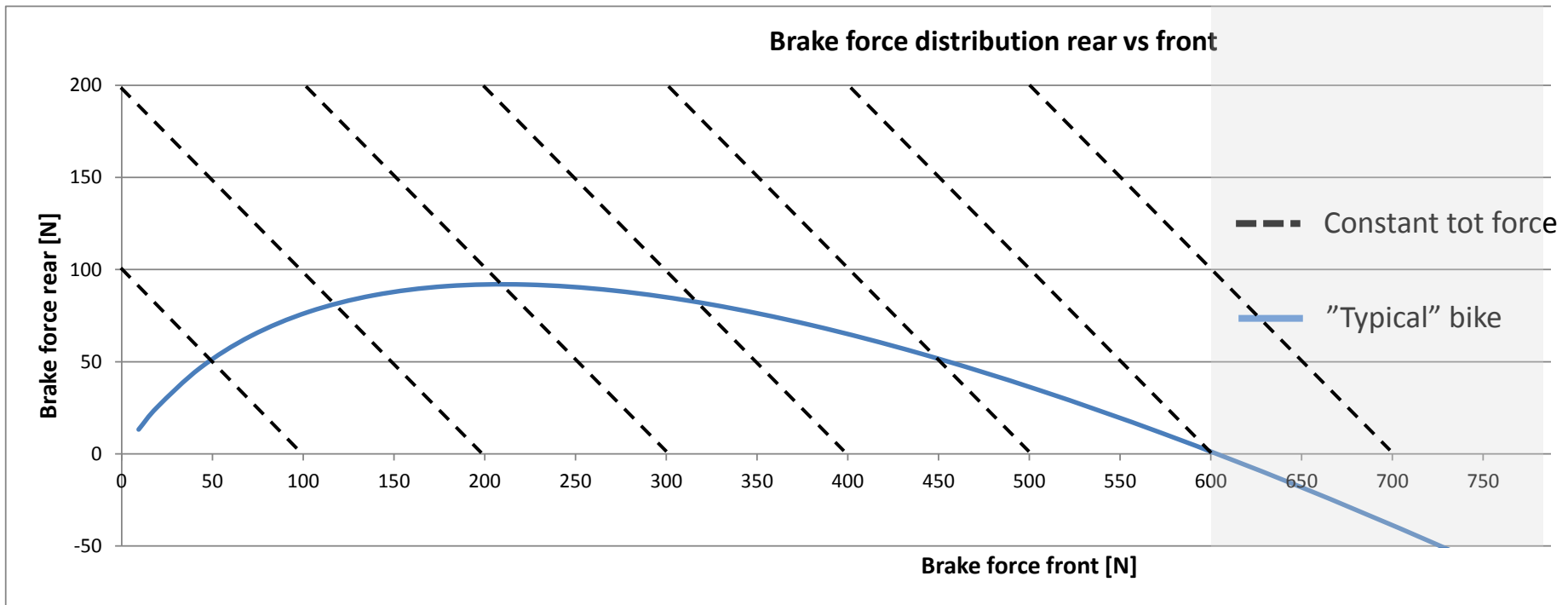
At the deceleration = 6.7 m/s<sup>2</sup> the rear brake force become negative and is not valid anymore. At this point, the rear wheel lifts and the driver fall over the handlebars.

# Brake force distribution for a “typical” bike



- This figure shows a common way to present the brake force distribution for a vehicle.
- Here the rear brake force  $F_R$  is plotted vs the front brake force  $F_F$ .
- The curve illustrates how the brake force must be distributed between the front and rear wheel for maximum utilization of the tyre/road friction (shortest stopping distance), i.e. optimal force distribution

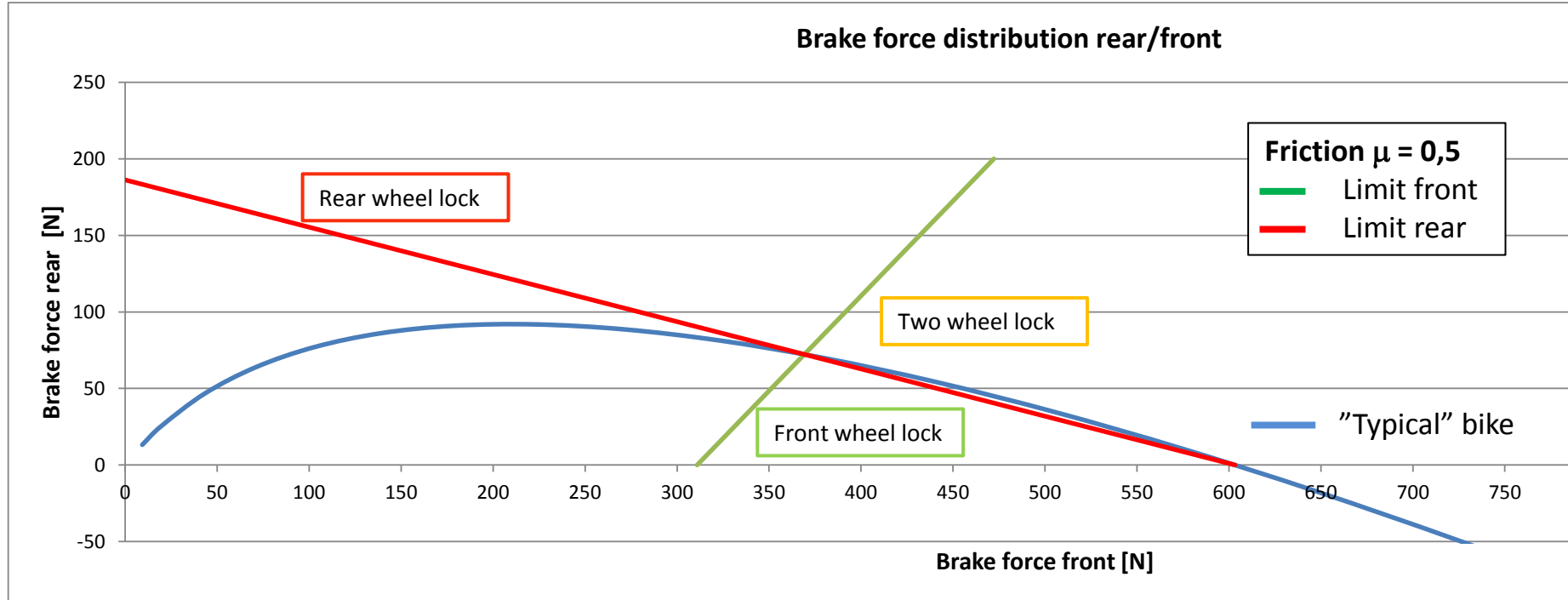
# Brake force distribution for a “typical” bike



In this figure dotted lines are added showing constant total brake force. If tyre-road friction allows a brake force distribution anywhere one the line would give the same deceleration.



