OPTIMUM

Race Car Engineering Seminar & Consulting

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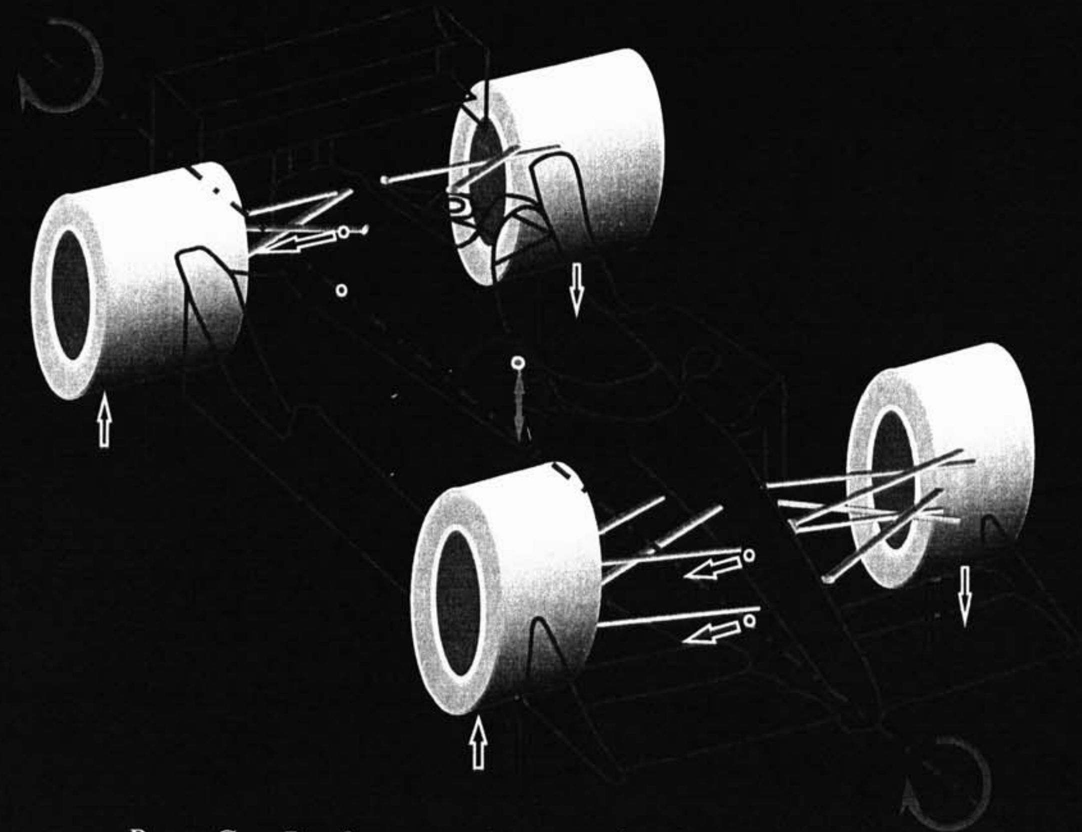

Race Car Engineering

& Data acquisition Seminar

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Race Car Performance is not only about maximum lateral acceleration.
It is also about longitudinal and vertical acceleration.
It is about maintaining at every position of the track the maximum possible tire grip and the maximum acceleration in the appropriative direction.
It is about the Optimum acceleration; the

Race Car performance is not only maximum about lateral acceleration.

It is also about longitudinal and vertical acceleration.

It is about maintaining the maximum possible grip and maximum acceleration at every position on the track in the appropriate direction.

It is about the optimum acceleration; the

If you want to be competitive you need to understand that to reach a successful level of performance, 2 essentials things are needed:

- Set up Accuracy & Precision
- Vehicle Dynamics Understanding
  - Understanding weight transfer, downforce, roll center, camber change, antidive…
  - Influence of each setup parameters on the car performance (*spring, shocks, camber, tire pressure, ride height, wings etc…*)
  - Interaction between the setup parameters *(if I put more wing should I change the static ride height, if I put more camber should I change the toe... and by how much?)*

Winston Cup:
Martinsville 500
2003

36 drivers in 0.43s

0.94%

Martinsville 500: Qualifying 2003					
Position	Driver	Team	Time	Behind	Percentage
1	Jeff Gordon	Hendrick Motorsports	20.22	0	0.00%
2	Ward Burton	Bill Davis Racing	20.32	-0.102	-0.50%
3	Dale Earnhardt Jr	Dale Earnhardt Inc	20.36	-0.138	-0.68%
4	Kenny Wallace	Bill Davis Racing	20.37	-0.147	-0.73%
5	Kevin Harvick	Richard Childress Racing	20.39	-0.174	-0.86%
6	Jimmy Spencer	Ultra Motorsports	20.41	-0.185	-0.91%
7	Rusty Wallace	Penske Racing	20.41	-0.186	-0.92%
8	Ryan Newman	Penske Racing	20.41	-0.188	-0.93%
9	Sterling Marlin	Chip Ganassi	20.43	-0.209	-1.03%
10	Jeff Green	Petty Enterprises	20.43	-0.21	-1.04%
11	Mike Skinner	MB2 Motorsports	20.46	-0.238	-1.18%
12	Ricky Rudd	Wood Brothers Racing	20.46	-0.239	-1.18%
13	Kurt Busch	Roush Racing	20.47	-0.245	-1.21%
14	Matt Kenseth	Roush Racing	20.49	-0.269	-1.33%
15	Michael Waltrip	Dale Earnhardt Inc	20.5	-0.275	-1.36%
16	Tony Stewart	Joe Gibbs Racing	20.5	-0.278	-1.37%
17	Jamie McMurray	Chip Ganassi	20.5	-0.28	-1.38%
18	Ken Schrader	B. A. M Racing	20.51	-0.288	-1.42%
19	Greg Biffle	Roush Racing	20.51	-0.294	-1.45%
20	Bobby Labonte	Joe Gibbs Racing	20.52	-0.295	-1.46%
21	Jeff Burton	Roush Racing	20.52	-0.298	-1.47%
22	Joe Nemechek	Hendrick Motorsports	20.52	-0.299	-1.48%
23	Mark Martin	Roush Racing	20.53	-0.313	-1.55%
24	Kevin Lepage	Morgan-McClure Motorsports	20.54	-0.315	-1.56%
25	Dave Blaney	Jasper Motorsports	20.54	-0.323	-1.60%
26	Jimmie Johnson	Hendrick Motorsports	20.56	-0.335	-1.66%
27	Ricky Craven	PPI Motorsports	20.56	-0.338	-1.67%
28	Bill Elliott	Evernham Motorsports	20.56	-0.34	-1.68%
29	Johnny Benson	MBV Motorsports	20.57	-0.353	-1.75%
30	Jeremy Mayfield	Evernham Motorsports	20.57	-0.354	-1.75%
31	Terry Labonte	Hendrick Motorsports	20.58	-0.358	-1.77%
32	Kyle Petty	Petty Enterprises	20.6	-0.375	-1.85%
33	Tony Raines	BACE Motorsports	20.61	-0.387	-1.91%
34	Jason Leffler	Haas CNC Racing	20.62	-0.399	-1.97%
35	Casey Mears	Chip Ganassi	20.64	-0.415	-2.05%
36	Todd Bodine	Haas/Carter Motorsports	20.65	-0.426	-2.11%

V8 Supercar: Bob Jane T Marts 1000 Mt Panorama 2003

Bob Jane T-marts 1000, Mount Panorama Bathurst							
Position	Car No.	Team	Driver	Make	Best Lap	Behind	Percentage
1	51	K-Mart Racing Team	Greg Murphy	Holden Commodore V	02:07.950		
2	1	Holden Racing Team	Mark Skaife	Holden Commodore V	02:07.990	**00:00.040**	0.03%
3	21	OzEmail Racing Team	John Bowe	Ford Falcon BA	02:07.995	**00:00.044**	0.03%
4	4	Pirtek Racing	Marcos Ambrose	Ford Falcon BA	02:08.269	**00:00.318**	0.25%
5	34	Garry Rogers Motorsport	Garth Tander	Holden Commodore VY	02:08.415	**00:00.464**	0.36%
6	11	Castrol Perkins Racing Team	Steven Richards	Holden Commodore VY	02:08.470	**00:00.519**	0.41%
7	6	Ford Performance Racing	Craig Lowndes	Ford Falcon BA	02:08.527	**00:00.576**	0.45%
8	2	Holden Racing Team	Jim Richards	Holden Commodore VY	02:08.666	**00:00.716**	0.56%
9	65	Betta Electrical	Paul Radisich	Ford Falcon BA	02:08.692	**00:00.742**	0.58%
10	17	Shell Helix Racing	Steven Johnson	Ford Falcon BA	02:08.772	**00:00.822**	0.64%
11	31	Super Cheap Auto Racing	Steve Ellery	Ford Falcon BA	02:08.775	**00:00.825**	0.64%
12	16	Team Brock	Greg Ritter	Holden Commodore VX	02:08.808	**00:00.857**	0.67%
13	29	Sirromet - Life Style Wine	Paul Morris	Holden Commodore VY	02:08.916	**00:00.966**	0.75%
14	18	Shell Helix Racing	Max Wilson	Ford Falcon BA	02:08.942	**00:00.991**	0.77%
15	50	Team Brock	Jason Bright	Holden Commodore VX	02:09.034	**00:01.083**	0.85%
16	8	Castrol Perkins Racing Team	P.Dumbrell/T.Mezera	Holden Commodore VX	02:09.105	**00:01.155**	0.90%
17	66	Betta Electrical	Dean Canto	Ford Falcon BA	02:09.163	**00:01.213**	0.95%
18	9	Caltex Havoline Race Team	Mark Winterbottom	Ford Falcon BA	02:09.190	**00:01.240**	0.97%
19	888	OzEmail Racing Team	John Cleland	Ford Falcon BA	02:09.430	**00:01.479**	1.16%
20	44	Team Dynamik	Simon Wills	Holden Commodore VY	02:09.602	**00:01.652**	1.29%
21	10	Orrcon Racing	Jason Bargwanna	Ford Falcon AU	02:09.641	**00:01.691**	1.32%
22	19	Ford Performance Racing	David Besnard	Ford Falcon BA	02:09.672	**00:01.722**	1.35%
23	13	Smiths Trucks/JTB Trucks	Steve Owen	Holden Commodore VY	02:09.795	**00:01.844**	1.44%
24	15	K-Mart Racing Team	Cameron McLean	Holden Commodore VX	02:09.888	**00:01.938**	1.51%
25	5	Ford Performance Racing	Adam Macrow	Ford Falcon BA	02:10.147	**00:02.197**	1.72%
26	21	Team Kiwi Racing	Craig Baird	Holden Commodore VX	02:10.373	**00:02.423**	1.89%
27	45	Team Dynamik	N.Minassian/J.Magnussen	Holden Commodore VY	02:10.567	**00:02.617**	2.05%
28	3	Lansvale Smash Repairs	Cameron McConville	Holden Commodore VX	02:10.625	**00:02.675**	2.09%
29	23	INXS Team Ford	N.Bates/R.Bates	Ford Falcon AU	02:11.082	**00:03.132**	2.45%
30	75	Toll Racing	Anthony Tratt	Ford Falcon BA	02:11.102	**00:03.151**	2.46%
31	72	Smiths Trucks Pty Ltd	Allan Gurr	Holden Commodore VX	02:11.599	**00:03.649**	2.85%
32	33	Garry Rogers Motorsport	Nathan Pretty	Holden Commodore VX	02:11.845	**00:03.895**	3.04%
33	20	Orrcon Racing	Grant Johnson	Ford Falcon BA	02:12.418	**00:04.468**	3.49%
34	46	Holden Young Lions	D.Brede/T.Ricciardello	Holden Commodore VX	02:12.604	**00:04.654**	3.64%
35	55	Fujitsu	J.Fernandez/D.Russell	Ford Falcon AU	02:14.767	**00:06.817**	5.33%
36	59	Pedders Suspension Transtar	J.Miller/R.Searle	Ford Falcon AU	02:14.918	**00:06.968**	5.45%
37	89	Gulf Western Racing	G.Elliott/M.Rose	Ford Falcon AU	02:15.230	**00:07.280**	5.69%
38	69	Spies Hecker Racing	R.Jones/P.Doulman	Holden Commodore VX	02:15.709	**00:07.759**	6.06%
39	99	Thexton Motor Racing	David Thexton	Ford Falcon AU	02:16.725	**00:08.774**	6.86%

} 0.05s (positions 1–3)

1% (positions 1–18)

F1 Japanese GP: Qualifying Session

Japanese GP 2003: Qualifying Session 1					
Position	Driver	Team	Time	Behind	Percentage
1	Jarno Trulli	Renault	1m30.281s	0.000	0.00%
2	Ralf Schumacher	Williams	1m30.343s	-0.062	-0.07%
3	Michael Schumacher	Ferrari	1m30.464s	-0.183	-0.20%
4	David Coulthard	McLaren	1m30.482s	-0.201	-0.22%
5	Kimi Raikkonen	McLaren	1m30.558s	-0.277	-0.31%
6	Fernando Alonso	Renault	1m30.624s	-0.343	-0.38%
7	Rubens Barrichello	Ferrari	1m30.758s	-0.477	-0.53%
8	Juan Pablo Montoya	Williams	1m31.201s	-0.920	-1.02%
9	Mark Webber	Jaguar	1m31.305s	-1.024	-1.13%
10	Nick Heidfeld	Sauber	1m31.783s	-1.502	-1.66%
11	Takuma Sato	BAR	1m31.832s	-1.551	-1.72%
12	Heinz-Harald Frentzen	Sauber	1m31.892s	-1.611	-1.78%
13	Olivier Panis	Toyota	1m31.908s	-1.627	-1.80%
14	Cristiano da Matta	Toyota	1m32.256s	-1.975	-2.19%
15	Justin Wilson	Jaguar	1m32.291s	-2.010	-2.23%
16	Jenson Button	BAR	1m32.374s	-2.093	-2.32%
17	Ralph Firman	Jordan	1m33.057s	-2.776	-3.07%
18	Giancarlo Fisichella	Jordan	1m33.313s	-3.032	-3.36%
19	Jos Verstappen	Minardi	1m34.836s	-4.555	-5.05%
20	Nicolas Kiesa	Minardi	1m36.181s	-5.900	-6.54%

0.53%

0.8%

4.4%

World Rally Championship: Rally Catalunya 2003

World Rally Championship: Rally Catalunya 2003					
Position	Driver	Team	Time	Time behind (s)	Percentage
1	Gilles Panizzi	Peugeot Sport (A8)	3h55m09.400s		
2	Sebastian Loeb	Citroen (A8)	3h55m22.400s	13.0	0.09%
3	Markko Martin	M-Sport Ford (A8)	3h55m23.000s	13.6	0.10%
4	Francois Duval	M-Sport Ford (A8)	3h56m04.800s	55.4	0.39%
5	Petter Solberg	Prodrive Subaru (A8)	3h56m20.200s	70.8	0.50%
6	Marcus Gronholm	Peugeot Sport (A8)	3h56m38.500s	89.1	0.63%
7	Carlos Sainz	Citroen (A8)	3h56m42.200s	92.8	0.66%
8	Tommi Makinen	Prodrive Subaru (A8)	3h57m04.500s	115.1	0.82%
9	Colin McRae	Citroen (A8)	3h58m24.600s	195.2	1.38%
10	Philippe Bugalski	Citroen (A8)	4h00m23.000s	313.6	2.22%

} 0.82%

Road Course

10 Corners

Lap time = 1 ‘’40 “ = 100 seconds

Car A is 5/10 of a second quicker than Car B which is 0.5 %

That means, that A is 5/100 of a second quicker per corner

That means, as an average, that A is 25/1000 of a second going in and 25/1000 of a second going out of each corner. 10Hz data acq : 0.1s

Oval

4 Corners

Lap time = 24 “

Car A is 0.12 second quicker than Car B which is 0.5 %

That means, that A is 3/100 of a second quicker per corner

That means, as an average, that A is 15/1000 of a second going in and 15/1000 of a second going out of each corner.

Will you see the difference in the car handling and driver input (steering, throttle, brake, clutch gear) if you log at 10 Hz ?

Parameters must be measured periodically to show progress

Sponsor BEST **EXACT RACING**

SET UP NO. FINAL

ISSUED ON: 9/14/99 14:42

EVENT	RACE
DRIVER	Mr DRIVER

CIRCUIT	VANCOUVER
LAP DIST	1.648

DATE	SEPTEMBER 1 ST 2000
CHASSIS	T00/20-28 ? miles

DIFF	HEWLAND SALISBURY
PLATES	2 PLATES
RAMPS	45 / 80
PRE-LOAD	none

ENG. NO / MILES	080	358	REV LIM	7390
M/C FRONT	Ft .750		Rr .750	
DISCS	AP Solid	PADS	CM	93
BRAKE BIAS	T from full front			

FUEL	10 GALLONS
RACK	6 TEETH
RAD INLET	FULLY OPEN

RATIOS	1st	15 : 31	2nd	18 : 30	3rd	21 : 29	4 th	22 : 25	5th 23 : 24
					CWP	10 : 31			

FRONT WING

	26.00 °				ANGLE	27.00 °				
out.	.750 .750	in	none	in	GURNEY	none	in.	.750 .750	out.	
Ft		Rr			SKIRTS	Ft		Rr		

LEFT FRONT

TOE	.060 ins	OUT
CASTER	5.50 °	Trail STD
CAMBER	- 3.50 °	
TIRE PRESS.	C 12.5	H 19.0
DUCTS	50 % open	

		TILT 0.00		
Low RC	No antidive	GEOMETRY	Low RC	No antidive
	1.225 ins	RIDE HT	1.225 ins	
500	lb/in	SPRINGS	500	lb/in
		ROLL BAR	.590	
fixed .250	90 °	BLADE	.250 x .150	90 °

RIGHT FRONT

TOE	.060 ins	OUT
CASTER	5.50 °	Trail STD
CAMBER	- 3.00 °	
TIRE PRESS.	C 13.5	H 19.0
DUCTS	50 % open	

X WEIGHT	

X WEIGHT	+20

FRONT SHOCKS

Type	Piston	Needle	HSB sh	HS B	LSB sh	LS B	R sh.	REB	Gas
P	D 10 D14	5 deg	Std	**4.0**	a+	**-6.0**	C	**-0.5**	150

Type	Piston	Needle	HSB sh	HS B	LSB sh	LS B	R sh.	REB	Gas
P	D 10 D14	5 deg	Std	**4.0**	A+	**-6.0**	C	**-0.5**	150

LEFT REAR

TOE	.120 ins	IN
CAMBER	- 2.20 °	
TIRE PRESS.	C 12.0	H 18.0
DUCTS	50 % open	

		RAKE 0.725		
High RC	Antisquat	GEOMETRY	High RC	Antisquat
	1.950 ins	RIDE HT	1.950 ins	
800	lb/in	SPRINGS	800	lb/in
Double Adjustable		ROLL BAR	x	
.350 x .250	45 °	BLADE / ADJ	.350 x .250	90 °

RIGHT REAR

TOE	.080 ins	IN
CAMBER	- 1.80 °	
TIRE PRESS.	C 12.0	H 18.0
DUCTS	50 % open	

REAR SHOCKS

Type	Piston	Needle	HSB sh	HS B	LSB sh	LS B	R sh.	REB	Gas
P	D 16 L 2	5 deg	Std	**5.0**	B	**-6.0**	D	**-18**	180

Type	Piston	Needle	HSB sh	HS B	LSB sh	LS B	R sh.	REB	Gas
P	D 16 L 2	5 deg	Std	**5.0**	B	**-6.0**	D	**-18**	180

REAR WING

HOLE	HOLE 11
GURNEY	.875

MISCELLANEOUS NOTES

New FWEP

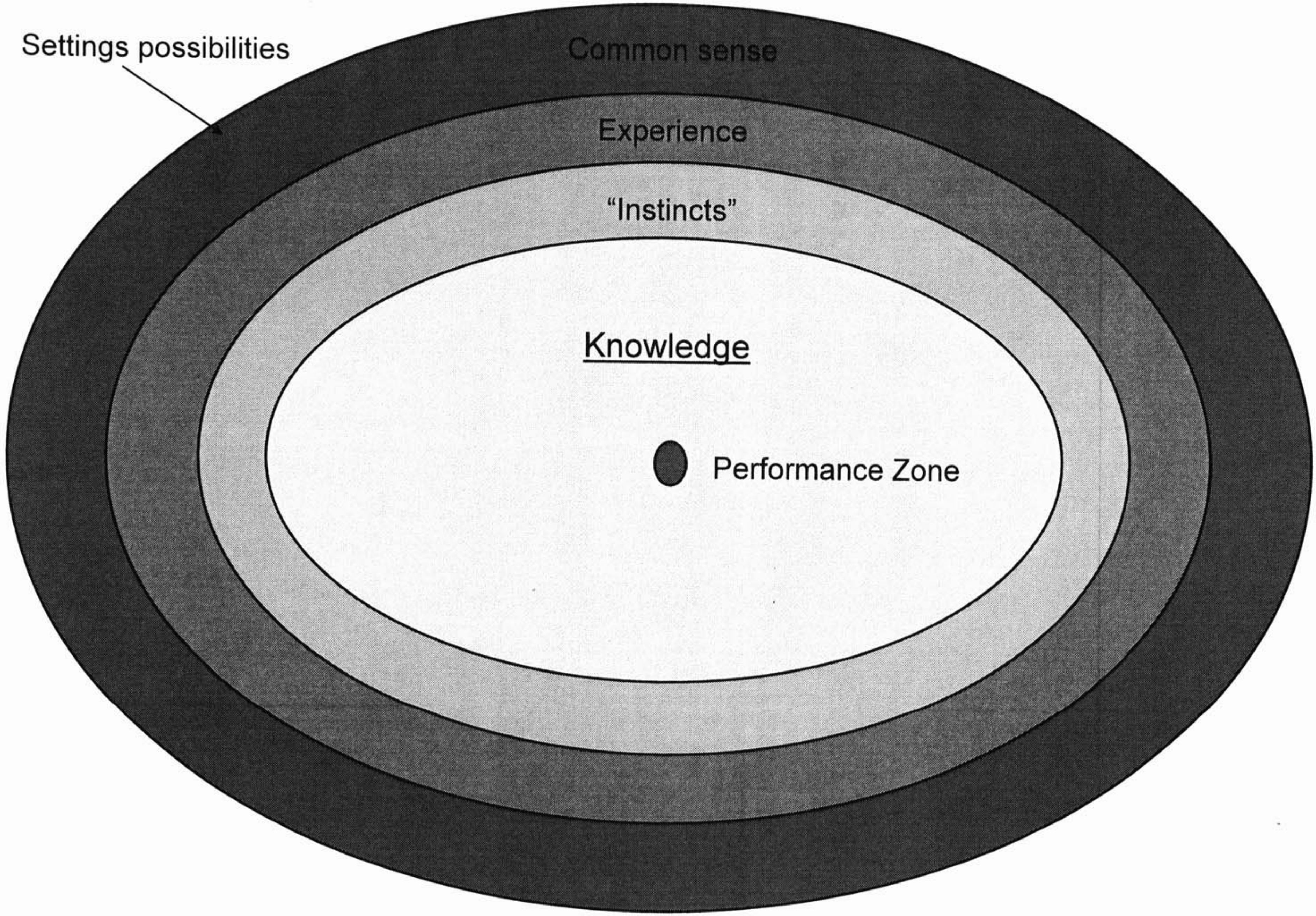
Set up possibilities

Busetti

1. Ride Height
2. Caster
3. Camber
4. Toe
5. Springs
6. Shock Low Speed Bump
7. Shock High Speed Bump
8. Shock Low Speed Rebound
9. Shock High Speed Rebound
10. Shock Piston
11. Shock Pressure
12. Shock Bump Shimming
13. Shock Needle
14. Shock Rebound Shimming
15. Roll Center
16. Antidive / Antilift /Antisquat
17. Wings Setting
18. Gurney flaps
19. Tire pressure
20. Antiroll Bar
21. Antiroll Bar Blades
22. Antiroll Bar Blades Position
23. Bump Rubber
24. Brake Master Cylinders

$3^{(2*24)} = 3^{48} =$ 79,766,443,076,872.5 Trillions possibilities….

3 settings per parameter


Settings possibilities
Common sense
Experience
"Instincts"
Knowledge
Performance Zone

If you want to be competitive you need to understand that to reach a successful level of performance, 2 essentials things are needed:

Set up Accuracy and Vehicle Dynamics Understanding

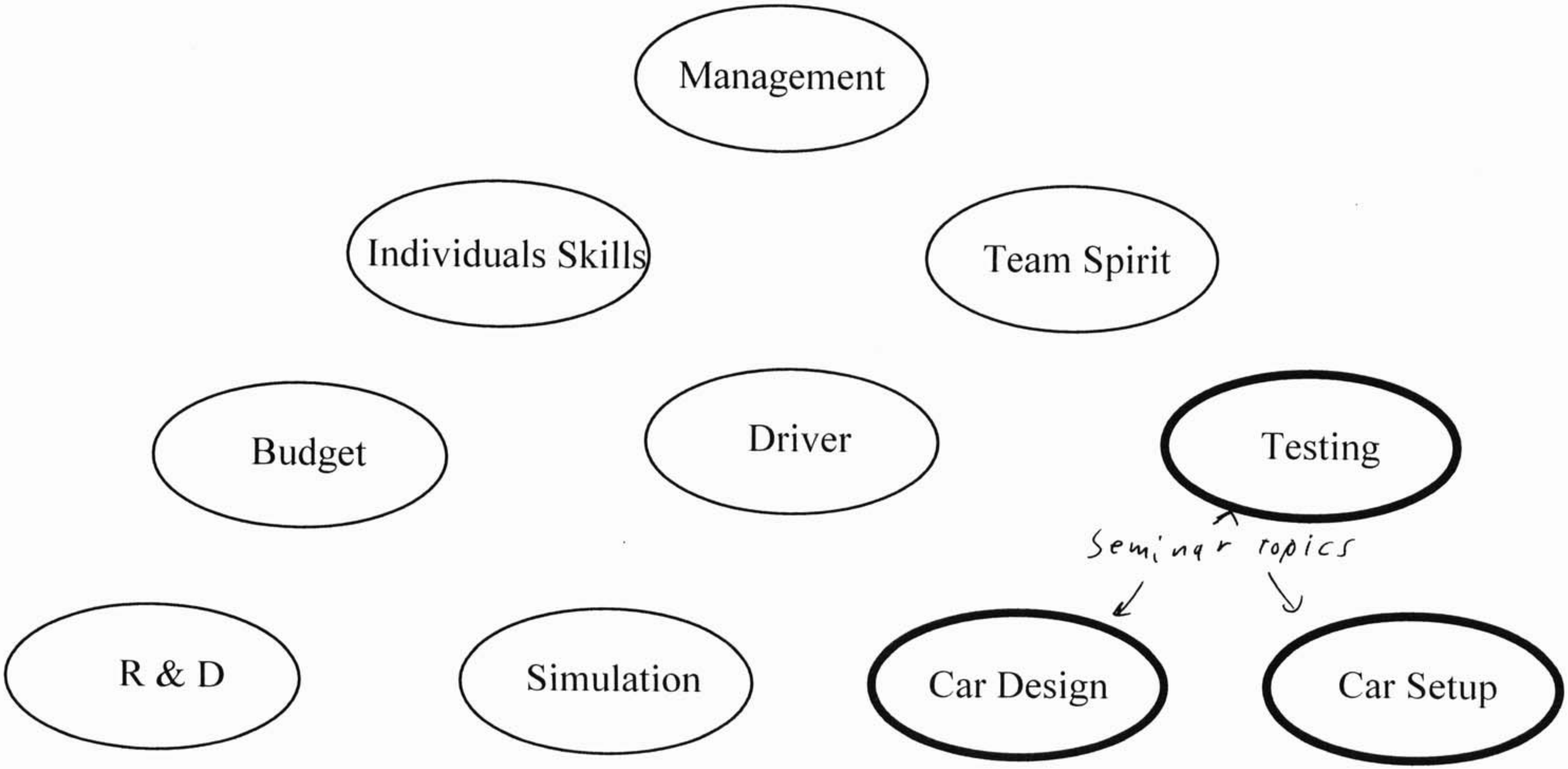
If you also want to be *quickly* competitive *for a reasonable budget* you need to *quickly and more accurately:*

- *Observe* the car and driver's performances
- *Measure and compare* the car and driver's performances

That is what data acquisition is made for!

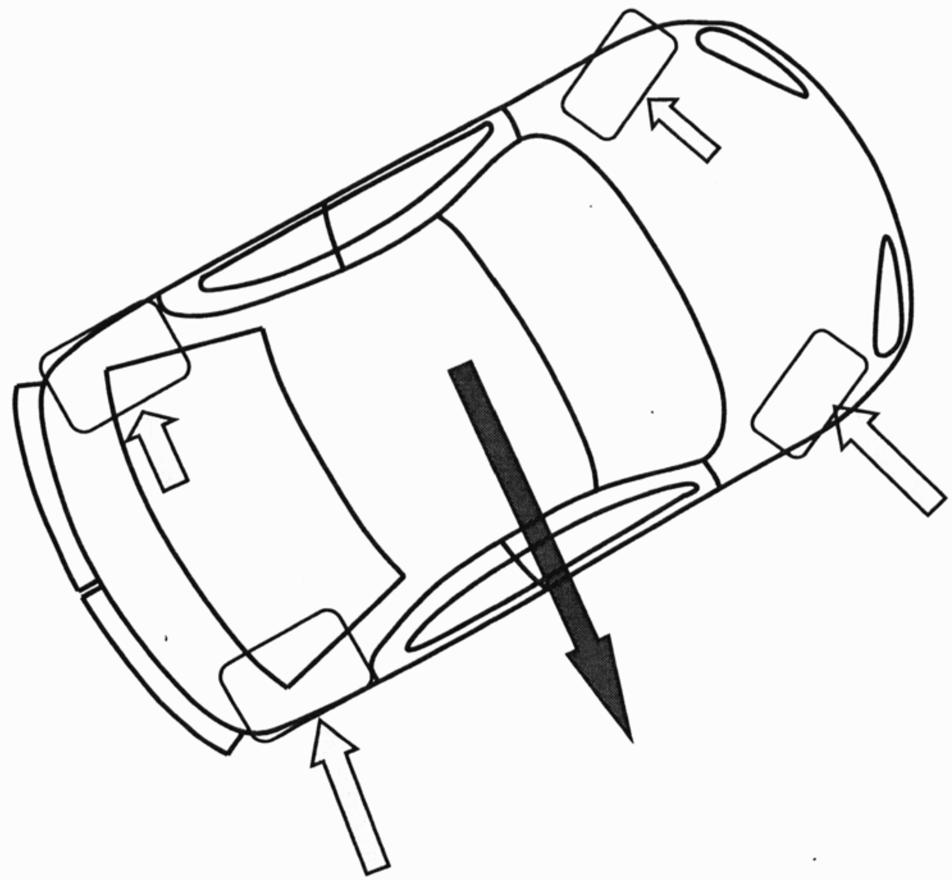
- *Understand, analyze and quantify* the reasons , in the setup or / and the driver input, of the difference between 2 performances
- From there *choose the setup changes* (educated guess, calculation, simulation)
- *Predict* the handling changes
- *Improve* the car and driver's performances

Ten Things to Make a Successful Racing Team



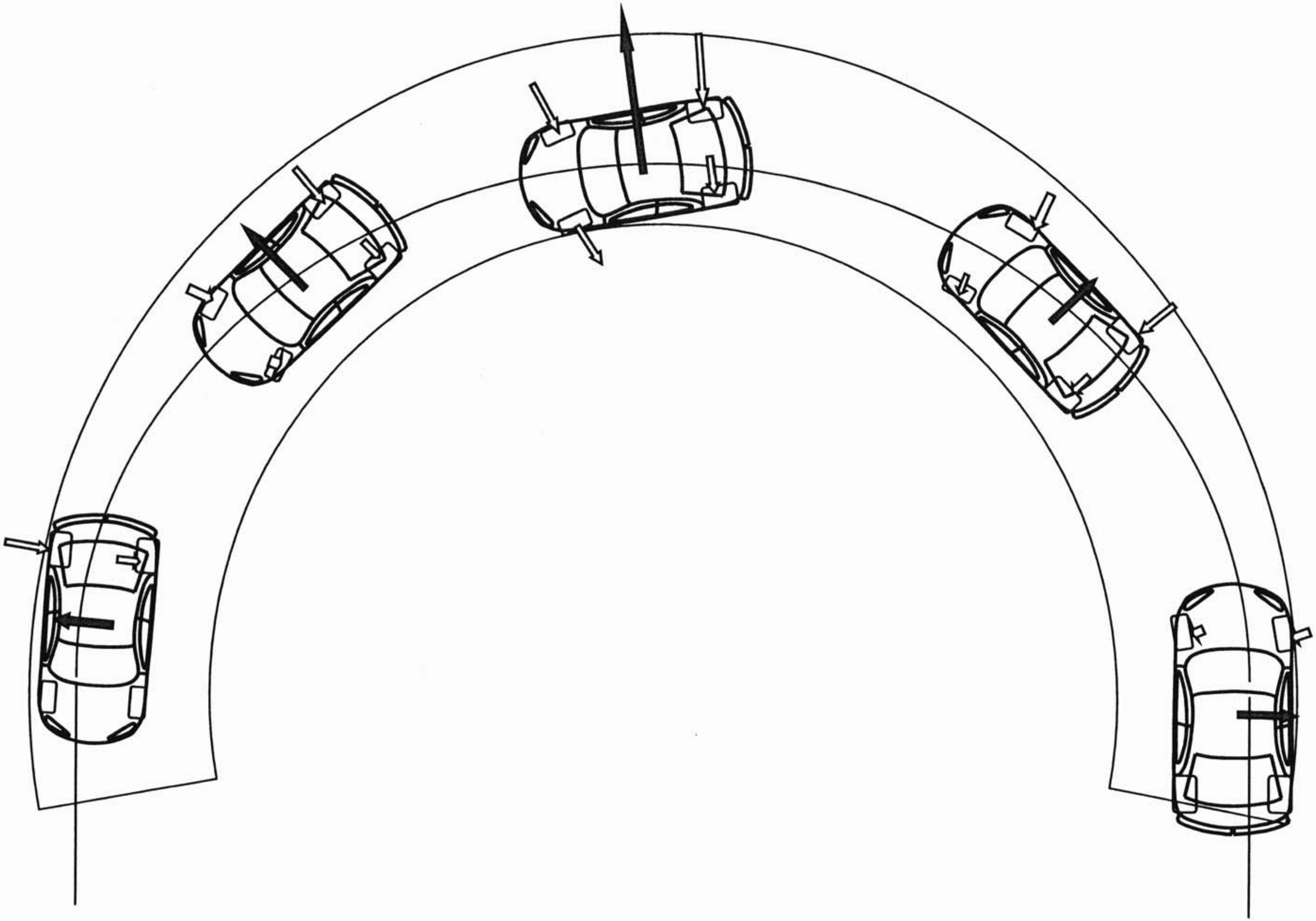
2 essential questions

1. What gives maximum acceleration ?



2 essential questions

2. What makes the car turn?



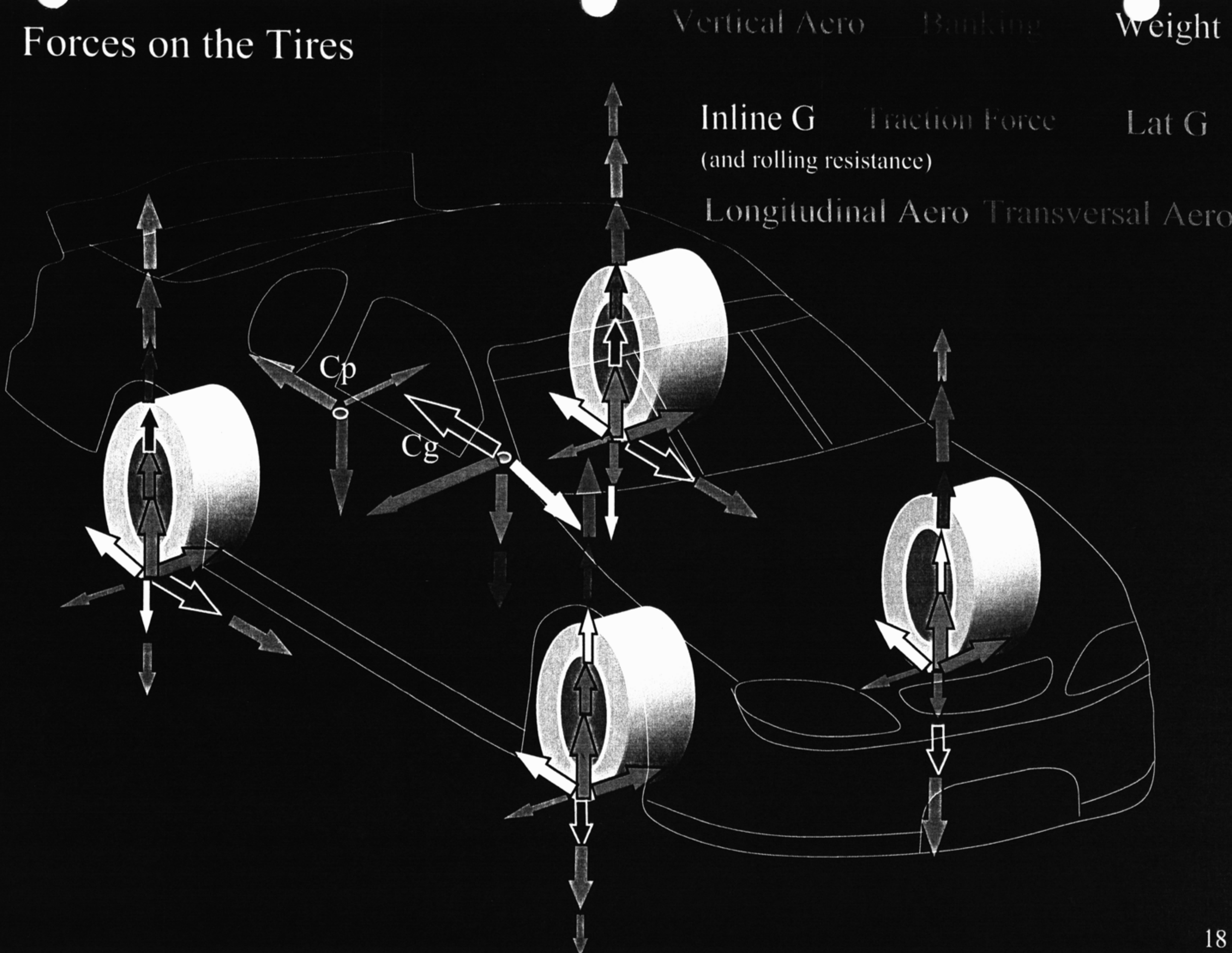
Content

- 1. Tire
- 2. Aerodynamics
- 3. Kinematics
- 4. Steady State Weight Transfers
- 5. Dampers, Ride and Transient Weight Transfers
- 6. Organizing the Data Acquisition Work
- 7. Data Analysis and Car Tuning.
- 8. Car Setup

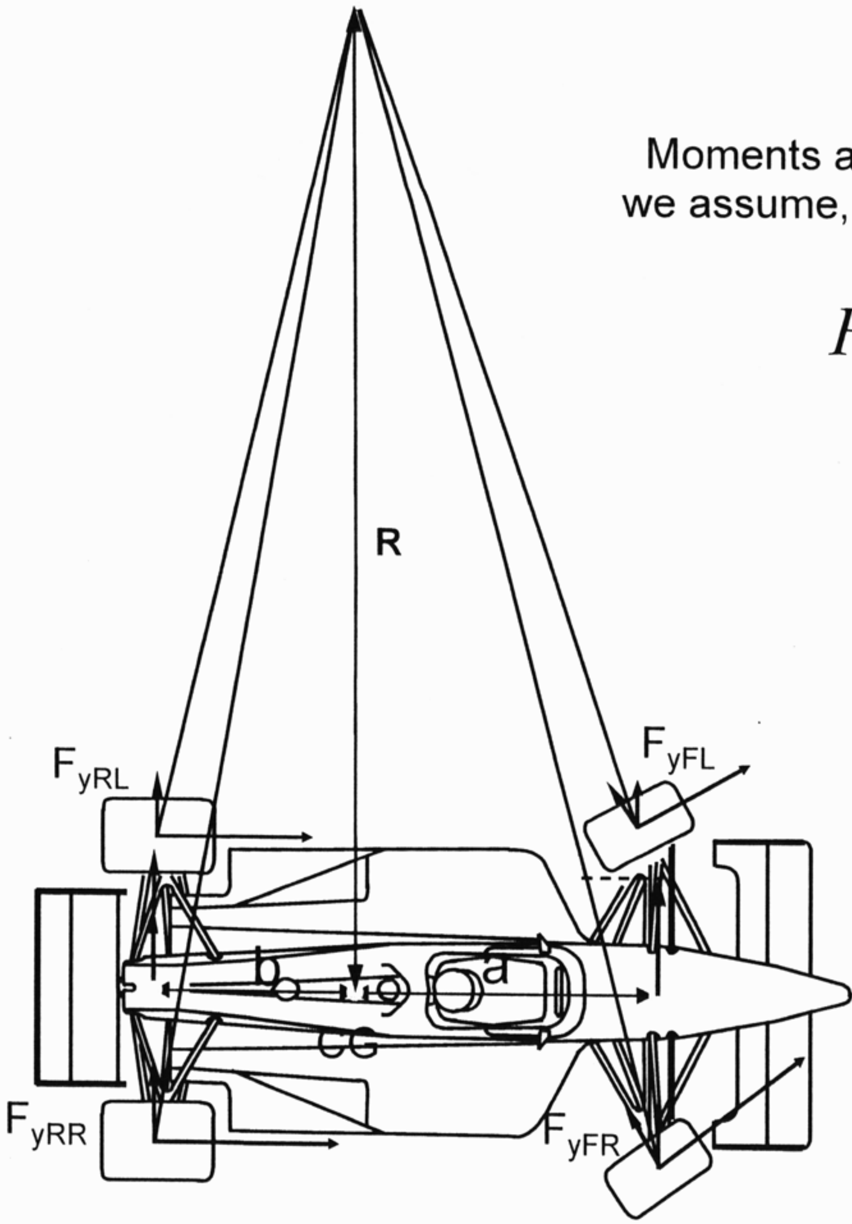
1. Tire

- Forces Acting on the Tire
- Friction Coefficients
- Vertical, Lateral. Longitudinal and Torsion Tire Deformations
- Slip Ratio and Longitudinal Tire Force
- Longitudinal and Lateral grip VS Vertical Load
- Rolling Radius
- Slip Angle
- Lateral Grip, Slip Angle and Vertical Load
- Measure of Tire Forces on Laboratory.
- Ackermann Steering Geometry Influences on Front inside Slip Angle

Forces on the Tires



First incomplete and inaccurate definition of a steady state neutral car in cornering



Moments around CG (for simplification and because of R>>WB, we assume, that wheel lateral force direction ↖ is F_y direction ↑) :

$$F_{yLF} \cdot a + F_{yRF} \cdot a = F_{yLR} \cdot b \cdot + F_{yRR} \cdot b$$

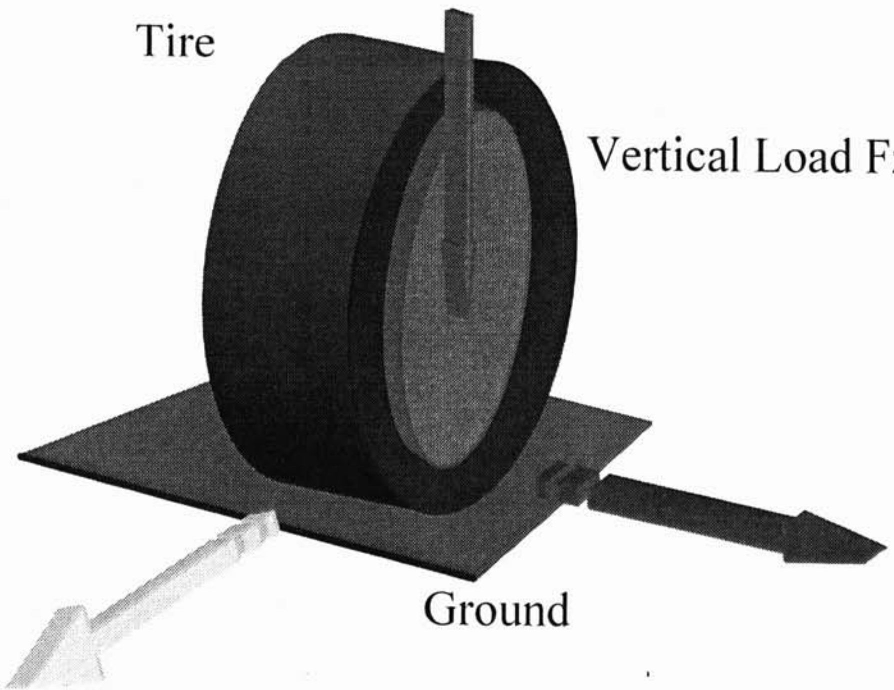
$$\frac{b}{a+b} = \frac{W_F}{W_F + W_R}$$

W_F -**Weight in front**

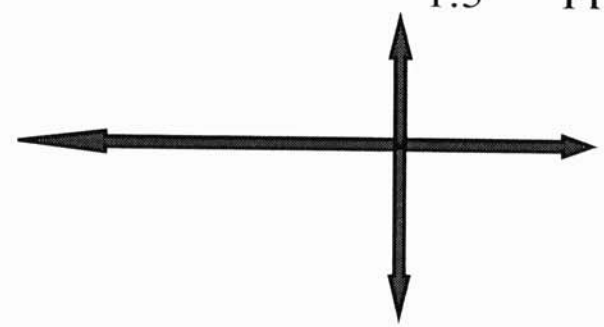
W_R - **Weight in rear**

$$\frac{F_{yRL} + F_{yRR}}{F_{yRL} + F_{yRR} + F_{yLR} + F_{yRR}} = \frac{W_F}{W_F + W_R}$$

Friction Coefficients Definition



Different Friction Coefficient along Lateral and Longitudinal Axis



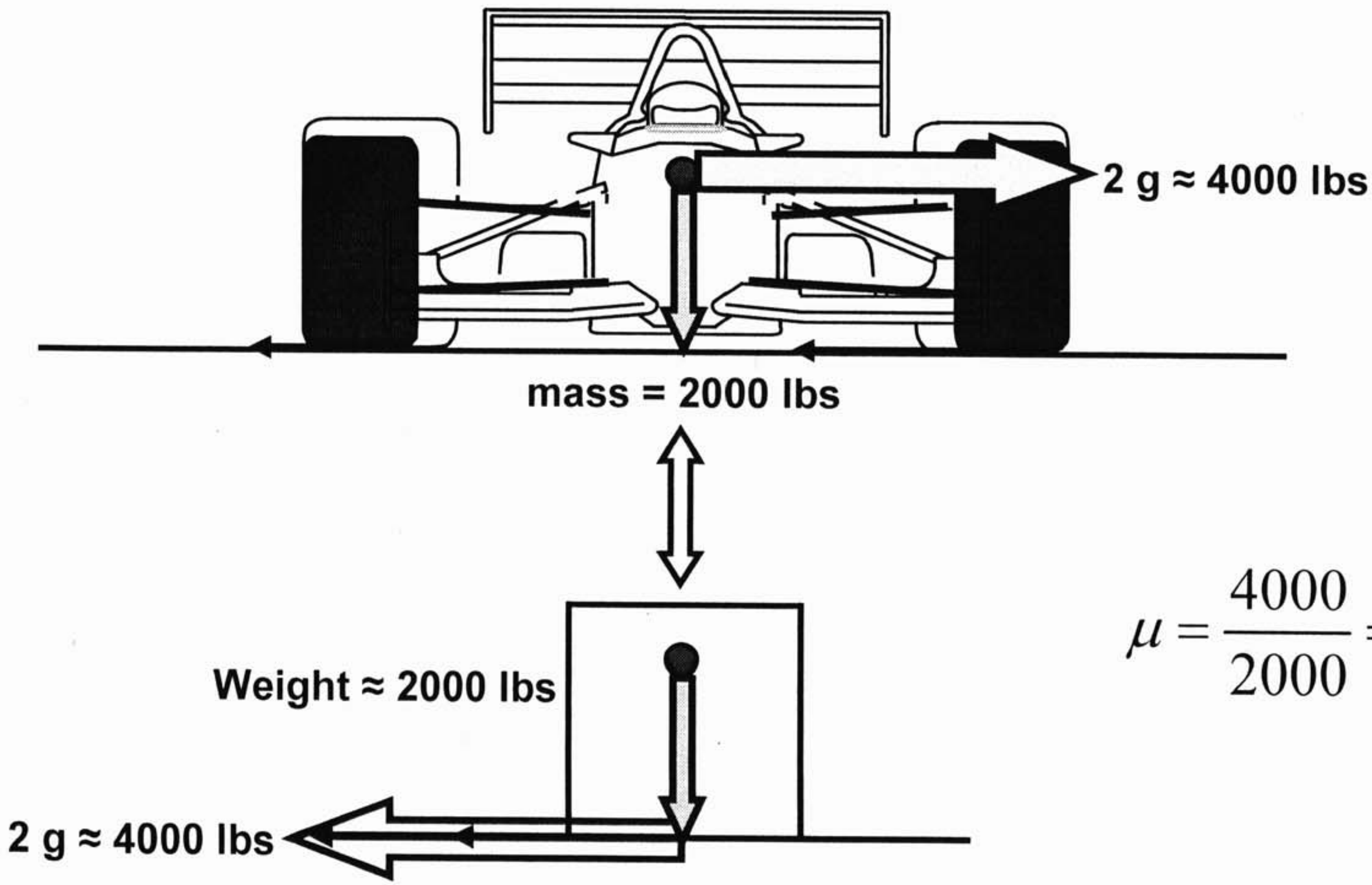
$$Fx = \mu x * Fz$$

$$Fy = \mu y * Fz$$

The tire coefficient of friction

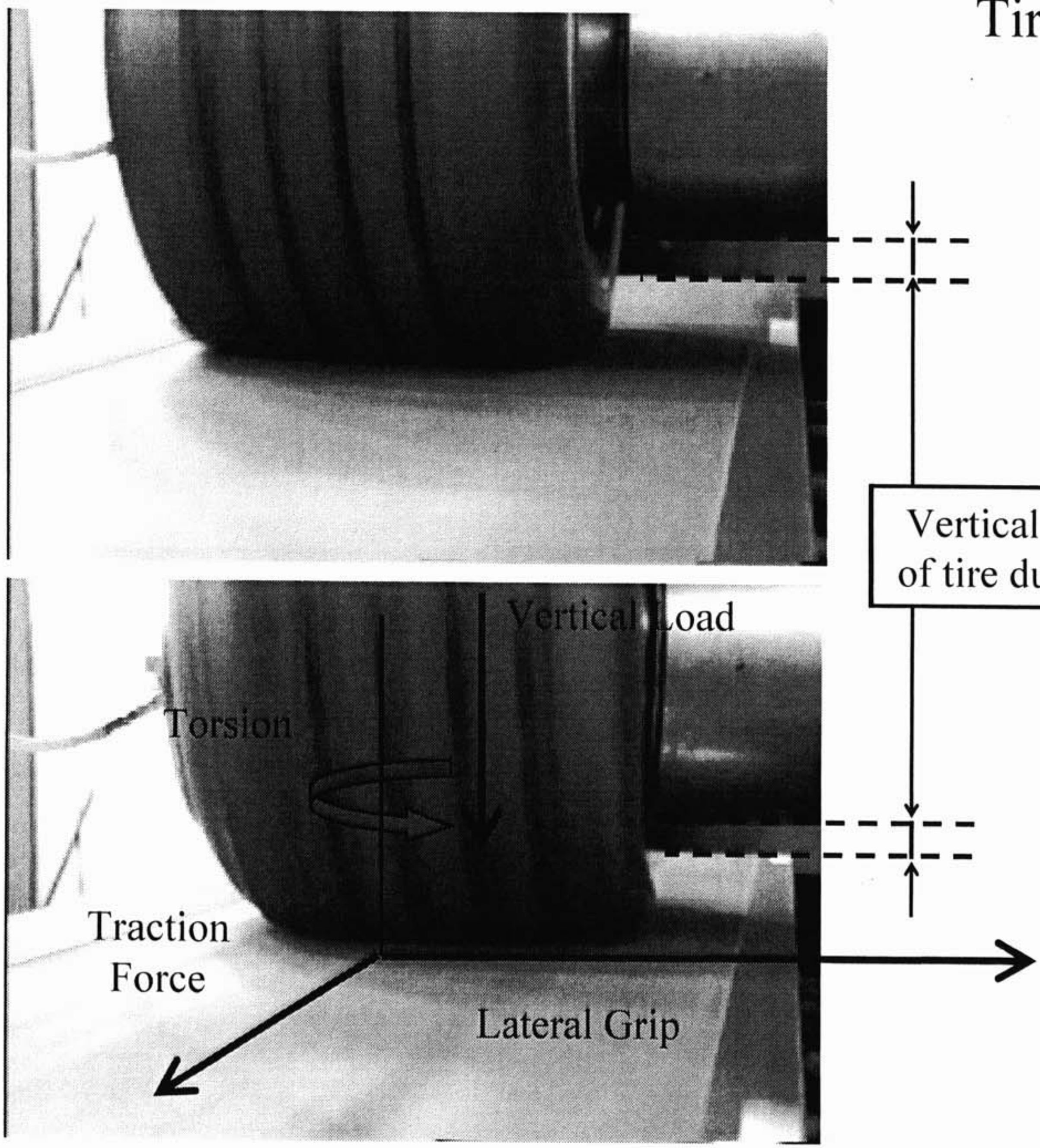
The average of the 4 tires' coefficient of friction equals the car's lateral acceleration measured in g.

