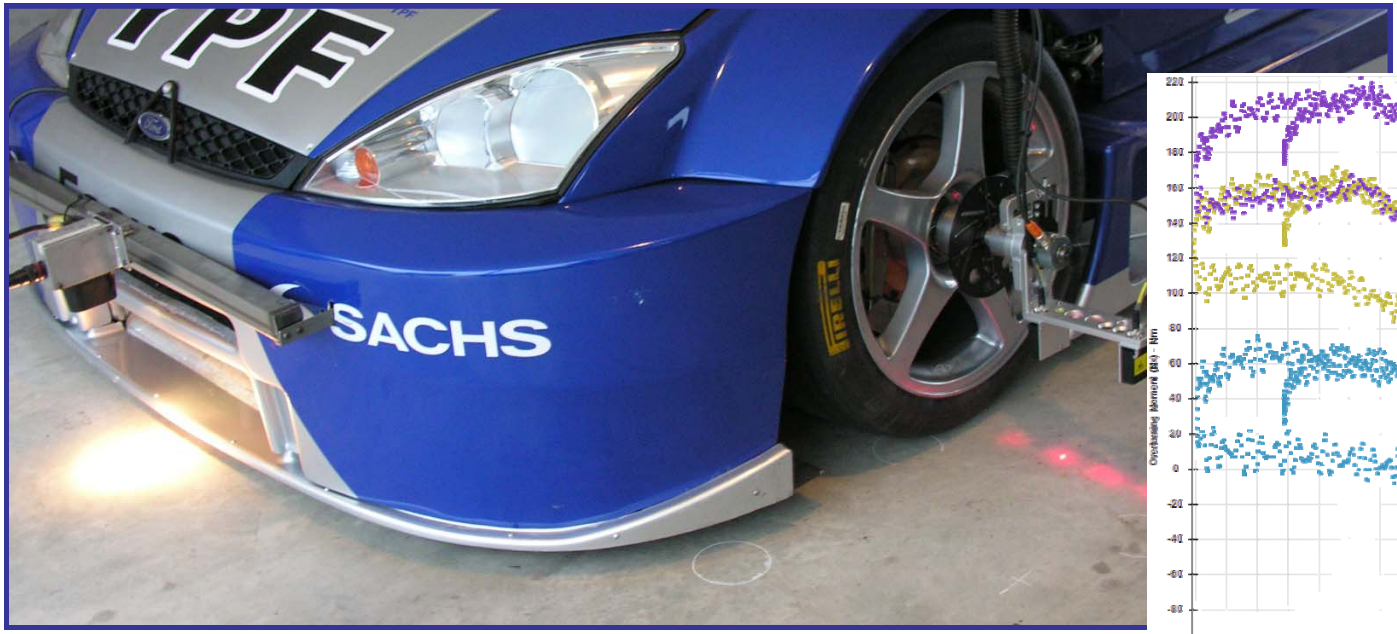
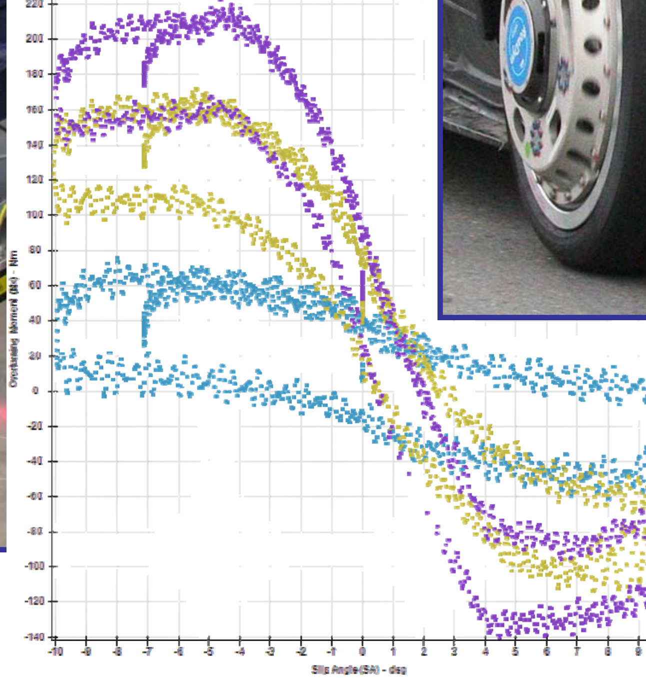
Efficient use of professional sensors in car and tire performance measurement and comparison





Presentation
By Stefan Kloppenborg

Vehicle Dynamics Expo

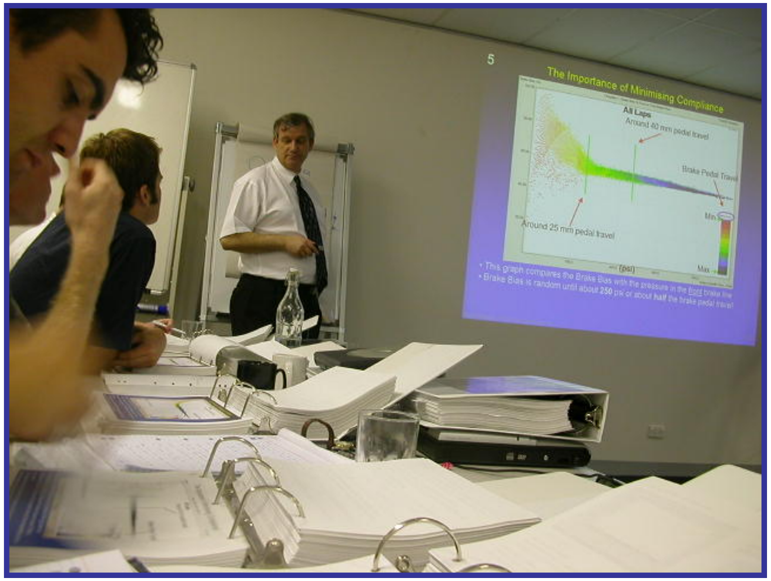
June 16nd-18th 2009

Topics

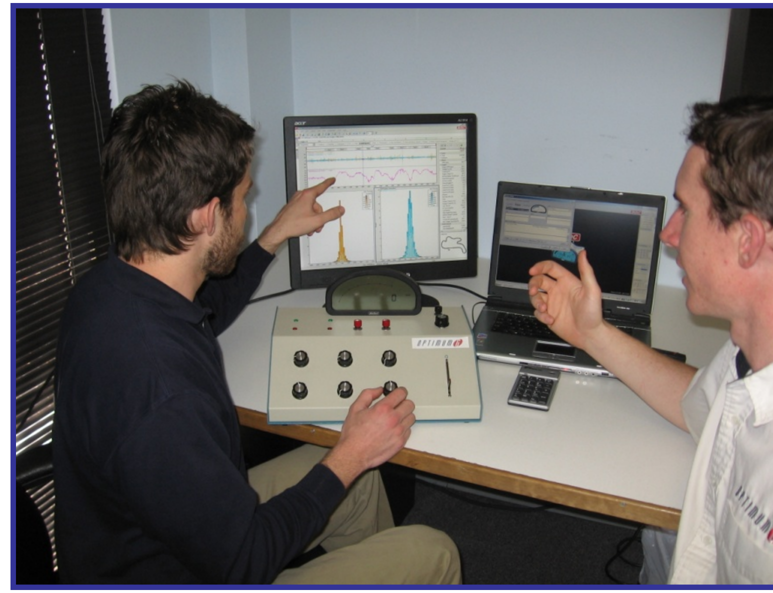
- What is OptimumG
- Yaw moment
- Using sensors to characterize Tire and their effect on handling
- Examples of component evaluation


Consulting
Software
Seminars

In-House seminars



One-on-one training



Public seminars

OptimumG Seminars

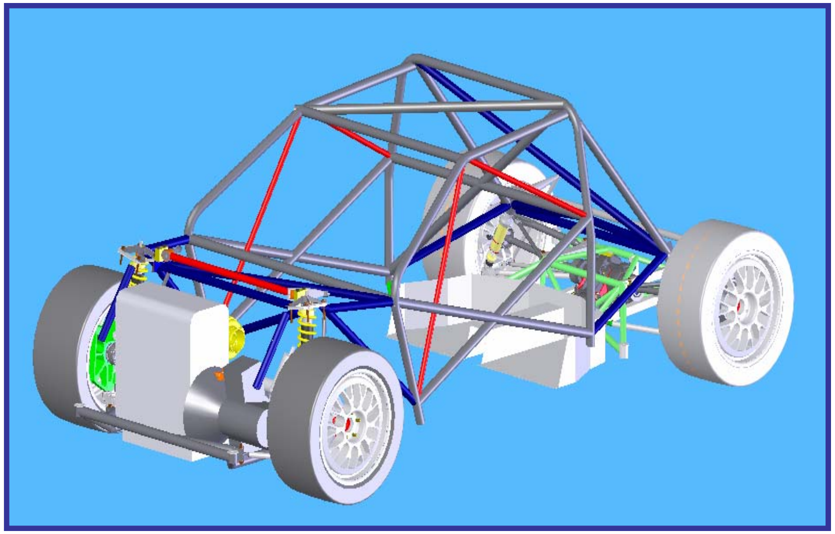
- Public & In-House
- 3 and 4 Day
- 12 Day Workshop
- Design Around Customer Needs
- 8900 Power Point Slides to choose from

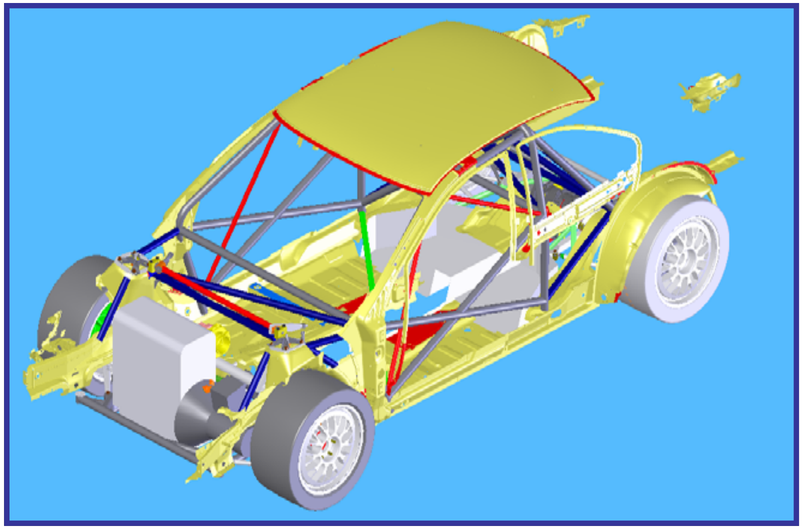
OptimumG – Seminars Customers

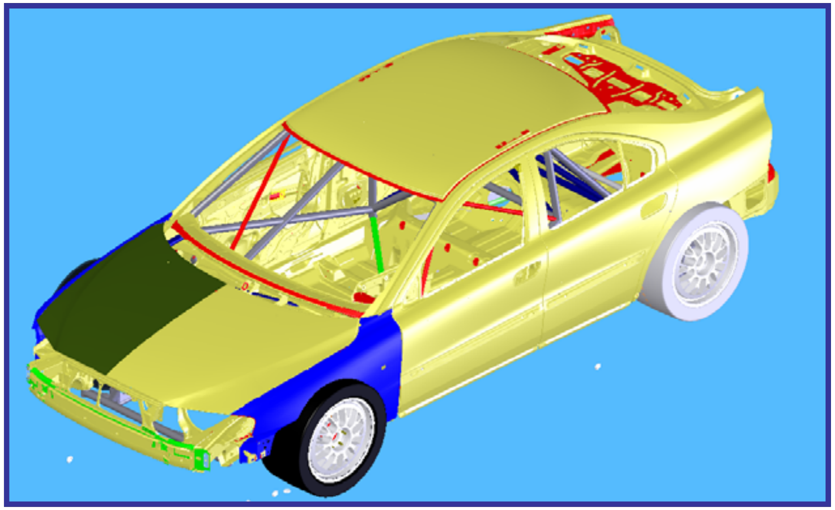
312 Seminars / 12 Years
Over 6000 Satisfied Customers

- Alcon
- AP Brakes
- Brembo
- Bridgestone-Firestone USA
- Bridgestone Tech. Center Europe
- BMW
- Citroen Sport
- Corrsys-Datron
- Chrysler
- Dunlop
- Ferrari
- Ford Advanced Vehicle Operations
- Goodyear
- Mac Laren
- Magneti-Marelli,
- Michelin
- Mitsubishi
- Multimatic
- MoTeC
- Nascar
- Ohlins
- Oreca
- Penske
- Pi Research
- Pirelli
- Porsche
- PSA Peugeot Citroen
- Toyota
- ZF-Sachs.