# Brake forces at low $\mu$



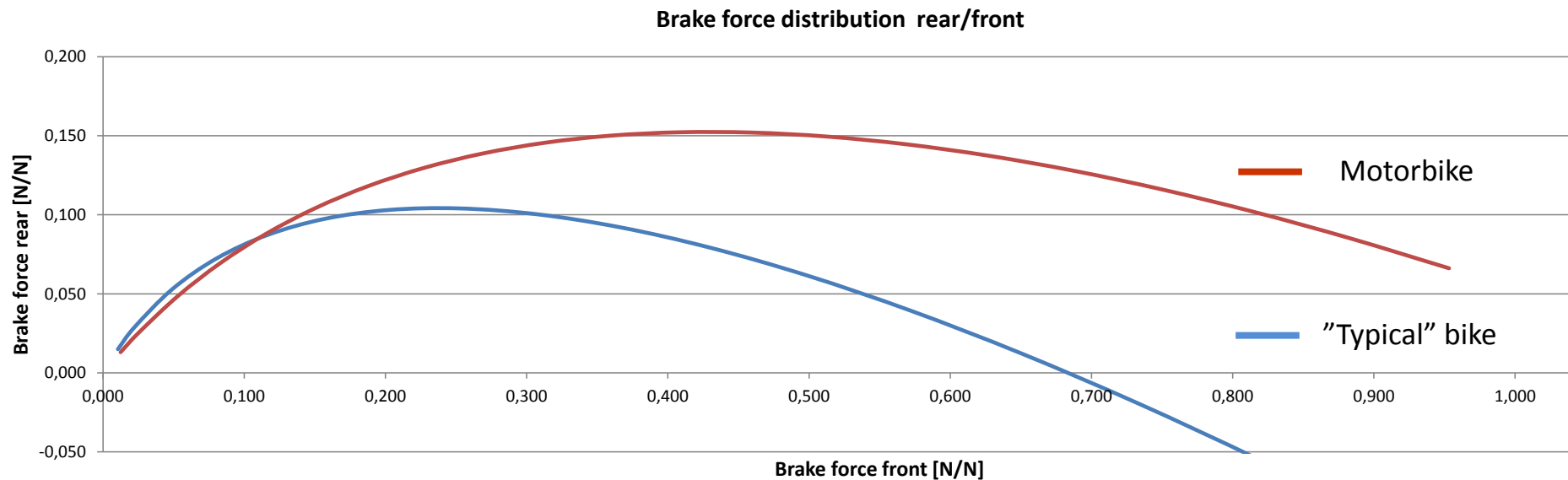
- The maximum force utilization is based on the normal load on the tyres and the tyre-to-road friction value,  $\mu$
- In this figure friction limitations for the front and rear wheels for  $\mu = 0,5$  are shown.
- In the area under the red line and to the left of the green line, the balance between the front and rear brake can be chosen freely. The optimal brake force distribution is at the intersection between the two lines (maximum total brake force).



# Brake force distribution for a motorbike

For a motorbike the centre-point of gravity (CoG) is lower and the wheelbase is larger than for a bicycle.

The brake force distribution in this case is much better, see red curve.



To compare vehicles with different mass the brake forces has been normalized by dividing with the total normal force.

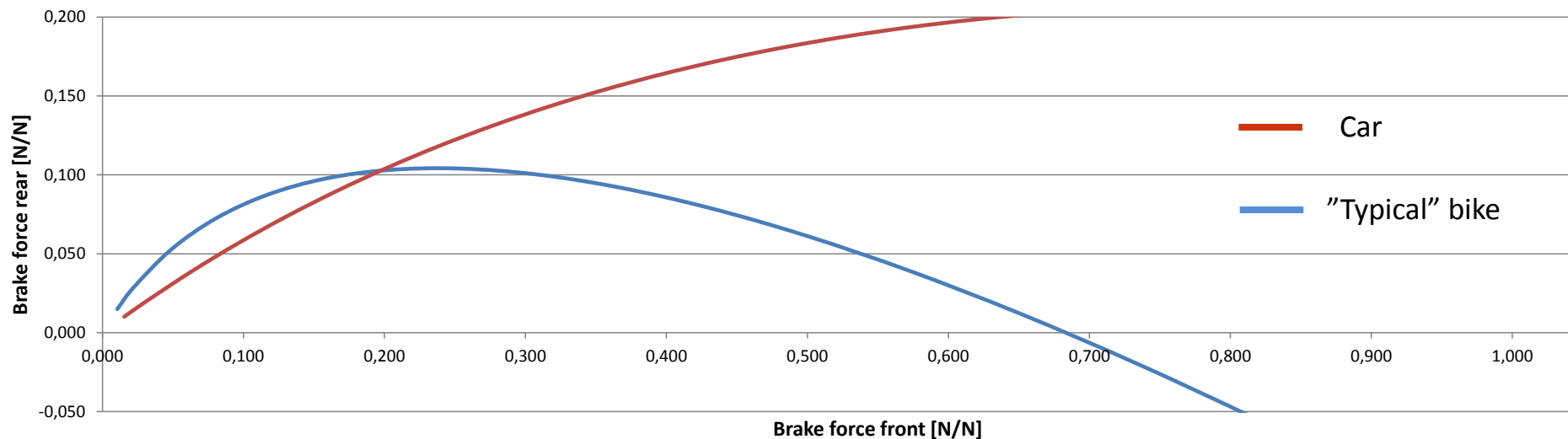
# Brake force distribution for passenger car

For a passenger vehicle the CoG is much lower and the wheelbase is much longer than for the bicycle.

The brake force distribution is significantly improved over the bicycle. Here all four wheels are properly utilized.