Eg. Imagine a 2000 lbs car, cornering at 2 g as measured by the car's lateral accelerometer:



$$\mu = \frac{4000}{2000} = 2$$

Tire deformations / Load



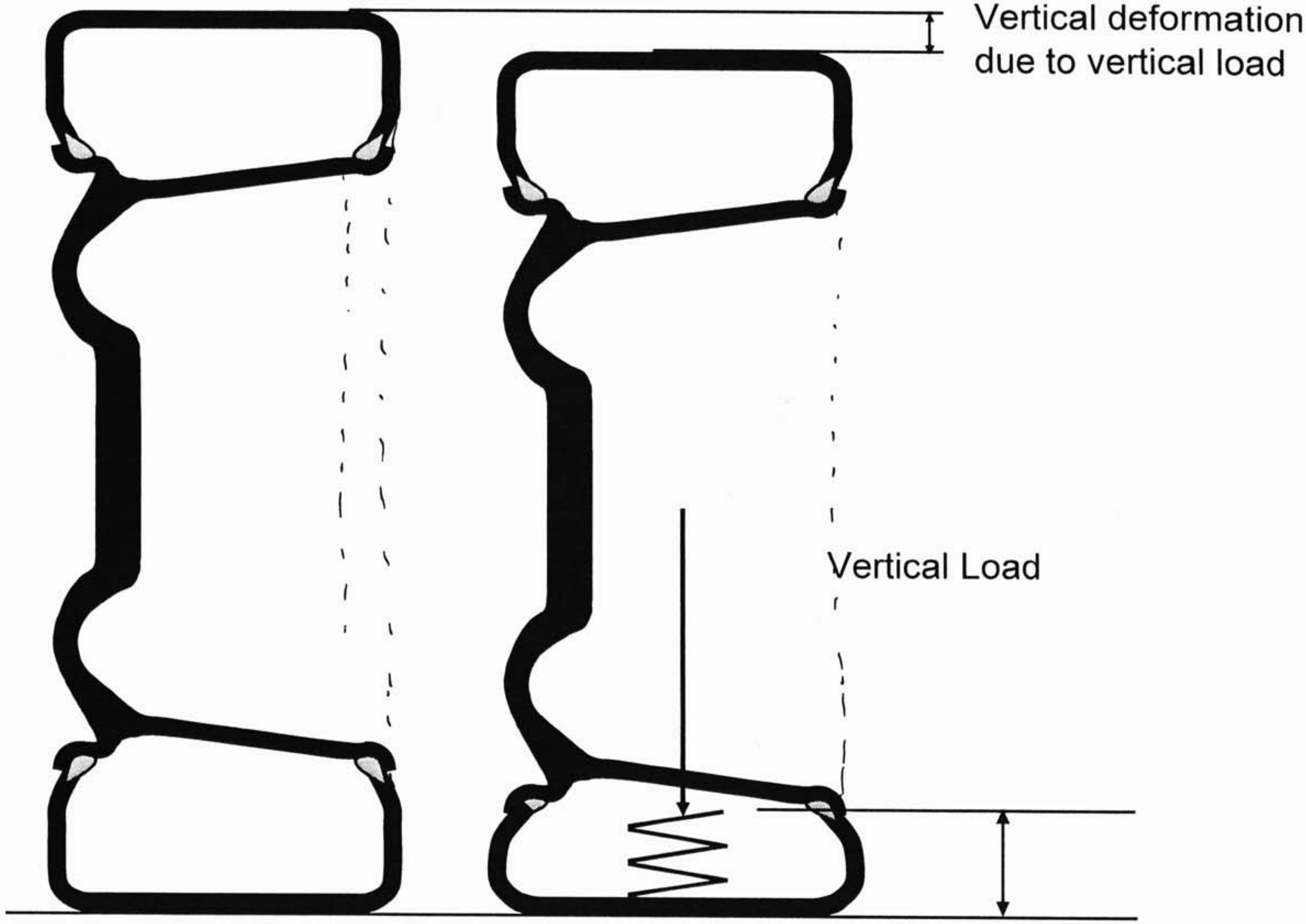
Vertical Load

Lateral Grip

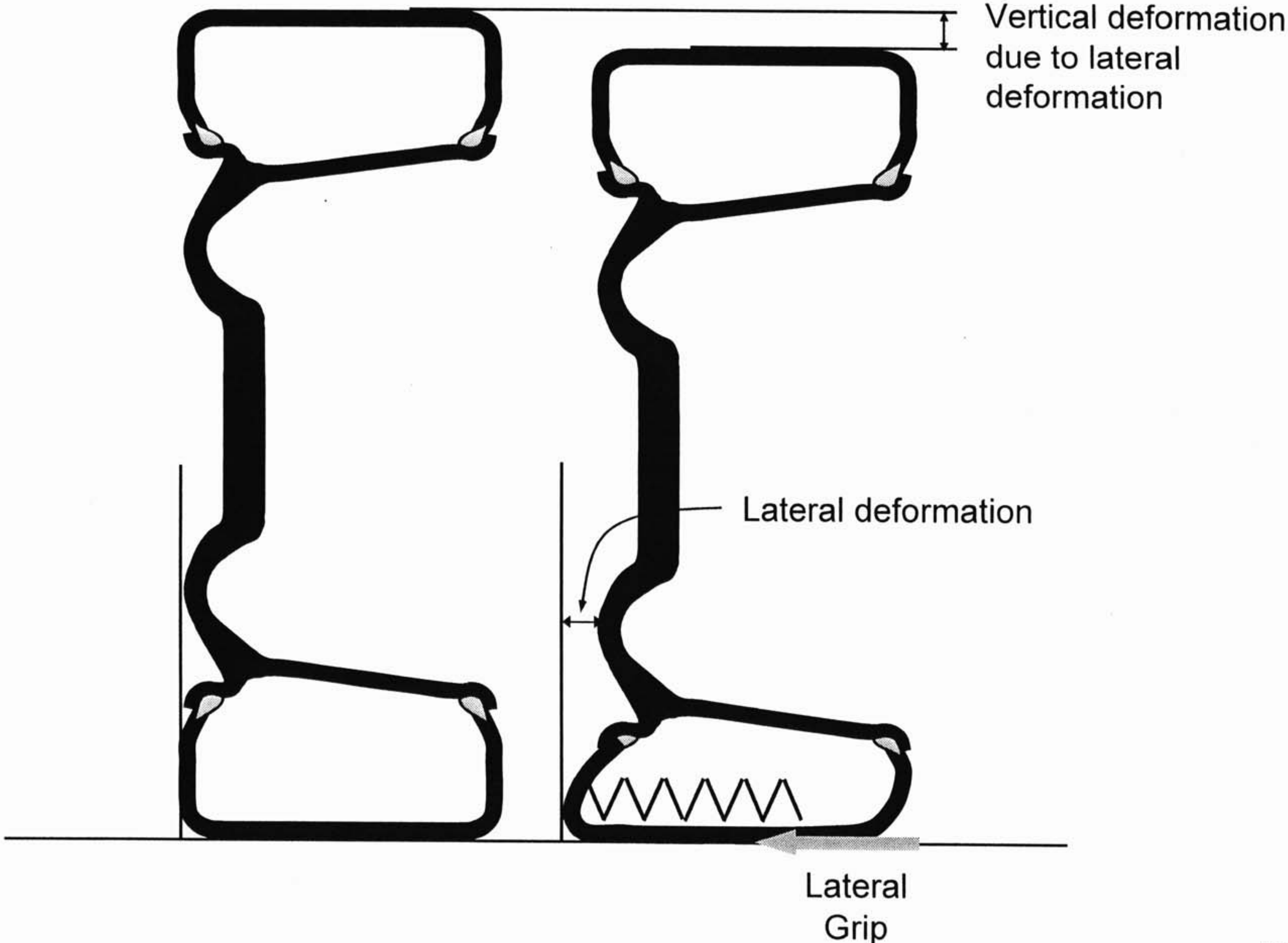
Traction Force

Torsion Torque

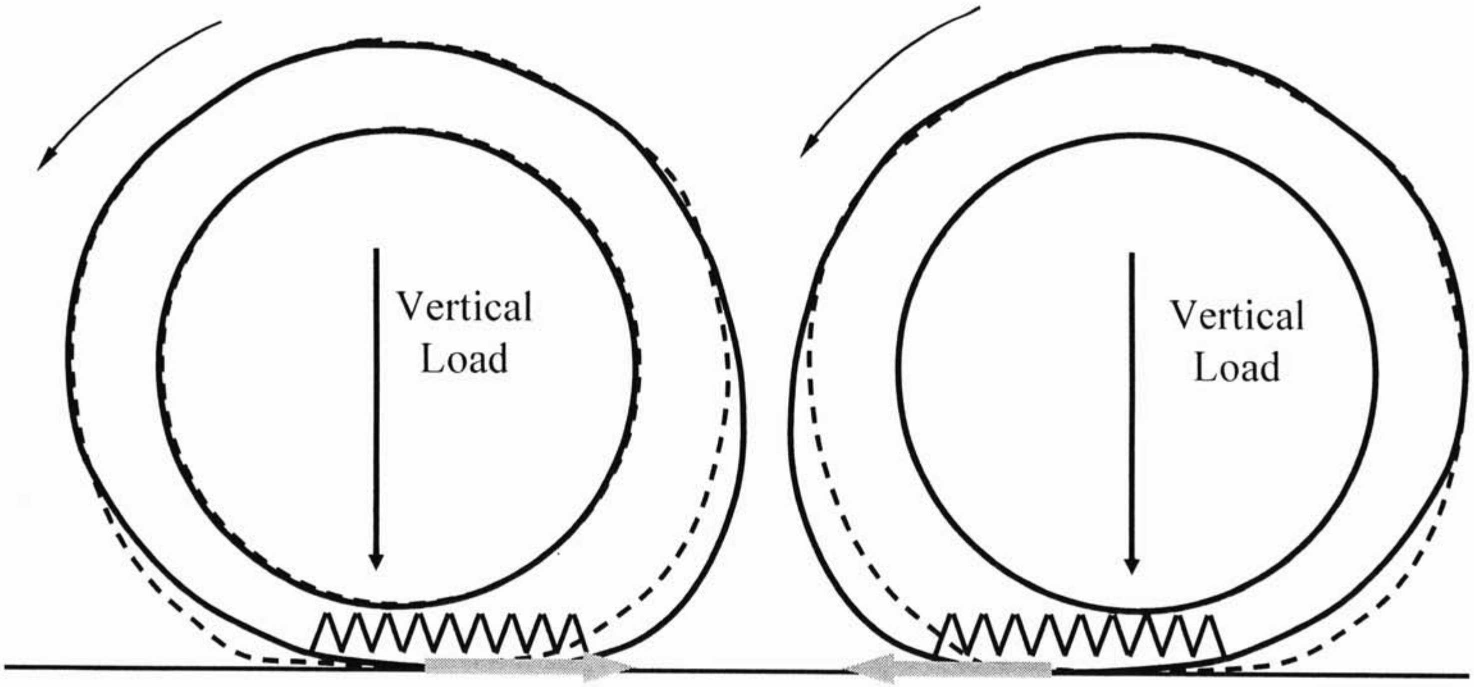
Vertical Deformation



Lateral Deformation

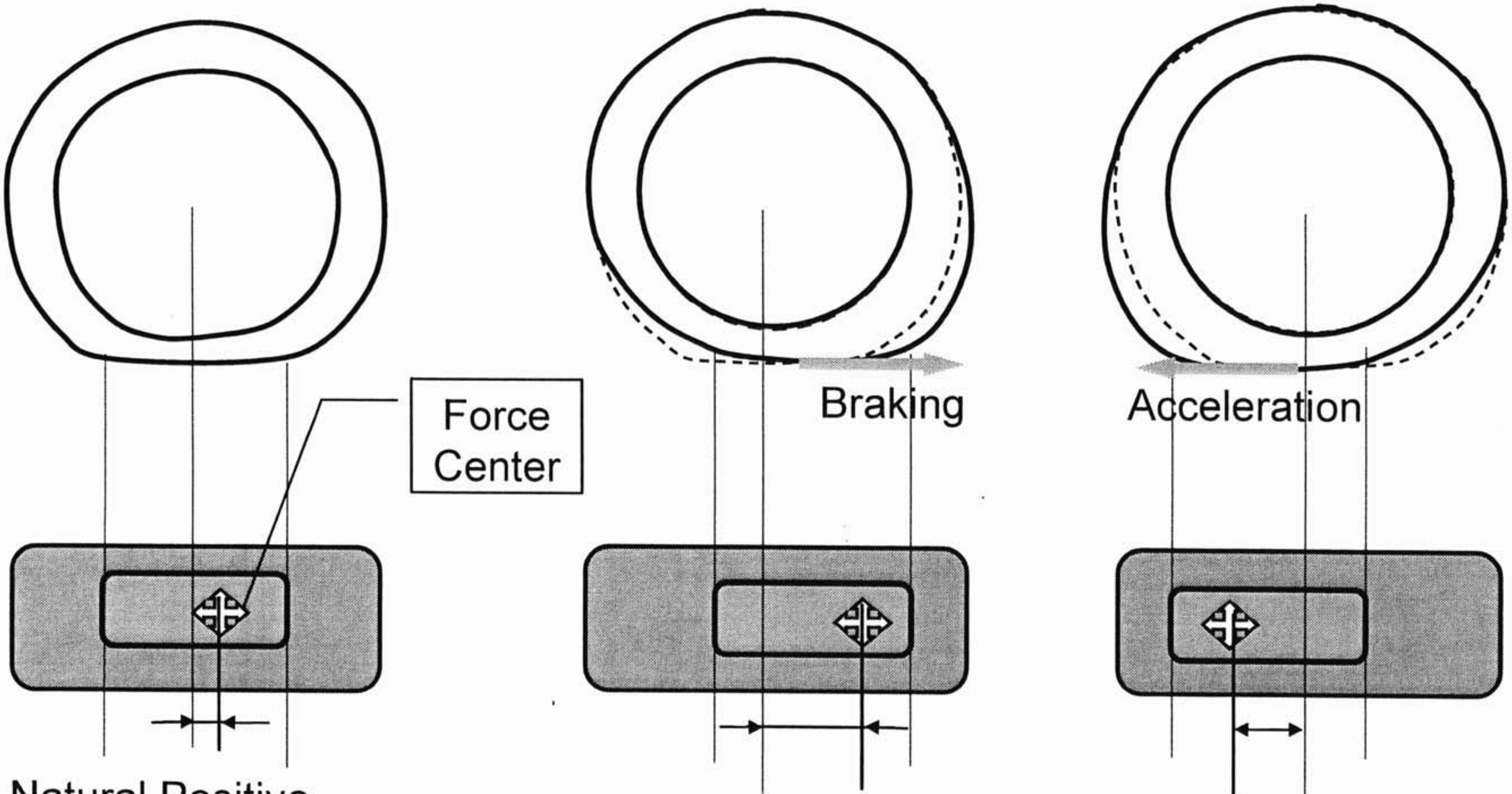


Longitudinal Deformation



effective wheelbase is changed under longitudinal braking and acceleration

Longitudinal Tire Deformations under Tractive or Braking Forces

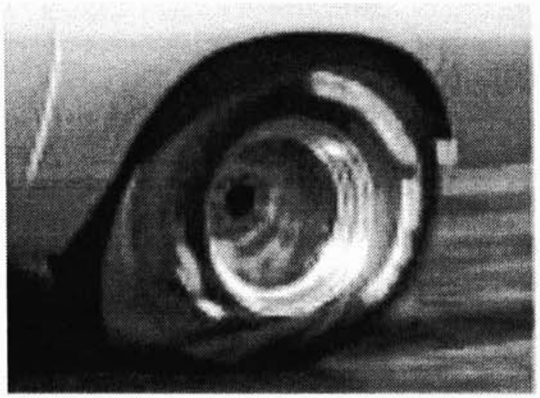


Natural Positive Longitudinal Tire Caster

Tire caster trail is :

- Increased by braking.
- Decreased by acceleration, may be negative.

Slip Ratio Definition



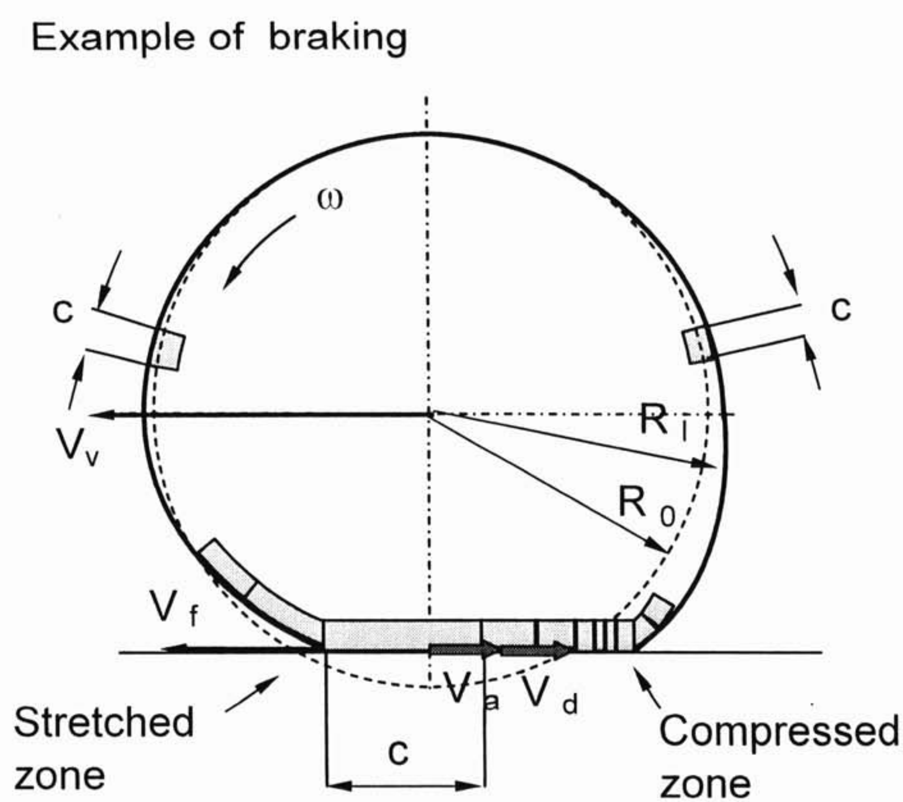
Sr is 'Slip Ratio' :

The contact patch longitudinal speed and the vehicle longitudinal speed could be different.

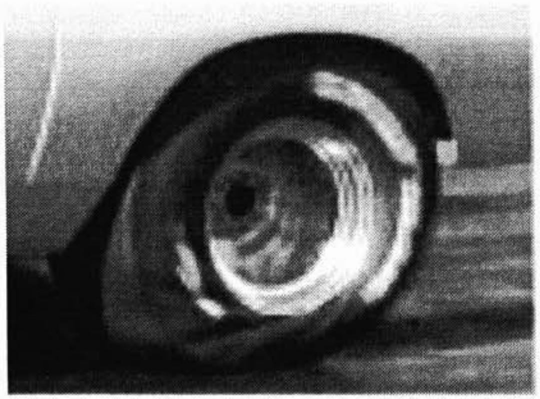
2 essential reasons: - **Wheel spin**

- **Movement of the contact patch Vs the wheel**

Longitudinal Tire Deformations under Traction or Braking Forces (2)

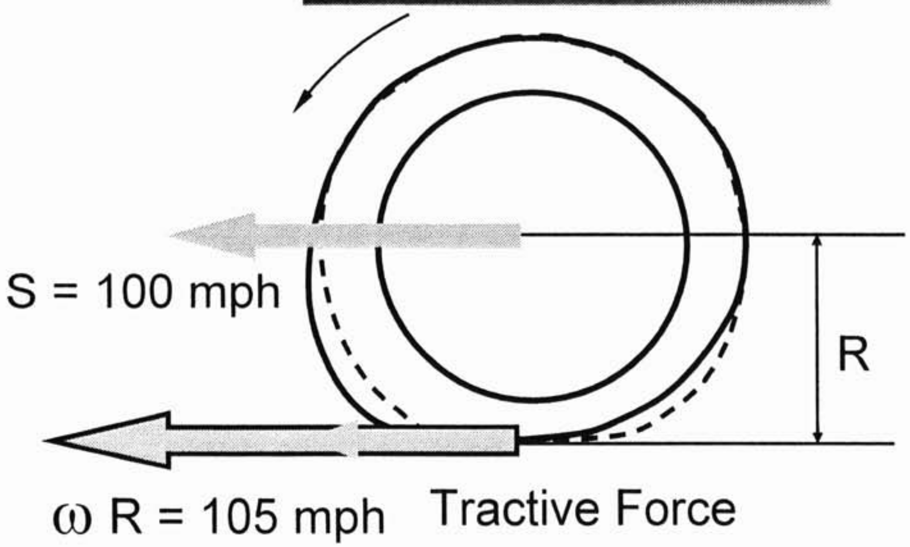


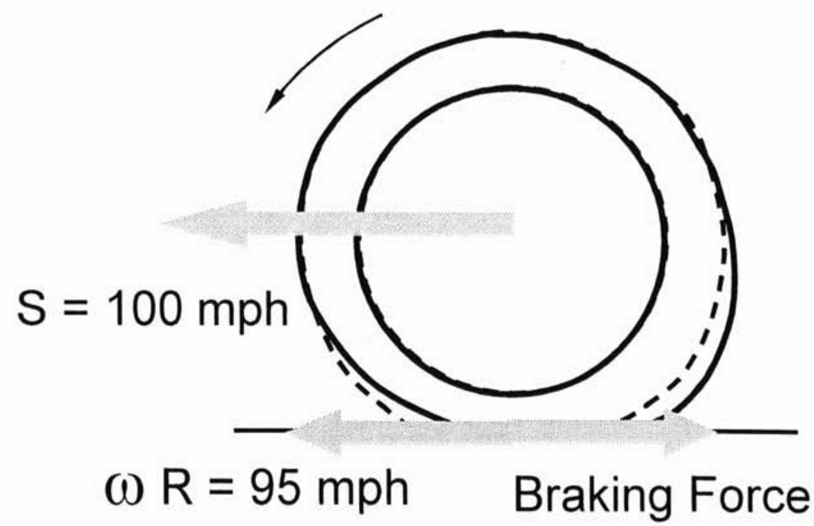
Slip Ratio Definition



Sr is 'Slip Ratio' :

$$Sr = \frac{S - \omega \cdot r}{S}$$

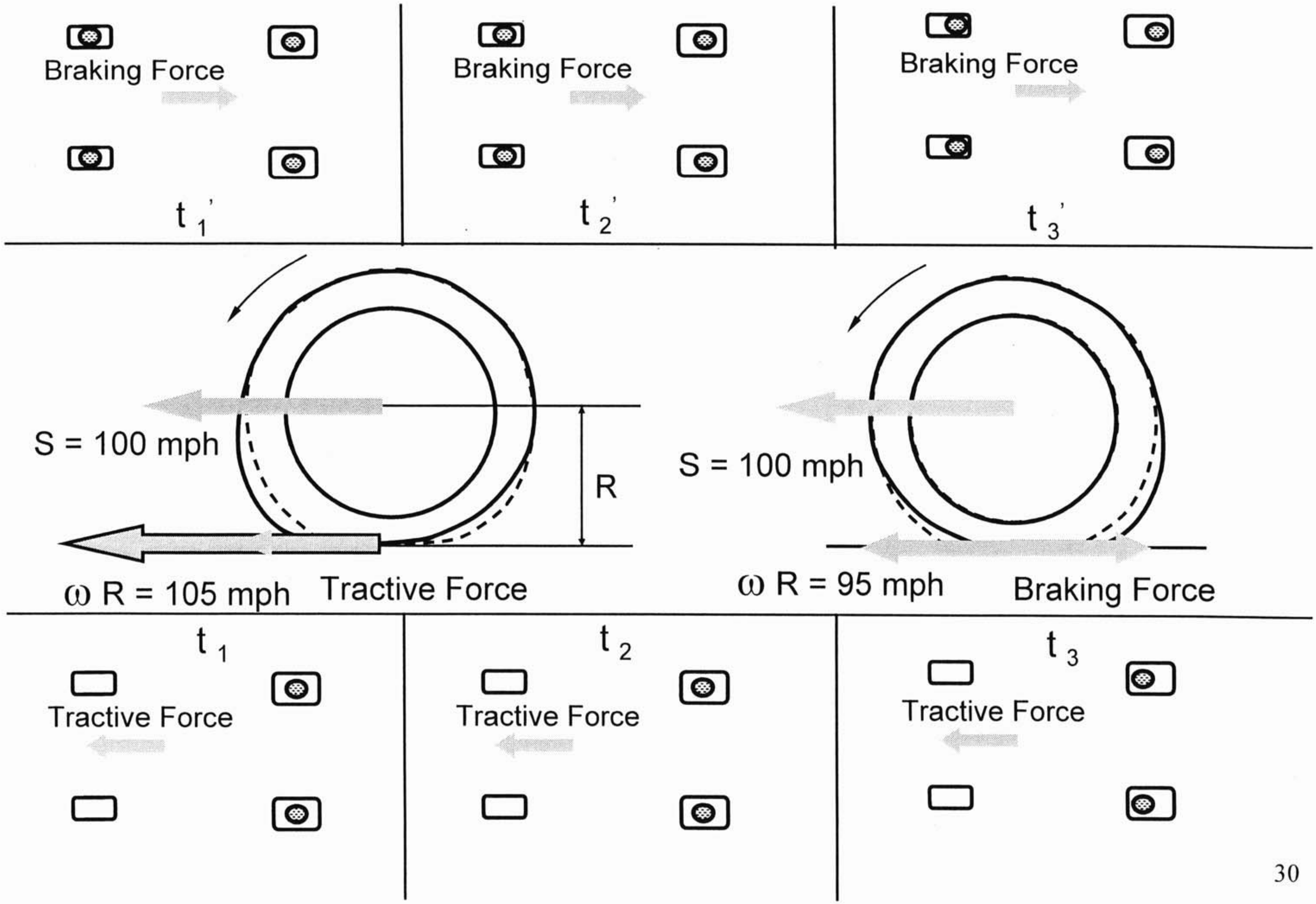




Sr = (100-105)/100 = - 5 %

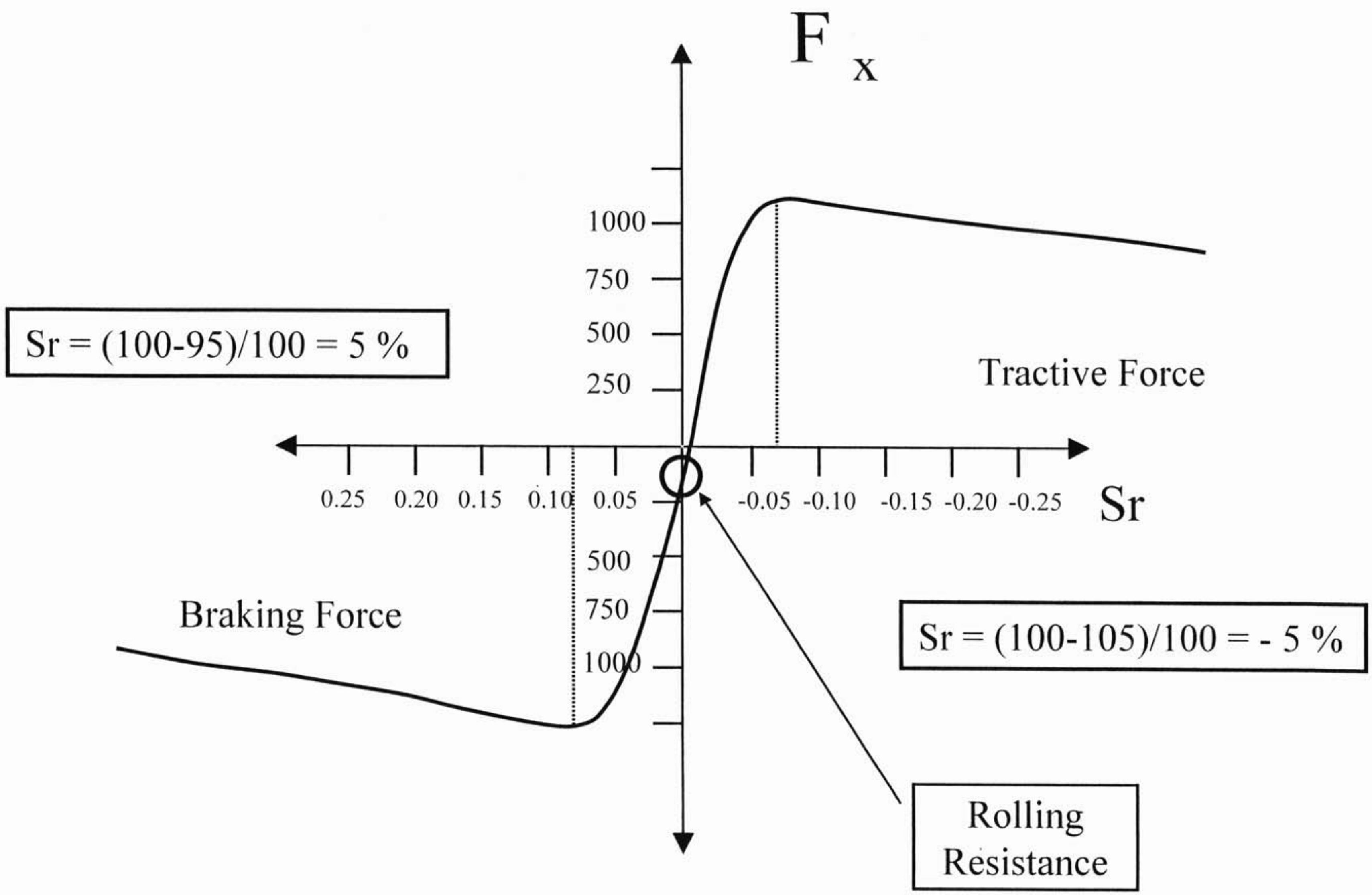
Sr = (100-95)/100 = 5 %

Slip Ratio Definition

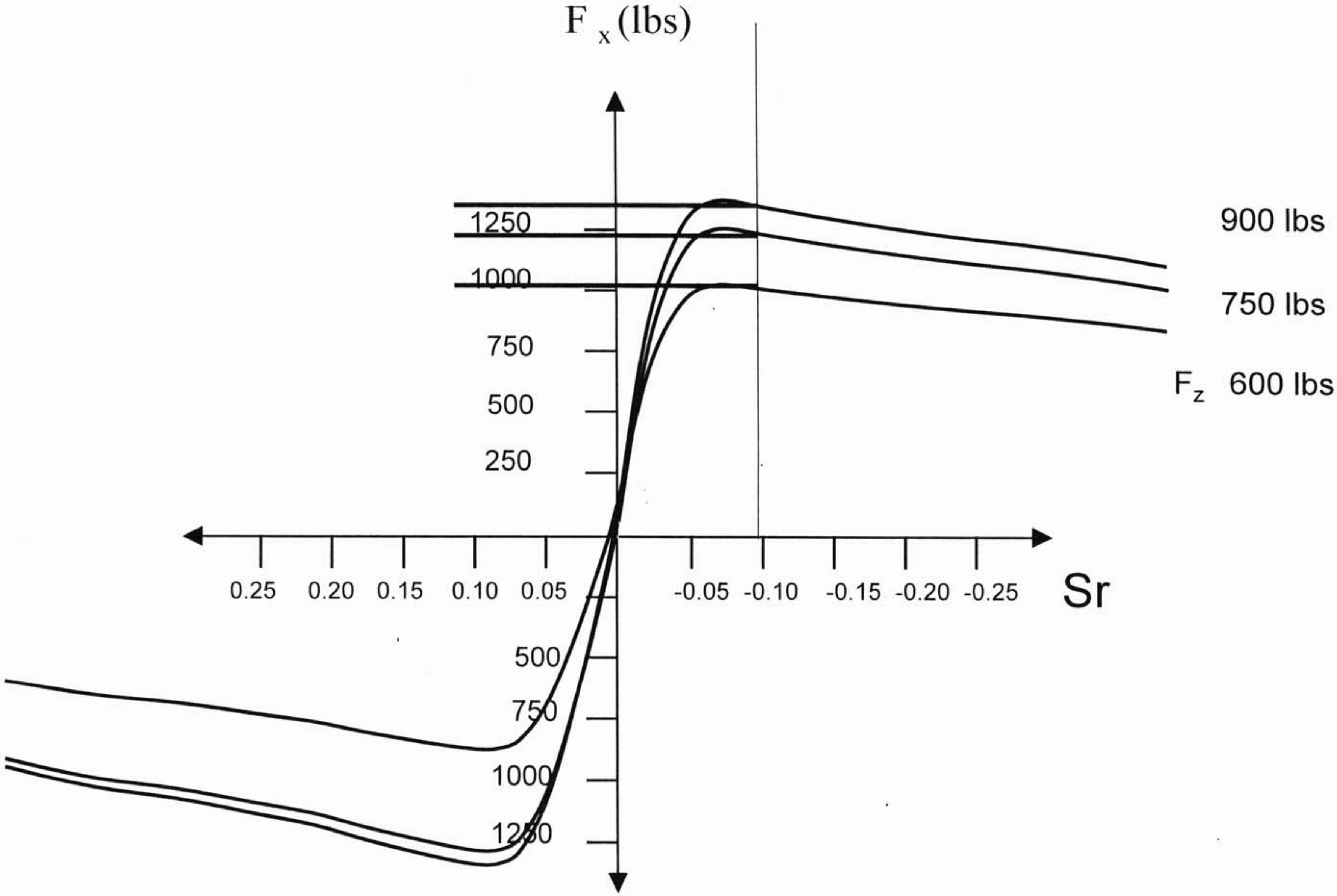


Tire Longitudinal Friction Coefficient Variation

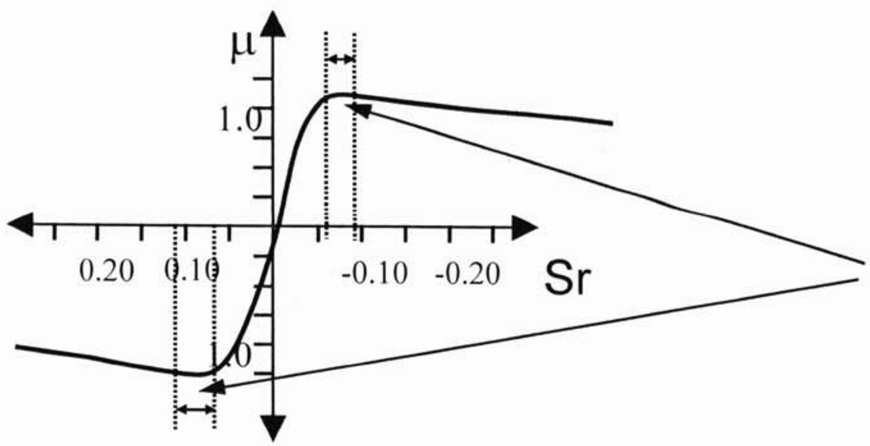
μ = f (Rubber, Temperature, Pressure, Ground, Slip ratio…)



Longitudinal Grip, Slip Ratio and Vertical Load

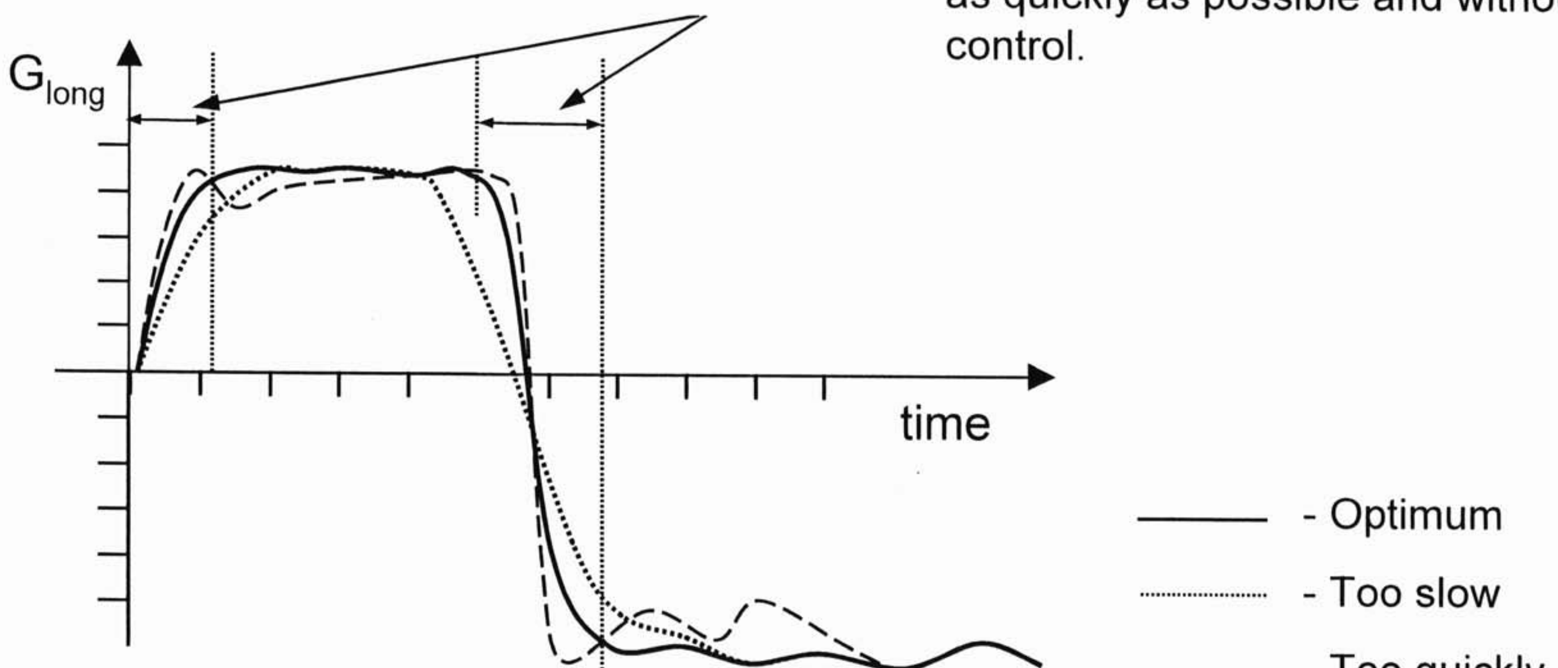


Jumping on the brake pedal and throttle

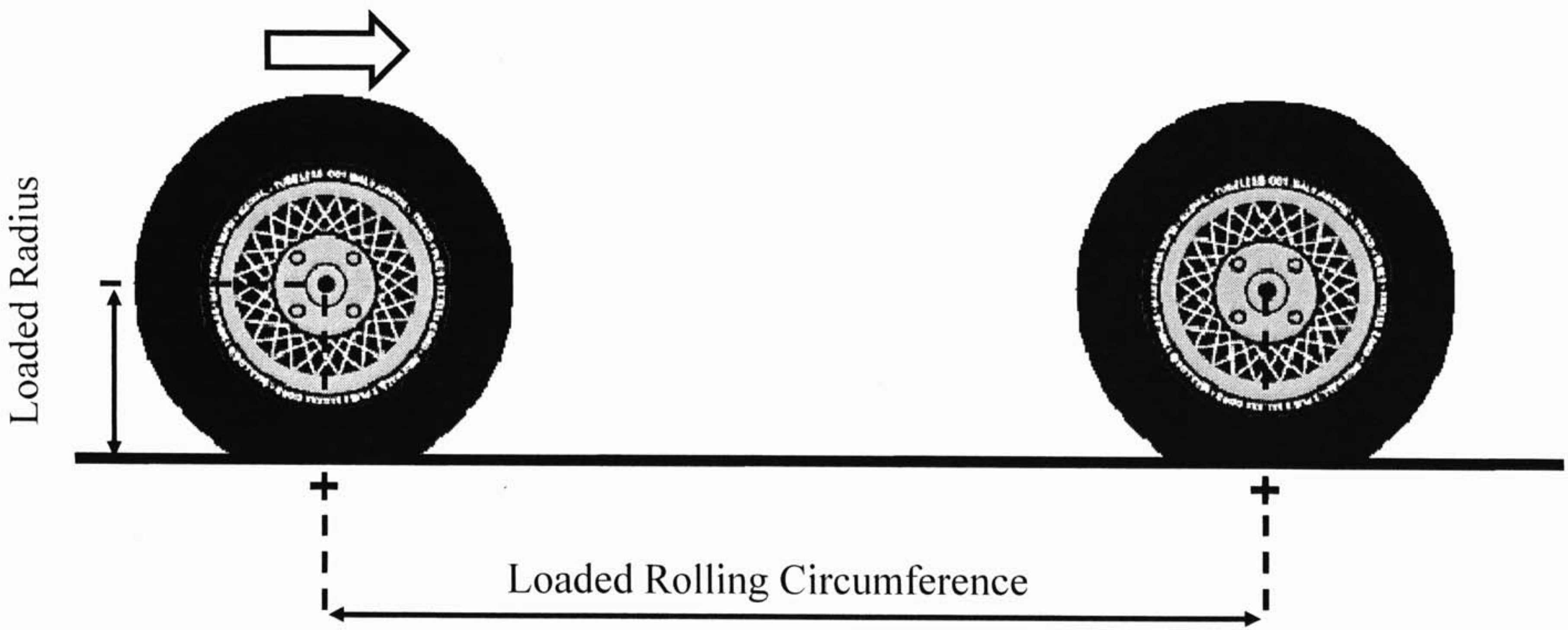


The goal is to be in this part of graph as long as possible.

So it's also important to achieve maximum grip as quickly as possible and without loosing a control.



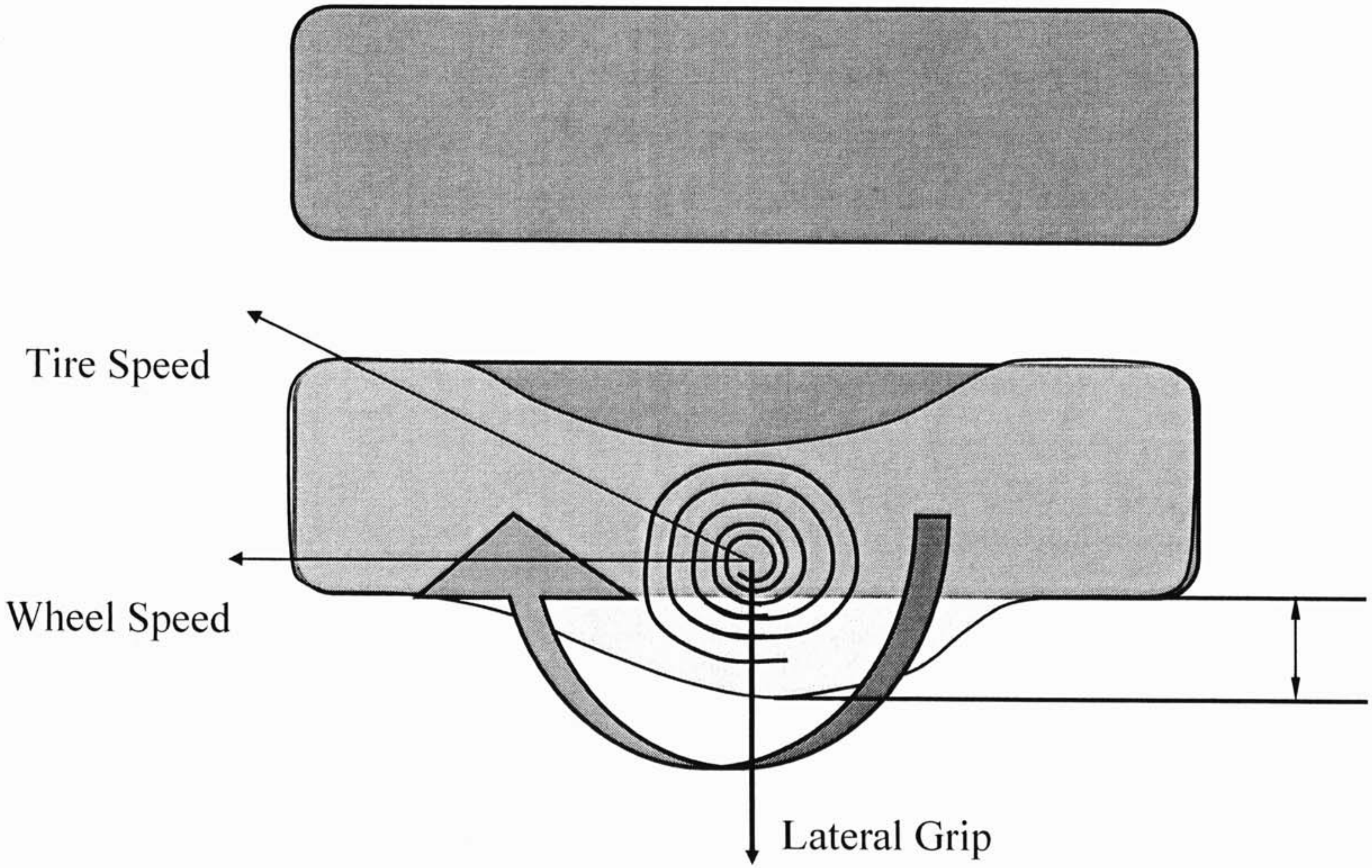
Rolling Radius



<u>Rolling Radius ≠ Loaded Radius</u>

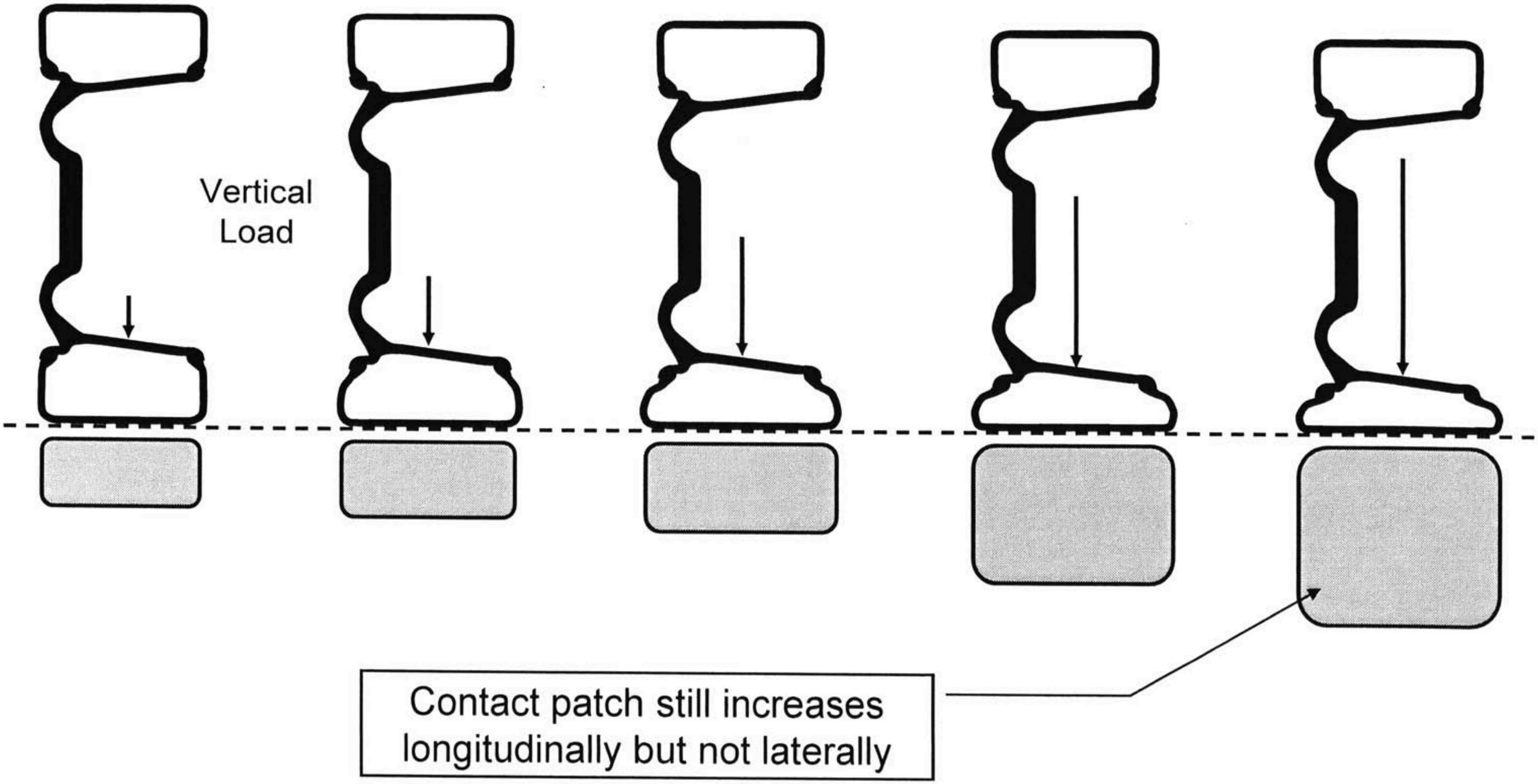
$$\frac{C_{roll}}{2\pi} = R_{roll}$$

"Torsional" Deformation

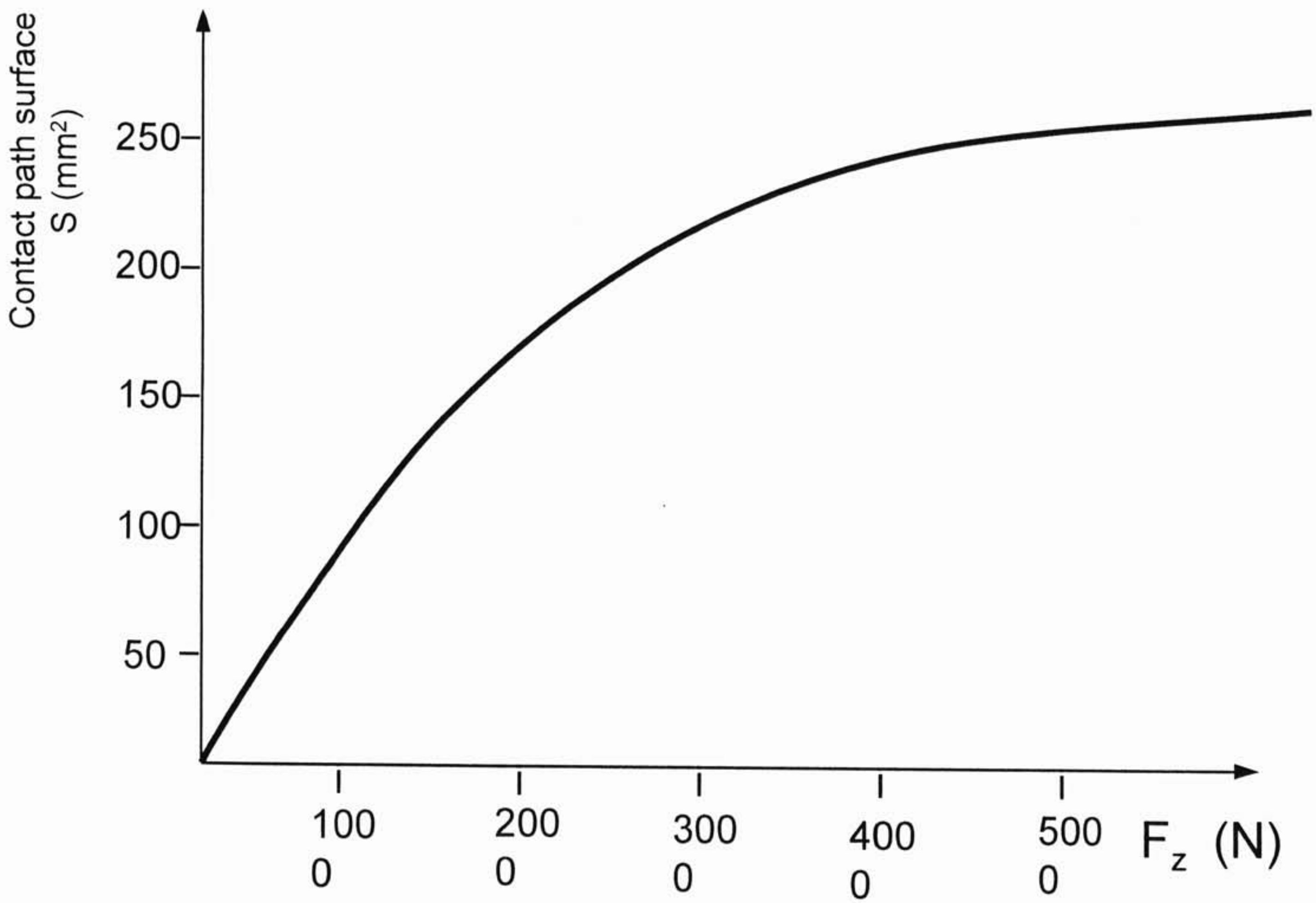


Vertical Load Effect on Contact Path Shape, Macro Deformation

Patch area increases with vertical load



Vertical Load Effect on Contact Path Surface



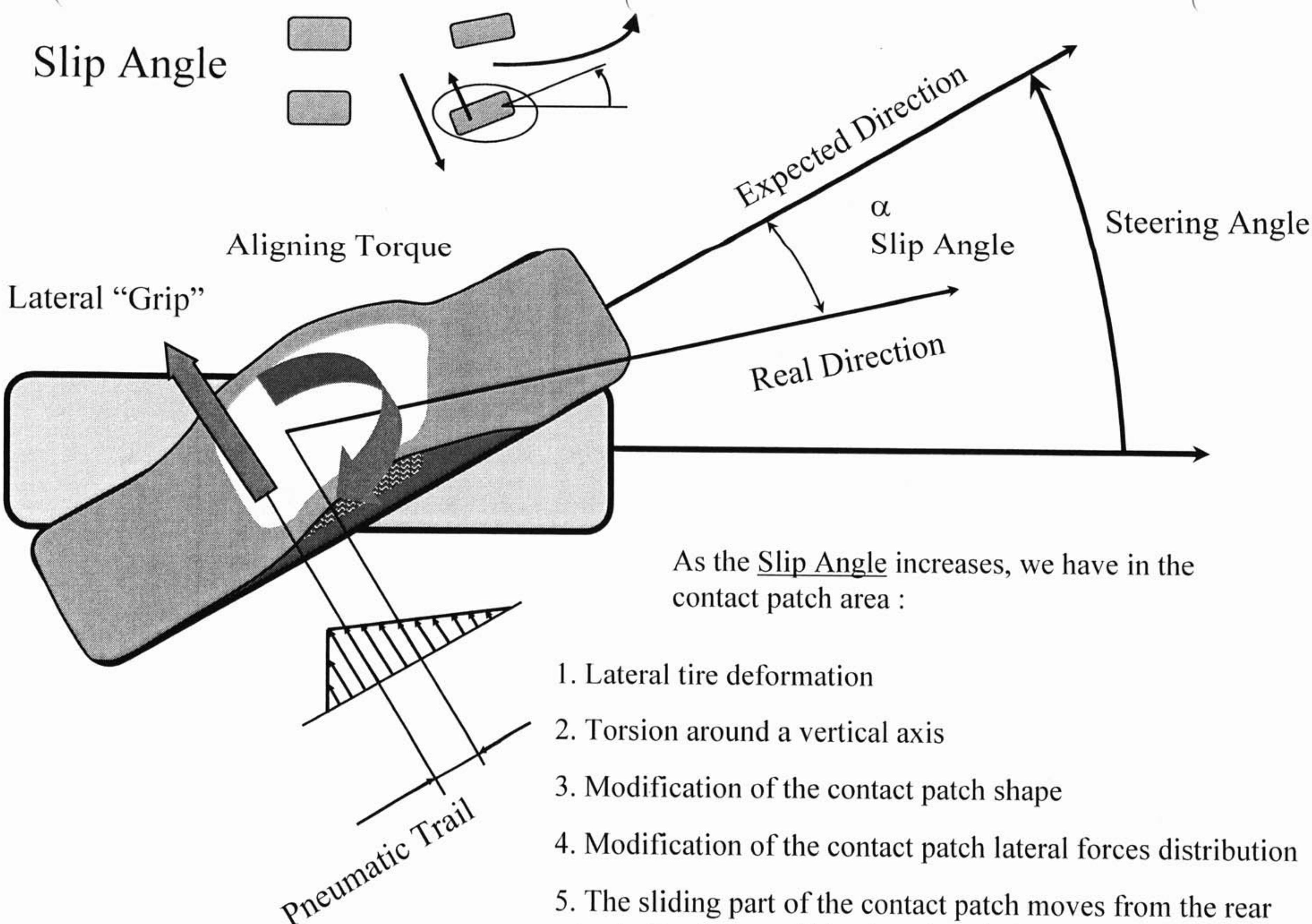
Vertical Load Effect on Contact Path Surface

Load (lb)	Contact patch surface (in²)
100	7.5
200	15.0
300	20.0
400	23.0
500	25.0

With weight transfer we loose more from inside, than gain from outside. For example without weight transfer the total contact patch area is 400 (mm^2), with weight transfer 200 kg the total contact patch area is 275 mm

with different tires inside & out, weight transfer may be beneficial

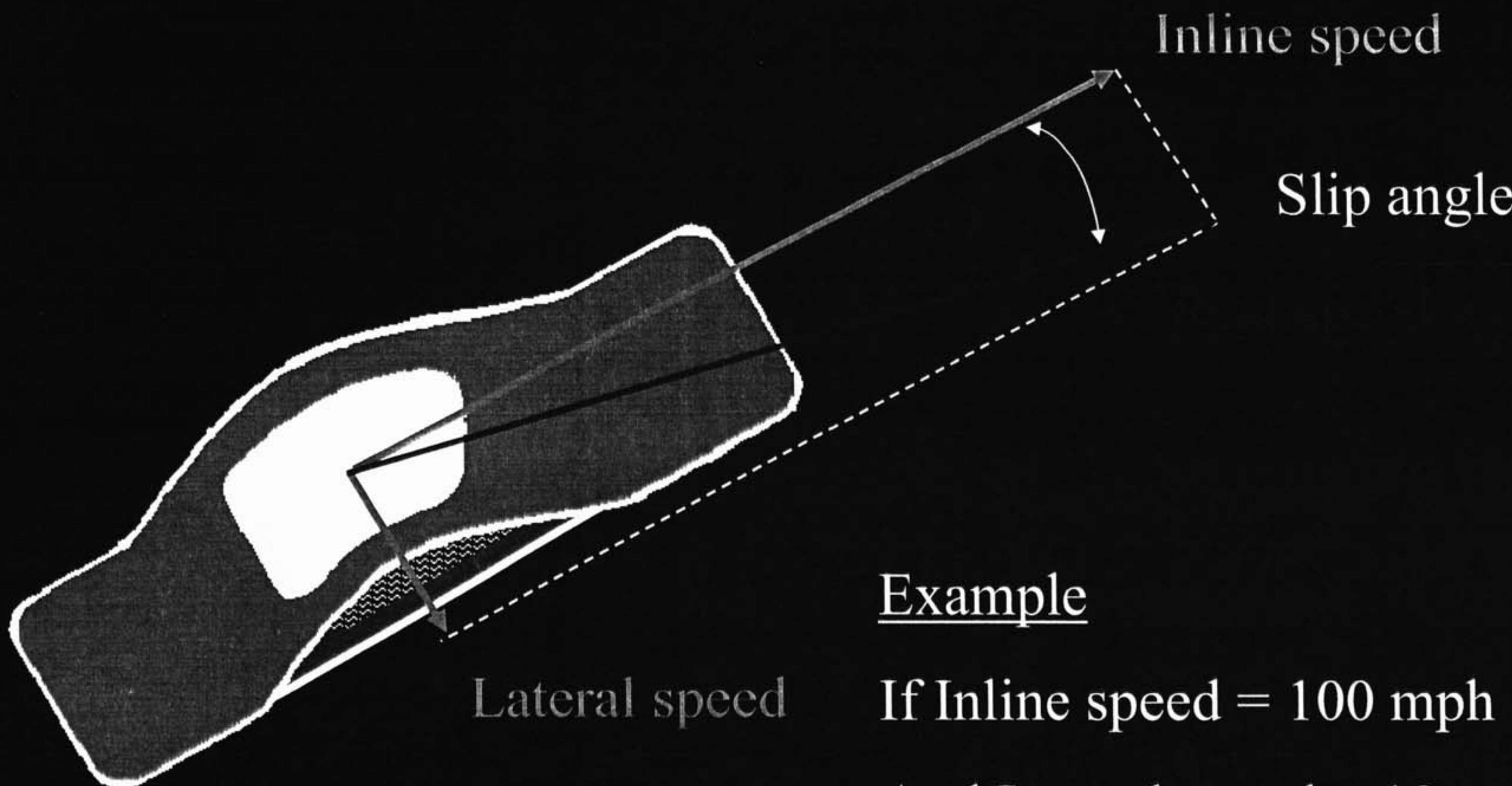
Slip Angle



As the <u>Slip Angle</u> increases, we have in the contact patch area :

1. Lateral tire deformation
2. Torsion around a vertical axis
3. Modification of the contact patch shape
4. Modification of the contact patch lateral forces distribution
5. The sliding part of the contact patch moves from the rear edge to the front until it takes the whole contact patch surface.