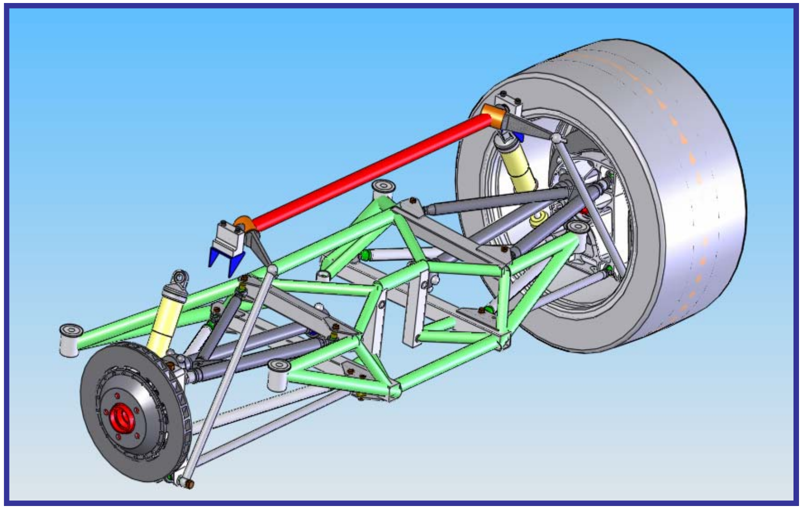
Chassis design

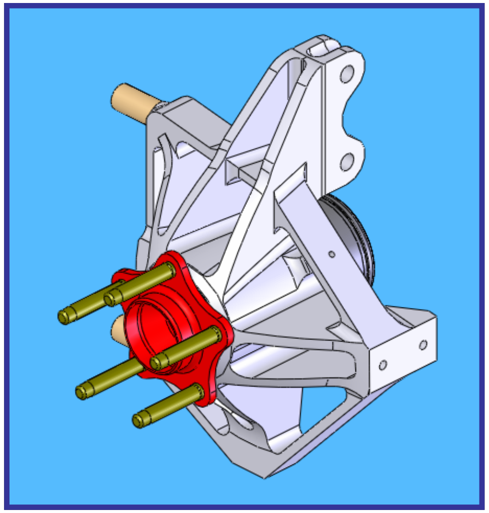


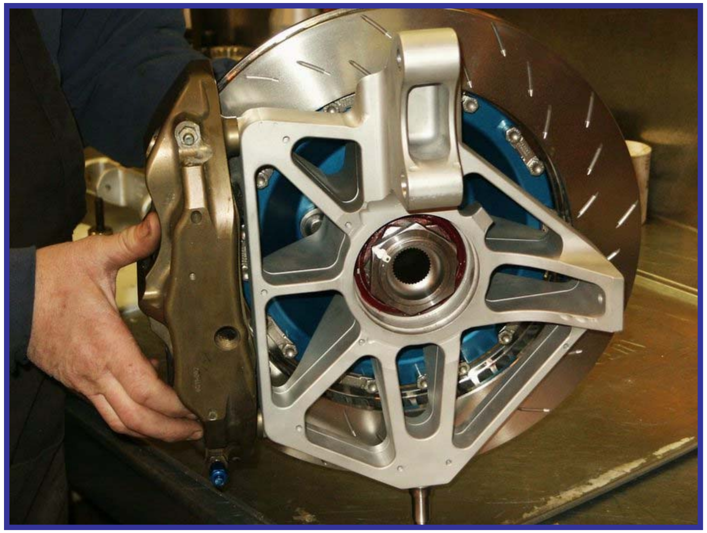




Suspensions Design

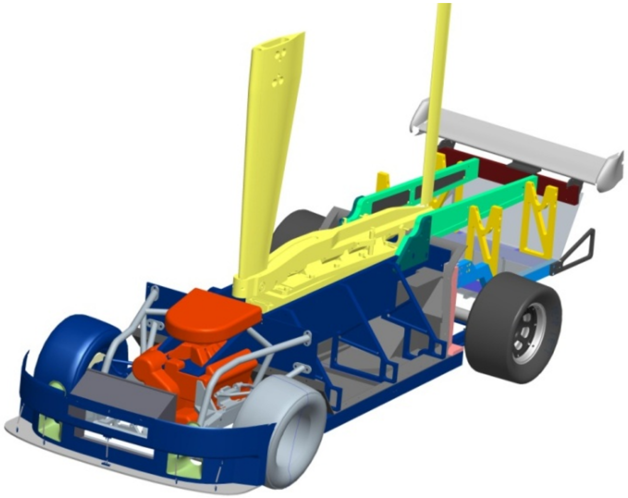




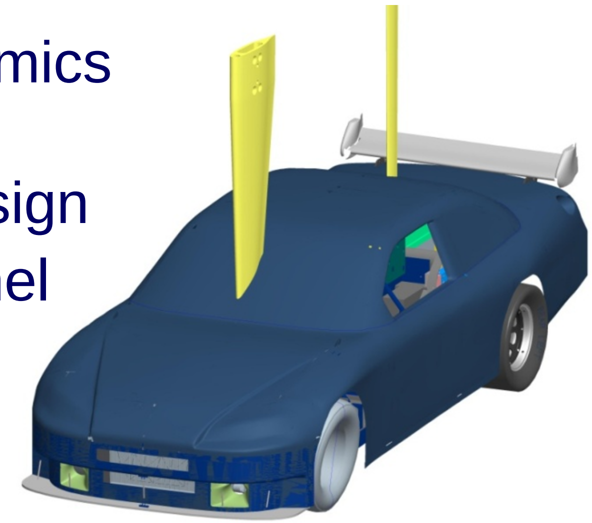


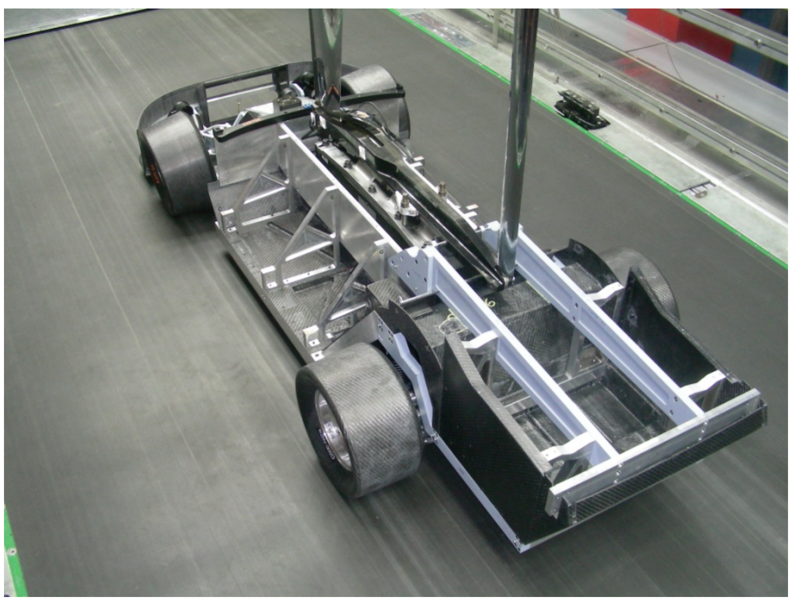
Testing and Development

OptimumG Consulting

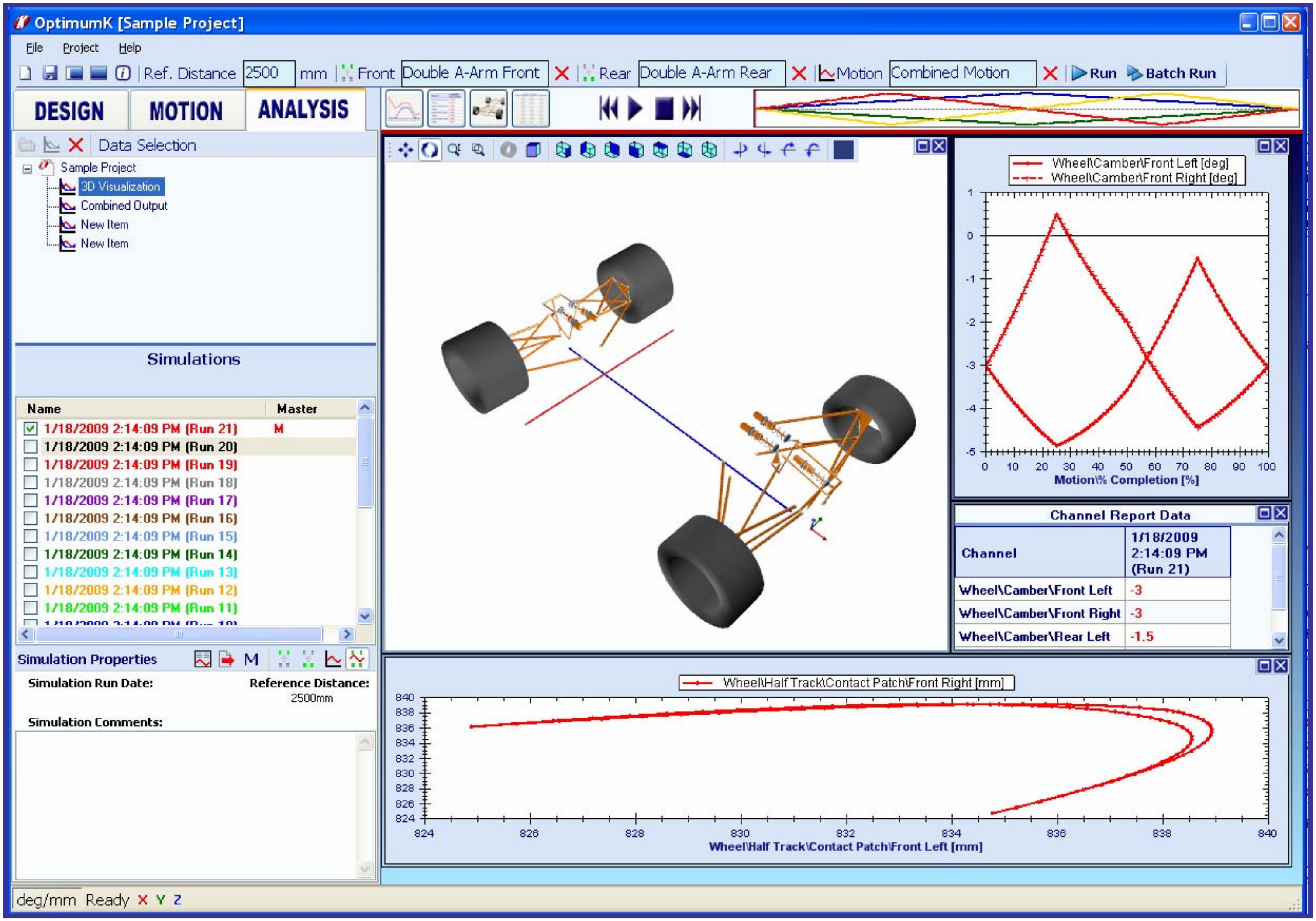


- Aerodynamics studies
- Model design
- Wind tunnel
- Testing

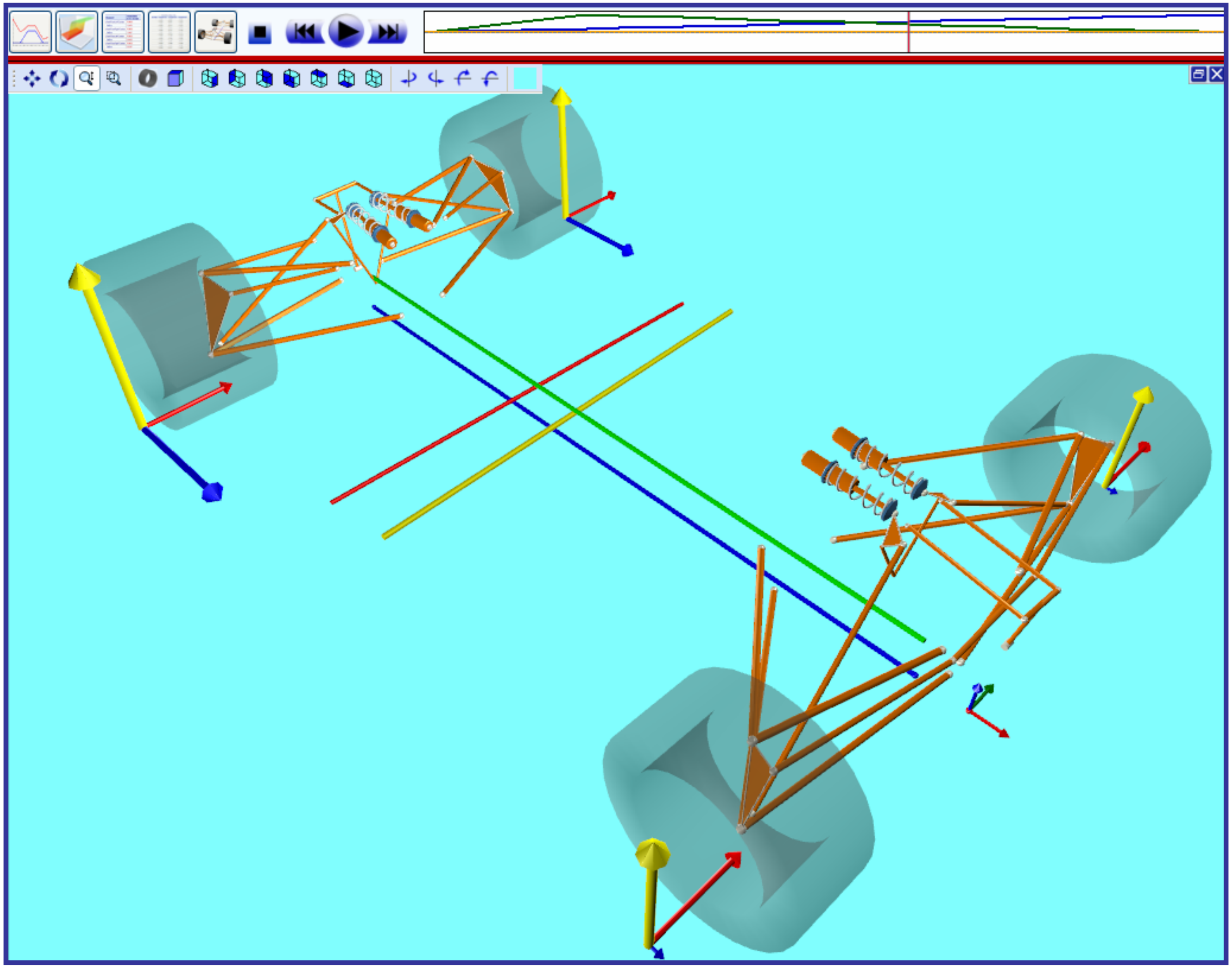




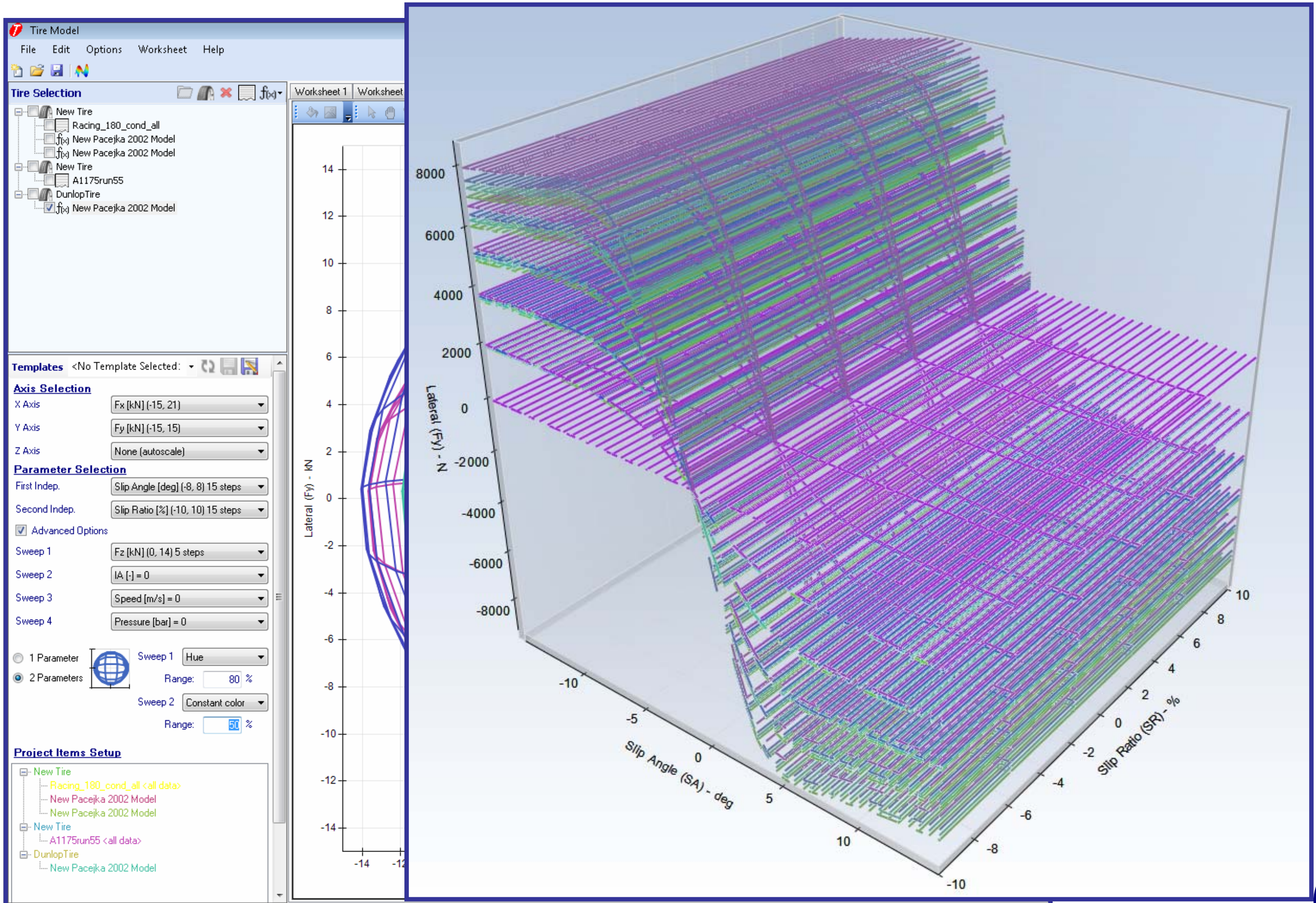
OptimumK Kinematics Software



Steady State Computational Vehicle Dynamics

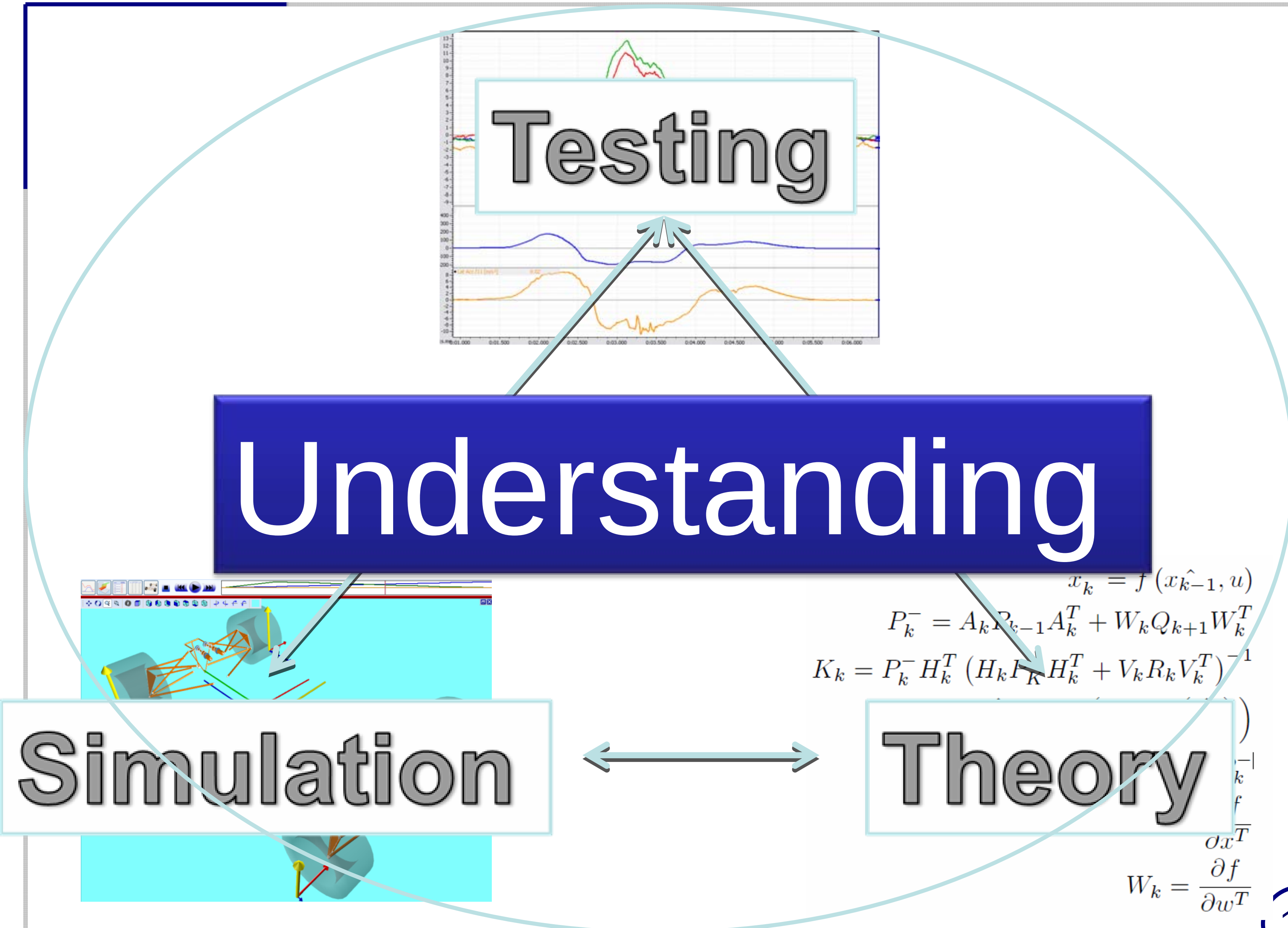


OptimumT Tire test data visualization and modeling

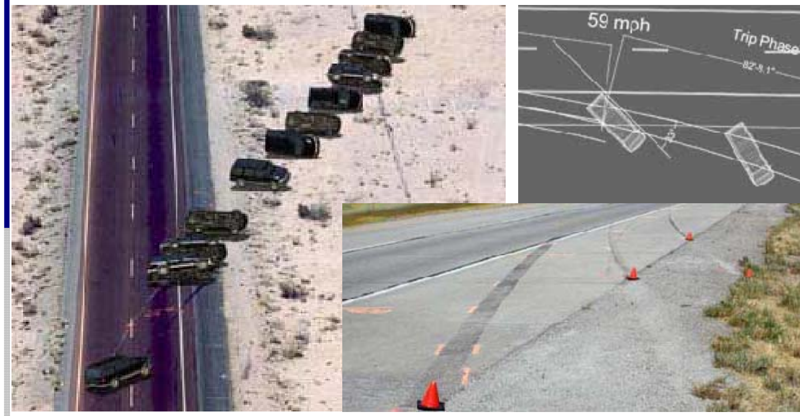


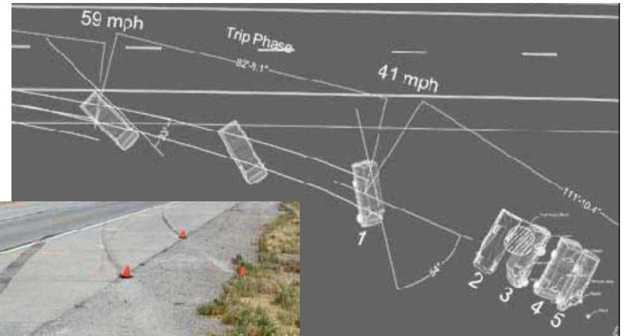

Consulting
Software
Seminars

Understanding Vehicle Behavior



Whether it is about Safety…



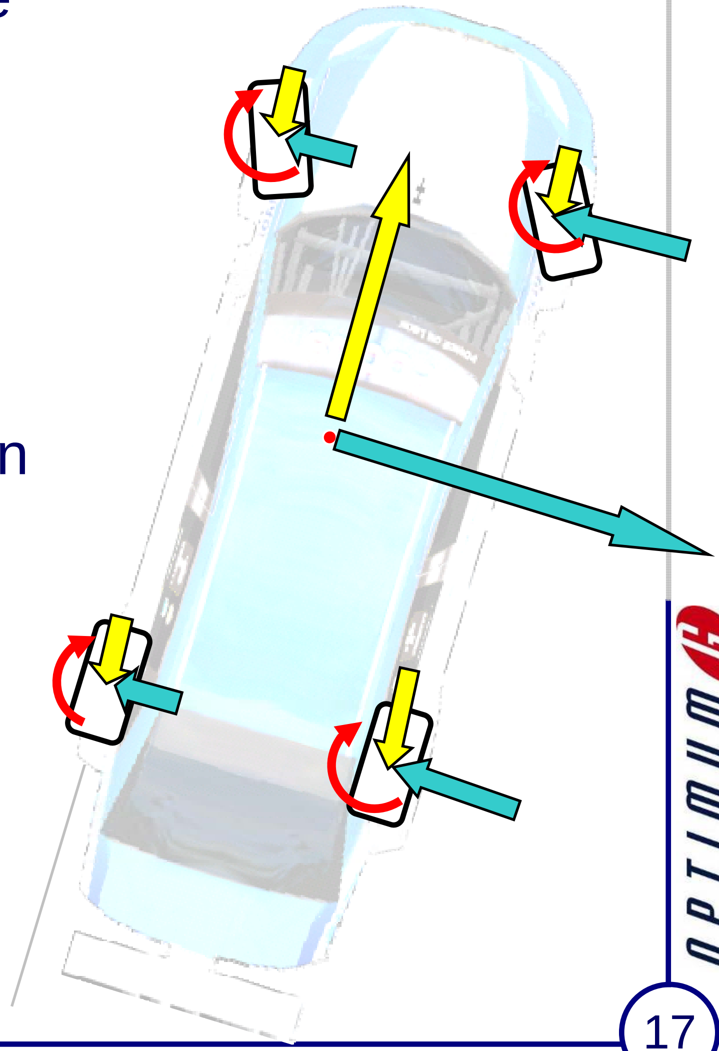


…Or about performance

16

Tire forces and moments

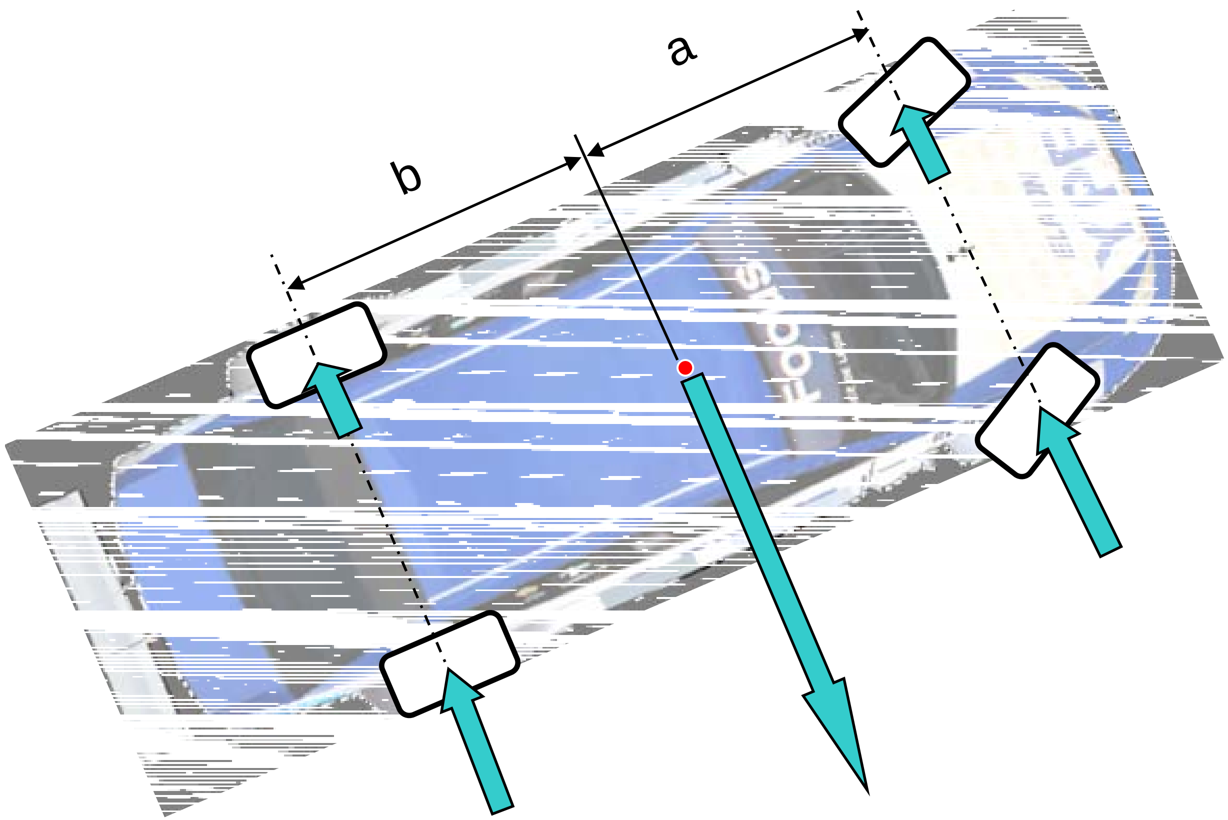
- Yaw moment
- Agility / Stability / Crash Avoidance
- Performances
