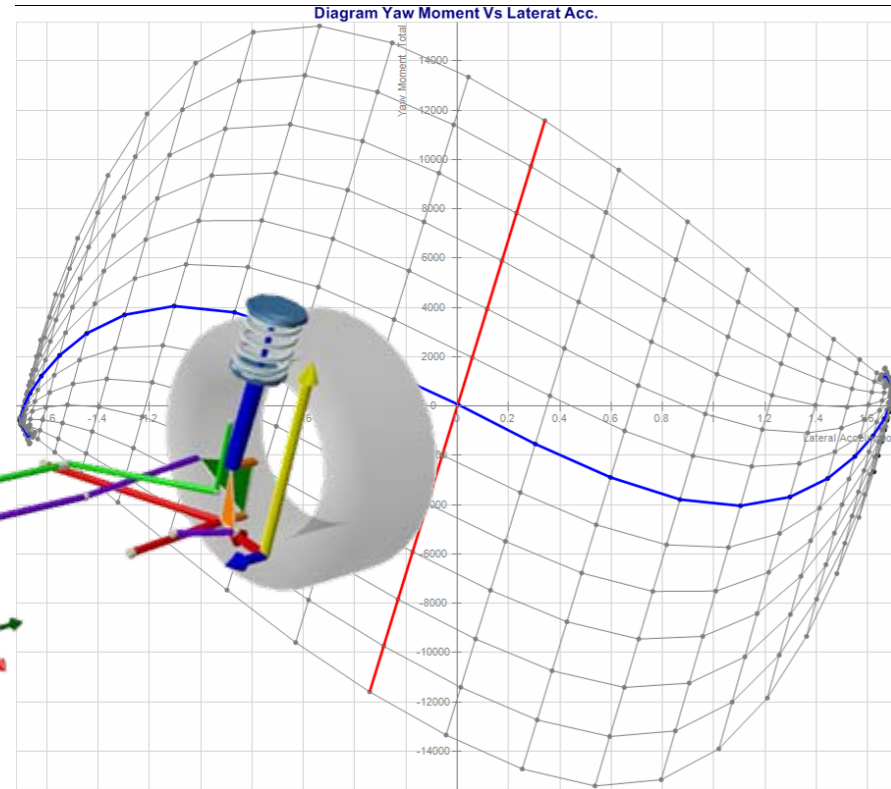
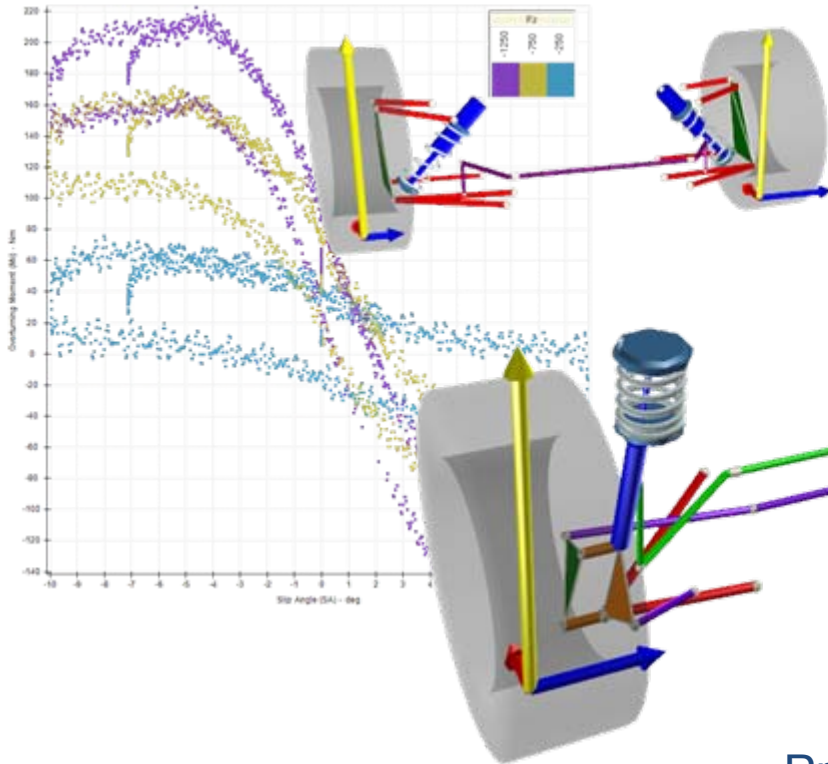


A new approach to steady-state and quasi-steady state vehicle handling analysis



Presentation

By Claude Rouelle

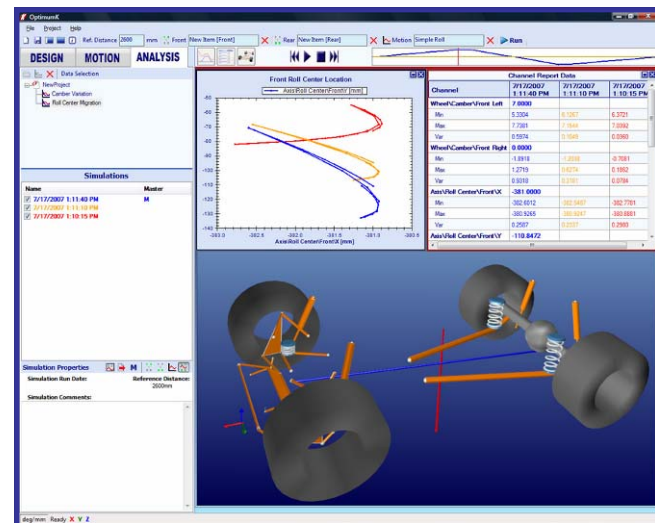
OPTIMUM 

Vehicle
Dynamics
Expo

June
16nd-18th
2009

OptimumG - Overview

- Vehicle Dynamics & Data Acquisition Seminars
 - In-House Seminar
 - Public Seminar
- Consulting
 - Track Testing
 - Race Engineering
 - Data Acquisition
 - Mechanical Design
 - ...
- Software Development
 - OptimumK
 - Simulation

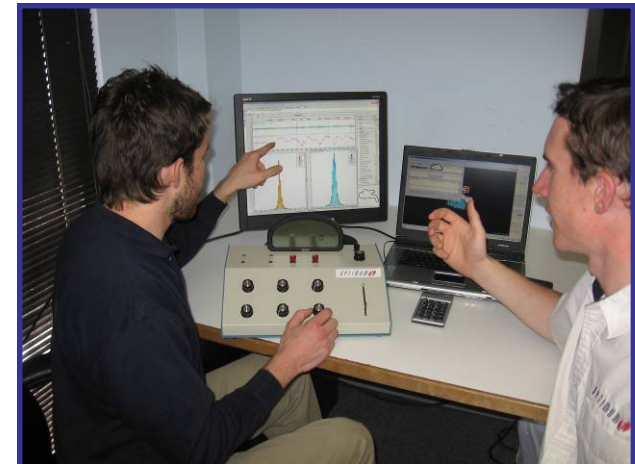


OptimumG - Seminars

Vehicle Dynamics & Data Acquisition Seminars

- In-House Seminar
- Public Seminar
- One-on-One training

- From 1 to 12 days
- Design around customer needs
- 8900 Power Point Slides to choose from

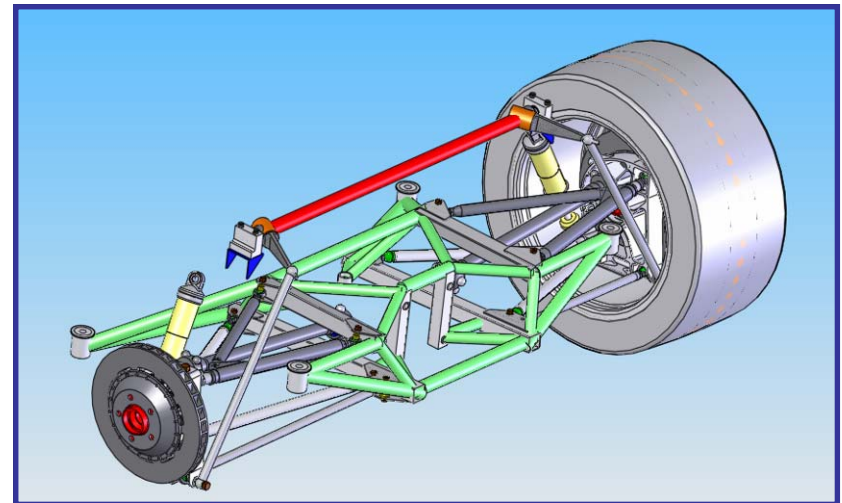
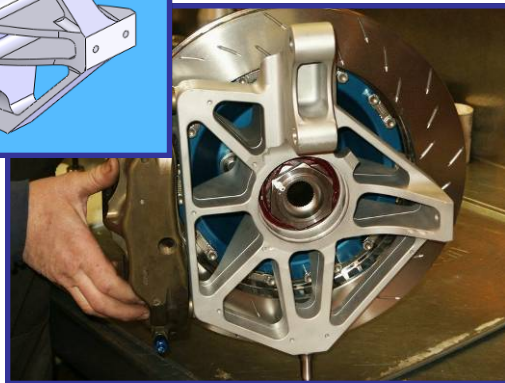
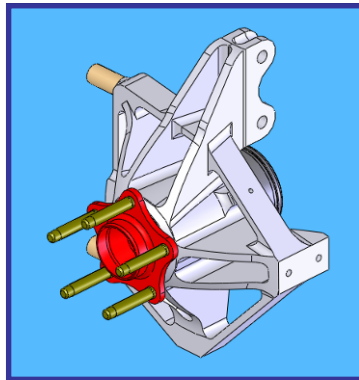
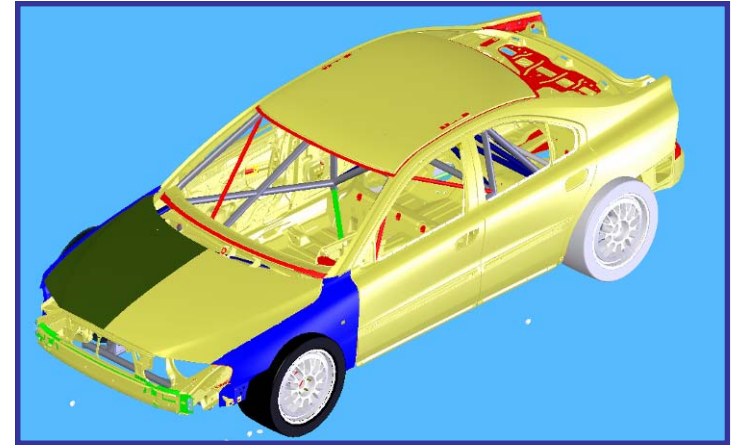


OptimumG – Seminars Customers

**312 Seminars / 12 Years
Over 6000 Satisfied Customers**

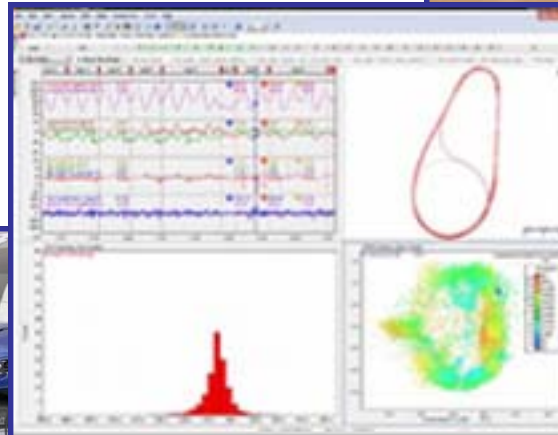
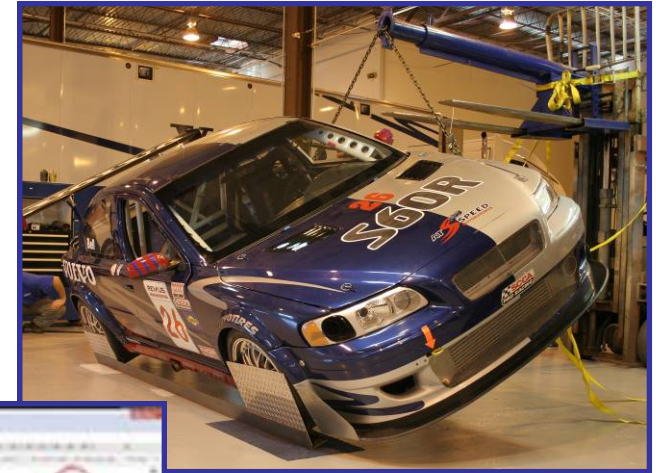
- Alcon
- AP Brakes
- Brembo
- Bridgestone-Firestone USA
- Bridgestone Tech. Center Europe
- BMW
- Citroen Sport
- Corrsys-Datron
- Chrysler
- Dunlop
- Ferrari
- Ford Advanced Vehicle Operations
- Goodyear
- Mac Laren
- Magneti-Marelli,
- Michelin
- Mitsubishi
- Multimatic
- MoTeC
- Nascar
- Ohlins
-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