Brake force distribution rear/front



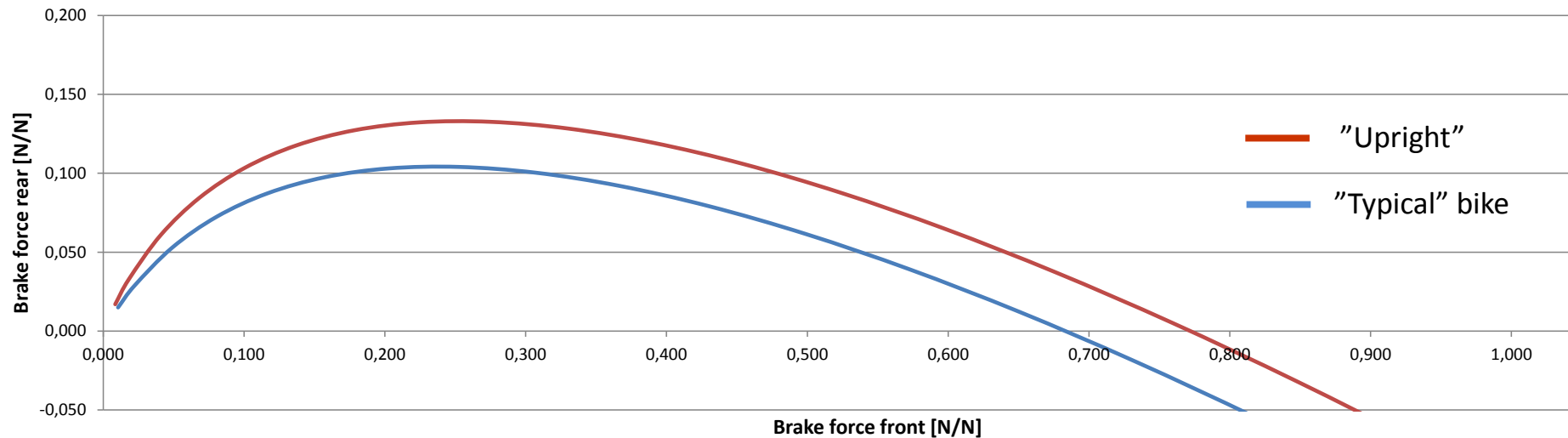
# Brake force distribution for an “upright” driver

The picture show a lady bicycle with an upright driver position.

In this case the CoG is far back.



Brake force distribution rear/front



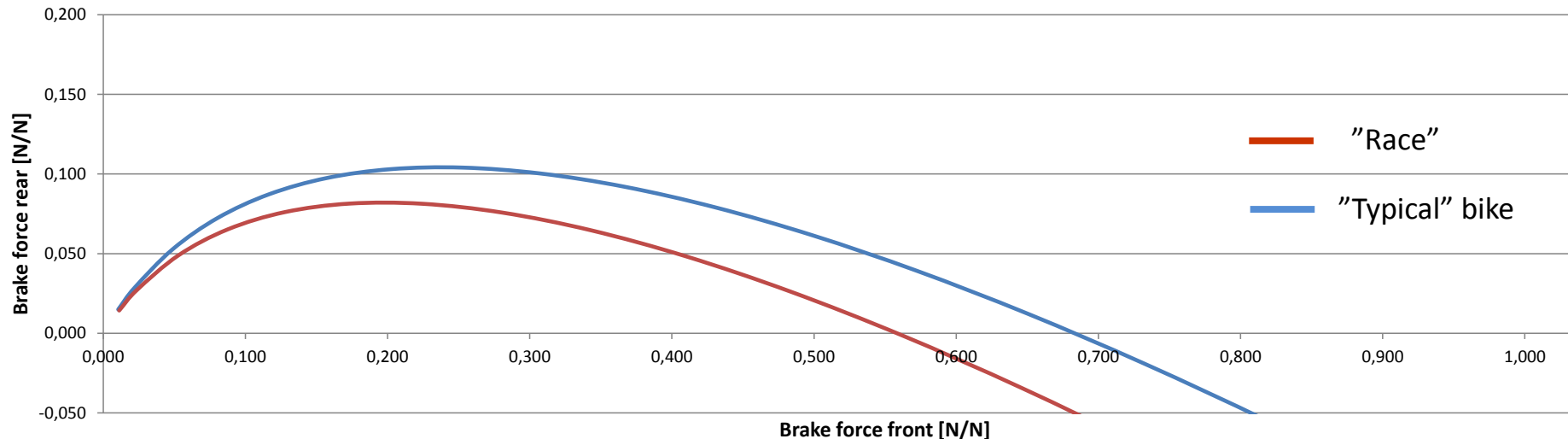
# Brake force distribution for a "Race"-bike

This picture show an extreme race-bike with a short wheelbase and the driver far forward.

The CoG is far forward, which impact the brake performance negatively, see red curve.



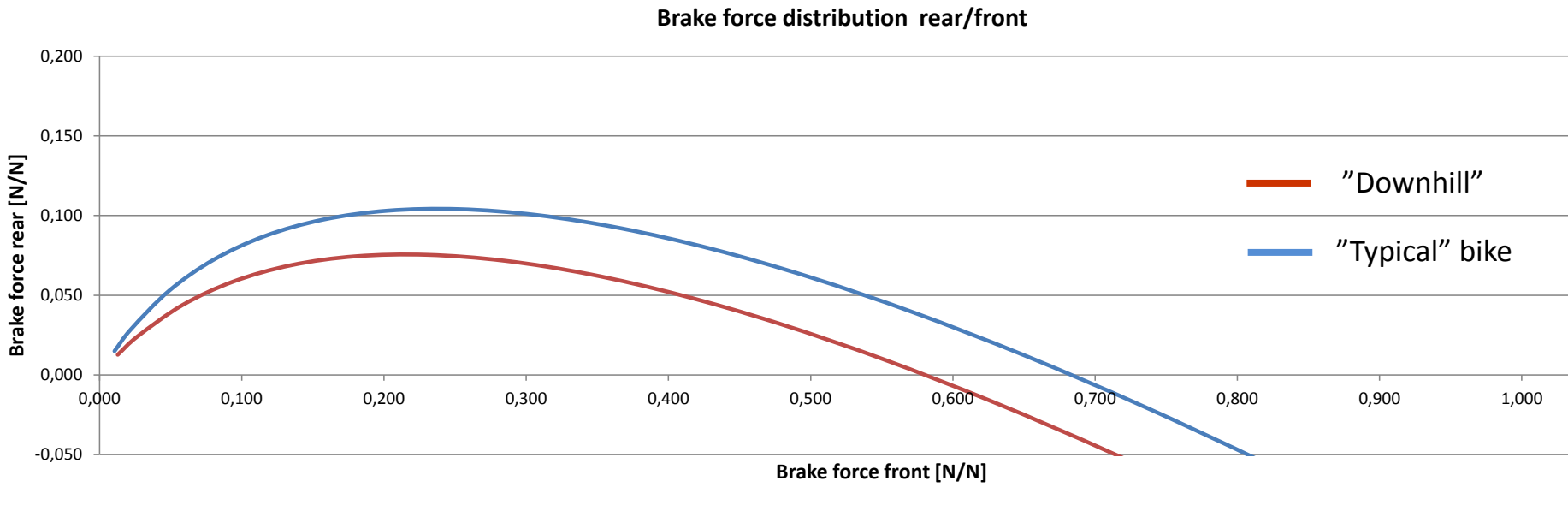
Brake force distribution rear/front



# Brake force distribution driving downhill

When driving downhill the CoG effectively moves forward. That offloads the rear wheel.

