



SWANSEA METROPOLITAN UNIVERSITY
PRIFYSGOL METROPOLITAN ABERTAWE

School of Automotive Engineering

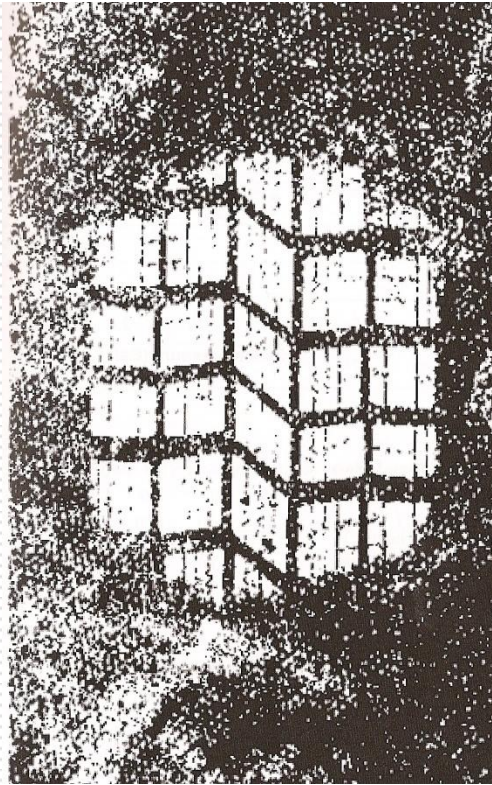
Introduction to Vehicle Driveline and traction

Mark Sandford

Why tyres are important

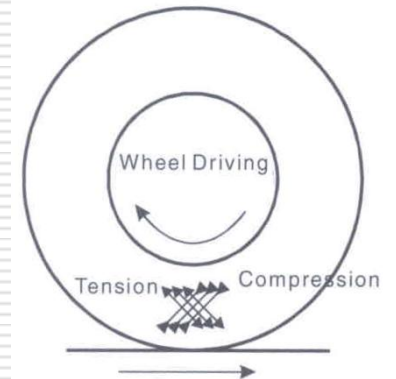
- Whatever you do to improve the vehicle performance the forces go through the tyres
 - Acceleration
 - Braking
 - Cornering
 - Tyre selection is critical
 - Performance verses wear
 - Handling feel - feedback
 - Comfort – ride and noise
 - Economy – fuel consumption
 - Tyre properties and dynamics are an important area of study
-

Contact patch

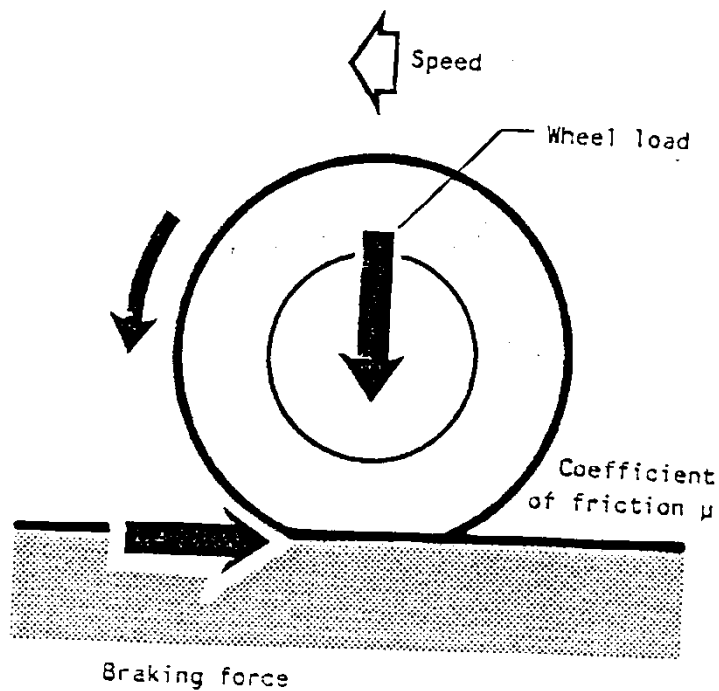


Basic tyre forces - traction

- ❑ Sidewalls in shear due to traction / drive forces

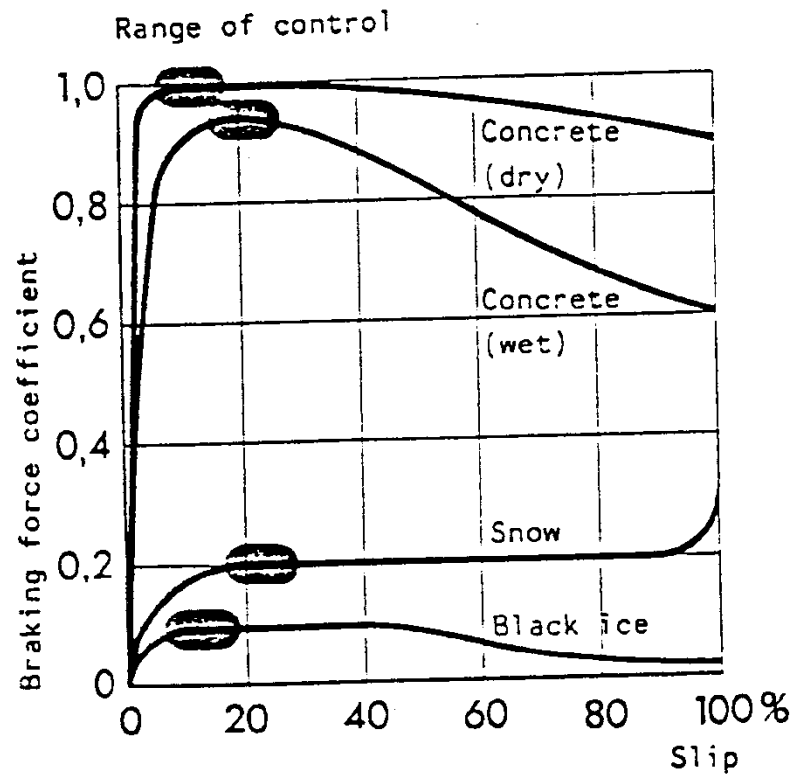


Mu – Coefficient of friction



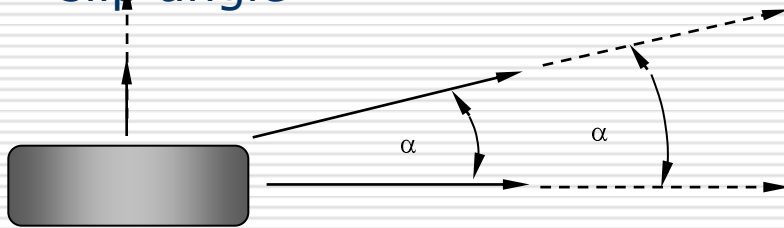
MU Block

Mu – Coefficient of friction

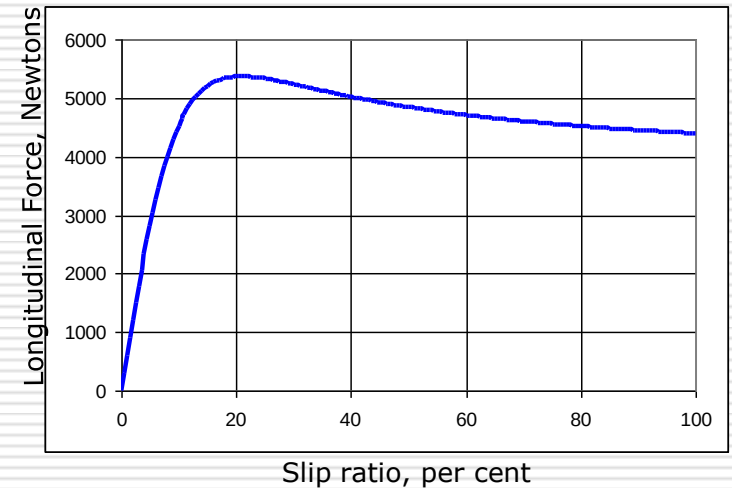
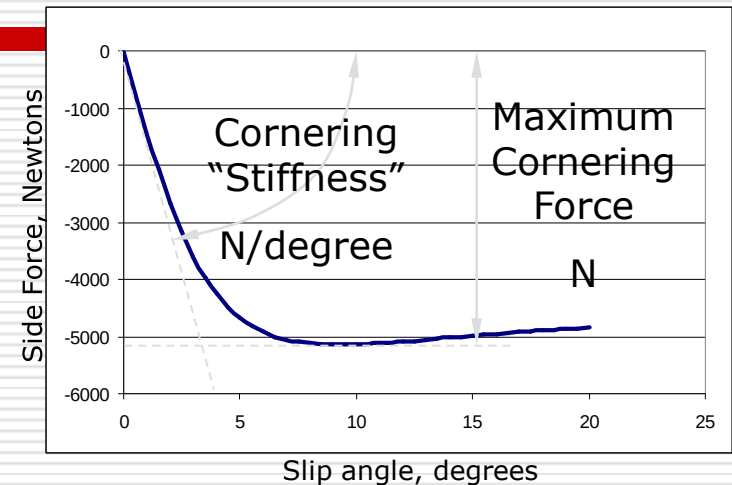


Handling - tyre behaviour

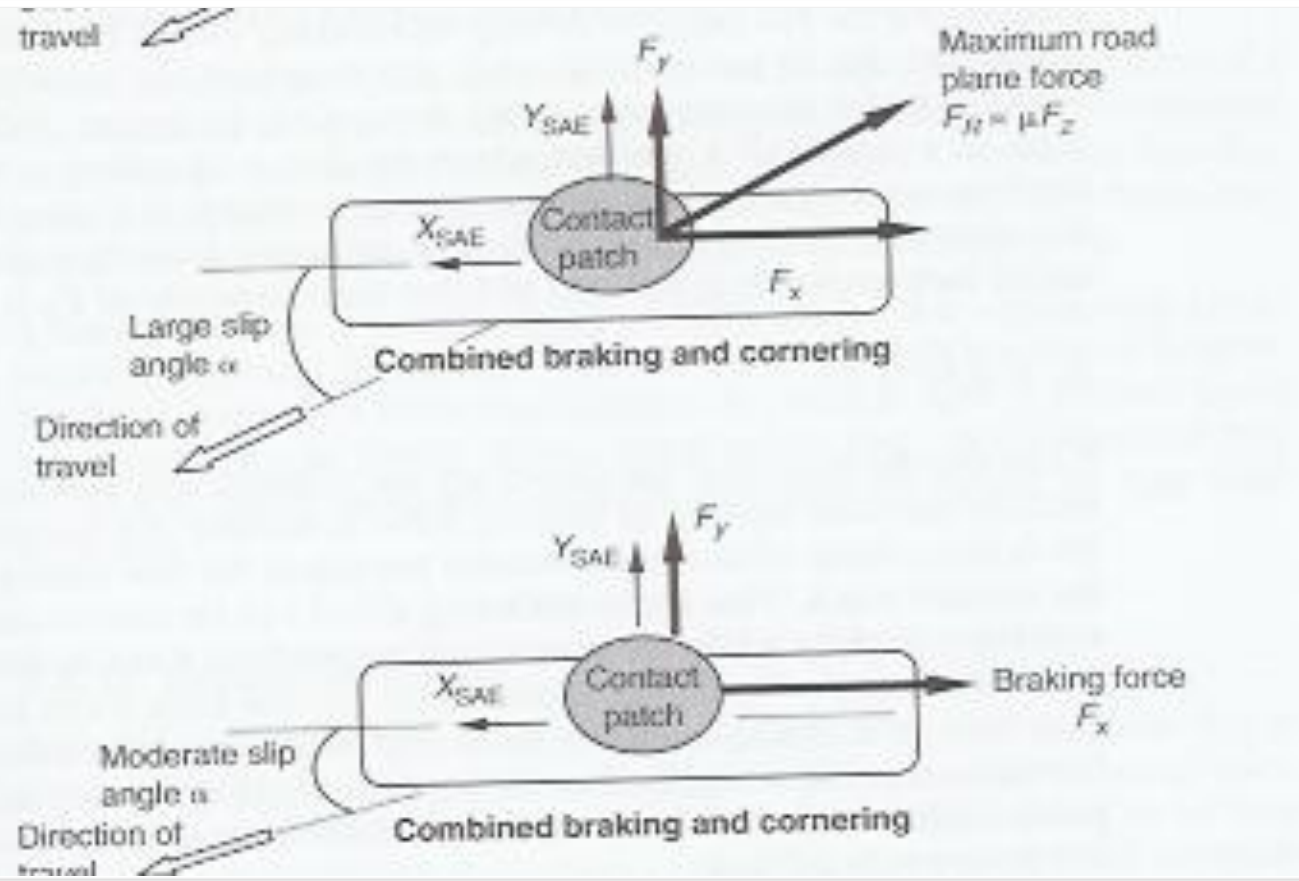
- A running tyre has NO LATERAL STIFFNESS but instead generates cornering forces by operating at a slip angle