  - Cornering
  - Braking
  - Combined accelerations
- Indispensable in car and tire design
- Car and tire simulation
- Car and tire development
- ESP / ABS / Traction control



Steady State Vehicle Dynamics Basics

Cornering

$$F_{yFL} + F_{yFR} + F_{yRL} + F_{yRR} = Mass * latG$$



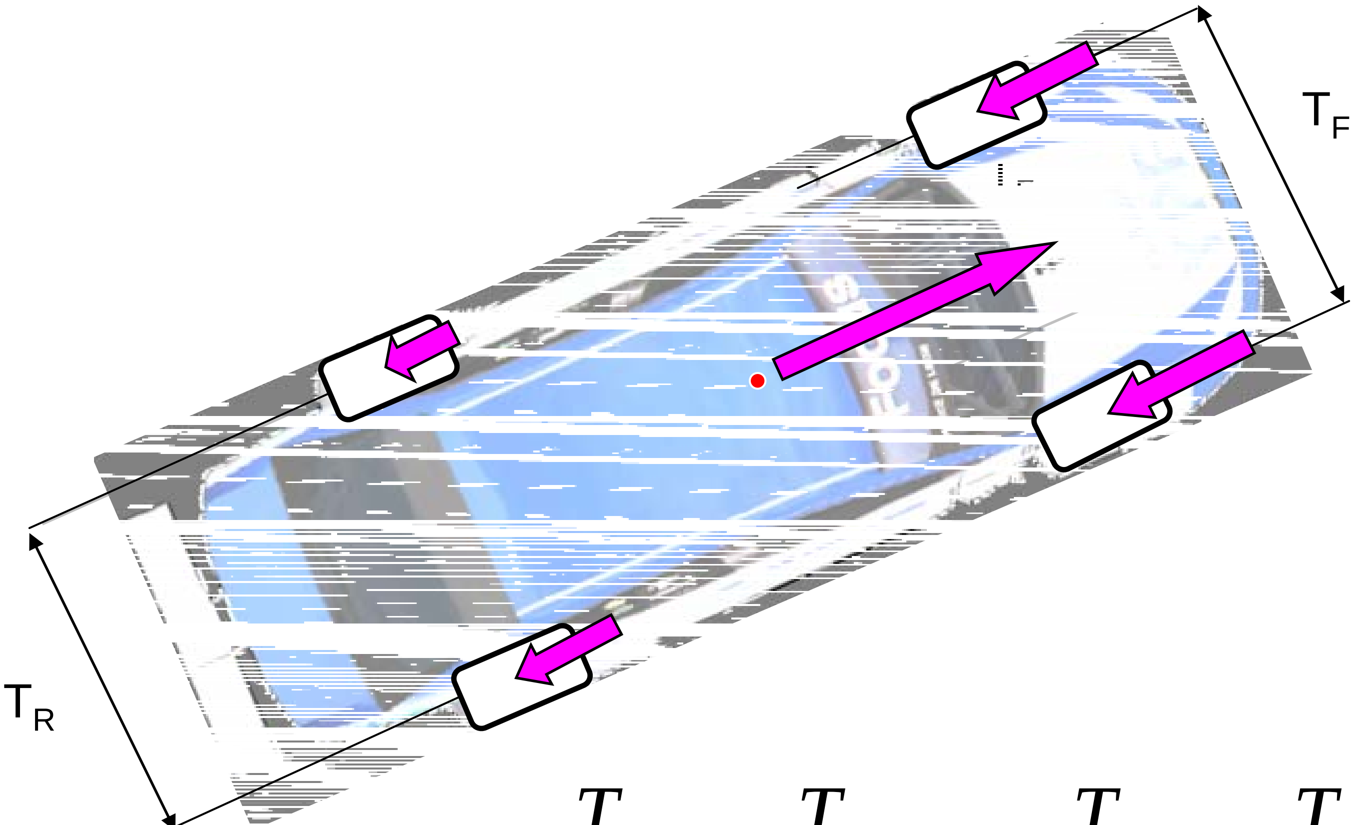
$$\sum M = 0$$

$$(F_{yFL}+F_{yFR})\,a-(F_{yRL}+F_{yRR})\,b = 0$$

Steady State Vehicle Dynamics Basics

Braking

$$F_{xFL} + F_{xFR} + F_{xRL} + F_{xRR} = Mass * longG$$



$$\sum M = 0$$

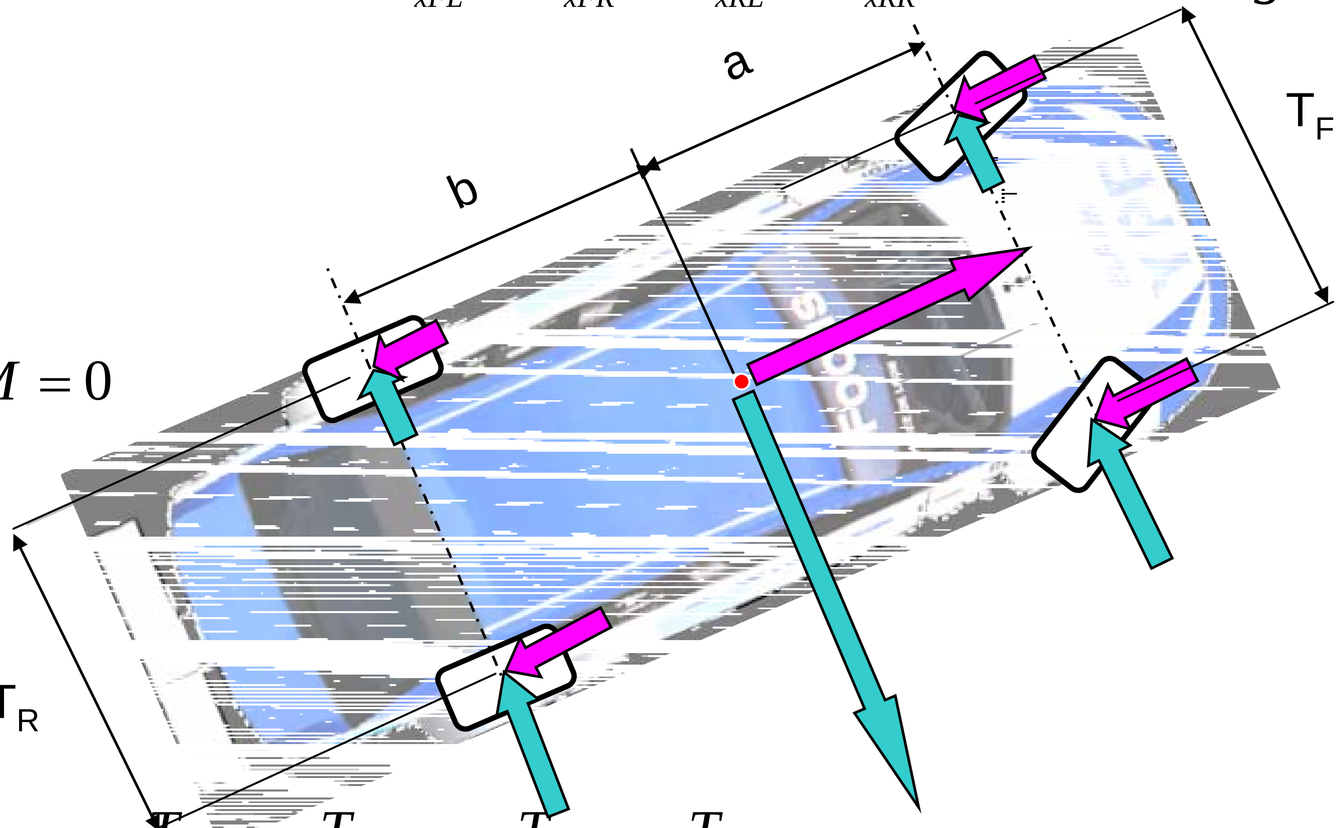
$$(F_{xFR}\frac{T_F}{2} + F_{xRR}\frac{T_R}{2}) - (F_{xFL}\frac{T_F}{2} + F_{xRL}\frac{T_R}{2}) = 0$$

Steady State Vehicle Dynamics Basics

Braking and Cornering

$$\sum F_y : \quad F_{yFL} + F_{yFR} + F_{yRL} + F_{yRR} = Mass * latG$$

$$\sum F_x : \quad F_{xFL} + F_{xFR} + F_{xRL} + F_{xRR} = Mass * longG$$



$$\sum M = 0$$

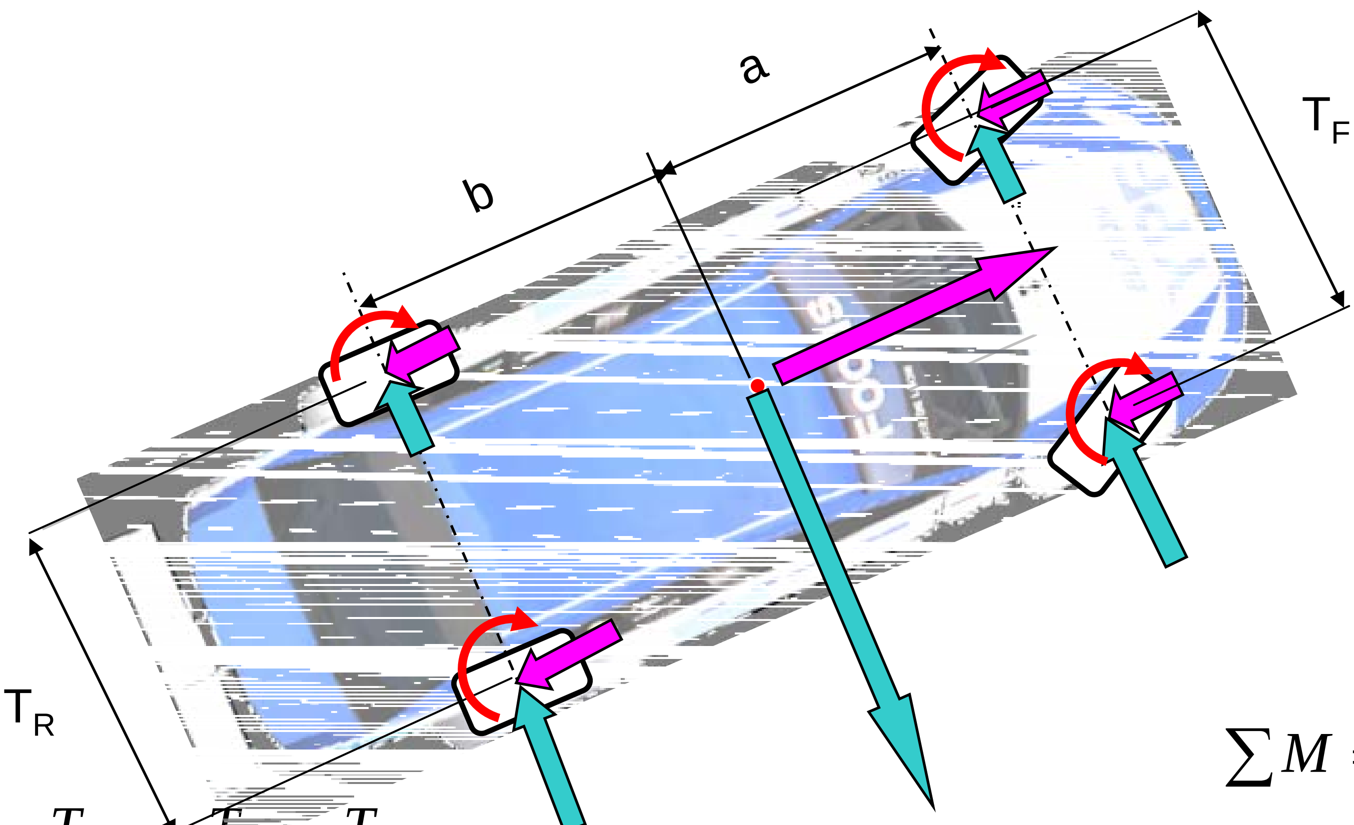
$$[(F_{xFR}\frac{T_F}{2} + F_{xRR}\frac{T_R}{2}) - (F_{xFL}\frac{T_F}{2} + F_{xRL}\frac{T_R}{2})] + [(F_{yFL} + F_{yFR})a - (F_{yRL} + F_{yRR})b] = 0$$