- Mechanical Studies
- Chassis Design
- Suspension Geometry Design



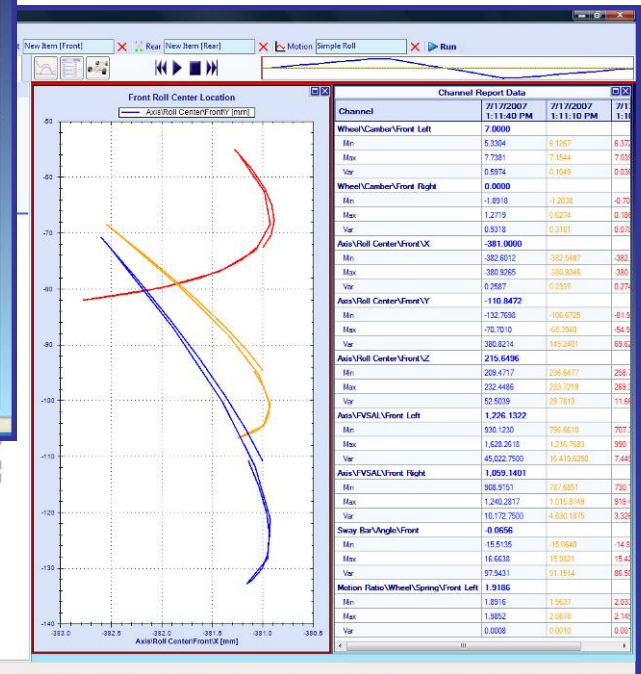
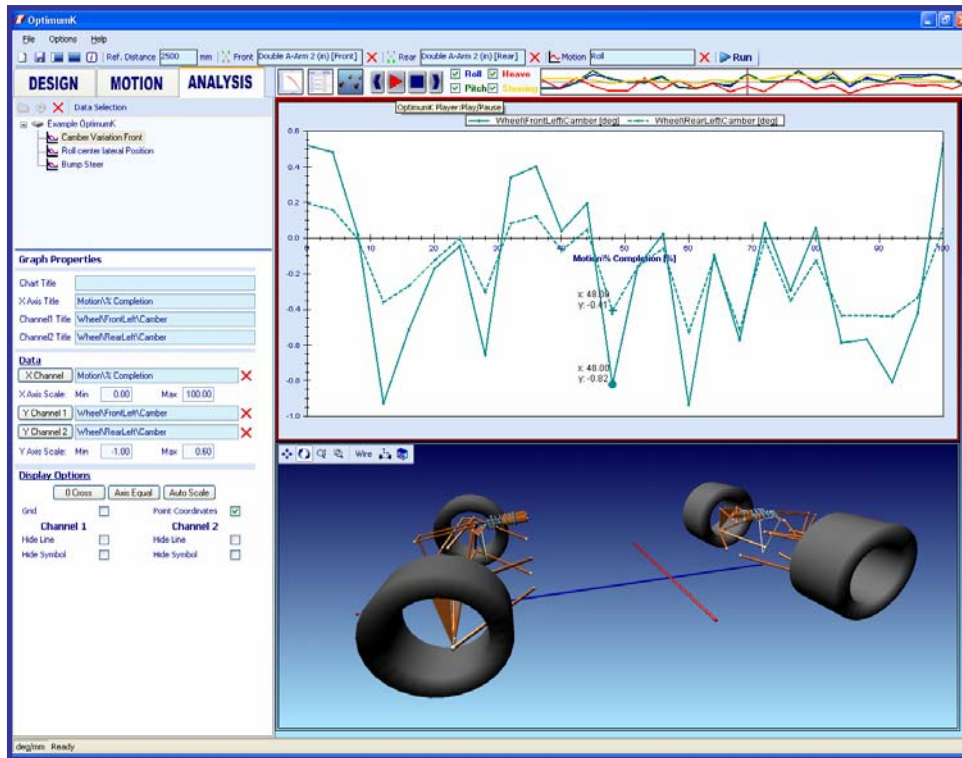
OptimumG - Consulting

- Race Car Engineering
- On Track Engineering
- On Track Testing
- Lab Testing
- Data Acquisition



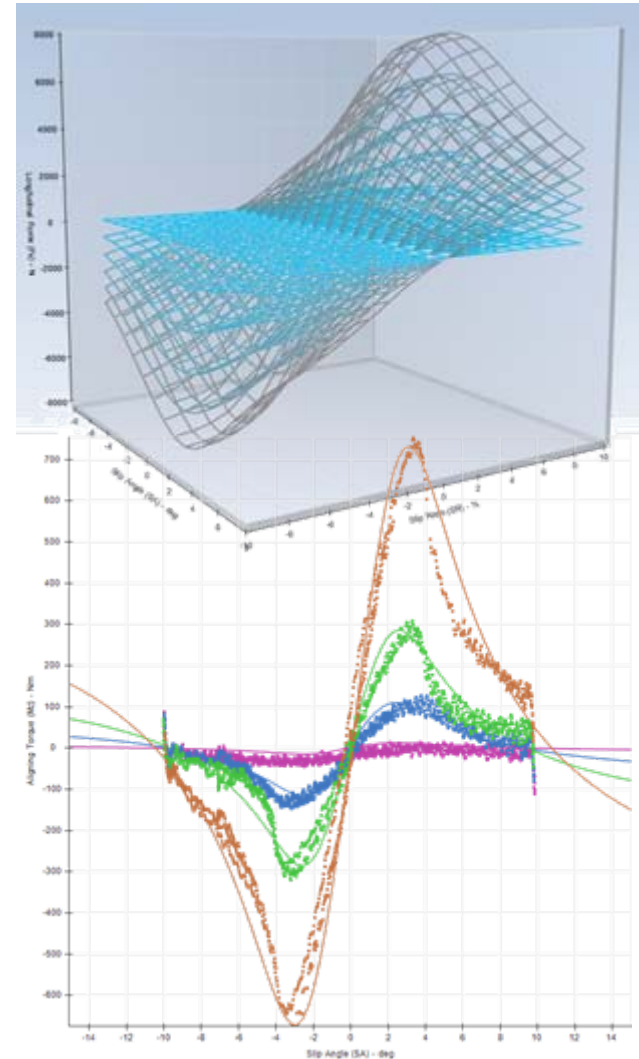
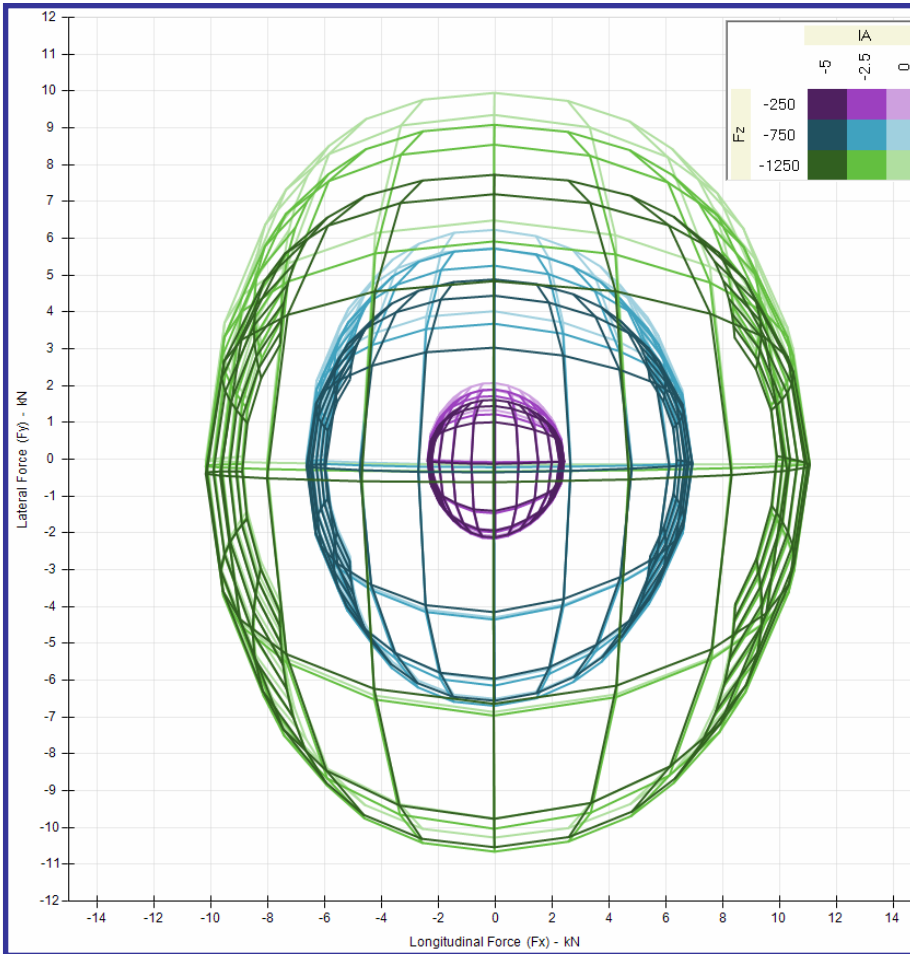
OptimumG – Software Development

- OptimumK : Kinematics software



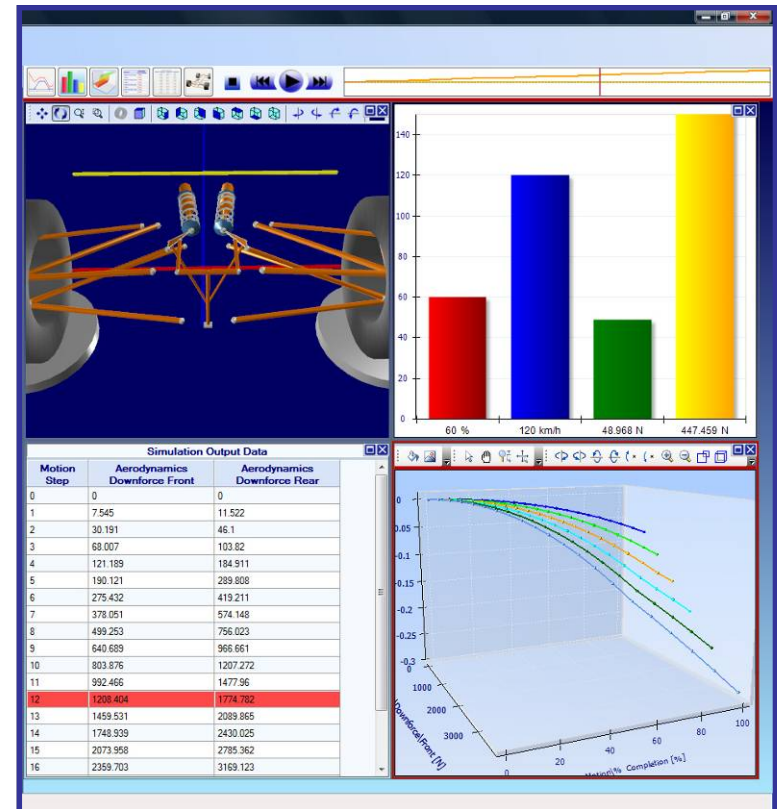
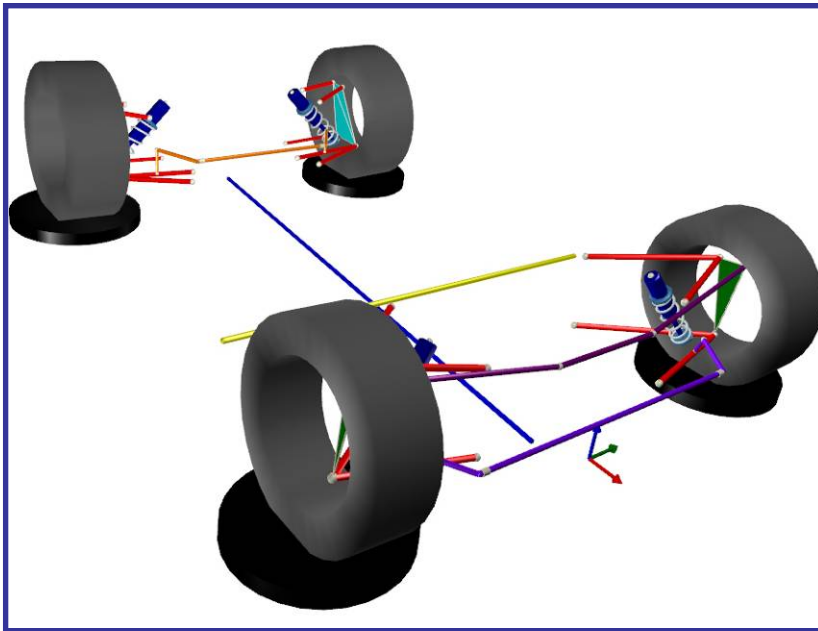
OptimumG – Software Development