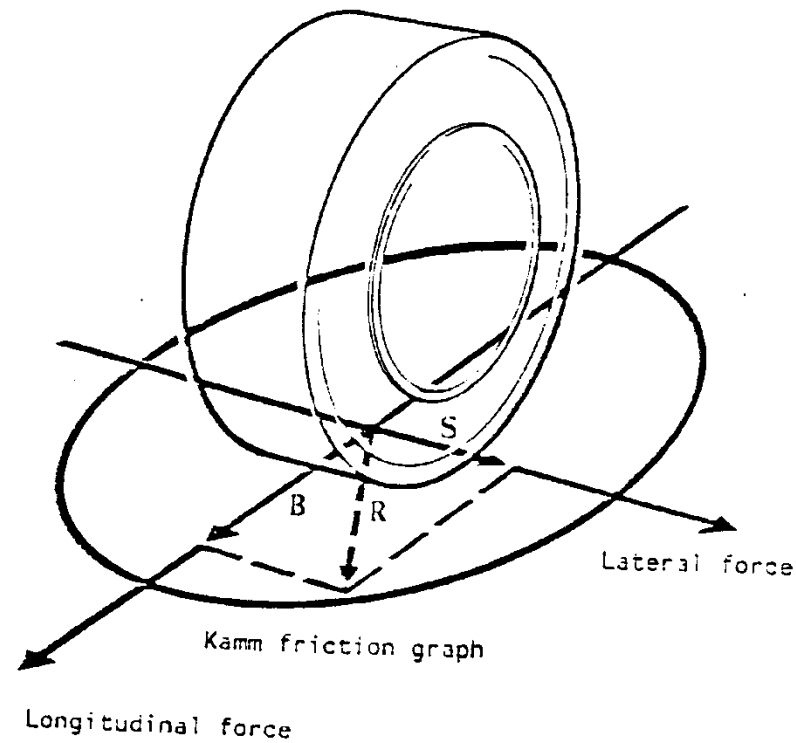
- Vehicles lose lane-following ability with speed directly because of this
- A running tyre has NO LONGITUDINAL STIFFNESS but instead generates brake/drive forces by operating at a slip ratio



Tyre characteristics

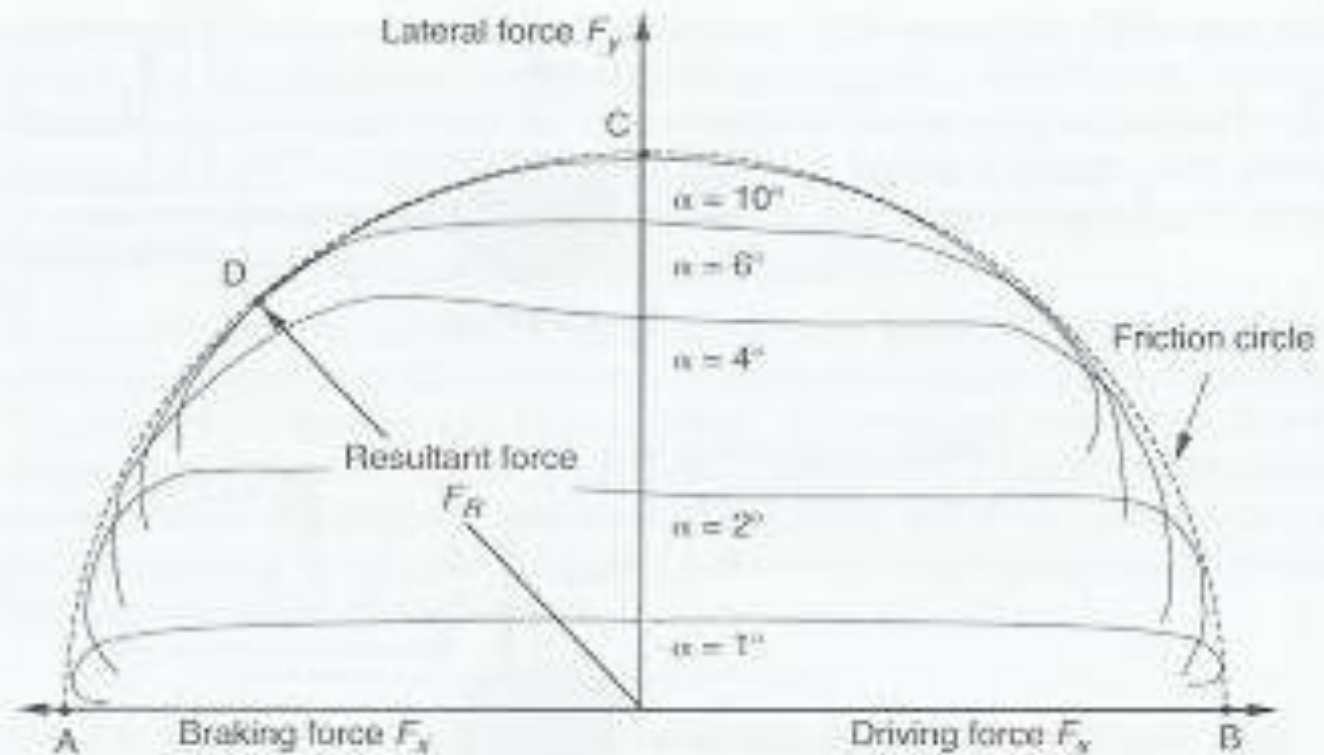


Tyre Characteristics

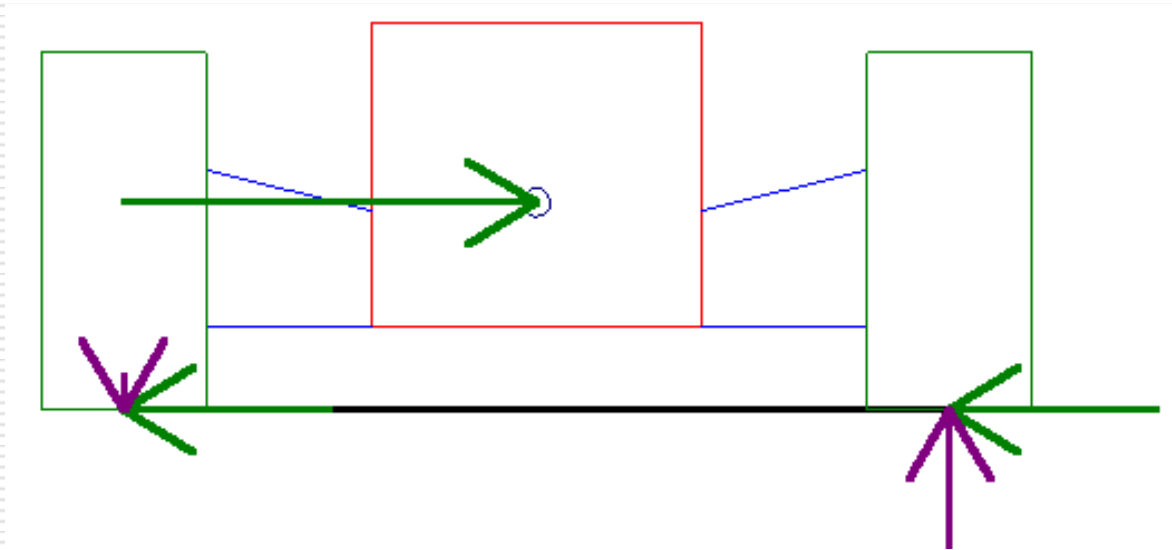


Tyre characteristics

Friction circle (ellipse)



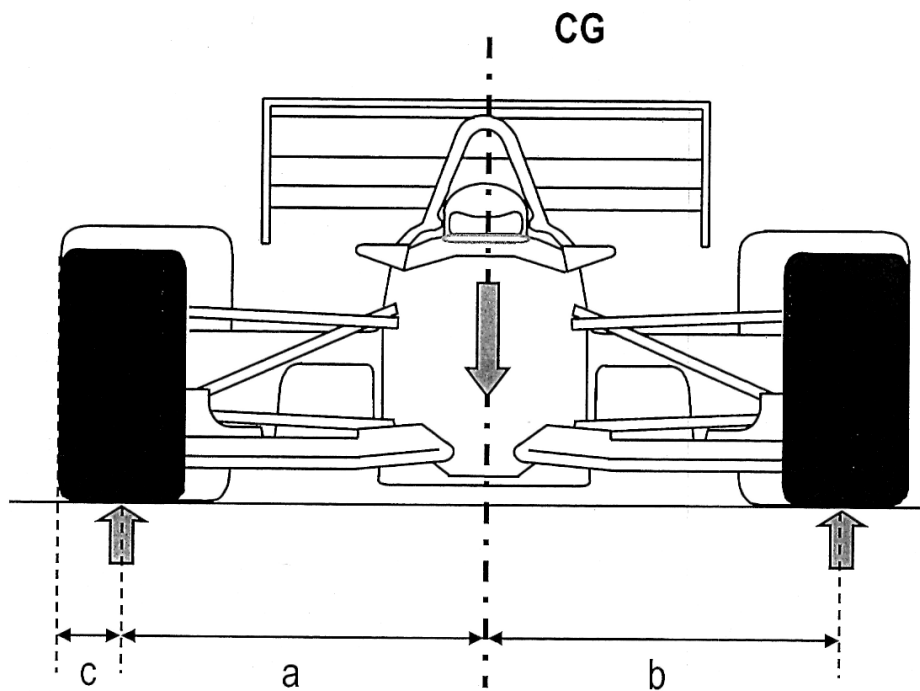
Load Transfer



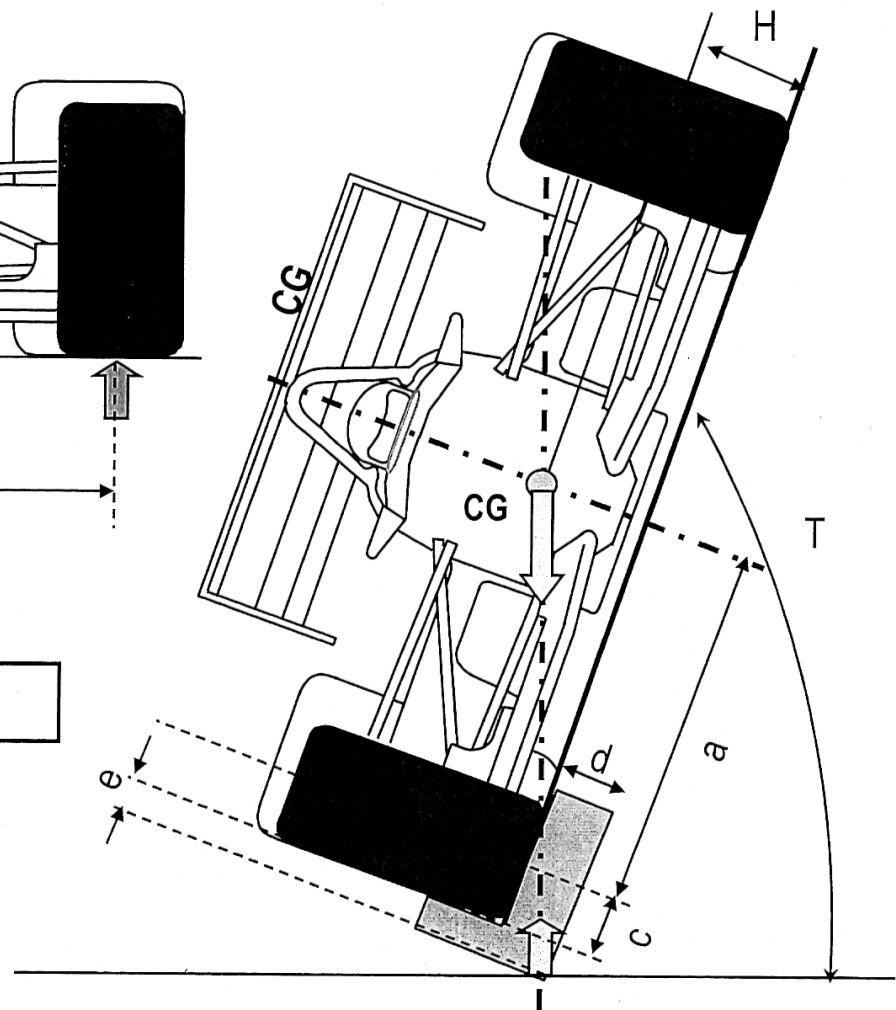
$$\text{Load Transfer} = \frac{\text{Cornering force} \times \text{Height of c of g}}{\text{Track width}}$$

Load transfer

- About 80% of vehicle handling relates to load transfer
 - Load transfer characteristics are affected by
 - Spring rates
 - Anti roll bars (sway bars)
 - Dampers (shock absorbers)
 - Ride height, roll centre height
 - Weight distribution, front to rear
 - Weight distribution, c of g height
-