20

Tire self aligning torque

$$\sum F_y \quad F_{yFL} + F_{yFR} + F_{yRL} + F_{yRR} = Mass * latG$$

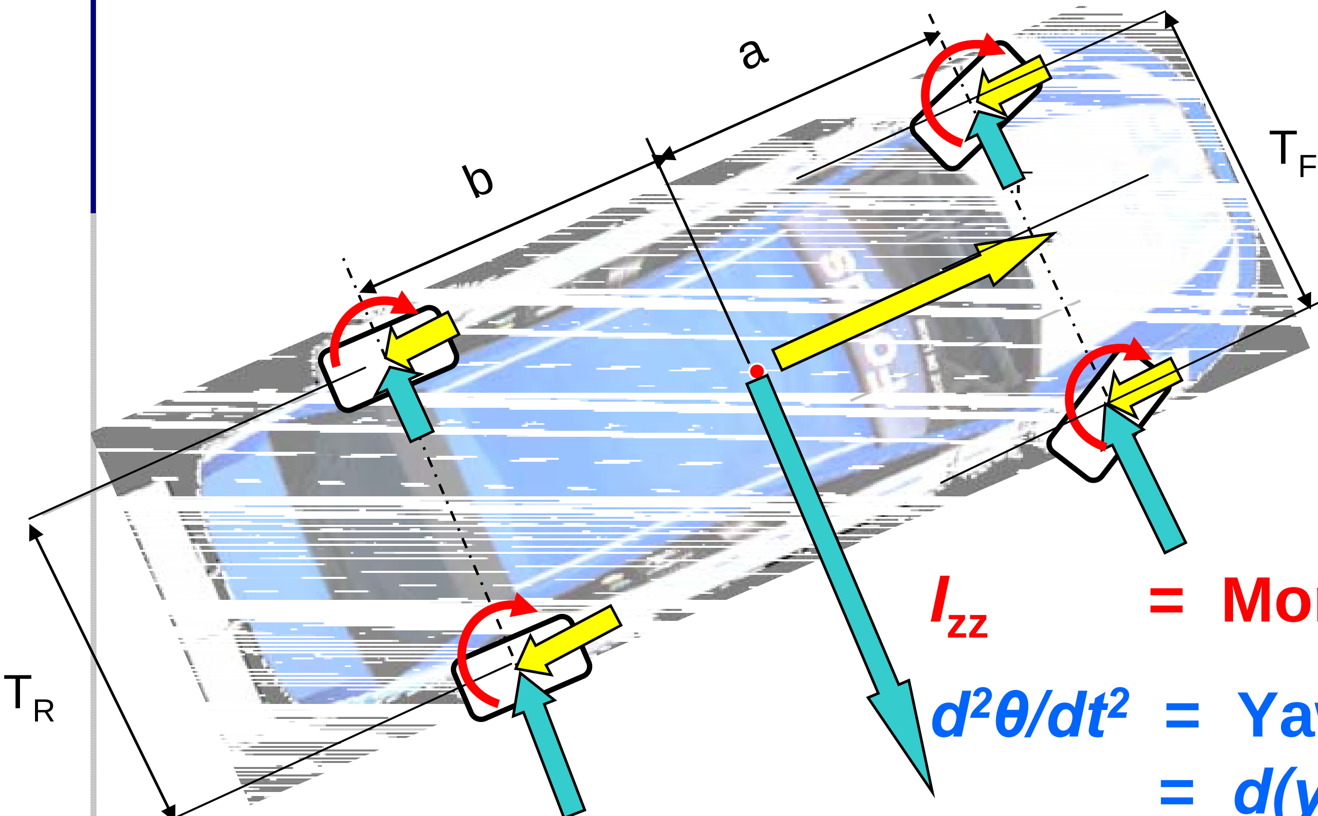
$$\sum F_x \quad F_{xFL} + F_{xFR} + F_{xRL} + F_{xRR} = Mass * longG$$



$$\sum M = 0$$

$$[(F_{xFR}\frac{T_F}{2} + F_{xRR}\frac{T_R}{2}) - (F_{xFL}\frac{T_F}{2} + F_{xRL}\frac{T_R}{2})] + [(F_{yFL} + F_{yFR})a - (F_{yRL} + F_{yRR})b] - M_{zRF} - M_{zLF} - M_{zRR} - M_{zLR} = 0$$

Transient Vehicle Dynamics Basics



I_{zz} = Moment of Inertia

$d^2\theta/dt^2$ = Yaw acceleration

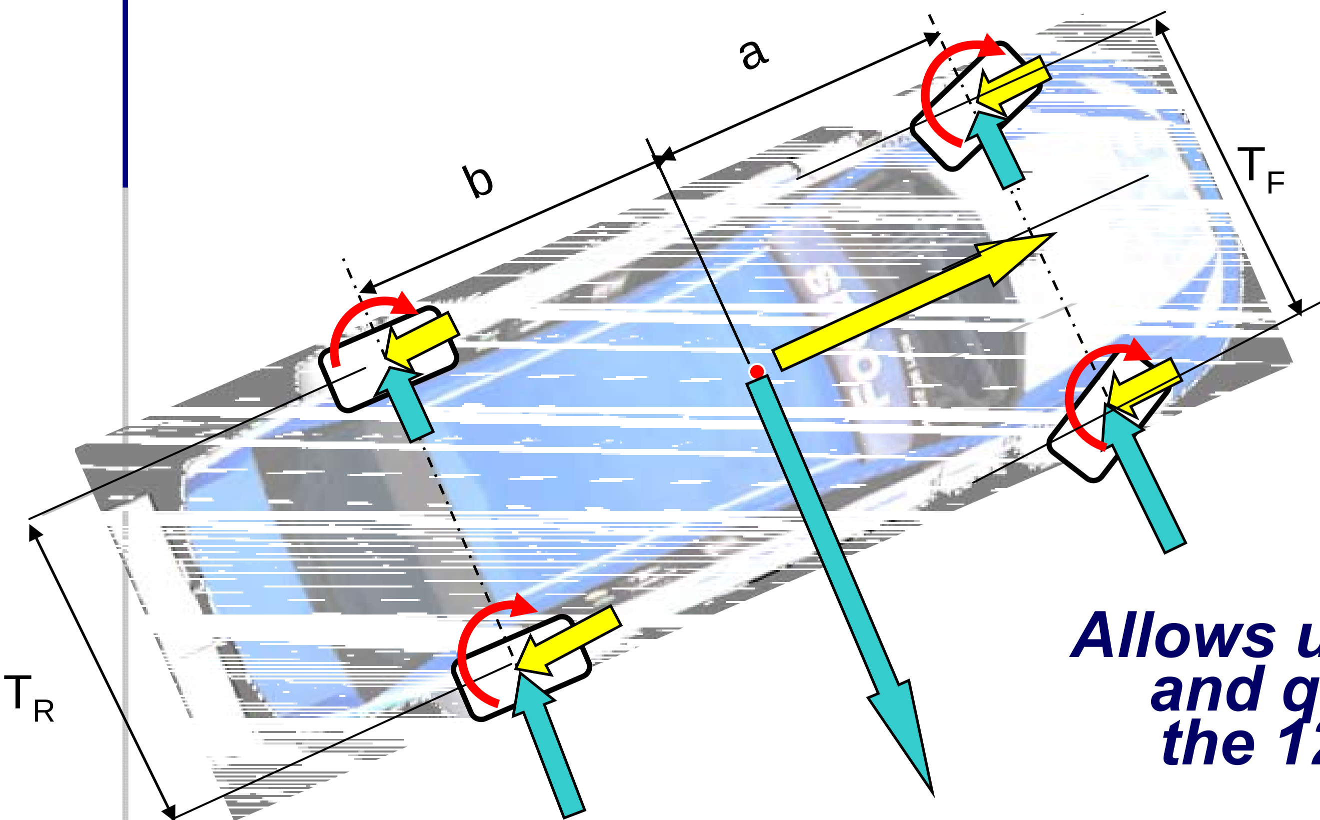
= *d(yaw rate)/dt*

= *d(gyro)/dt*

$$[(F_{XLF}\frac{T_F}{2}+F_{xLR}\frac{T_R}{2})-(F_{xRF}\frac{T_F}{2}+F_{xRR}\frac{T_R}{2})]+[(F_{yFL}+F_{yFR})\,a-(F_{yRL}+F_{yRR})\,b]-M_{zRF}-M_{zLF}-M_{zRR}-M_{zLR}$$

$$=I_{zz}\,d^2\theta/dt^2$$

Measuring Yaw Moment



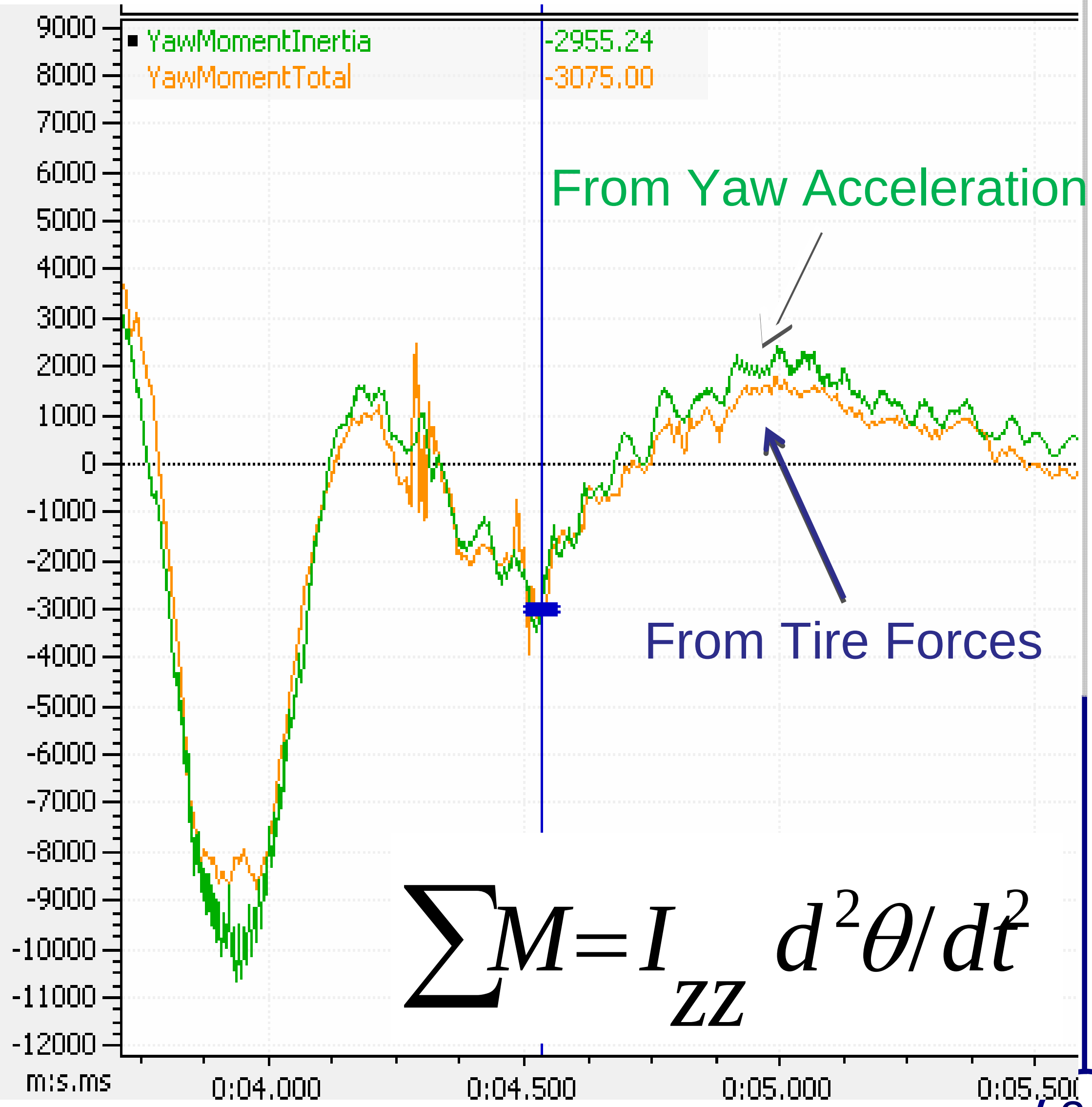
Allows us to determine and quantify each of the 12 causes of the yaw moment

$$[(F_{XLF}\frac{T_F}{2}+F_{xLR}\frac{T_R}{2})-(F_{xRF}\frac{T_F}{2}+F_{xRR}\frac{T_R}{2})]+[(F_{yFL}+F_{yFR})a-(F_{yRL}+F_{yRR})\,b]-M_{zRF}-M_{zLF}-M_{zRR}-M_{zLR}$$

$$=I_{zz}\,d^2\theta/dt^2$$

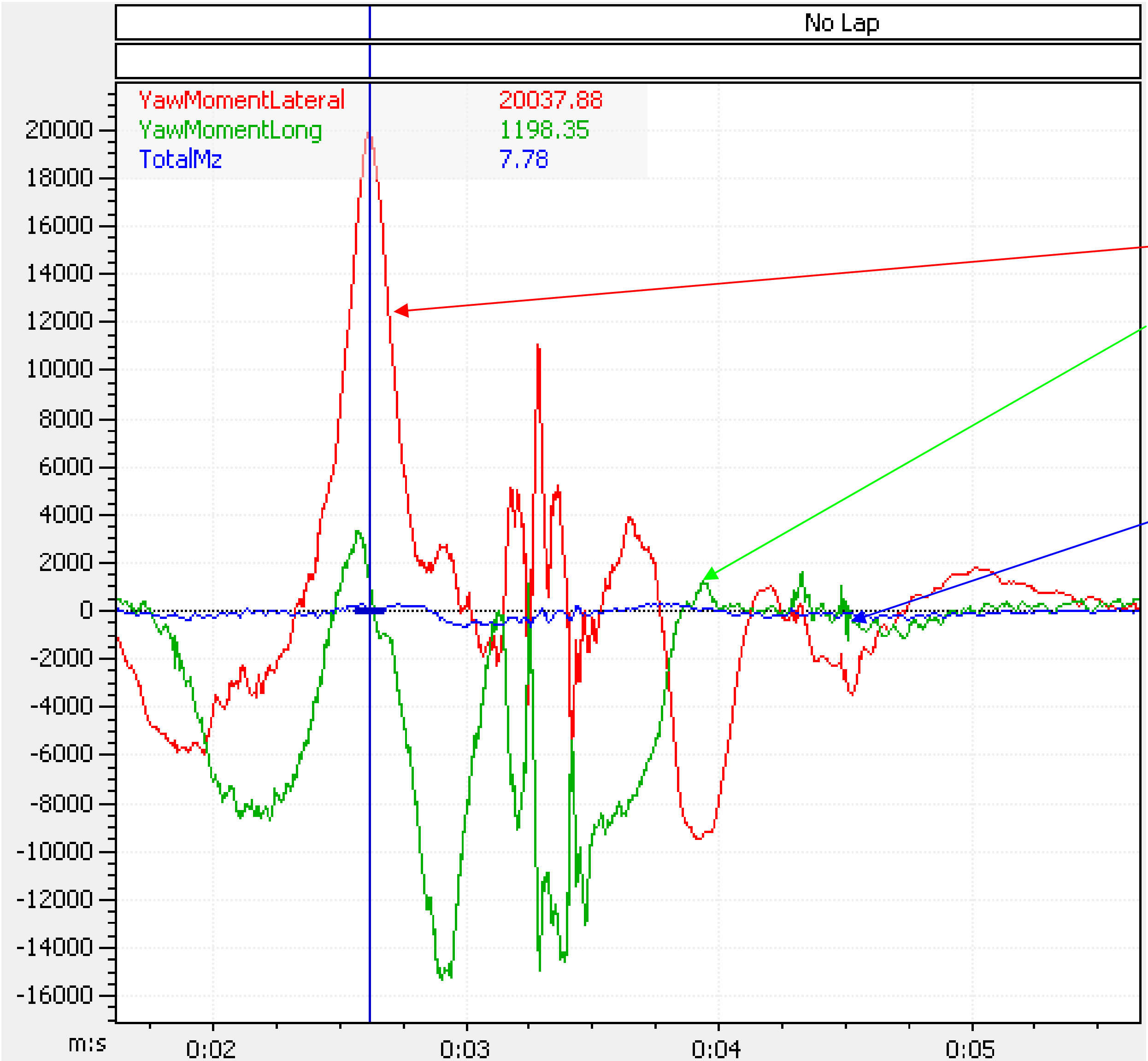
Yaw Moment

- Two Methods of Calculating Yaw Moment
- There is some difference between the yaw moment calculated with the wheel forces and the yaw moment calculated with the gyro.
- On cars with a lot of suspension compliance, there is a lag between the tire forces and the yaw acceleration.



$$\sum M = I_{zz} \, d^2\theta / dt^2$$

Yaw Moment: The 3 Types of Causes



The yaw moment from lateral forces and longitudinal forces are usually the greater than the yaw moment from Mz

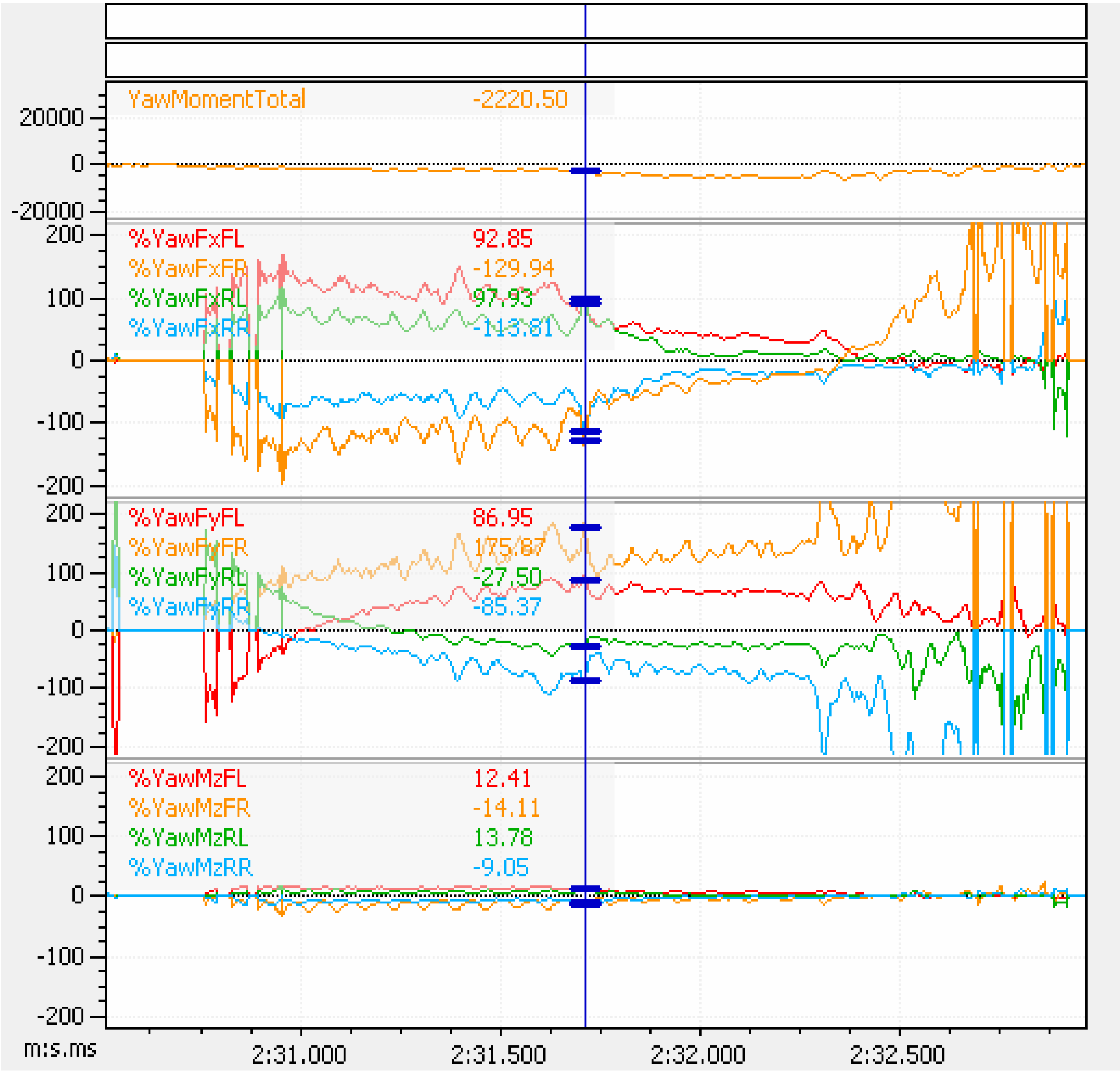
Yaw Moment: The 12 Causes

Total Yaw Moment

Yaw Moment from Fx (longitudinal)

Yaw Moment from Fy (lateral)

Yaw Moment from Mz (tire self aligning torque)