Measure of Slip Angle with Optical Sensors



Example

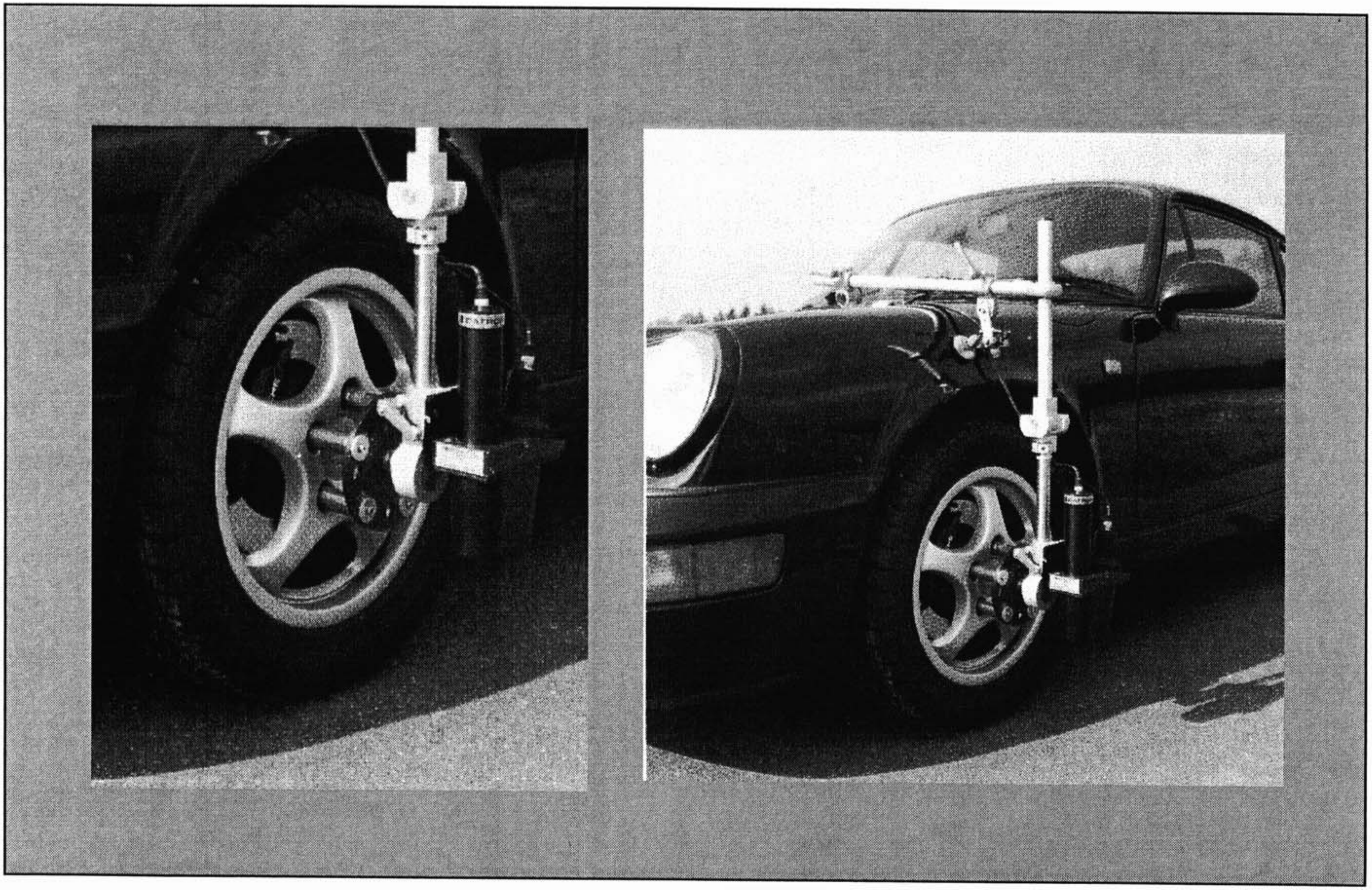
If Inline speed = 100 mph

And Lateral speed = 10 mph

Slip angle = arc tang (10/100)

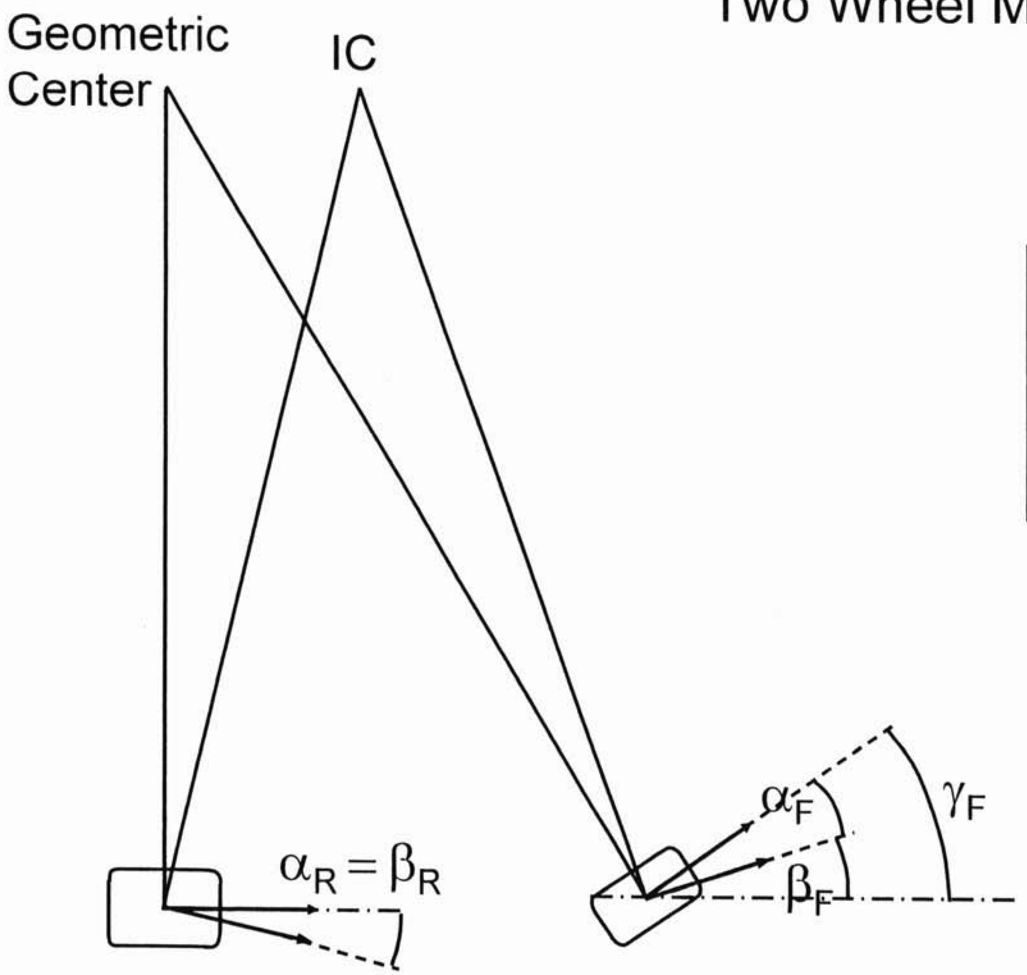
= 5.71 °

Measure of Slip Angle with Optical Sensors



Second incomplete and inaccurate definition of a steady state neutral car in cornering
Equal Slip Angles

Two Wheel Model



$$\alpha_F = \alpha_R$$

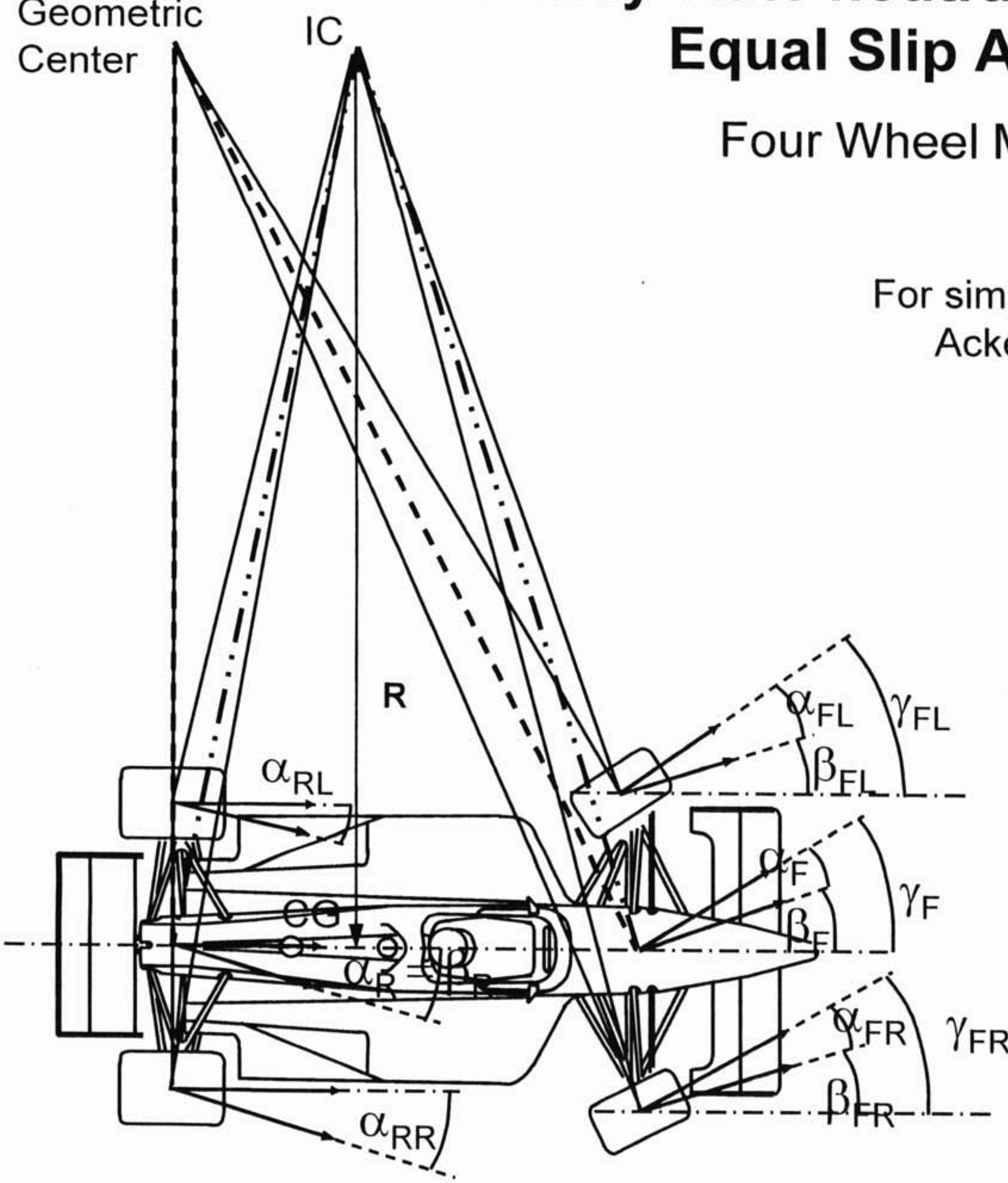
α – *slip angle*

γ – *steering angle*

β – *attitude angle*

Second incomplete and inaccurate definition of a steady state neutral car in cornering
Equal Slip Angles

Four Wheel Model



For simplification we assume, that car has perfect Ackerman and there is a geometric center.

$$\alpha_F = \alpha_R$$

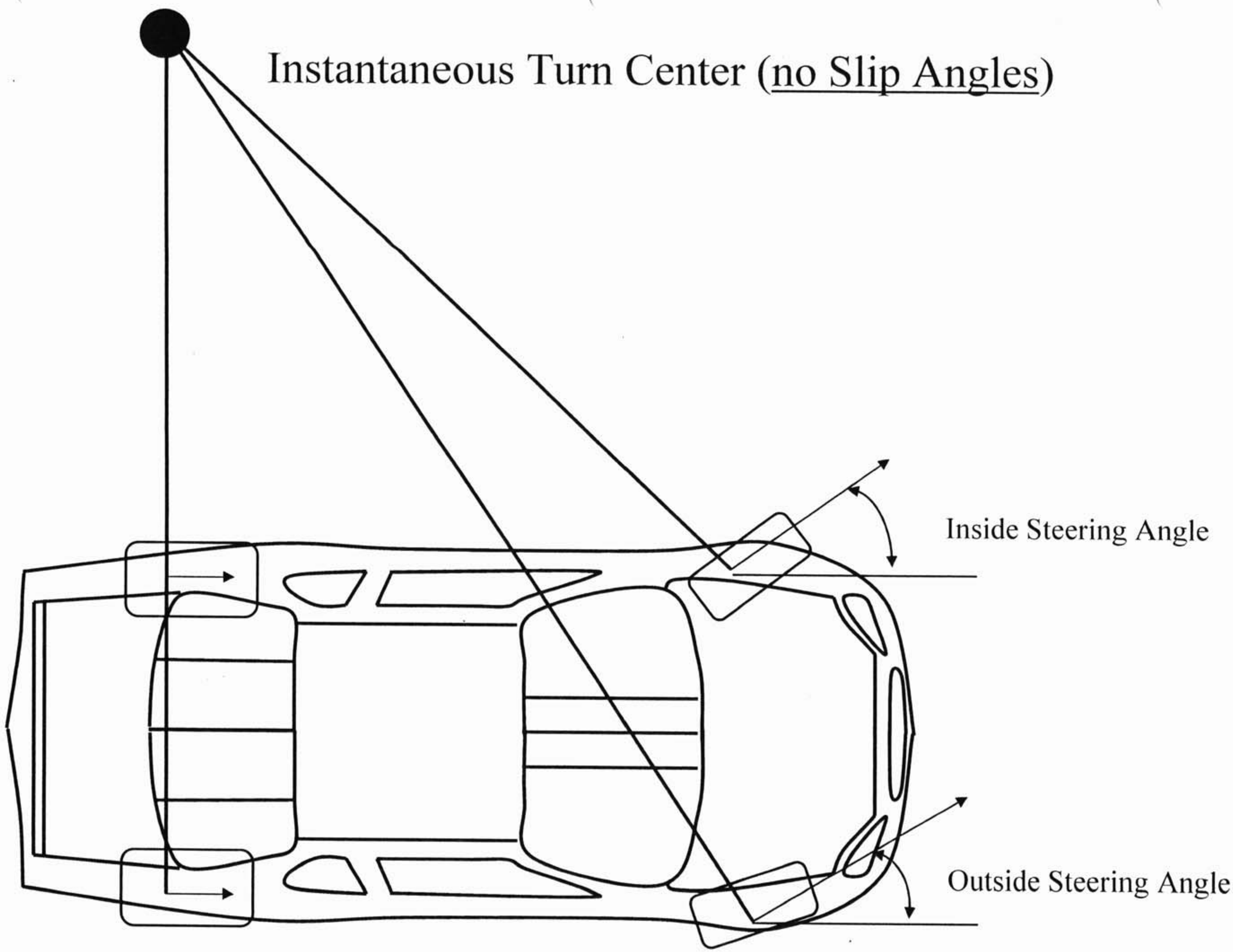
α – *slip angle*

γ – *steering angle*

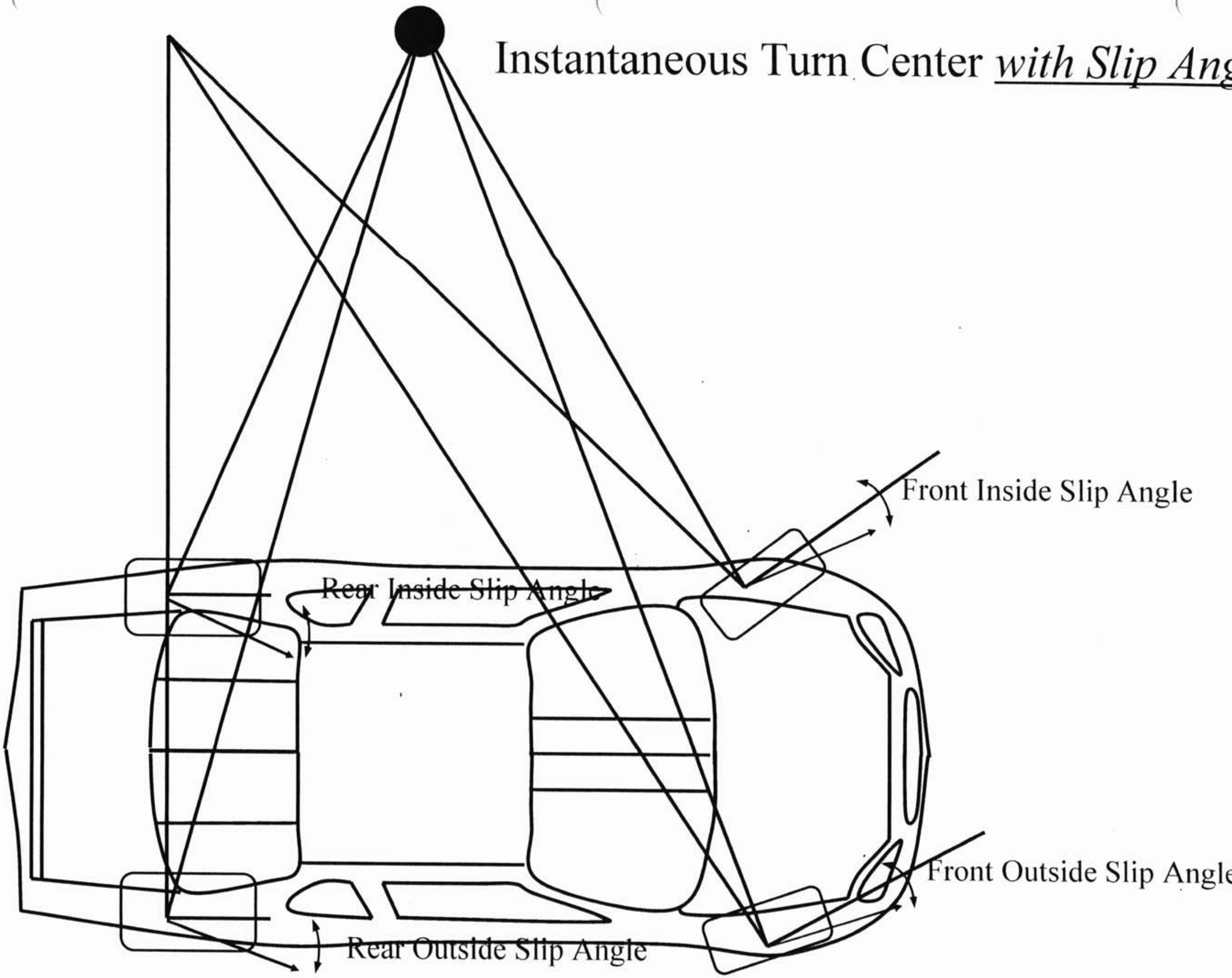
β – *attitude angle*

No toe at rear and front steering angle includes toe

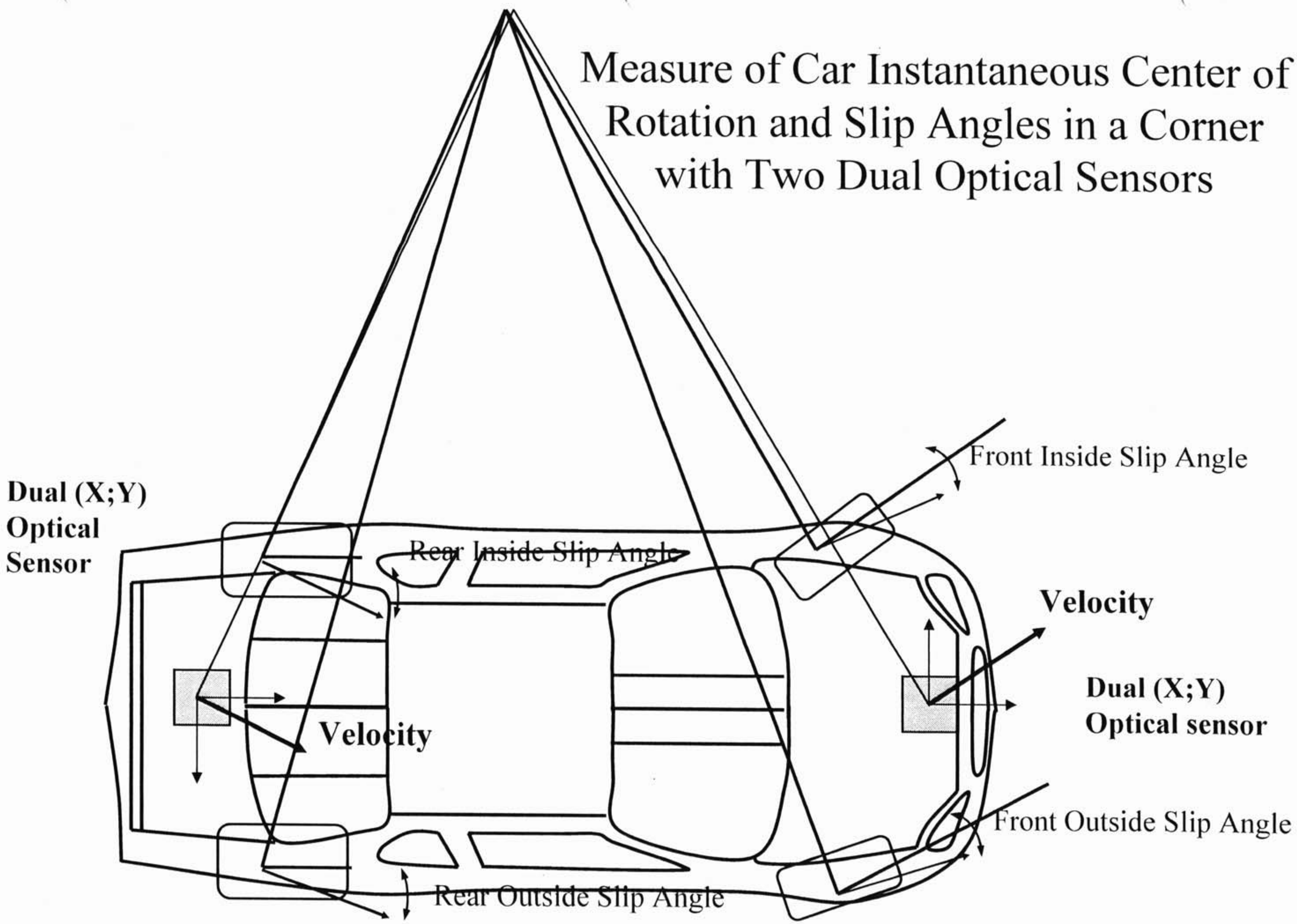
Instantaneous Turn Center (no Slip Angles)



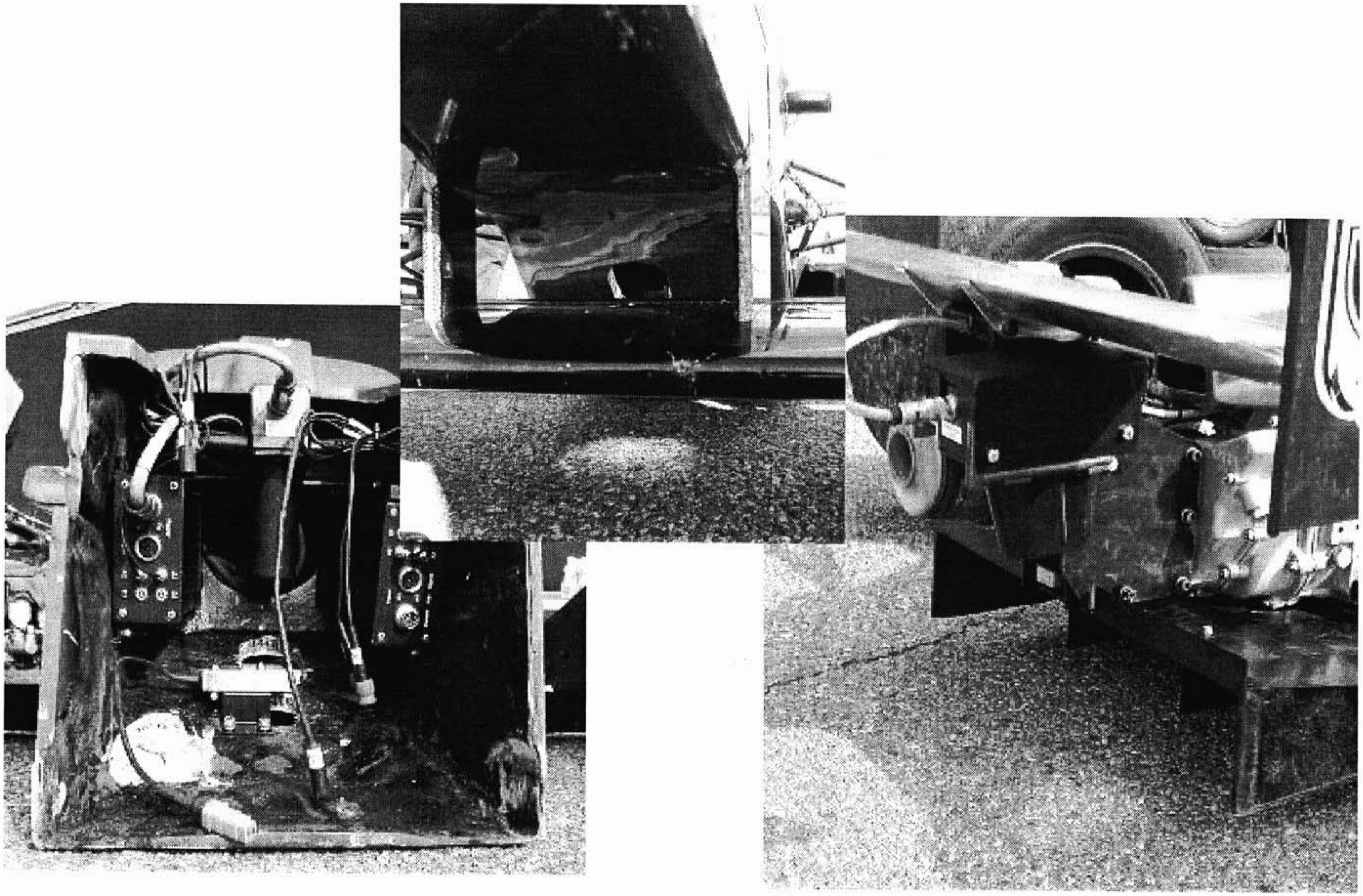
Instantaneous Turn Center *with Slip Angles*



Measure of Car Instantaneous Center of Rotation and Slip Angles in a Corner with Two Dual Optical Sensors

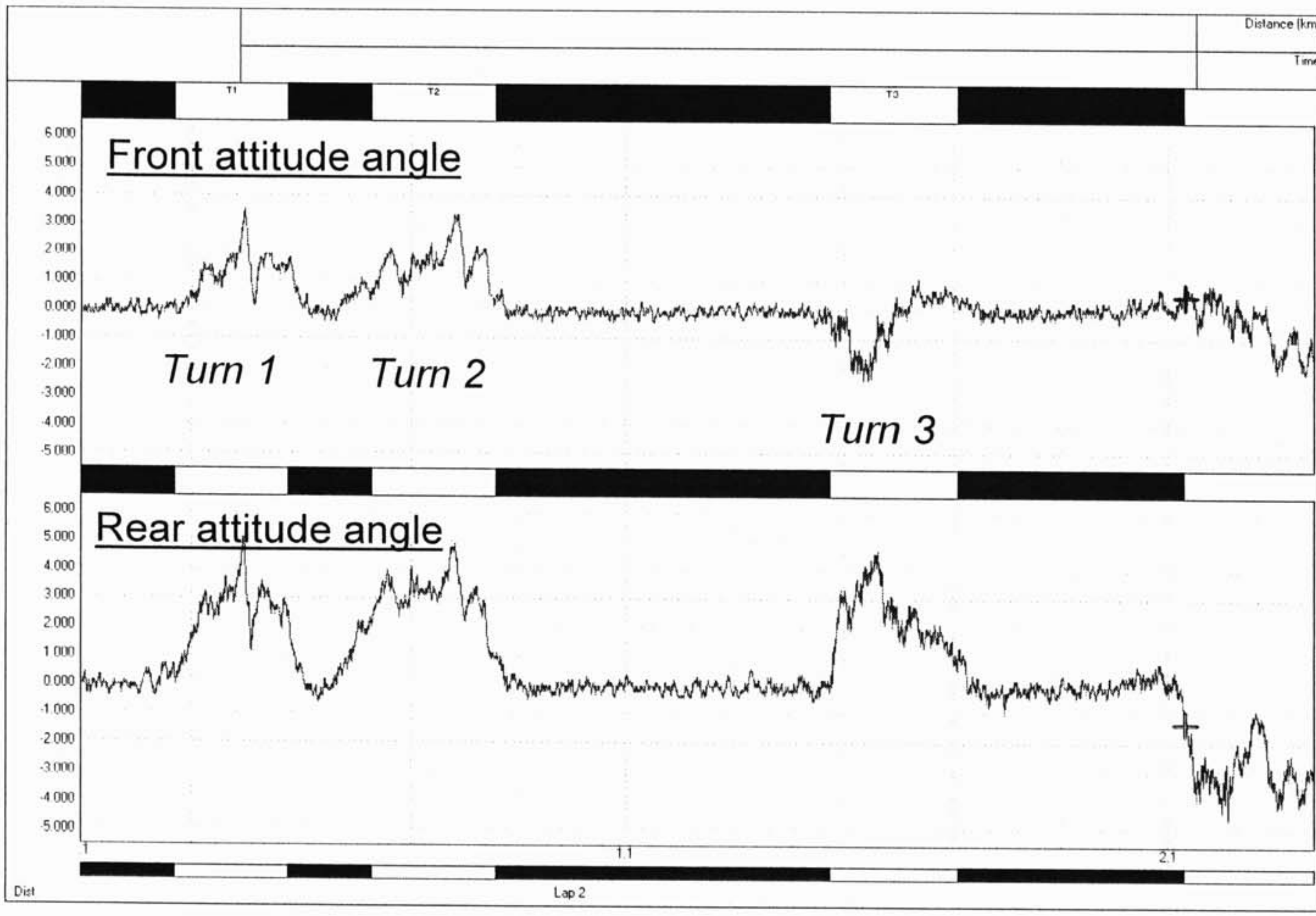


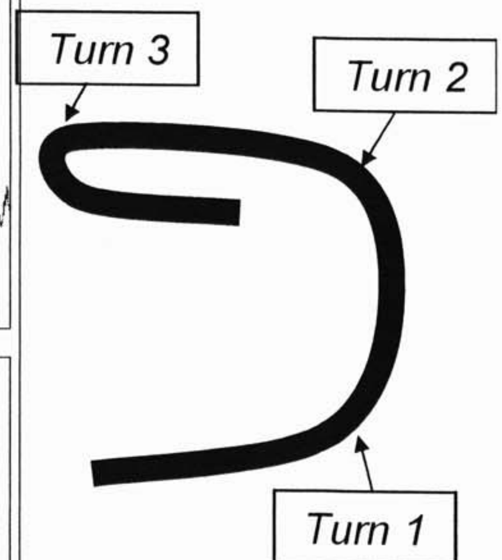
Lateral and Longitudinal Speed with Slip Angle Sensors



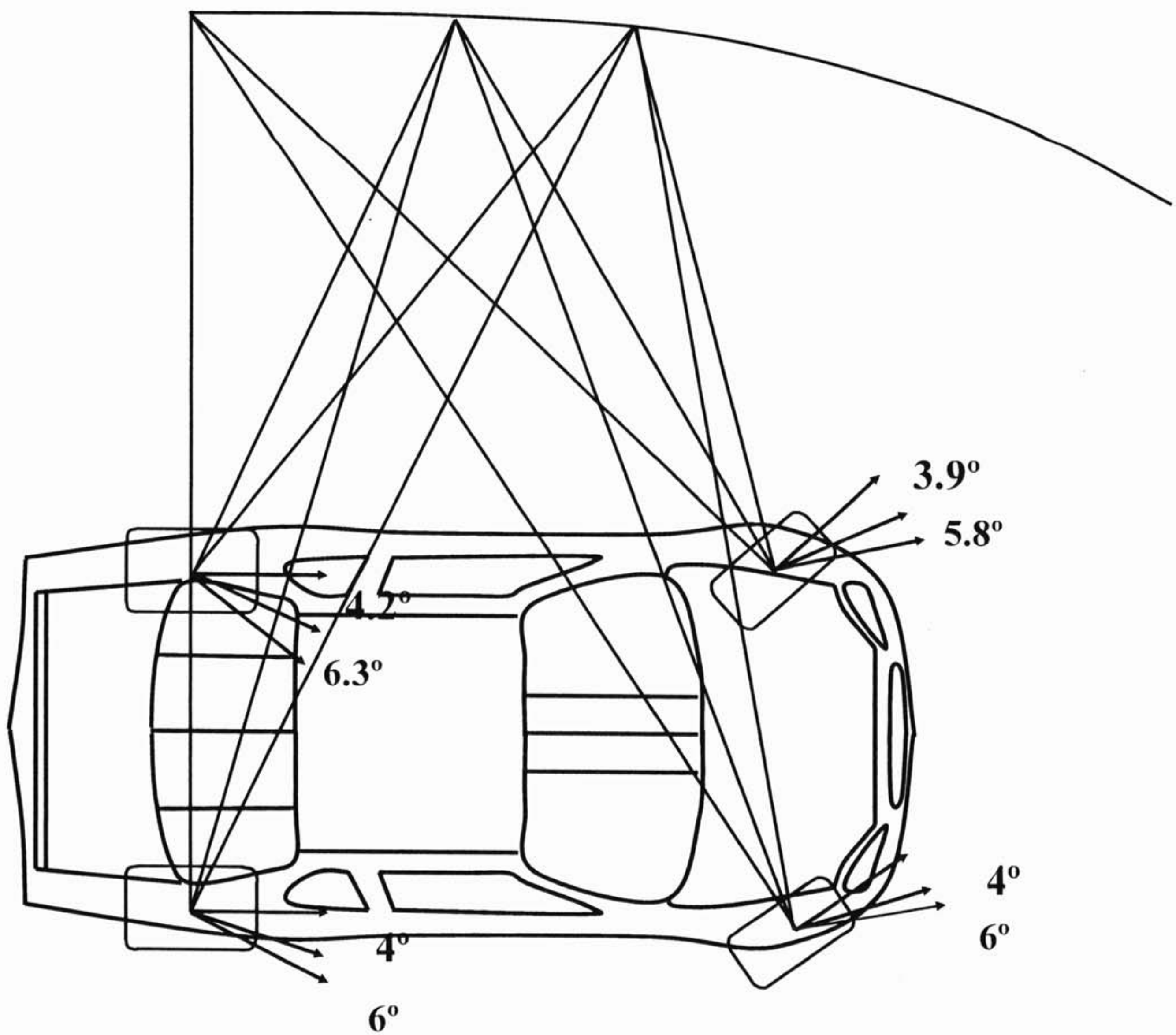
Example of Slip Angle sensors curves obtained

The slip angle sensors could have the same sign (most of the time fast, long corners) or the opposite sign (most of the time slow, tight corners).

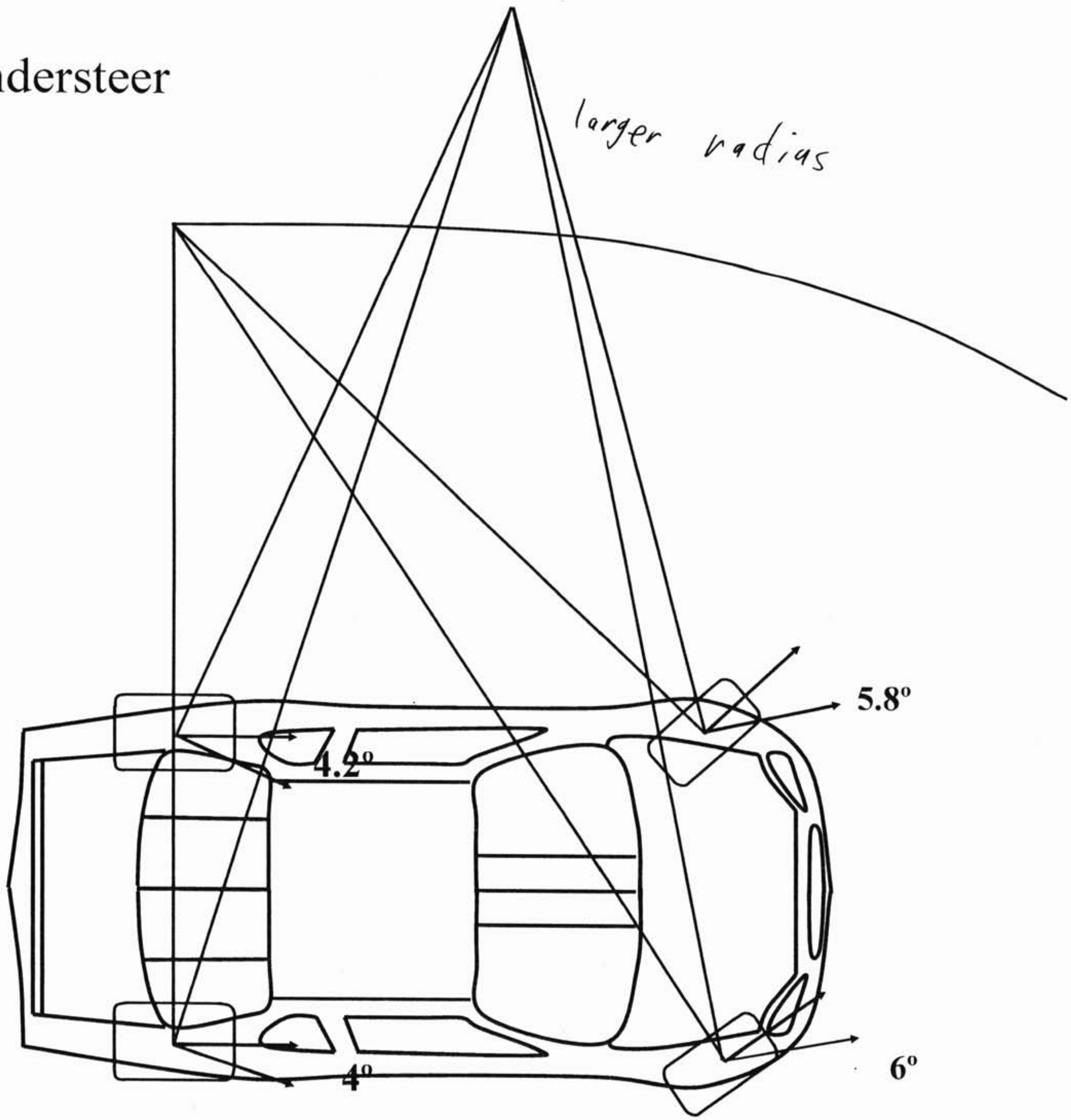




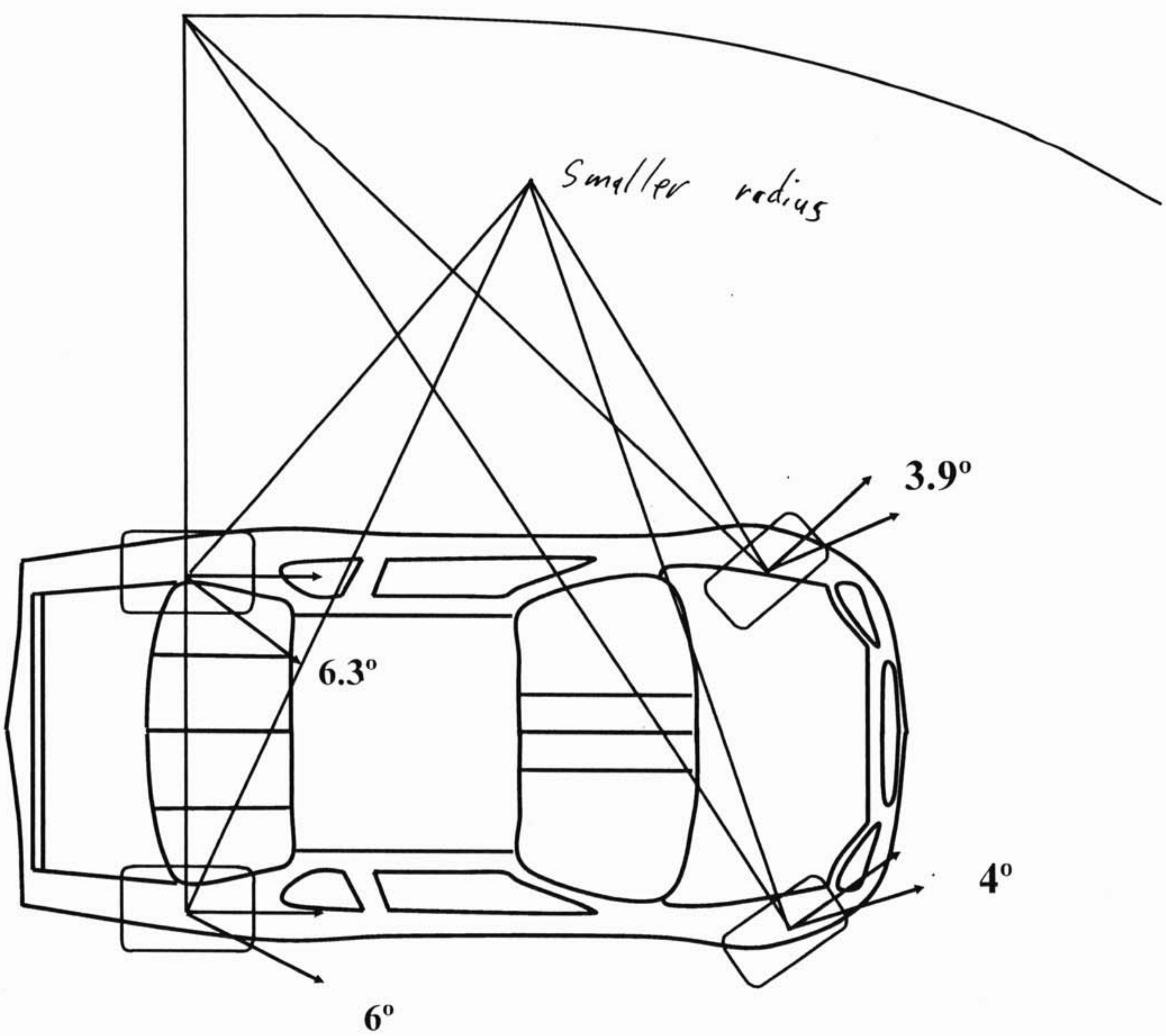
Neutral



Understeer

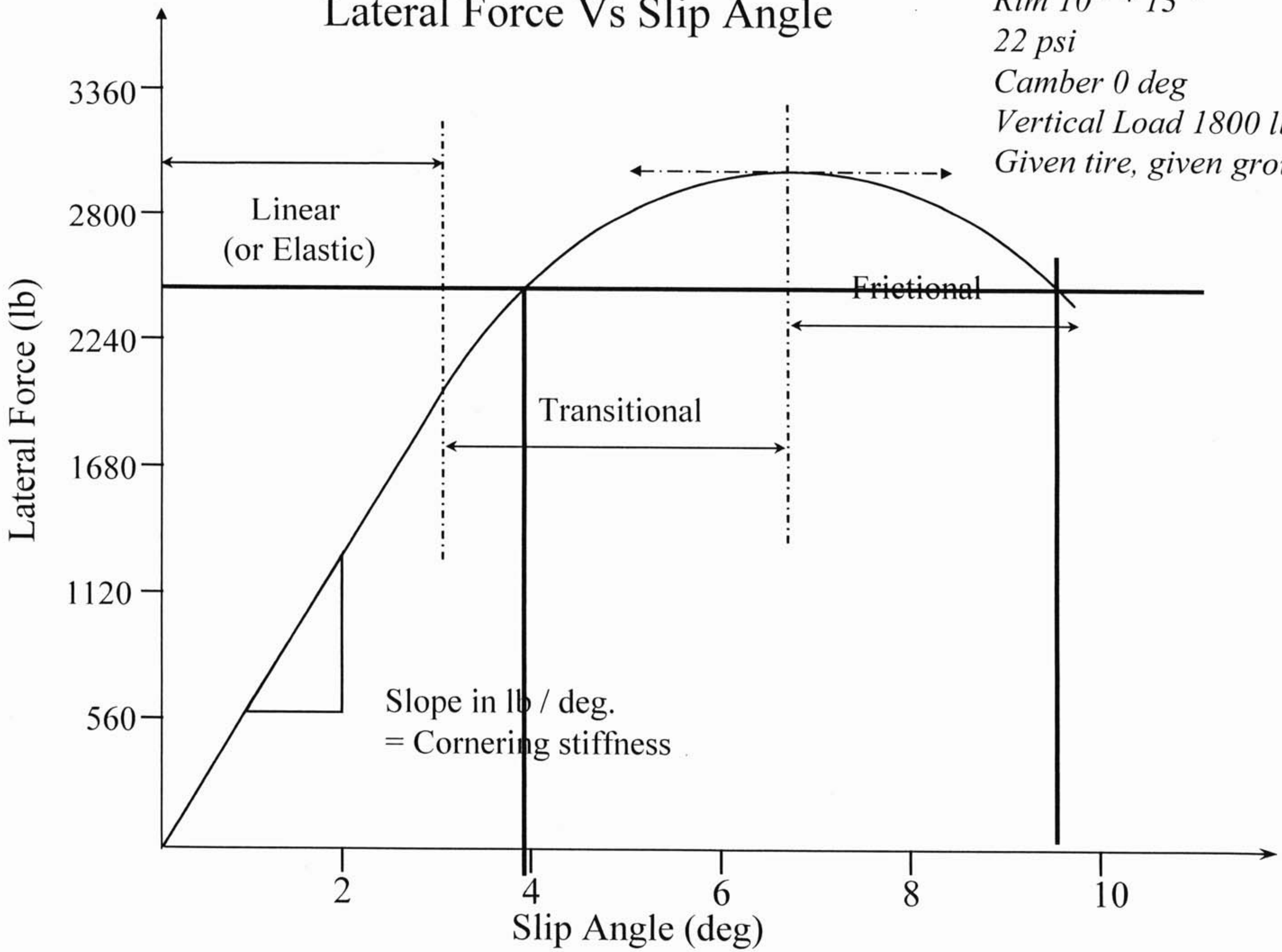


Oversteer

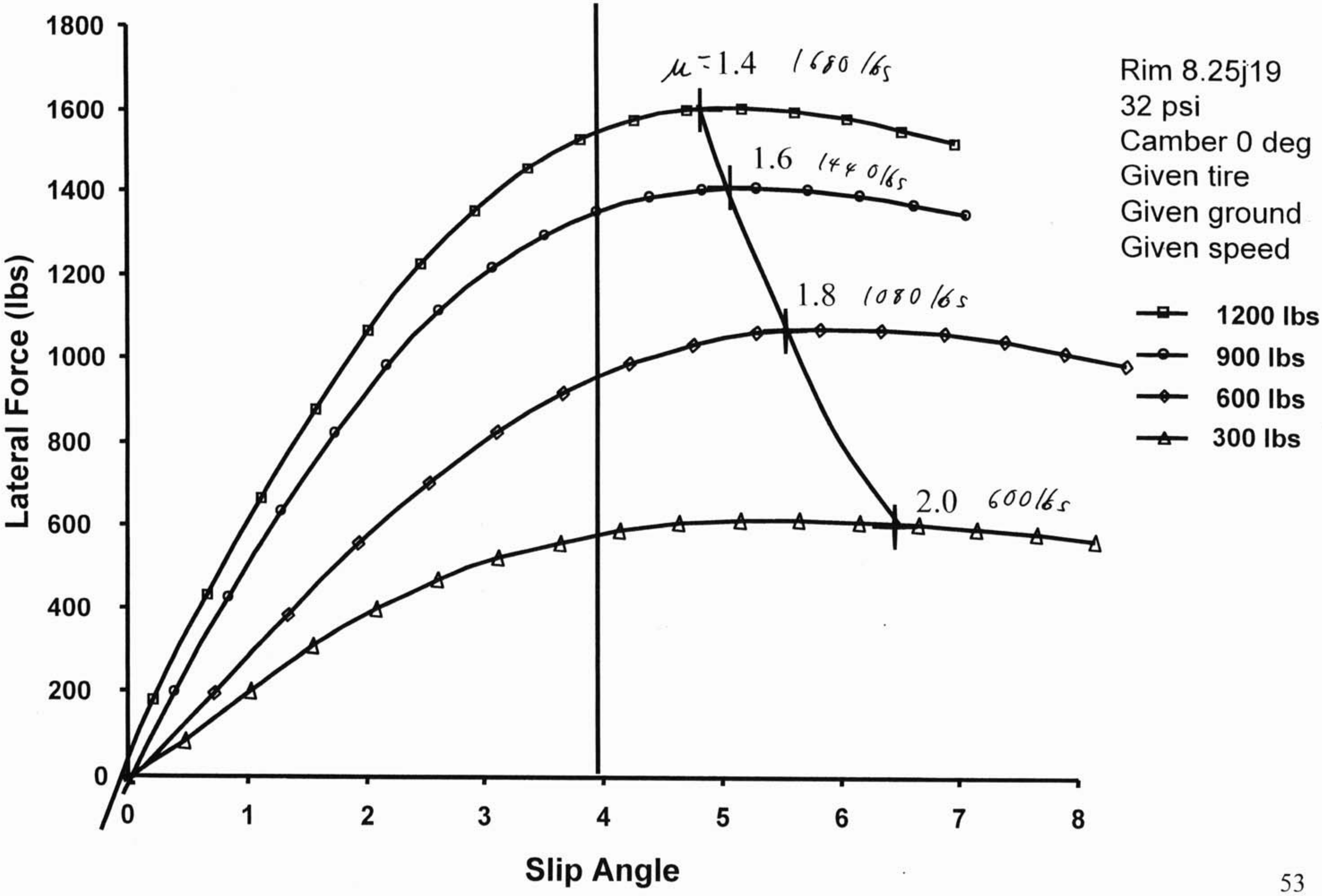


Lateral Force Vs Slip Angle

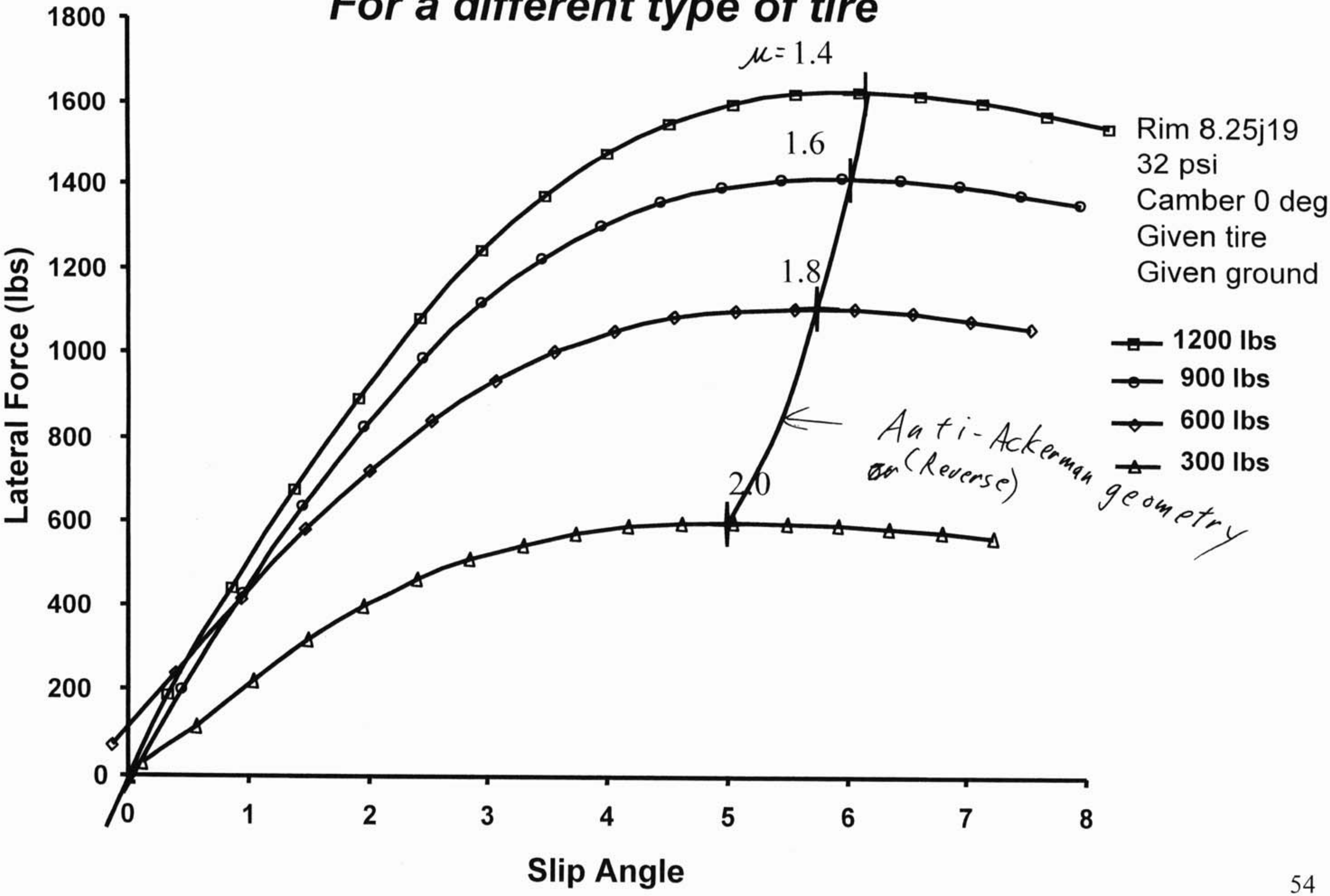
*Rim 10" * 13 "*
22 psi
Camber 0 deg
Vertical Load 1800 lb
Given tire, given ground