$$H = \tan(90^\circ - T) \times (a + c + e) - d$$

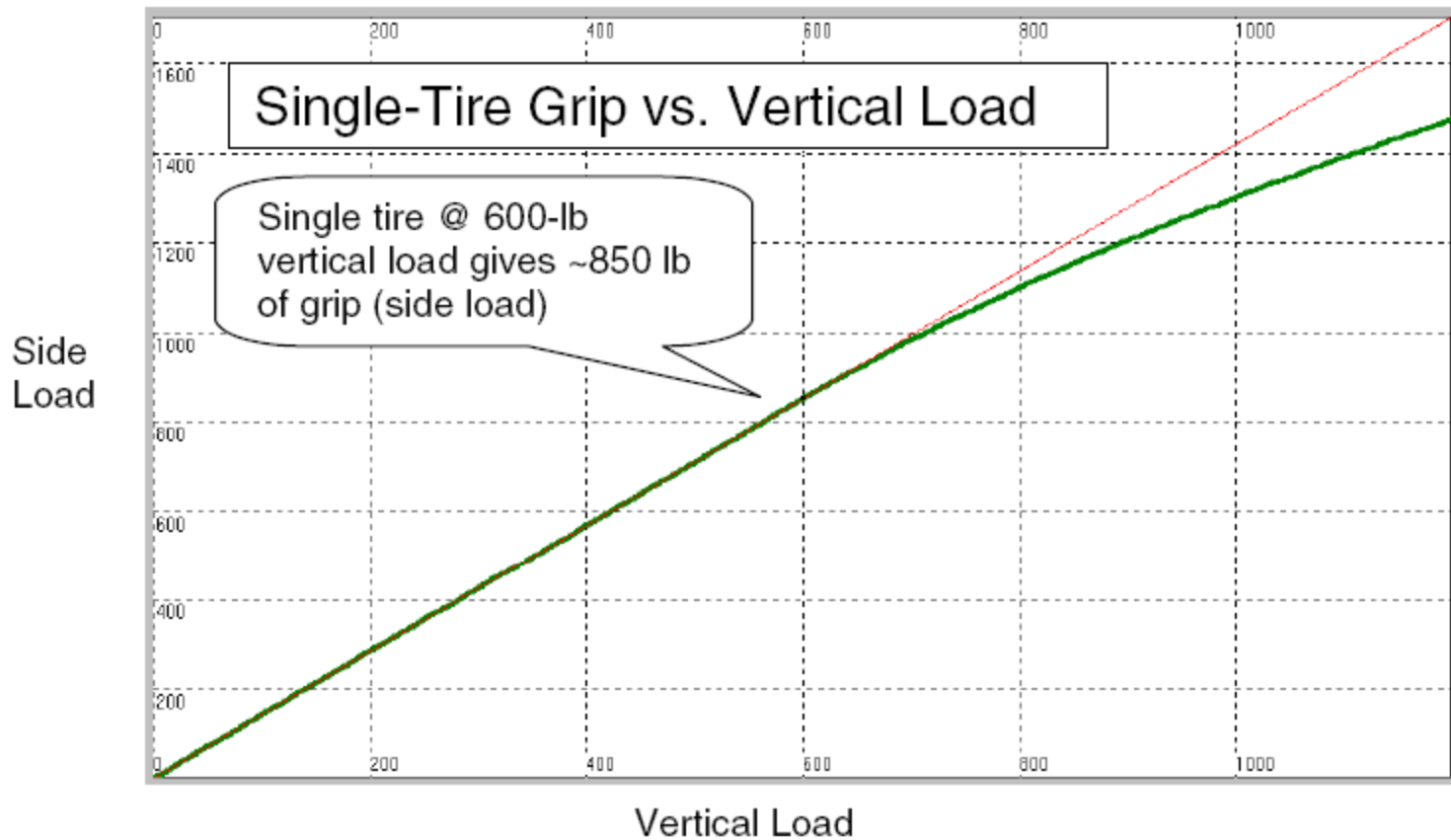


Claude Rouelle

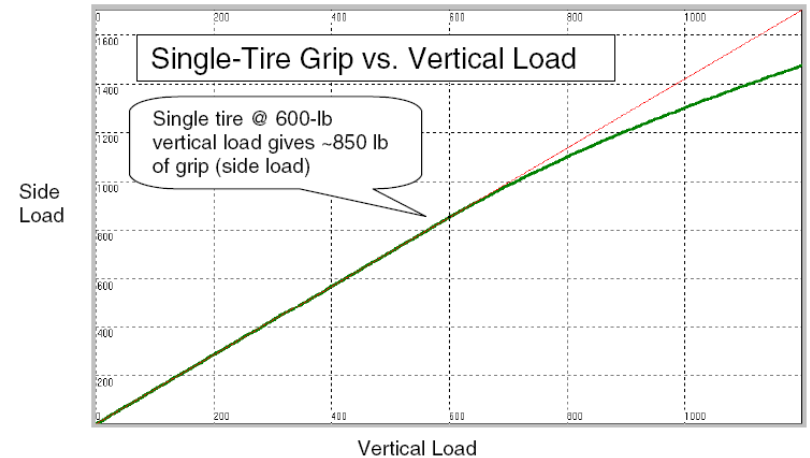
Establishing the height of the centre of gravity



Grip and vertical load



Grip and vertical load



Note

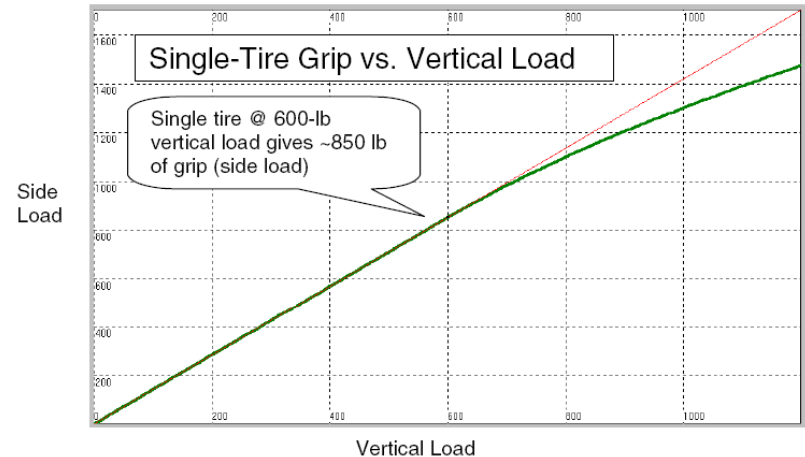
- A. Increasing the load increases the grip
- B. The amount of grip gained decreases and the load increases

Considering the tyre (tire)

Tyre friction coefficient decreases as the tyre load increases

More weight transfer produces less grip

Grip and vertical load

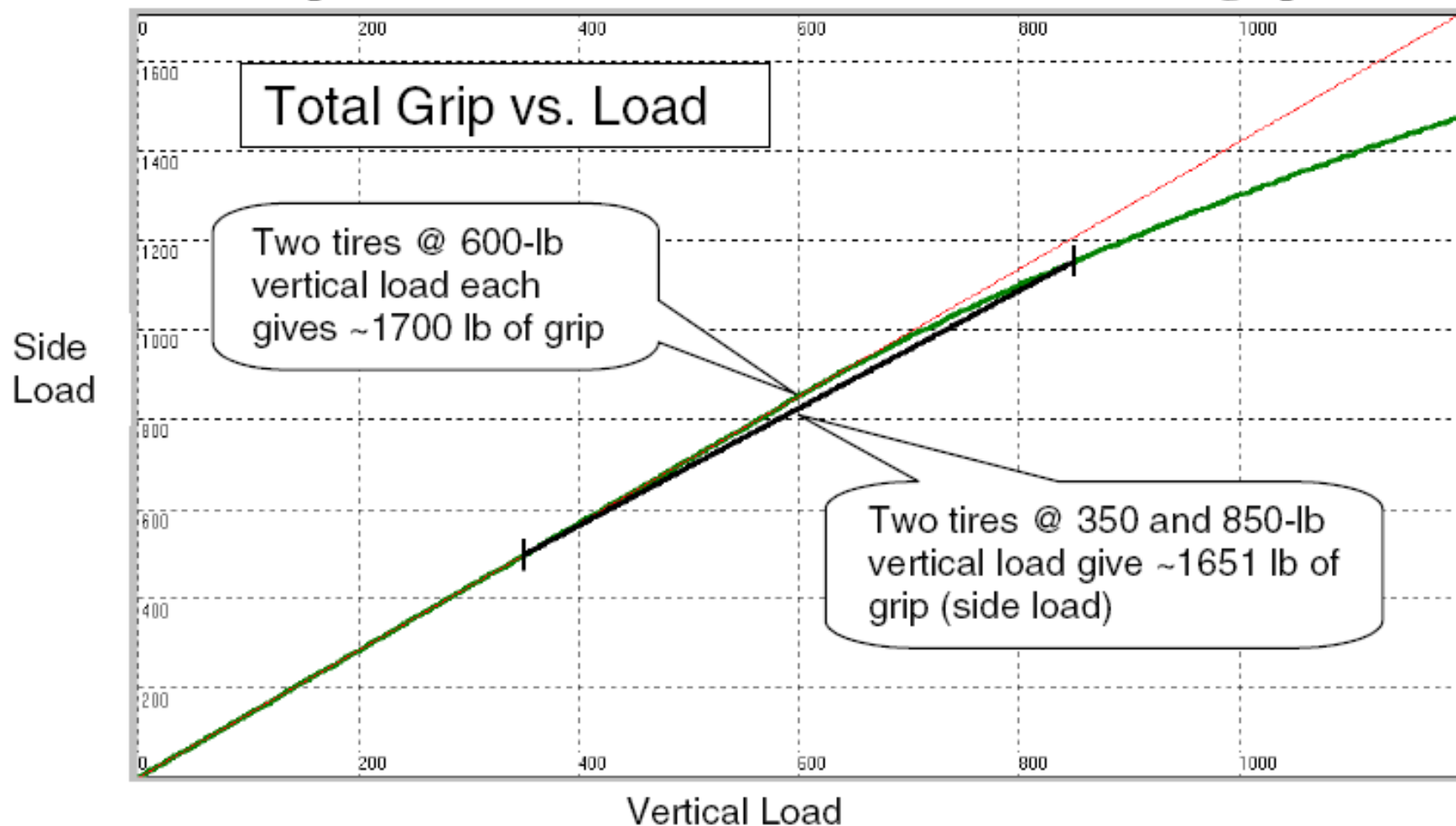


Note

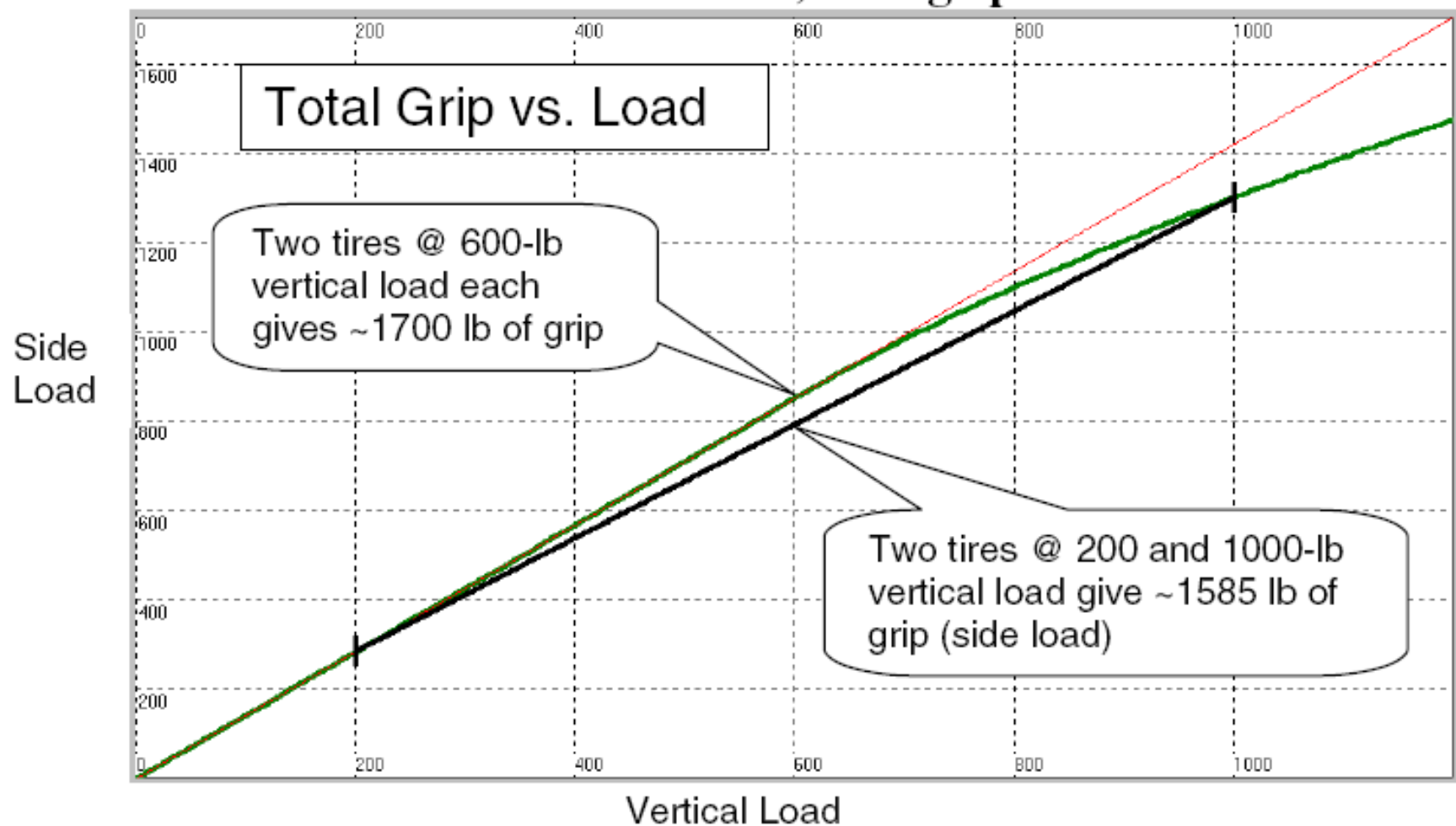
In steady state cornering

- A. Total grip is the sum of all the tyres grip added
 - B. Total grip is highest when all tyres have equal load
 - C. As the disparity in load grow with weight transfer the total grip declines
-

Tire Grip with load transfer: 500 lbs transfer, total grip 1651



800 lbs transfer, total grip 1585



Grip and weight transfer

- Consequently: to get max grip.
- Minimise weight transfer
 - Get the c of g as low as possible
 - Get the vehicle as wide as possible

Picture of lemans car

Weight Transfer and body roll

☐ Body roll

- Is a result of cornering force
- Does not cause load transfer
- Increasing total roll stiffness does not really effect load transfer