Validating

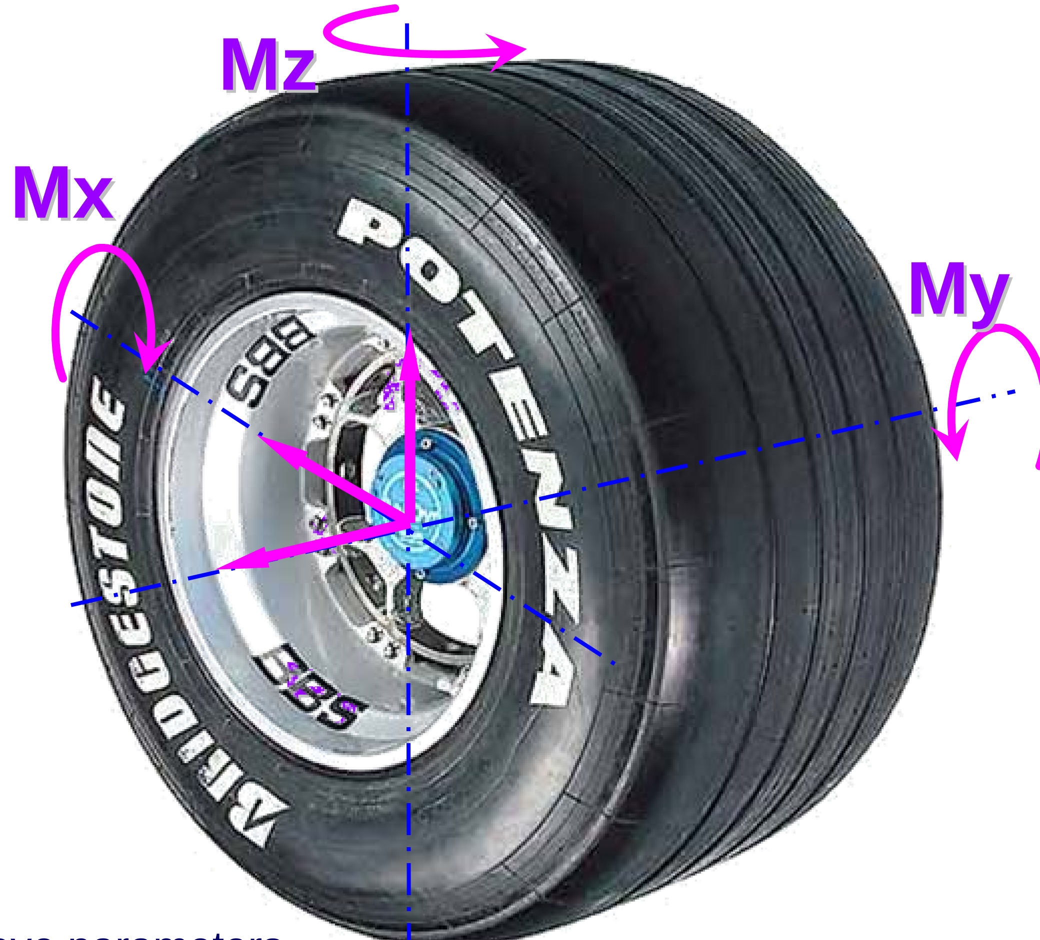
- OptimumG has been developing vehicle dynamics software and needed a way to validate it

ORESTE BERTA S.A.

- Oreste Berta Motorsports provided a car, test-track and mechanics to allow OptimumG test

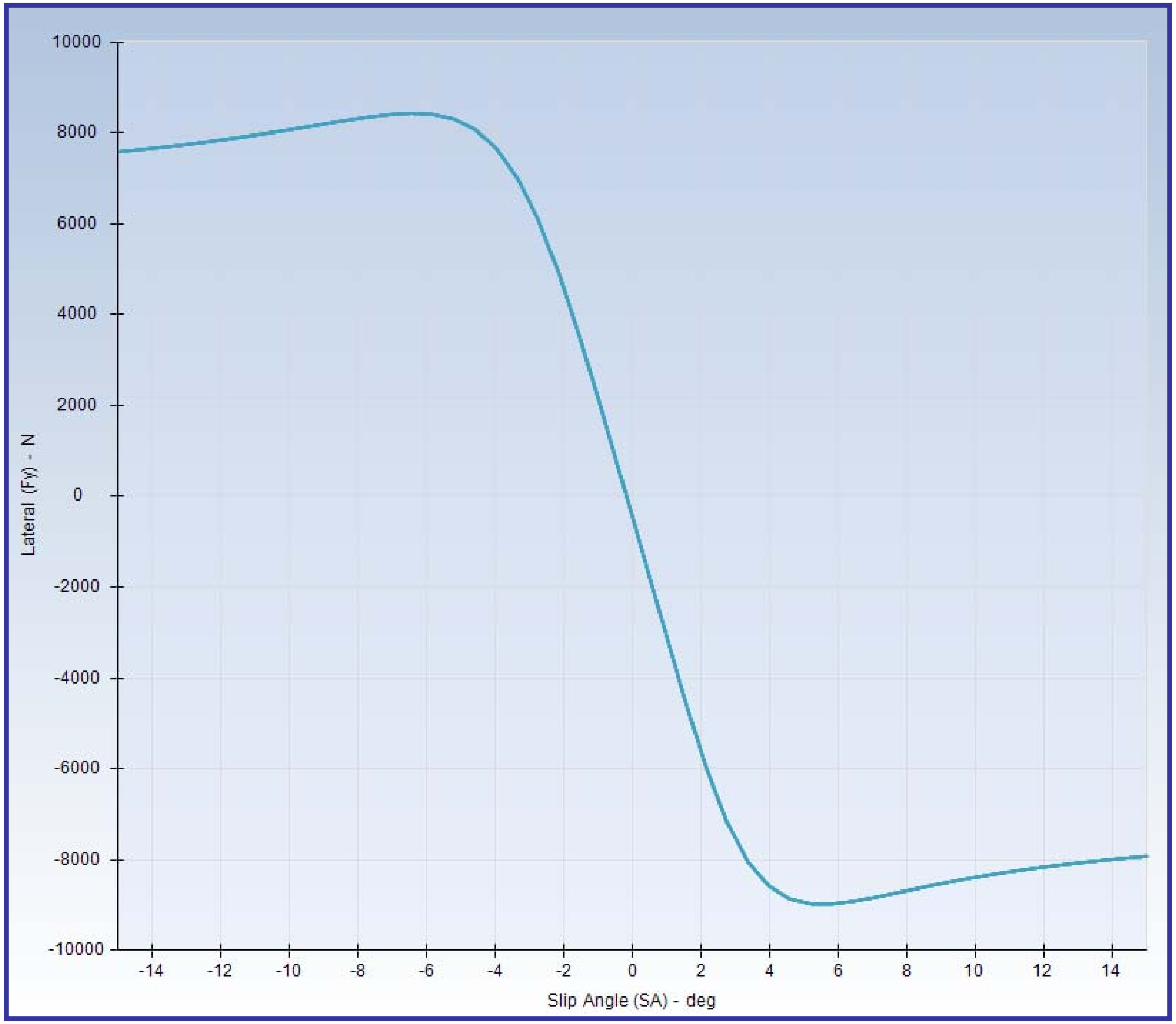
What Determines Tire Forces and Moments?

- Tire construction
- Tire compound
- Rim
- Road surface
- Slip angle (including toe)
- Slip ratio
- Camber
- Vertical load
- Pressure
- Speed
- Wear
- Temperature
- Ground
- Air, nitrogen
- Compound core
- Tread Surface
- All the derivatives of the above parameters



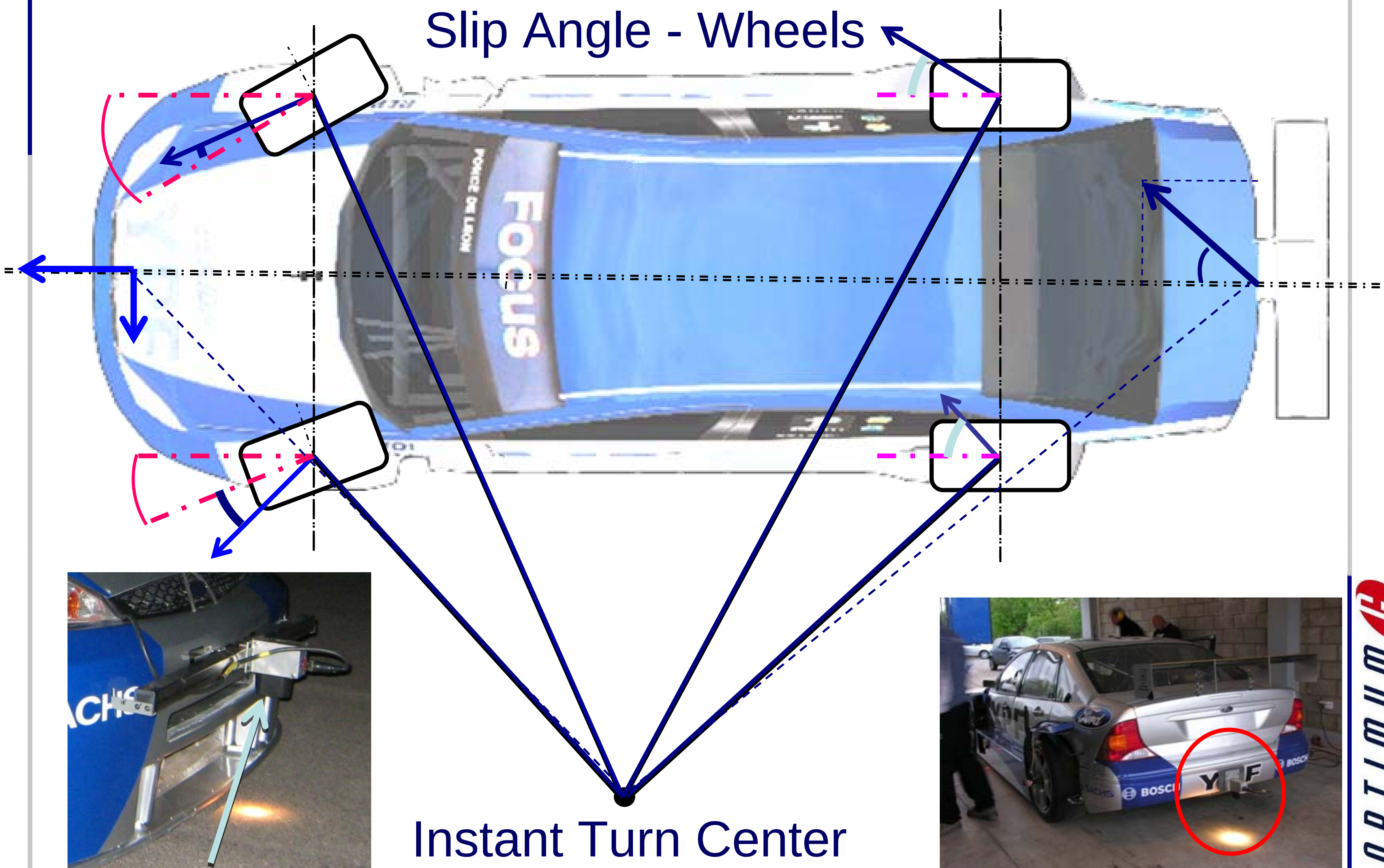
And what can we do to change them?