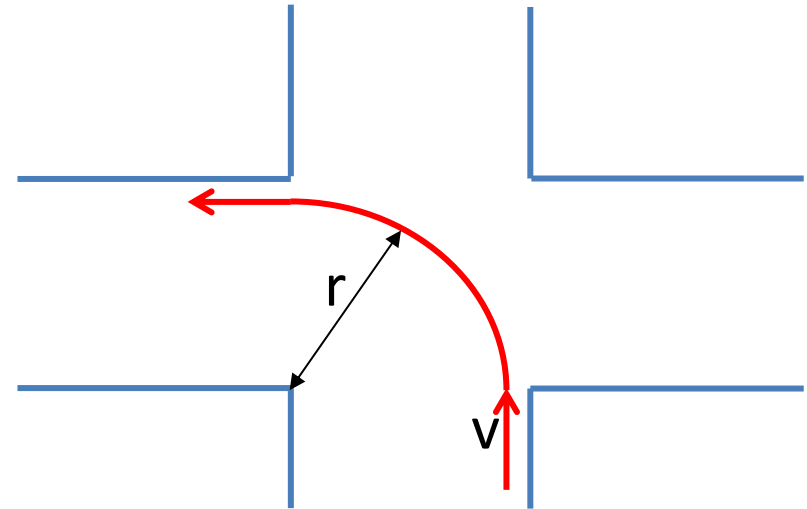
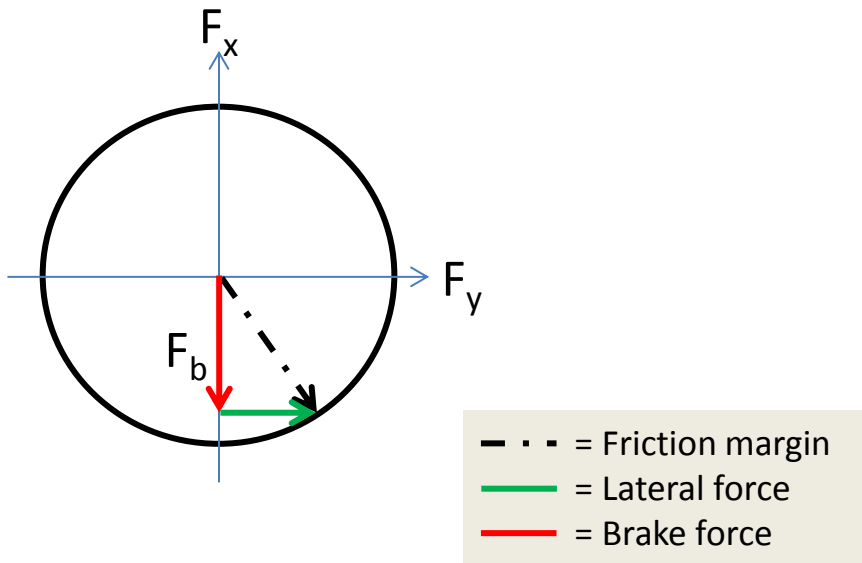
The risk for “head over handlebar” increases.



# Brake force distribution in a turn

Driving in a turn can be compared to driving on low- $\mu$  surface. When driving in a turn, the power capacity between the tire and the road is primarily used to handle lateral forces. It is therefore less capacity left for the braking.

The friction circle can be used to calculate the maximum possible brake force.



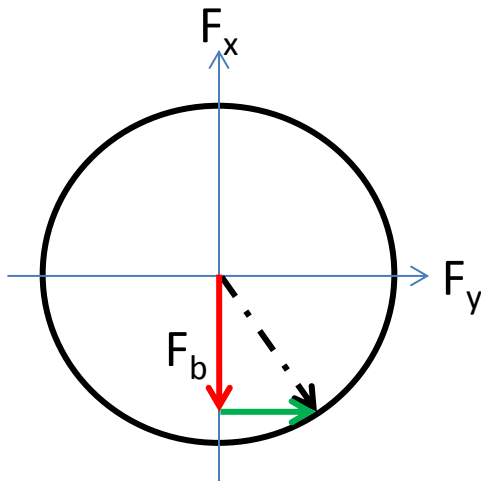
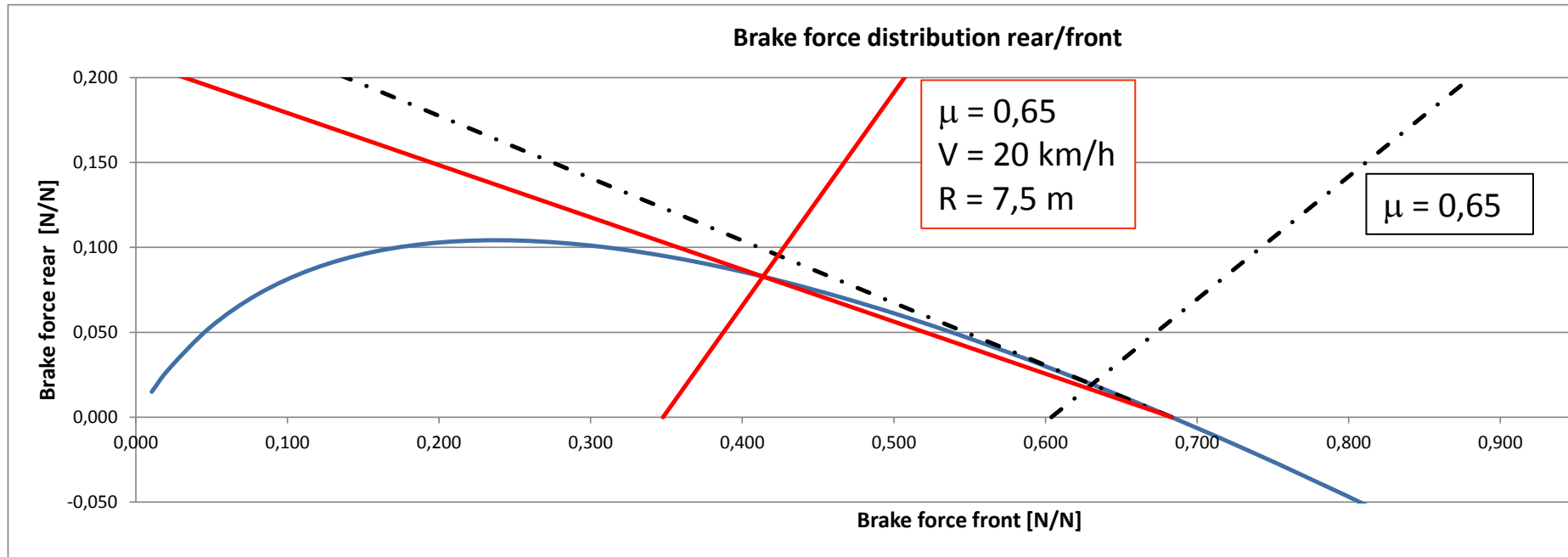
$$\text{Sideforce } F_y = m v^2 / r$$