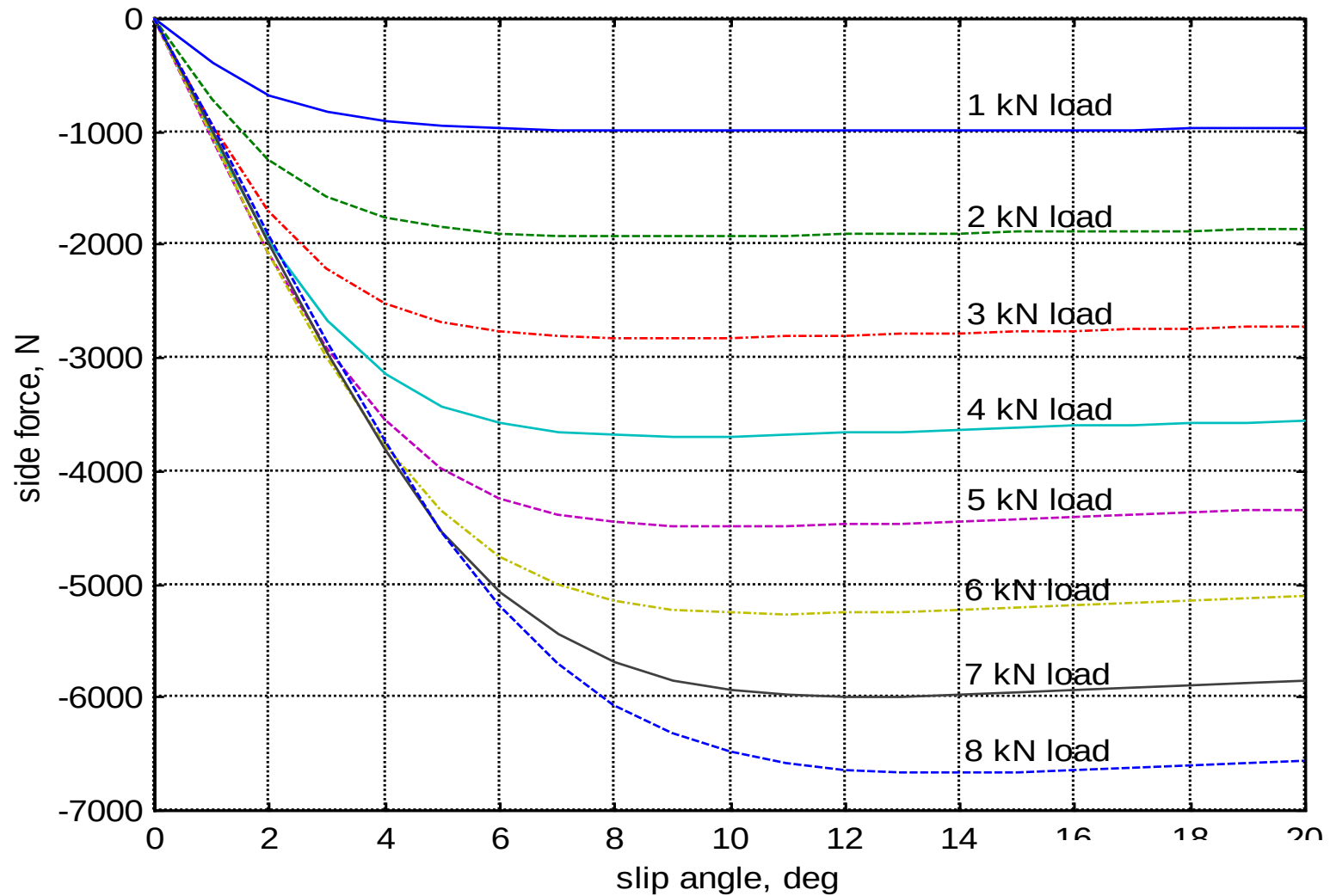
☐ Think about

- Cornering, turn in and steady state
 - Braking and pitch
-

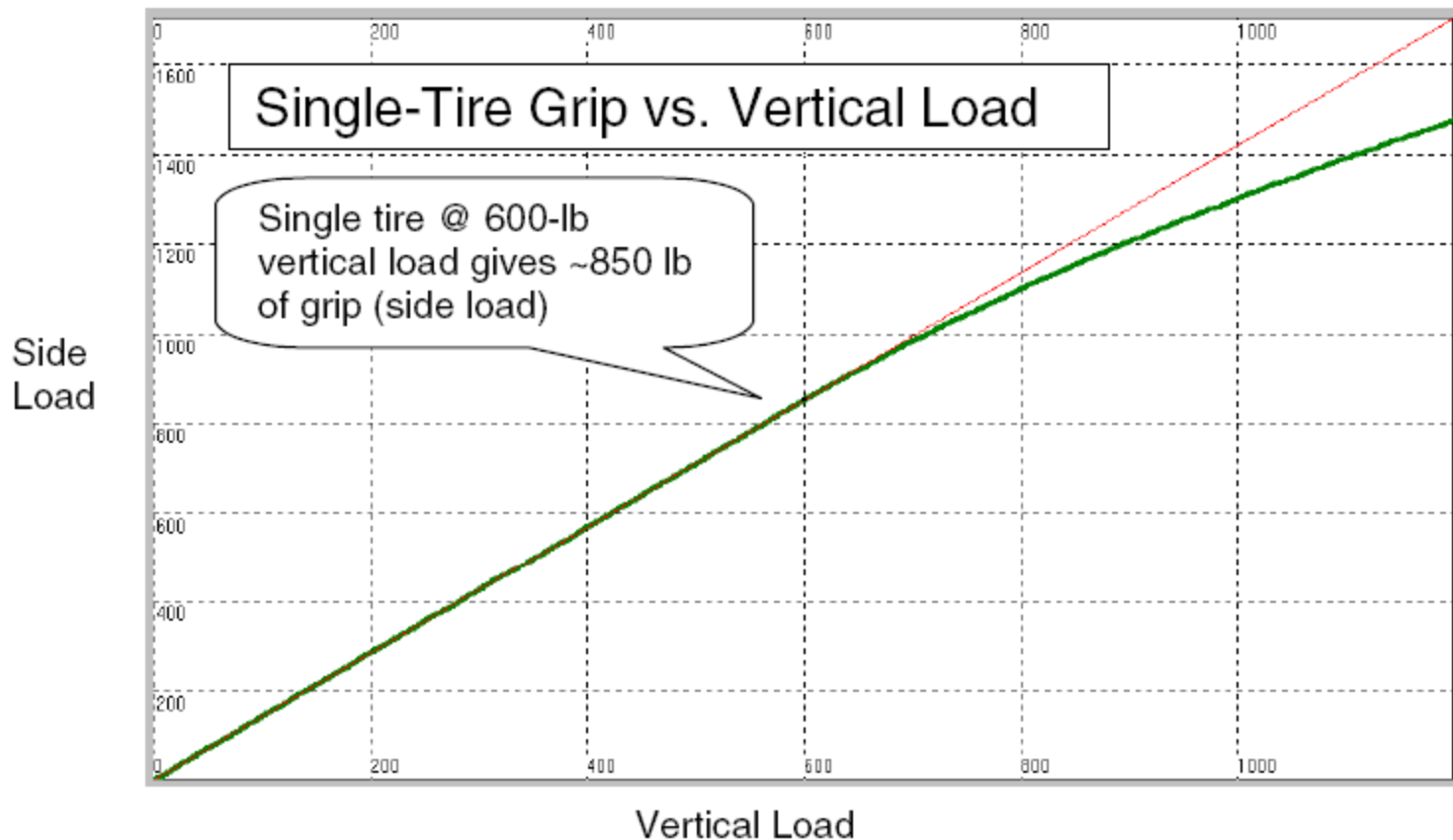
Roll stiffness and chassis stiffness

- ❑ Front roll 1.2 degrees
 - ❑ Front roll stiffness 1.2 degs per g
 - ❑ Then rear should roll 1.2 degs
 - ❑ If they do not roll the same then you have a flexible chassis in torsion
 - ❑ This is bad because any tuning that you do will be less effective
-

Side force vs slip angle



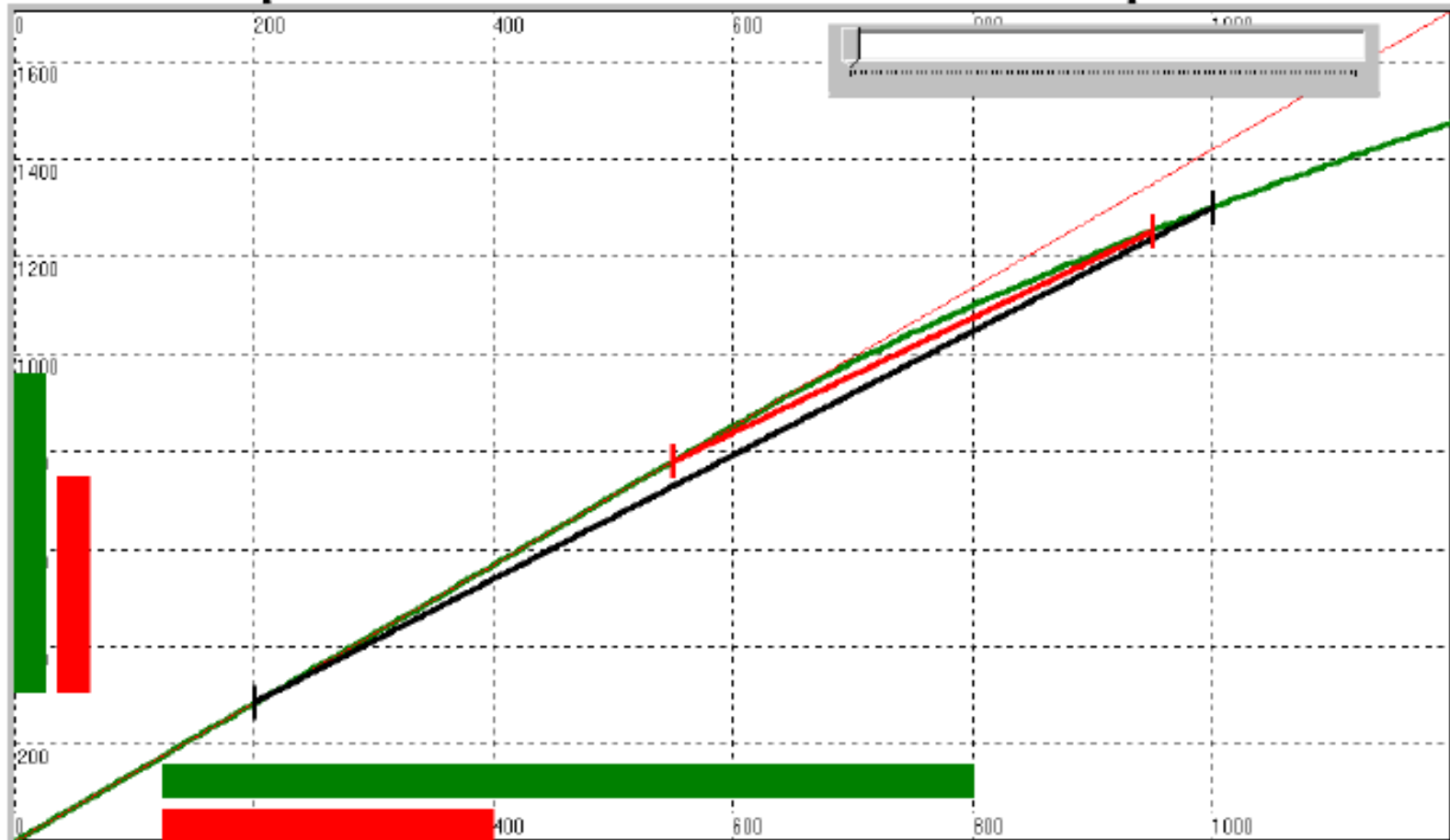
Grip and vertical load



500 lbs transfer at front (green): 700 at rear (red)
Grip 1651 front and 1959 rear: Roll Couple 42%

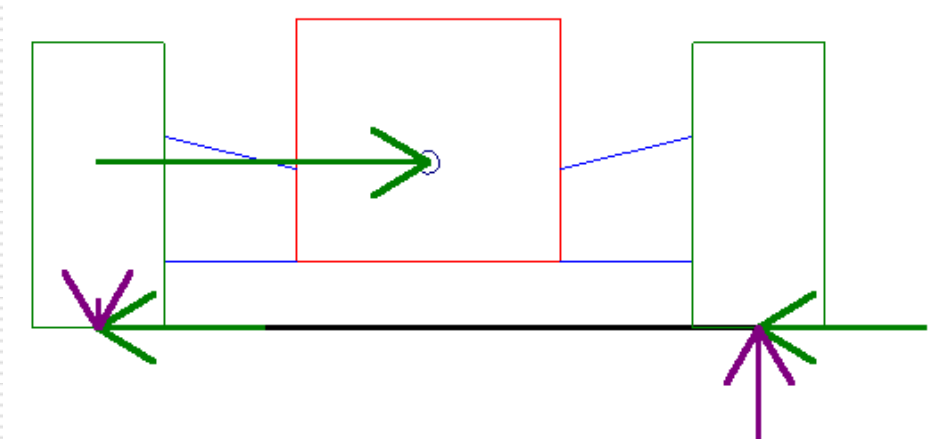


800 lbs transfer front (green); 400 at rear (red)
Grip 1585 front and 2035 rear: Roll Couple 67%