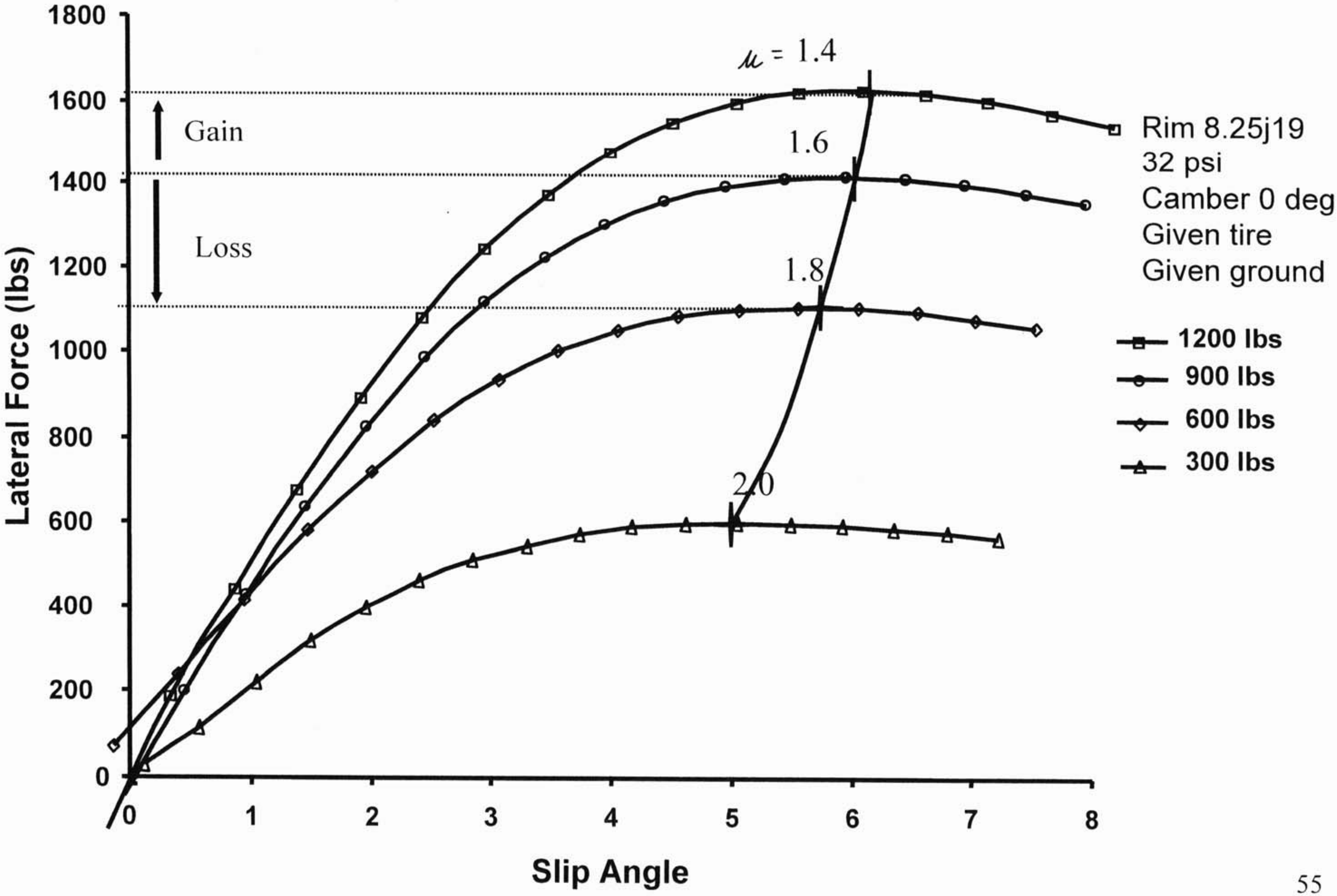
Lateral Force Vs Slip Angle for different Normal Load



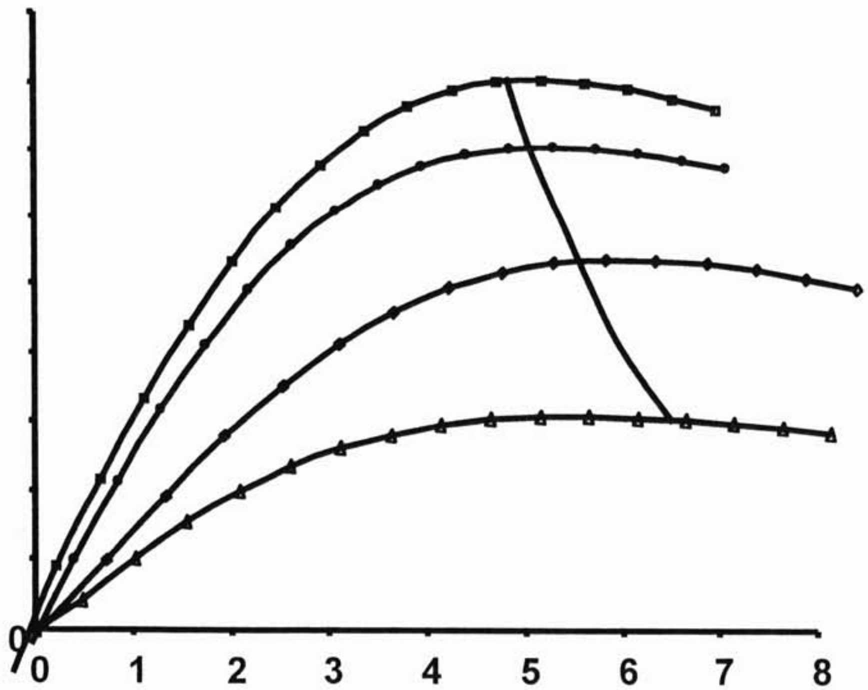
Lateral Force Vs Slip Angle for different Normal Load
For a different type of tire



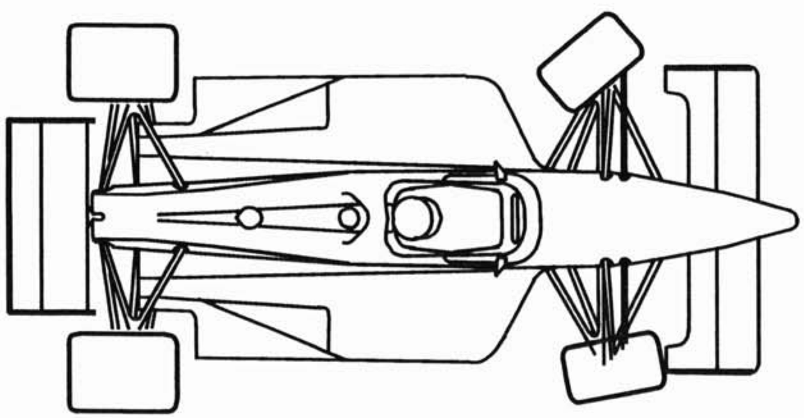
Lateral Force Vs Slip Angle for different Normal Load

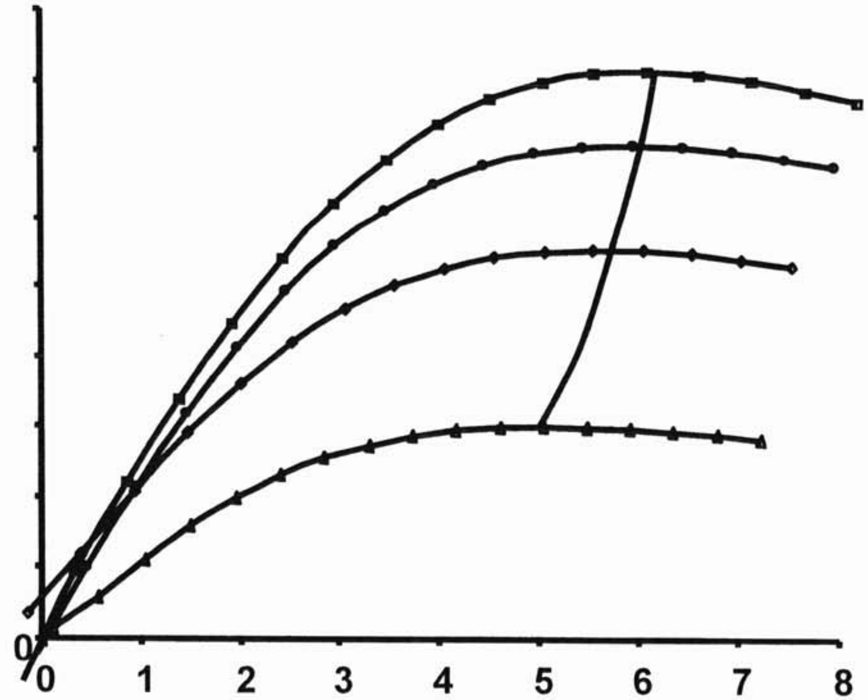


Lateral Force Vs Slip Angle for different Normal Load

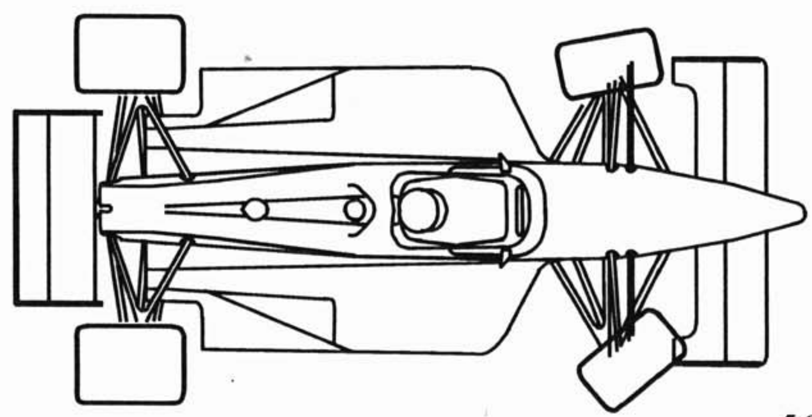


Pro Ackerman



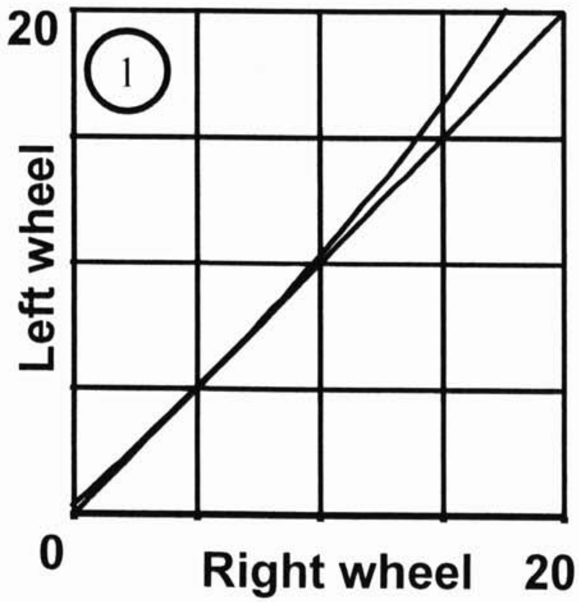


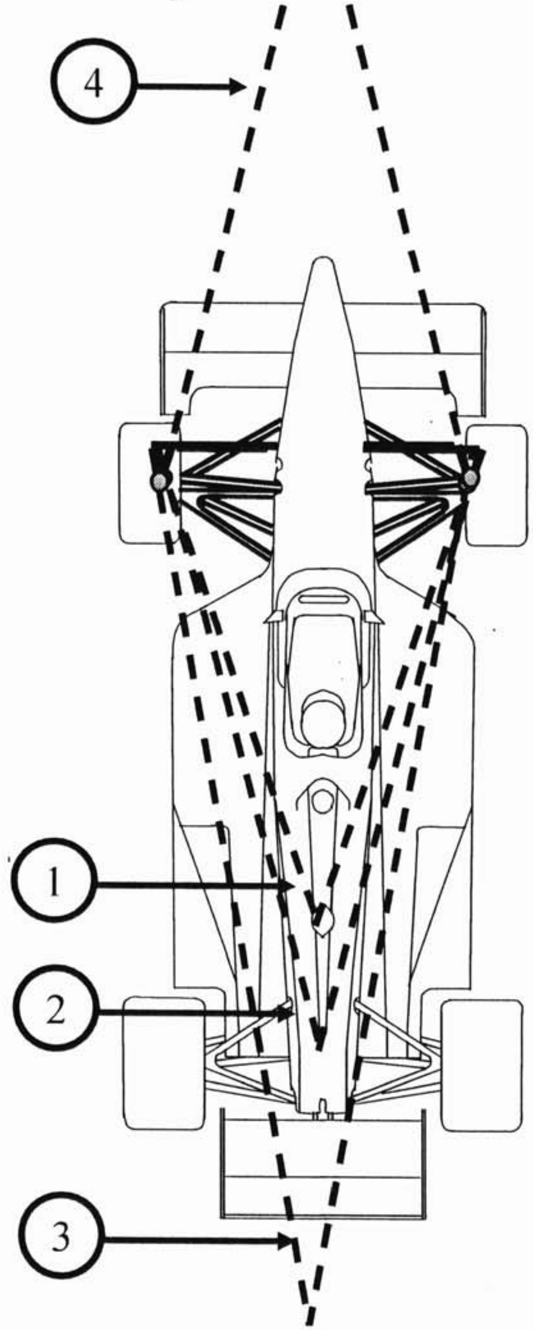
Anti Ackerman

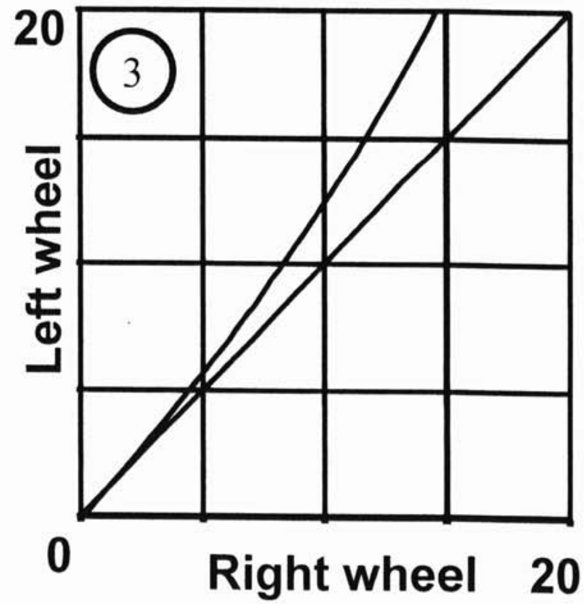


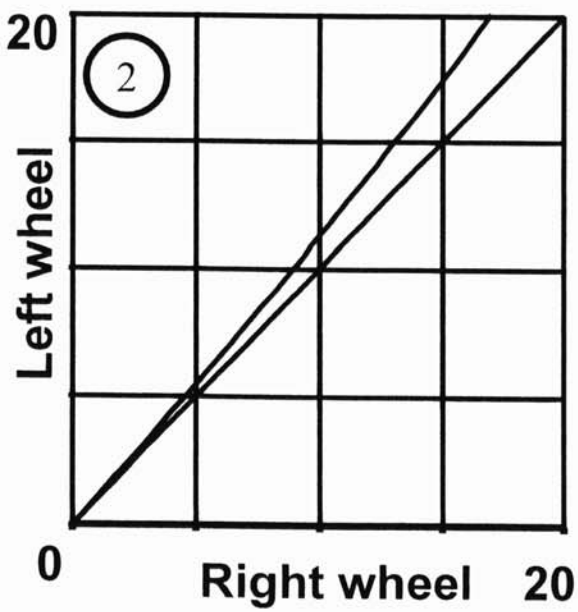
Ackermann Steering Geometry

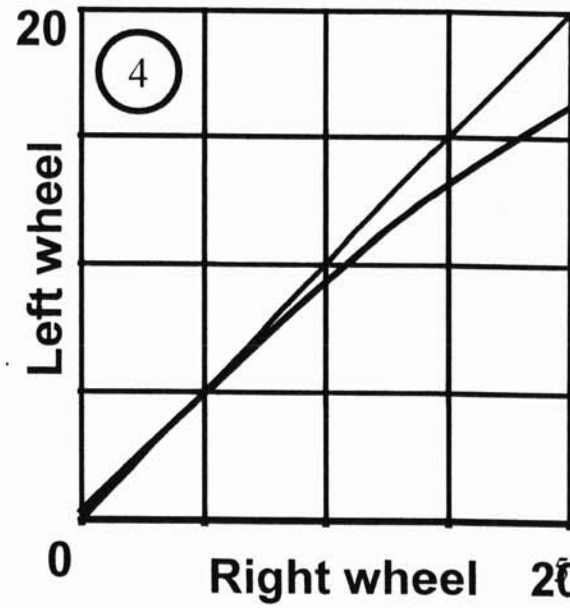
Left corner











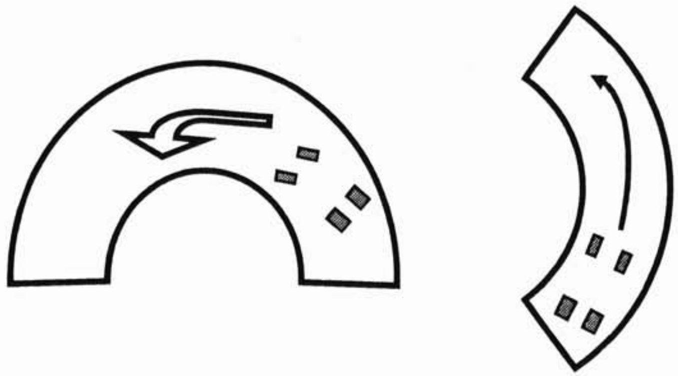
Why reverse Ackermann ? (Example)

Front Toe in Test

	Slow Corner	Fast Corner
Static Toe In	+++	-
Static Toe Out	-	+++

Driver's comments :

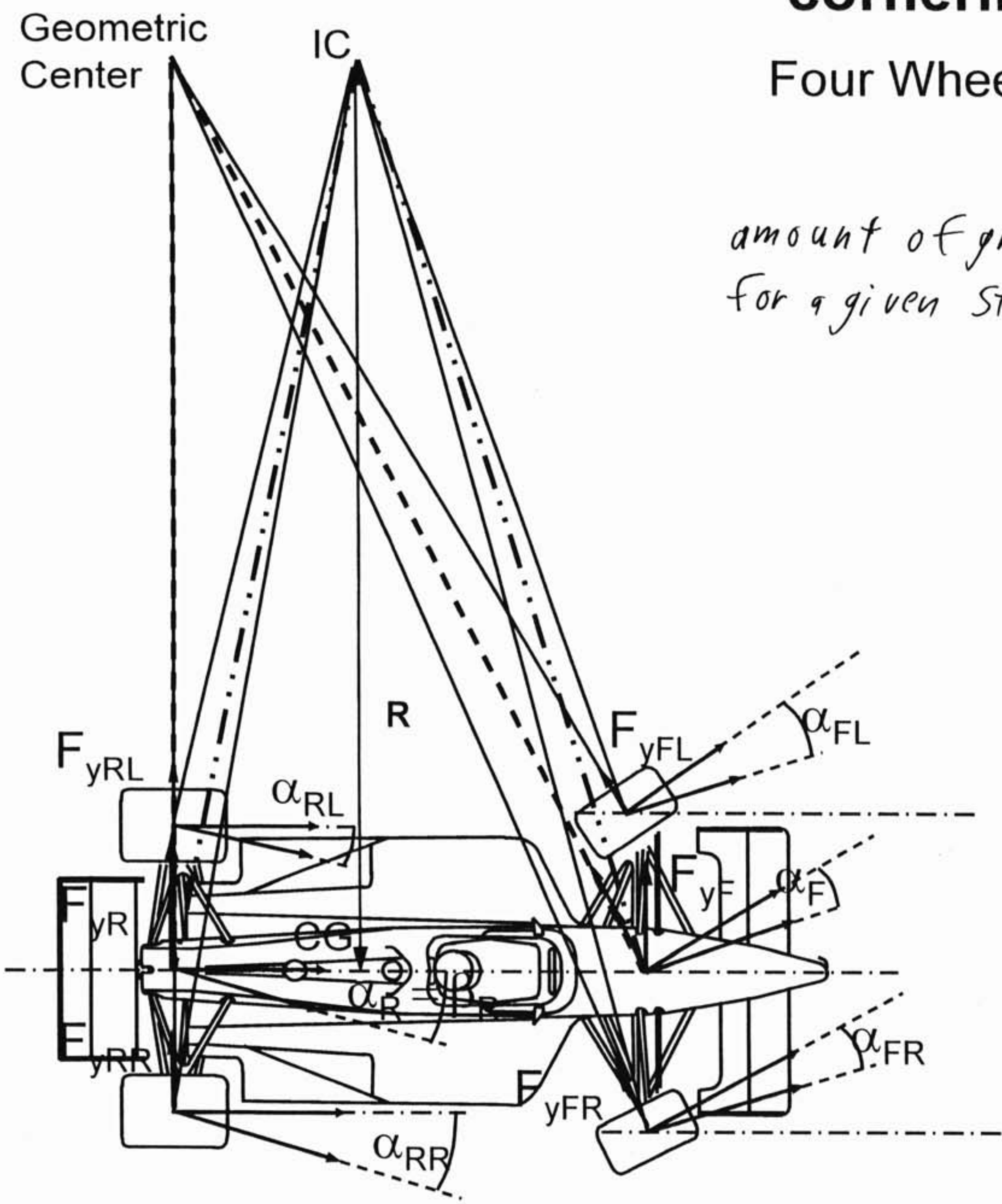
Toe-out is better in fast corner.
To-in is better in slow corner.



Solution is Static Toe Out with Reverse Ackermann Geometry because :

- fast corner ←→ small steering angle ←→ toe out setting practically unchanged
- slow corner ←→ high steering angle ←→ fast variation from toe out to toe in

Complete definition of a steady state neutral car in cornering



Four Wheel Model

amount of grip for a given steer angle

$$\frac{A_F}{\alpha_F} = \frac{A_R}{\alpha_R}$$

A – lateral acceleration in g

$$A_F = \frac{F_{yF} \cdot 9.81}{F_{zF}}$$

$$A_R = \frac{F_{yR} \cdot 9.81}{F_{zR}}$$

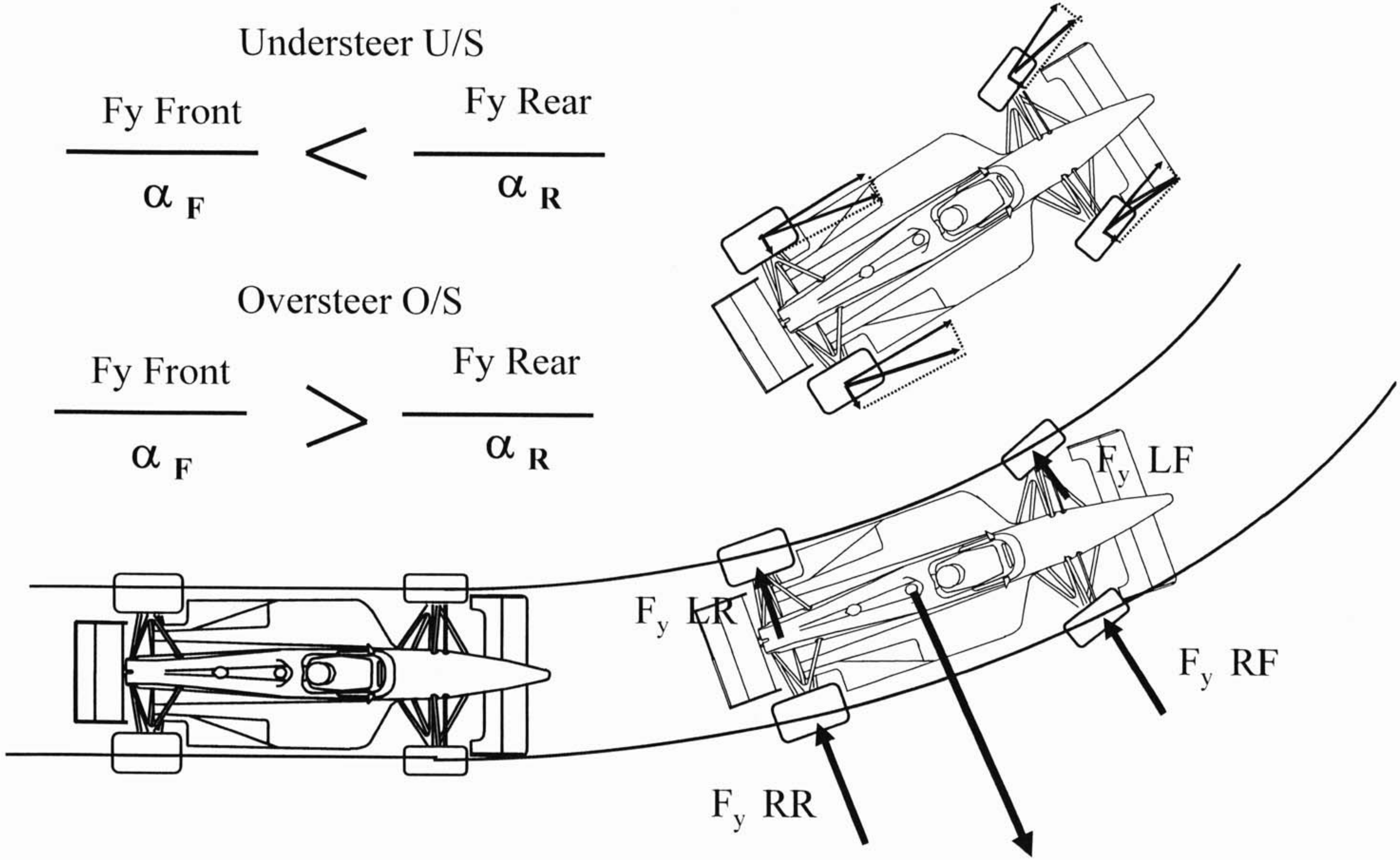
The Complete Definition of Understeer and Oversteer

Understeer U/S

$$\frac{Fy\ Front}{\alpha_F} < \frac{Fy\ Rear}{\alpha_R}$$

Oversteer O/S

$$\frac{Fy\ Front}{\alpha_F} > \frac{Fy\ Rear}{\alpha_R}$$



F = Mass x Lateral Acceleration

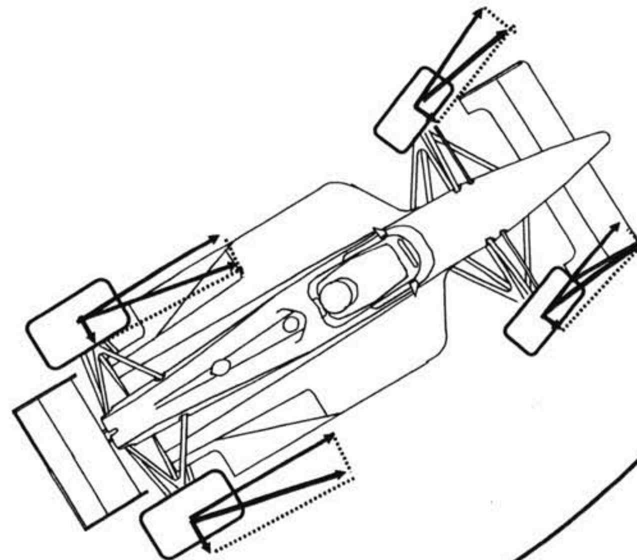
The Complete Definition of Understeer and Oversteer

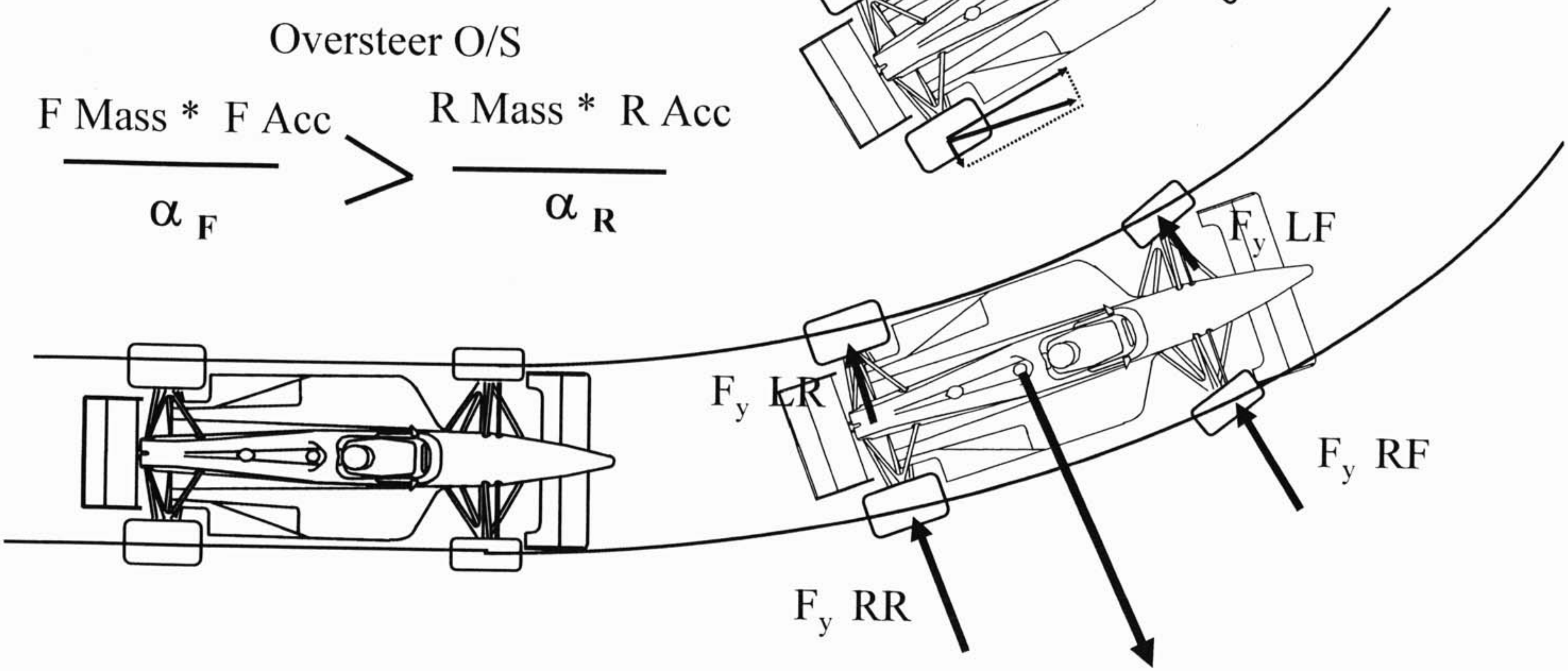
Understeer U/S

$$\frac{\text{F Mass} * \text{F Acc}}{\alpha_{\mathbf{F}}} < \frac{\text{R Mass} * \text{R Acc}}{\alpha_{\mathbf{R}}}$$

Oversteer O/S

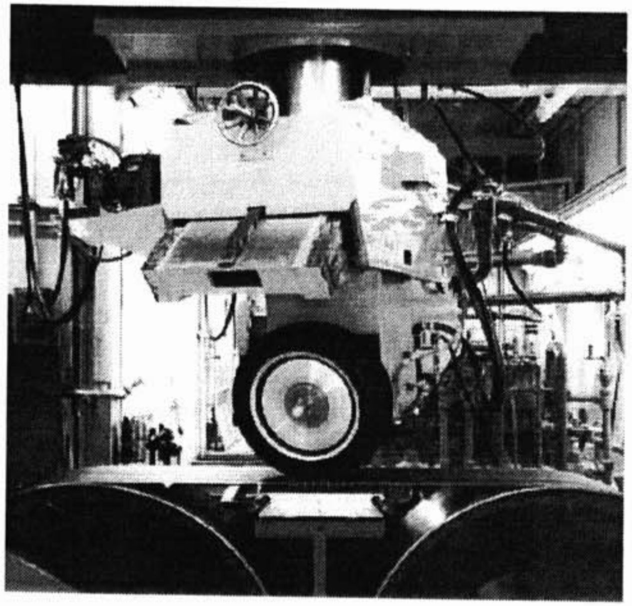
$$\frac{\text{F Mass} * \text{F Acc}}{\alpha_{\mathbf{F}}} > \frac{\text{R Mass} * \text{R Acc}}{\alpha_{\mathbf{R}}}$$

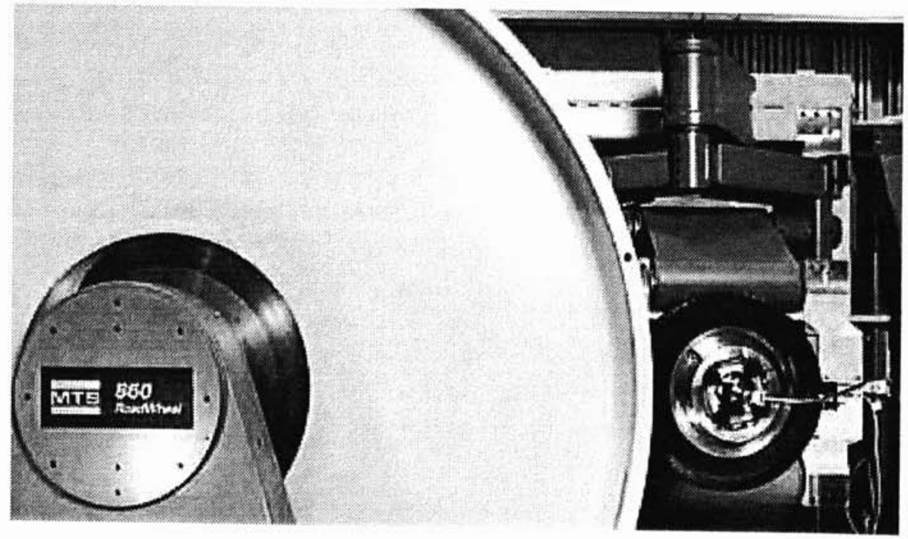


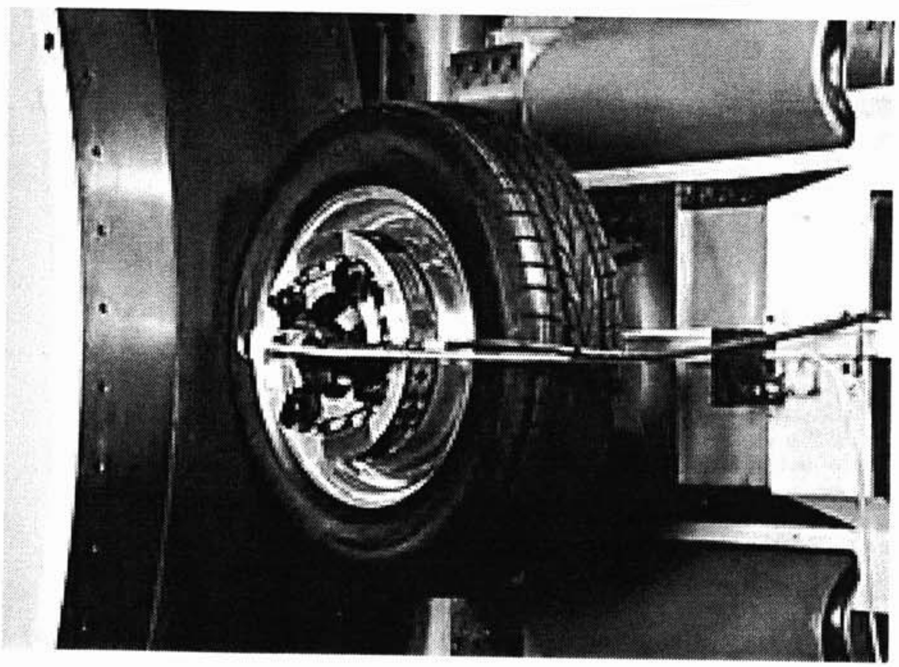


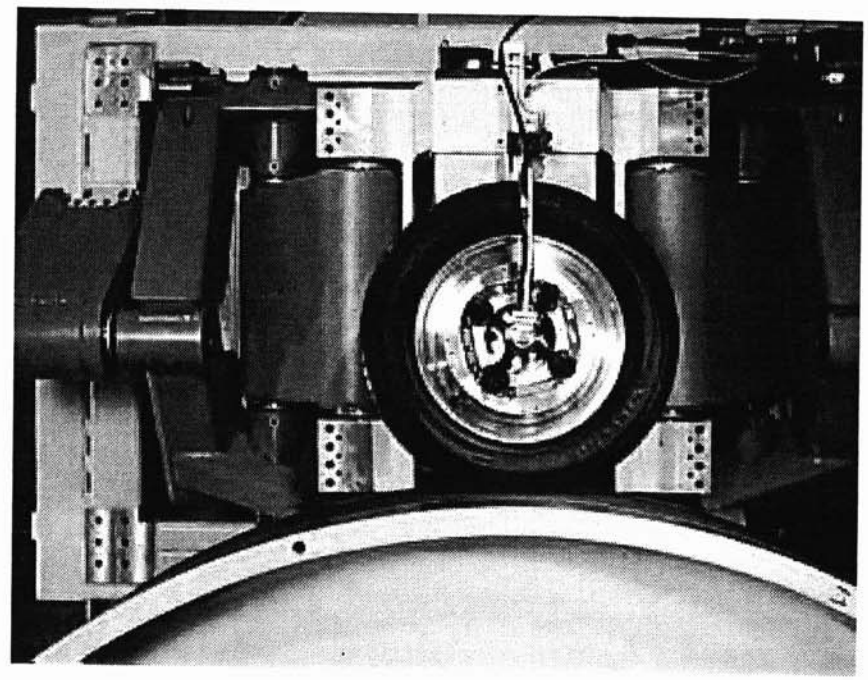
F = Mass x Lateral Acceleration

Measure of Tire Forces and Slip Angle in Laboratory

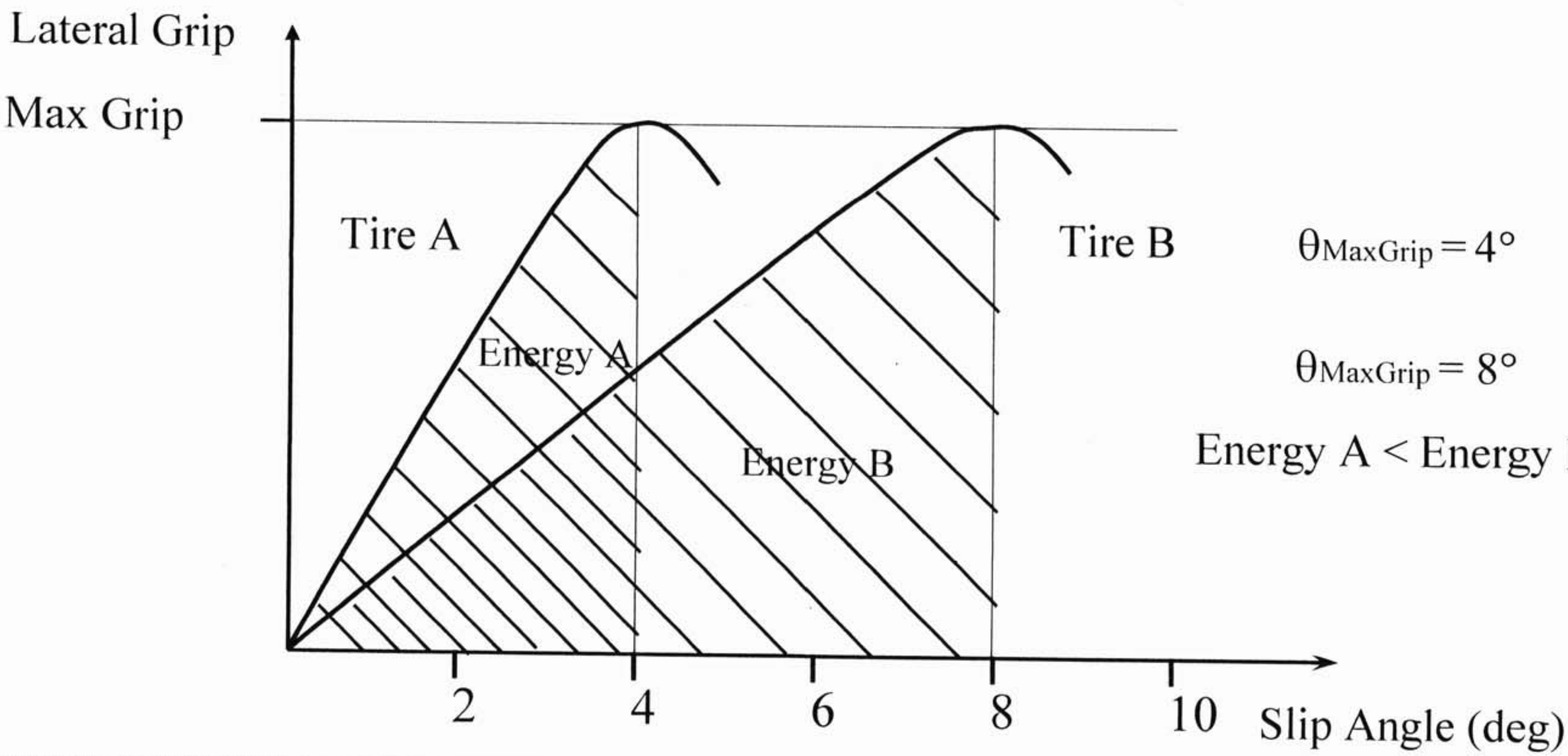








Lateral Grip & Slip Angle for a given Vertical Load



$\theta_{MaxGrip} = 4°$

$\theta_{MaxGrip} = 8°$

Energy A < Energy B

$$E = F(N) \times d(m) = F(N) \times \theta(\text{deg}) \approx \tfrac{1}{2} \times MaxGrip \times \theta_{MaxGrip}$$

Tire A

- Less feeling
- Less waste of energy

faster response

Tire B

- More feeling
- More waste of energy

less wear

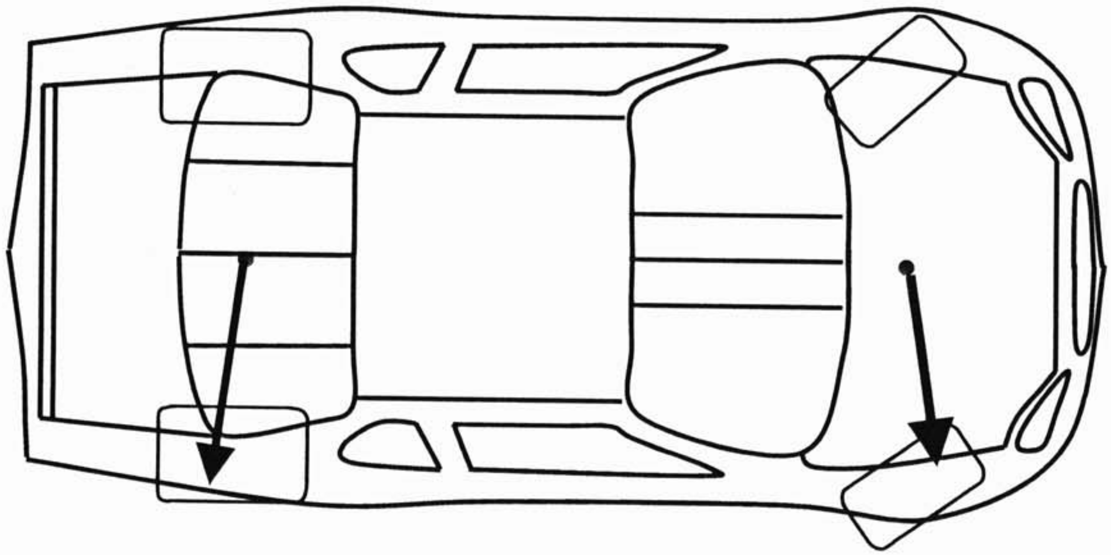
Car Handling feeling VS Slip angle difference

	Front	Rear	Δ	Δ%
SPRINT	40°	44°	4°	10%
Nascar	4°	4.4°	0.4 °	10%
IRL	1°	1.1°	0.1°	10%

Δ%Sprint = Δ% Nascar but:

It is more difficult to feel the Nascar

Evaluating Under and Oversteer with a Front and a Rear Lateral Accelerometers



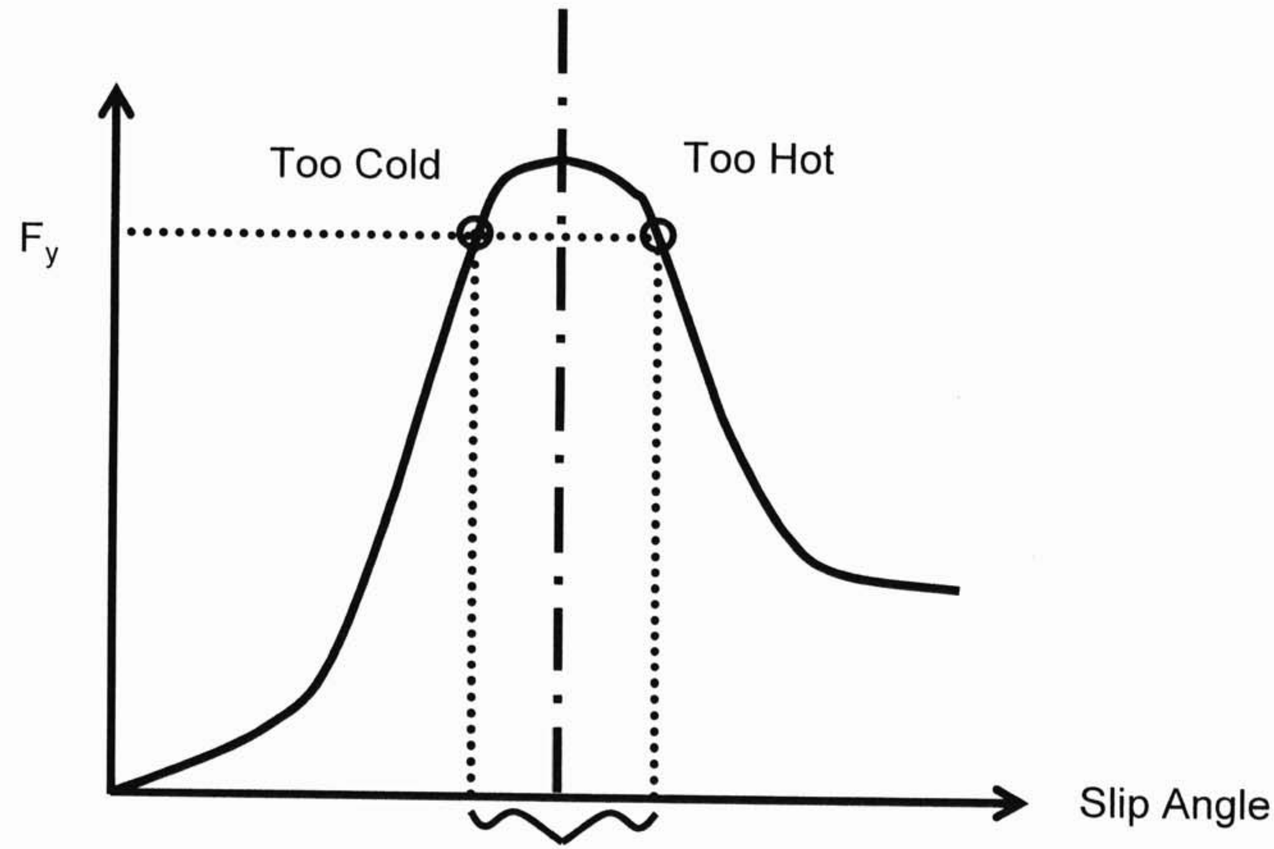
If Rear Lateral Acceleration > Front Lateral Acceleration : Understeer

If Front Lateral Acceleration > Rear Lateral Acceleration : Oversteer

Very useful to analyze the car handling in transients : corner entry and exit

Data Analysis

Effects of Slip Angle and Lateral Grip on Tire temperature



Different SA

But same lateral Grip

Data Analysis

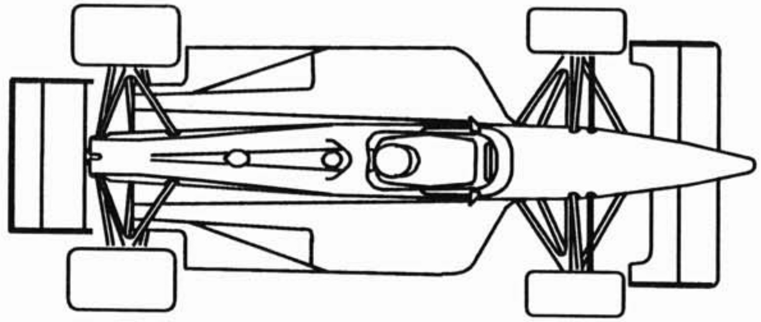
Accessing vehicle balance from tire temperatures and lateral G Force data.

T_F – average of 6 front tire temperature
T_R – average of 6 rear tire temperature

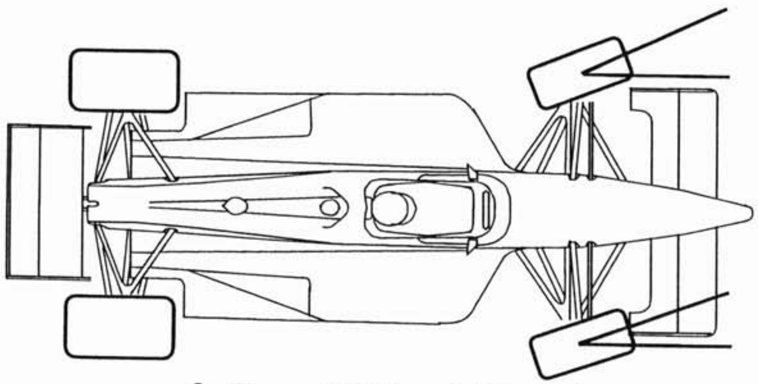
	Lat G_F > Lat G_R O/S	Lat G_F < Lat G_R U/S
$T_F > T_R$	**Rear Too Cold**	**Front Too Hot**
$T_F < T_R$	**Rear Too Hot**	**Front Too Cold**

Tire Lateral Force Sequence in a Corner Introduction to Transient

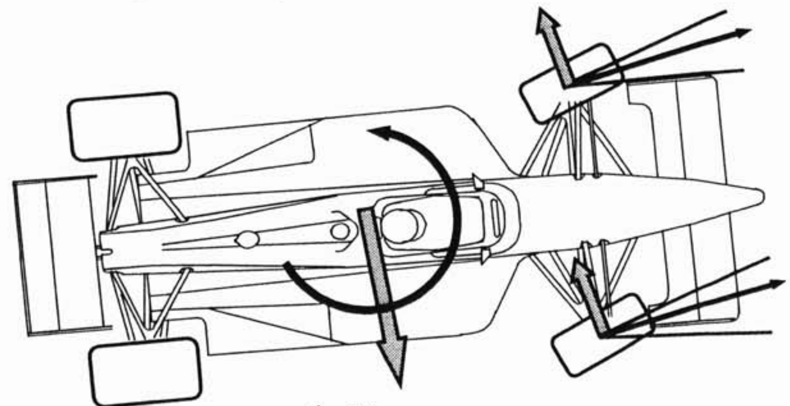
(see slide 15)



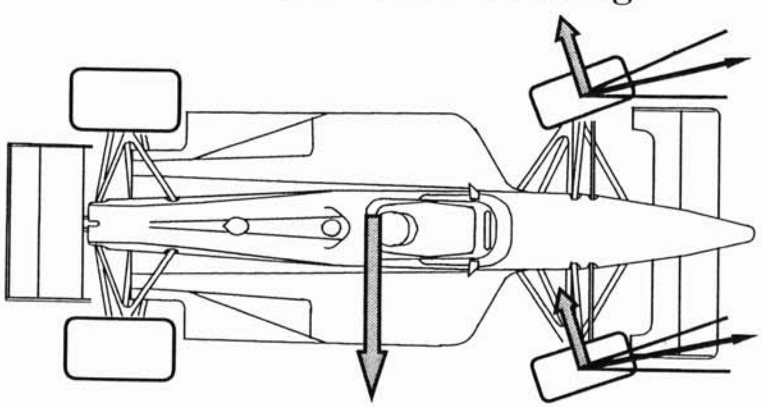
1. Straight away



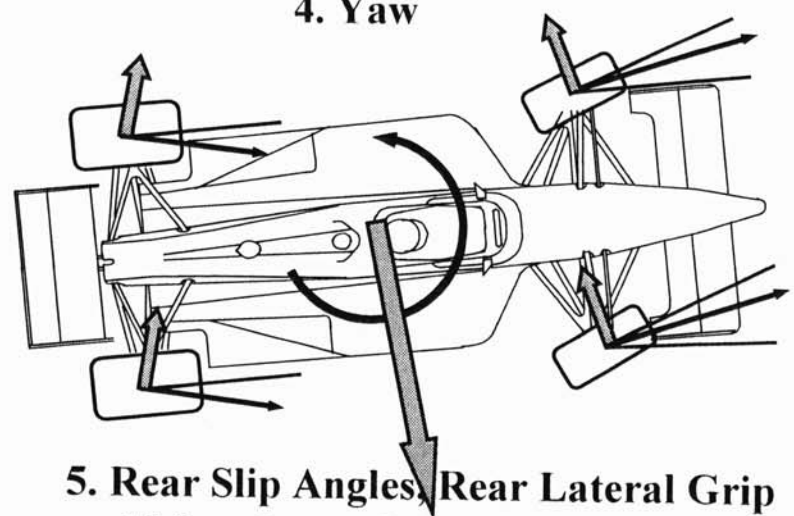
2. Front Wheel Steering



4. Yaw



3. Front Wheel Slip Angle, Front Lateral Grip, Lateral Acceleration



5. Rear Slip Angles, Rear Lateral Grip and More Lateral Acceleration

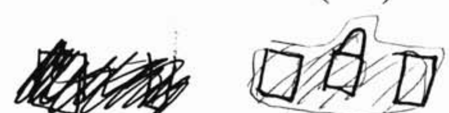
2. Aerodynamics

- Basic Formula
- Aeromaps

Basic Aerodynamic Equation

$$F = 0.5 * d * A * C * S^2$$

- Speed ^{2} $(\text{ft / sec})^2$
- Coefficient of Lift / Drag (non dim)
- Front Area (ft^2)



- Air density (lb / ft^3)
  Fn = Atm. P, Temp.
- Aero Force $(F = \text{lb/ft}^3 \times \text{ft}^2 \times \text{ft}^2/\text{sec}^2 = \text{lb} \times \text{ft / sec}^2)$

$$F = [0.5 * d * A * C * S^2] / 32.174$$

Downforce example

$$F = [0.5 * d * A * Cl * S^2] / 32.174$$

At 50 mph

assumed constant

$F = [0.5 * 0.0765 * 13.75 * 3.2 * ((1.466 * 50)^2)] / 32.174 = 282$ lb

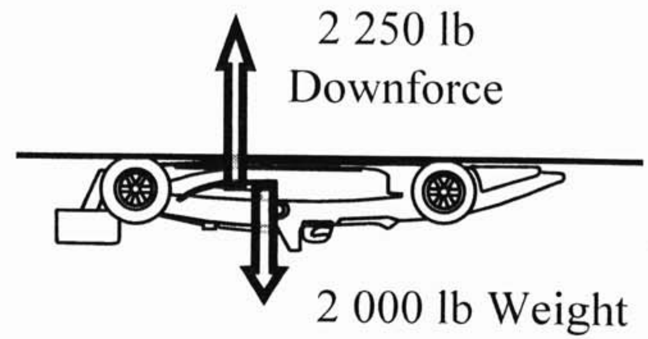
At 50 mph ------------> 282 lb

At 100 mph ------------> 1 125 lb

At 141.2 mph ------------> 2 250 lb

At 200 mph ------------> 4 502 lb

At 250 mph ------------> 7 034 lb



Aeromap

Drag (lb) Vs Front and Rear Ride Height (in)

		Rear Ride Height					
		0.125	0.500	0.875	1.250	1.625	2.000
Front	1.120	969	984	998	1009	1016	1023
Ride	0.875	975	991	1009	1018	1025	1029
Height	0.500	984	998	1014	1023	1032	1036
	0.125	987	1000	1016	1027	1032	1041

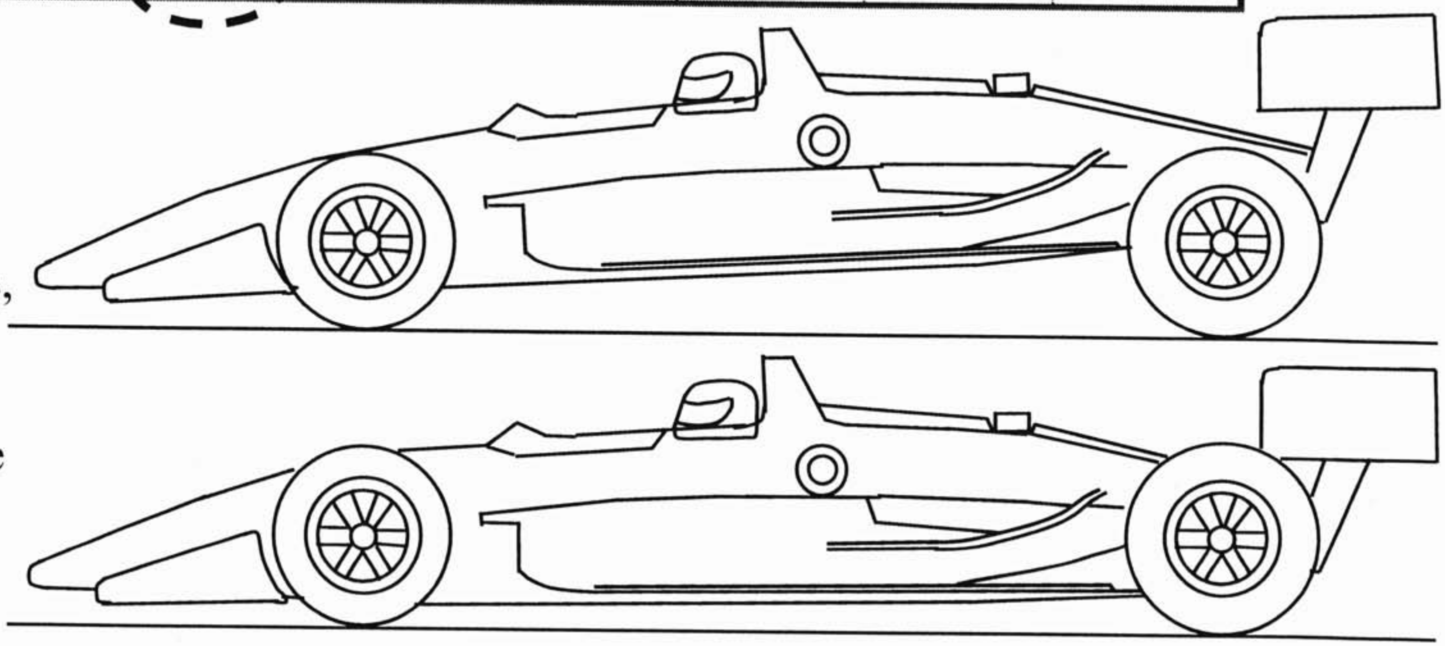
Lift over Drag (efficiency) Vs Front and Rear Ride Height (in)

		Rear Ride Height					
		0.125	0.500	0.875	1.250	1.625	2.000
Front	1.120	1.62	1.93	2.03	2.06	2.02	1.96
Ride	0.875	1.68	1.96	2.08	2.12	2.09	2.05
Height	0.500	1.76	1.62	2.16	2.02	2.17	2.13
	0.125	1.87	2.15	2.26	2.30	2.30	2.25

Aeromap

Aerobalance (% front downforce / total downforce)

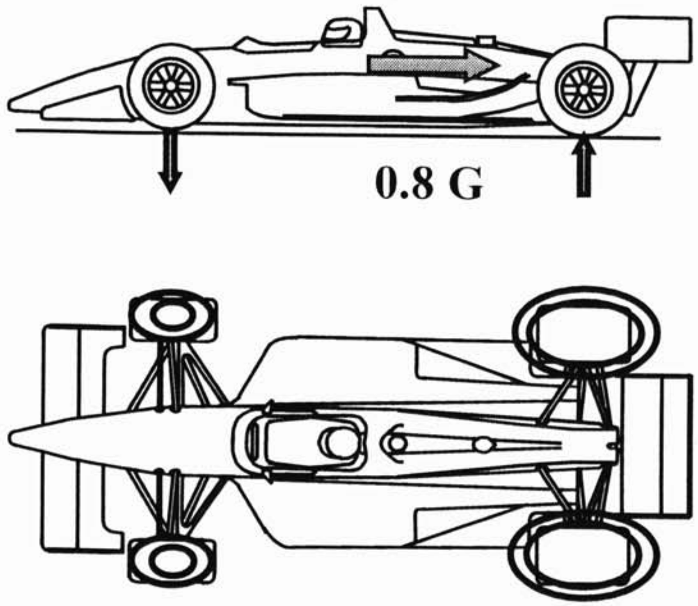
		Rear Ride Height					
		0.125	0.500	0.875	1.250	1.625	2.000
Front	1.120	34.07	32.98	33.01	33.48	35.14	36.54
Ride	0.875	36.05	35.28	35.27	36.20	37.53	39.08
Height	0.500	38.80	37.87	37.83	38.33	39.58	41.21
	0.125	41.26	40.66	40.92	41.67	43.37	45.30



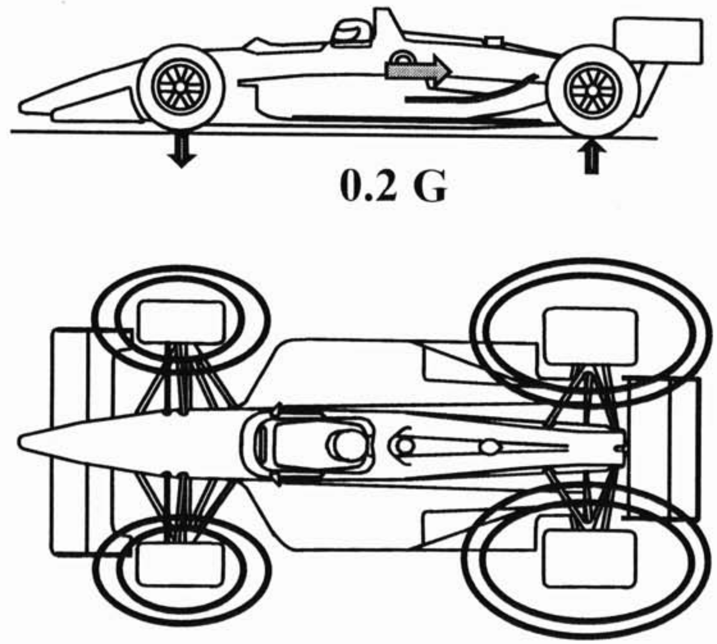
Rule of thumb

For one step of front ride height variations, we need 3 or 5 steps of rear ride height variations to keep the same aerodynamic balance.