maximum possible braking force  $F_b$  is

$$F_b = ((\mu F_n)^2 - F_y^2)^{1/2}$$

where  $F_n$  is the normal force

# Brake force distribution in a turn






The picture show the brake force available for deceleration in a turn (left and below of the red lines).

Braking in turn is more critical than braking straight forward.

- - - = Friction margin
- = Lateral force
- = Brake force



# Summary

- The key to short stopping distance is a good brake balance front/rear.
- The bicycle becomes instable if a wheel locks.
- Locking the front wheel is clearly worse than locking rear.
- On high- $\mu$  surfaces the brake force on the front wheel have to be limited to prevent "head over handlebar". 
- On medium to low- $\mu$  surfaces anti-locking brakes prevents wheel lock-up and thereby reduce the risk of falling.
- To brake away grip in a turn is clearly more unsafe than to do it at straight driving (time for correction is shorter). 
- A suspended front fork easier gives front wheel lock-up at transient manoeuvres. 

# Measures, brake functions and implementations

1. To prevent the driver to fall over the handle bar the **front brake force** need to be **limited**.
2. To maximize the brake force (minimizing stopping distance) the **brake force distribution** front/rear need to be optimized.
3. To prevent wheel lock-up an **anti-lock braking (ABS)** system need to be applied.
4. To reduce the risk of falling when driving in a turn, the **brake force** need to be **limited**, for example **based on roll angle detection**.

# 1. Front brake force limitation

Front brake force limitation prevents “Head over handlebar”

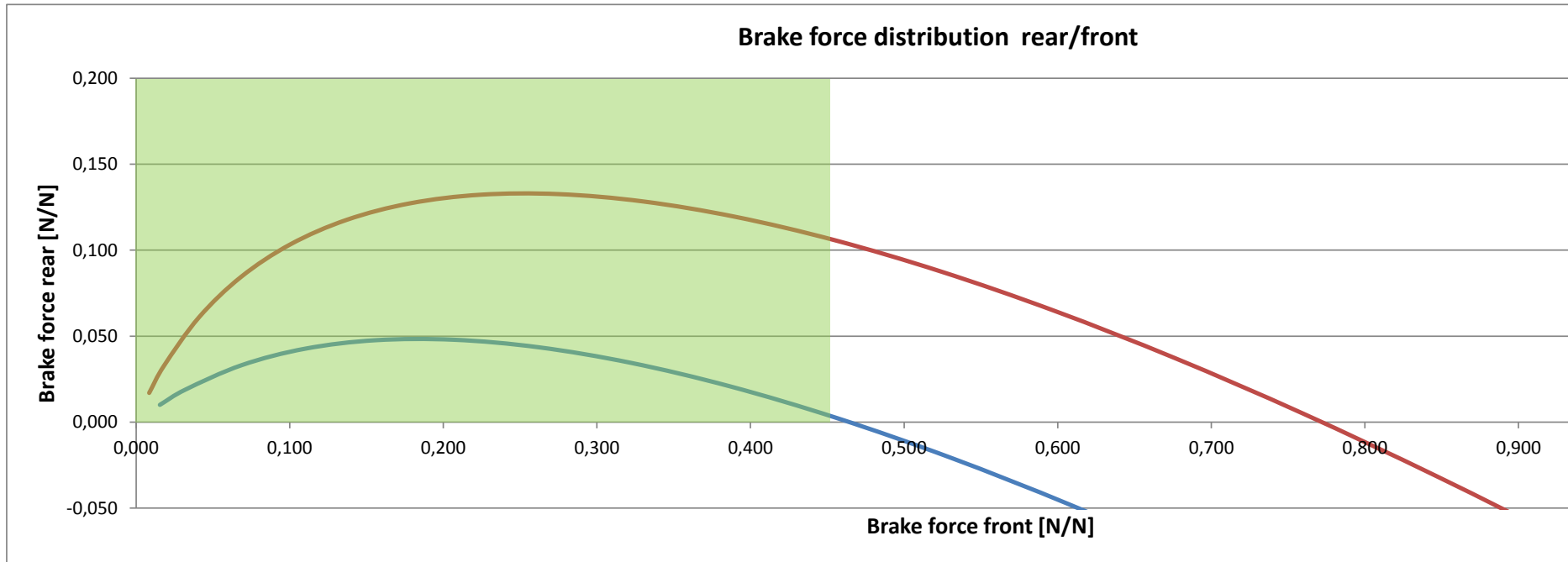


Figure show the spread between two different bicycle styles driven on different road slopes