- OptimumT : Tire Data Fitting and Visualization Software



OptimumG – Software Development

- Computational Vehicle Dynamics
 - Steady State simulation
 - Quasi-Steady State simulation
 - Yaw Moment Diagram – Moment Method



Motion Step	Aerodynamics Downforce Front	Aerodynamics Downforce Rear
0	0	0
1	7.545	11.522
2	30.191	46.1
3	68.007	103.82
4	121.189	184.911
5	190.121	289.808
6	275.432	419.211
7	378.051	574.148
8	499.253	756.023
9	640.589	966.661
10	803.676	1207.272
11	992.456	1477.96
12	1208.404	1774.702
13	1459.531	2089.865
14	1748.539	2430.025
15	2073.958	2785.362
16	2359.703	3169.123

- About CVD
- CVD Presentation
 - Design
 - Motion
 - Setup
 - Analysis
- Quasi Steady State Simulation
- Pure Steady State Simulation
- Steering Simulation
- Yaw Moment Diagram Simulation

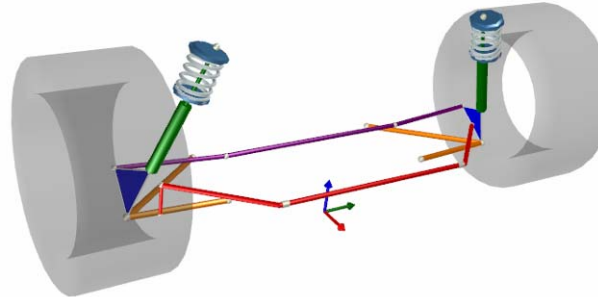


COMPUTATIONAL
VEHICLE
DYNAMICS

- CVD (Computational Vehicle Dynamics) calculates the behavior of the car in steady state
- Steady state: all the forces and moments are balanced in each step of the simulation
 - No inertia
 - No damping
- Calculation of lateral and longitudinal grip
 - Reaction of both suspended and non suspended mass
 - Weight Transfer
 - Tire Deflection
 - ...
- However, CVD could consider the case where the yaw moment is not equal to zero allowing the user to analyze parameters like understeer or oversteer.

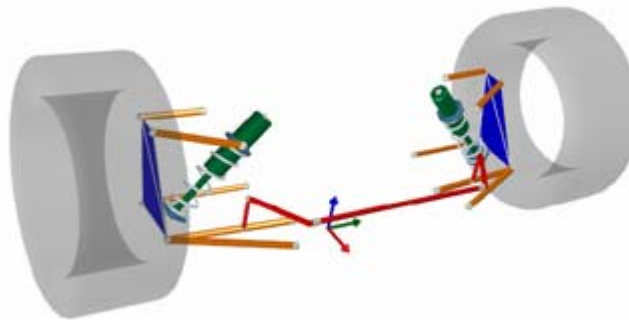
Front Suspension Templates:

- Double A-Arm
- Nascar
- Mac Pherson
- Mac Pherson Pivot Arm



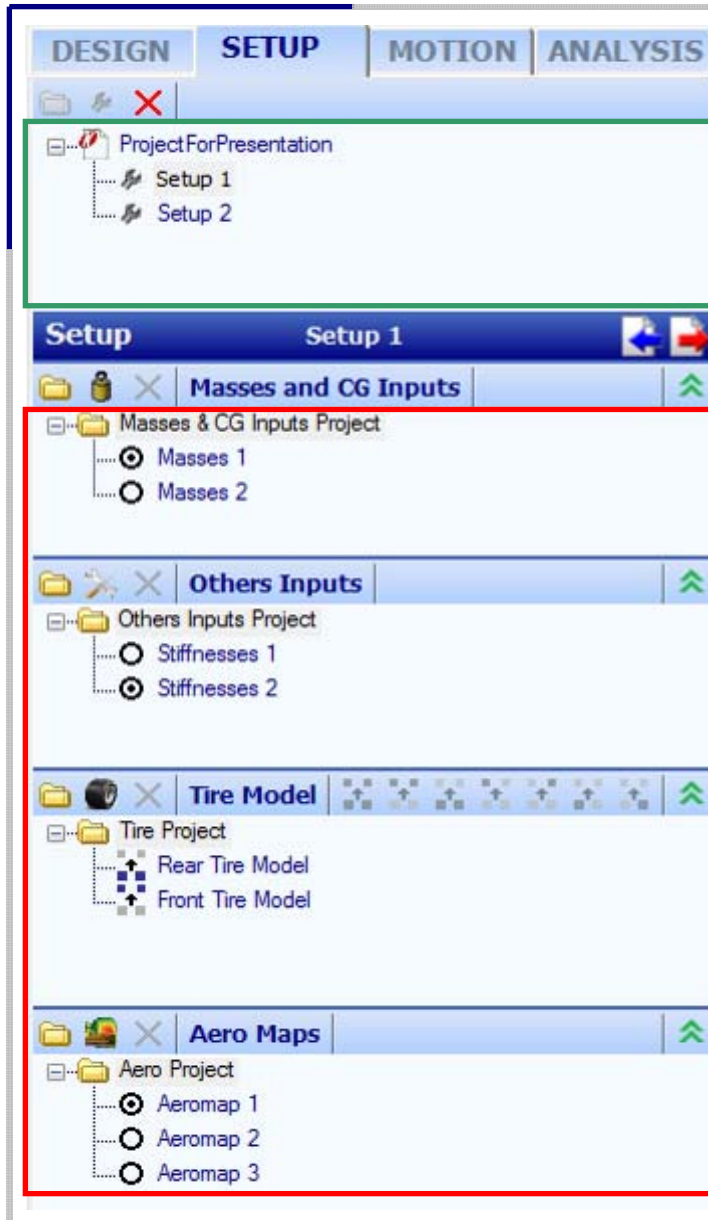
Rear Suspension Templates:

- Double A-Arm
- Mac Pherson
- Nascar
- V8 Supercar
- Five Link



Summary		Mac Pherson Geometry			Options (mm)		
Summary		<input type="checkbox"/> Symmetry					
Left			Right				
Wishbone							
Chassis Fore	X	Y	Z	X	Y	Z	
	-293	356.6	122.29	-293	-356.6	122.29	
Chassis Aft	8.7899	379.04	135.29	8.7899	-379.04	135.29	
Upright	-24	694	127	-24	-694	127	
Strut							
Upper Point	58	487	676	58	-487	676	
Lower Point	-4	635	283	-4	-635	283	
Steering Type Rack and Pinion							
Tie Rods							
	X	Y	Z	X	Y	Z	
Rack	-111	333.85	219.1	-111	-333.85	219.1	
Upright	-151.7	684.81	221.73	-151.7	-684.81	221.73	
Steering Ratio							
Steering Rack Displacement/Steering Wheel Revolution						1	
Wheel geometry							
Half Track	798		798				
Longitudinal Offset	0		0				
Vertical Offset	0		0				
Static Camber	0		0				
Static Toe	-0.43		-0.43				
Rim Diameter	450		450				
Tire Diameter	650		650				
Tire Width	270		270				
Spring							
	X	Y	Z	X	Y	Z	
Upper Center	56	508	660	56	-508	660	
Lower Center	41	553	512	41	-553	512	
Anti-Roll Bar							
Pivot							
	X	Y	Z	X	Y	Z	
Chassis Pivot	250	350	250	250	-350	250	
Drop Link							
Attachment Wishbone							
Anti-Roll Bar	0	600	230	0	-600	230	
Attachment	0	600	130	0	-600	130	

CVD - Setup



← Create as many Setup as you want

Setup split in 4 :

- Masses and CG
- Others (Stiffness, Brake, Diff...)
- Tire Model
- Aero Maps

→ Fast Setup changes

Masses and CG Inputs

- Corners Masses
- Non Suspended Masses
- CG Total Height
- Non Suspended Masses CG

Import - Export

Print

MASSES and CG INPUTS Setup 1 >> Masses 1 Units (Metric) [Import] [Export] [Print]

	Left	Right
Corner Mass (Kg)		
Front	340	340
Rear	355	355

	Left	Right
Non suspended Mass (Kg)		
Front	25	25
Rear	30	30

Mass Distribution (%)	
Total (Kg)	1390
% Front	48.92
% Left	50.00
% Diag. FL-RR	50.00

CG Position (mm)	Z
Center Of Gravity Total	380
Non Suspended Mass FL	310
Non Suspended Mass FR	310
Non Suspended Mass RL	310
Non Suspended Mass RR	310

Comments

Masses and CG 1

Other Inputs

- Spring Stiffness
- Anti Roll Bar Stiffness (or Belleville Washers Stiffness)
- Brake Distribution
- Drivetrain Configuration
- Static Ride Height
- Non Suspended Mass CGs
- Chassis Torsional Stiffness

The screenshot shows the 'OTHERS INPUTS' window with the following settings:

- Stiffnesses**
 - Front**
 - Two Springs: 330 N/mm (Left), 330 N/mm (Right)
 - Anti Roll Bar: 50000 N/mm / deg
 - Rear**
 - Two Springs: 220 N/mm (Left), 220 N/mm (Right)
 - Anti Roll Bar: 8000 N/mm / deg
- Brake**
 - Brake Distribution (% Front): 50
- Drivetrain**
 - Driven Wheels: Front Wheel Drive
 - Differential: Mechanical
 - Torque Distribution (% Inside Wheel): 40 / 60
- Ride Height (mm)**

	X	Y	Z
Ride Height Front	0	0	65
Ride Height Rear	-2700	0	70
- Chassis Torsion**
 - Infinite Stiffness: 0 Nmm/Deg
- Comments**
 - Empty text box

Tire Model

- Pacejka
- Fiala
- STI
- Harty

- Visualization Tools:
 - 2D Graph
 - 3D Graph
 - Tire Forces Calculator

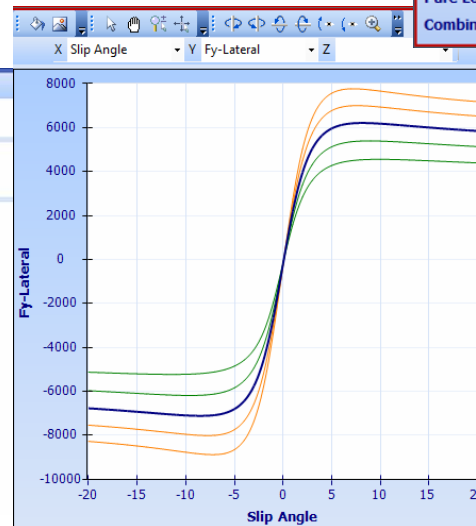
TIRE MODEL Setup 1 >> Front Tire Model

Vertical Stiffness: 350 [N/mm]

Nominal load - Fz0: 5560.21 [N]
Unloaded Tire Radius - R0: 0.448 [m]