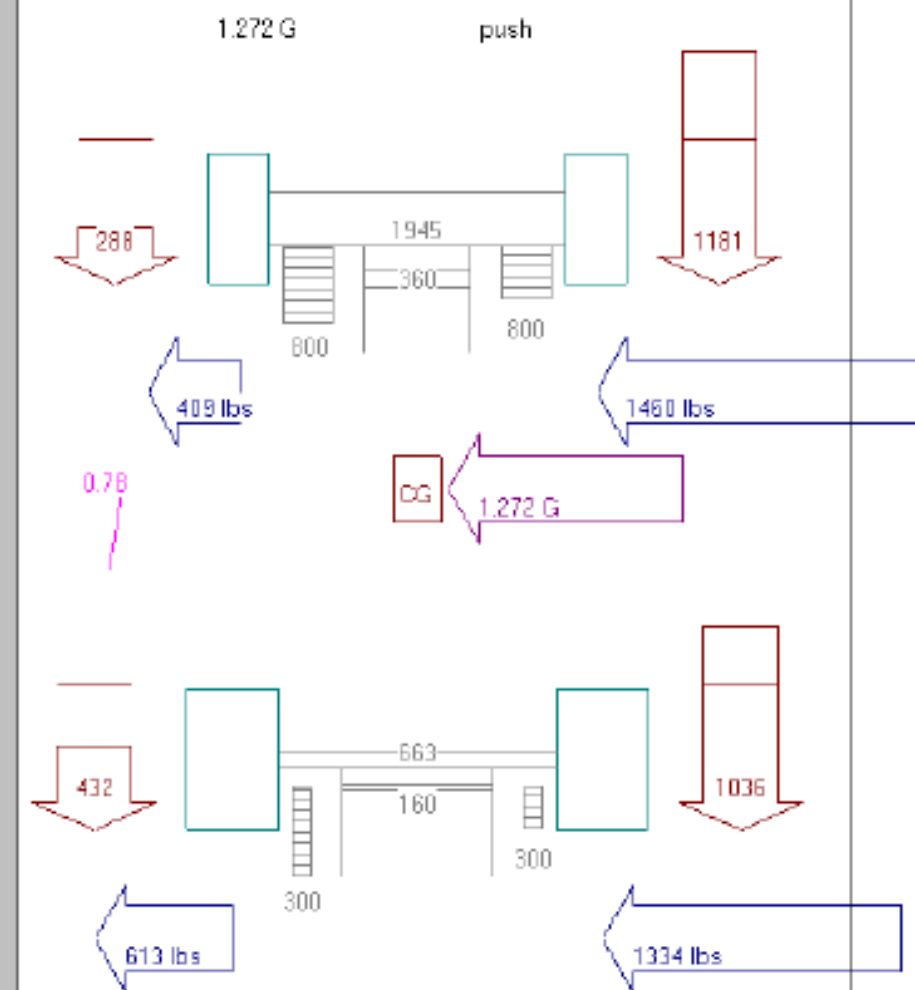


Centre of Gravity

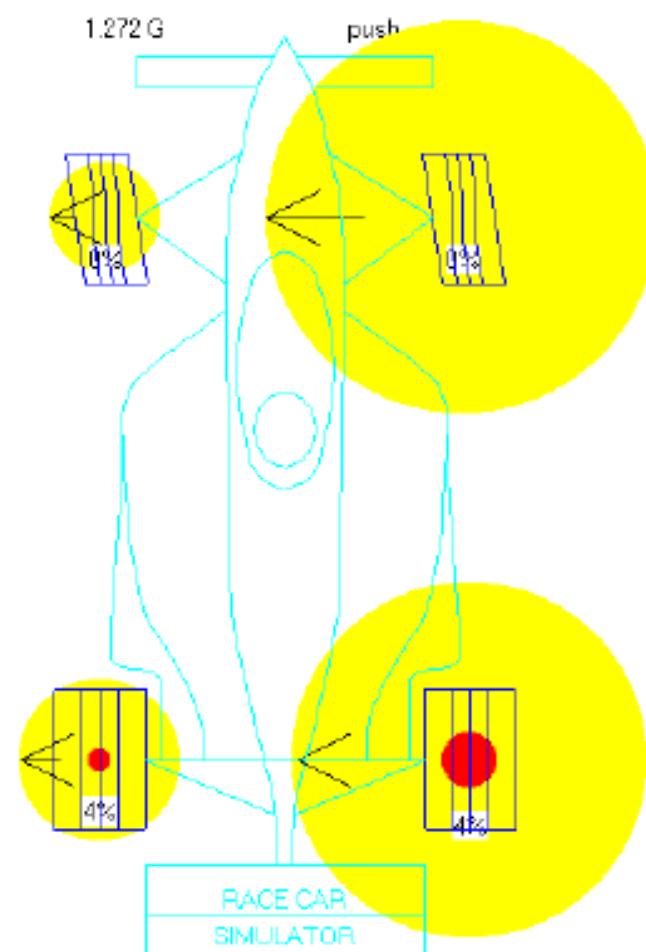
- Given that rules give us a limited track width.
- To reduce weight transfer we try to lower the centre of gravity.



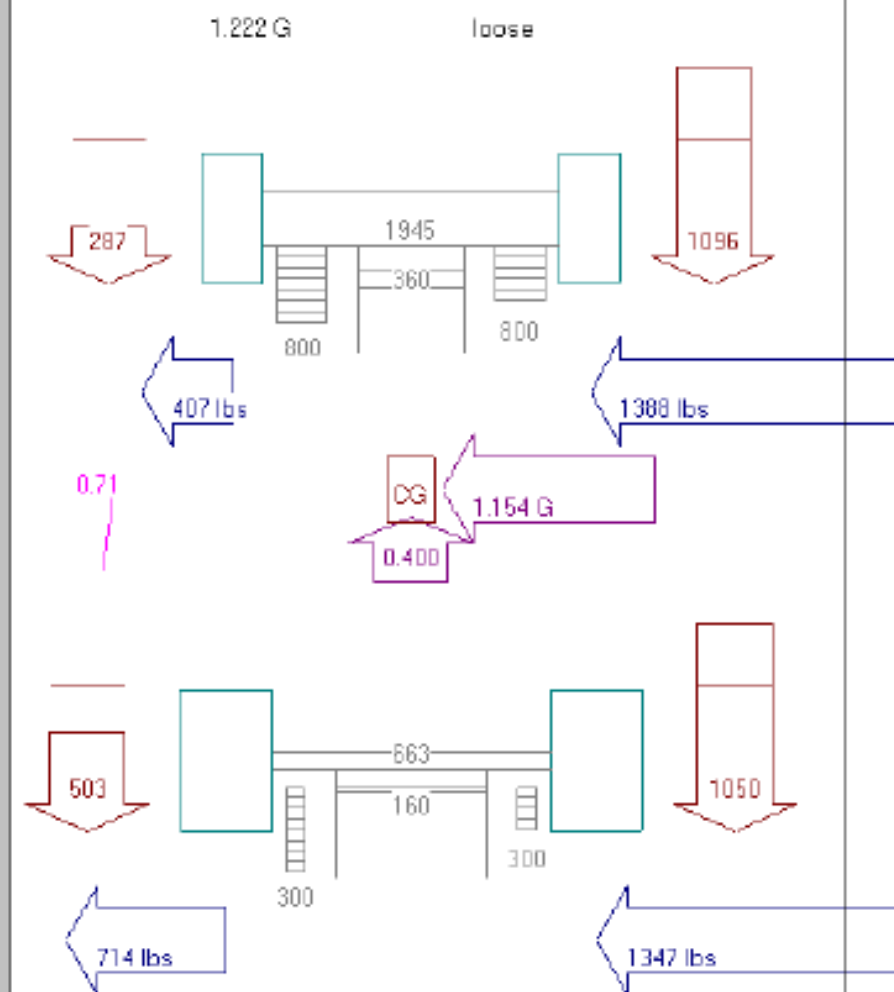
First Setup



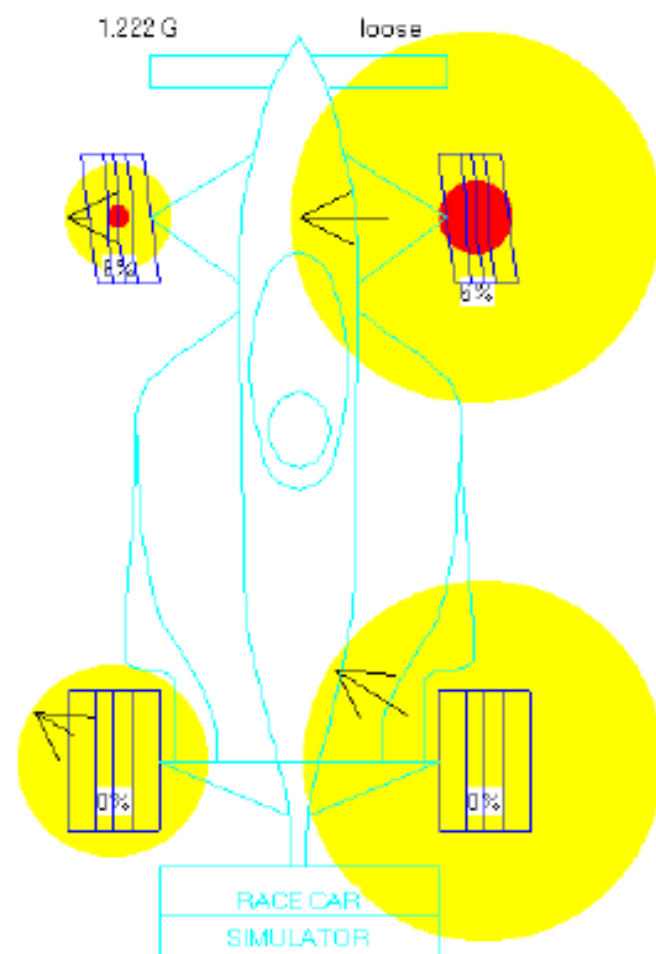
First Setup



First Setup



First Setup



Roll stiffness and chassis stiffness

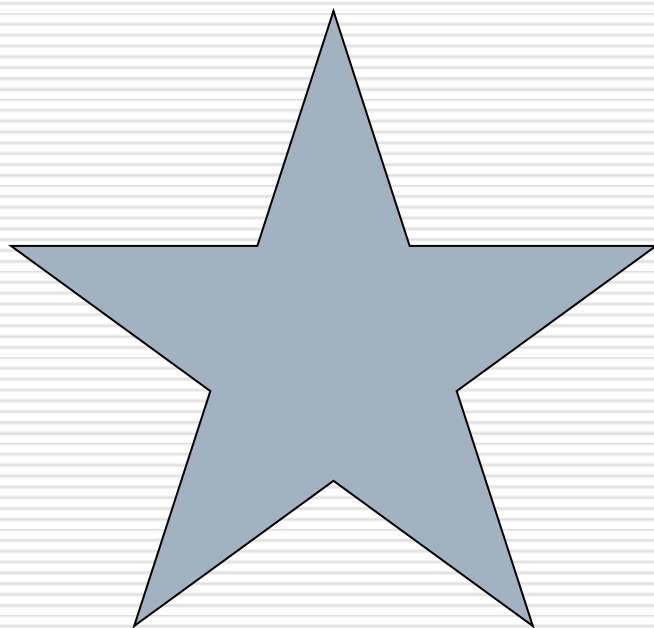
- If the front wants to roll more than the rear
 - Chassis stiffness prevents the front from rolling
 - Reducing roll at the front
 - Decreasing load transfer at the front
 - Increasing load transfer at the rear
-

Weight transfer tuning

How to Tune Your Handling

To get more understeer (to get more oversteer)

- *More weight in front (rear)* – more mass means less tire grip
 - *Soften or lower rear (front) springs, shocks, swaybars* – roll couple
 - *Wider rear (front) or narrower front (rear) tires* – load pressure
 - *Wider rear (front) or narrower front (rear) tires* – load pressure
 - *Change tire pressures*
 - *Diagonal weight jacking*
-



Rotation – Linear Parallels

Linear Motion

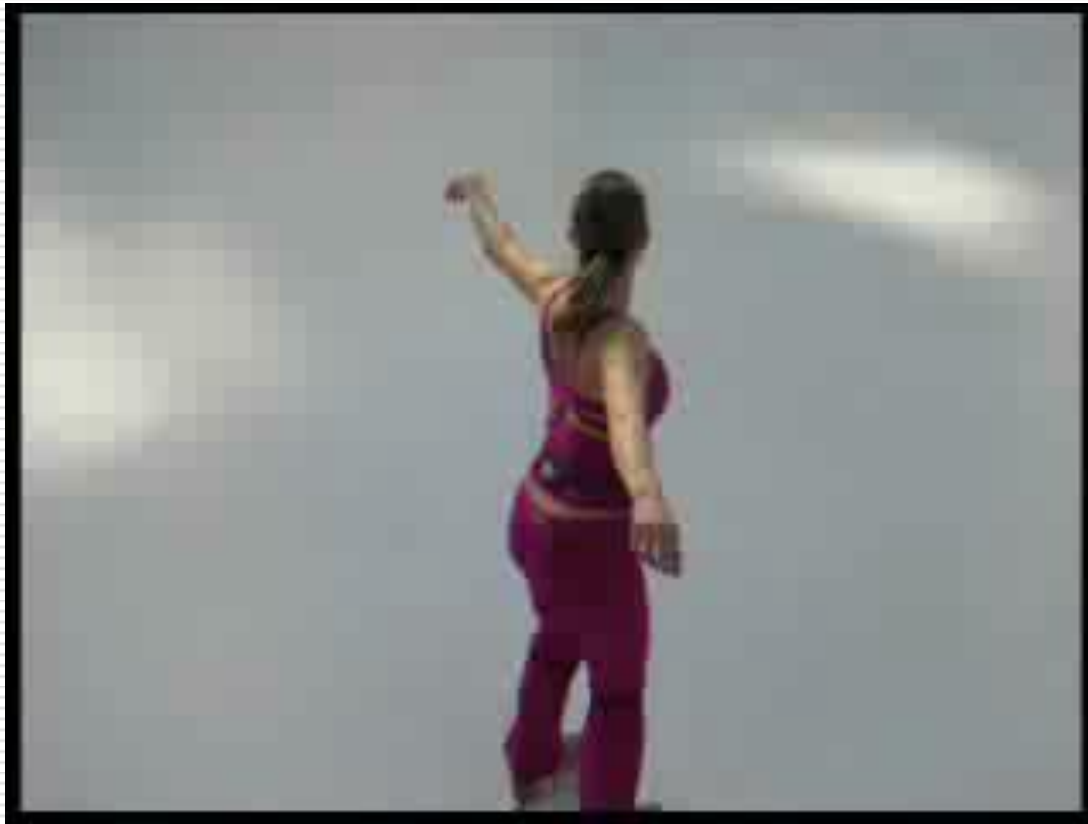
Rotational Motion

Position	x	θ	Angular position
Velocity	v	ω	Angular velocity
Acceleration	a	α	Angular acceleration
Motion equations	$x = \bar{v}t$	$\theta = \bar{\omega}t$	Motion equations
	$v = v_0 + at$	$\omega = \omega_0 + \alpha t$	
	$x = v_0t + \frac{1}{2}at^2$	$\theta = \omega_0t + \frac{1}{2}\alpha t^2$	
	$v^2 = v_0^2 + 2ax$	$\omega^2 = \omega_0^2 + 2\alpha\theta$	
Mass (linear inertia)	m	I	Moment of inertia
Newton's second law	$F = ma$	$\tau = I\alpha$	Newton's second law
Momentum	$p = mv$	$L = I\omega$	Angular momentum
Work	Fd	$\tau\theta$	Work
Kinetic energy	$\frac{1}{2}mv^2$	$\frac{1}{2}I\omega^2$	Kinetic energy
Power	Fv	$\tau\omega$	Power