Acceleration exit of slow corner

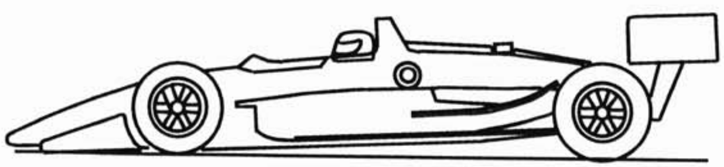


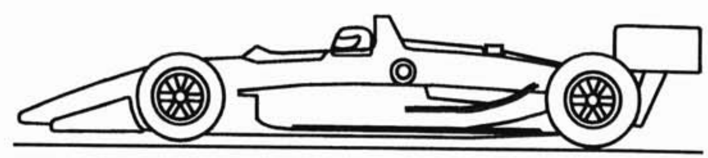
Acceleration exit faster corner



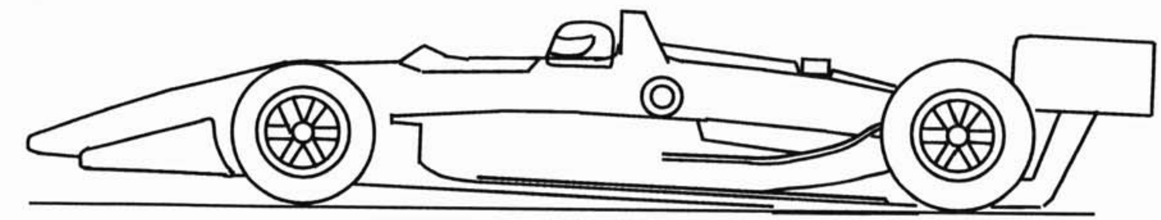
⇒ Much more potential for power understeer at the exit of slow corner

⇒ Balanced with aerodynamic downforce distribution, which is a function of front and rear ride height

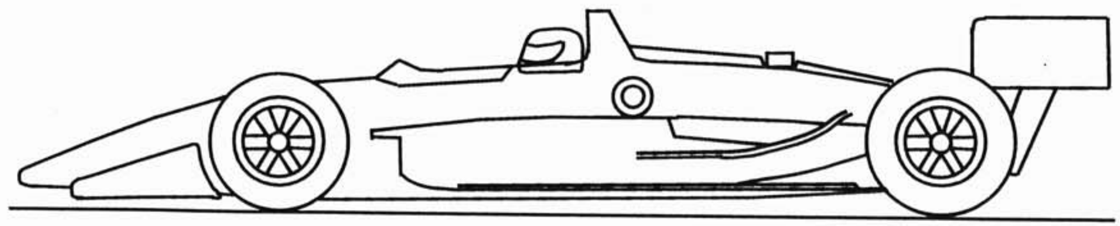




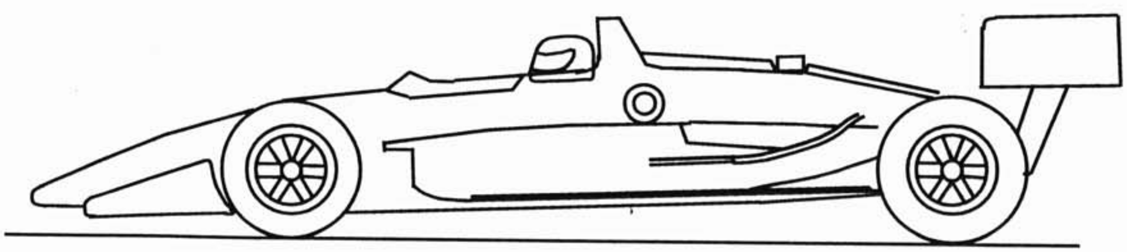
Ideal Ride Heights



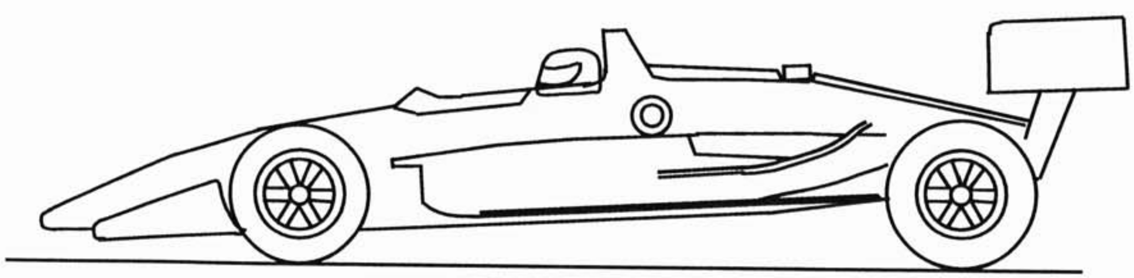
Straight Away



High Speed Corner



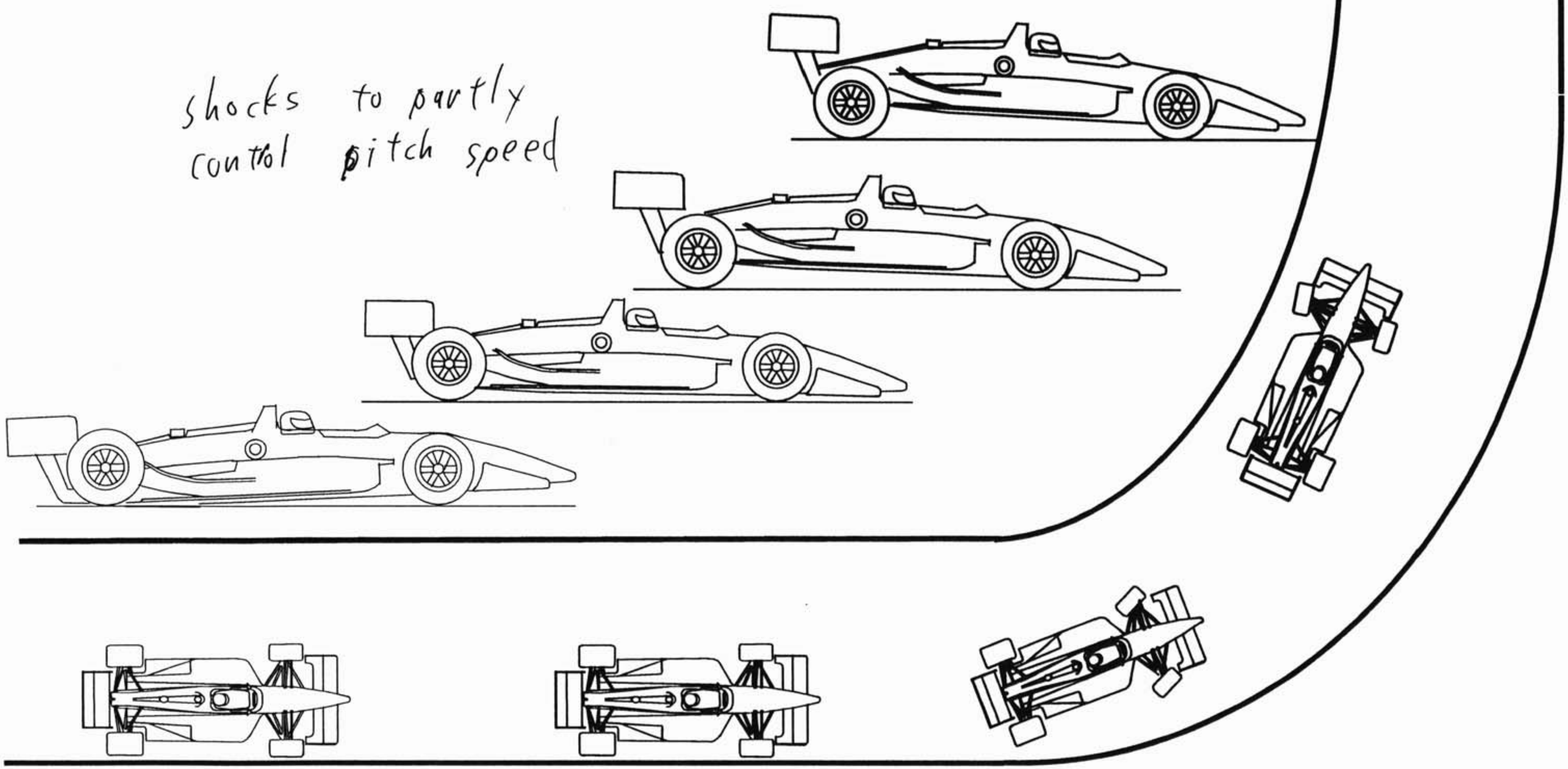
Medium Speed Corner



Low Speed Corner

The pitch speed and ride height variations will be conditioned by the change of front and rear aerodynamic forces and the way shocks are set to resist this force changes.

shocks to partly control pitch speed



Basic Aerodynamic Equation (again)

$$F = 0.5 * d * A * C * S^2$$

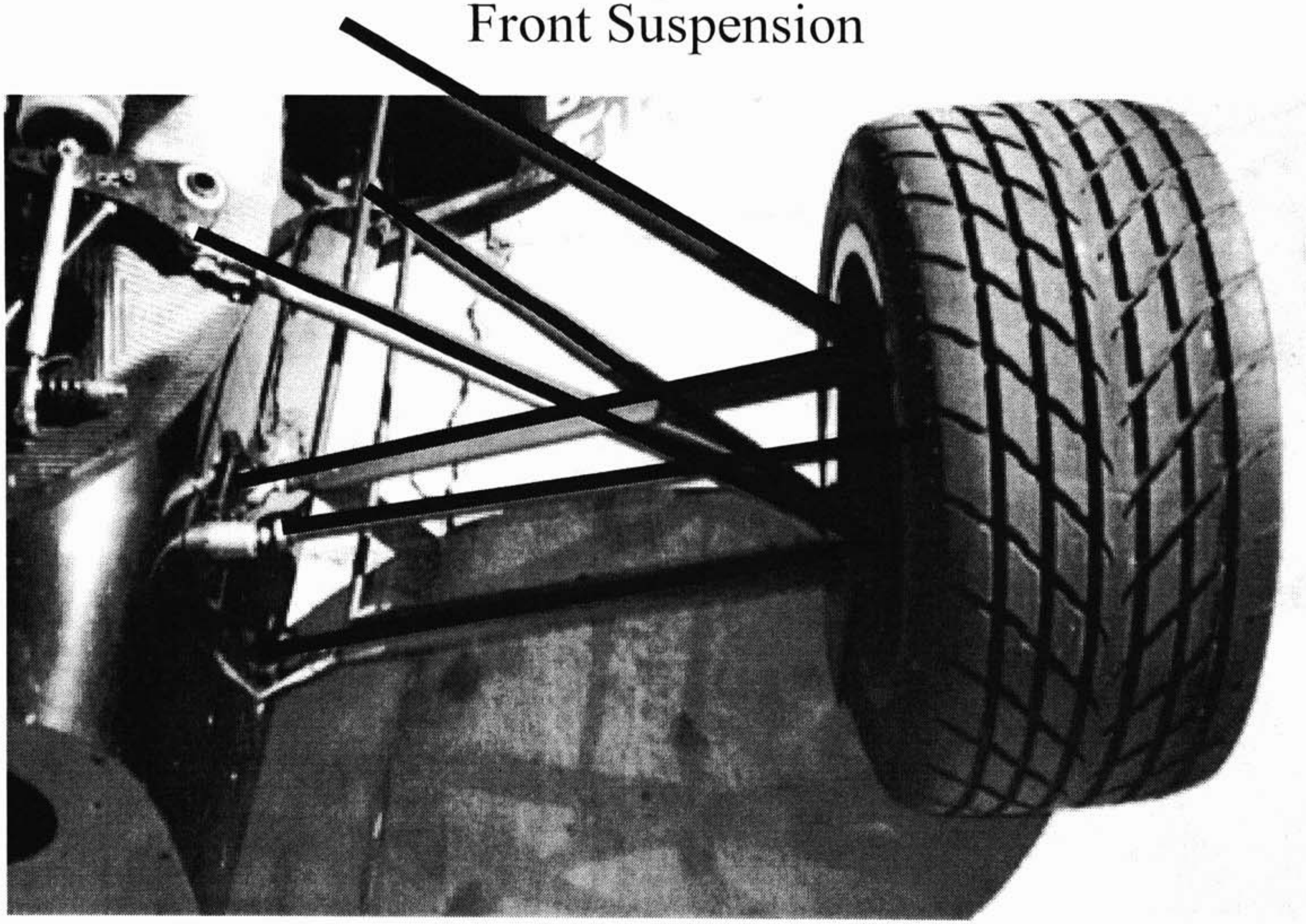
- S^2 → Speed ^{2} $(ft / sec)^2$
- C → Coefficient of Lift / Drag (non dim)
- A → Front Area (ft^2)
- d → Air density (lb/ft^3)
  Fn = Atm. P, Temp.
- F → Aero Force $(F = lb/ft^3 \times ft^2 \times ft^2/sec^2 = lb \times ft / sec^2)$

$$F = [0.5 * d * A * C * S^\wedge 2] / 32.174$$

3. Kinematics

- Definitions
- Suspension DOF (Degrees of Freedom)
- Front and Rear View
- Side View
- Plan View
- 3D Kinematics
- Steering Effects on Camber and Ride Height
- Kinematics of Other Suspension Types

Front Suspension



Top Suspension Wishbone

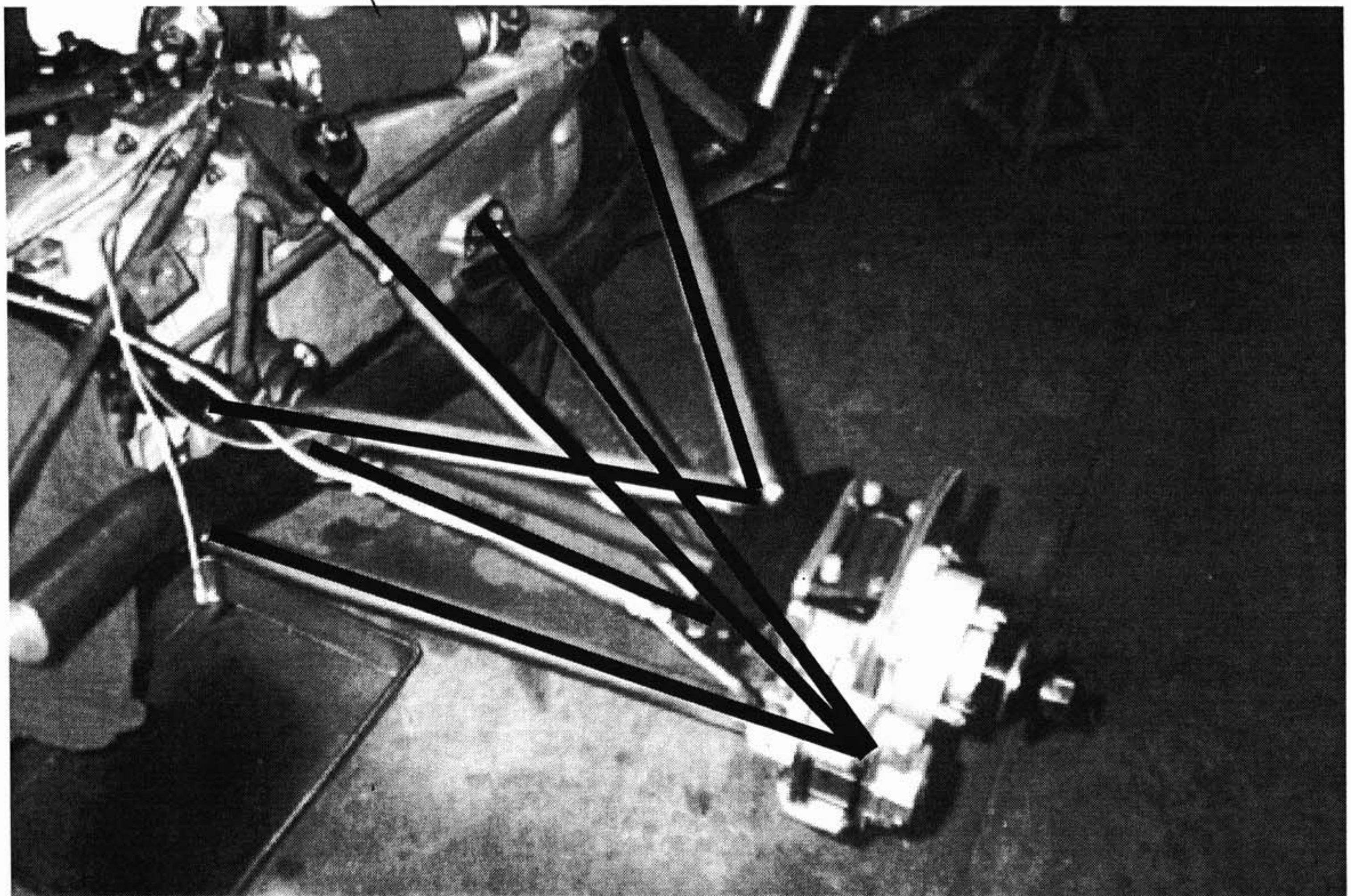
Steering Arm

Bottom Suspension Wishbone

Pushrod

protection from stray materials

Rear Suspension



Top Suspension Wishbone

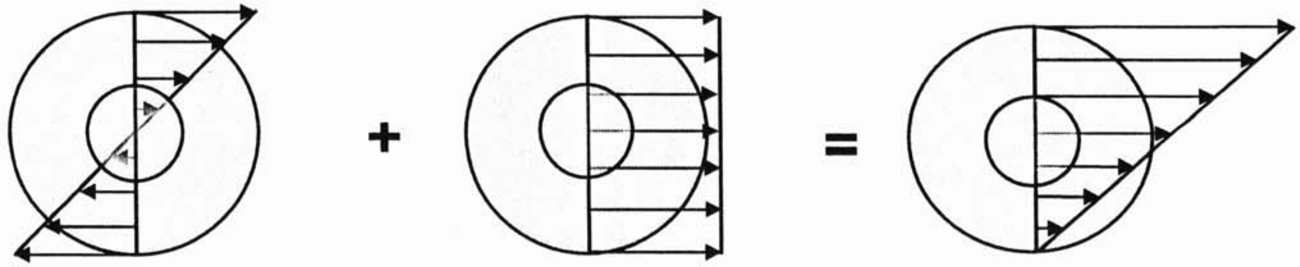
Steering Arm use the same handed-thread but w/ different pitches

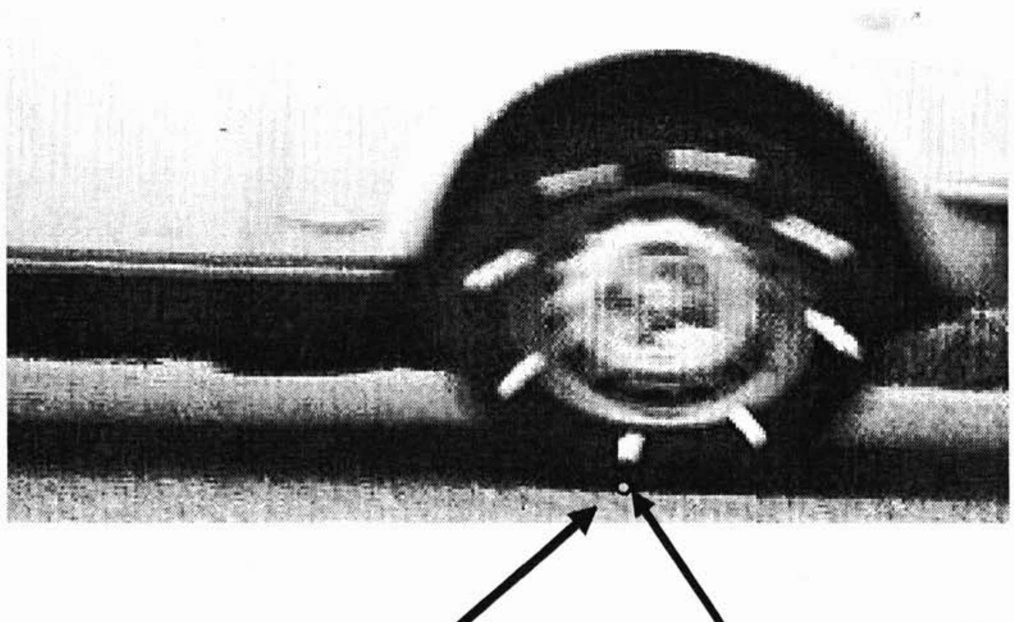
Bottom Suspension Wishbone

Pushrod

Front and Rear View 2D Kinematics

The Instantaneous Centre of Rotation





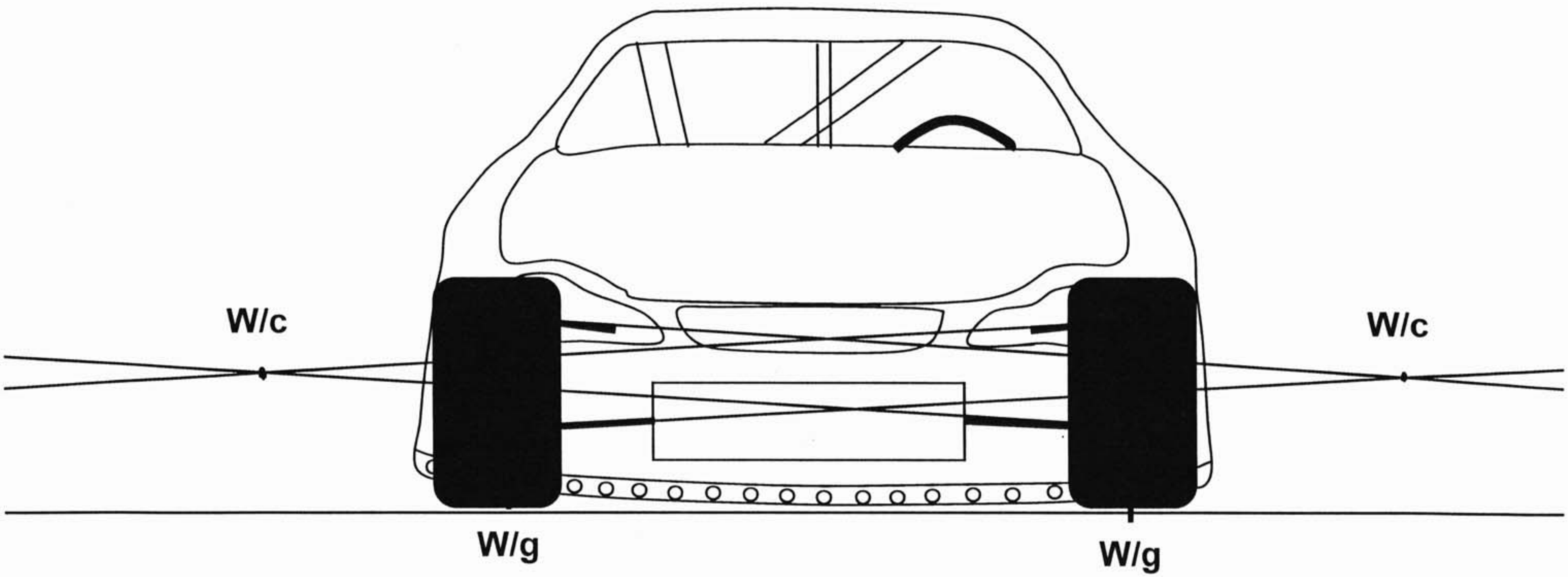
Instantaneous Centre of Rotation

Instantaneous Speed = 0

wheel - ground

Front and Rear View Kinematics

Instantaneous center of rotation of the wheel about the ground
Instantaneous center of rotation of the wheel about the chassis

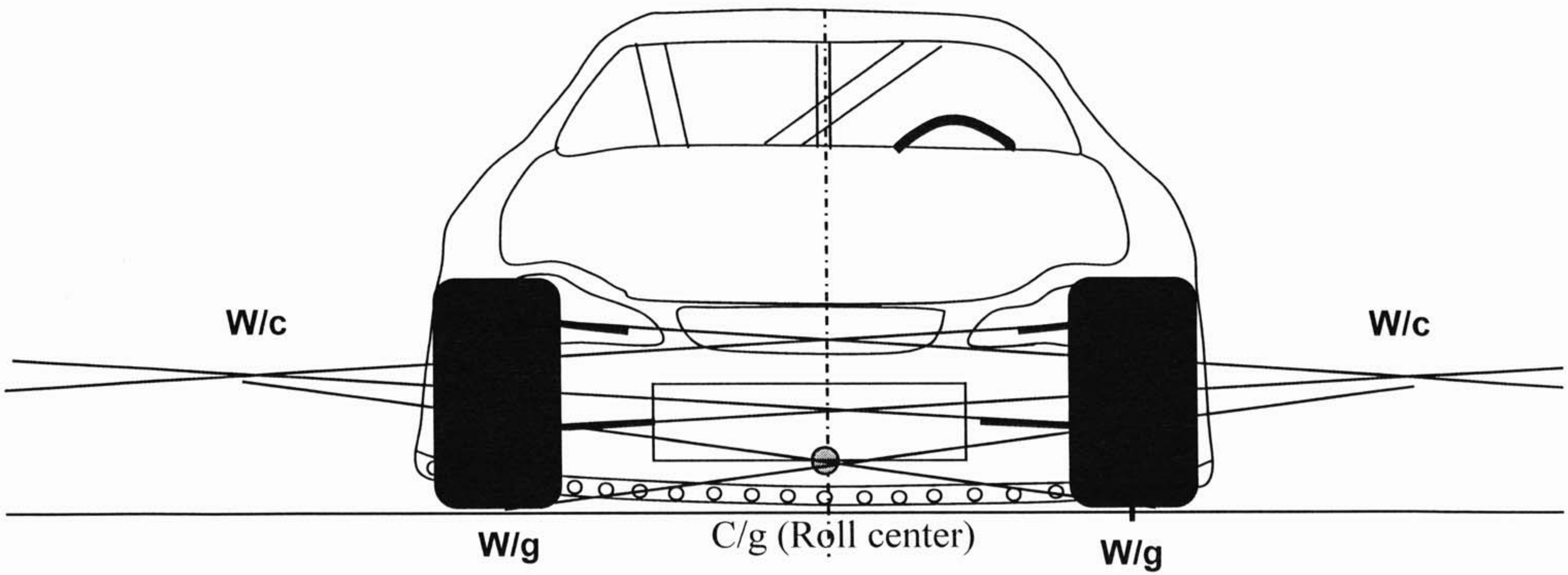


Front and Rear View Kinematics

Instantaneous center of rotation of the wheel about the ground

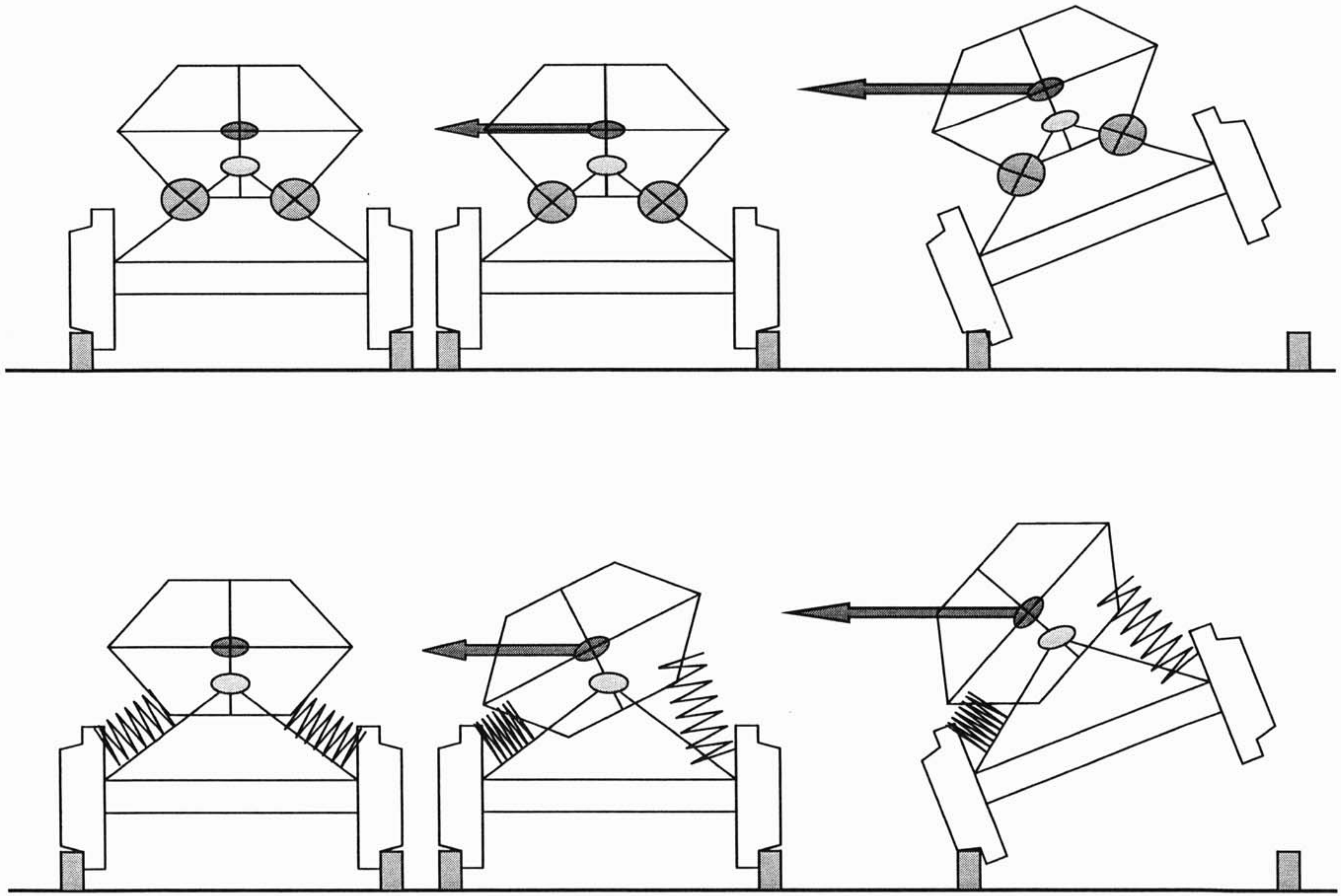
Instantaneous center of rotation of the wheel about the chassis

Instantaneous center of rotation of the chassis about the ground *(roll center)*



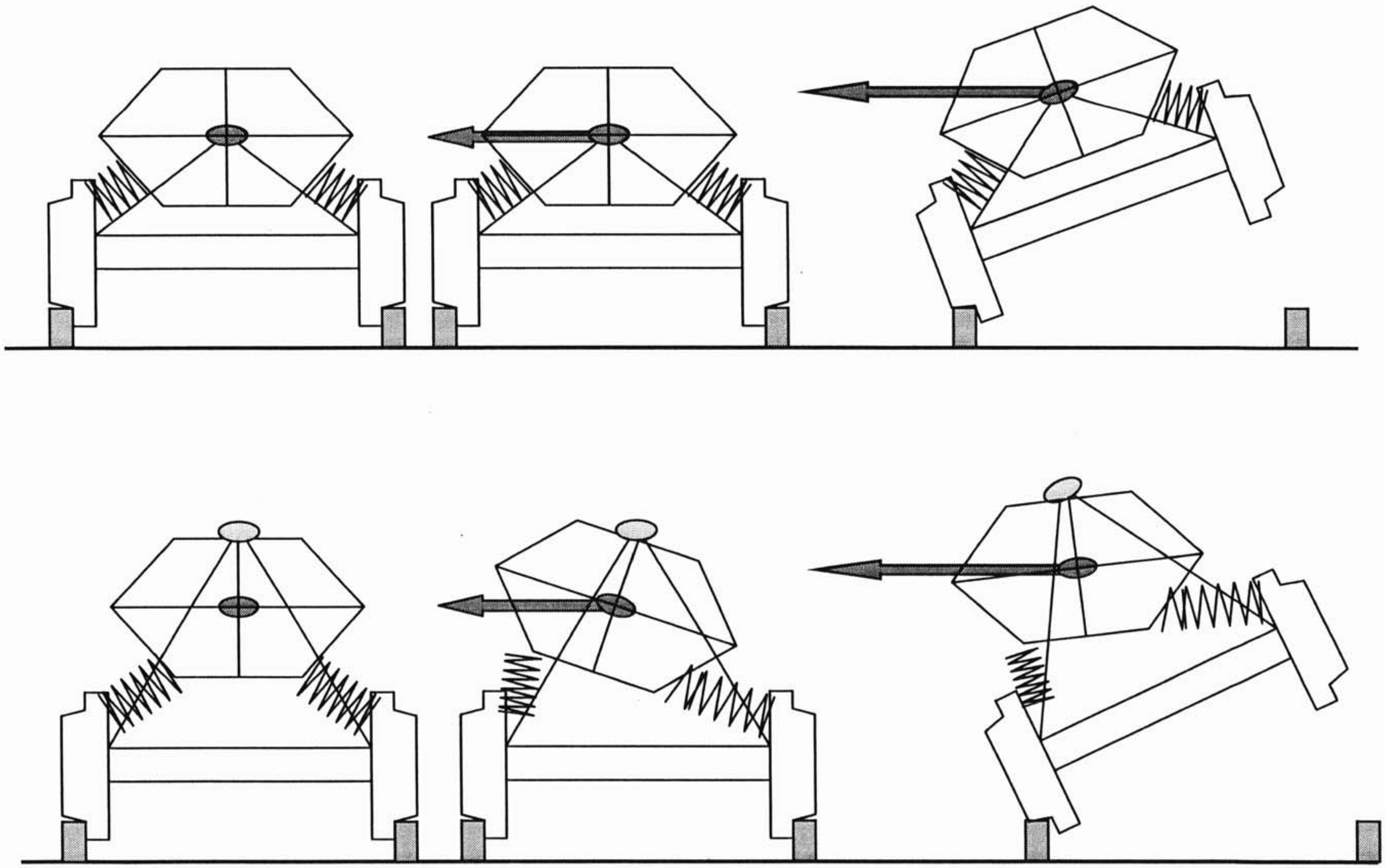
Roll

Front view

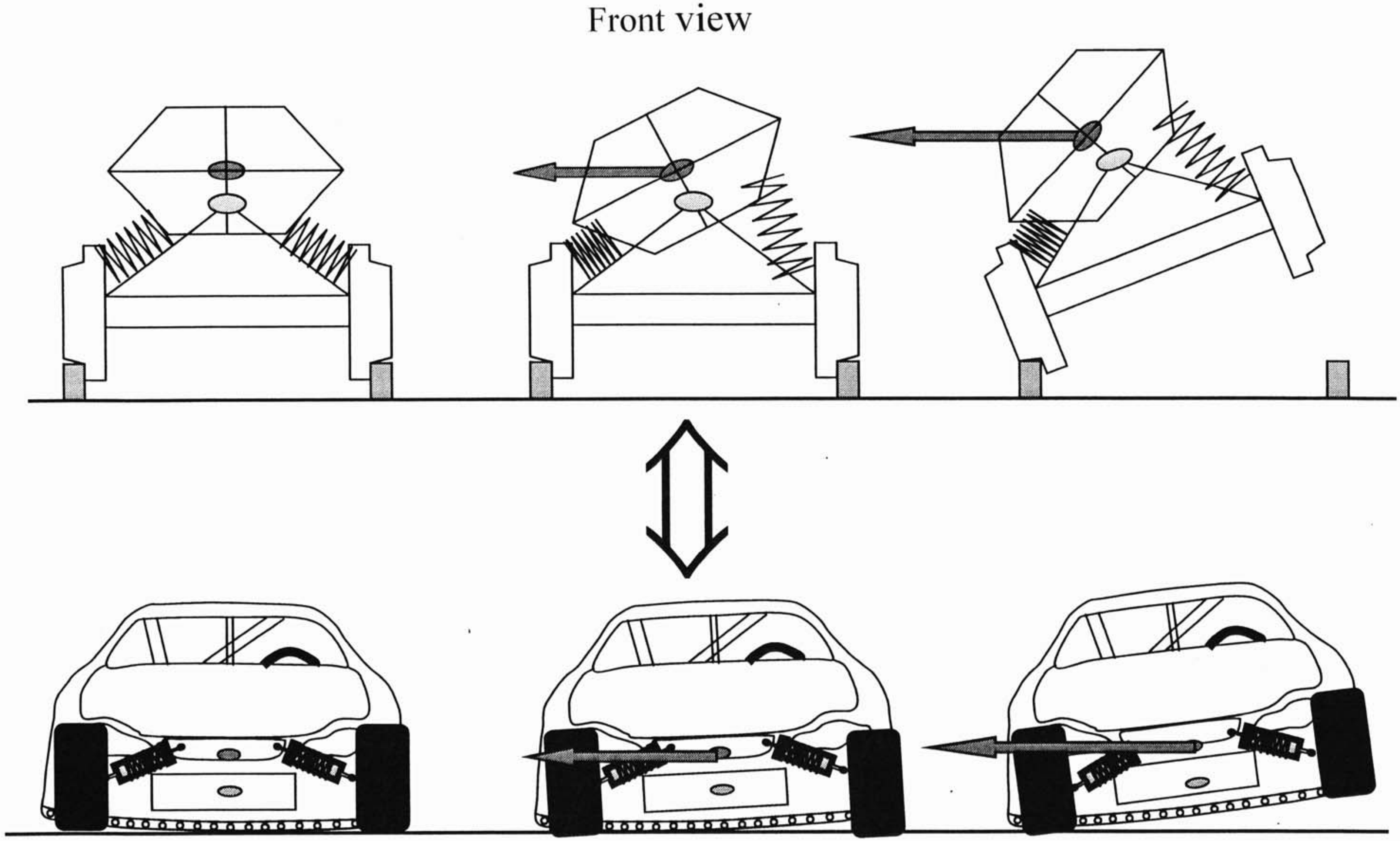


Roll

Front view

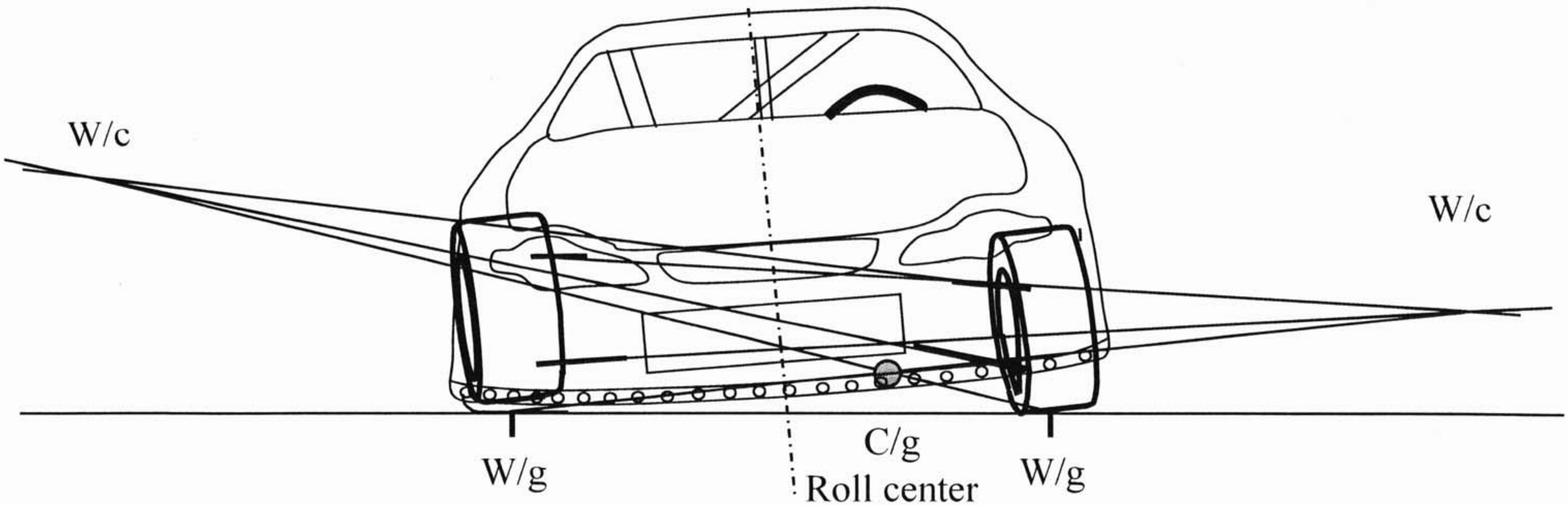


Roll



Front and Rear View Kinematics

The roll center is not always in the middle of the car : example of roll



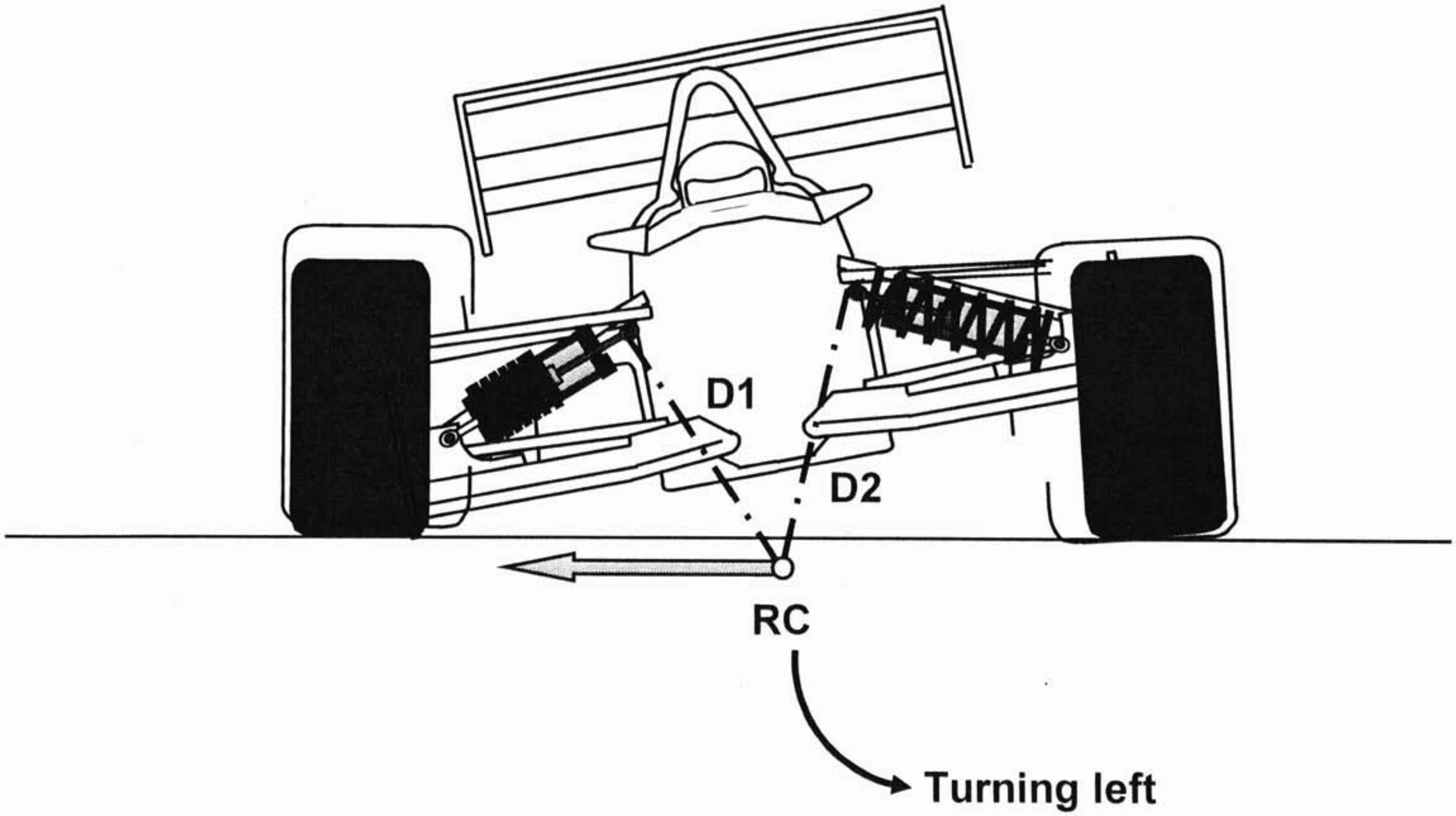
<u>Roll center definition</u>

The Chassis Roll Center is the point in the vertical plane (which passes through the wheel center points) at which transverse forces can be exerted on the sprung mass without kinematics roll angle occurring.

The body roll center is therefore the point around which the body begins to roll when a lateral force acts. The reaction forces are absorbed between wheels and body though suspension.