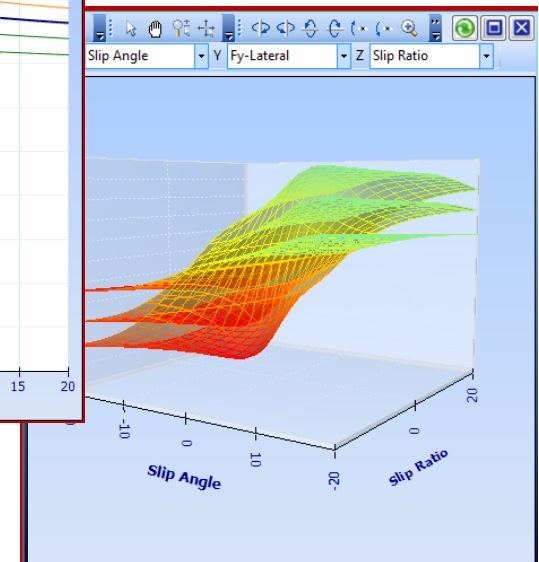
Lateral						Longitudinal									
Cy1 1.1256;	Dy1 1.7546;	Rby1 13.218;	Rby2 5.7998;	Cx1 1.1536;	Dx1 -1.8870;	Rbx1 2.8100;	Rbx2 9.1731;	Dy2 -0.3482;	Dy3 10.559;	Rby3 -0.0222;	Rcy1 1.0480;	Dx2 0.1920;	Dx3 0;	Rcx1 2.7503;	Rcx2 0;
Ey1 -0.9376;	Ey2 -0.9977;	Rey1 0;	Rey2 0;	Ex1 -0.9598;	Ex2 -0.9947;	Rex2 0;	Rhx 0.0006;	Ey3 0.2113;	Ey4 0.0358;	Rhy1 0.0006;	Rhy2 0;	Ex3 0.0490;	Ex4 0.0704;		
Ky1 61.686;	Ky2 2.5586;	Rvy1 -0.0170;	Rvy2 -0.0105;	Kx1 47.801;	Kx2 -9.7819;			Ky3 1.0008;	Hy1 0.0015;	Rvy3 -0.2764;	Rvy4 -62.441;	Kx3 -0.2559;	Hx1 -0.0010;		
Hy2 -0.0009;	Hy3 -0.0272;	Rvy5 1.6385;	Rvy6 0.0011;	Hx2 0.0005;	Vx1 0.0752;			Vy1 -0.0522;	Vy2 0.0498;			Vx2 0.0634;			
Vy3 2.0685;	Vy4 0.0783;														

Comments



TIRE FORCES CALCULATOR

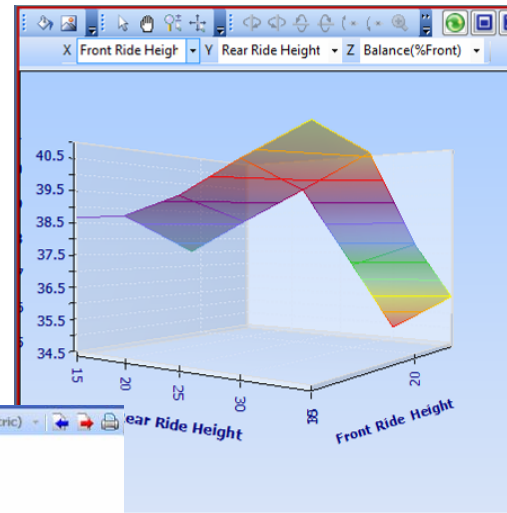
	Slip Angle	Slip Ratio	Camber	Fz (N)	Fx (N)	Fy (N)
Pure Lateral	2	1.8	1.8	3500		4284.468
Pure Longitudinal		1.2	1.5	3800	1850.208	
Combined	1.8	1	2.1	4000	1489.769	4408.820



Aero Maps

- Cz Front and Rear
- Cx
- Aero Balance
- Efficiency

- Aero Map Visualization:
 - 3D Graph
 - Iso Lines



AERO MAPS | Setup 1 >> Aeromap 1 Units: (Metric)

Ambient Conditions

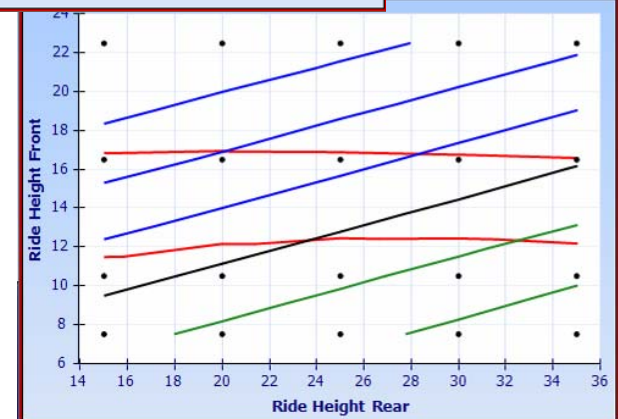
Ambient Temperature (degC): 21
 Ambient Pressure (bar): 1
 Density: 1.200
 Reference Area (m2): 1.5

Comments

Aero Maps

13 Type of Input for the Maps: Cz Total + Balance + Cx

RH Front	RH Rear	Czf	Czr	CzTotal	Balance(%F)	Cx	Efficiency
15.0	20.0	0.6049	1.0042	1.6091	37.59	0.7957	2.0222
10.0	20.0	0.6373	1.0102	1.6475	38.68	0.7953	2.0715
10.0	15.0	0.5936	0.9420	1.5356	38.66	0.7867	1.9520
10.0	25.0	0.6549	1.0159	1.6708	39.20	0.7980	2.0937
10.0	30.0	0.6729	1.0060	1.6789	40.08	0.8028	2.0913
15.0	30.0	0.6408	0.9846	1.6254	39.42	0.7998	2.0323
15.0	25.0	0.6217	0.9917	1.6134	38.53	0.7948	2.0299
15.0	35.0	0.6543	0.9675	1.6218	40.34	0.8017	2.0230
10.0	35.0	0.6907	0.9997	1.6904	40.86	0.8084	2.0910
20.0	35.0	0.6032	0.9912	1.5944	37.83	0.8070	1.9757



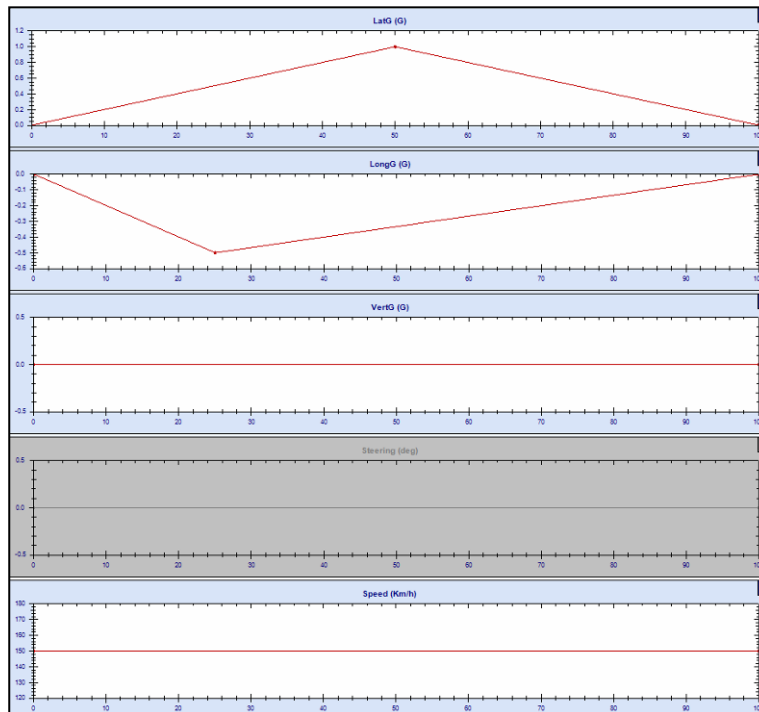
- In CVD the inputs are based on forces and speed
- 3 types of motion can be generated according to the need of the user.
 - Pure Steady State
 - Quasi Steady State
 - Yaw Moment vs. Lateral Acceleration diagram

Pure Steady State (PSS)

PSS motion:

Yaw moment equal to zero → Steering wheel angle is calculated in order to maintain the equilibrium.

➔ Skid Pad Simulation



Parameters

Yaw Moment = 0

Lateral Acceleration = Input

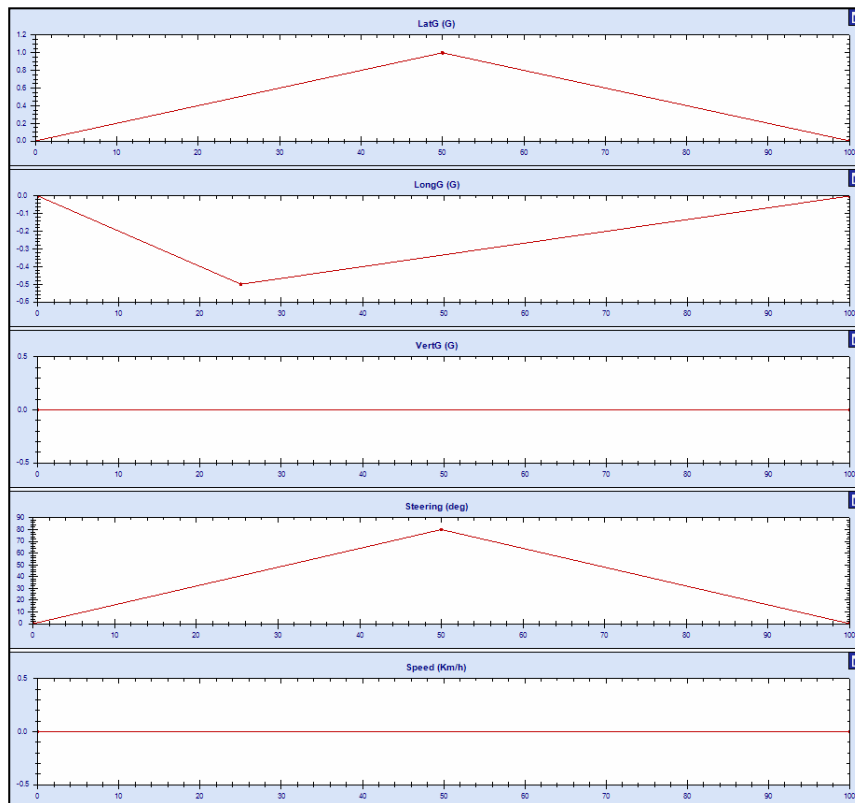
Steering Wheel Angle = Output

Body Slip Angle = Output

Quasi Steady State (QSS)

- QSS motion: the steering angle is an input and therefore the yaw moment is not zero anymore.

➔ Forces, Roll and Pitch Moments are in equilibrium.

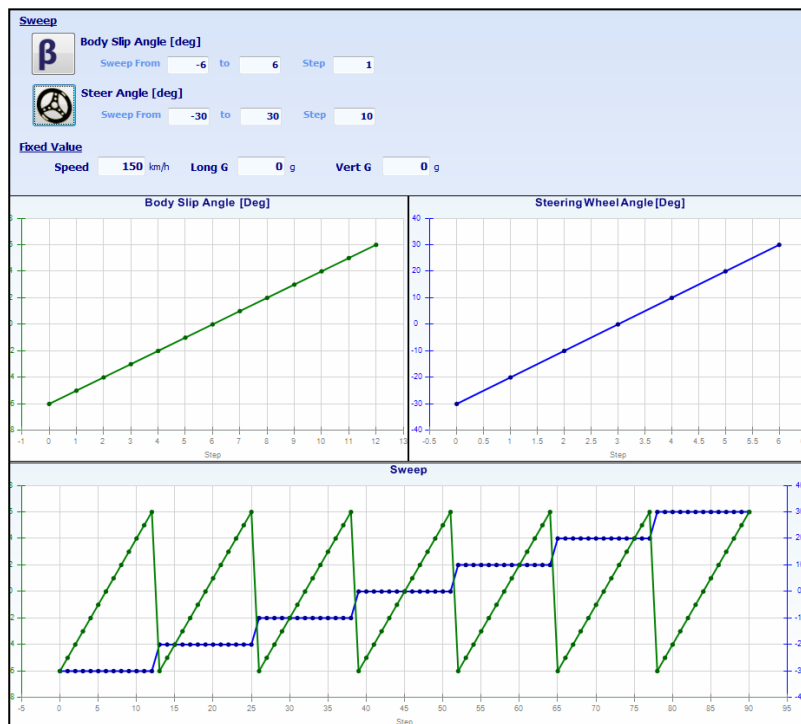


Parameters

Yaw Moment = Output
Lateral Acceleration = Input
Steering Wheel Angle = Input
Body Slip Angle = Output

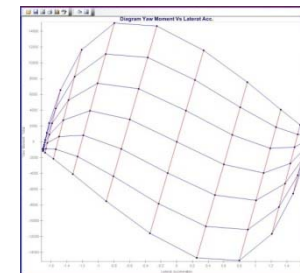
Yaw Moment Diagram

- In a diagram motion the input is a sweep for both body SA and steering wheel angle. For each point the lateral acceleration and yaw moment are calculated and then a diagram can be generated. This gives a quick visualization of parameters such as control, stability, behavior at the limit.