Tire forces and moments – Slip Angle

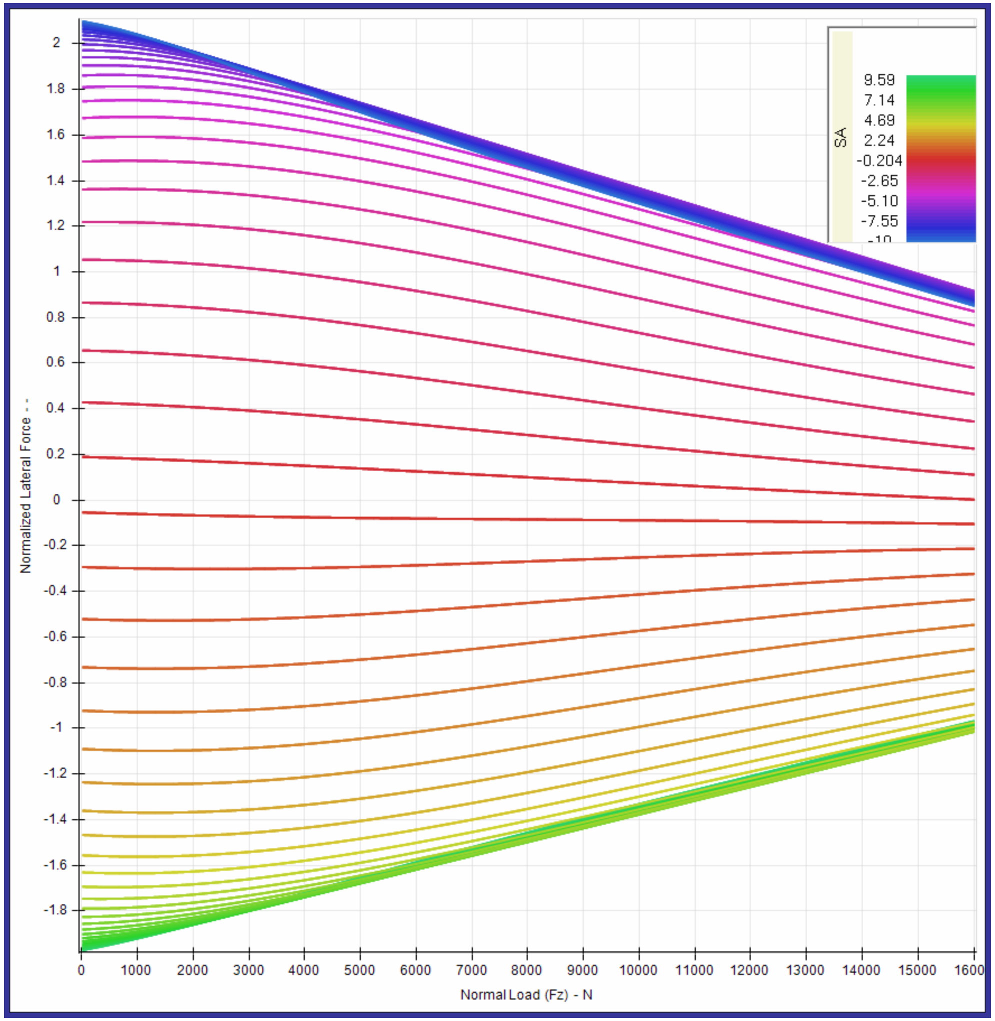


Lateral tire force vs. Slip angle

Measuring Slip Angle



Tire forces and moments – Vertical Load

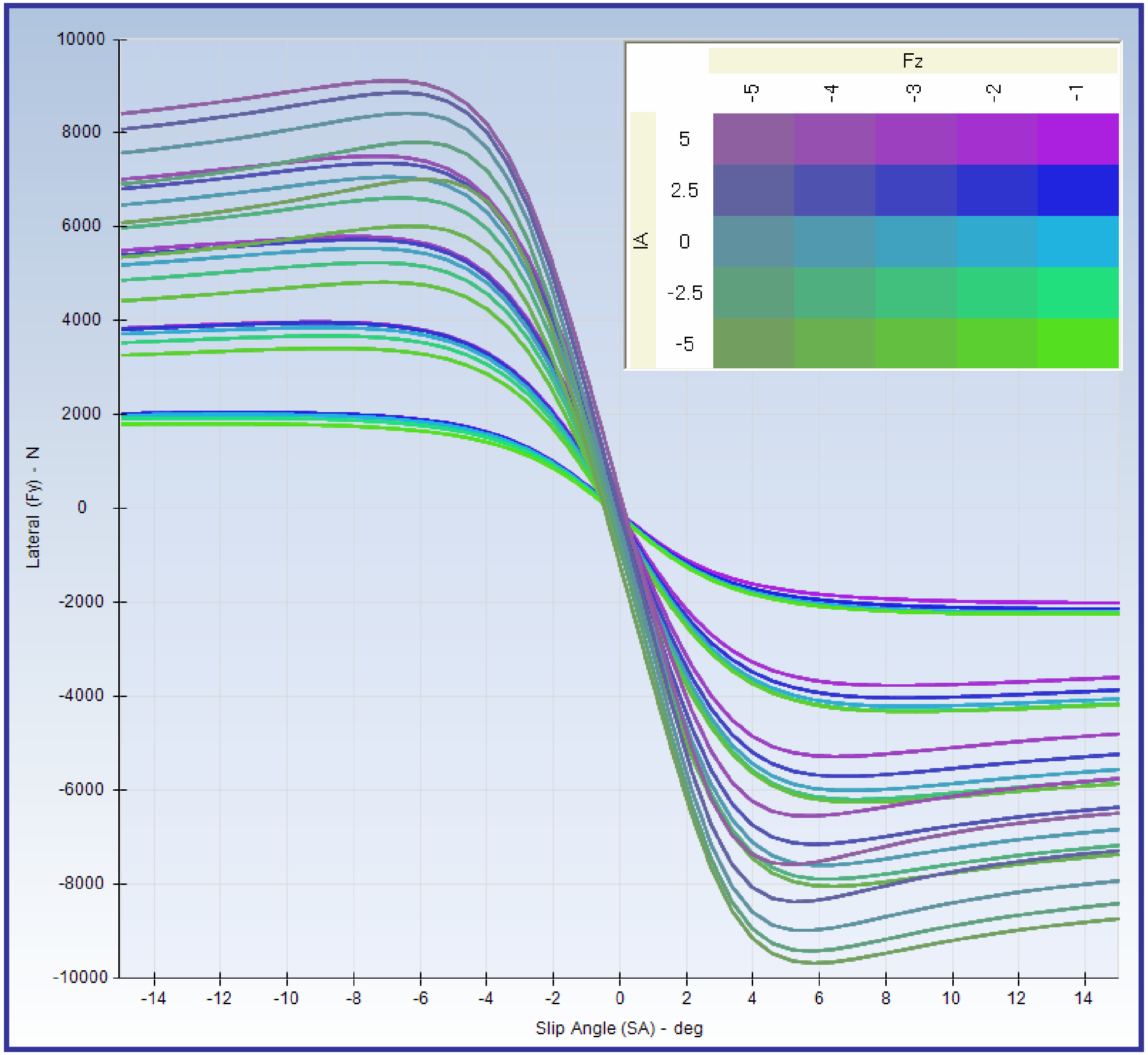


Tire lateral force Vs. slip angle and vertical load

Measuring Vertical Load

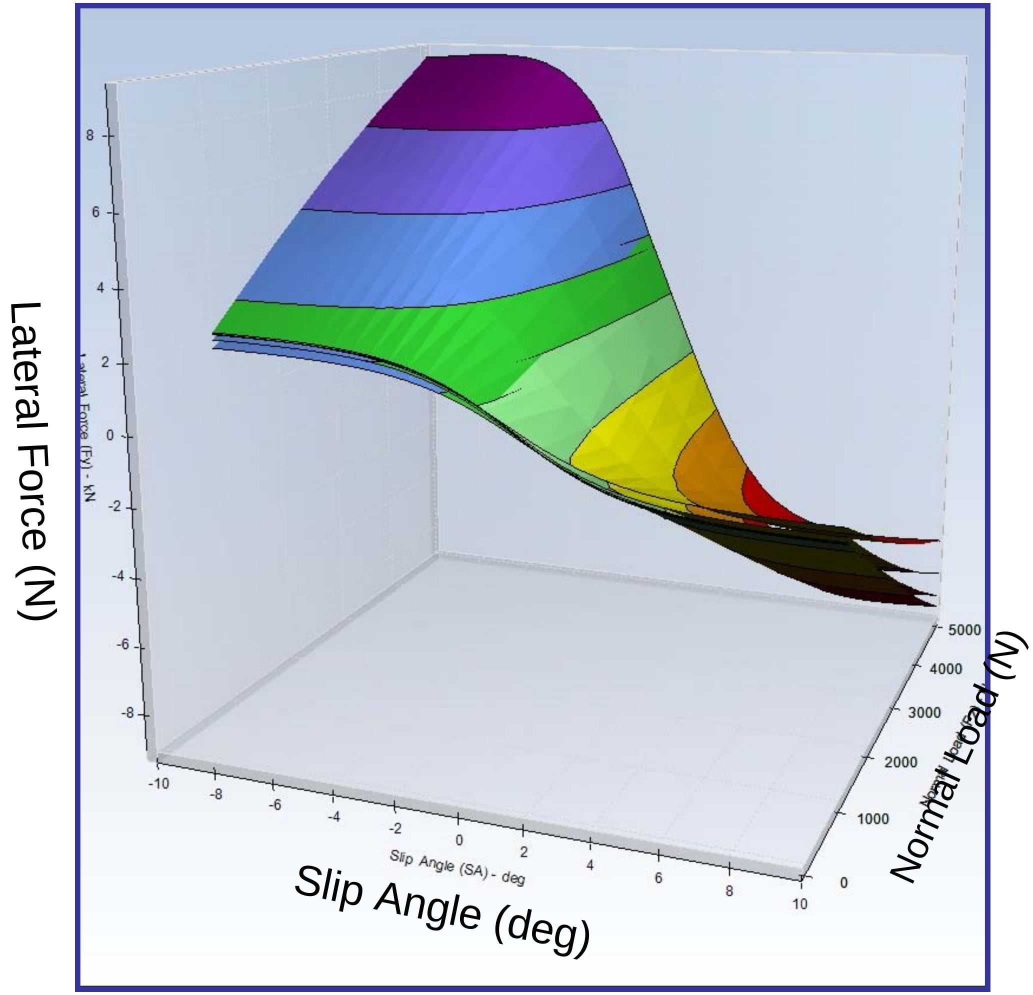
Kistler Wheel Force Transducer

Tire forces and moments – Camber



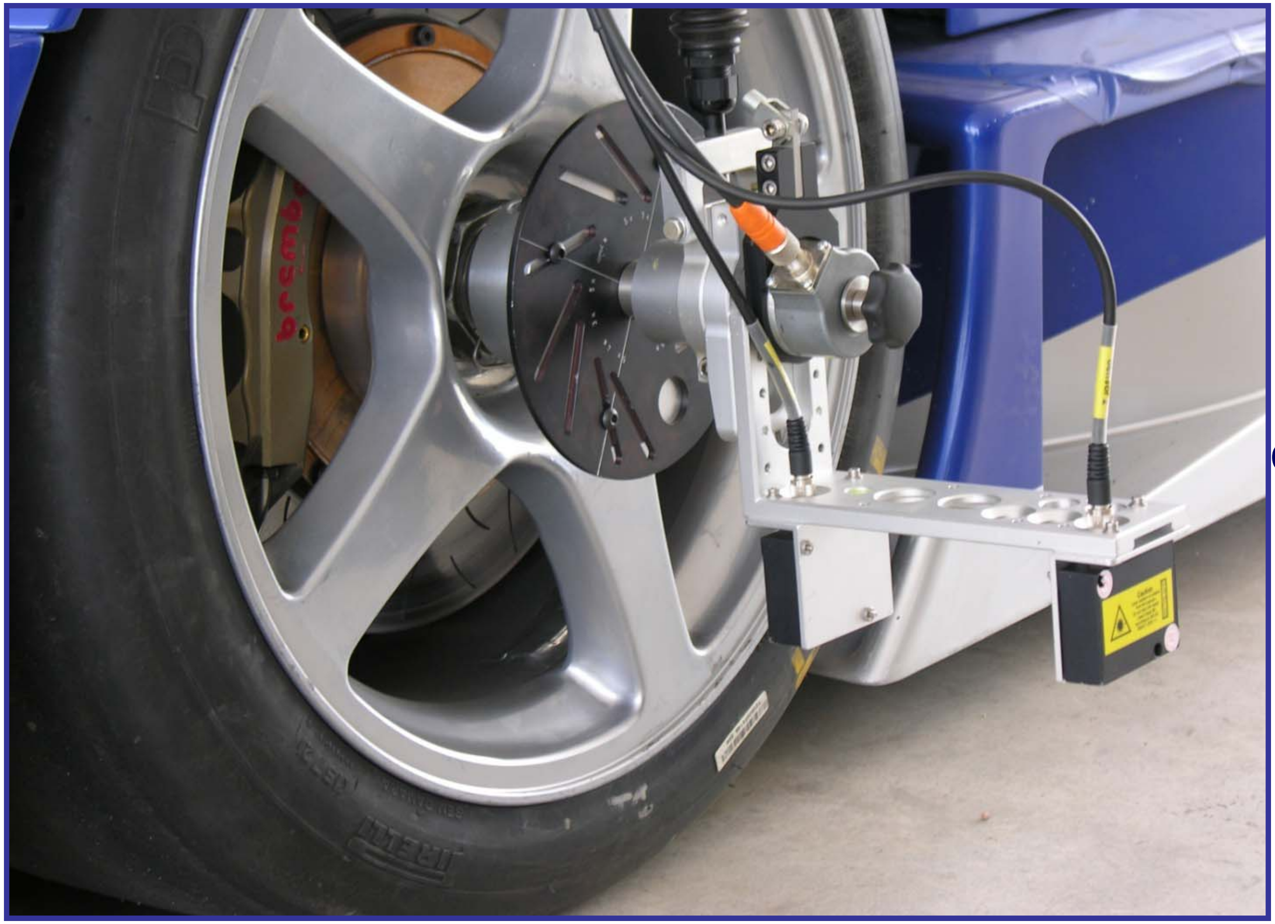
Tire lateral force Vs slip angle, vertical load, camber

Tire forces and moments – Camber



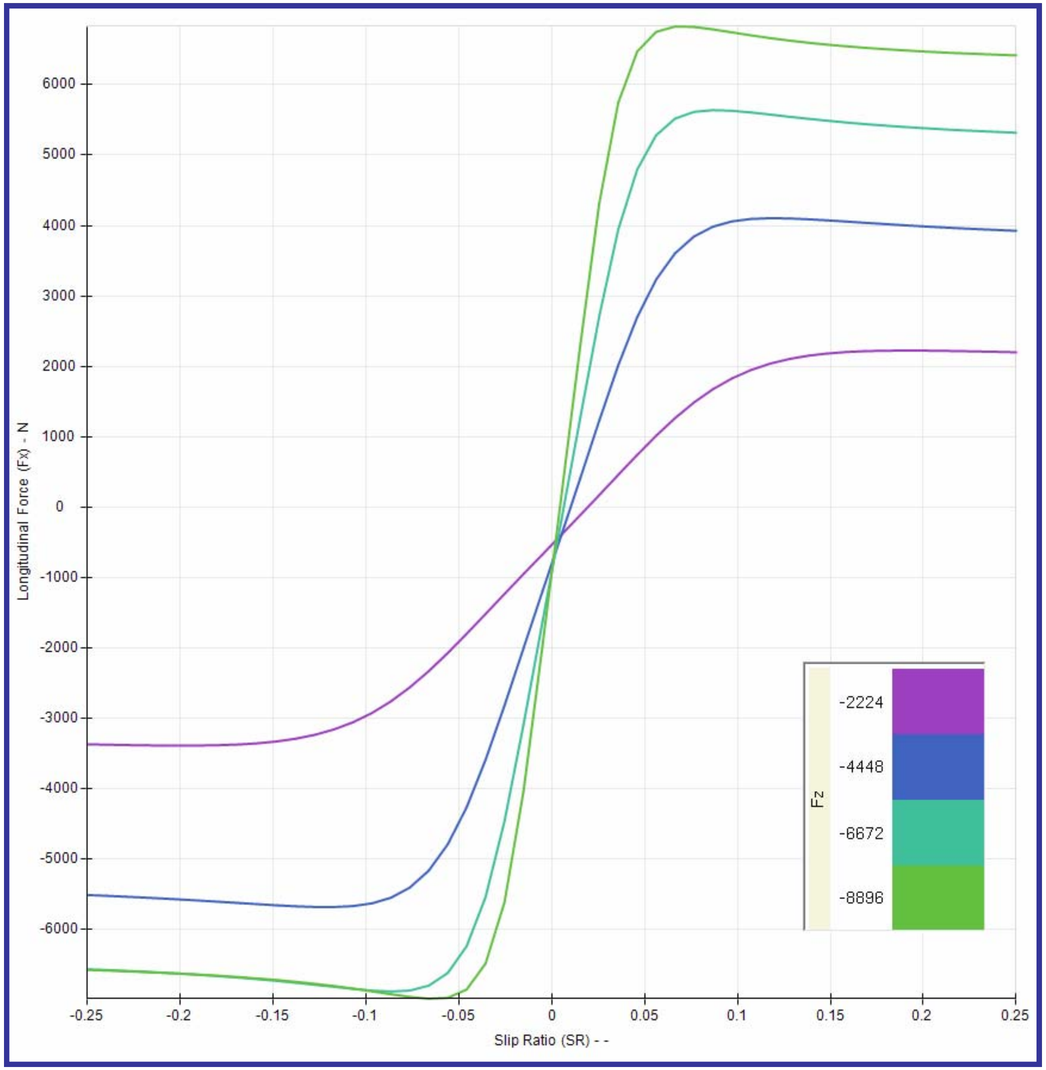
Tire lateral force Vs slip angle, vertical load, camber

Measuring Camber



Corrsys-Datron DCA Sensor

Tire forces and moments – Slip Ratio



Tire longitudinal force vs. slip ratio and vertical load

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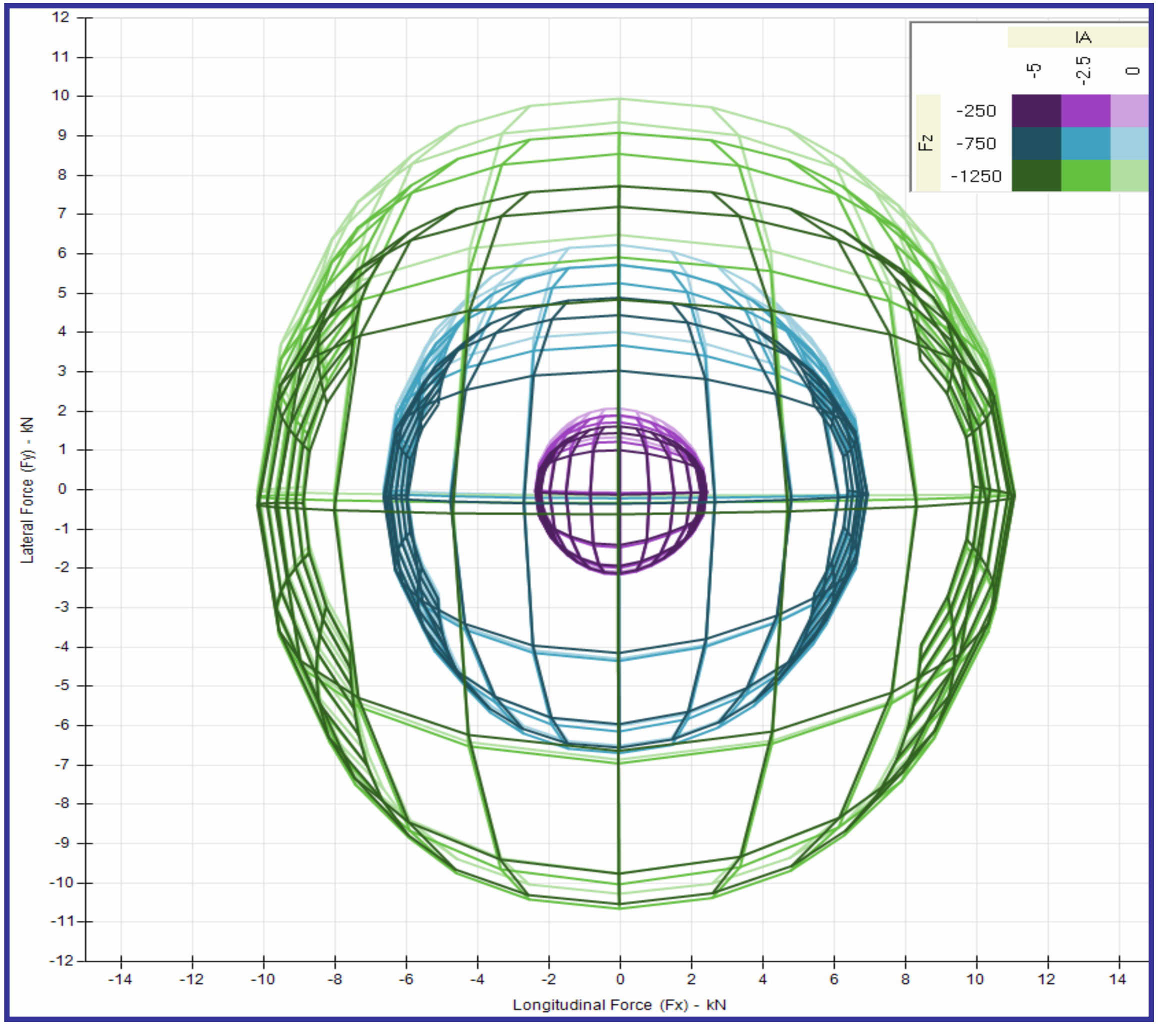
Measuring Slip Ratio

$$Sr = \frac{R_e\Omega - V}{V}$$

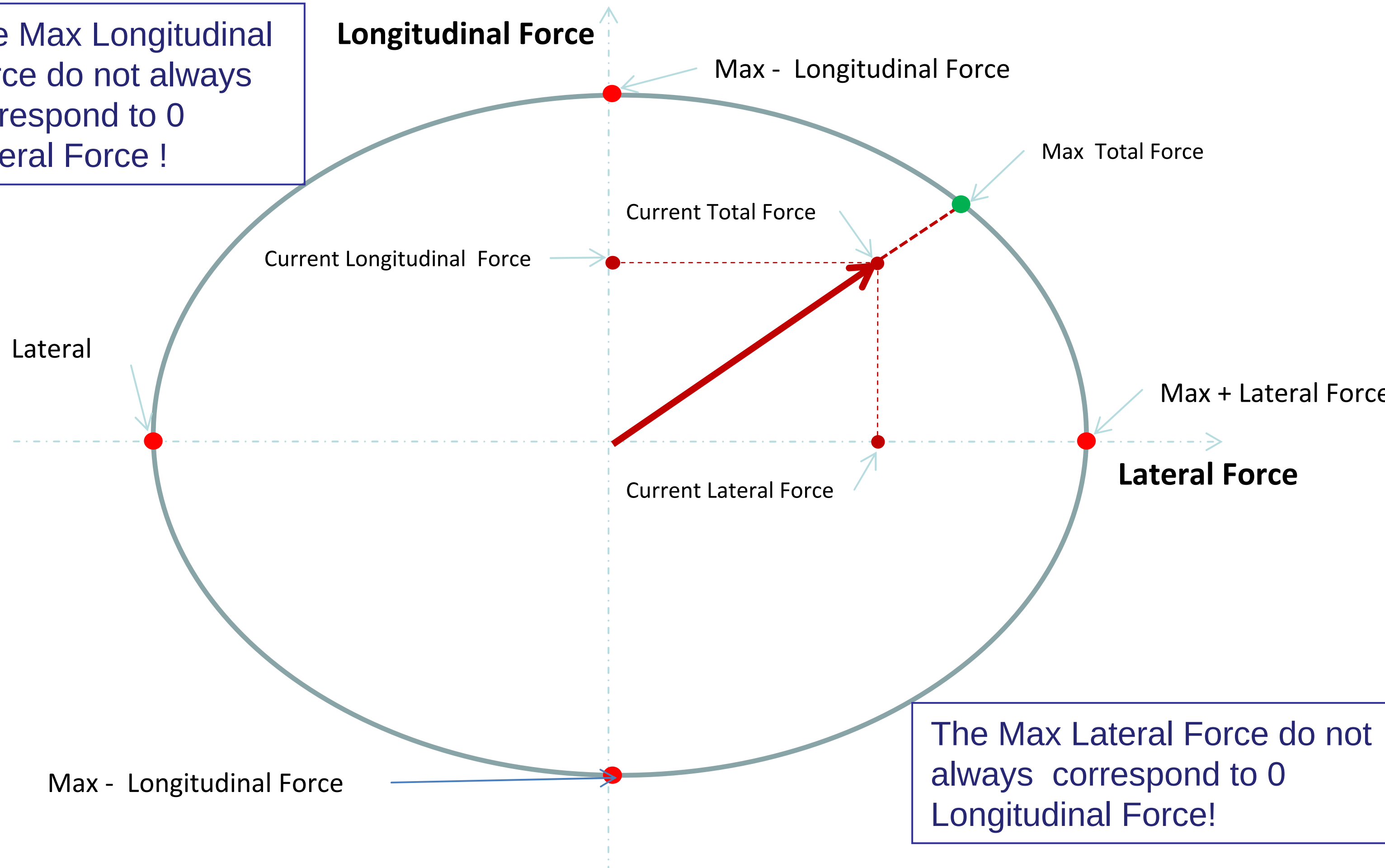
Tire forces and moments



Combined tire forces

What is a Friction Ellipse ?

The Max Longitudinal Force do not always correspond to 0 Lateral Force !