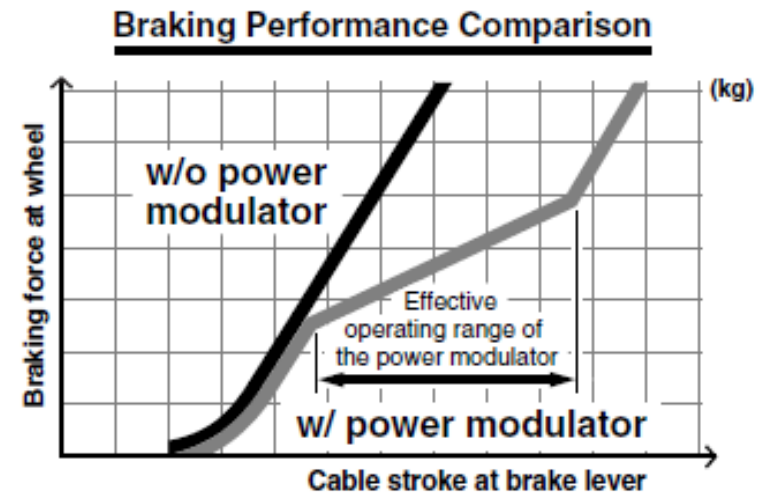
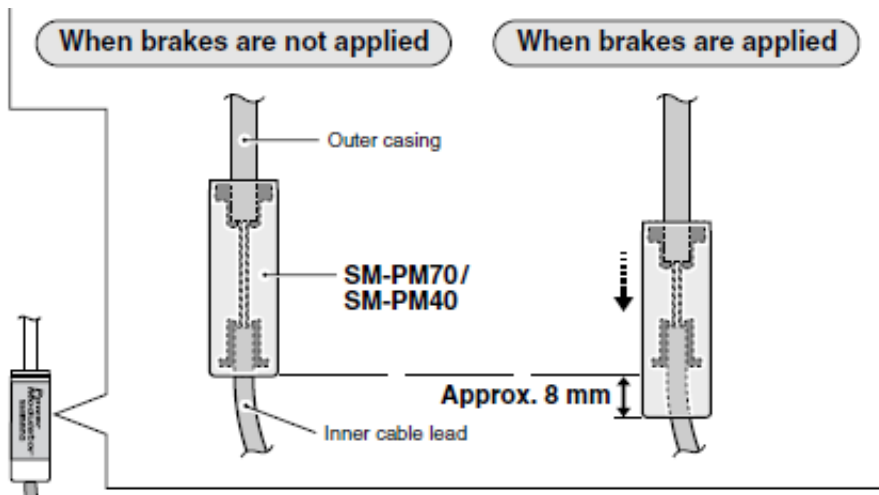
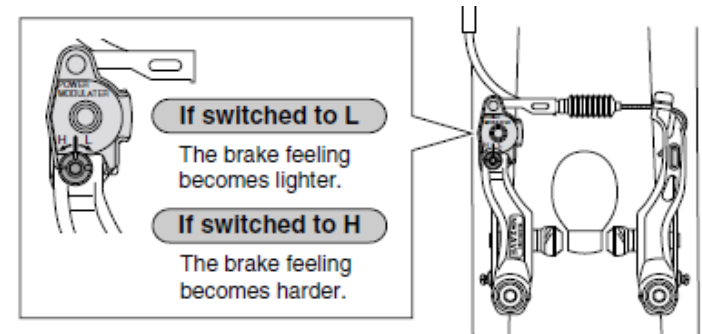
— = "Up-right", horizontal driving  
— = "Race-bike", downhill 10%

Front brake force limitation =  $0.45 \cdot mg$

# 1. Front brake force limitation

## “Shimano Power modulator”

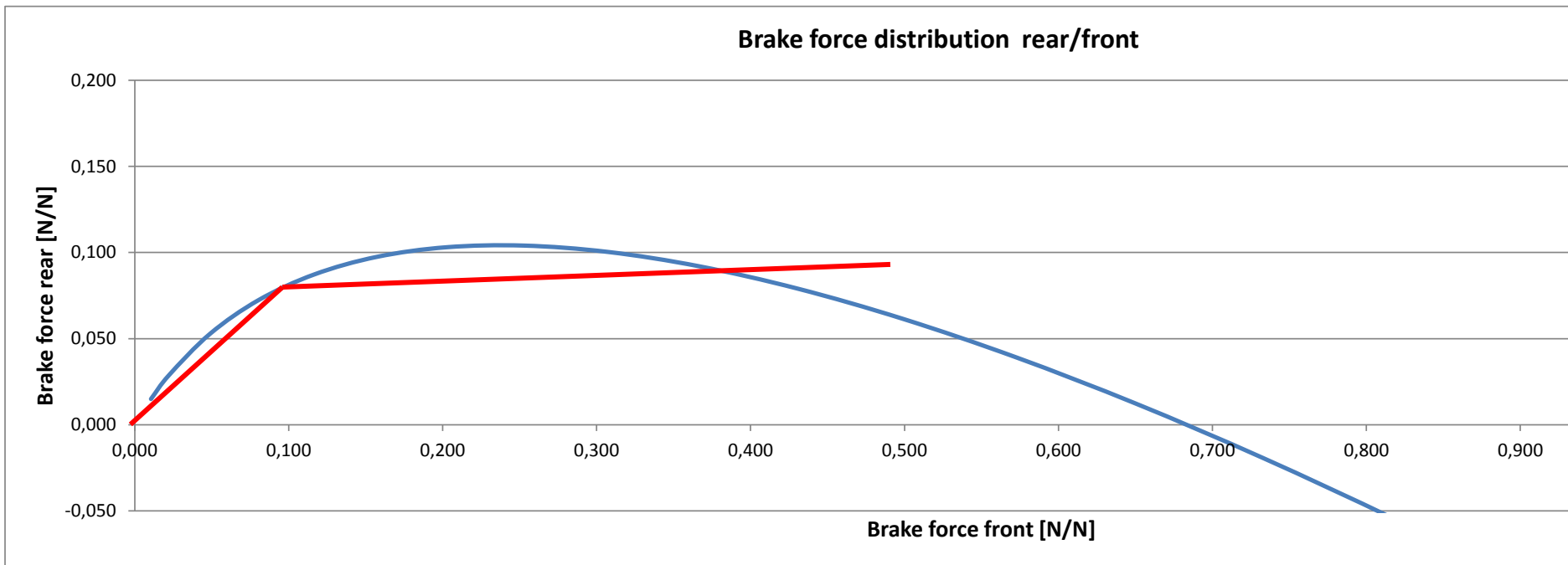
Force limitation using pre-loaded spring in series with cable actuator



Pictures from Shimano homepage

## 2. Brake force distribution

Improved brake force distribution reduces brake distance



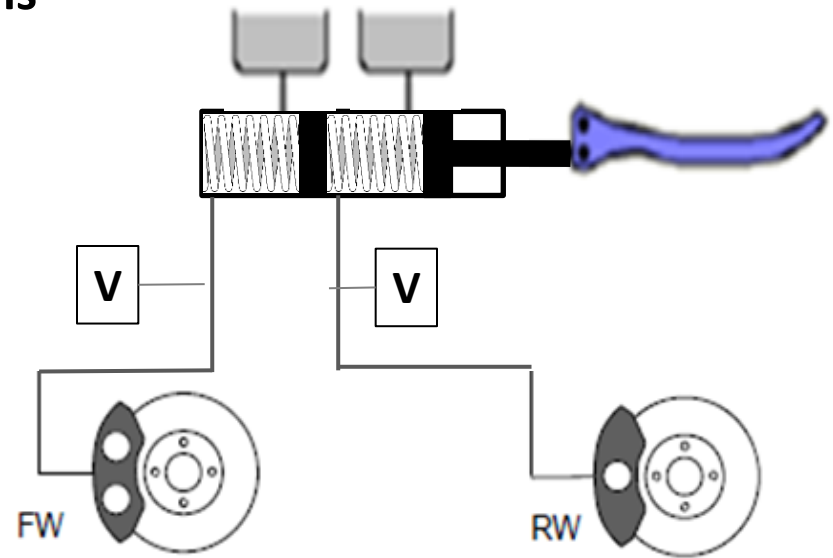
The red curve illustrates a brake force distribution accomplished with a mechanical/hydraulic integrated brake system with force limitation, see next slide.