Parameters

Yaw Moment = Output
Lateral Acceleration = Output
Steering Wheel Angle = Input
Body Slip Angle = Input



CVD – Analysis Tools

The screenshot displays several analysis windows from a vehicle dynamics software package:

- Channel Report Data:** A table showing lateral and vertical force data for all four tires.
- Weight Transfer:** A bar chart showing the distribution of weight transfer across the four corners.
- 3D Plot:** A 3D plot of Tire Vertical Force (N) vs. Front/Left vs. Lateral Acceleration.
- Diagram Yaw Moment Vs Laterat Acc:** A 2D plot showing the relationship between yaw moment and lateral acceleration.
- Tire Vertical Force Report:** A detailed table of vertical force data over time.
- Vehicle Model:** A 3D schematic of the vehicle chassis and suspension.
- Corner Plots:** Four circular plots showing lateral force vs. lateral acceleration for each corner, including Total, Lateral, and Longitudinal Force Error (FE) values.

Channel	Accelerating and Braking	QSS LateralG	PSS LateralG
Tire\Lateral Force\Front Left	-706.499		
Min	-1206.345	-1006.245	-989.715
Max	-648.823	2308.271	1038.762
Tire\Lateral Force\Front Right	691.548		
Min	635.905	983.903	1000.438
Max	1167.694	7907.347	5237.929
Tire\Lateral Force\Rear Left	1146.45		
Min	754.177	1251.751	1234.654
Max	1234.526	1944.874	2981.085
Tire\Lateral Force\Rear Right	-1131.5		
Min	-1213.249	-1229.409	-1245.378
Max	-715.516	1073.197	3975.914
Tire\Vertical Force\Front Left	2528.462		
Min	2353.553	1879.391	1826.299
Max	4076.118	3441.968	3442.359
Tire\Vertical Force\Front Right	2535.055		

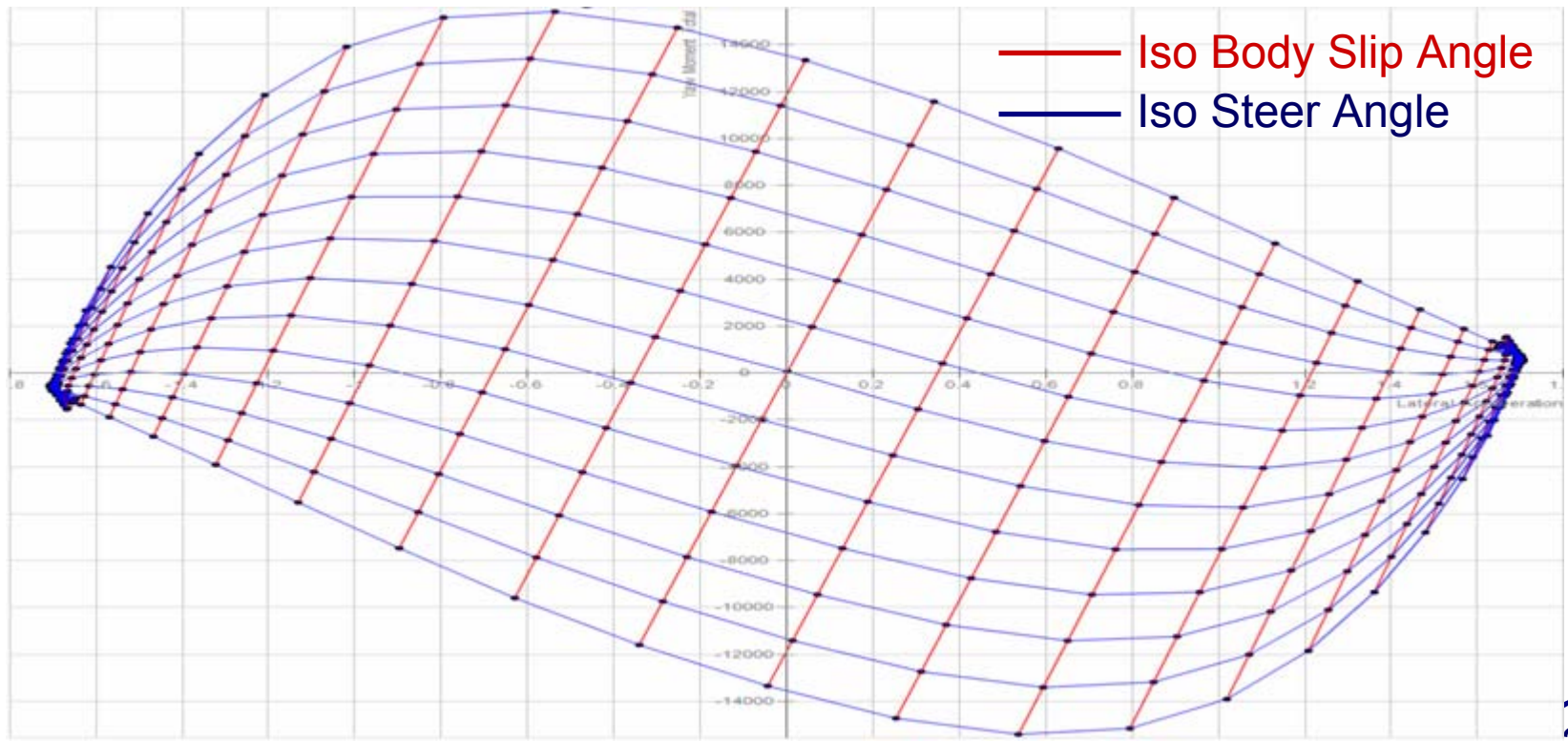
	3540.284	3715.389	3890.595	4065.741	4415.756	4237.337	4060.158	3882.4	3704.592	3526.74	3349.783	3172.647	2995.248	2817.578	2692.87
1	3053.697	3055.528													
2	2878.555	2882.113													
3	2703.469	2708.628													
4	2528.462	2535.055	4240.802												
5	2353.553	2361.36													
6	2531.789	2537.988													
7	2709.037	2713.769													
8	2886.735	2889.86													
9	3064.478	3065.87													
10	3242.261	3241.818													
11	3419.212	3418.593													
12	3596.346	3595.697													
13	3773.744	3773.054													
14	3951.412	3950.664													
15	4076.118	4075.305													

Yaw Moment Diagram - Presentation

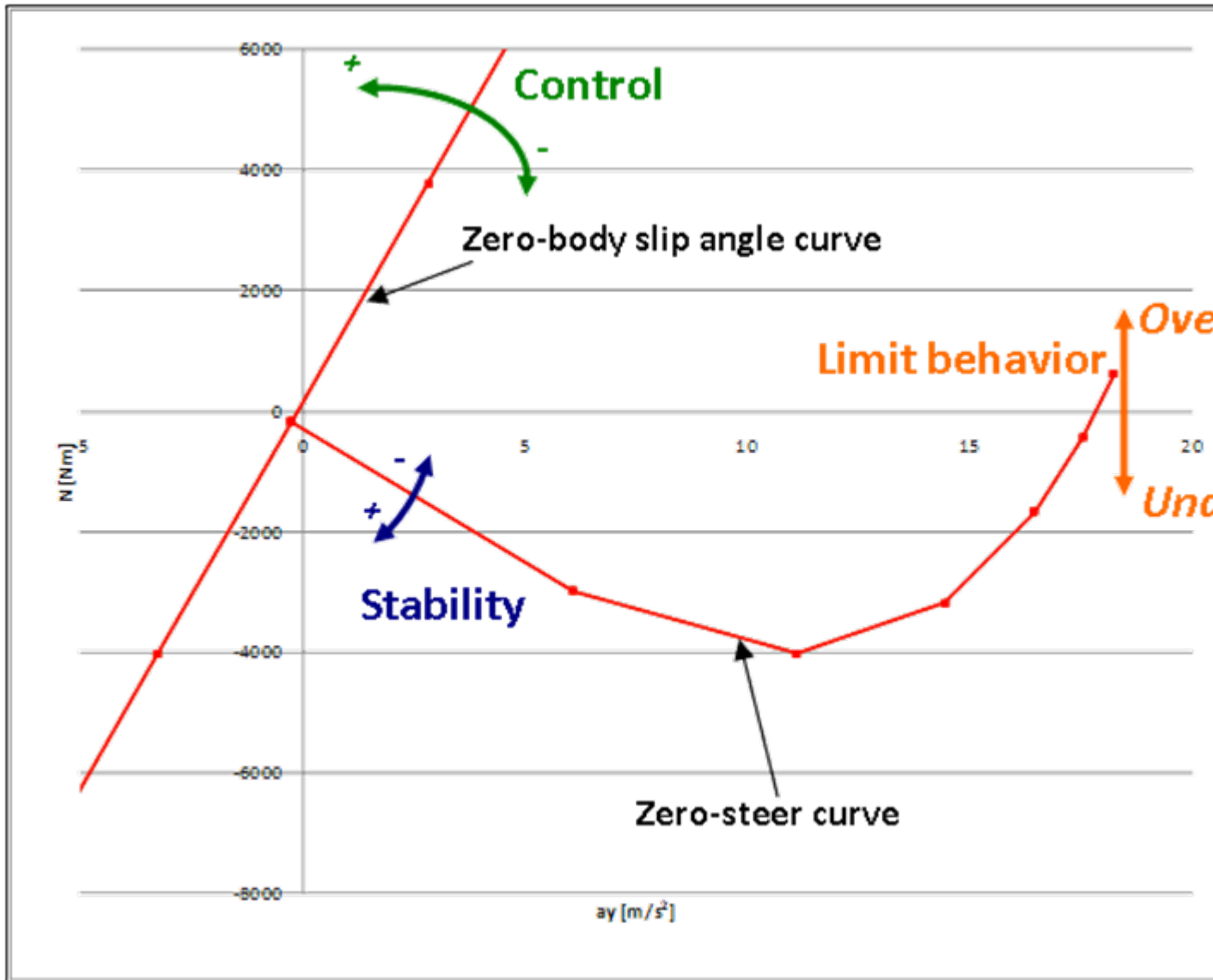
- For a given speed and longitudinal acceleration, the **yaw moment diagram** covers the full maneuvering envelope and presents the results graphically in one graph.
- Graphic analyze of the stability and control of an automobile.
- Analogy with aeronautical techniques.
- Force/Moment study instead of motion study avoids filtering effects of the inertias and give the ability to isolate results of small changes in the vehicle configuration not discernible in a transient response.

Yaw Moment Diagram - Construction

- ↻ Sweep of Steering Wheel Angle
- ↻ Sweep of Body Slip Angle
- ↻ Vehicle Speed
- ↻ Longitudinal Acceleration
- ↻ Vertical Acceleration



Yaw Moment Diagram – How to use it?



Yaw Moment Diagram – How to use it? (2)

Stability

- **STABILITY:** The slope of the zero-steer curve shows the yaw moment (N) for different CG body slip angle (β). This is called the directional stability of the car.
- The magnitude tells you how much yaw moment is acting on the car with zero steering input. The sign is always the opposite sign as the lateral acceleration sign, thus this yaw moment tends to reduce the body slip angle.