Capri Accelerating



Spinning Skater



Linear $F = ma$

Newton's Second
Law

Angular $\tau = I\alpha$

Linear $p = mv$

Momentum

Angular $L = I\omega$

Moment
of Inertia
 I

Linear $KE = \frac{1}{2}mv^2$

Kinetic Energy

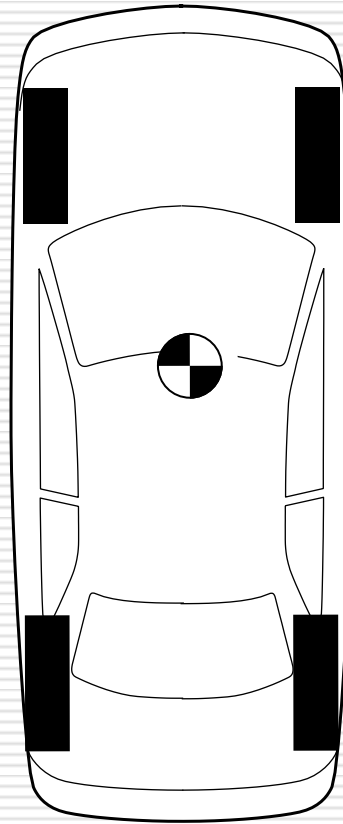
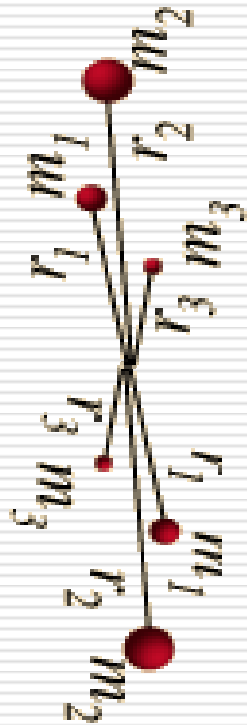
Angular $KE = \frac{1}{2}I\omega^2$

Linear $F_{net}d = \Delta \left(\frac{1}{2}mv^2 \right)$

Work-Energy

Angular $\tau_{net}\theta = \Delta \left(\frac{1}{2}I\omega^2 \right)$

Moment of Inertia



Vehicle Inertial measurement

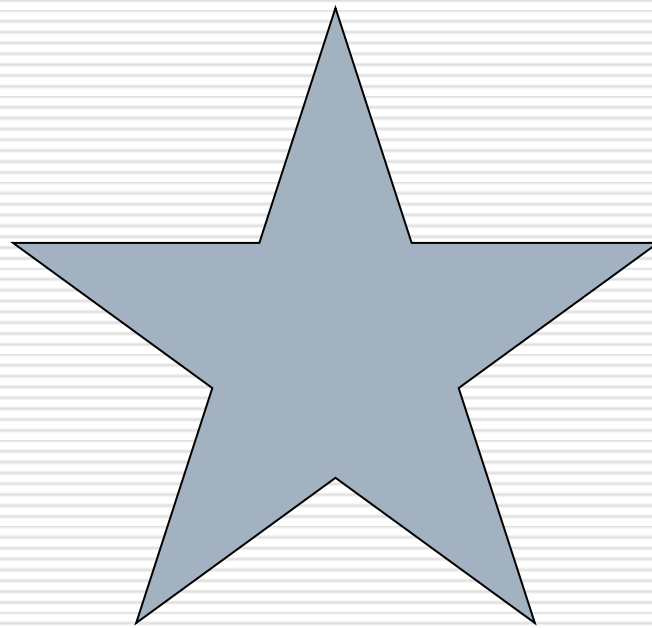


CIC's Moment of Inertia Facilities provide measurement of:

- 3-Axis, Moment and Product of Inertias
- Principal Inertias and their Direction Cosines
- Total Mass, Centre of Gravity Location and Mass Distribution

Mass range	From 1kg to 2,500kg
Dimension range	Nominally 6500 (L) x 2800 (W) x 2000 (H) mm max

LSD



Understeer and Oversteer

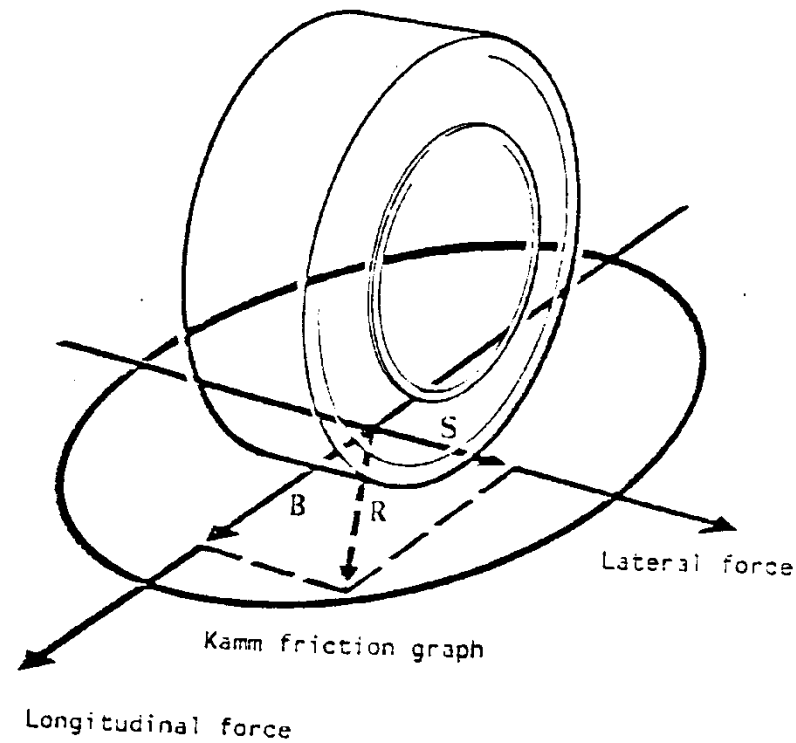
Blundel's Balance Lesson



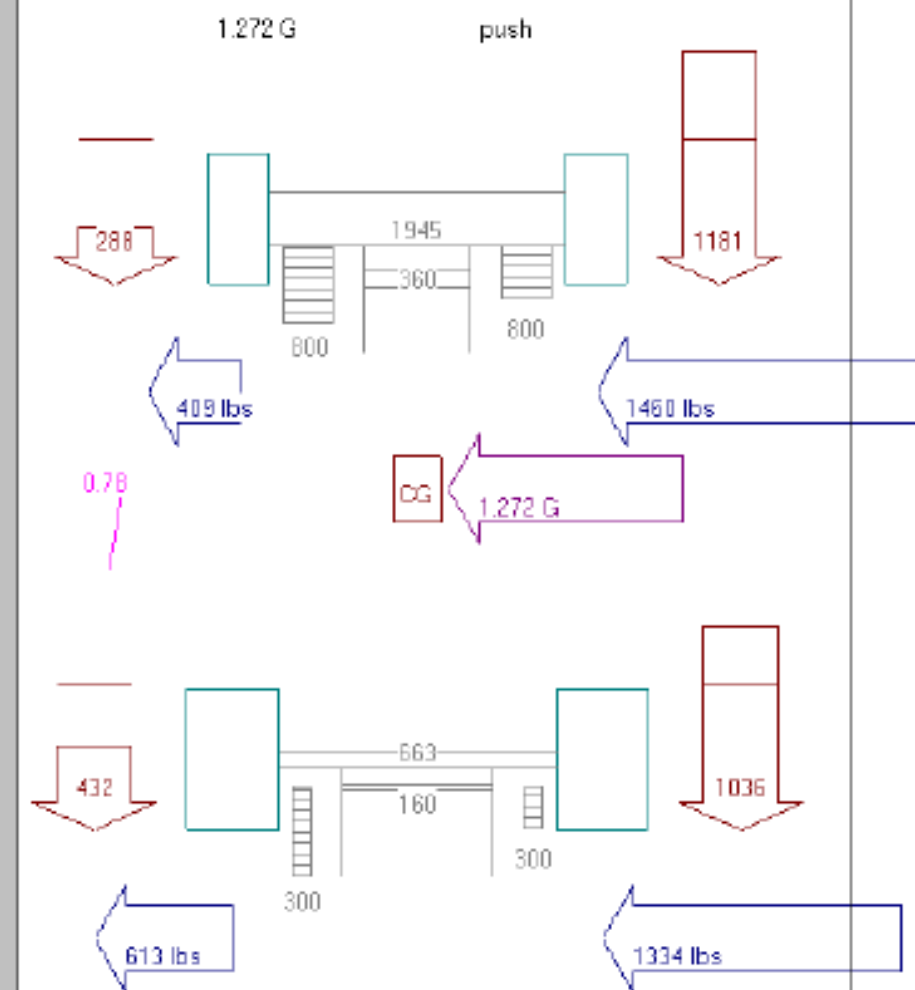
Traction is important

- ☐ After the Apex
 - ☐ Controlled acceleration
 - ☐ Maximum grip
 - ☐ Maximum traction
 - ☐ Two wheel drive
-

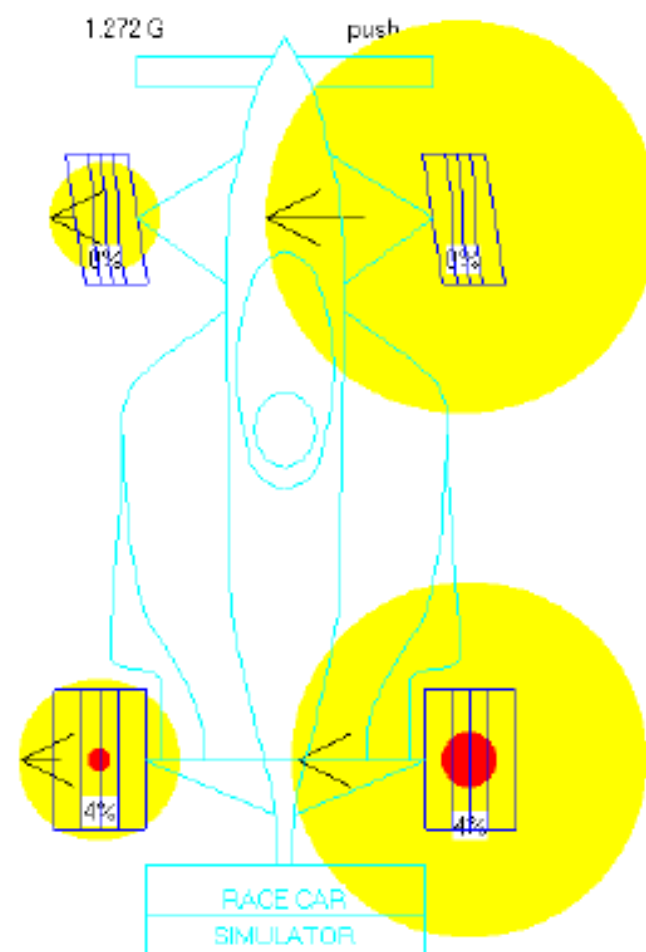
Tyre Characteristics



First Setup



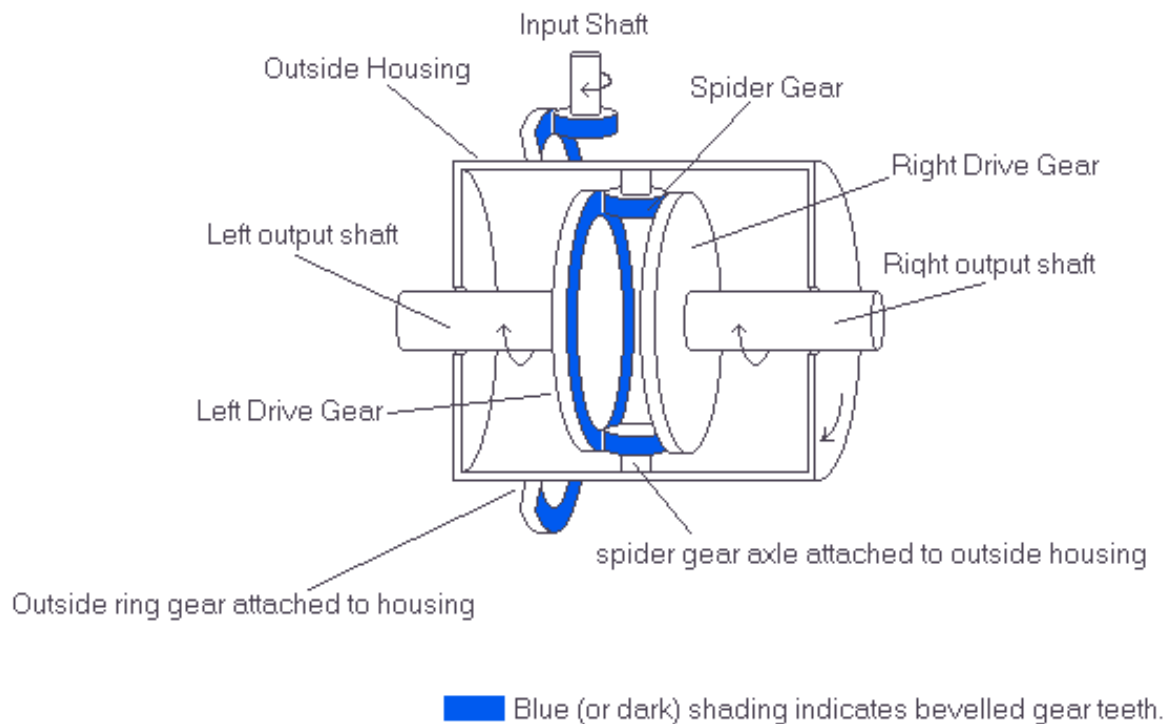
First Setup



Differential wheel travel

- ❑ In a turn L/R wheels different path
 - ❑ Hence want to have different speeds
 - ❑ A go kart has a solid axle or spool
 - ❑ Some lemans cars have spool diffs
-
- ❑ What happens to the tyres ?
 - ❑ What happens to the axles shafts?
-