— = distribution by mech/hyd system  
— = "Ideal" distribution

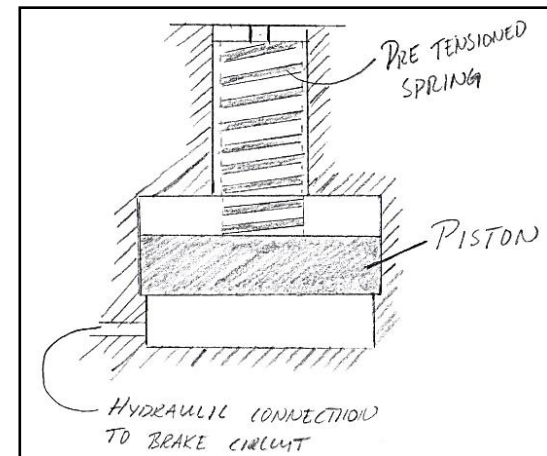
## 2. Brake force distribution

### Integral brake system with force limitations

Combining a tandem master cylinder actuated by one lever, and a “pressure relief valve” (see sketch) in each hydraulic circuit, could realize a distribution as shown in the previous slide.



Same principle can be used for a pure mechanical system with wire transmission and preloaded springs.



## 2. Brake force distribution

### Improved brake force distribution with 2-Chanel ABS with EBD functionality

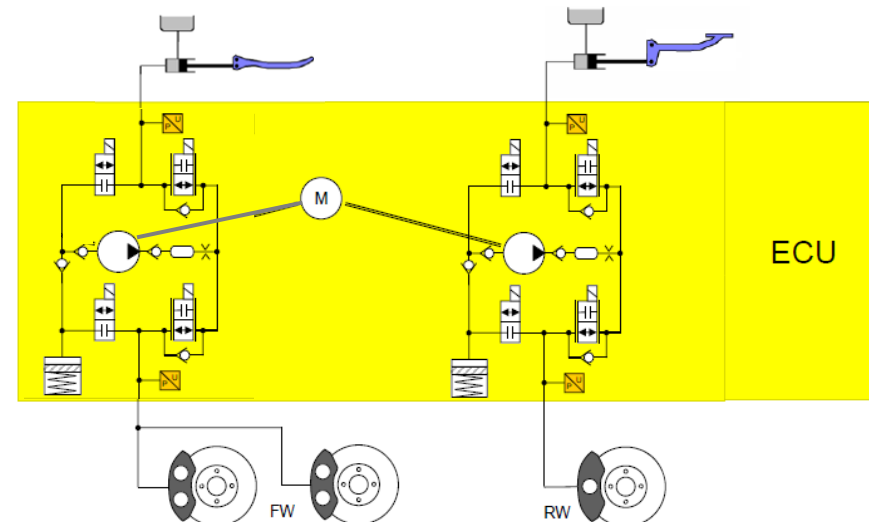
2-Channel ABS requires two hydraulic circuits and input from two wheel speed sensors (minimum).

The picture shows a system with two hydraulically independent circuits with an electrically integrated control.

The function Electronic Brake Force Distribution (EBD) controls the pressure balance based on wheel slip.