Yaw Moment Diagram – How to use it? (2)

Control

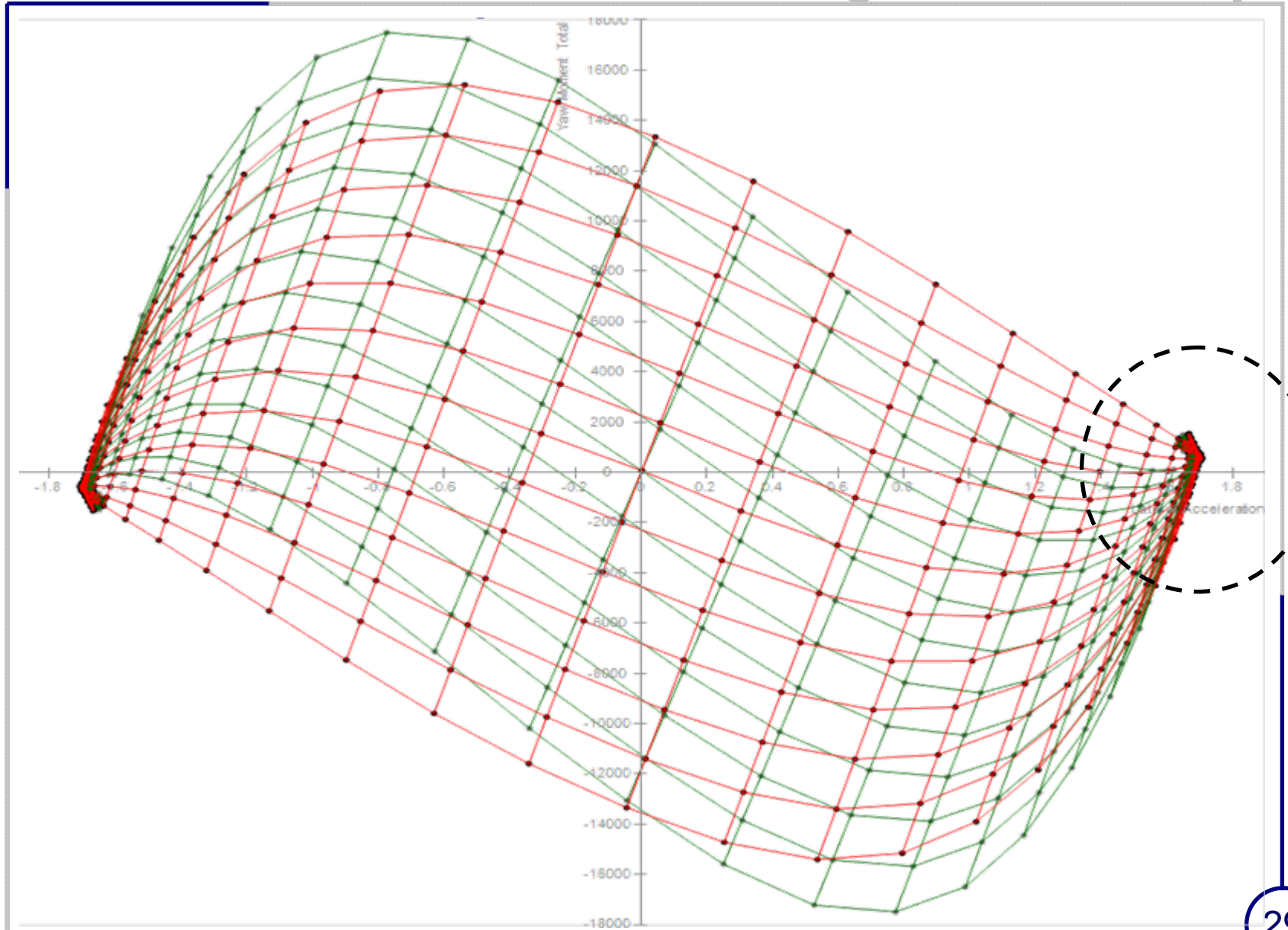
- **CONTROL:** The yaw moment generated at 1° of steering shows the derivative of yaw moment (N) with regard to steering angle. This is a measure of the yaw moment control that the driver has.
- Lateral acceleration generated at 1° of steering shows the derivative of lateral acceleration (Y) with regard to steering angle. This is a measure of the lateral-acceleration control that the driver has.

Yaw Moment Diagram – How to use it? (2)

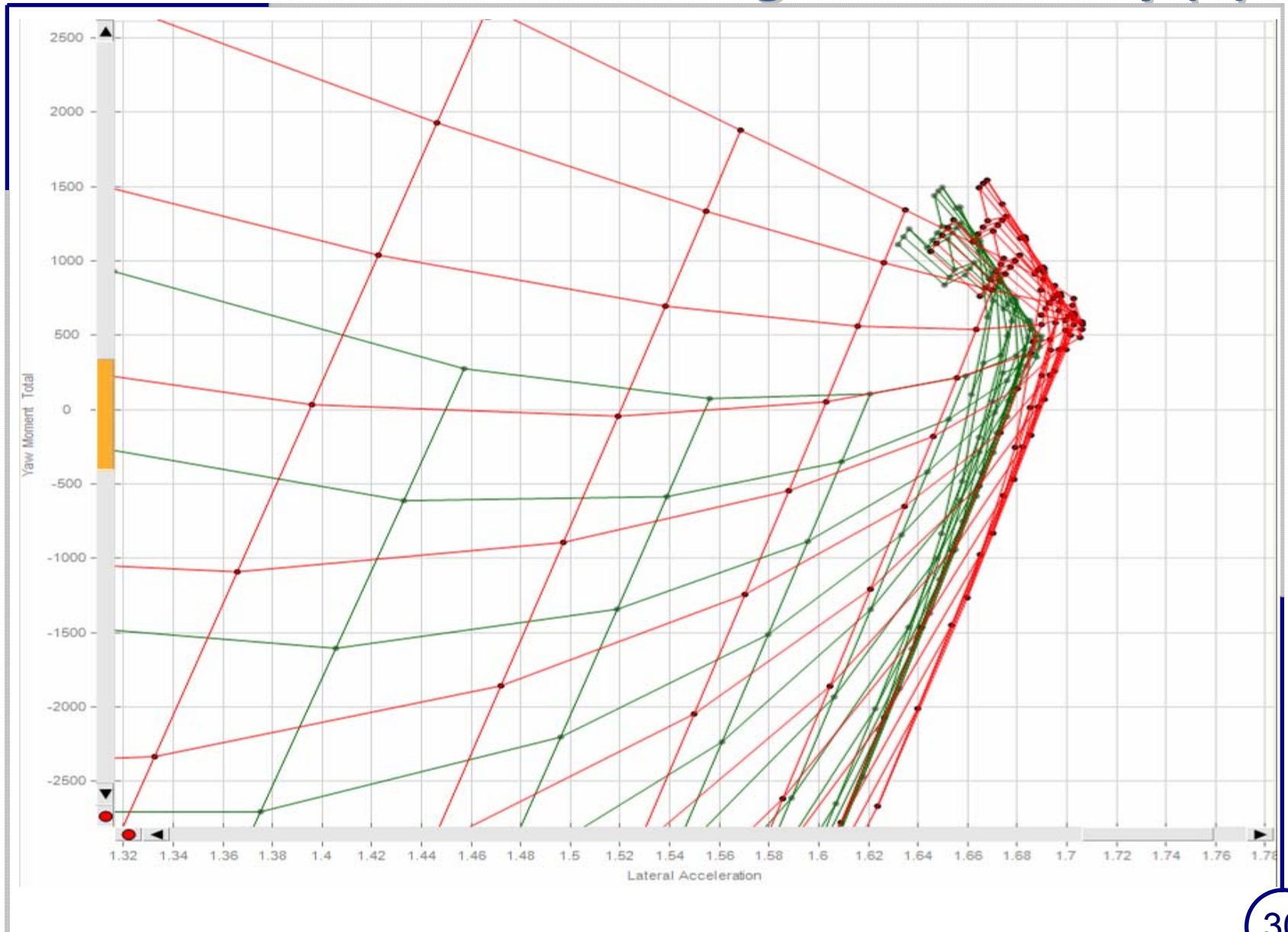
Limit Behavior

- **LIMIT BEHAVIOR:** If the tip of the diagram is above the line yaw moment (N) = 0 for positive lateral accelerations, then the car is limit oversteer (spin).
- If the tip of the diagram is below the yaw moment (N) = 0 for positive lateral accelerations, the car is limit understeer (plow).
- Note that a car can be limit oversteer but understeer in terms of trim behavior.

Yaw Moment Diagram – Overlay



Yaw Moment Diagram – Overlay (2)

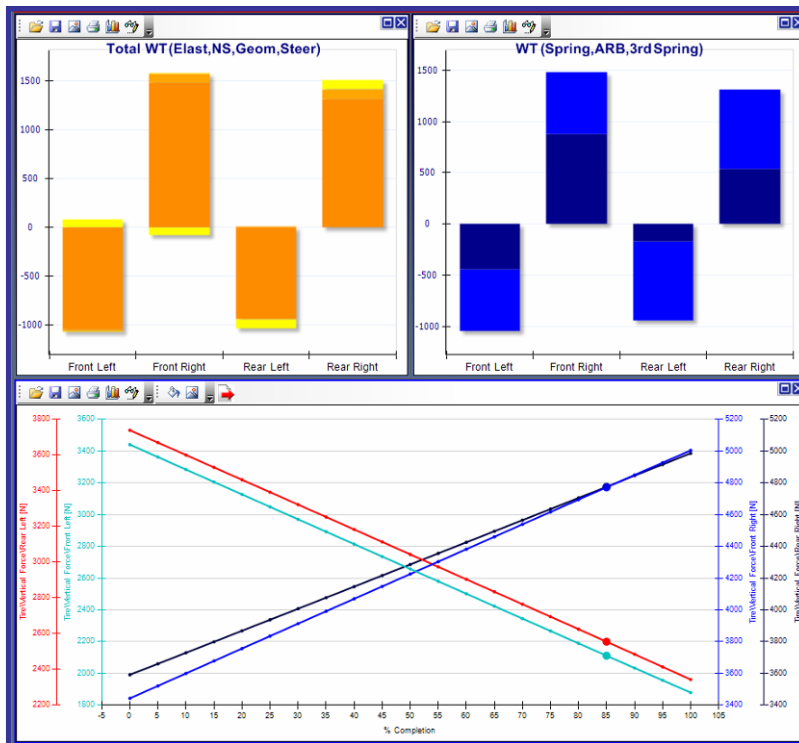


Analysis – QSS Simulation

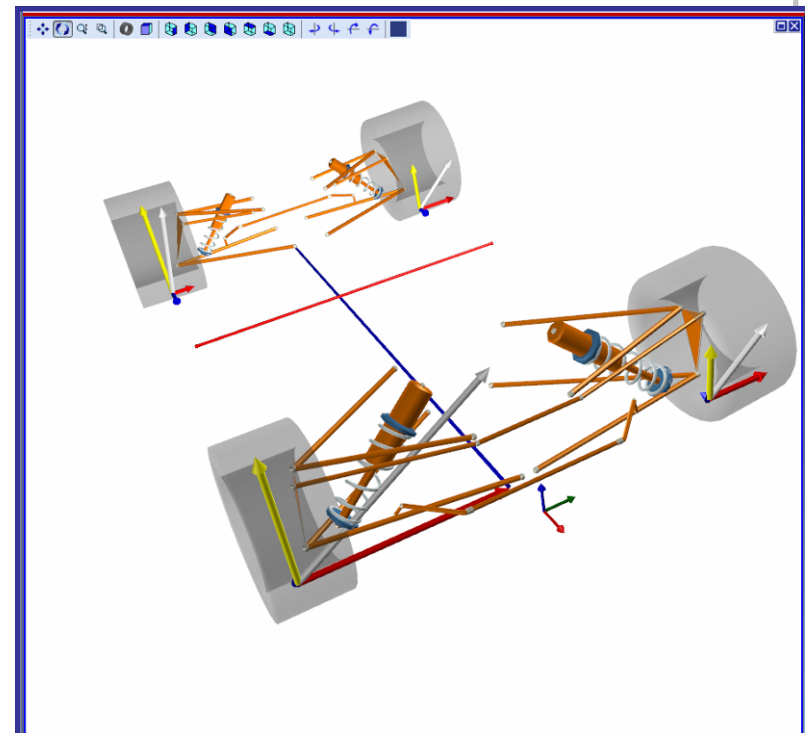
Motion:

- Lateral Acceleration : ramp from 0 to 1 G
- Speed : 200 Km/h
- Steering angle : 0 to 60 Deg