Open Differential



Open Differential

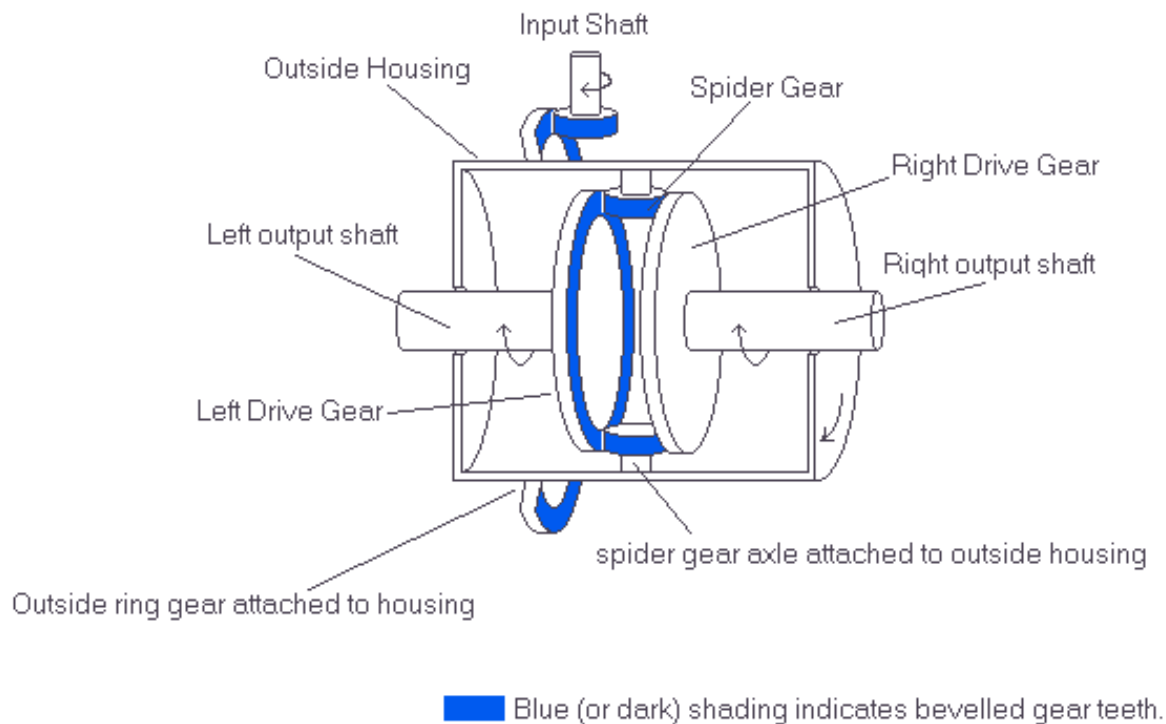
- Allows relative speed difference of wheels

Speed relationship

- Torque in each driveshaft must be the same
- Torque cannot 'be supplied'
- Torque must be 'demanded' or 'resisted'

Torque relationship

Open Differential



Tractive effort and vehicle dynamics

- Consider a T junction launch acceleration event
 - Consider a medium speed corner post apex acceleration event
-

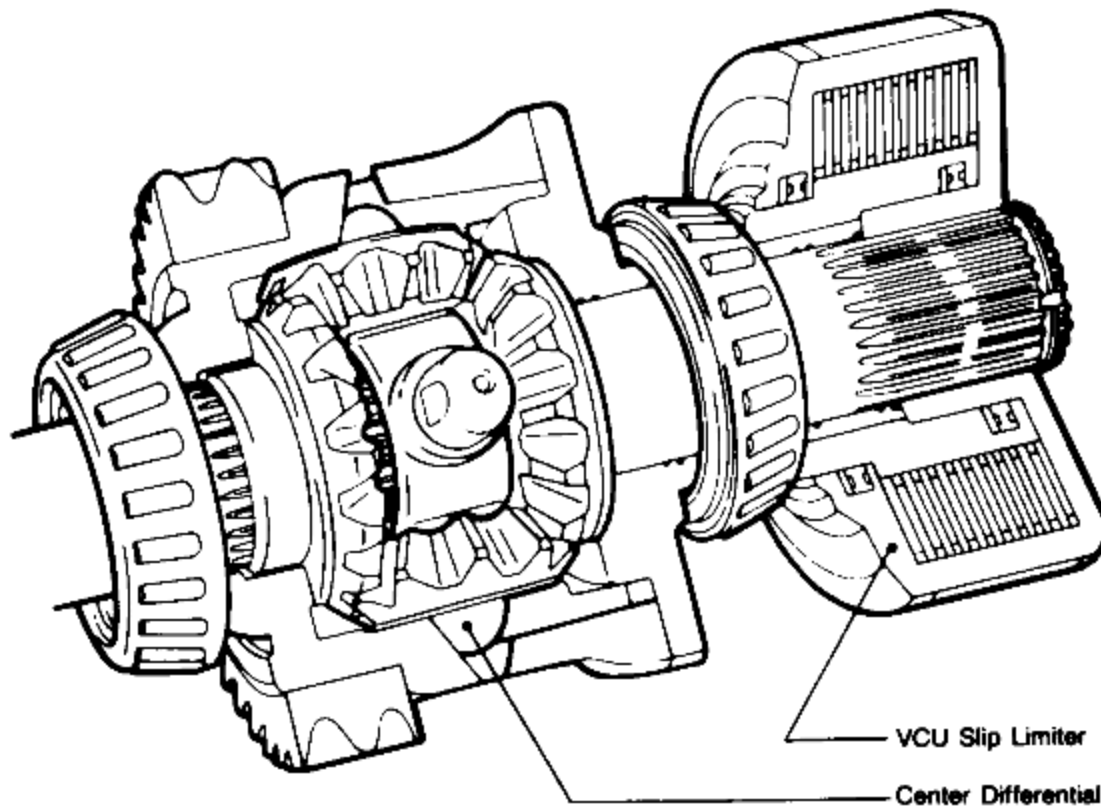
Tractive effort and vehicle dynamics

- ❑ Consider a T junction launch acceleration event
 - ❑ Consider a medium speed corner post apex acceleration event
 - ❑ What happens with a spool axle ?
 - ❑ What happens with an open differential ?
-

Limited Slip Differentials

- ❑ Alternative Technologies
 - ❑ Different characteristics
 - ❑ Differing affects on vehicle dynamics
-
- ❑ Speed dependant
 - ❑ Drive torque dependant
 - ❑ Torque biasing
 - ❑ Controlable
-

Open differential – with viscous coupling

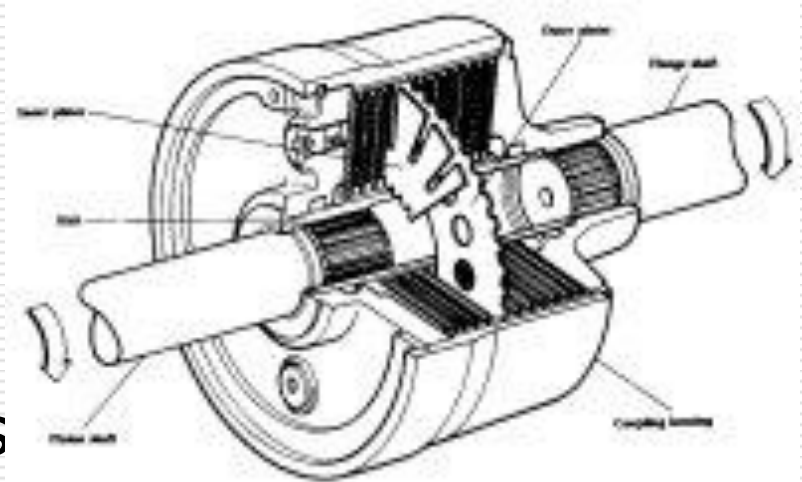


Viscous coupling characteristics

Viscous differential tuning

□ Tuning

- Fluid viscosity
- Fluid fill level
- Number of plates
- Gaps between plates
- Size of plates



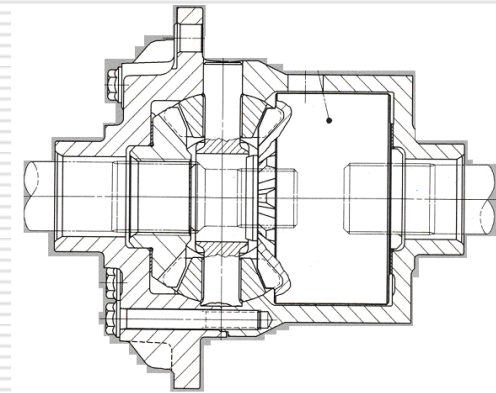
□ Temperature effects and 'humping'

Ferguson P99



Other speed dependant LSD's

- ☐ Eaton locker
- ☐ G rotor pump
- ☐ Hydratrack



Viscous or (speed dependant)couplings

- Advantages

- Disadvantages

Plate and Ramp

Drive torque dependant

☐ Characteristics



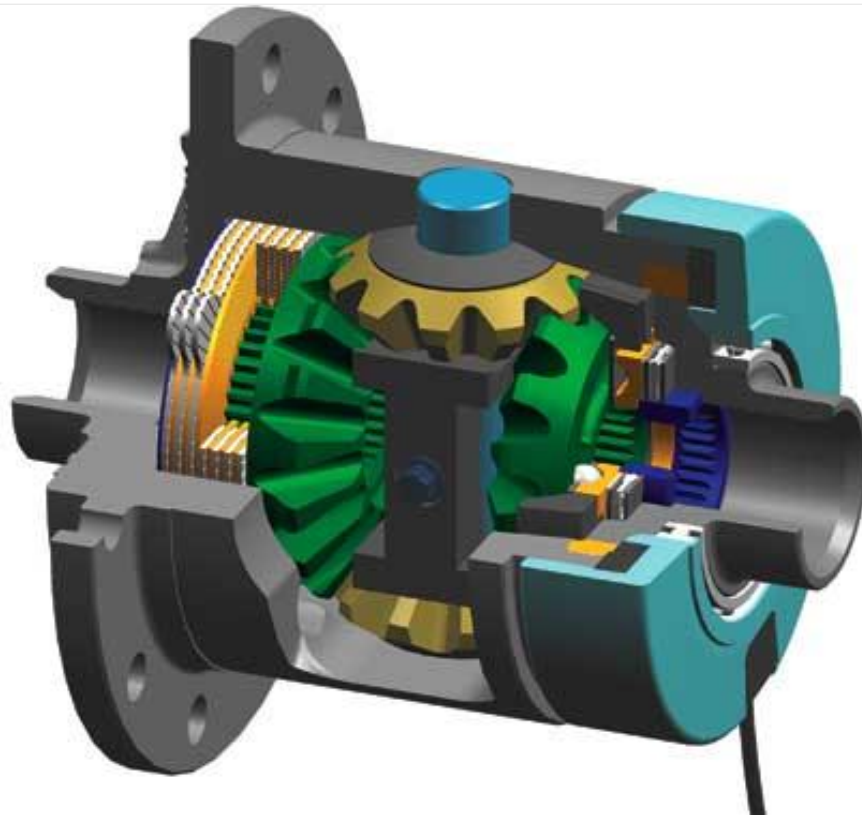


Plate and ramp Characteristic Tuning

- Ramp angles (drive and overrun)
 - Number of plates
 - Level of preload
 - Others
 - Plate (& oil) friction characteristics
 - Size of plates
-