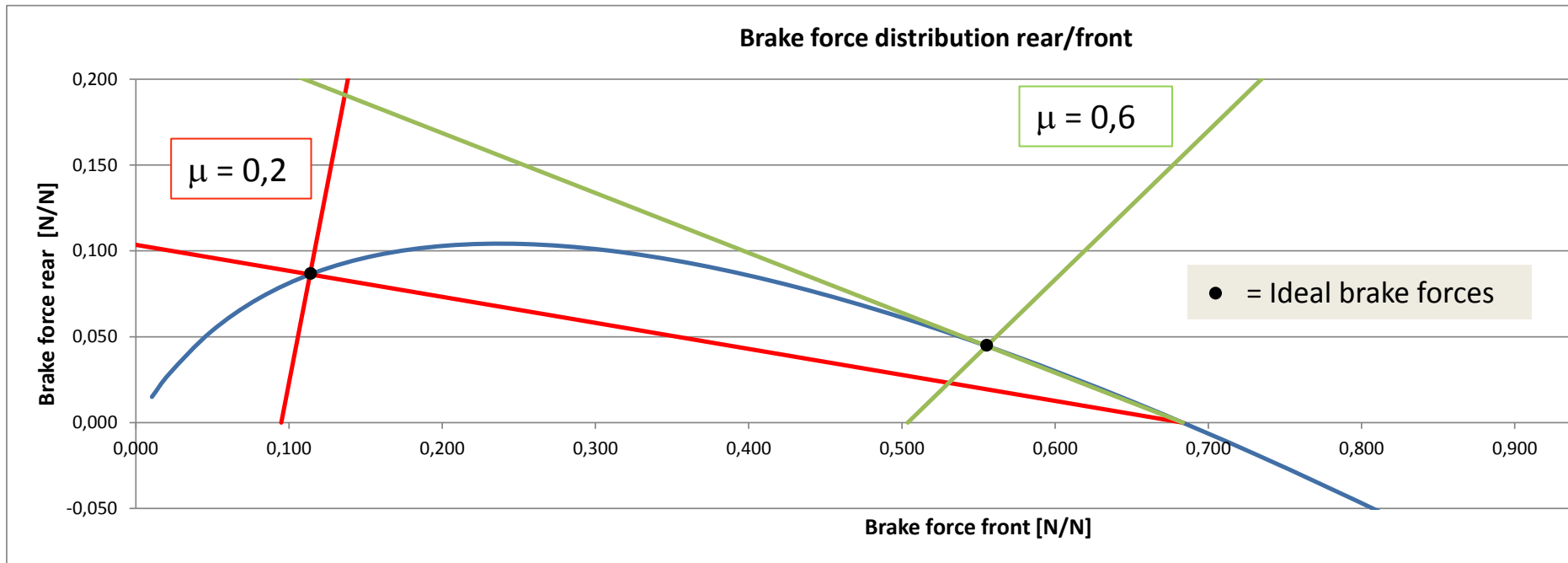
Picture from Continental





## 2. Brake force distribution

“Ideal” brake force distribution with 2-Chanel ABS with EBD functionality



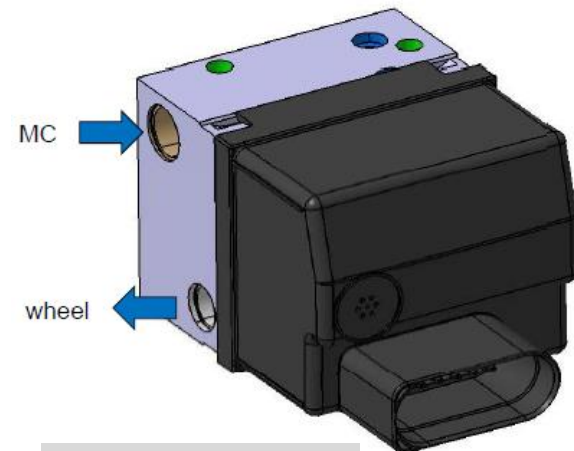
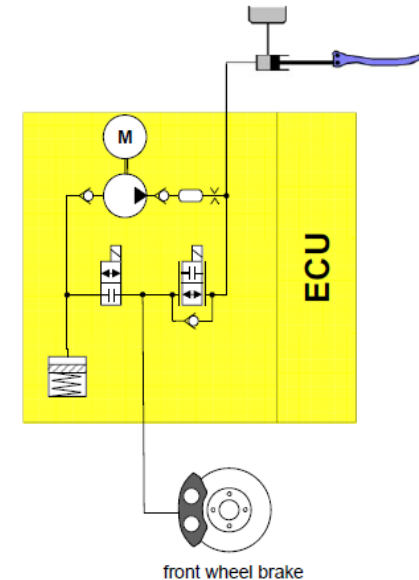
# 3. Anti-lock braking

## Anti-lock function of front wheel with 1-Chanel ABS

For the “entry segment” of motorcycles, the major suppliers of ABS-systems are developing one-channel ABS.

These systems provides full ABS functionality on the front wheel.

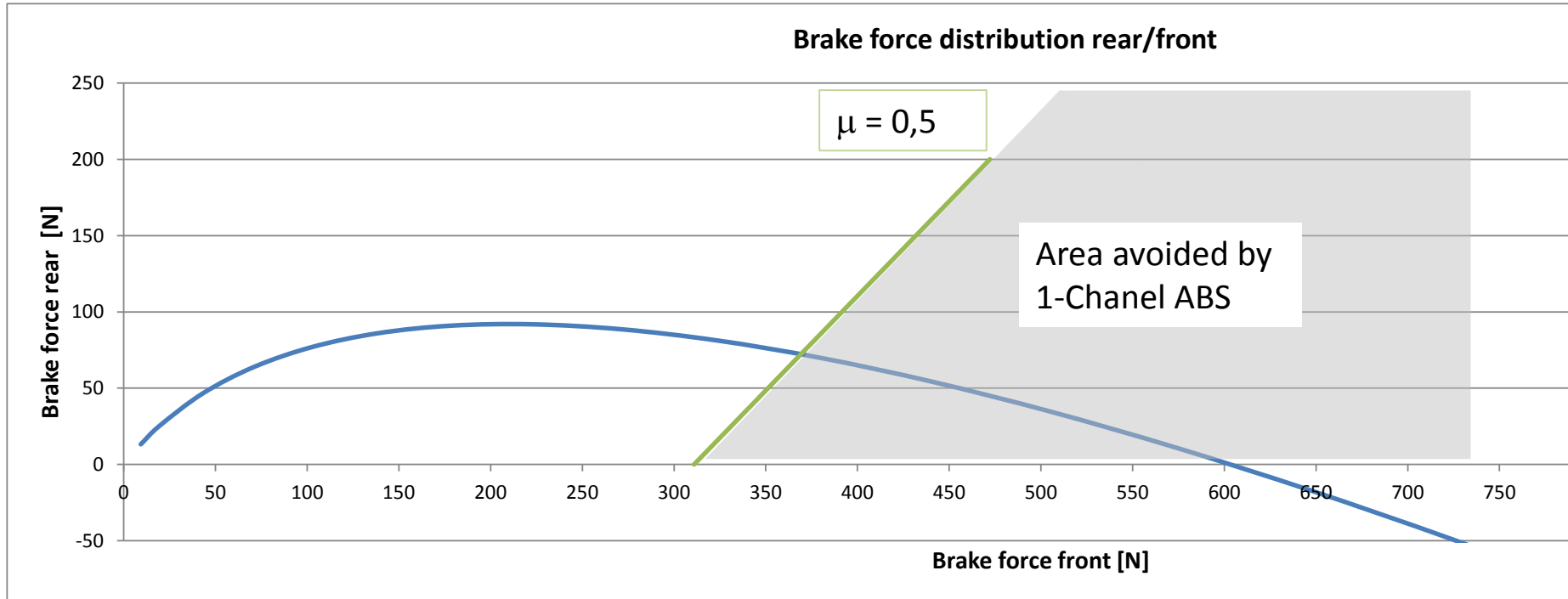
If additional sensors are added, rear wheel lift-off protection can be realized.



Picture from Continental

# 3. Anti-lock braking

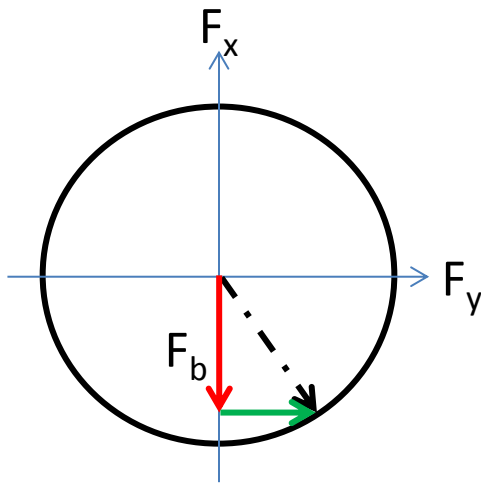
## Anti-lock function of front wheel with 1-Chanel ABS



# 4. Brake force limitation using roll angle detection



Adding a roll angle sensors to a two-channel ABS/ESC system an adaptation of the brake forces can be managed when making a turn.



- . - = Friction margin
- = Lateral force
- = Brake force



Picture from Bosch homepage

# Thank You!

## Questions?