Weight Transfer

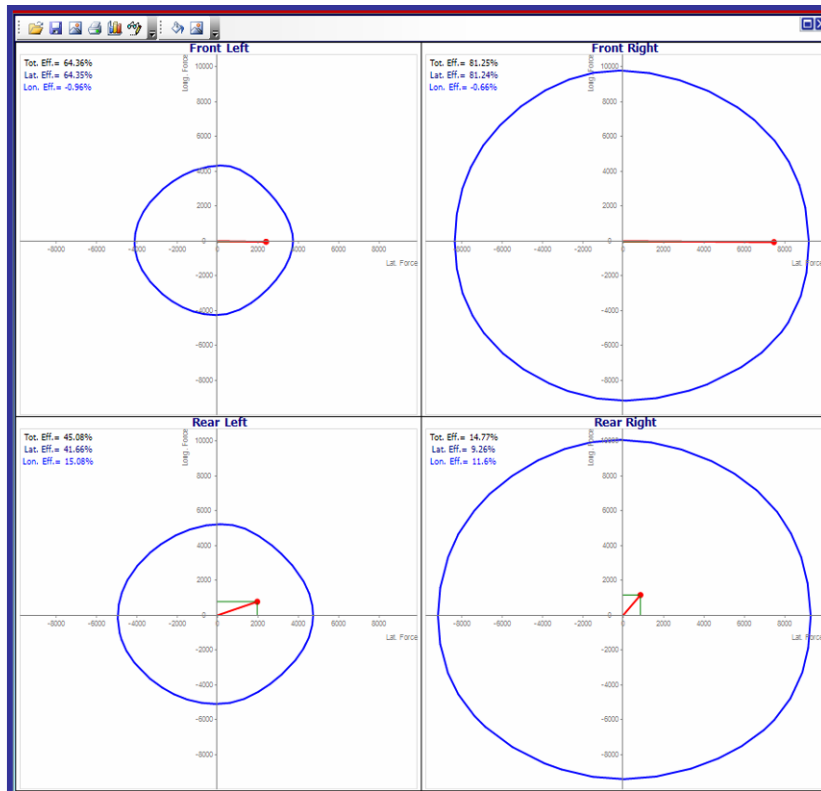


Visualization of forces

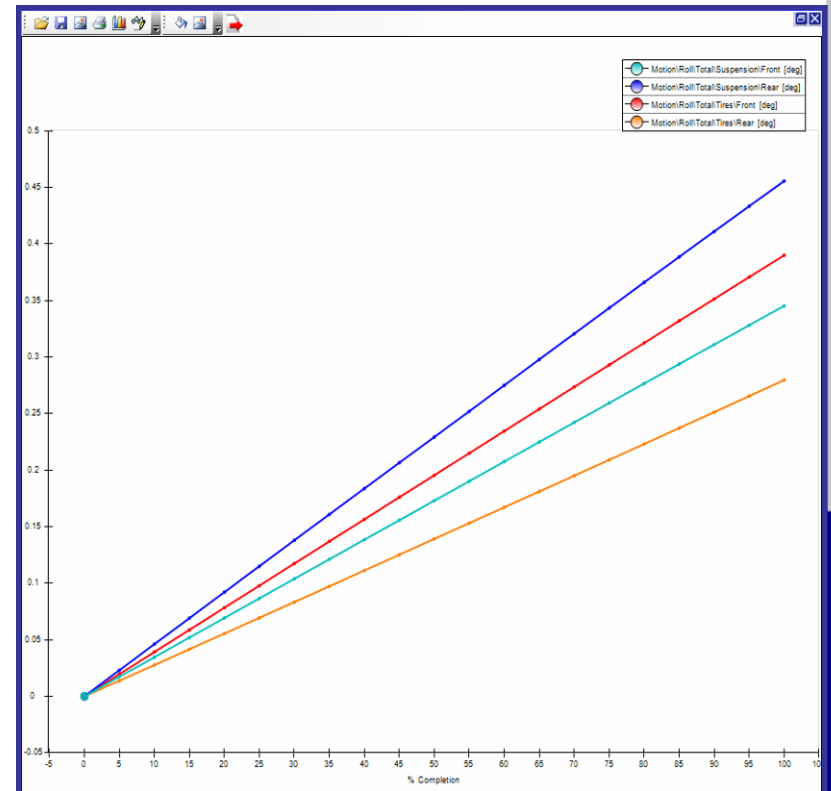


Analysis – QSS Simulation (2)

Friction Ellipse



Roll in suspension and tires

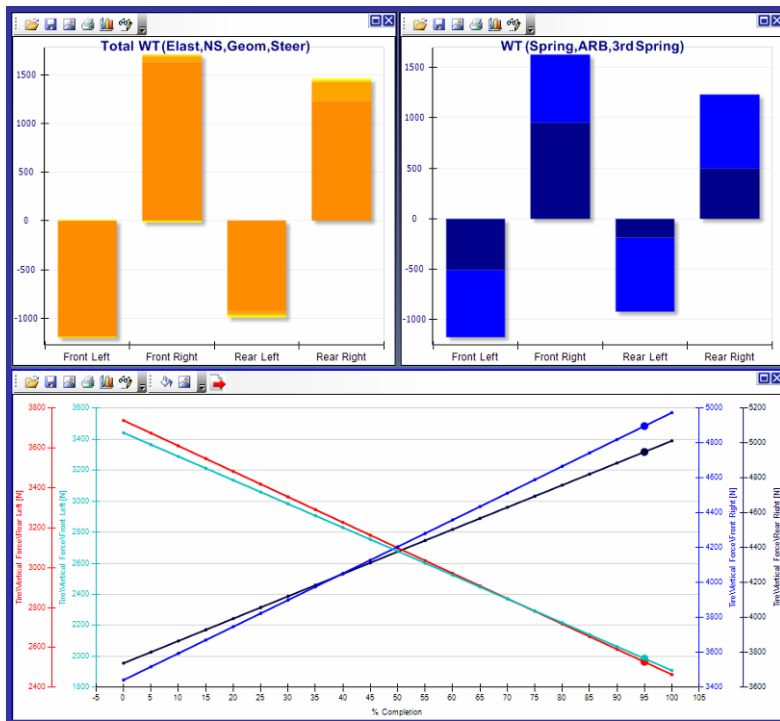


Analysis – PSS Simulation

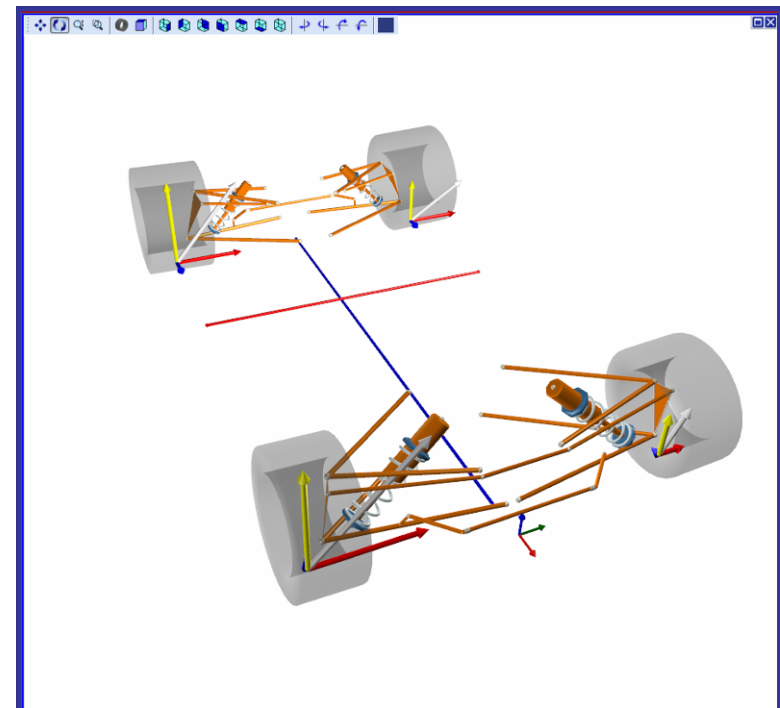
Motion:

- Same motion as QSS
- Calculating the steering wheel angle

Weight Transfer

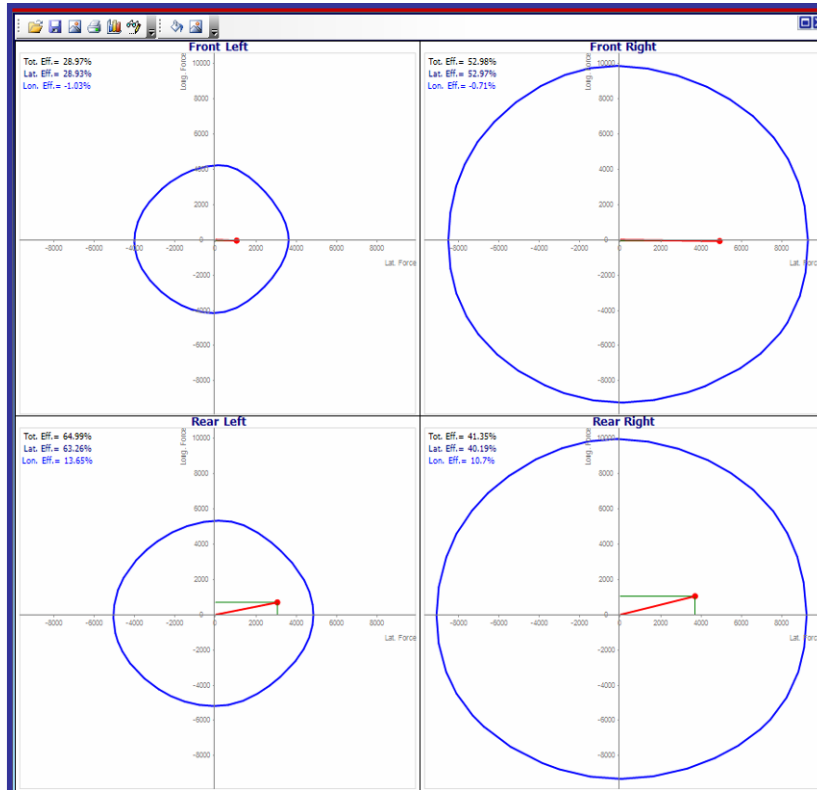


Visualization of forces

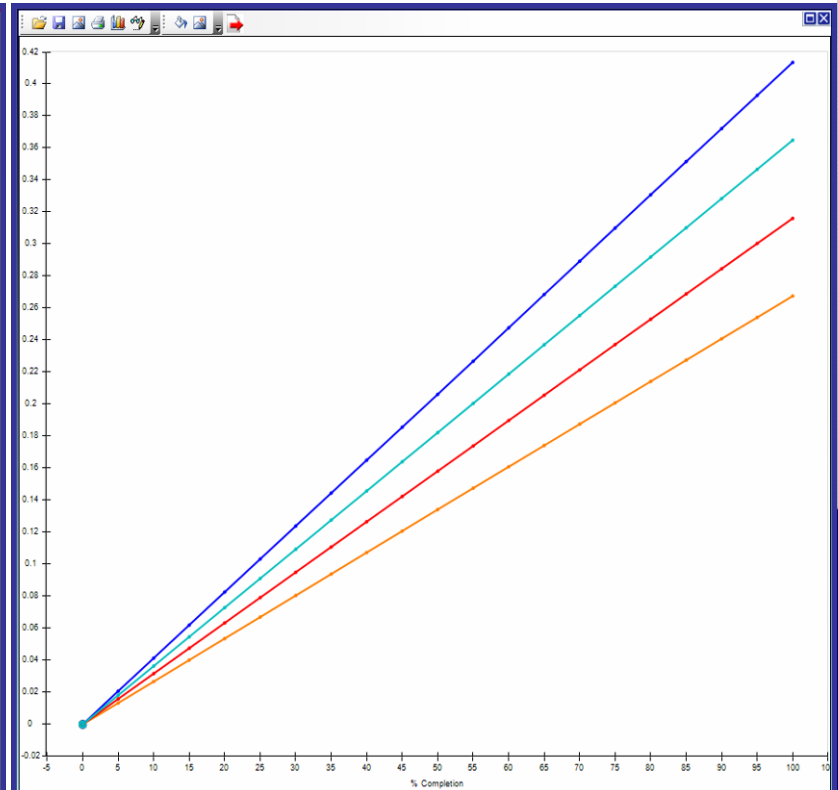


Analysis – PSS Simulation (2)

Friction Ellipse



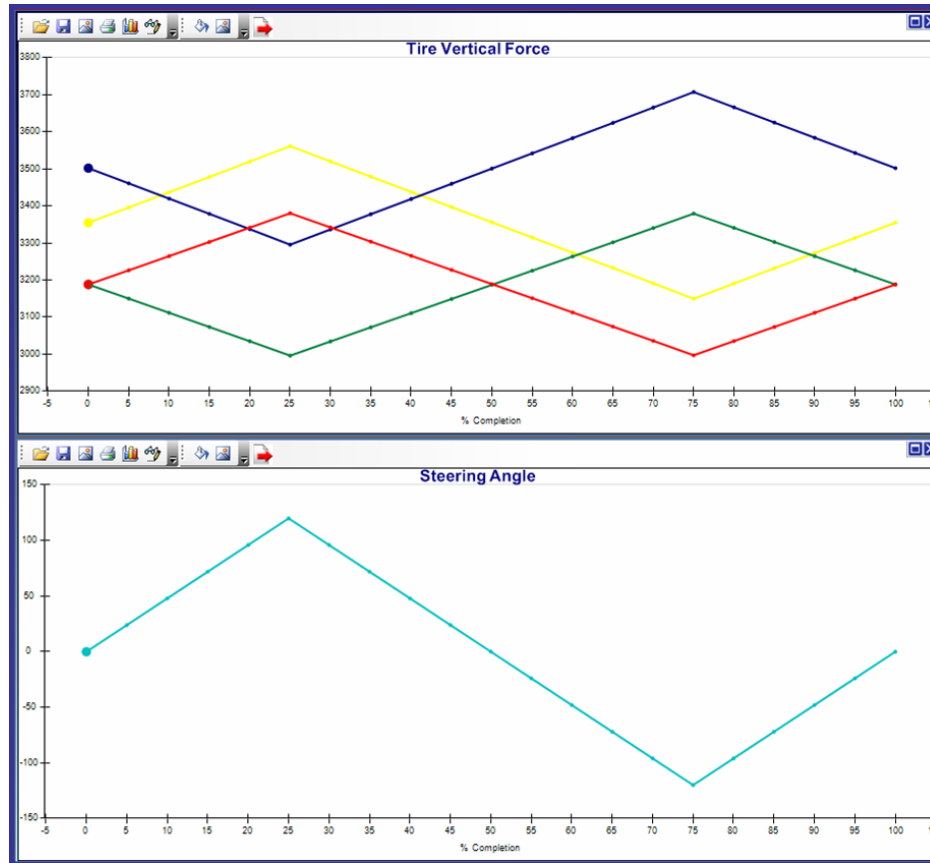
Roll in suspension and tires



Analysis – Steering Simulation

Motion:

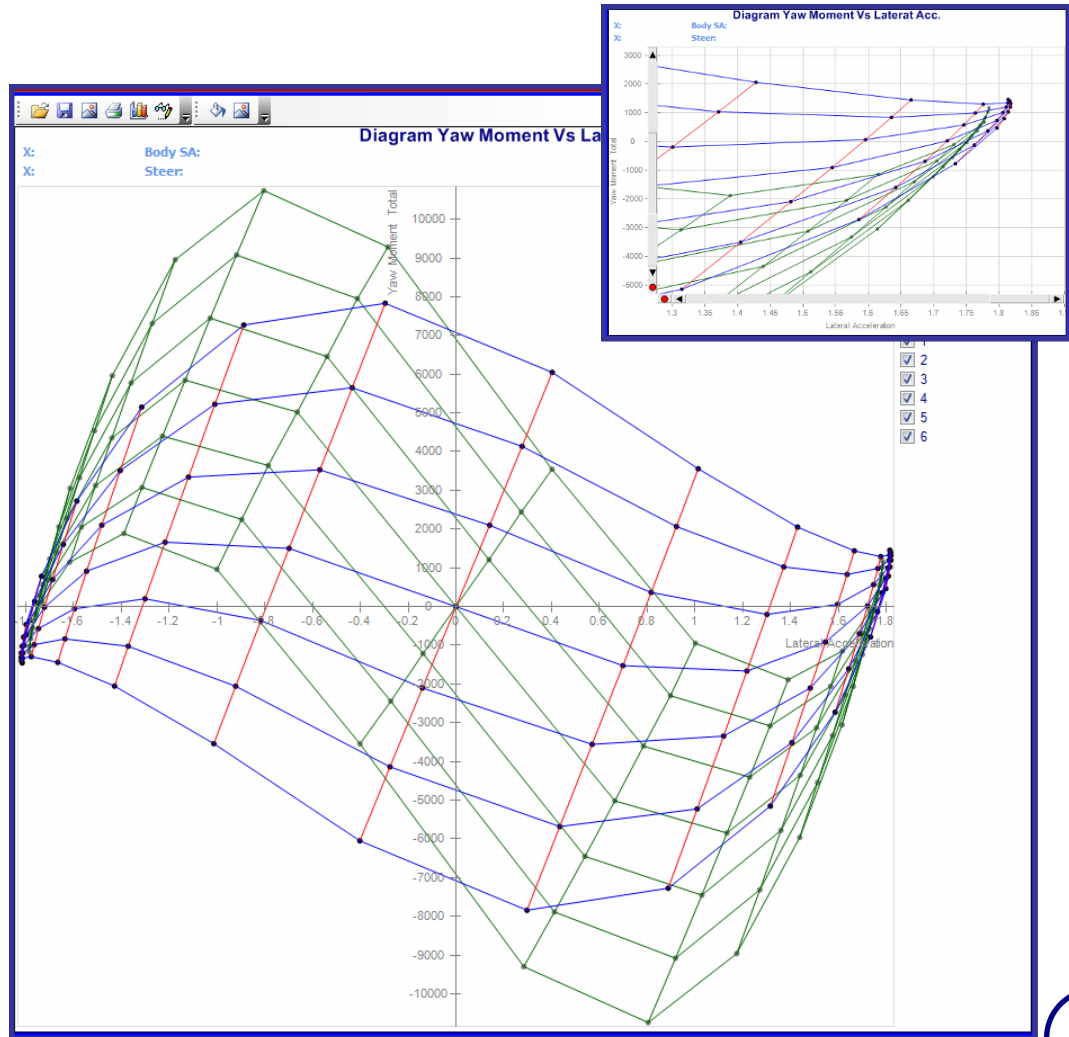
- Sweep of steering angle
- Analyze weight transfer due to steering geometry



Analysis – Yaw Moment Diagram

Motion: Sweep of the steering angle only to analyze the weight transfer due to the steering geometry

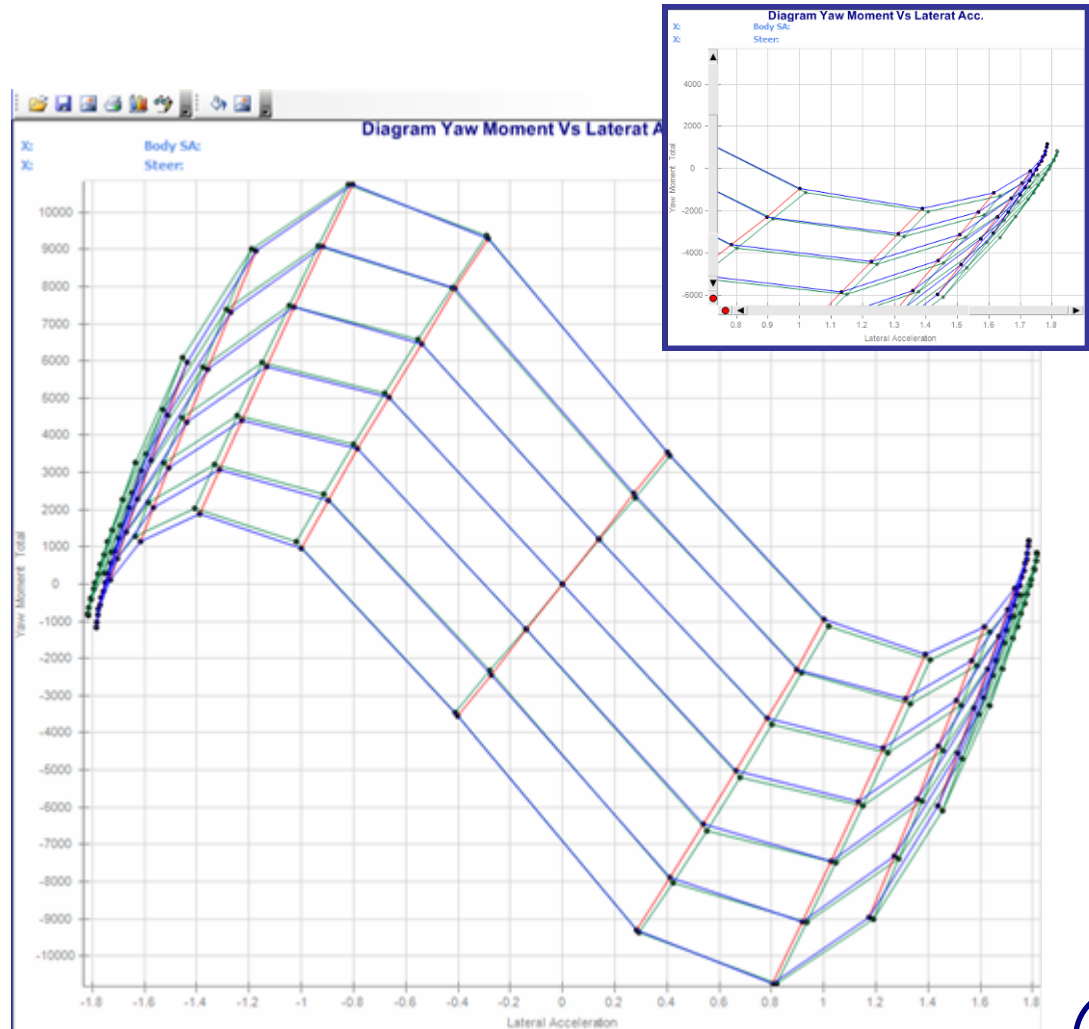
- **More Oversteer and lateral acceleration and higher speed**
- **More corner entry understeer at lower speed**
- **Less control at 100 km/h but more stability.**



Analysis – Yaw Moment Diagram (2)

Baseline Configuration, 100 Km/h and 150 km/h

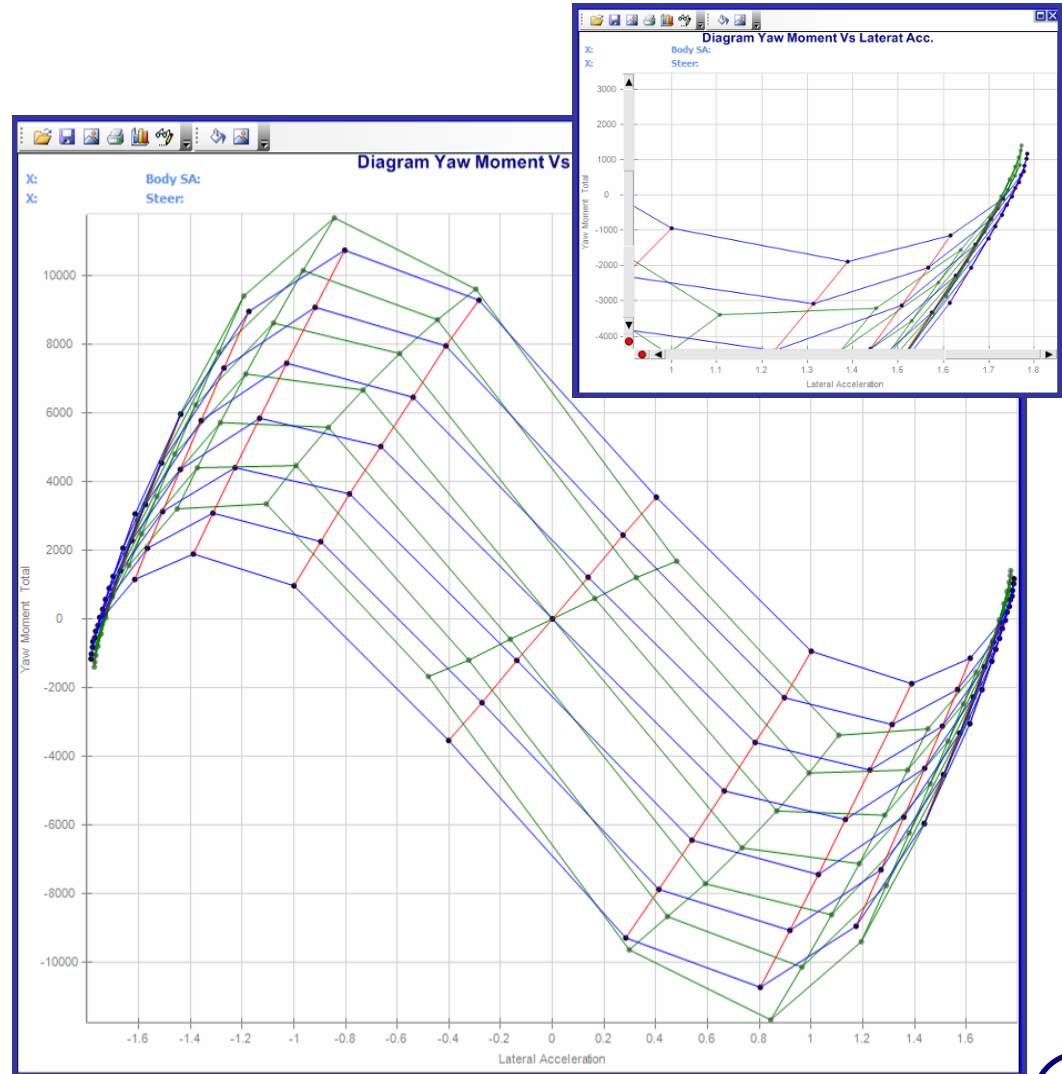
- Understeer tendency at the limit for stiffer front suspension
- Same corner entry behavior
- Less control with stiffer springs in the front



Analysis – Yaw Moment Diagram (3)

Baseline Configuration, Stiff Spring in the front

- Understeer tendency at the limit for stiffer front suspension
- Same corner entry behavior
- Less control with stiffer springs in the front



Questions? - Contacts



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**"There is no such thing as understeer or oversteer:
there is only under-yaw or over-yaw moment"**

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