Plate and ramp Limited slip couplings

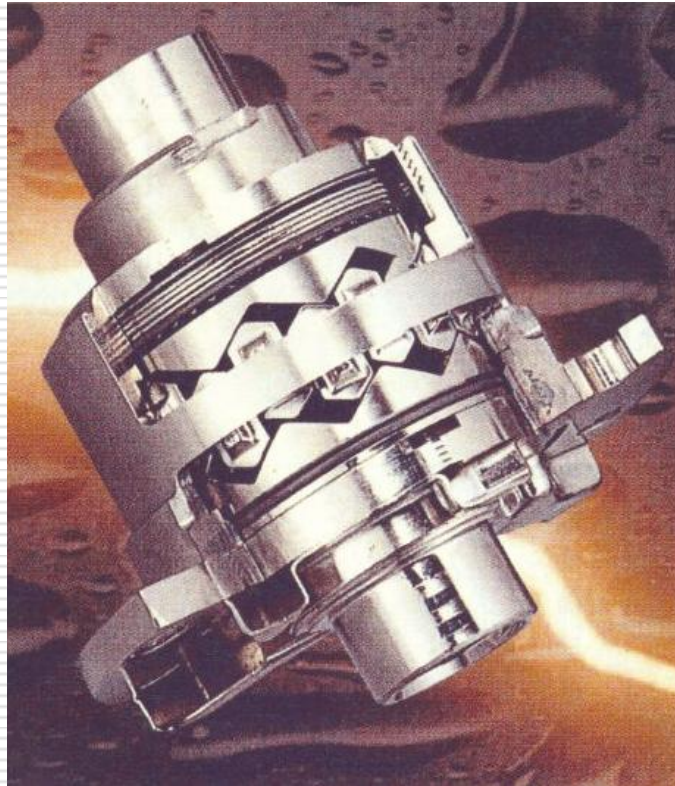
- Advantages

- Disadvantages

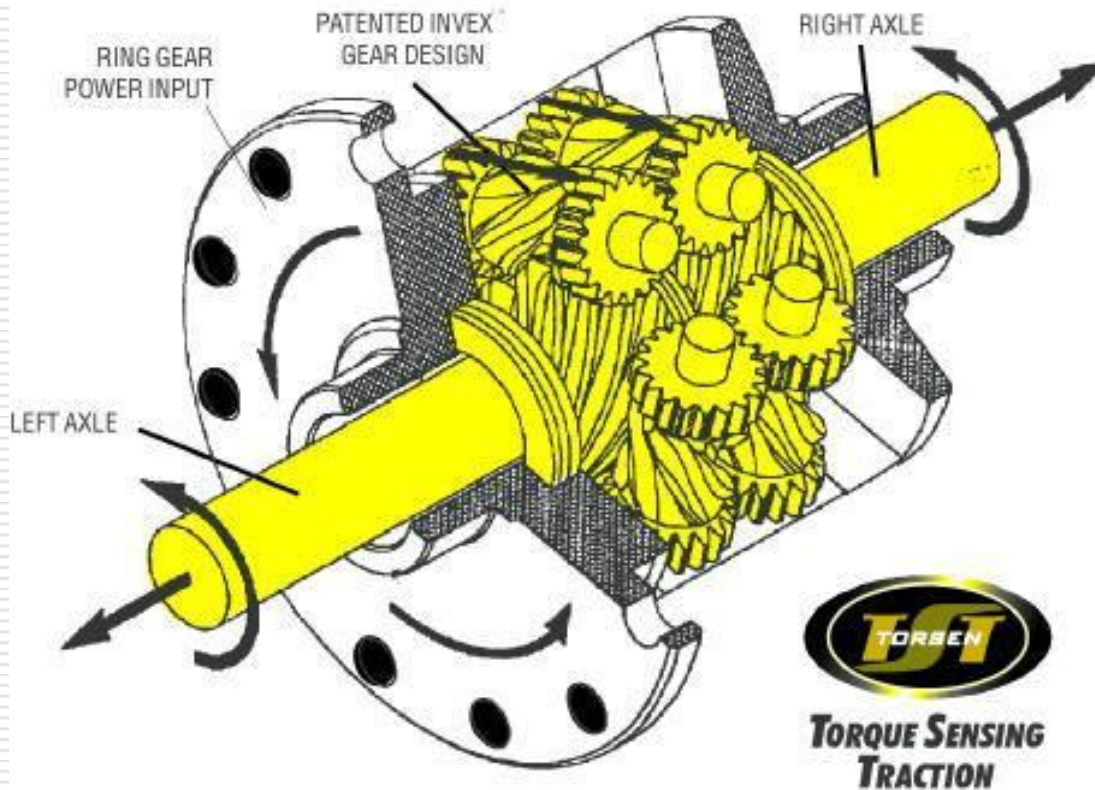
Torque biasing differentials

☐ Characteristics

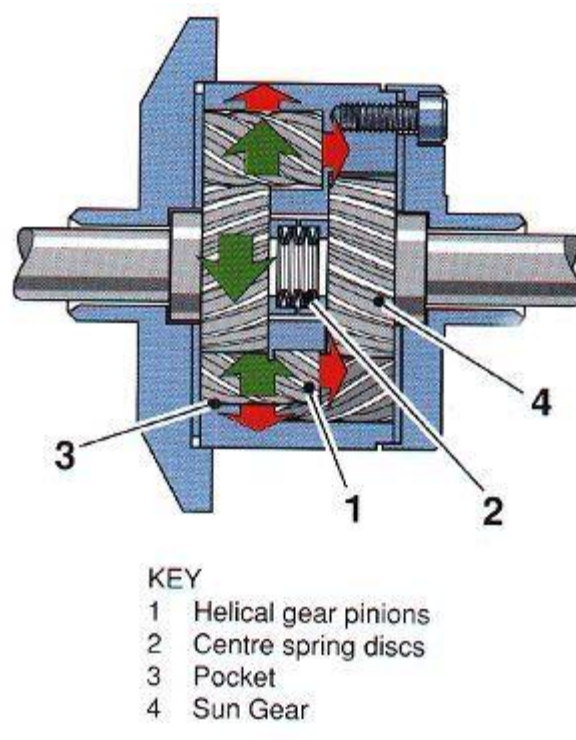
Surtrac – wedge effect Torque biasing differential



Torsen – geared type Torque biasing differential



Torsen – geared type Torque biasing differential



Torque biasing

Limited slip couplings

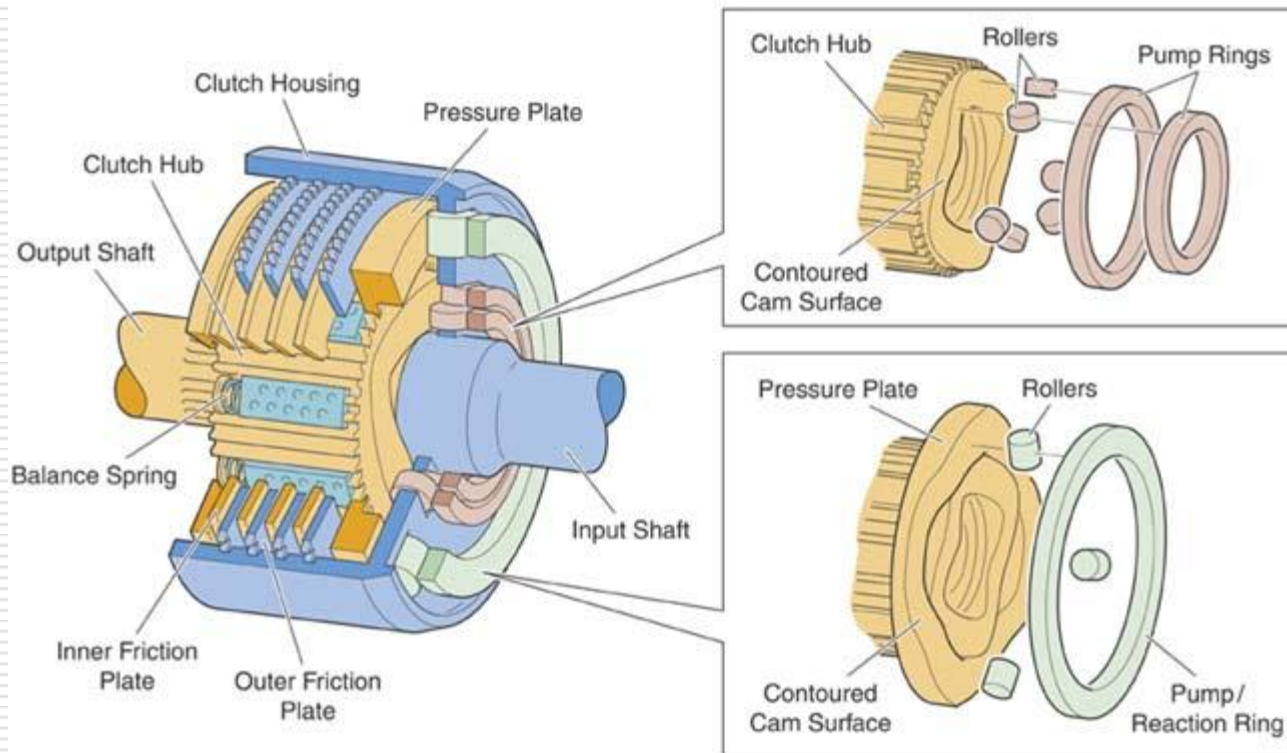
- Advantages

- Disadvantages

Controlable proportional clamping differentials

□ Characteristics

Electronically Controlled Coupling



Volvo XC70 AWD

VOLVO
Volvo Car Corporation

Proportional controllable Limited slip couplings

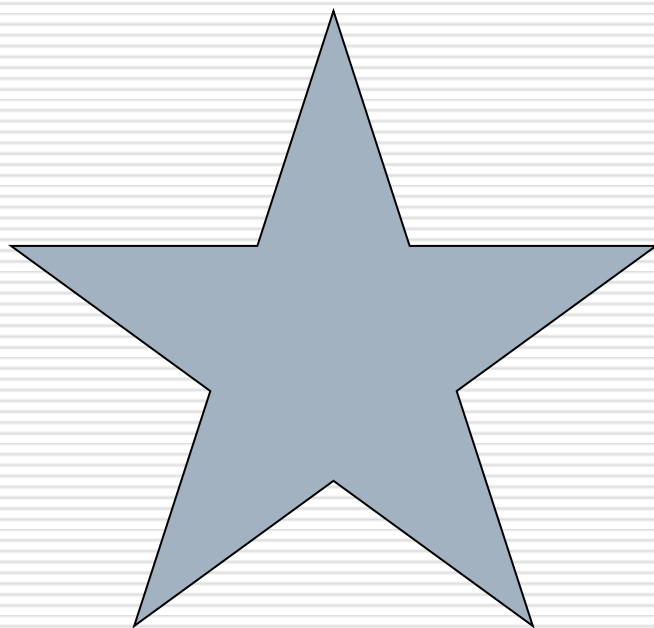
- Advantages

- Disadvantages



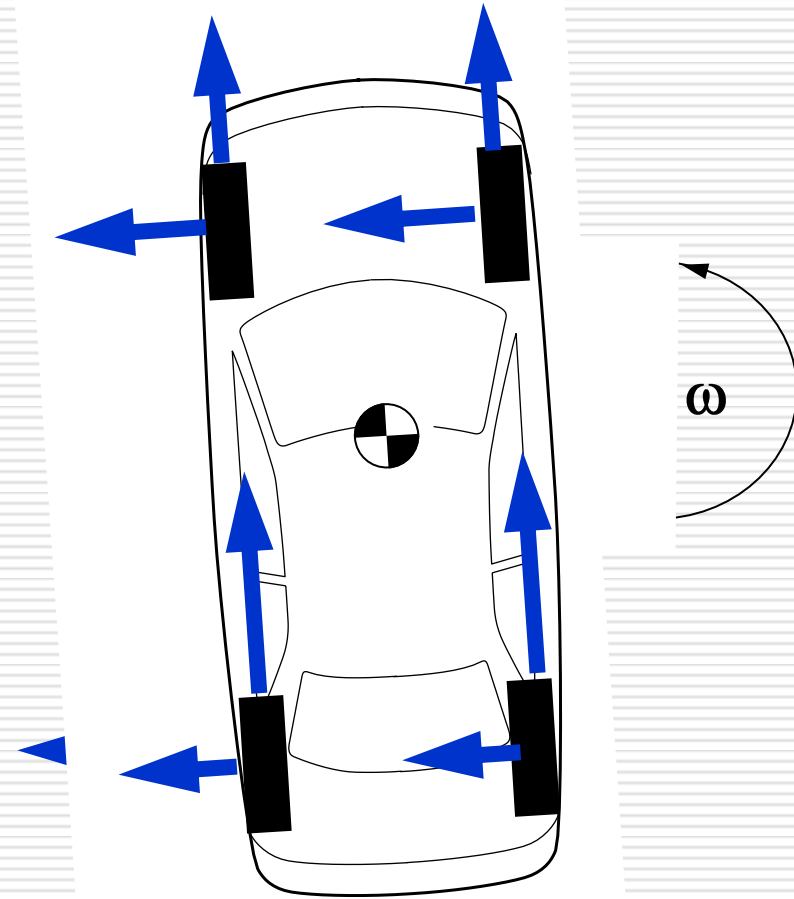
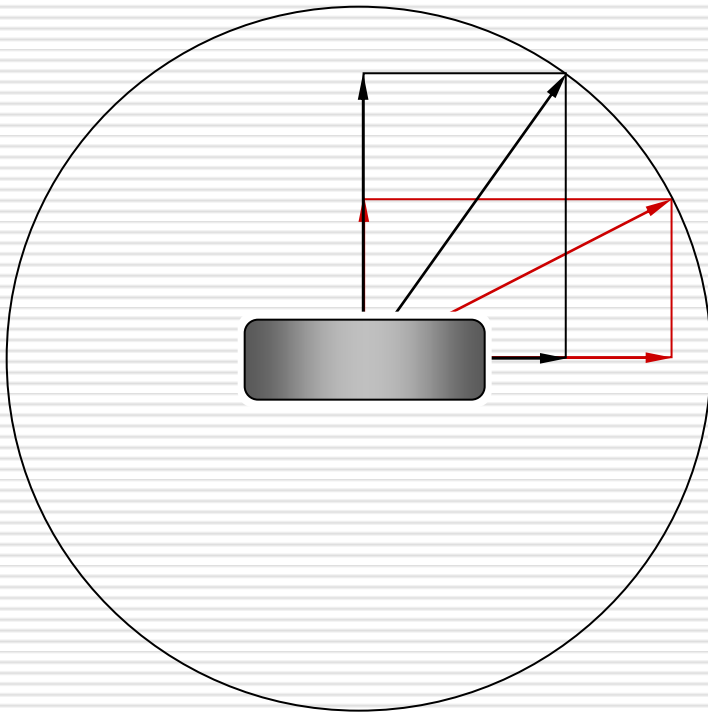
Ferrari F430





Traction effects

- ❑ Friction circle concept - inaccurate but useful
- ❑ Influence of driveline on limit behaviour





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School of Automotive Engineering

Introduction to Vehicle Transient Dynamics 3rd Yr