Introduction to the Roll Centre Problem (1)

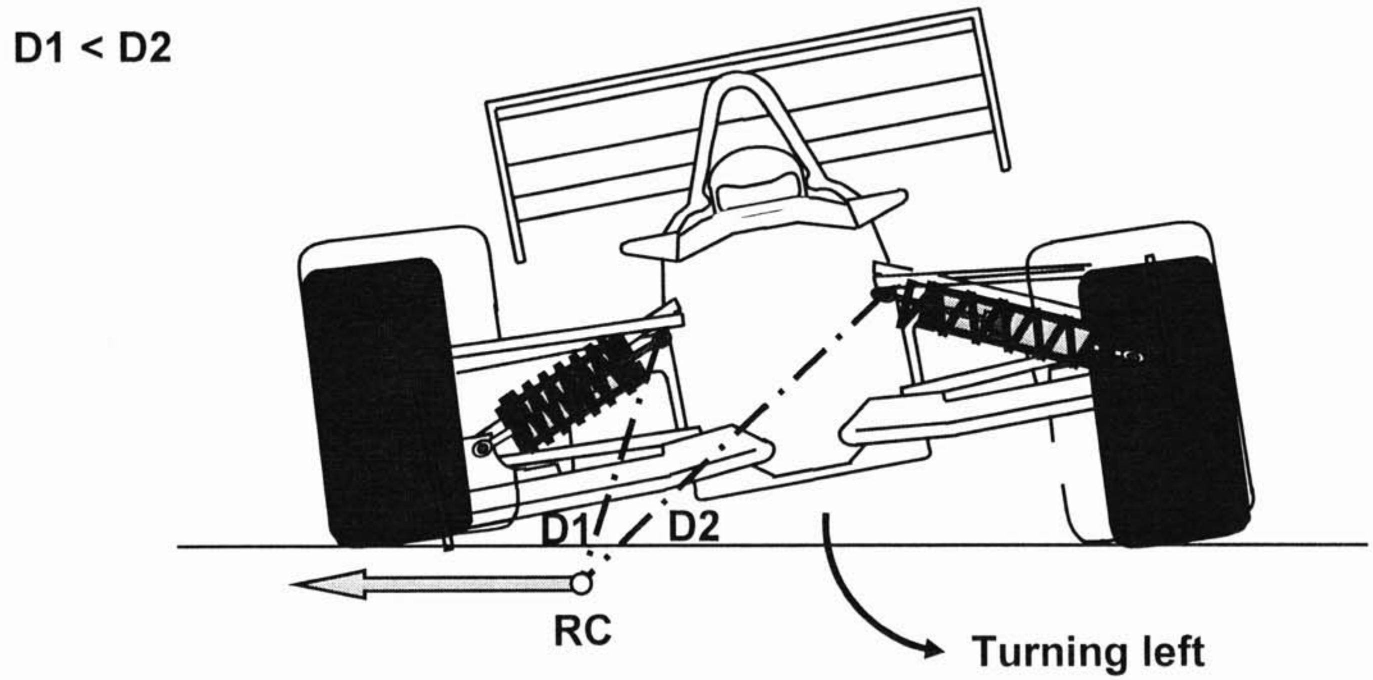
Roll Centre in the Middle of the Car



Right damper is in compression and left damper is in rebound

Introduction to the Roll Centre Problem (2)

Roll Centre Moving Towards the Outside Wheel

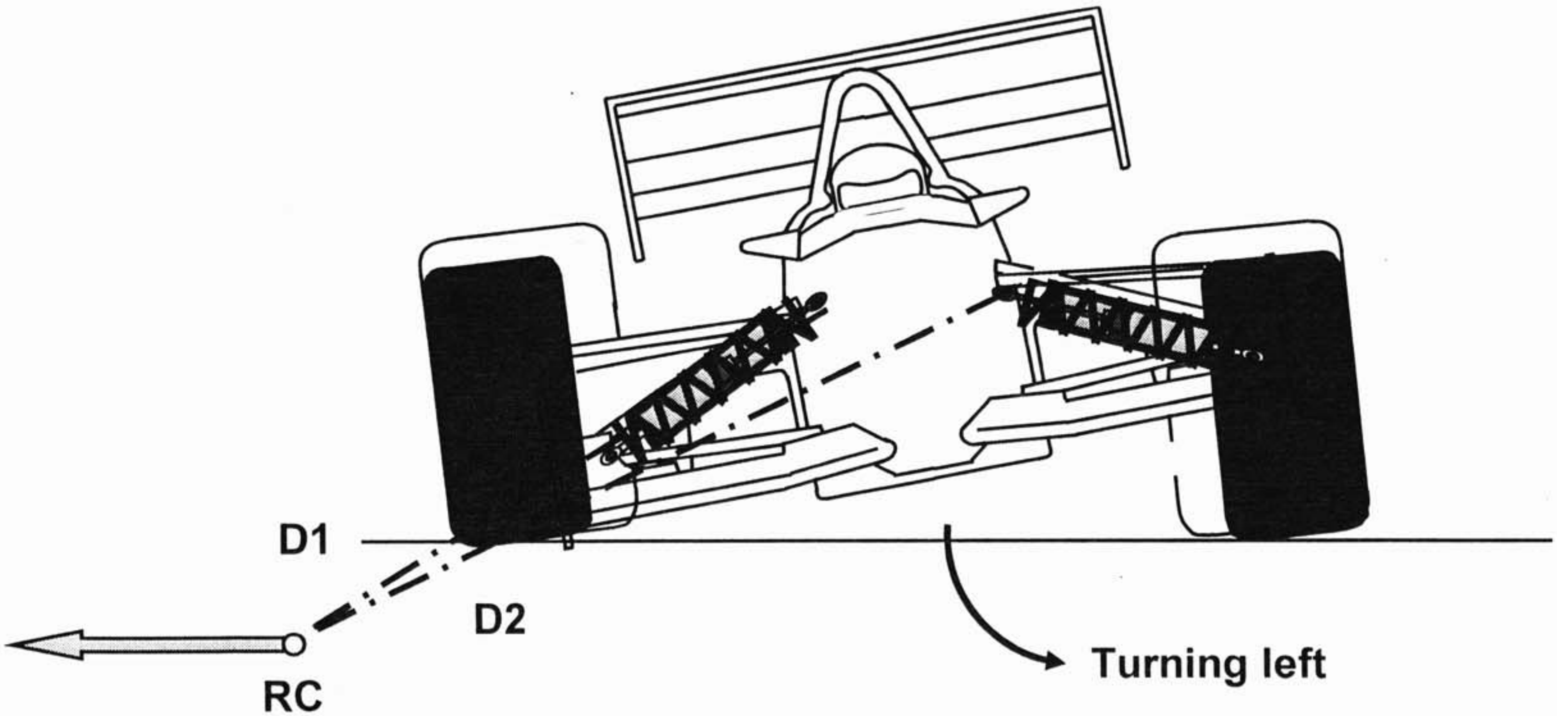


Right damper is in less compression and left damper is more rebound

Having the roll centre closer to one corner of the car and inside the track, is like having stiffer springs in that corner. This is because the kinematics is limiting the spring movement

Introduction to the Roll Centre Problem (3)

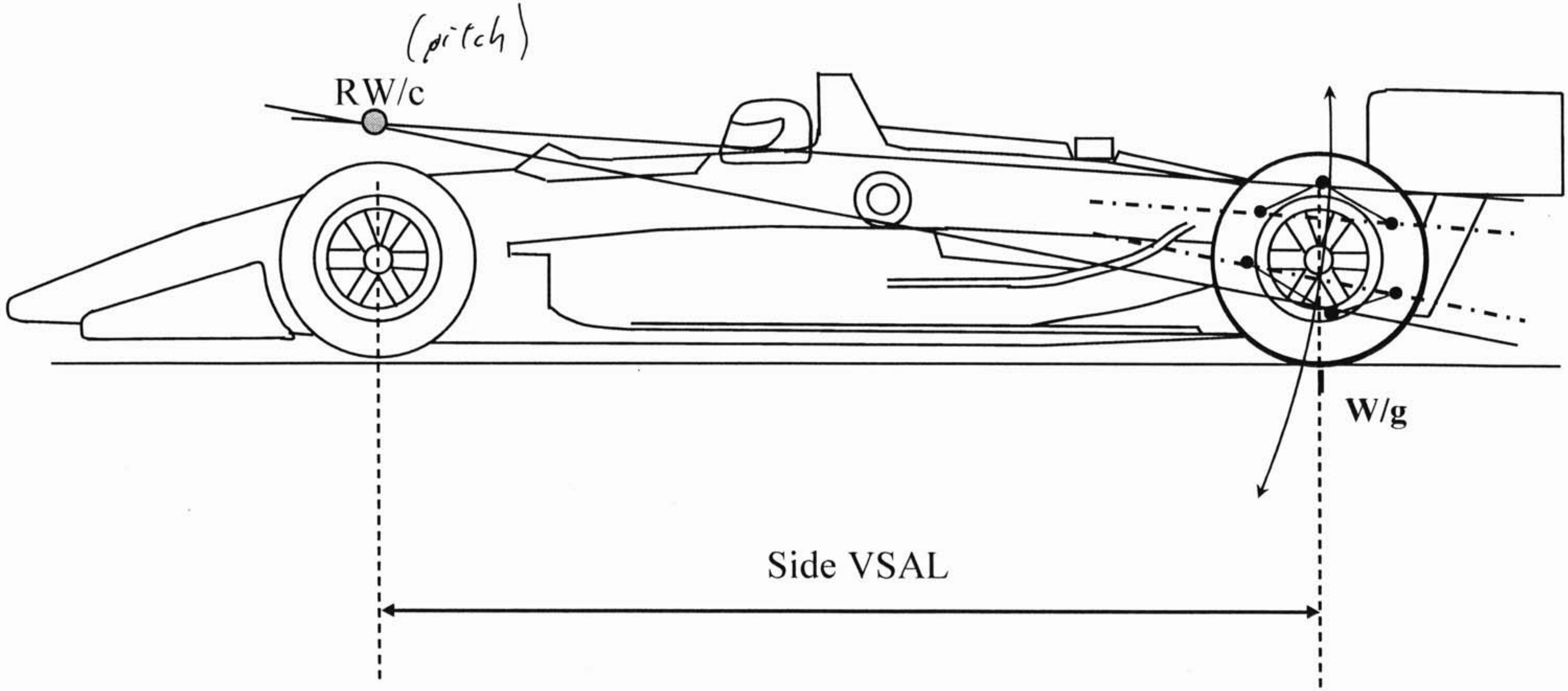
Roll Centre Outside the Car



Both left and right dampers are in rebound

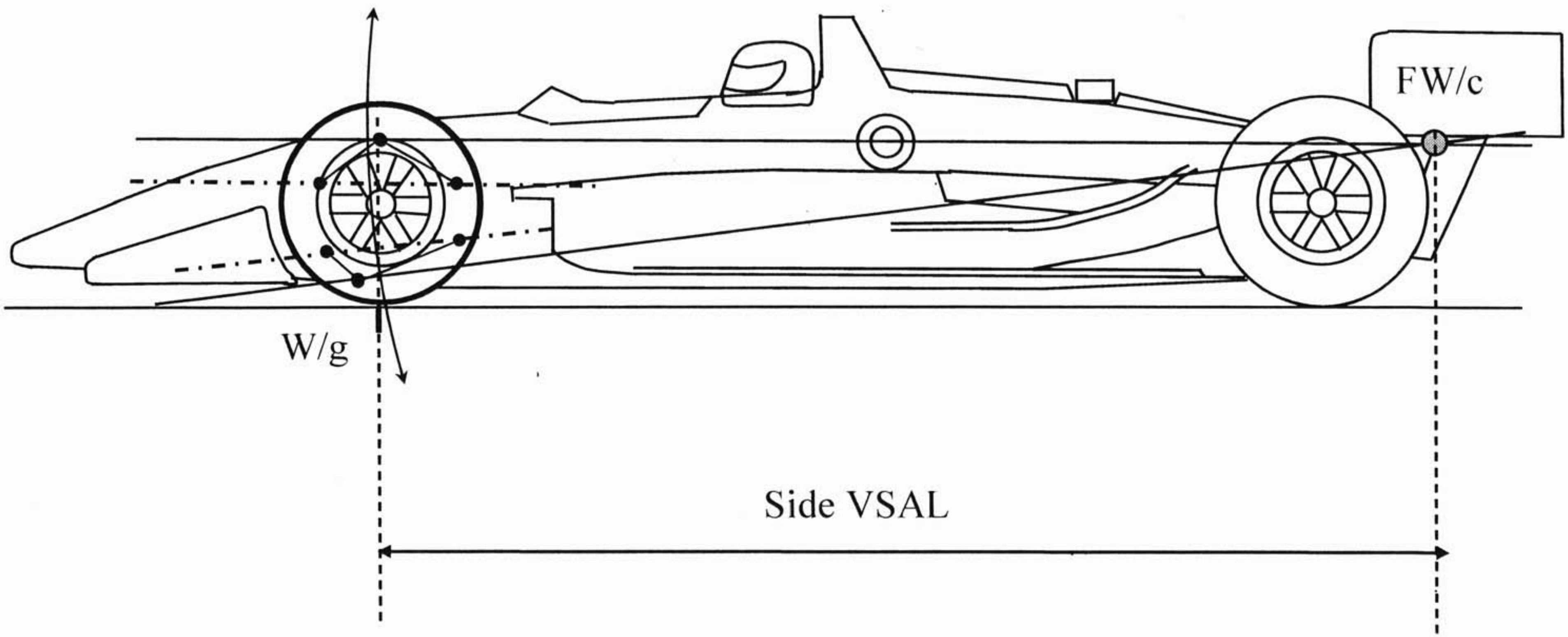
Side View Kinematics

Instantaneous center of rotation of the rear wheel about the ground
Instantaneous center of rotation of the rear wheel about the chassis



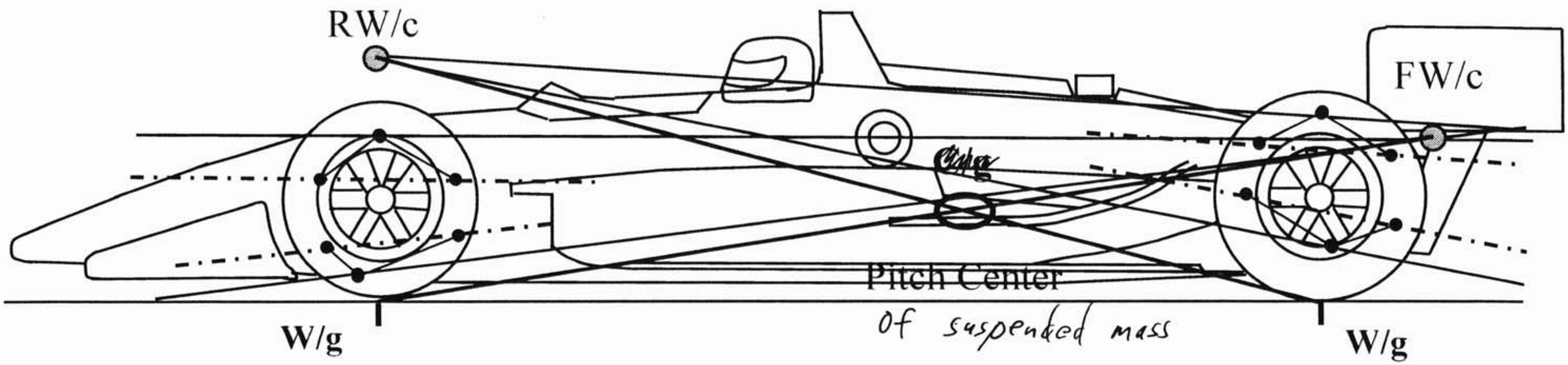
Side View Kinematics

Instantaneous center of rotation of the front wheel about the ground
Instantaneous center of rotation of the front wheel about the chassis



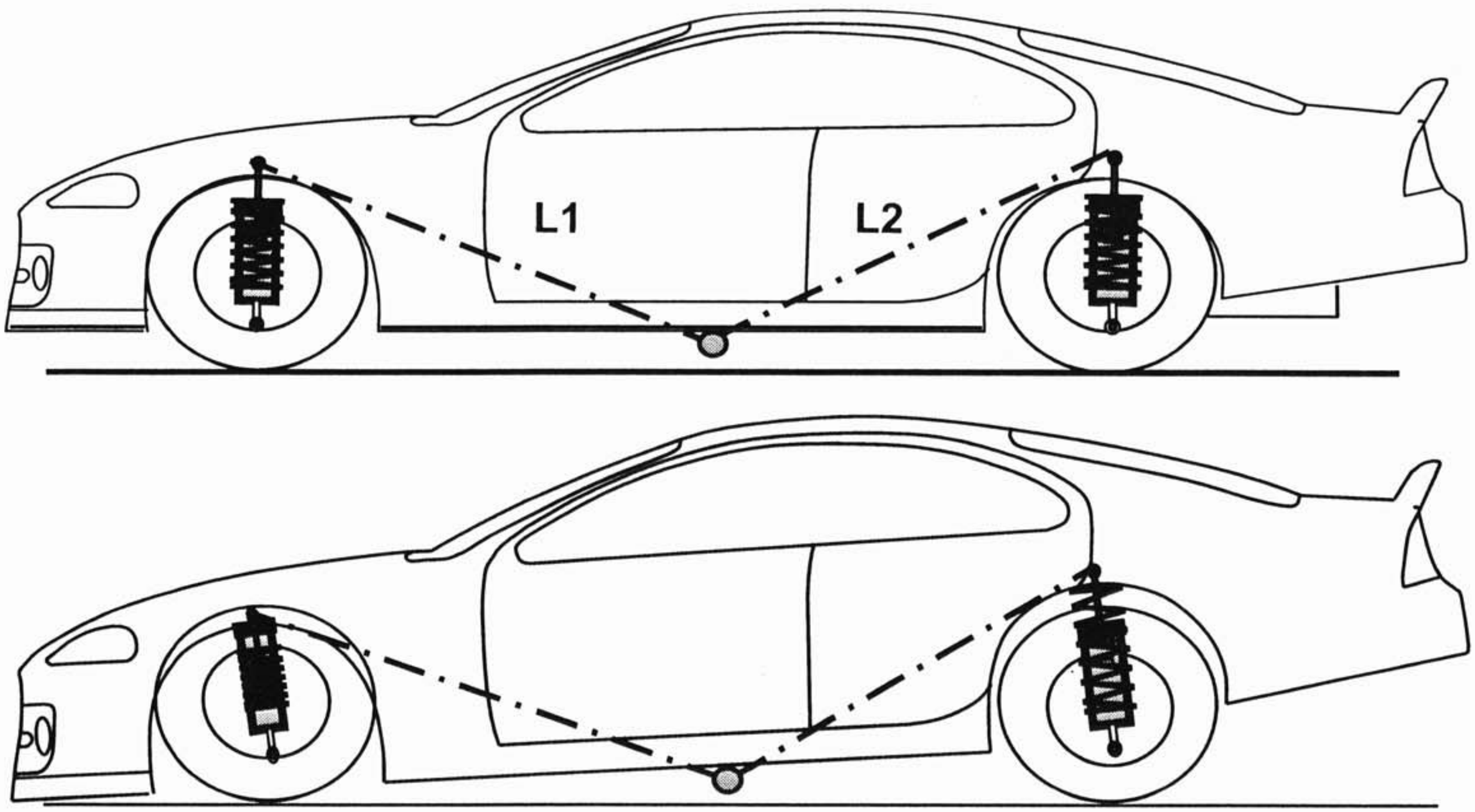
Side View Kinematics

Instantaneous center of rotation of the chassis about the ground *(pitch center)*



Introduction to the Pitch Center Problem

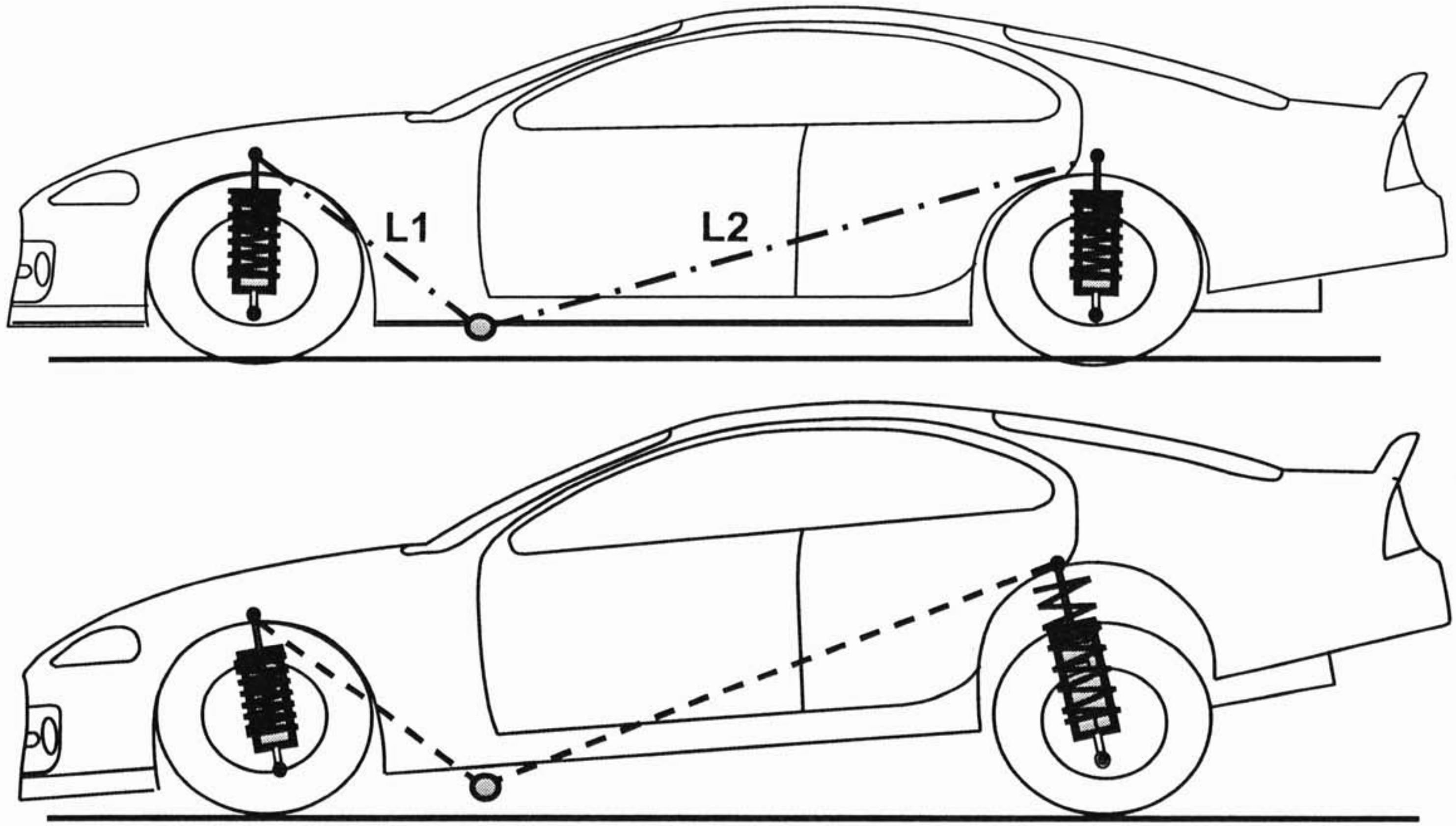
E.g.1 Pitch Center in the roughly in the middle of the car



As lengths a and b are the same, front bump compression and rear rebound extension have the same value

Introduction to the Pitch Center Problem

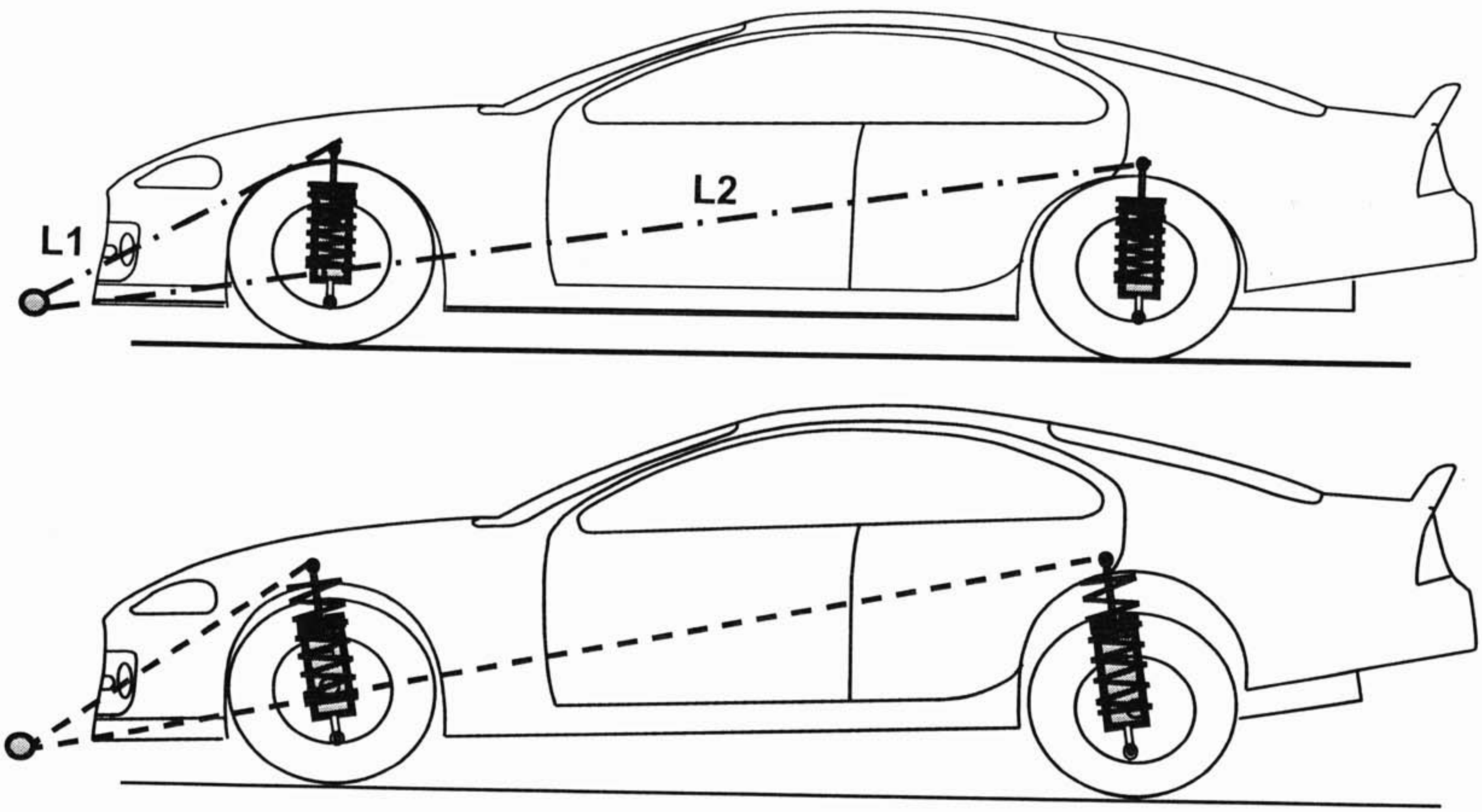
E.g.2 Pitch Center close to the front end



Less compression on the front and more rebound in the rear as lever lengths L1 and L2 are different

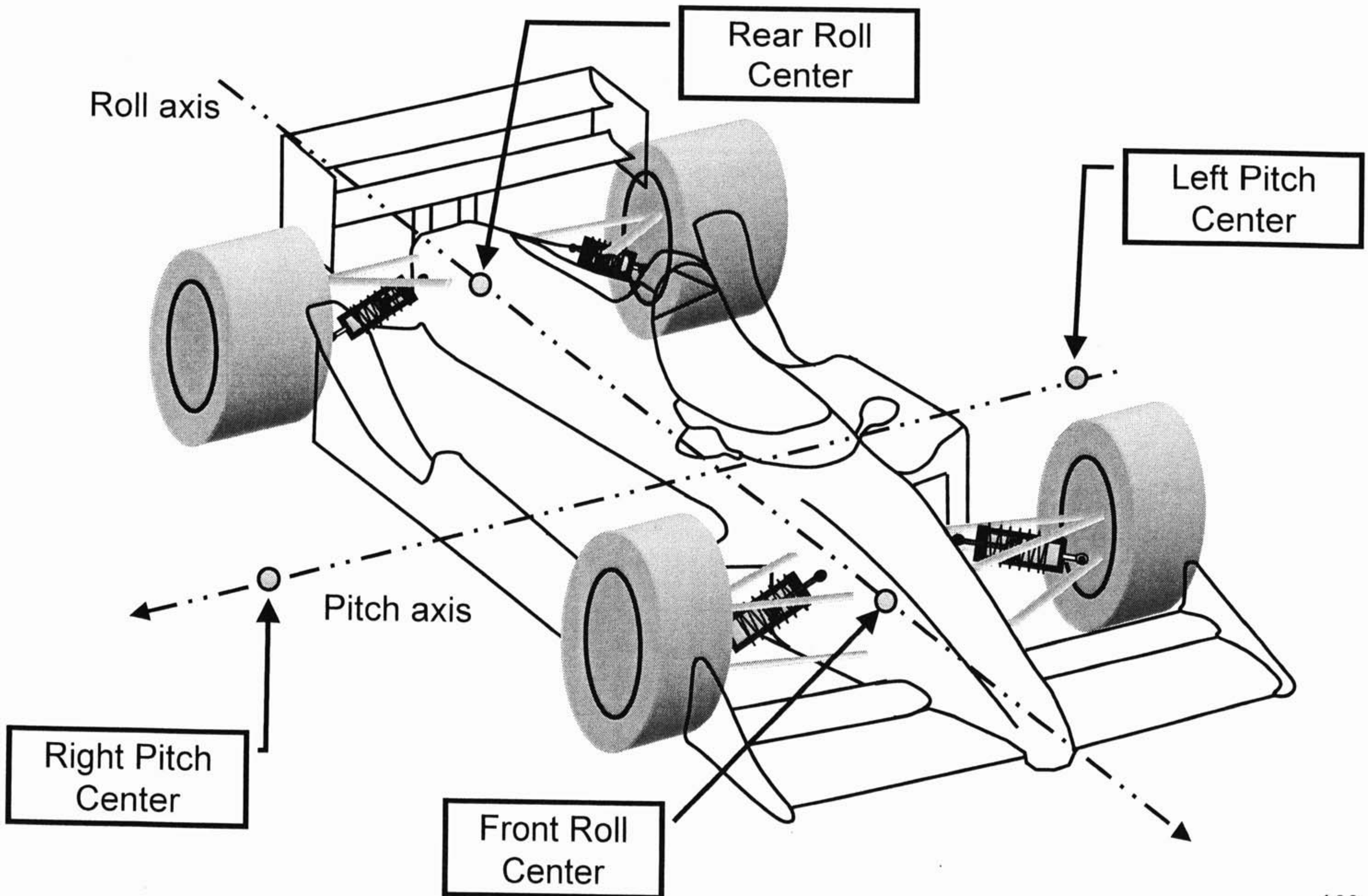
Introduction to the Pitch Center Problem

E.g.3 Pitch Center in front the front axis



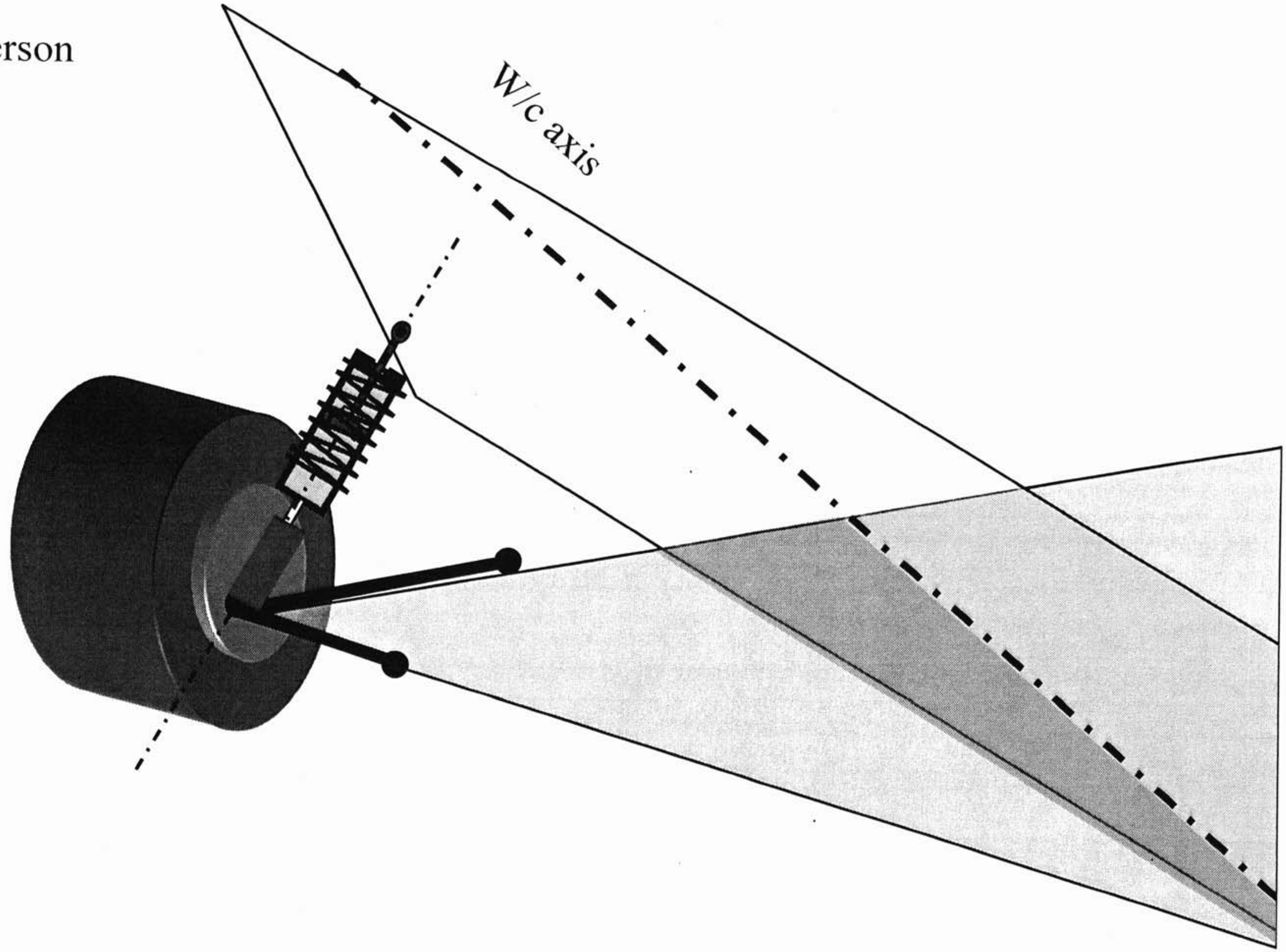
Both spring and damper are in rebound by an amount dependent on the lever arms L1 and L2

Roll and Pitch Axis



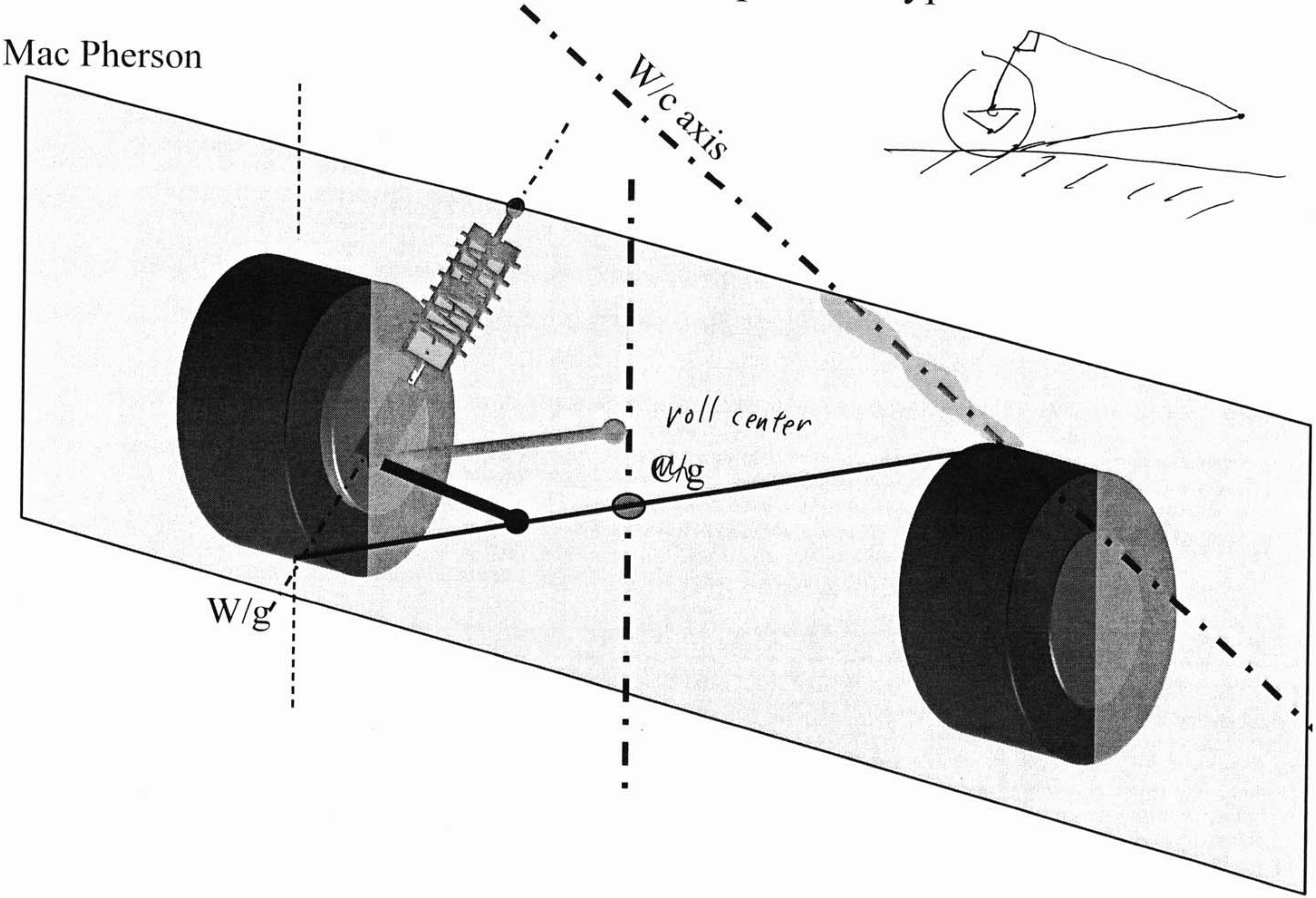
Kinematics of other suspension types

Mac Pherson

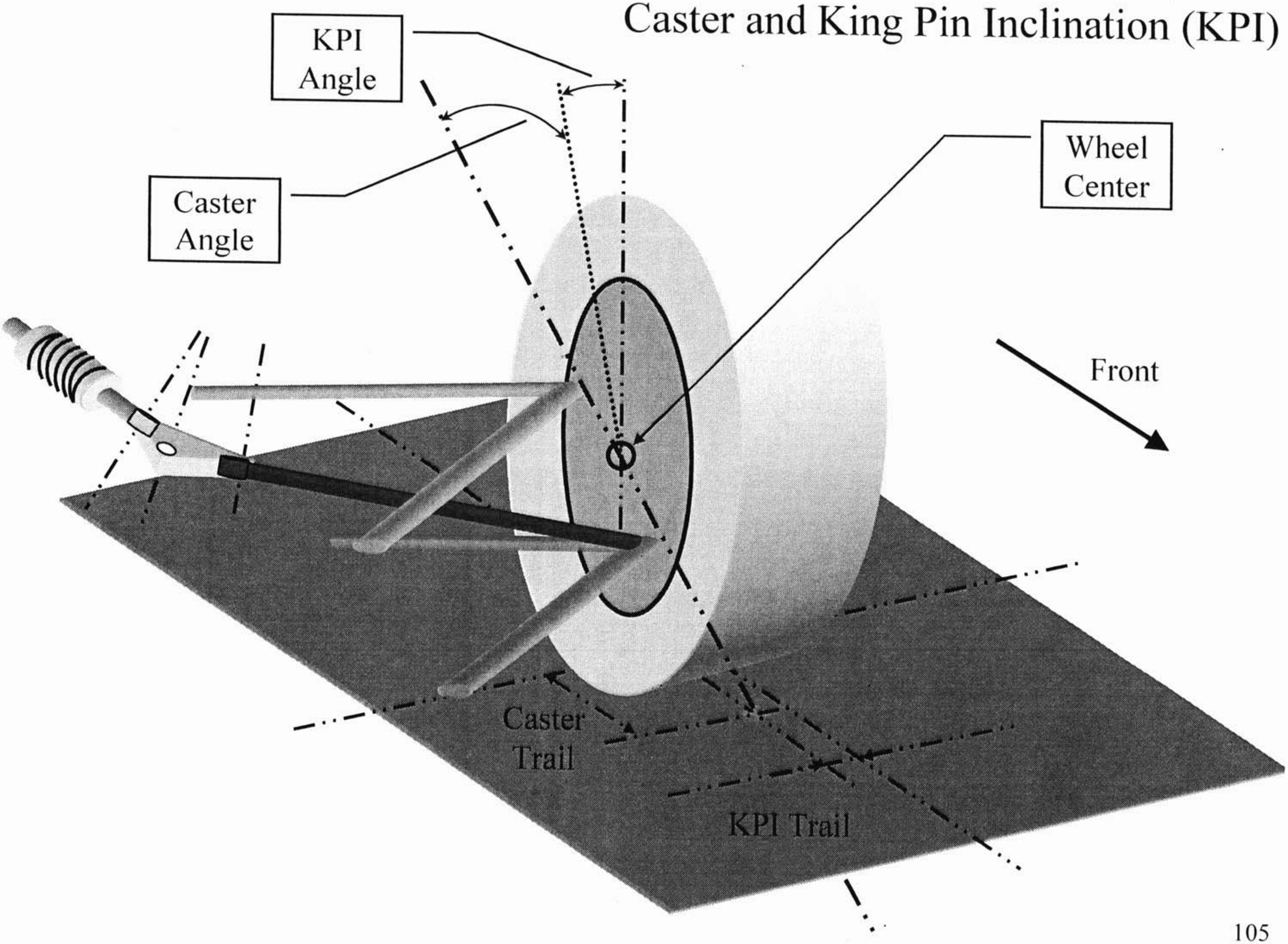


Kinematics of other suspension types

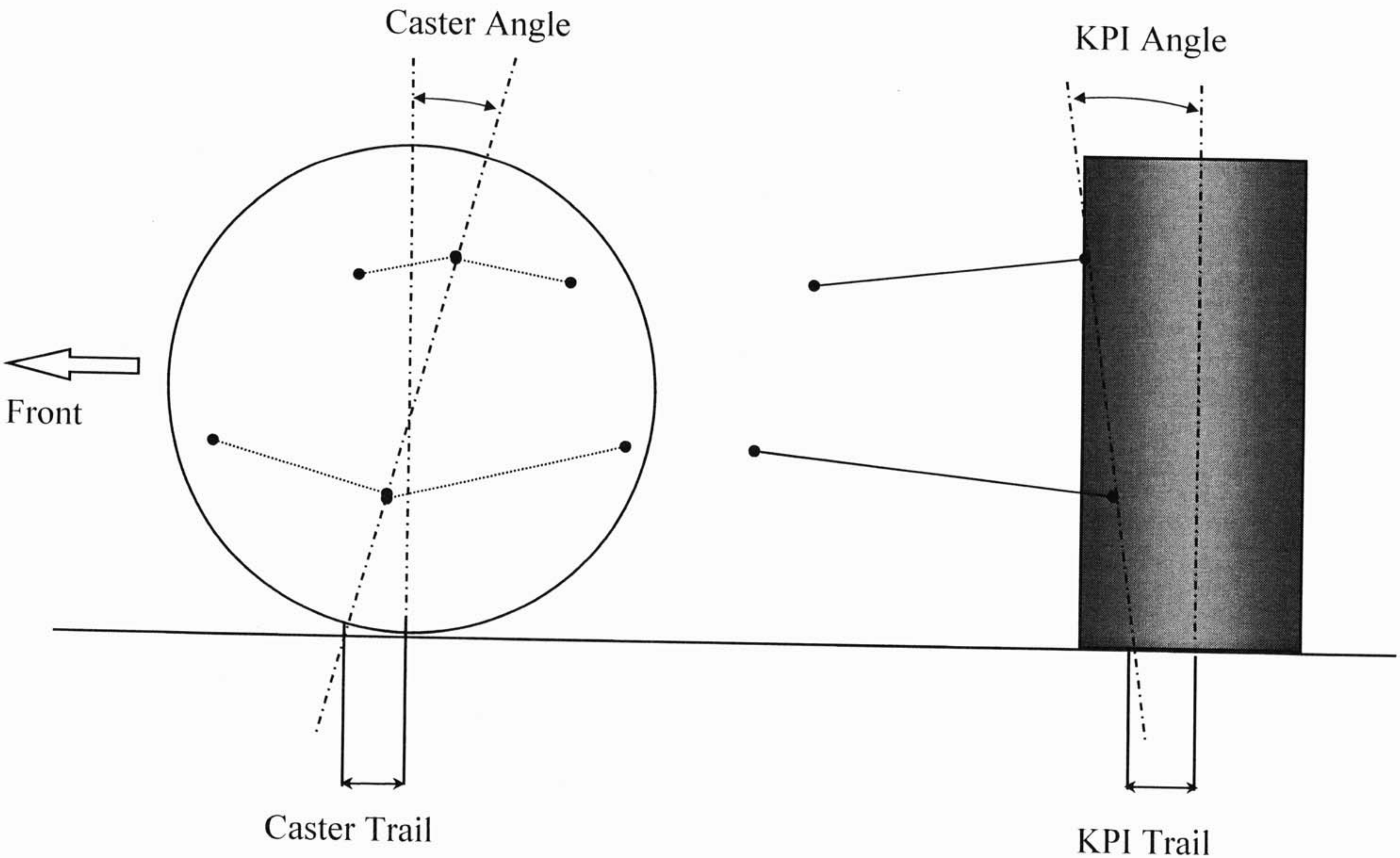
Mac Pherson



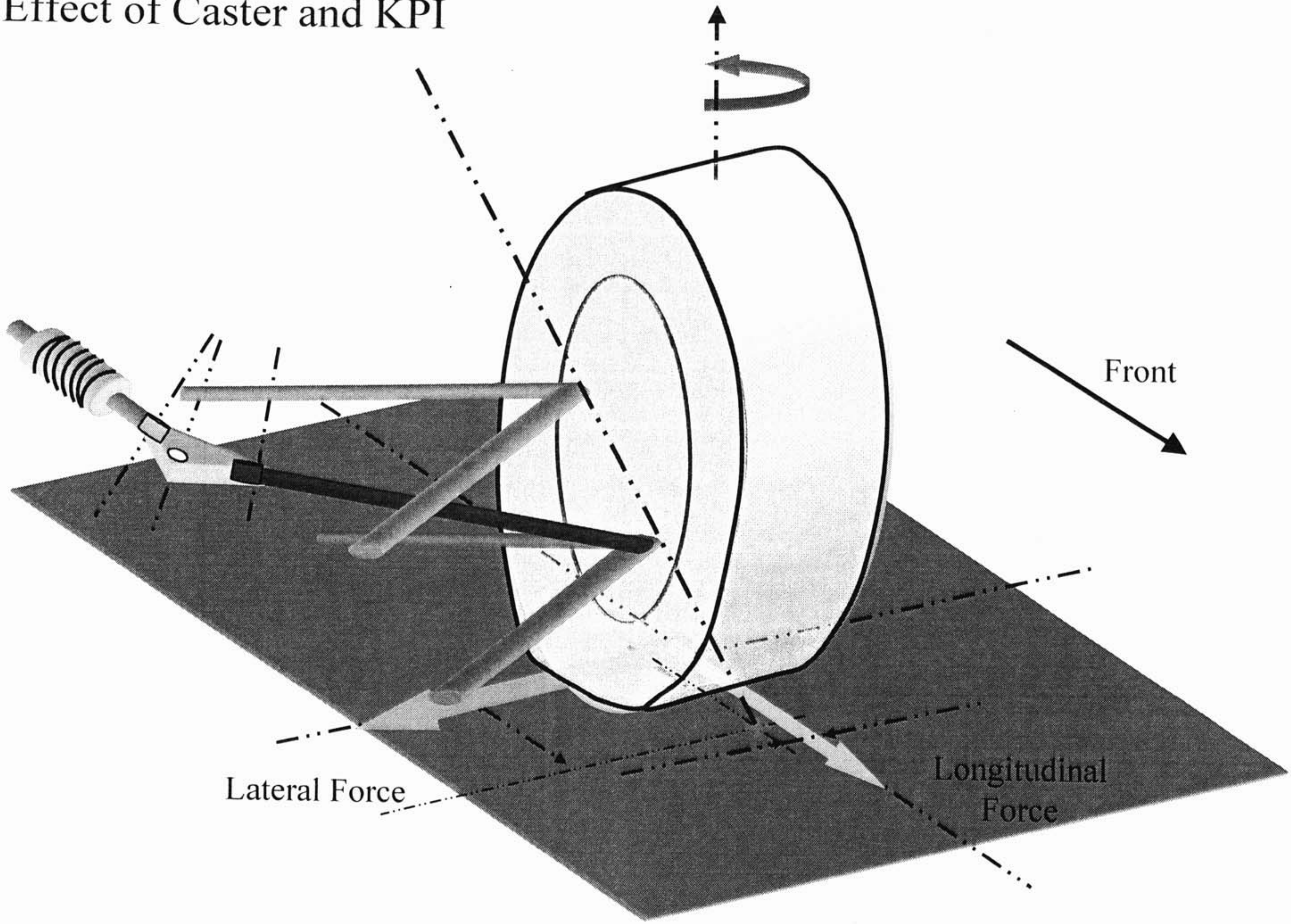
Caster and King Pin Inclination (KPI)



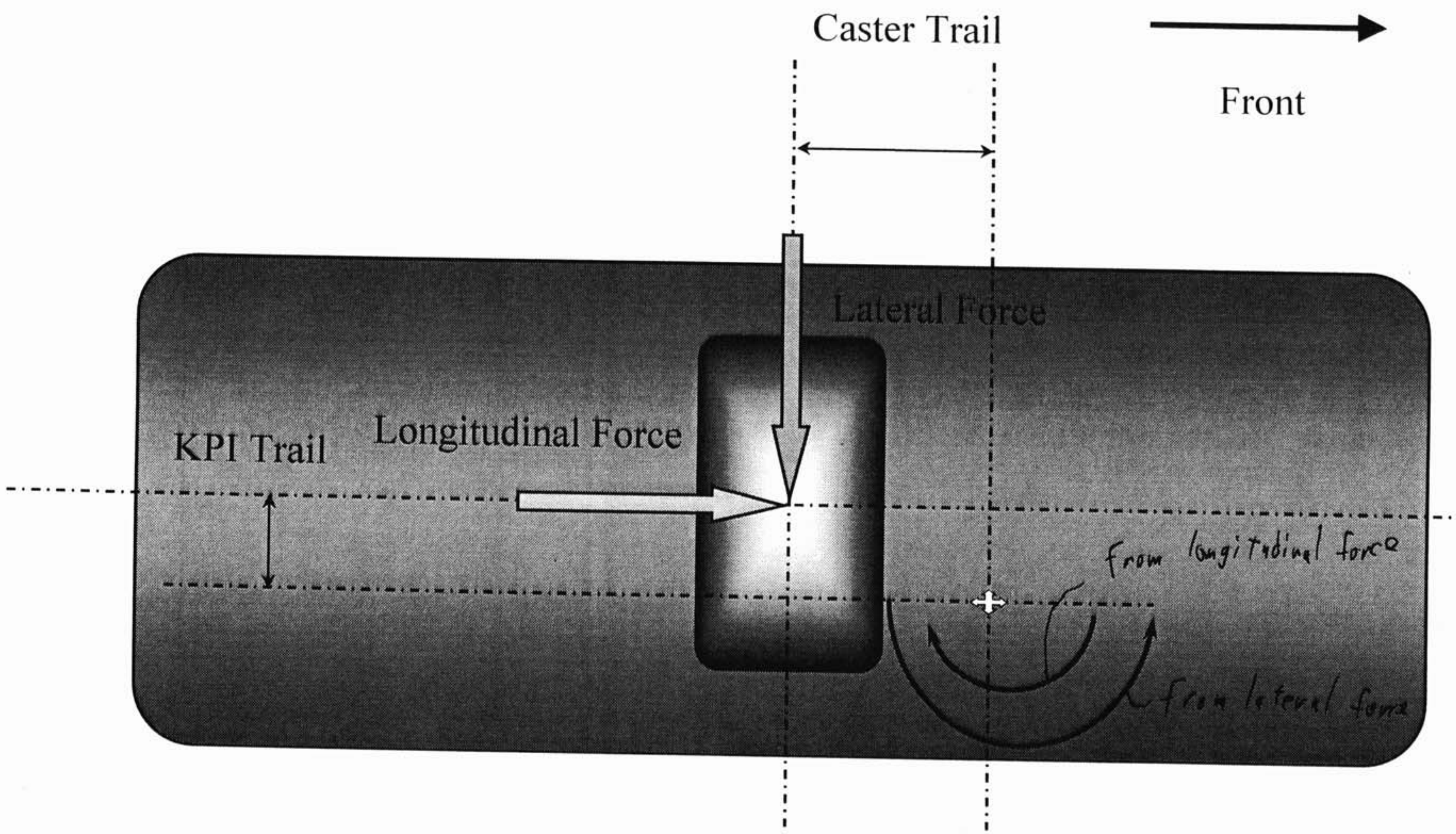
Caster and King Pin Inclination (KPI)



Effect of Caster and KPI



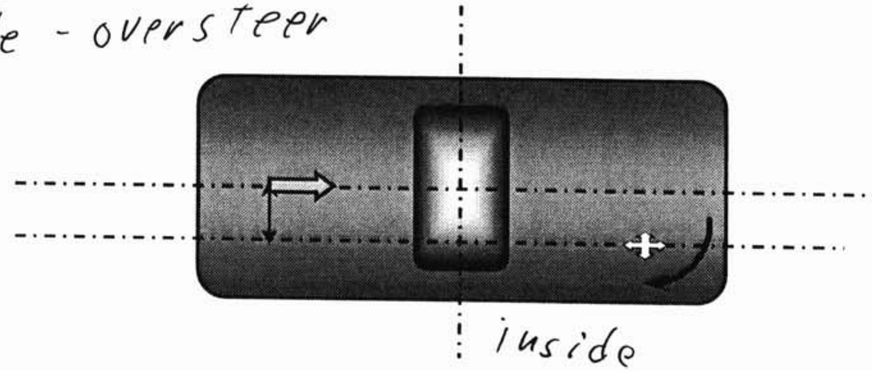
Effect of Caster and KPI



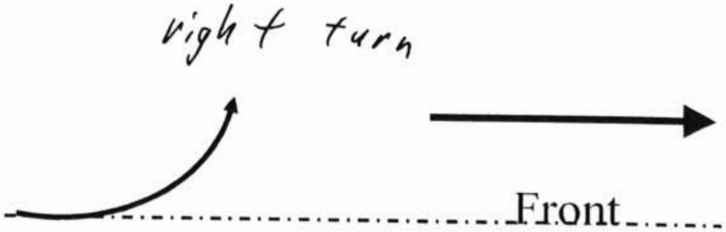
Steering torque under lateral and inline forces

Effect of KPI Trail in Straight Way

Throttle - oversteer

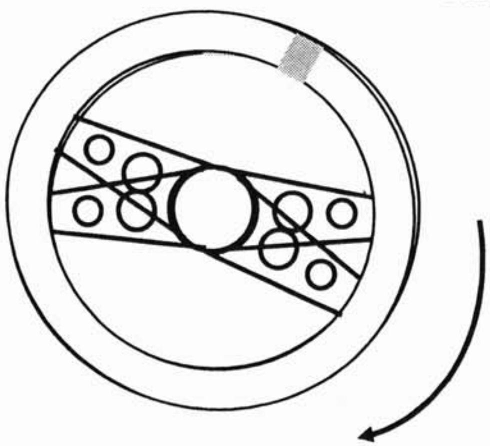


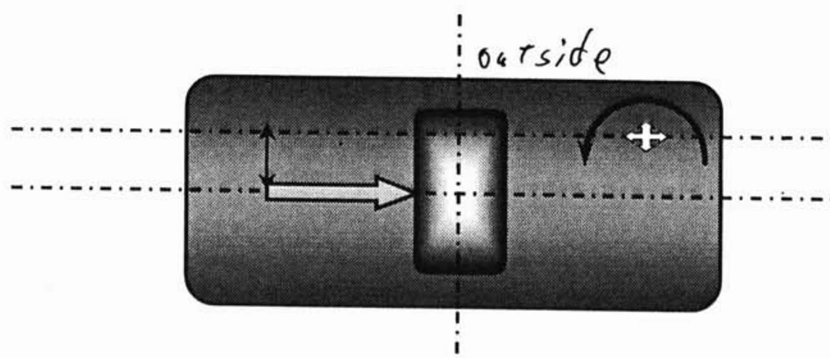
Right-Left difference of longitudinal forces creates different couple in the steering wheel.



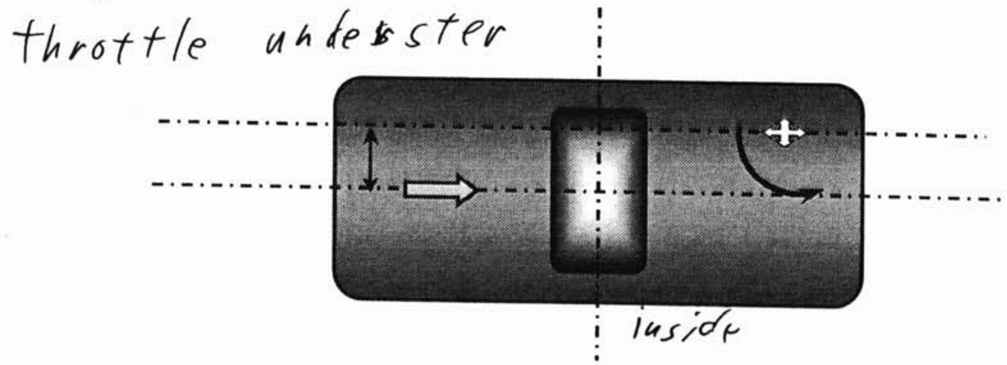
To keep the car straight on, driver must turn right

Resultant Torque



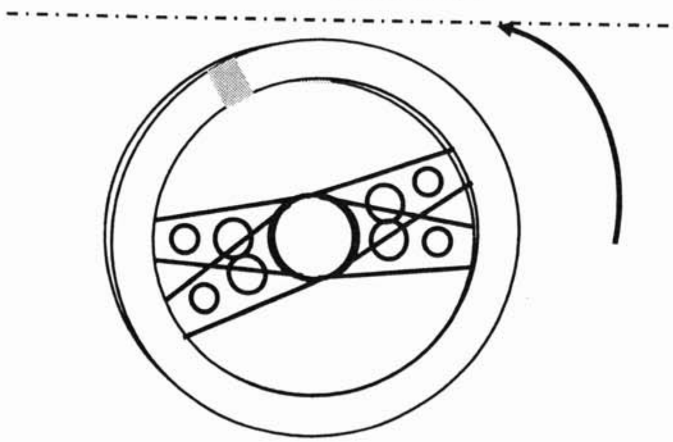


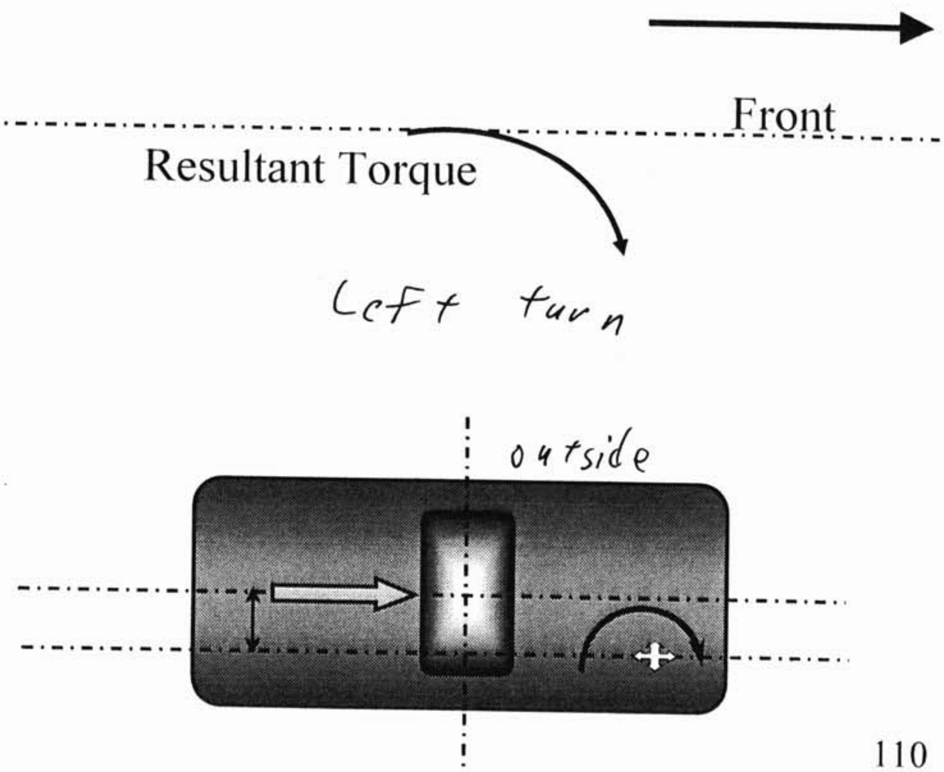
Effect of KPI Trail in Straight Way



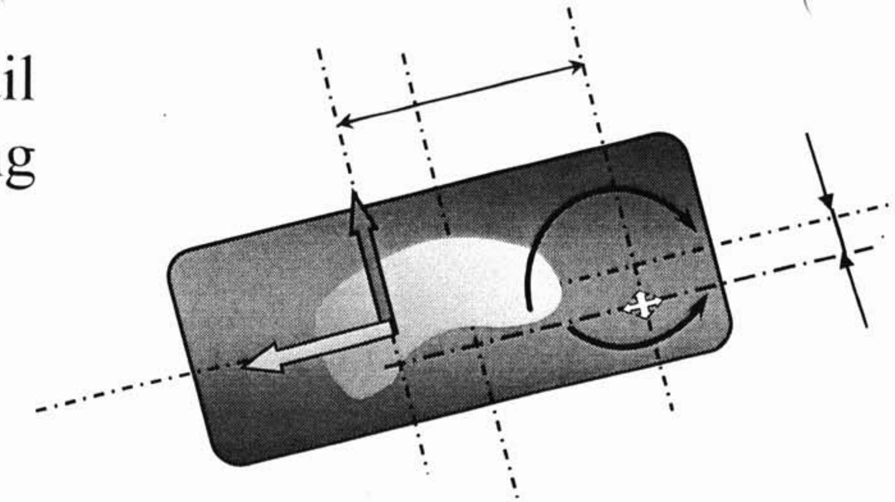
Right-Left difference of longitudinal forces creates different couple in the steering wheel.