The Max Lateral Force do not always correspond to 0 Longitudinal Force!

$$\text{Lateral Efficiency (\%)} = \frac{\text{Max Lateral Force}}{\text{Current Lateral Force}} \times 100$$

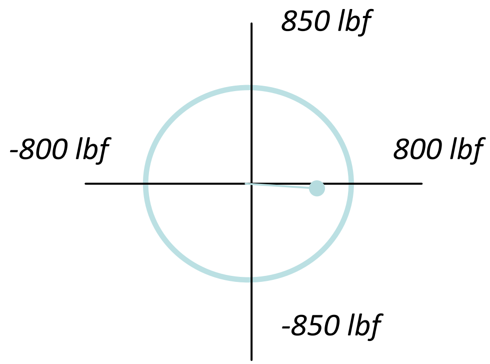
$$\text{Longitudinal Efficiency (\%)} = \frac{\text{Max Longitudinal Force}}{\text{Current Longitudinal Force}} \times 100$$

$$\text{Total Efficiency (\%)} = \frac{\text{Total Force}}{\text{Current Total Force}} \times 100$$

Friction Ellipse Per Tire (Baseline)

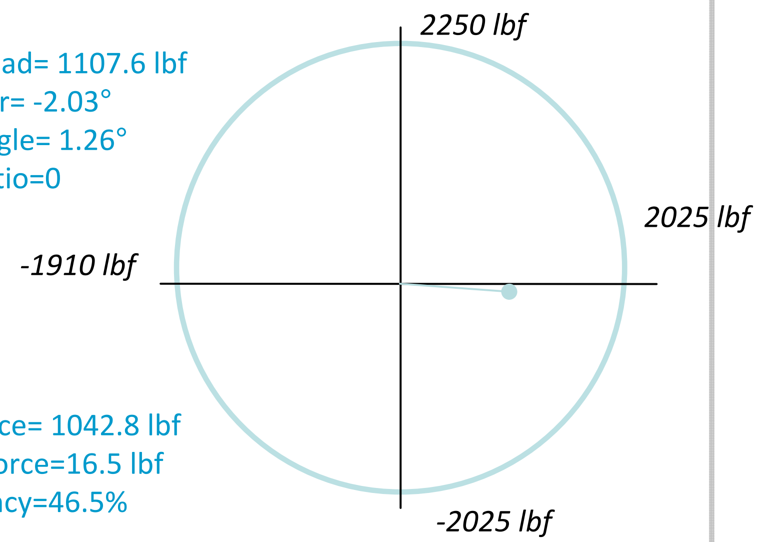
LatG=1, LongG=0, Speed=93 MPH, Yaw Moment=0

FL
Vert Load=399.5 lbf
Camber=-3.46°
Slip Angle= -2.47°
Slip Ratio=0



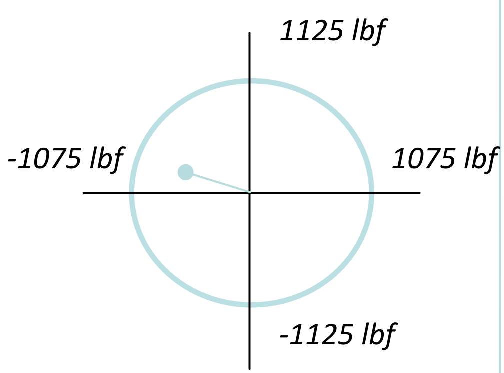
Lat Force= 508.9 lbf
Long Force=-8.9 lbf
Efficiency=68.9%

FR
Vert Load= 1107.6 lbf
Camber= -2.03°
Slip Angle= 1.26°
Slip Ratio=0



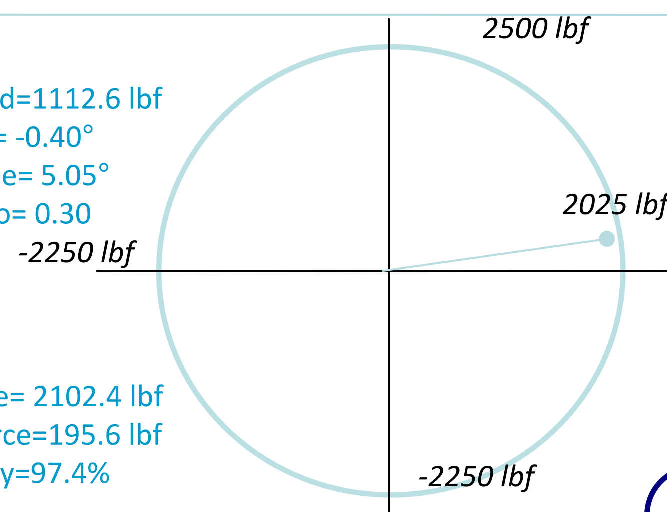
Lat Force= 1042.8 lbf
Long Force=16.5 lbf
Efficiency=46.5%

RL
Vert Load=509.8 lbf
Camber= -2.17°
Slip Angle= 1.66°
Slip Ratio= 0.46



Lat Force= -544.7 lbf
Long Force=130.4 lbf
Efficiency=51.1%

RR
Vert Load=1112.6 lbf
Camber= -0.40°
Slip Angle= 5.05°
Slip Ratio= 0.30

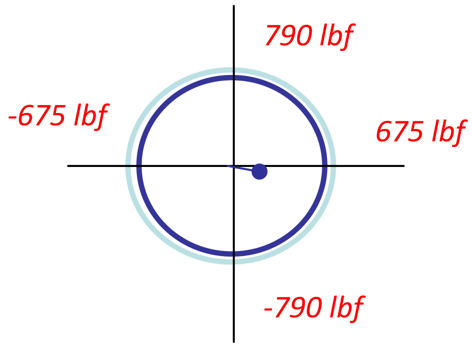


Lat Force= 2102.4 lbf
Long Force=195.6 lbf
Efficiency=97.4%

Friction Ellipse Per Tire (Comparison)

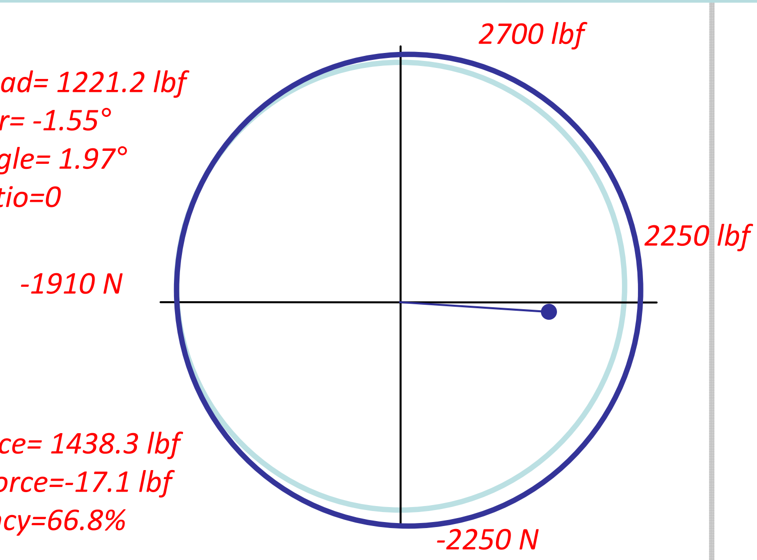
LatG=1, LongG=0, Speed=93 MPH, Yaw Moment=0, **Front suspension 1 deg toe-in**

FL
Vert Load=379.4 lbf
Camber=-3.96°
Slip Angle= -1.00°
Slip Ratio=0



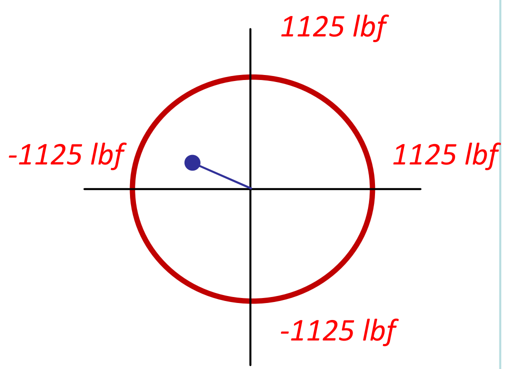
Lat Force= 254.0 lbf
Long Force=-8.7 lbf
Efficiency=37.1%

FR
Vert Load= 1221.2 lbf
Camber= -1.55°
Slip Angle= 1.97°
Slip Ratio=0



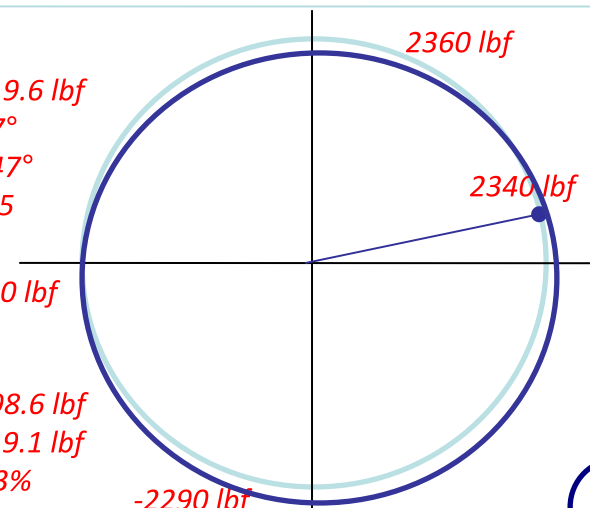
Lat Force= 1438.3 lbf
Long Force=-17.1 lbf
Efficiency=66.8%

RL
Vert Load=503.1 lbf
Camber= -2.32°
Slip Angle= 1.16°
Slip Ratio= 0.69



Lat Force= -421.2 lbf
Long Force=946.4 lbf
Efficiency=43.77%

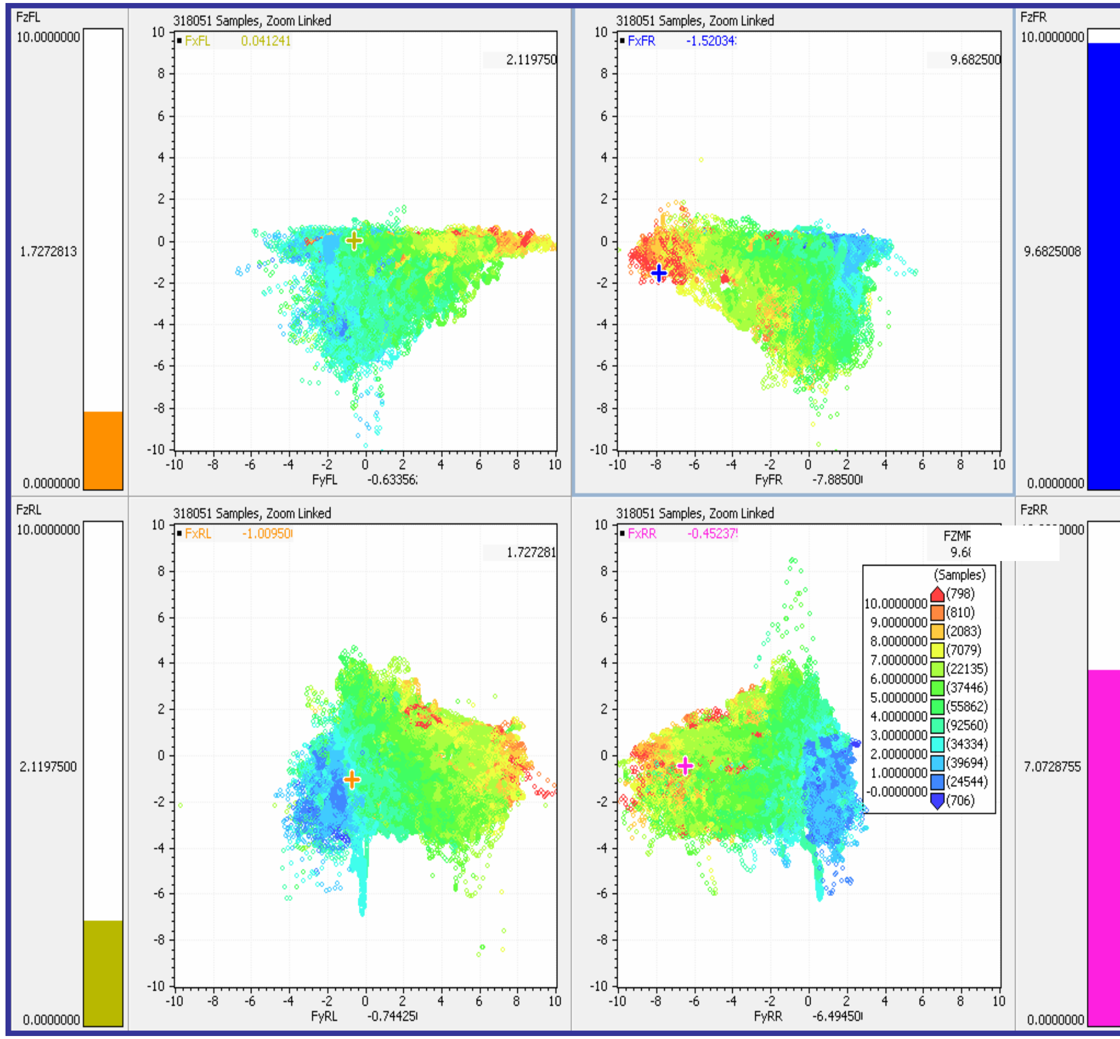
RR
Vert Load=1219.6 lbf
Camber= -0.27°
Slip Angle= 5.47°
Slip Ratio= 0.45



Lat Force= 2298.6 lbf
Long Force=319.1 lbf
Efficiency=99.3%

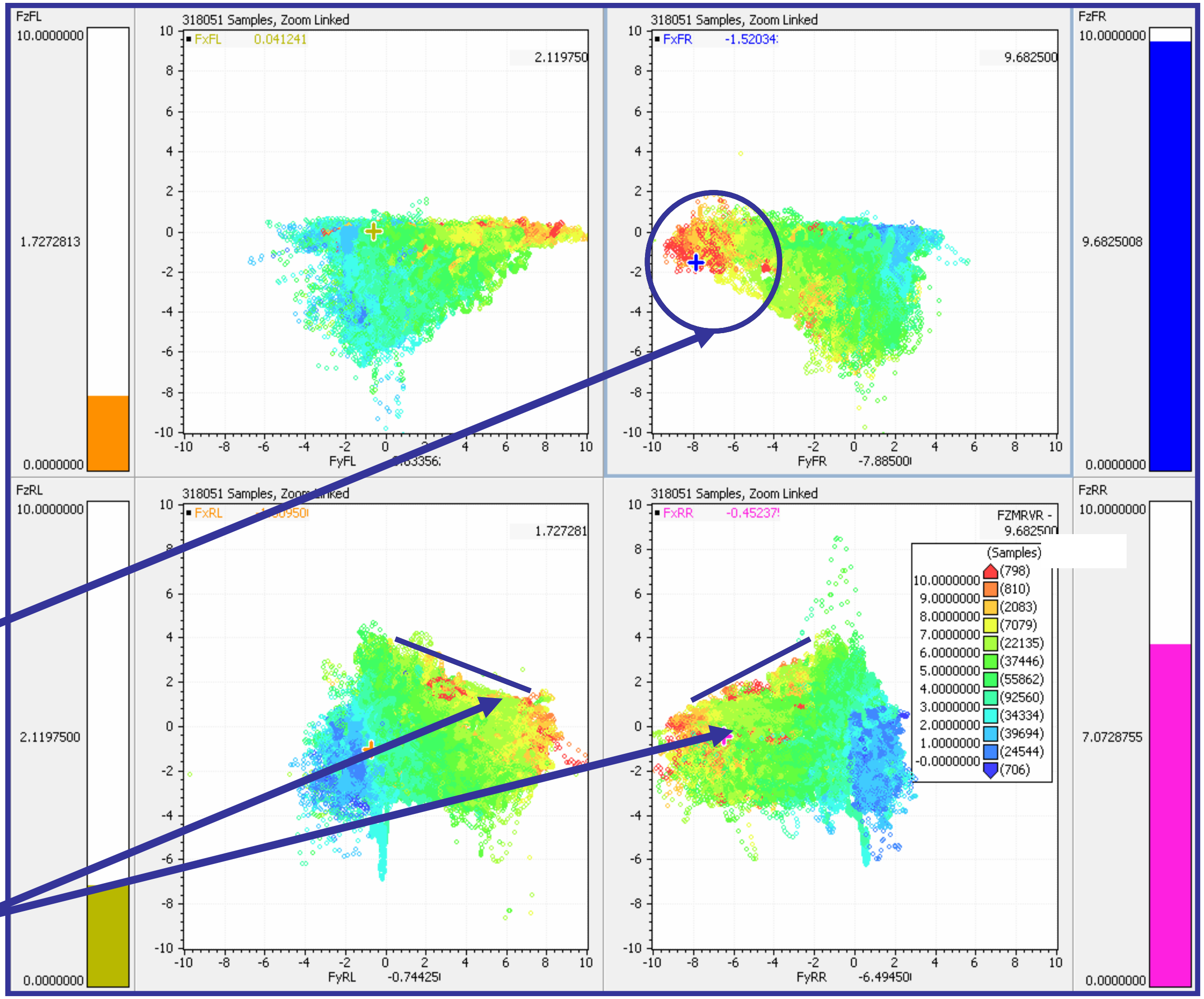
Measuring the Tire Force Vectors

- Each tire's force vector can be plotted in a scatter (XY) plot
- The vertical load can be displayed with a bar graph
- Data points are colored by vertical load (red being more load, blue being less)



Measuring the Tire Force Vectors

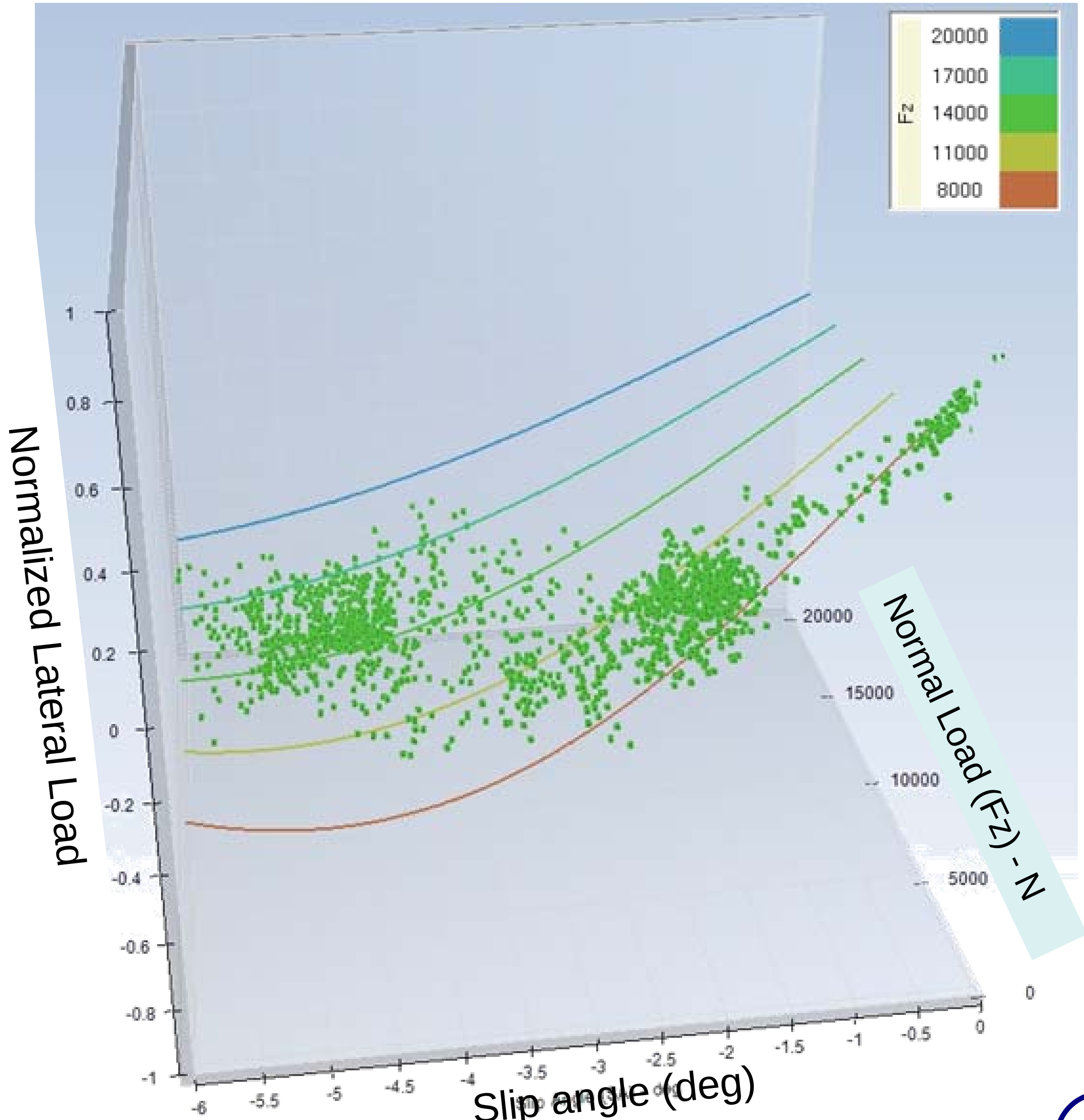
- Each tire's force vector can be plotted in a scatter (XY) plot
- The vertical load can be displayed with a bar graph
- Higher force in direction of inside of each tire due to lateral load transfer
- Maximum drive force (longitudinal) when no lateral force is exerted



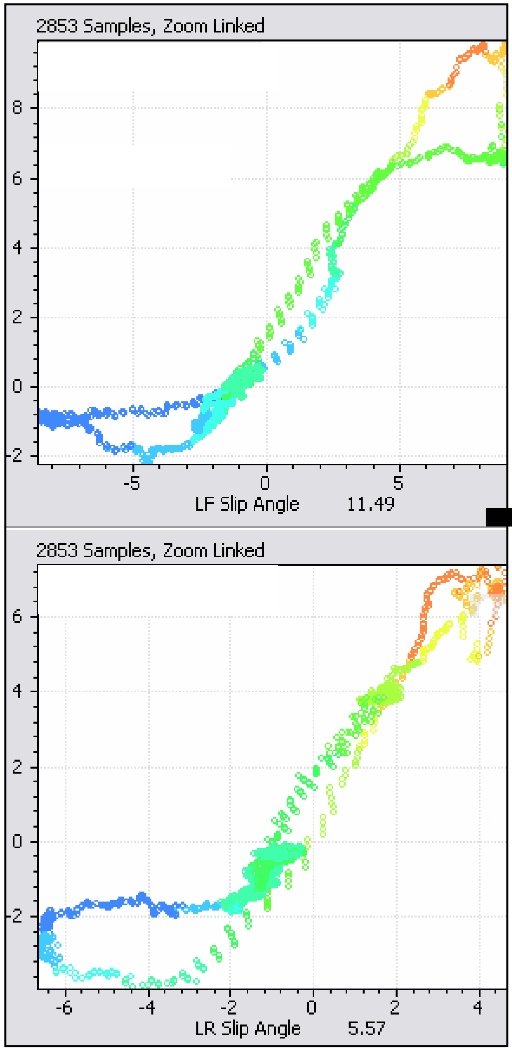
Tire Force Curves From WFT Data

- Tire force curves can be developed from wheel force transducer and slip angle sensor data

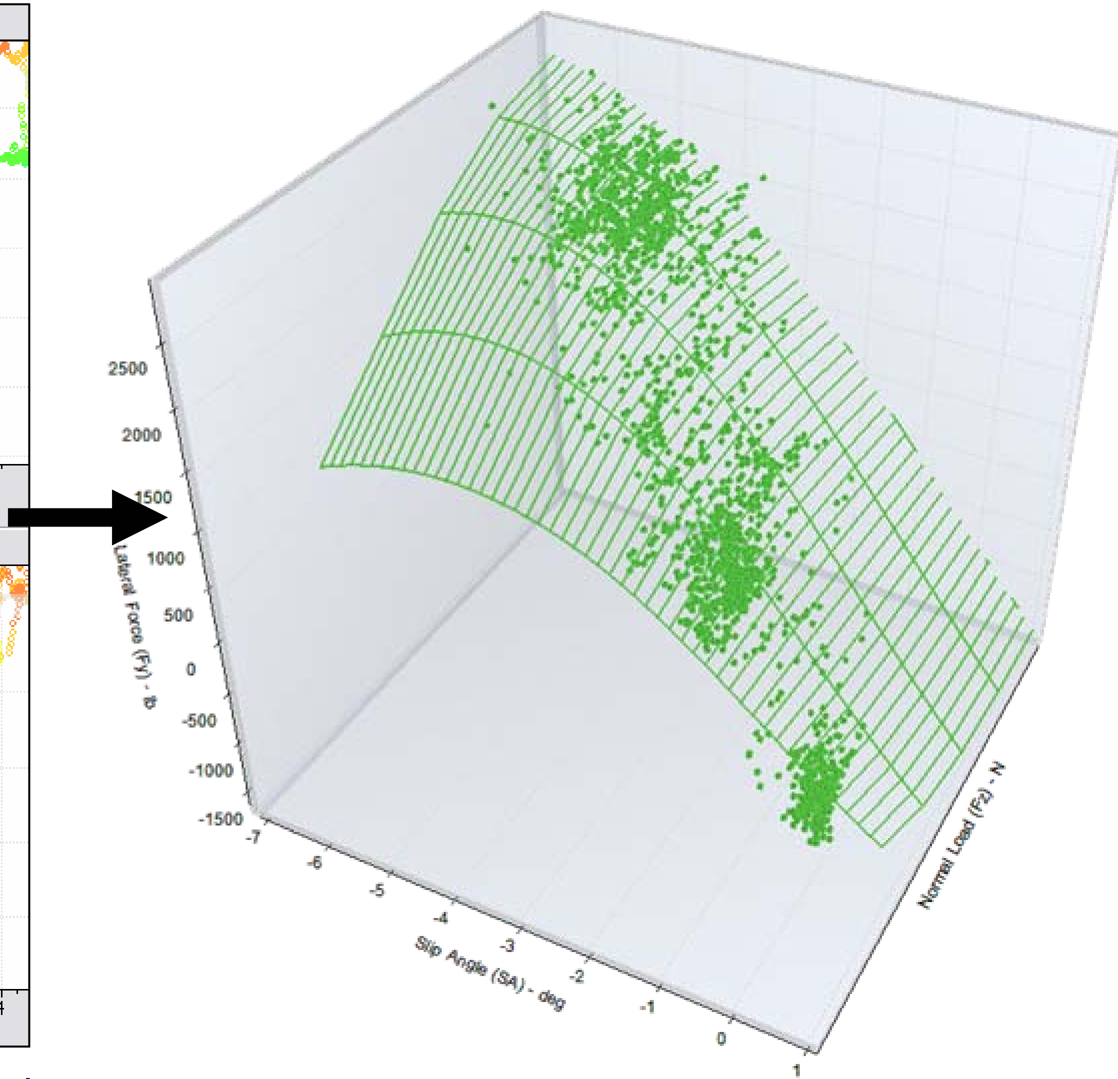
- OptimumT was used to fit a Pacejka 2002 Model



Tire Force Curves From WFT Data



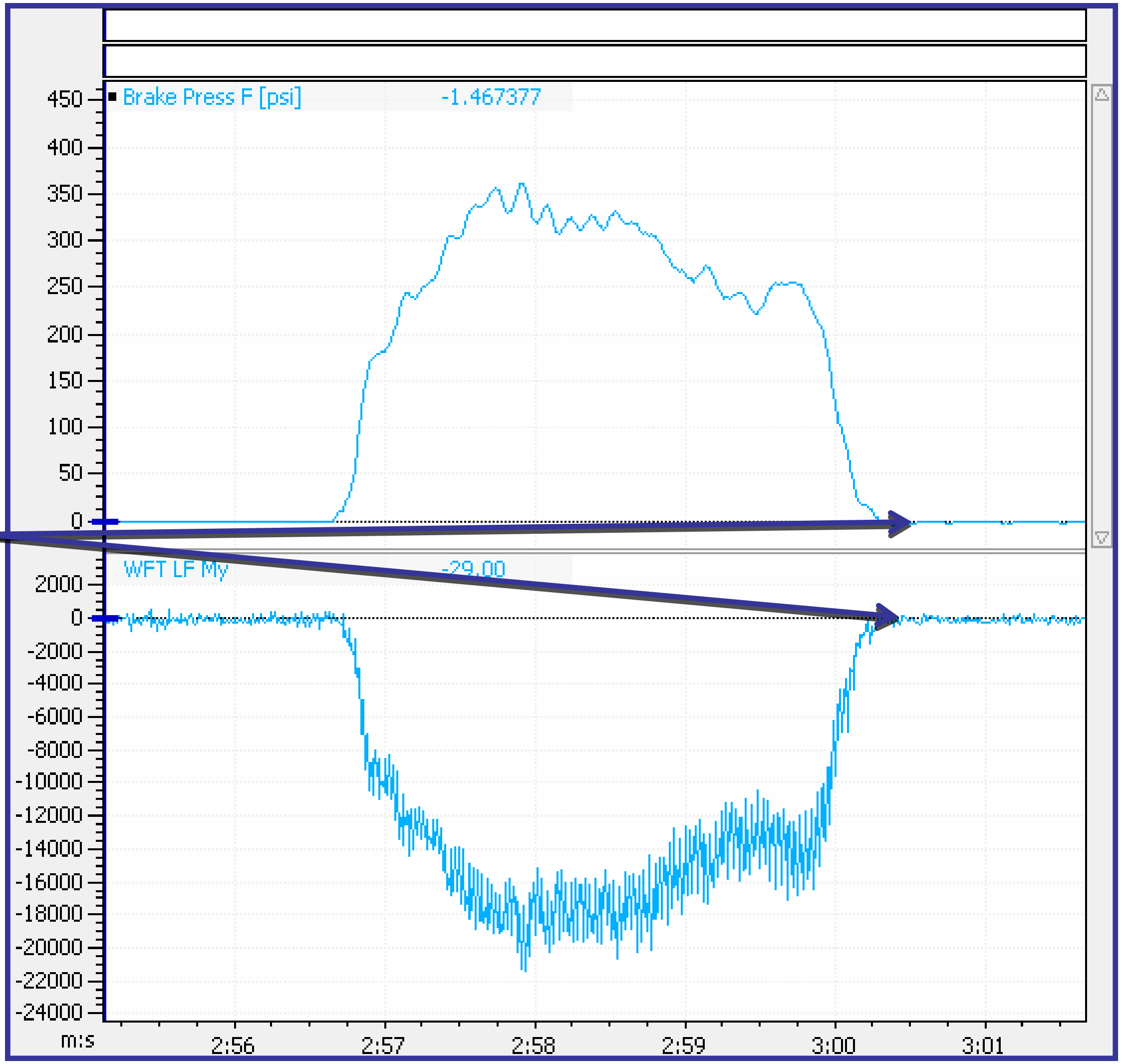
Logged WFT and slip angle data



Fitted tire model in OptimumT

Example of data analysis

Brake torque and brake pressure follow each other. If the calipers were sticking, the torque would lag the pressure.

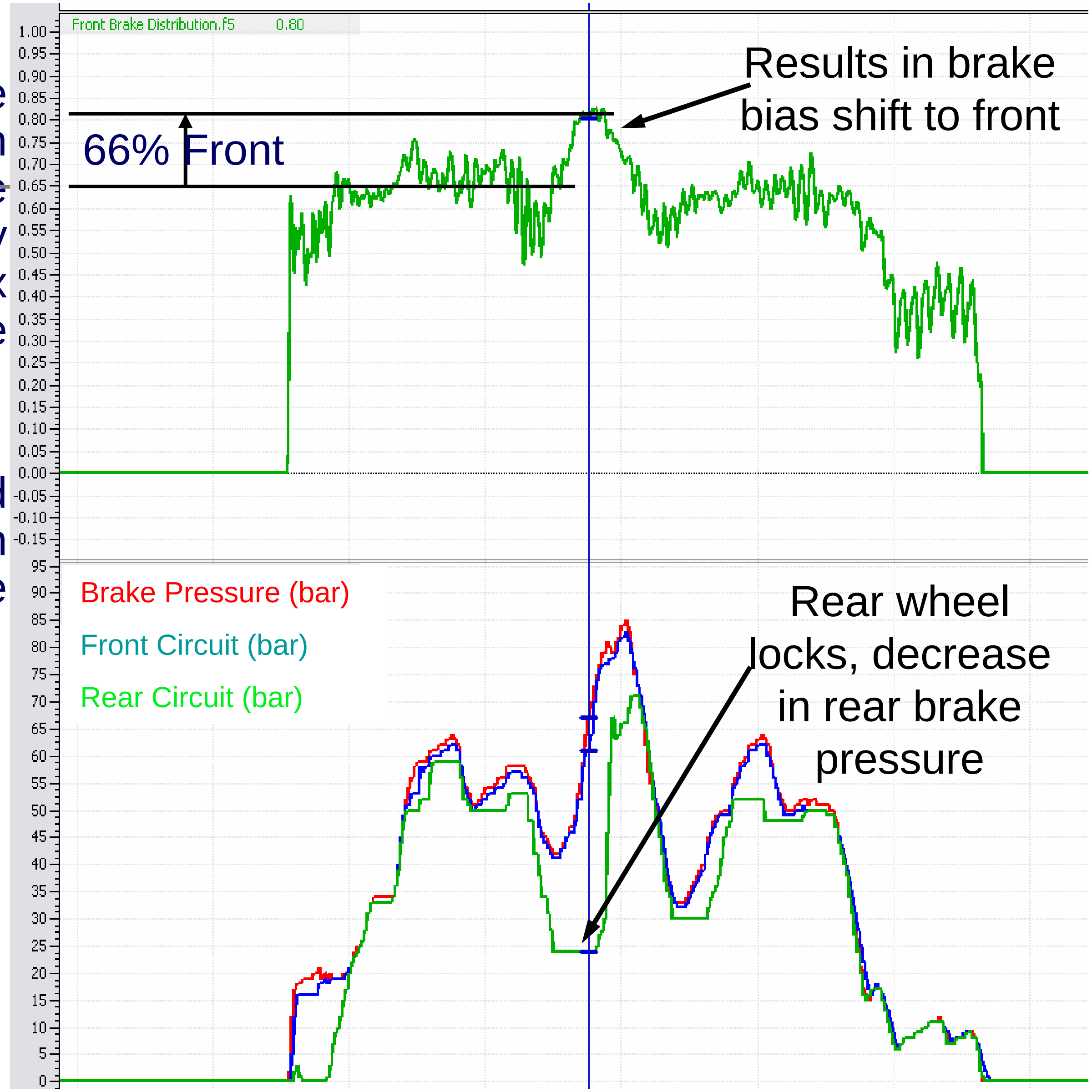


Brake Pressure and Torque

Example of data analysis

- The actual force brake bias can easily be determined by looking at the Fx load of the wheels.
- On cars equipped with ABS, shifts in brake balance can be detected.

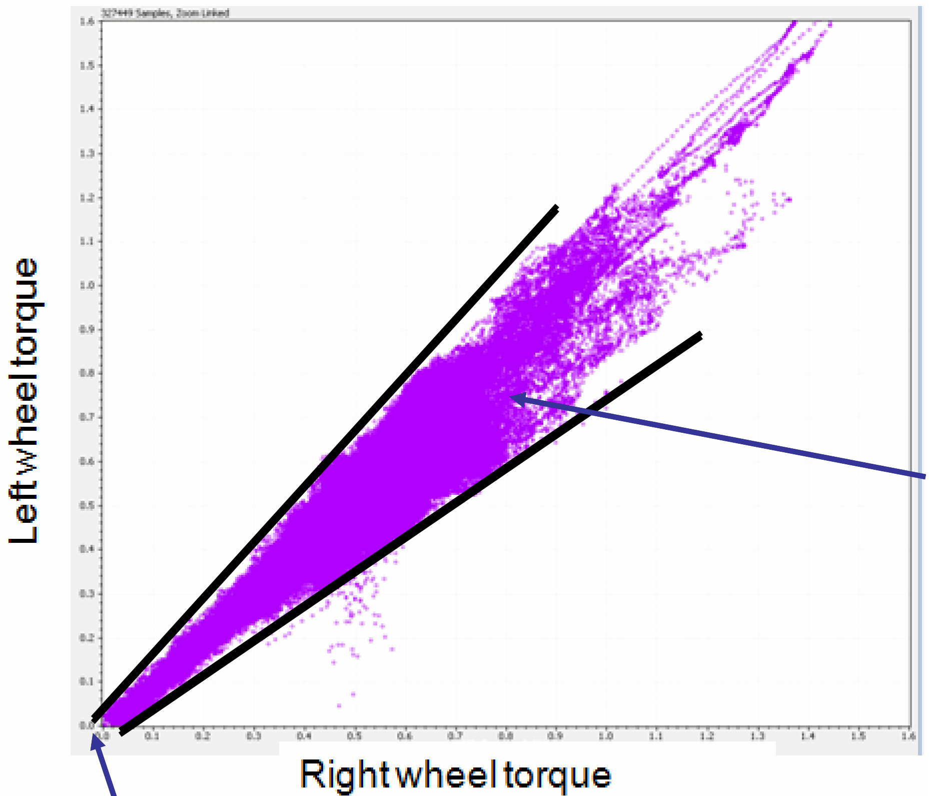
- Master cylinder
- Front circuit
- Rear circuit

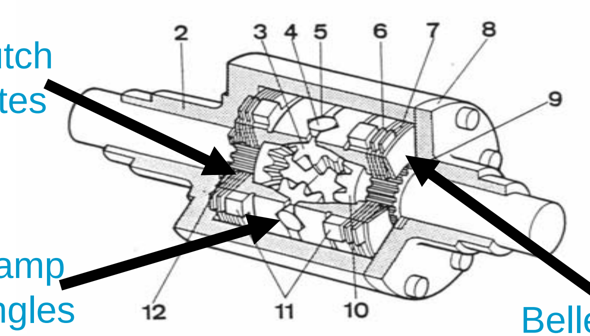


Example of data analysis

Diff Characteristics – Salisbury Diff

Left Torque VS Right Torque





Clutch plates

Ramp angles

Belleville washer

Slope of envelope indicates ramp angle and number of clutch plates

Size of “neck” indicates preload

Questions? - Contacts

OptimumG LLC.
8801 E. Hampden Ave.
Suite 210
Denver, CO 80231

engineering@optimumg.com
www.optimumg.com