To keep the car straight on, driver must turn left

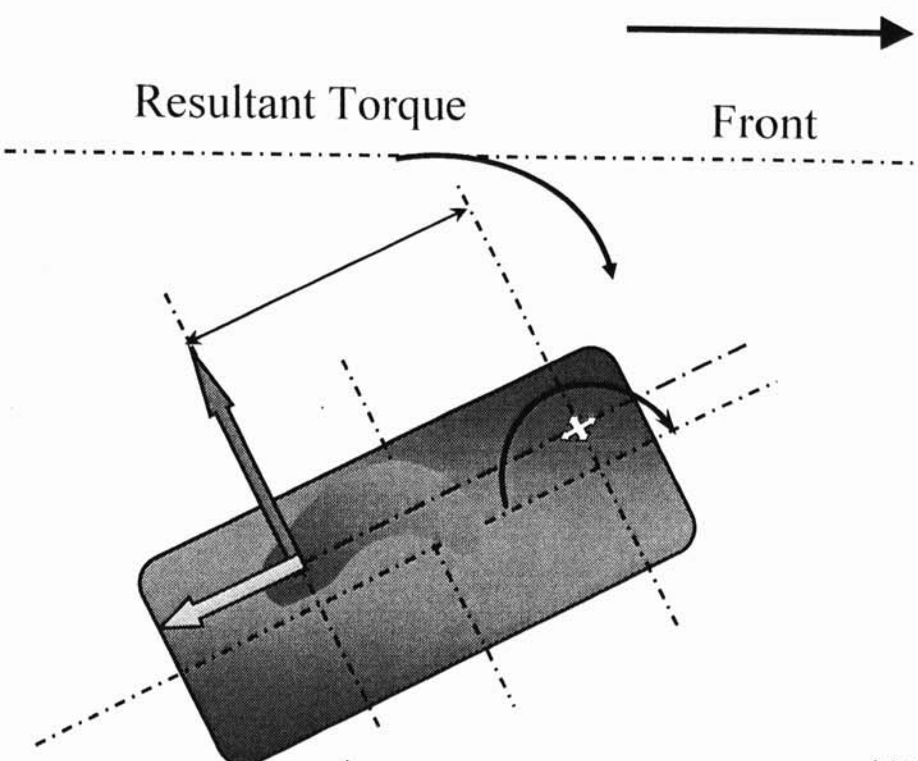




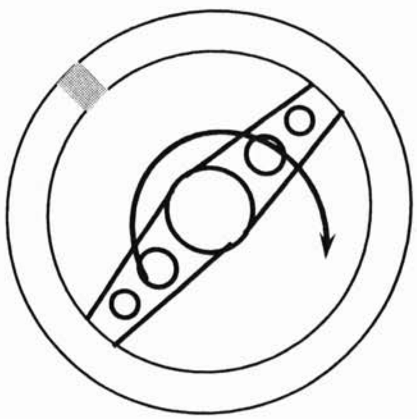
Effect of Caster Trail and KPI Trail in Corner : Aligning Torque, taking Tire Deformations into account.



When taking into account the tire longitudinal and lateral deformations, the aligning torque increases a lot.

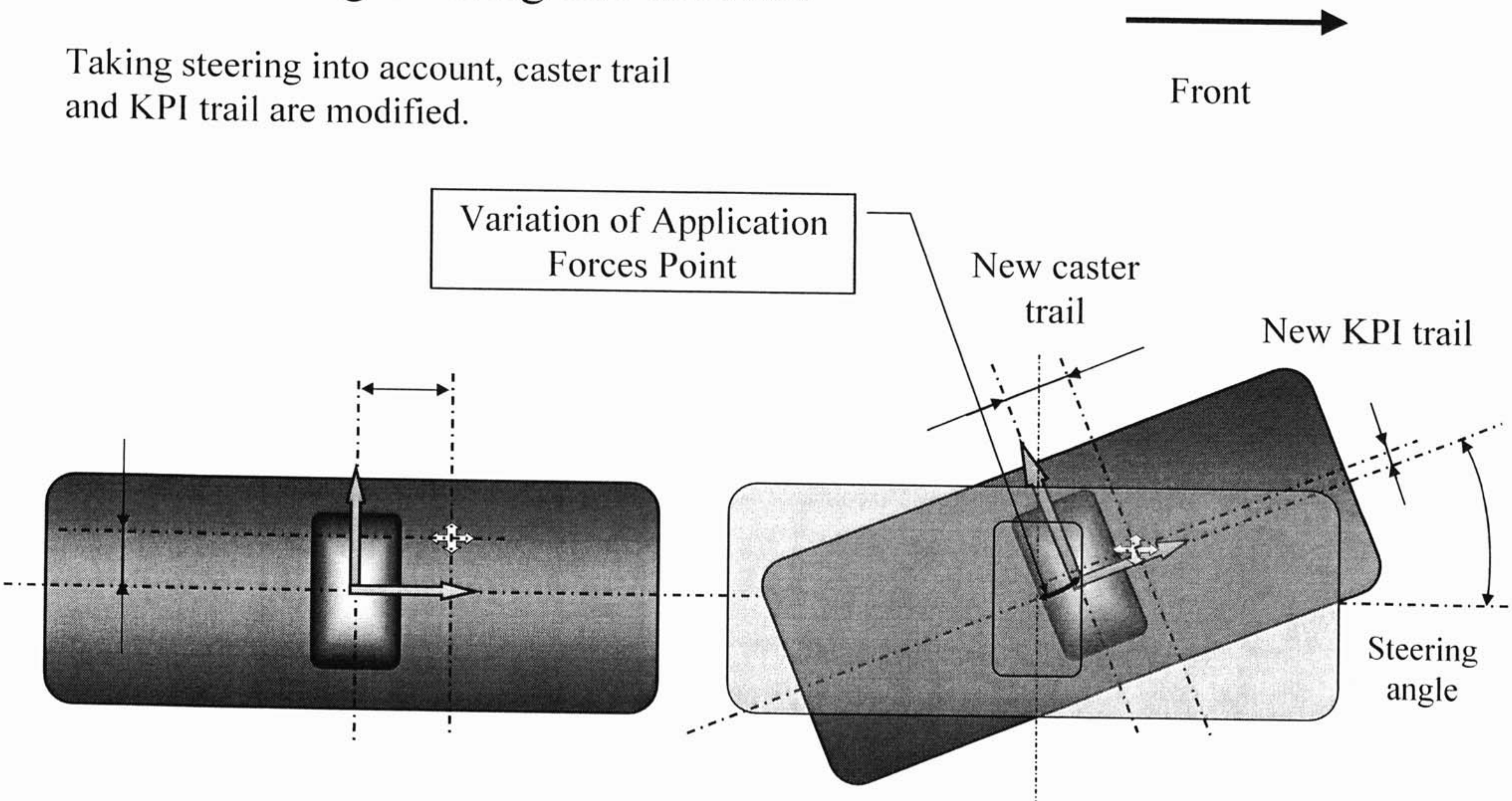


To keep the car in corner, driver must resist to this torque



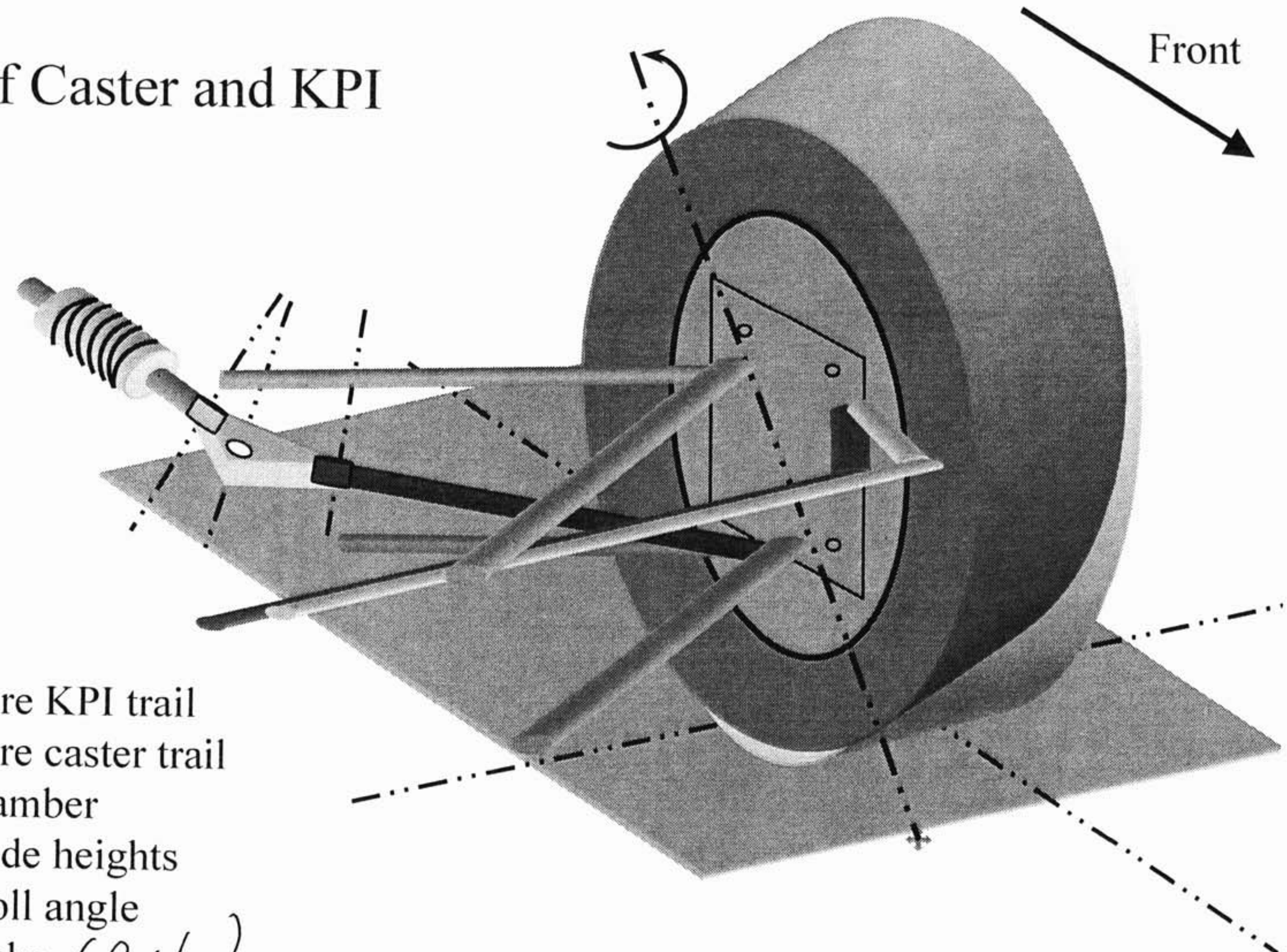
Variation of Caster Trail and KPI Trail in Corner : taking Steering into account.

Taking steering into account, caster trail and KPI trail are modified.



Right front tire
Left turn

Effect of Caster and KPI



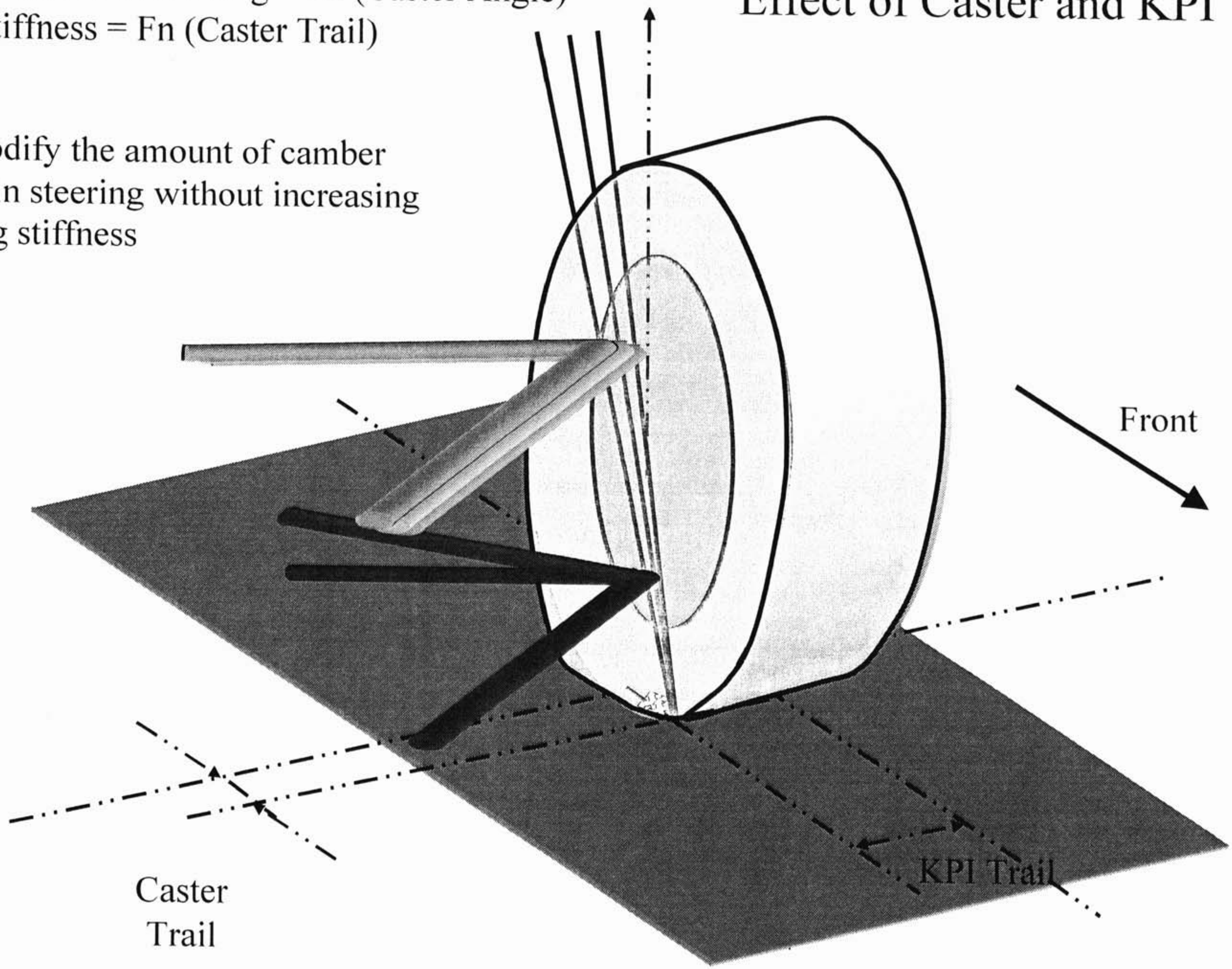
Variations in Steering:

Tire KPI trail
Tire caster trail
Camber
Ride heights
Roll angle
Rake (Pitch)
Corner weights
Steering stiffness
Front track
Wheelbases

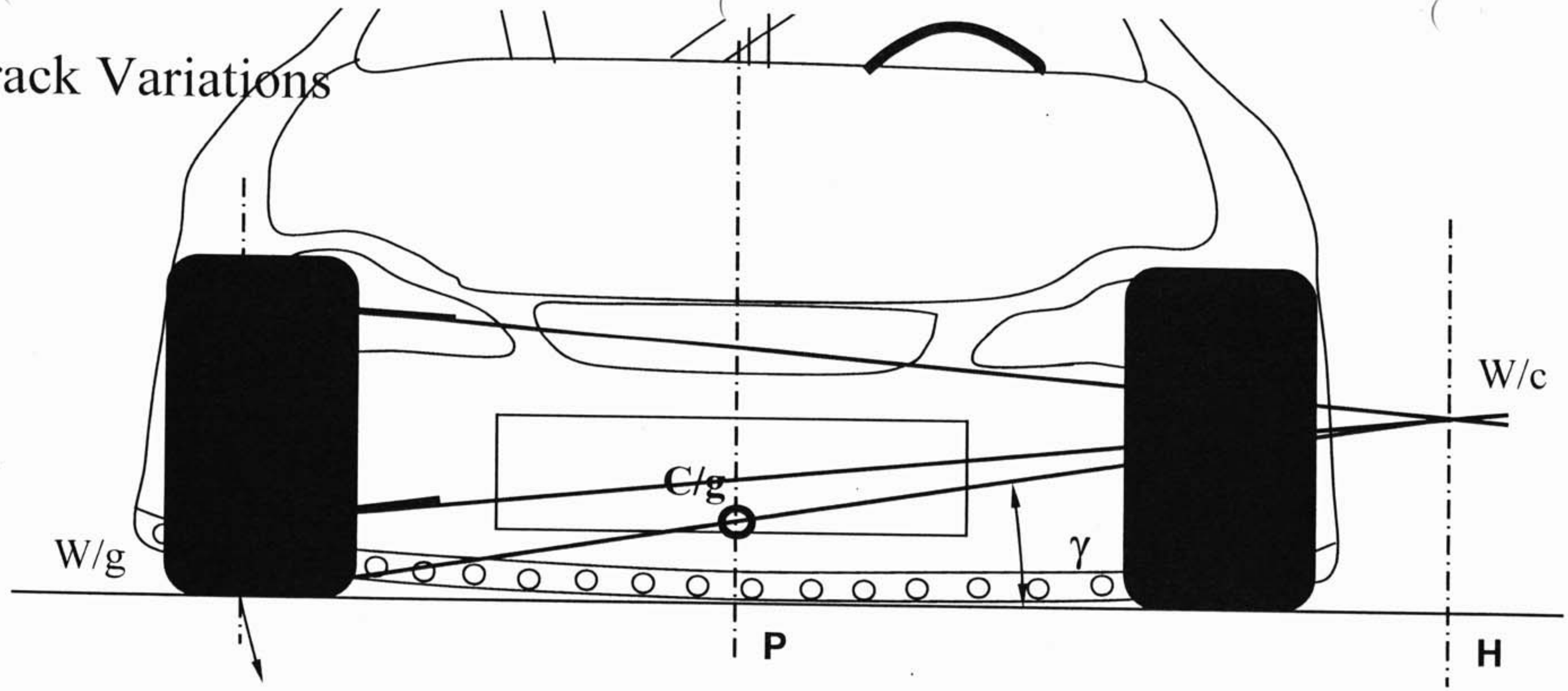
Camber variations in steering = Fn (Caster Angle)
Steering Stiffness = Fn (Caster Trail)

Effect of Caster and KPI

How to modify the amount of camber variations in steering without increasing the steering stiffness



Track Variations



Track variations in heave

A vertical mvt Δz of the chassis creates a rotation of W/g and a lateral motion of W/g = Δz * tan γ

The track variations will be < 0 if W/c is under the ground

Track variations in roll

For a rotation Δ R of the chassis about the ground and around C/g (roll center) W/g moves, compared to the center of the car, of a distance = Δ R * C/g - P

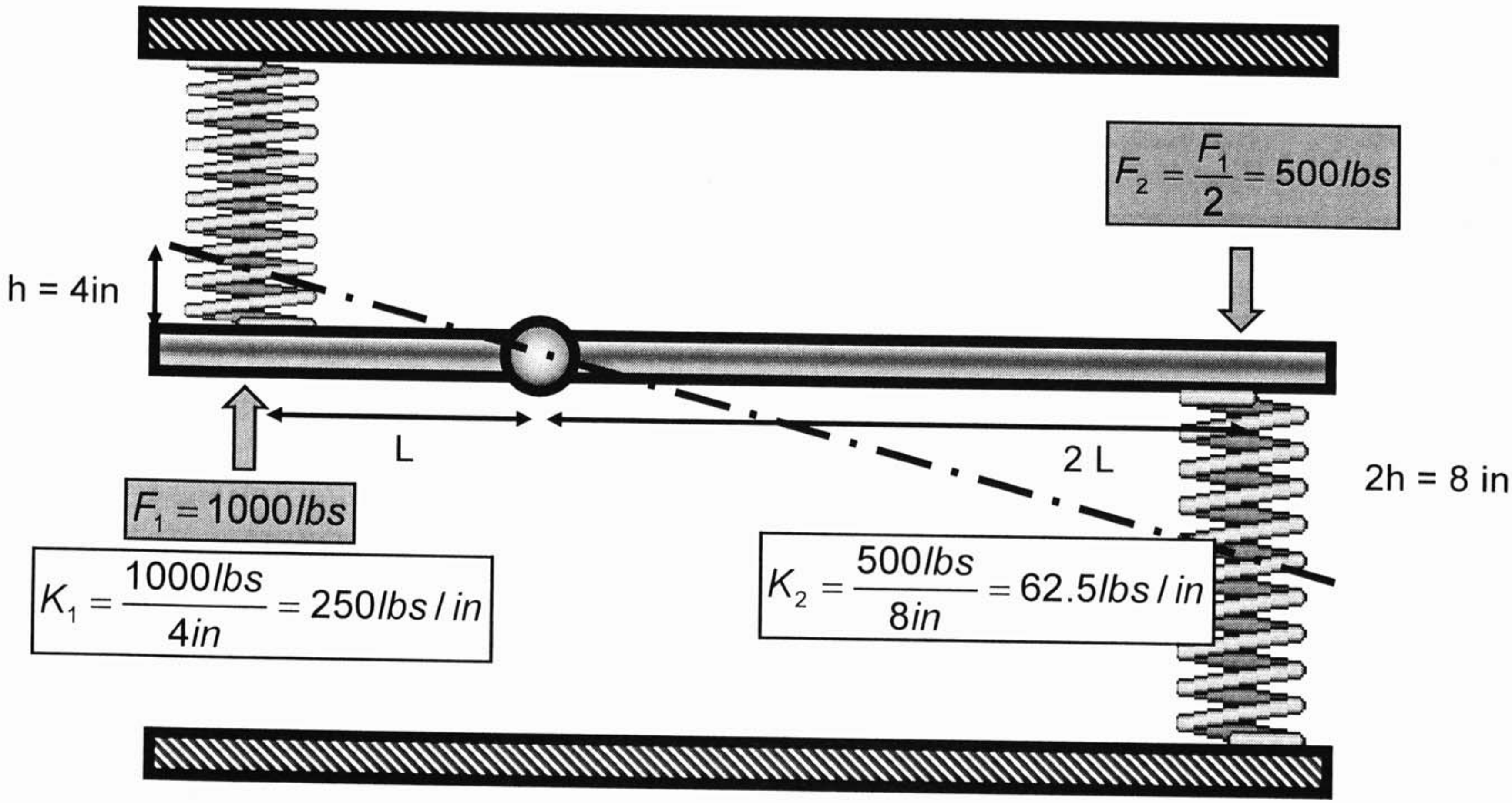
The left and right track variations will be equals but with opposite signs.

They will be the opposite sign if C/g is under the ground.

4. Steady State Weight Transfers

- Motion Ratio
- Lateral Weight Transfer
- Roll Center Movement
- Inline Weight Transfer
- Vertical Acceleration (Banking)

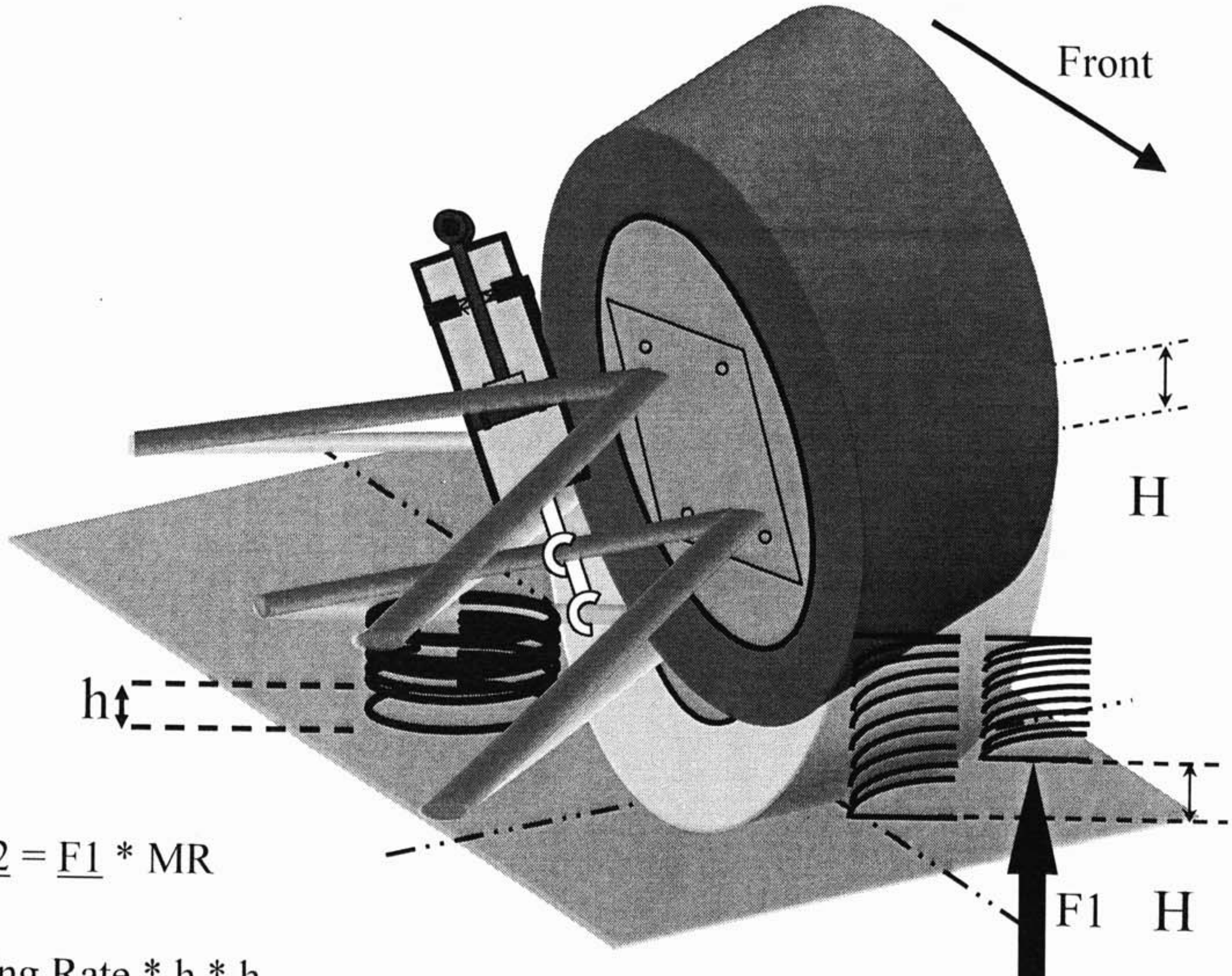
Motion Ratio (3)



$$K_2 = \frac{K_1}{MR^2}$$

$$K_2 = \frac{250}{2^2} = 62.5 lbs / in$$

Motion Ratio



Motion Ratio MR = H / h

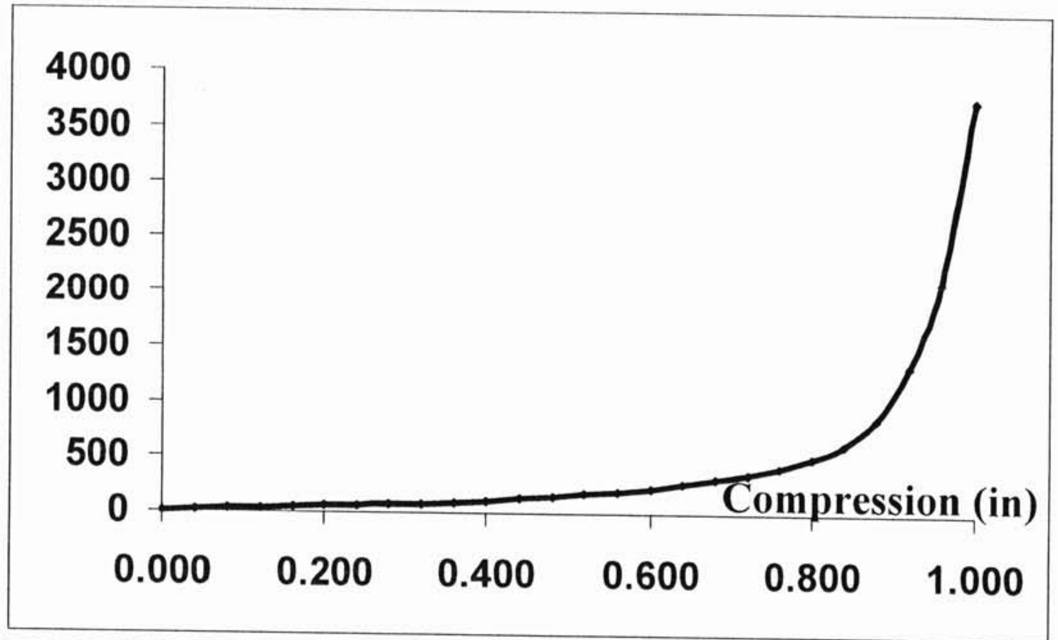
<u>F1</u> * H = <u>F2</u> * h   ----> <u>F2</u> = <u>F1</u> * MR

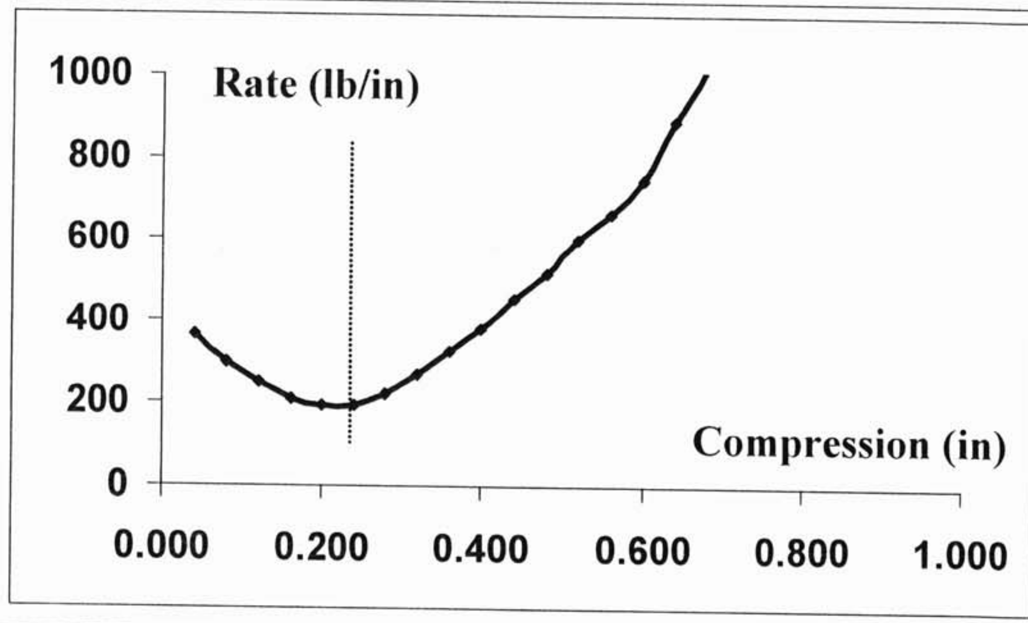
<u>Wheel Rate * H</u> * H = <u>Spring Rate * h</u> * h

→ *Wheel Rate = Spring Rate / (MR²)*

Bump Rubber

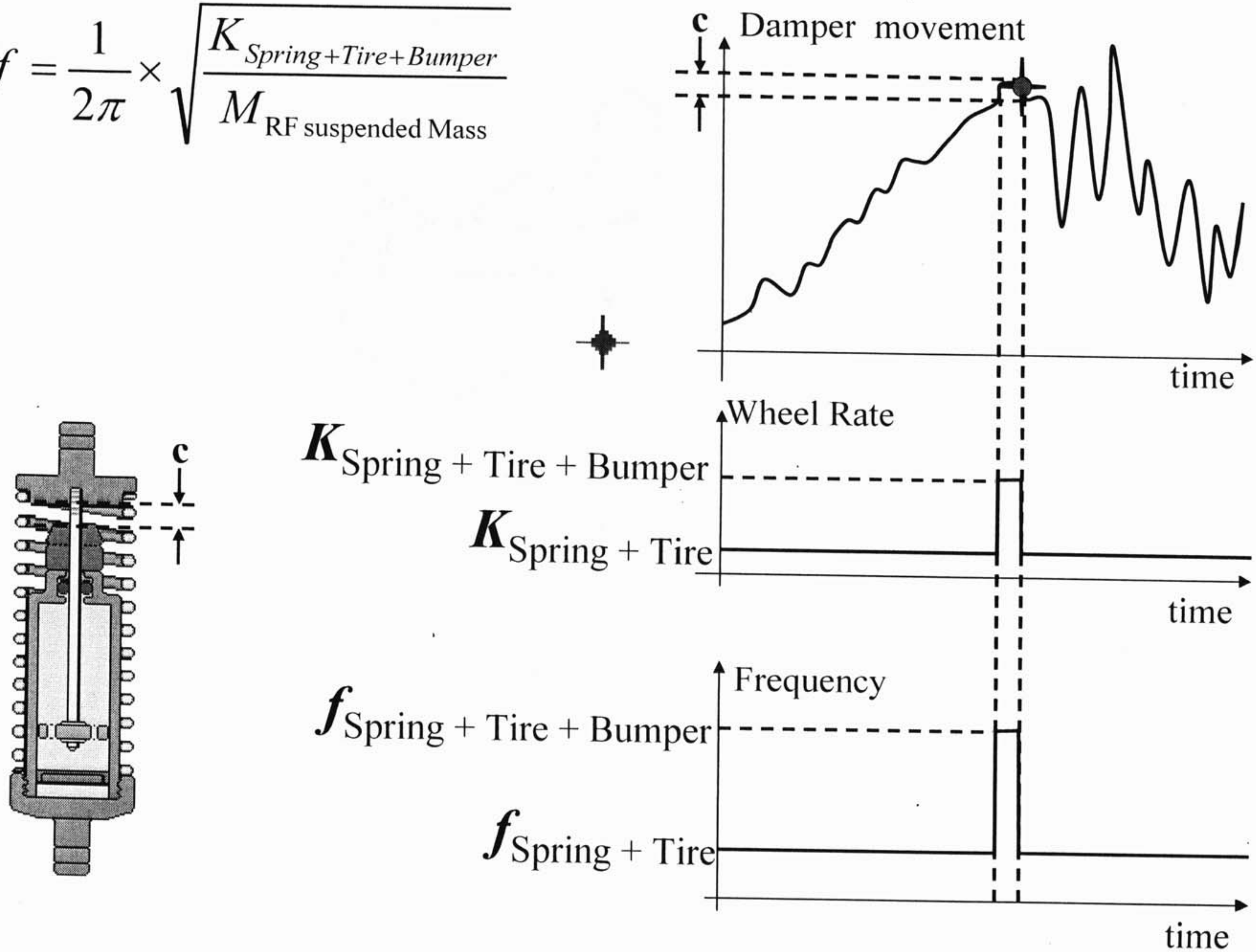
Compression (in)	Force (lb)	Rate (lb/in)
0.000	0.0	
0.040	14.5	362.5
0.080	26.4	297.5
0.120	36.4	250.0
0.160	44.8	210.0
0.200	52.5	192.5
0.240	60.2	192.5
0.280	69.1	222.5
0.320	79.9	270.0
0.360	92.9	325.0
0.400	108.1	380.0
0.440	126.3	455.0
0.480	147.0	517.5
0.520	171.0	600.0
0.560	197.6	665.0
0.600	227.5	747.5
0.640	263.0	887.5
0.680	303.9	1022.5
0.720	353.1	1230.0
0.760	416.2	1577.5
0.800	499.9	2092.5
0.840	621.2	3032.5
0.880	865.0	6095.0
0.920	1340.0	11875.0
0.960	2109.0	19225.0
1.000	3748.8	40995.0



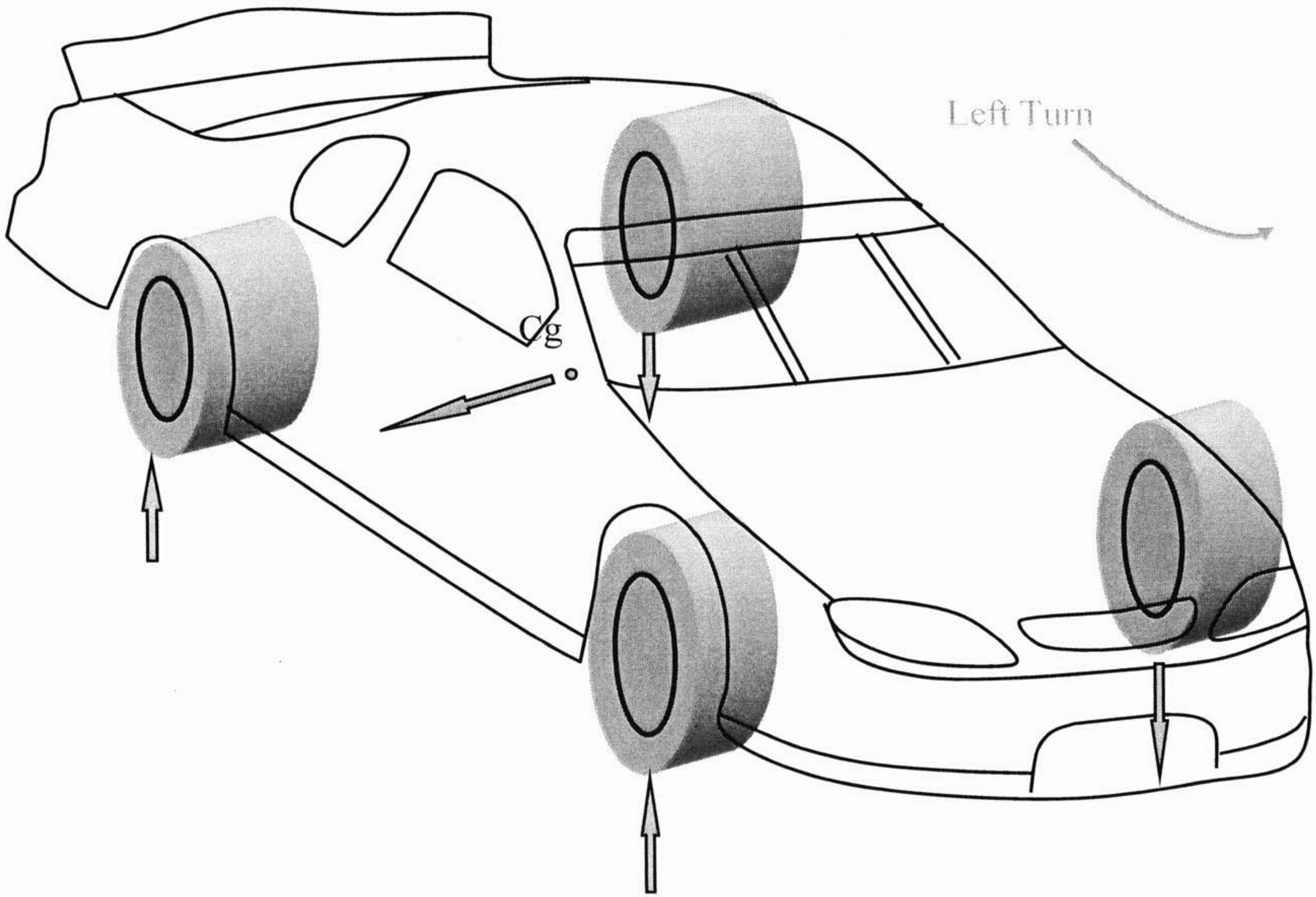


Abrupt variation of the suspension frequency when the shock absorber hit the bumper

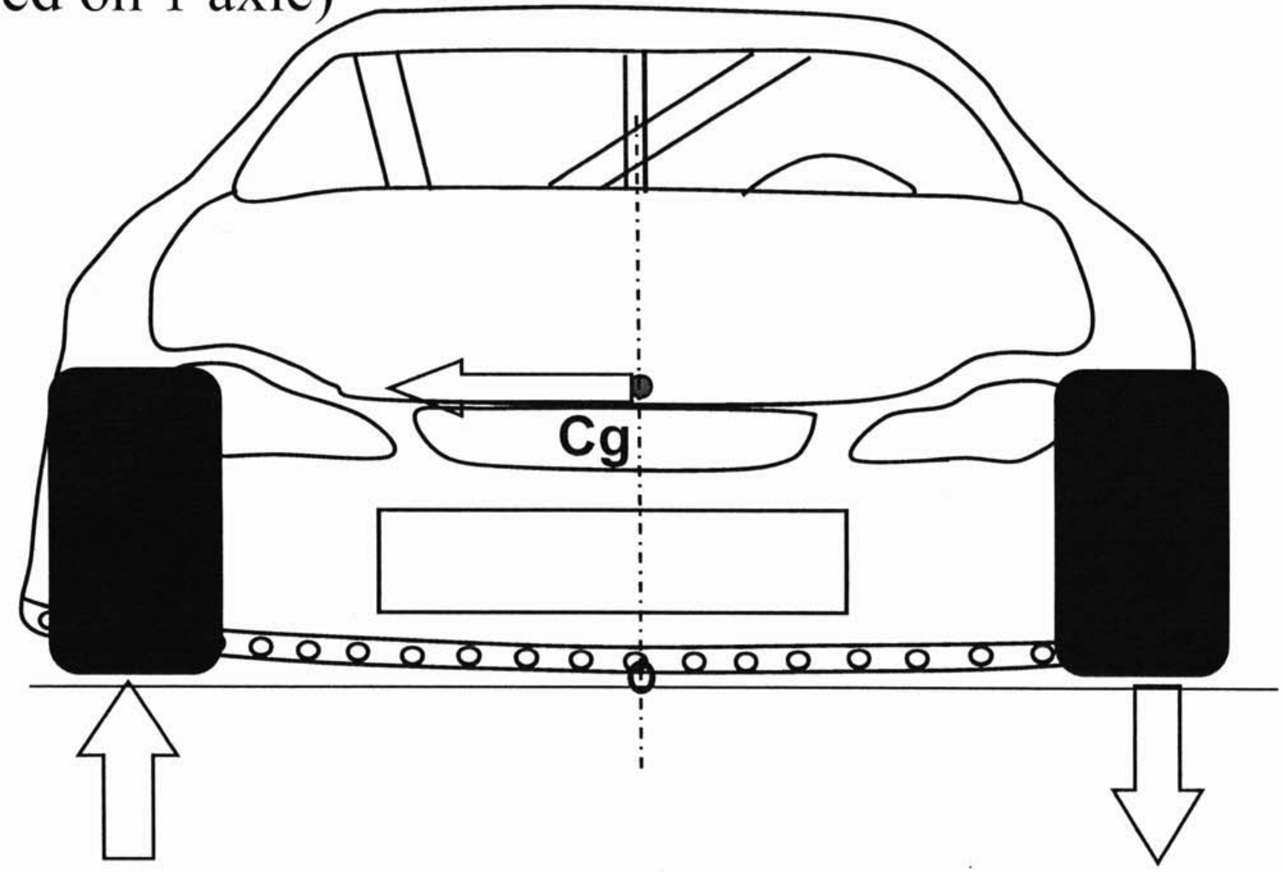
$$f = \frac{1}{2\pi} \times \sqrt{\frac{K_{Spring+Tire+Bumper}}{M_{\text{RF suspended Mass}}}}$$



Lateral Weight Transfer Basics



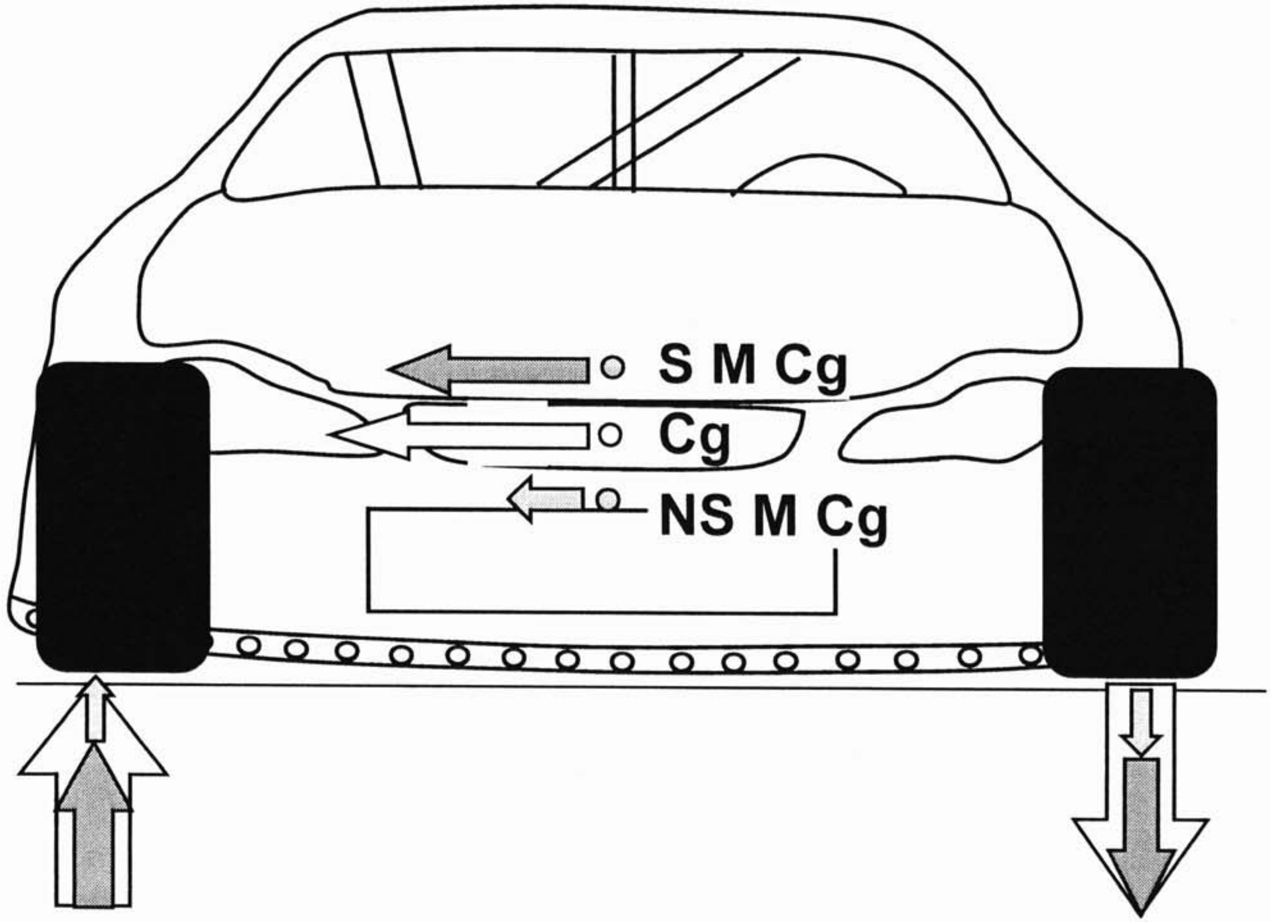
Lateral Weight Transfer Basics
(simplified on 1 axle)



Lateral Force = Mass * Lateral Acceleration

Lateral Weight Transfer = Lateral Force * Cg Height / Track

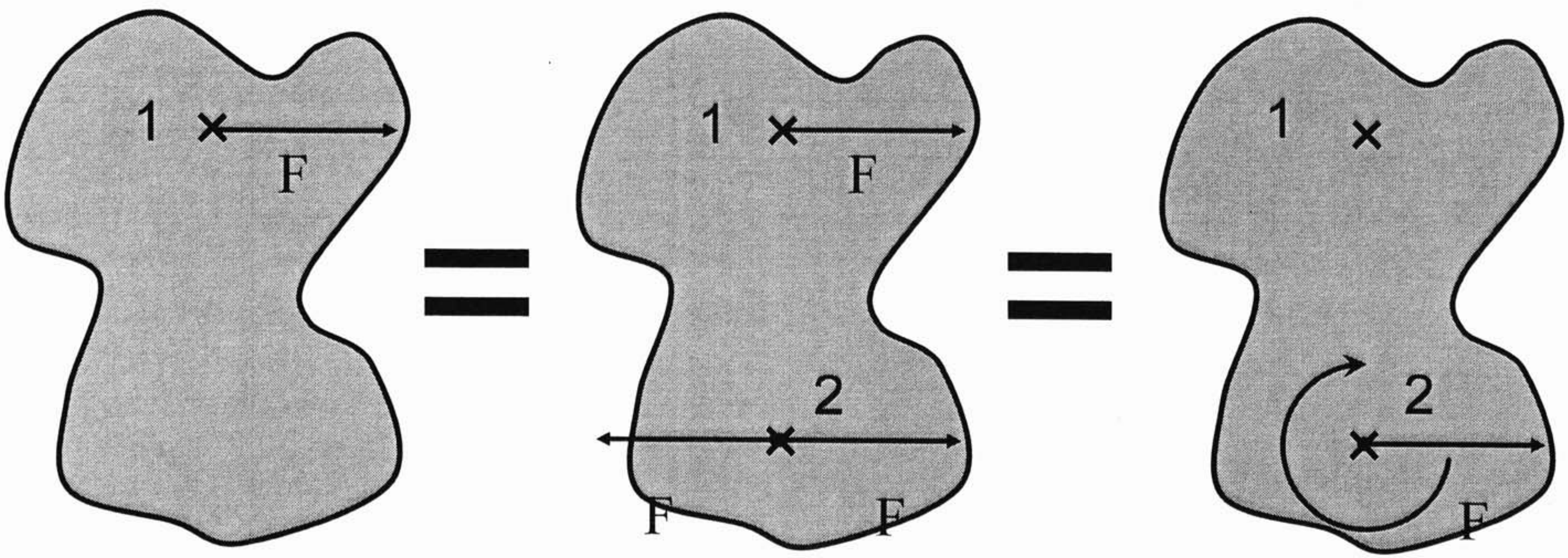
Lateral Weight Transfer



Lateral NS Weight Transfer = NS M * Lat Acc * NS M Cg Height / Track

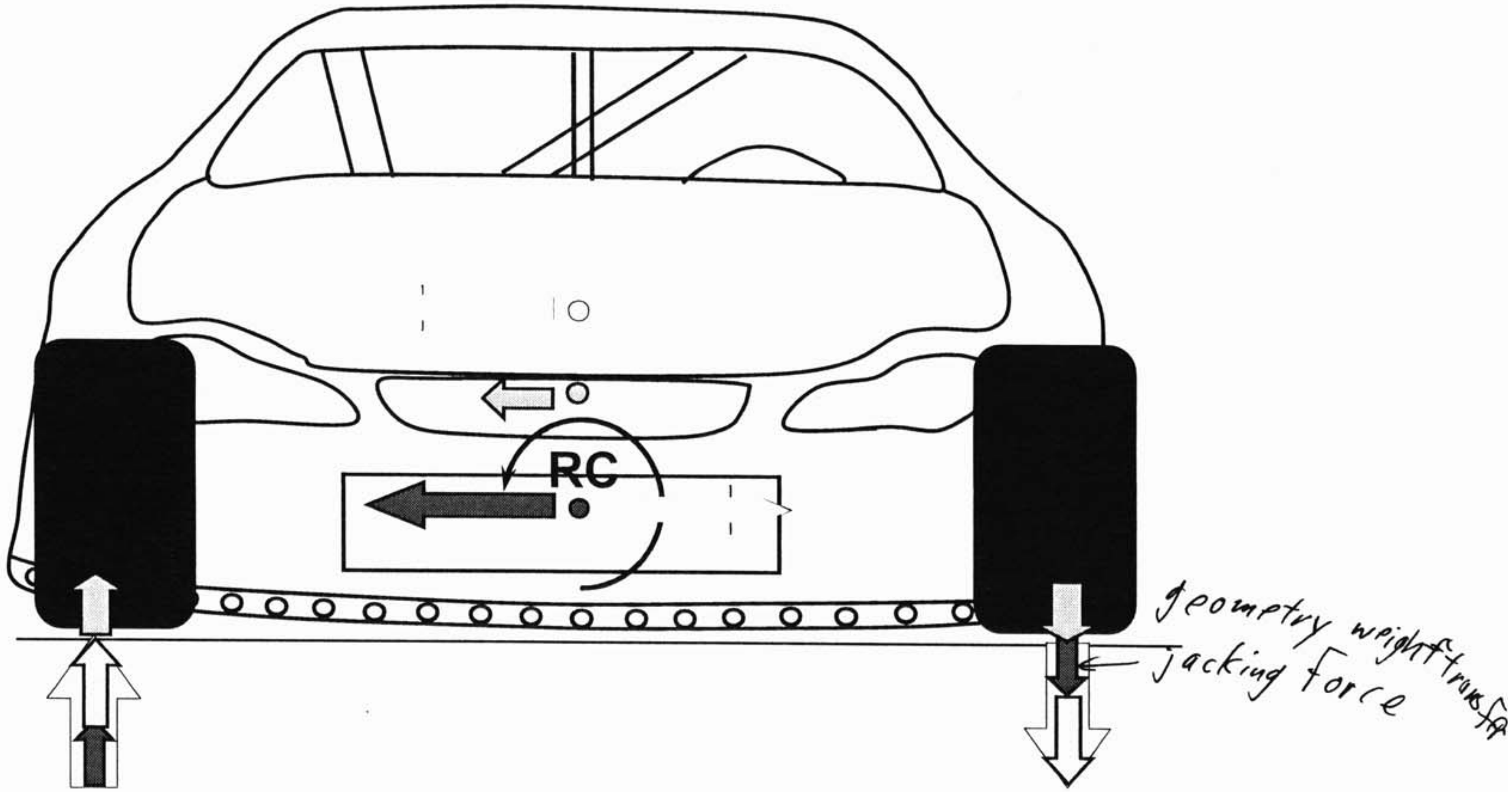
Lateral S Weight Transfer = S M * Lat Acc * S M Cg Height / Track

Equivalence between a force apply on one point and the same force plus a torque apply on another point



F apply on pt 1= F apply on pt 2 + Torque

Lateral Weight Transfer



Lateral S Weight "Geometric" Transfer = SM * Lat Acc * RC Height / Track

↳ happens immediately

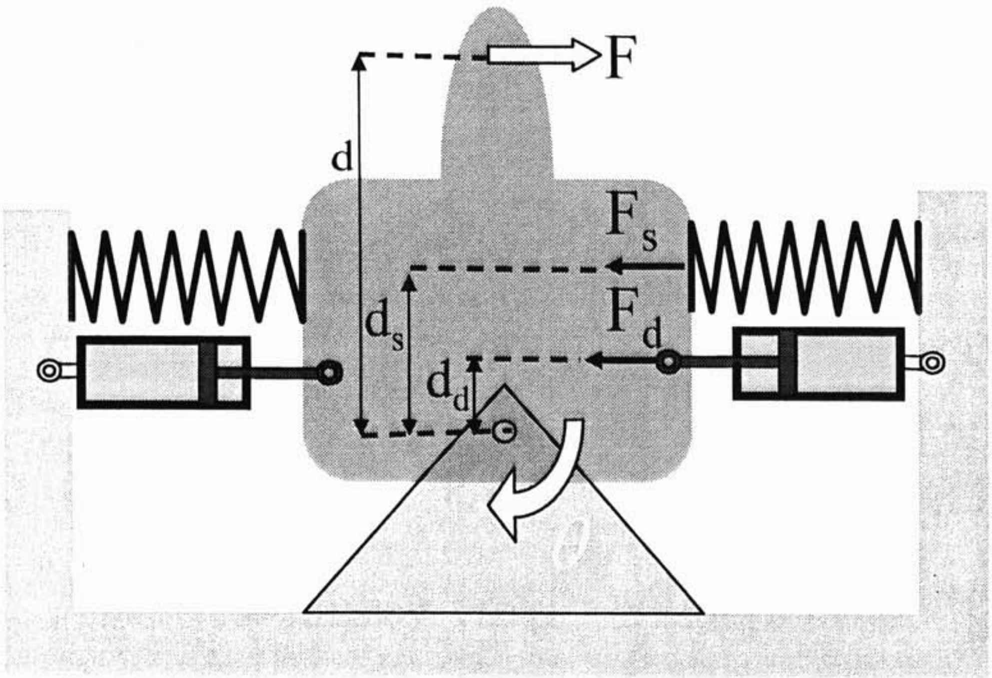
Lateral S Weight "Elastic" Transfer = SM * Lat Acc * (SMCg - RC) / Track

↳ reacted by springs, ARB, etc.

↳ delayed

SM Roll Moment

Effect of inertia on the handling



$$F_s = F_{Spring} = K \times dx$$

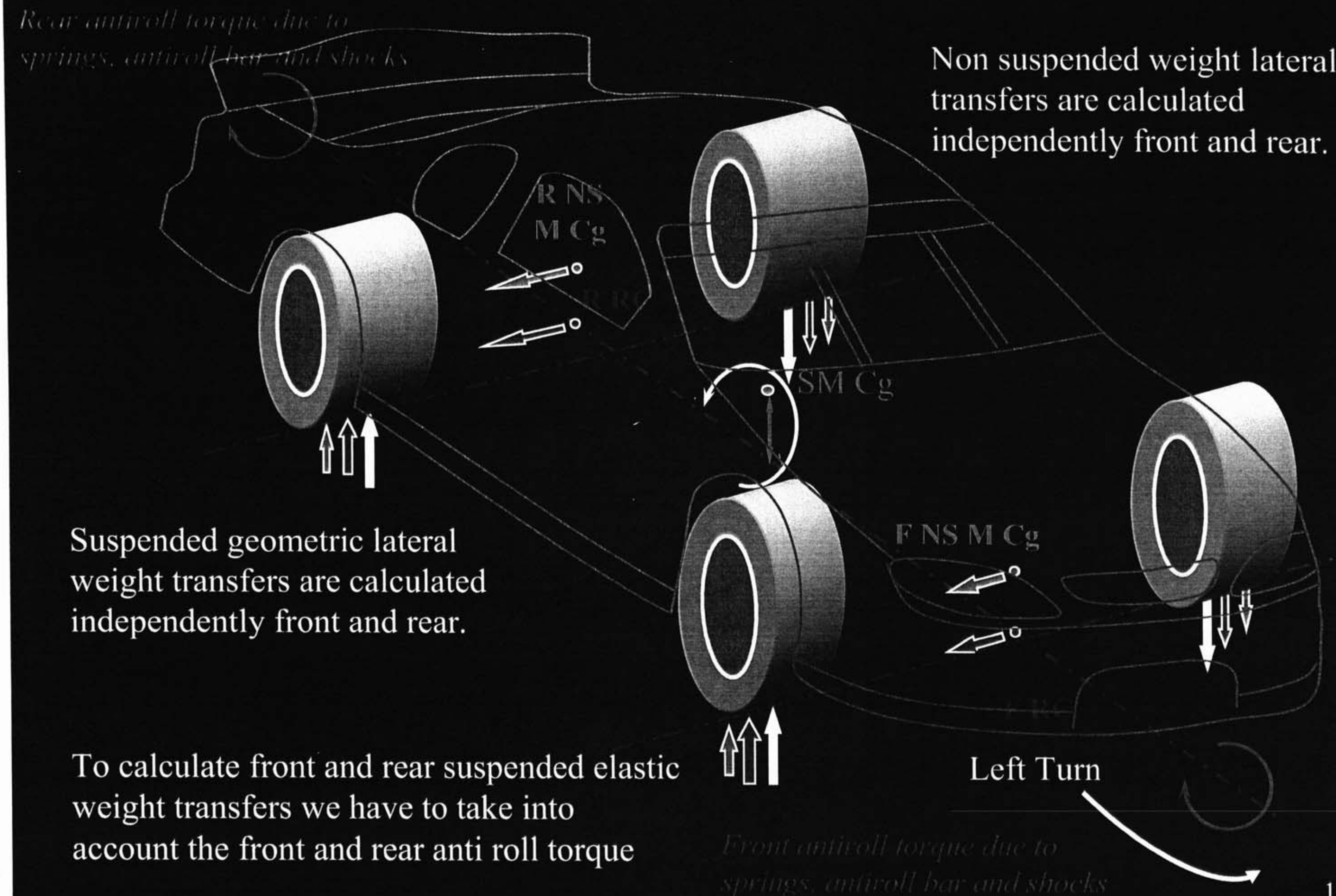
$$F_d = F_{Damper} = C \times \frac{dx}{dt}$$

dx = damper or spring movement

$$(F \times d) - 2 \times \{(F_s \times d_s) + (F_d \times d_d)\} = I \frac{d\theta^2}{dt^2}$$

If F = Cst , and Inertia value increases, then the roll acceleration will decrease

Lateral Weight Transfer Real Case : 4 wheels



Non suspended weight lateral transfers are calculated independently front and rear.

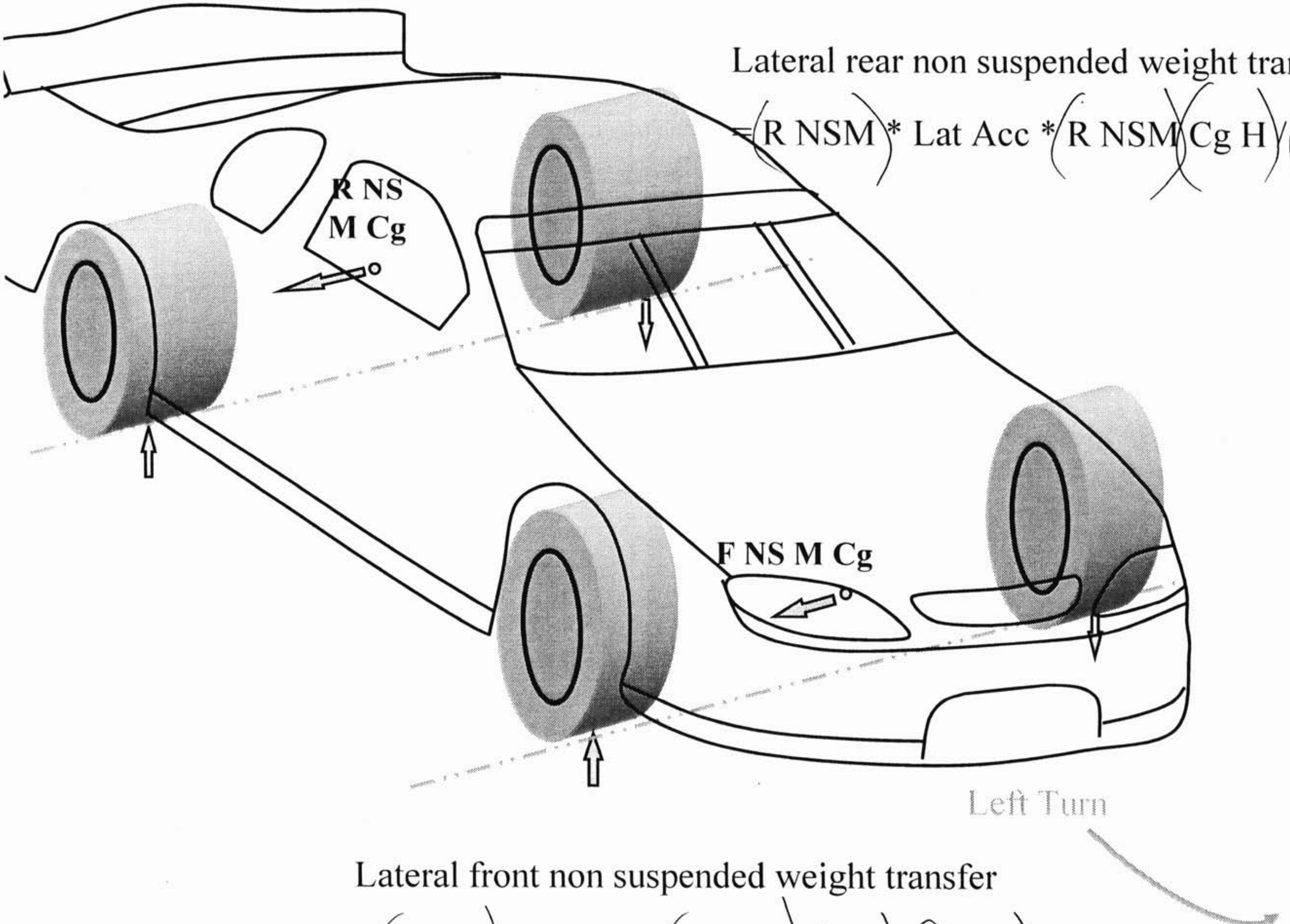
Suspended geometric lateral weight transfers are calculated independently front and rear.

To calculate front and rear suspended elastic weight transfers we have to take into account the front and rear anti roll torque

Lateral Front and Rear Non Suspended Weight Transfer

Lateral rear non suspended weight transfer

= (R NSM) * Lat Acc * (R NSM Cg H) / (R Track)



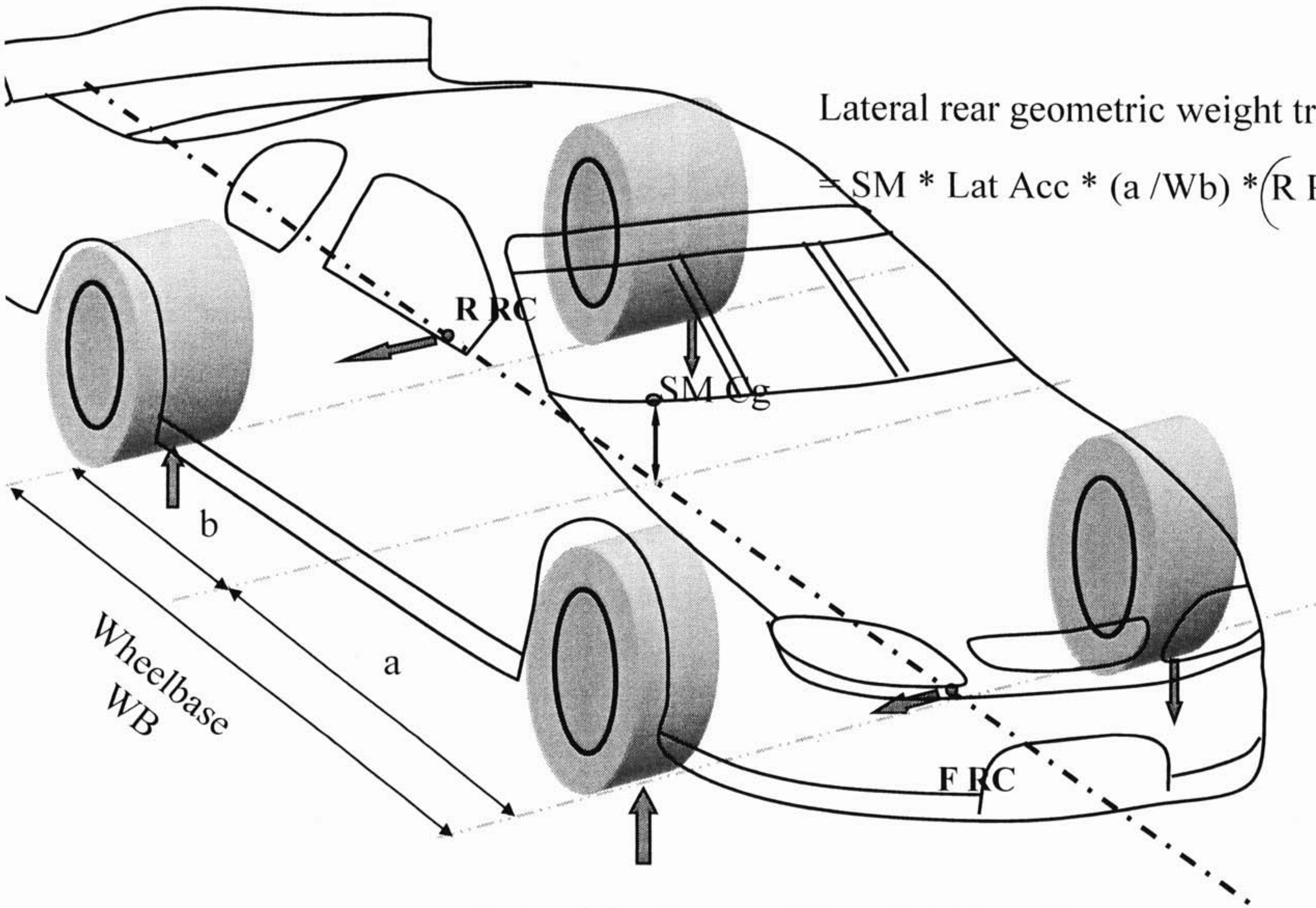
Lateral front non suspended weight transfer

= (F NSM) * Lat Acc * (F NSM Cg H) / (F Track)

Lateral Front and Rear Geometric Weight Transfer

Lateral rear geometric weight transfer

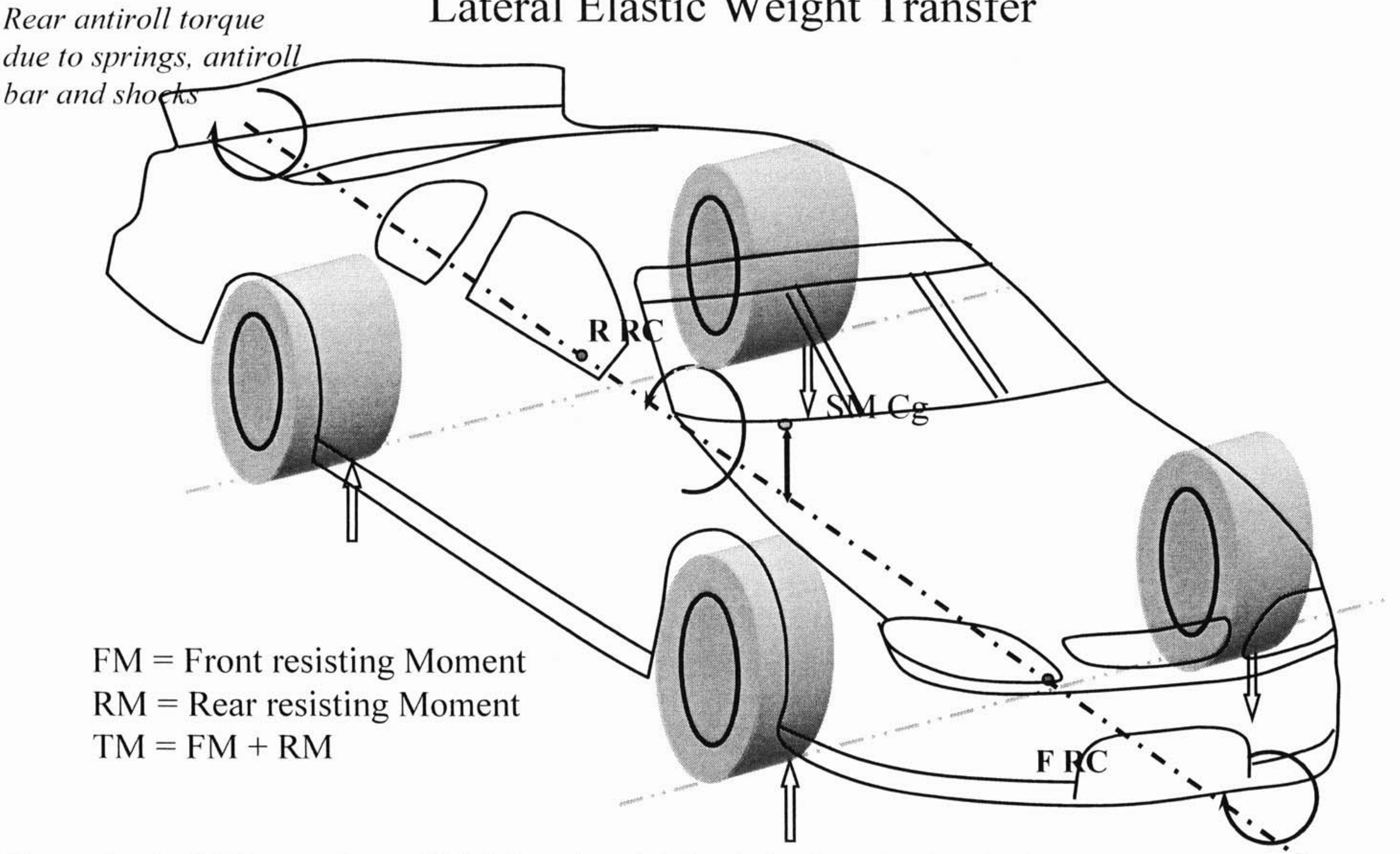
= SM * Lat Acc * (a /Wb) * (R RC H) / (R Track)



Lateral front geometric weight transfer

= SM * Lat Acc * (b /WB) * (F RC H) / (F Track)

Lateral Elastic Weight Transfer



FM = Front resisting Moment
RM = Rear resisting Moment
TM = FM + RM

Rear elastic S W transfer = SM * Lat Acc * Dist (SM Cg - Roll axis) * (RM / TM) /Rear Track
Front elastic S W transfer = SM * Lat Acc * Dist (SM Cg - Roll axis) * (FM / TM)/Front Track

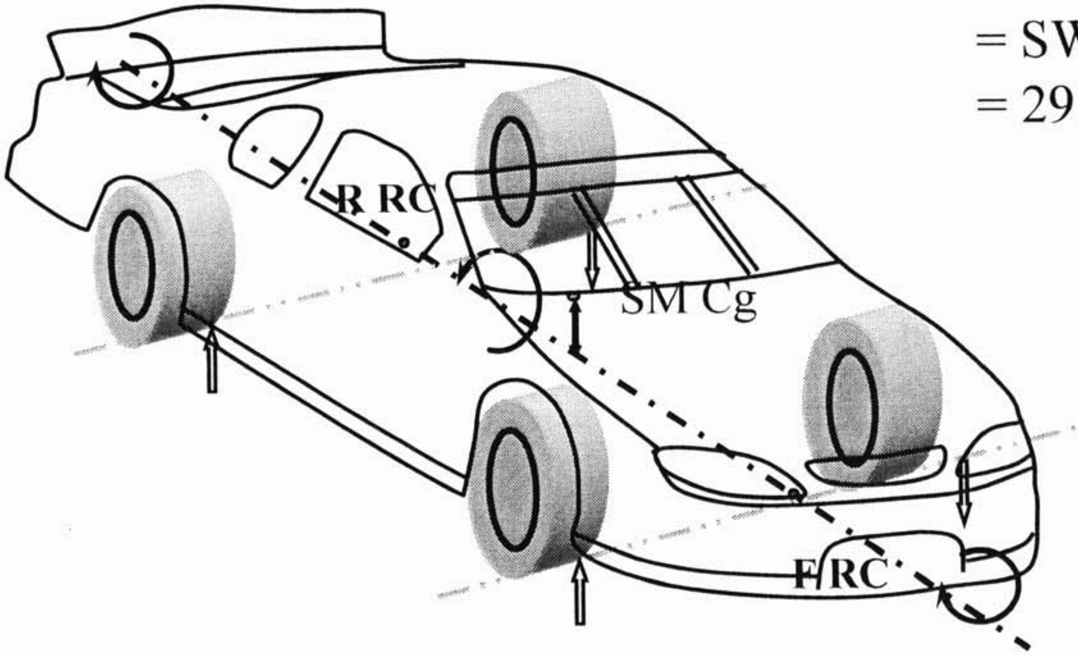
Front antiroll torque due to springs, antiroll bar and shocks

Lateral Elastic Weight Transfer : Example of Front and Rear Distribution

Rear antiroll torque due
to spring, antiroll bar and shocks
51,008 lb.in / deg (4,250 lb.ft /deg)

SMass = 2910 lb
Lat acc = 1.5 G
SM CG - Roll axis = 7.62 in

Moment due to lateral force
= SW * Lat Acc * Dist (SW Cg - Roll axis)
= 2910 * 1.5 * 7.62 = **33,261 lb.in**



Front antiroll torque due
to spring, antiroll bar and shocks
89,030 lb.in /deg (7,420 lb.ft / deg)

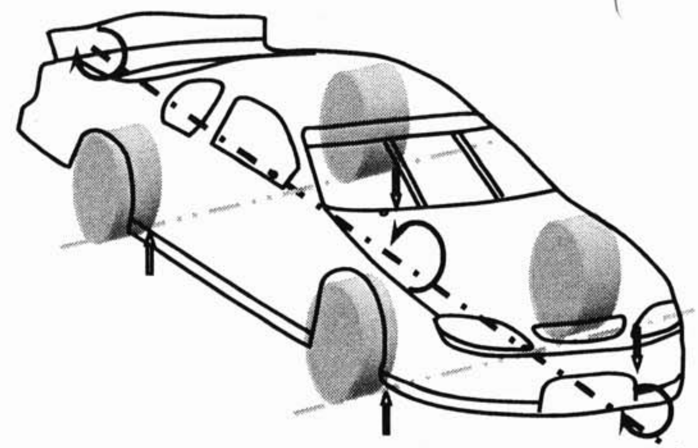
Roll Angle = 33,261 / (89,030 + 51,008)
= 0.237 deg.

% Front antiroll torque

= 100 * 89,030 / (89,030 + 51,008)
Pole **= 63.5 %**

DNQ: 62.5%　DNQ: 64.5%

Lateral Elastic Weight Transfer : Front and Rear Distribution



Front elastic SW transfer

$$= SM * Lat\ Acc * Dist\ (SM\ Cg - Roll\ axis) * \frac{Front\ Antiroll\ Torque}{Front\ Antiroll\ Torque + Rear\ Antiroll\ Torque} / F\ Track$$

$$= 2910 * 1.5 * 7.62 * \frac{89{,}030}{89{,}030 + 51{,}008} / 76 = 2910 * 1.5 * 7.62 * 0.6357 / 76 = 279.0\ \text{lb}$$

if change of front spring of ARB (stiffer) so that the Front Antiroll Torque goes up to 110,000 lb.in

$$= 2910 * 1.5 * 7.62 * \frac{110{,}000}{110{,}000 + 51{,}008} / 76 = 2910 * 1.5 * 7.62 * 0.683 / 76 = 298.9\ \text{lb}$$

Rear elastic SW transfer

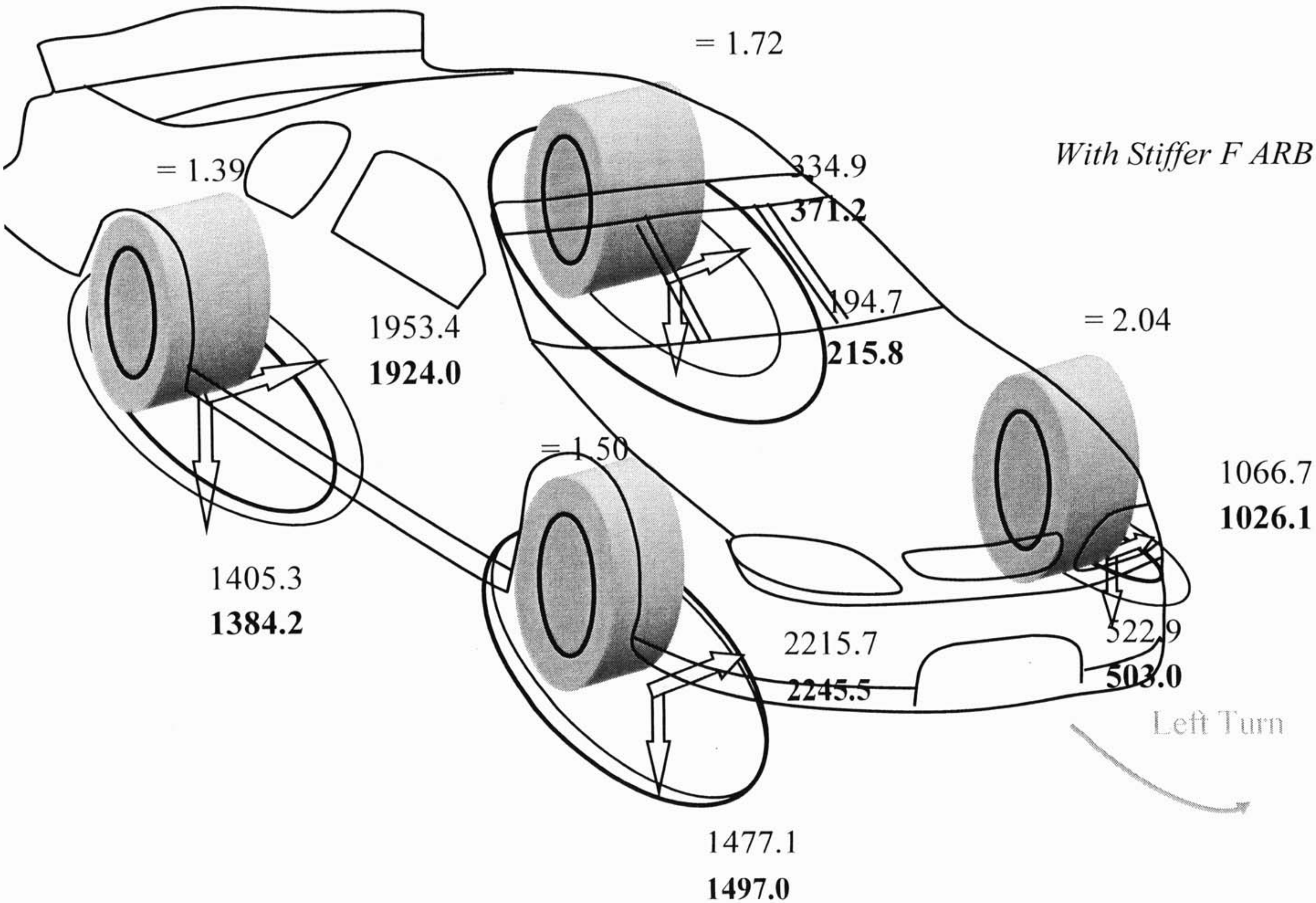
$$= SW * Lat\ Acc * Dist\ (SW\ Cg - Roll\ axis) * \frac{Rear\ Antiroll\ Torque}{Front\ Antiroll\ Torque + Rear\ Antiroll\ Torque} / R\ Track$$

$$= 2910 * 1.5 * 7.62 * \frac{51{,}008}{89{,}030 + 51{,}008} / 74 = 2910 * 1.5 * 7.62 * 0.364 / 74 = 163.6\ \text{lb}$$

$$= 2910 * 1.5 * 7.62 * \frac{51{,}008}{110{,}000 + 51{,}008} / 74 = 2910 * 1.5 * 7.62 * 0.317 / 74 = 142.5\ \text{lb}$$

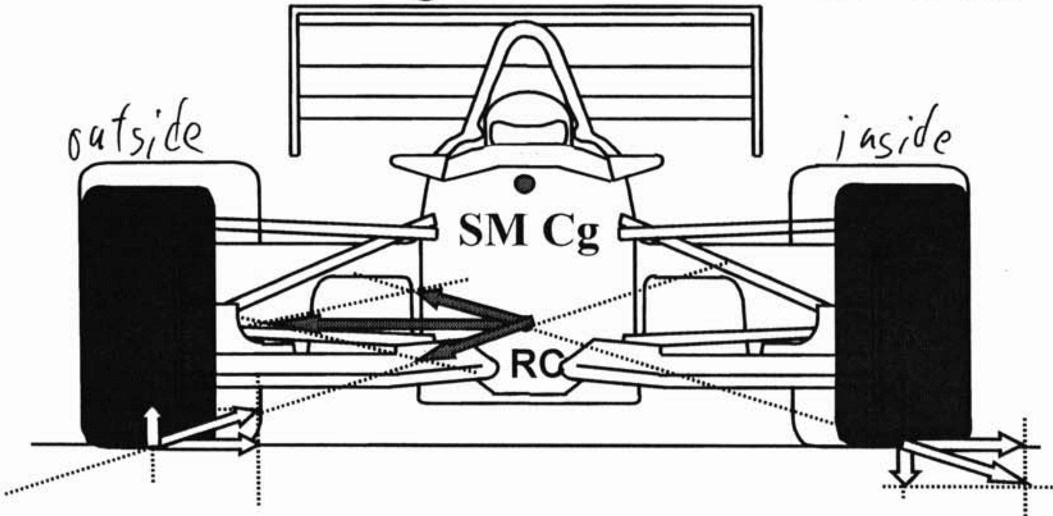
Effect of Front and Rear - Non Suspended Weight Transfers
- Suspended Geometric Weight Transfers
- Suspended Elastic Weight Transfers

	LF		RF	
Static Load	**1000**		**1000**	
- NSW Transfer	**- 59.2**		**+ 59.2**	
- SW Geometric Transfer	**- 138.9**		**+ 138.9**	
- SW Elastic Transfer	**- 279.0**	***- 298.9***	**+ 279.0**	***+ 298.9***
Dynamic Corner Weight	**522.9**	**503.0**	**1477.1**	***1497.0***
	800.0		**800.0**	
	- 115.3		**+ 115.3**	
With stiffer F ARB	**- 326.4**		**+ 326.4**	
	- 163.6	***- 142.5***	**+ 163.6**	***+ 142.5***
	194.7	***215.8***	**1405.3**	***1384.2***
	LR		RR	


= 1.72
= 1.39
With Stiffer F ARB
334.9
371.2
194.7
215.8
1953.4
1924.0
= 2.04
= 1.50
1066.7
1026.1
1405.3
1384.2
2215.7
2245.5
522.9
503.0
Left Turn
1477.1
1497.0

Roll center vertical position and 'geometric' lateral suspended weight transfer

Roll center above the ground and between the wheels

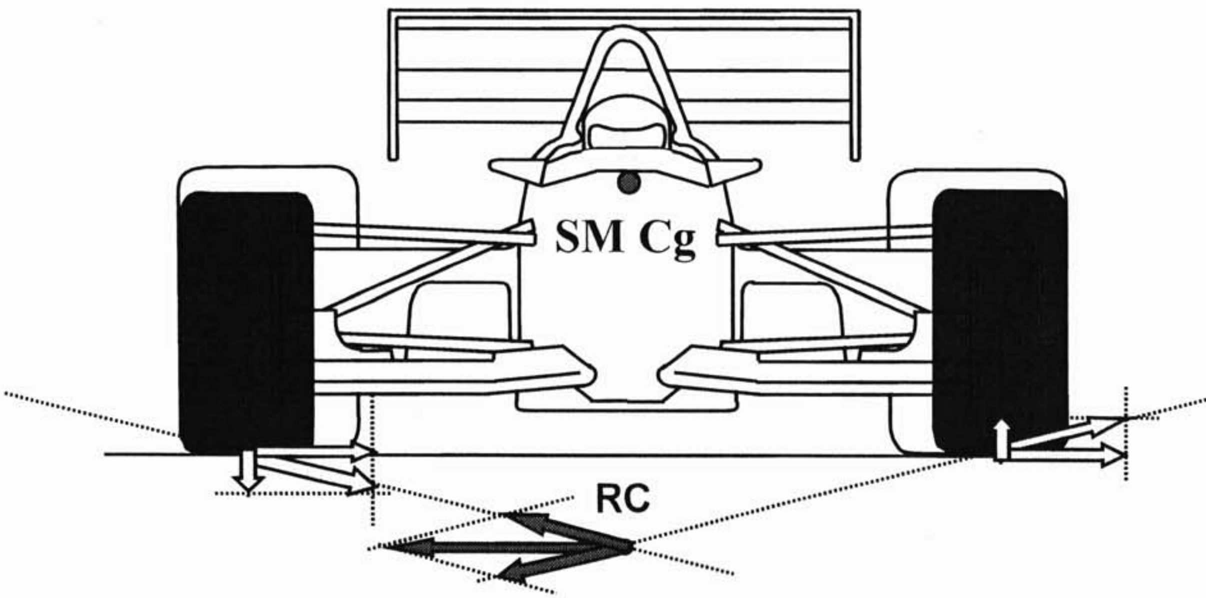


Less roll
More jacking
Ride height increases
Instant geometric transfer
- loads the outside tire
- unloads the inside tire

Increases turn in response

Chicanes

Roll center under the ground and between the wheels

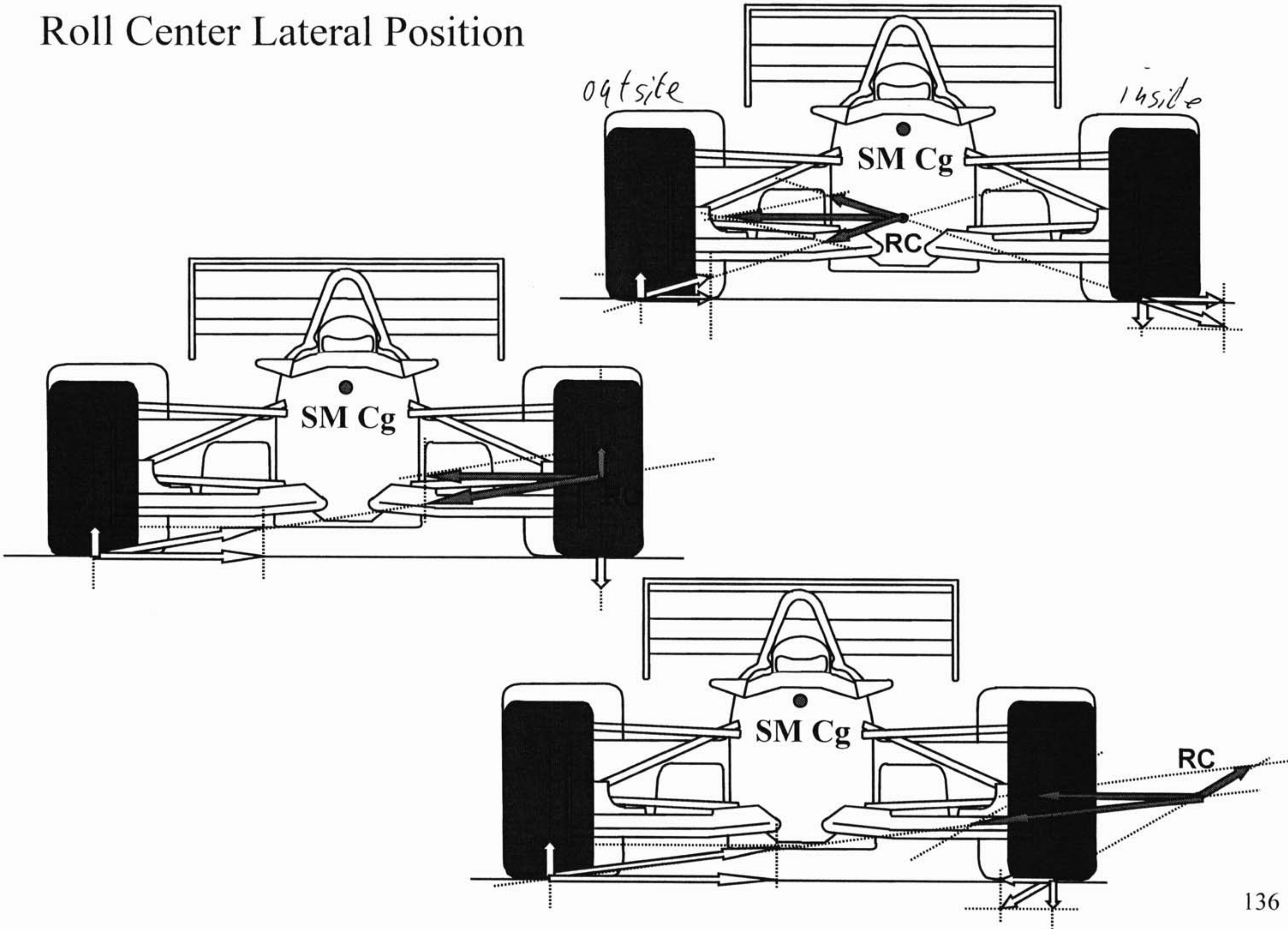


More roll
Anti jacking
Ride height decreases
Instant geometric transfer
- loads the inside tire
- unloads the outside tire

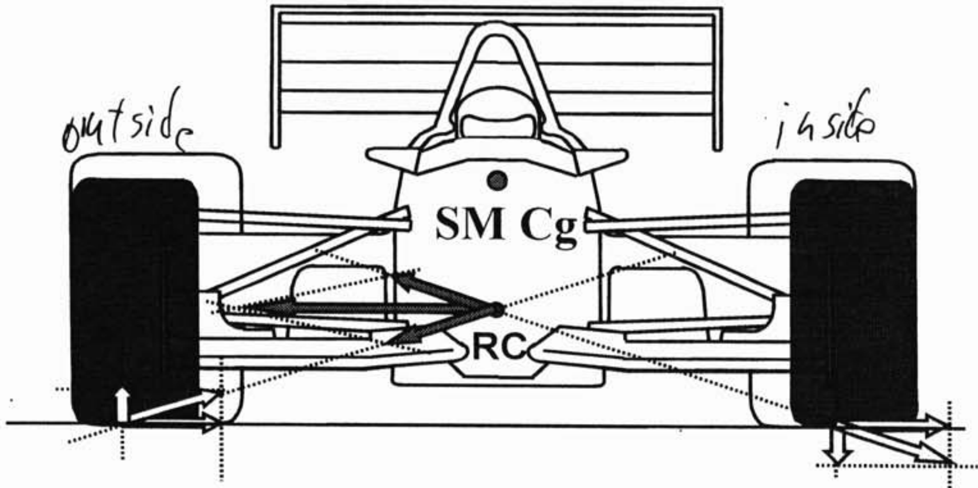
"Sluggish" turn in response

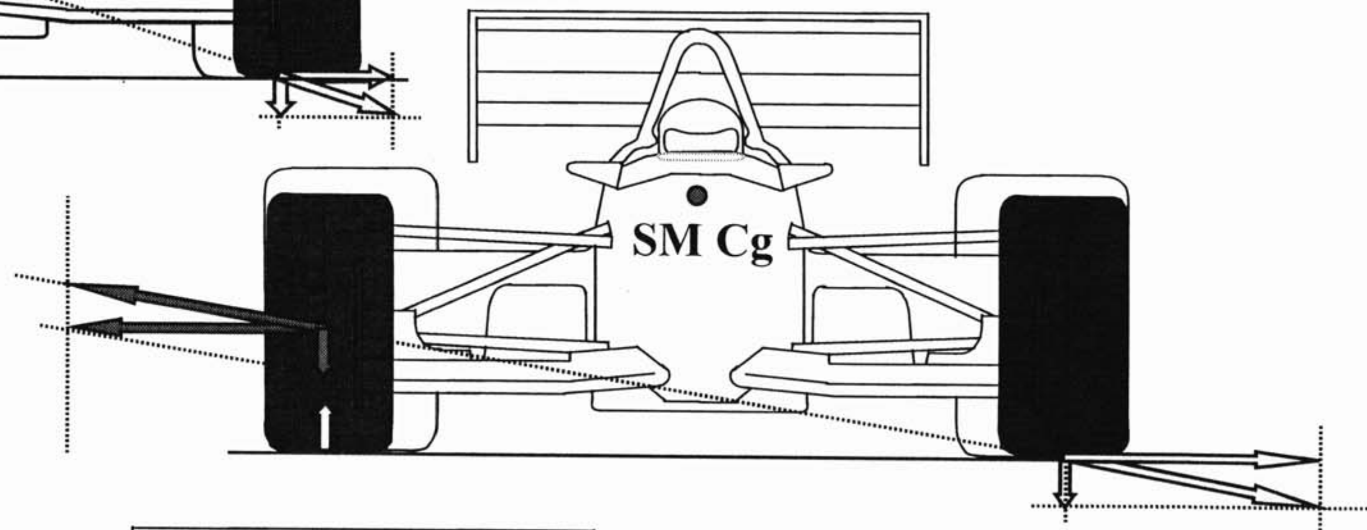
Fast corners

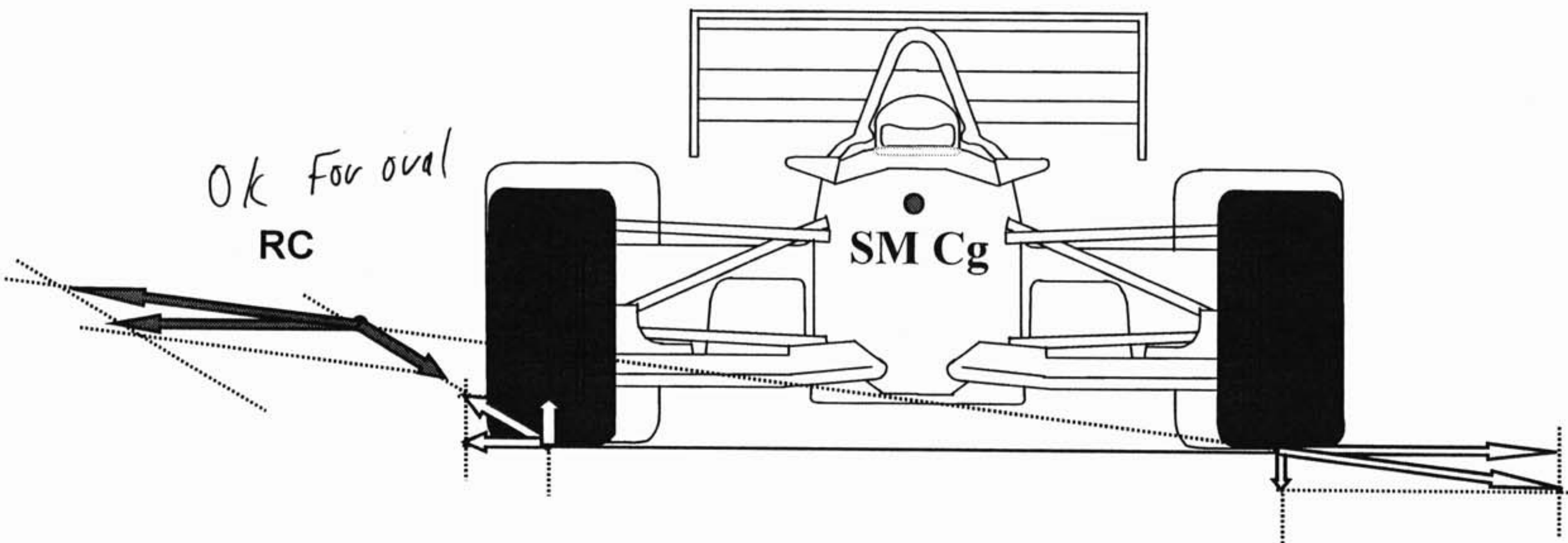
Roll Center Lateral Position



Roll Center Lateral Position





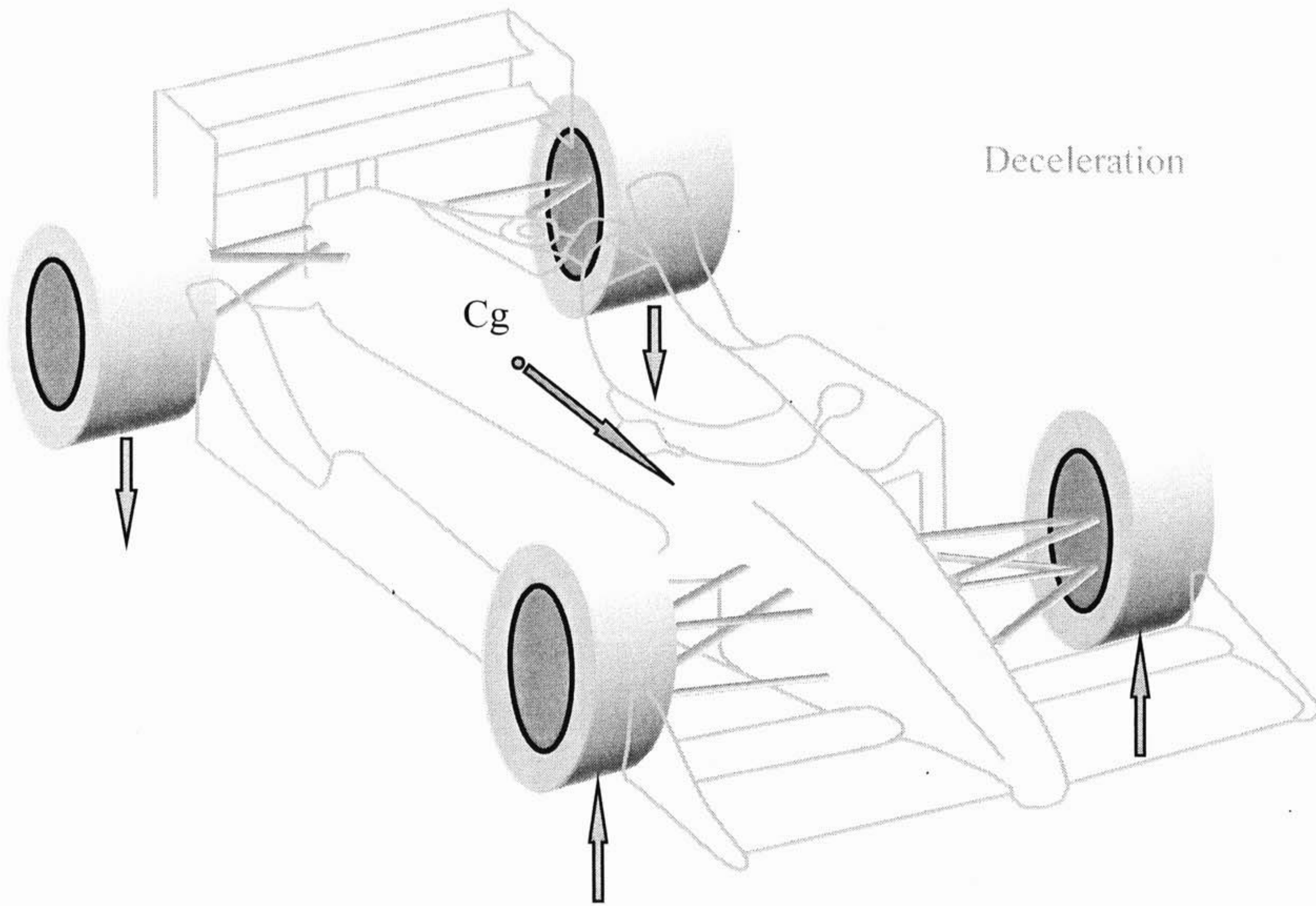


Roll Center Vertical and Lateral Movements. Influence on Handling

10%

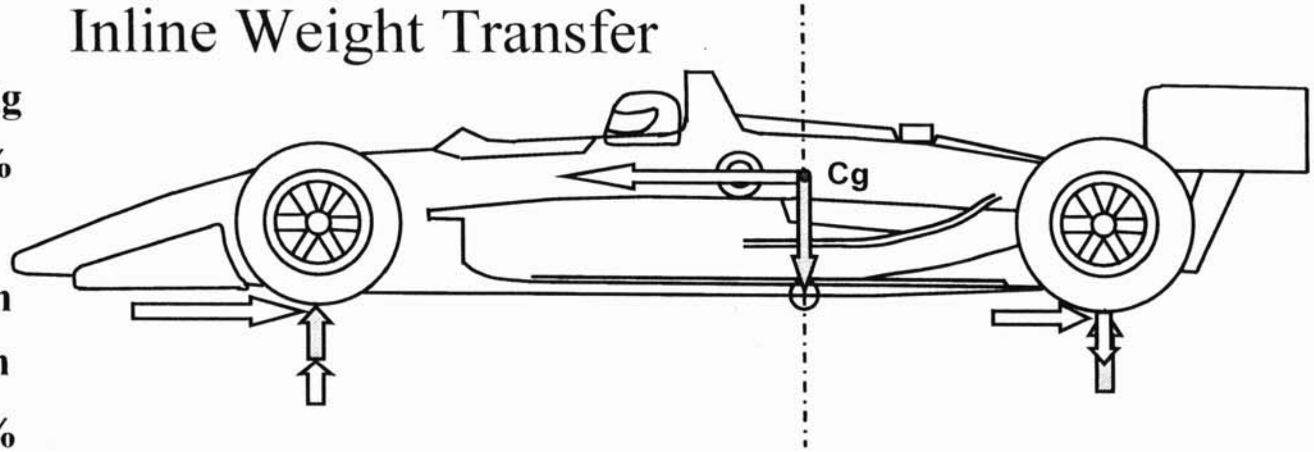
- 80 % of the corner speed is determined in the first 20 % of the corner
- It is at the beginning and at the end of the corner that we see the biggest change
  in the steering angle,
  the lateral acceleration,
  the slip angle,
  and the corner radius
- During the beginning of these first 20 % the non suspended weight transfer and the elastic part of the suspended weight transfer are not controlled especially if the suspended mass have a high moment of inertia.
- To illustrate the idea let's say this: the higher suspended mass inertia (and also the bigger distance between the suspended mass center of gravity and the roll axis) the less efficient each shock adjustment at the corner entrance.
- But during the first appearance of the lateral acceleration the geometric weight transfer are quasi instantaneous.
- The lateral and vertical initial position and movement of the roll center at the corner entry phase entry will determine the handling of the car.
- There is no easy answer about how to find where the roll centers should be and how they should move.
- It is part art (and experience), part engineering and part testing.
- But one thing is sure: On top of the car set up. the knowledge of the tires curves, forces and angles would help in a major way to find where the roll centers should be and how they should move one way or the other and ***why.***

In line Weight Transfer Basics



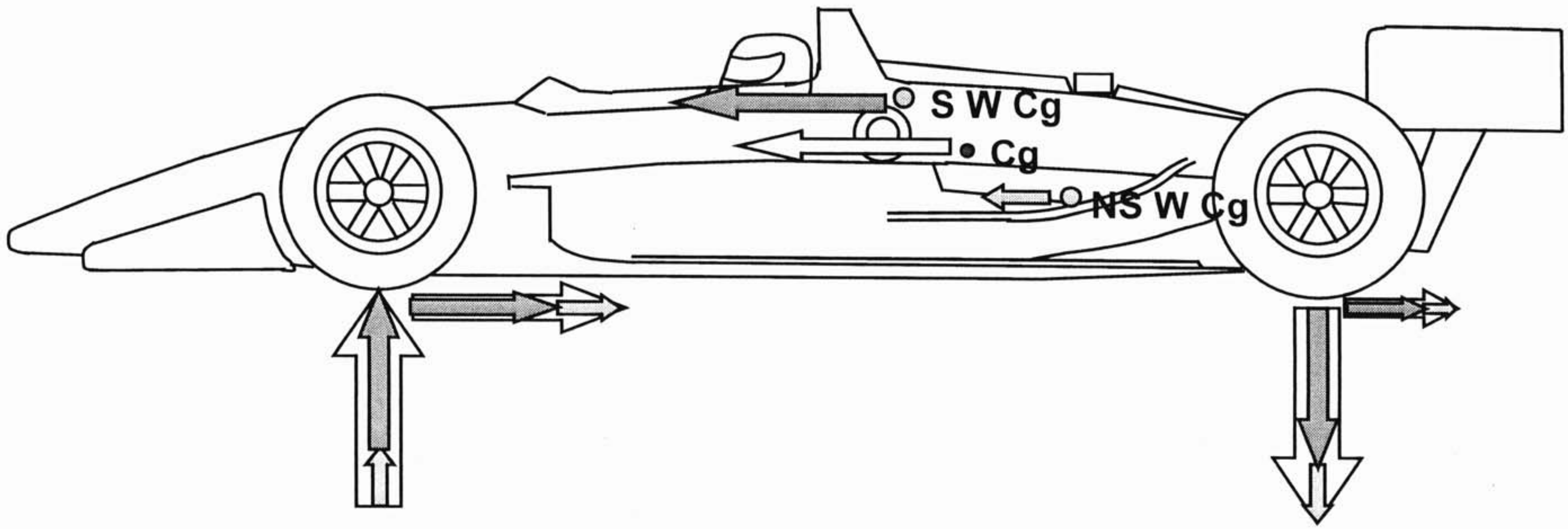
Inline Weight Transfer

Mass	**900.0 Kg**
Mass distribution	**44.4 %**
Inline deceleration	**2.0 G**
Cg Height	**0.348 m**
Wheelbase	**3.048 m**
Brake Bias (on front)	**70.0 %**



Static Front Corner Mass = Mass * Mass distribution / 2	**900 * 0.444 / 2**	**200 kg**
Static Rear Corner Mass = Mass * (1 -Mass distribution) / 2	**900 * 0.556 / 2**	**250 kg**
Inline Force = Mass * Inline Deceleration	**900 * 2.0 * 9.81**	**18000 N**
Weight Transfer = (Inline force * Cg Height / Wheelbase) / 2 =	**(18000 * 0.348 /3.048) / 2**	**1027 N**
Front Corner Weight = Static Weight + Weight Transfer	**2000 + 1027**	**3027 N**
Rear Corner Weight = Static Weight - Weight Transfer	**2500 - 1027**	**1473 N**
Front Corner Braking Force = In line Force * Brake Bias / 2	**(18000 * 0.70) / 2**	**6300 N**
Rear Corner Braking Force = (In line Force * (1 - Brake Bias)) / 2	**(18000 * 0.30) / 2**	**2700 N**

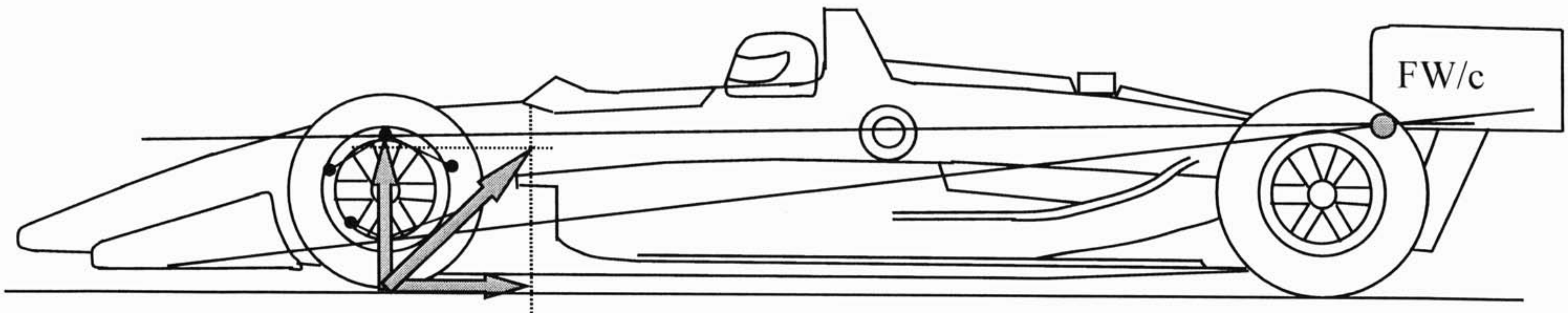
Inline Weight Transfer



Inline NS W Transfer / Wheel = (NS M * Inline Acc * NS W Cg Height / Wheelbase) / 2

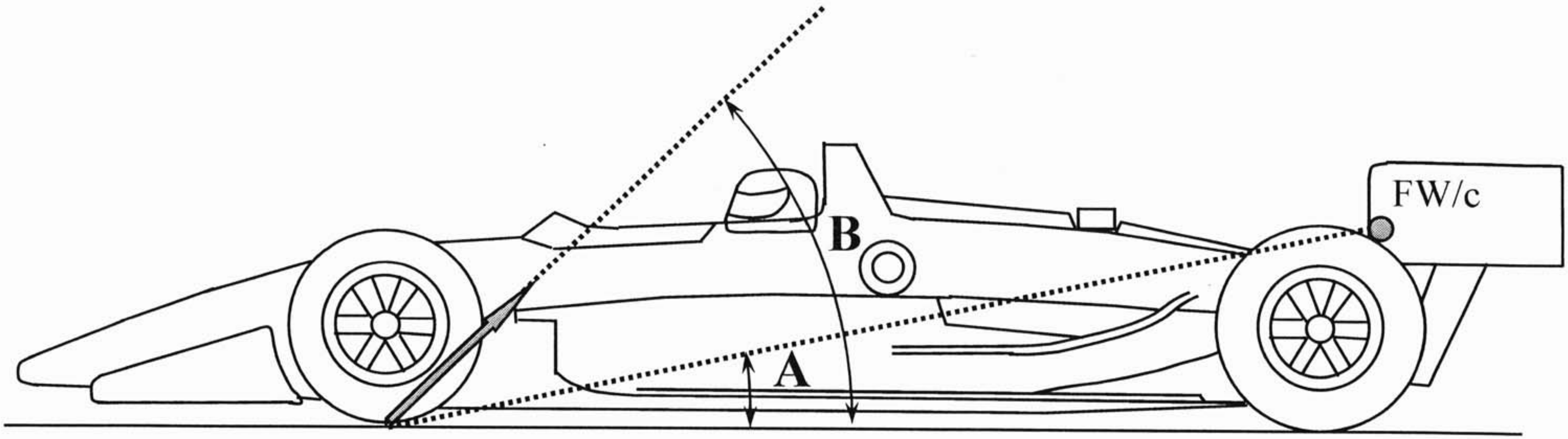
Inline S W Transfer = (S M * Inline Acc * SW Cg Height / Wheelbase) / 2

Inline Weight Transfer



Forces are applied at the front tire contact patch center if brakes are outboard (in the wheel)

Front Antidive and Inline Braking

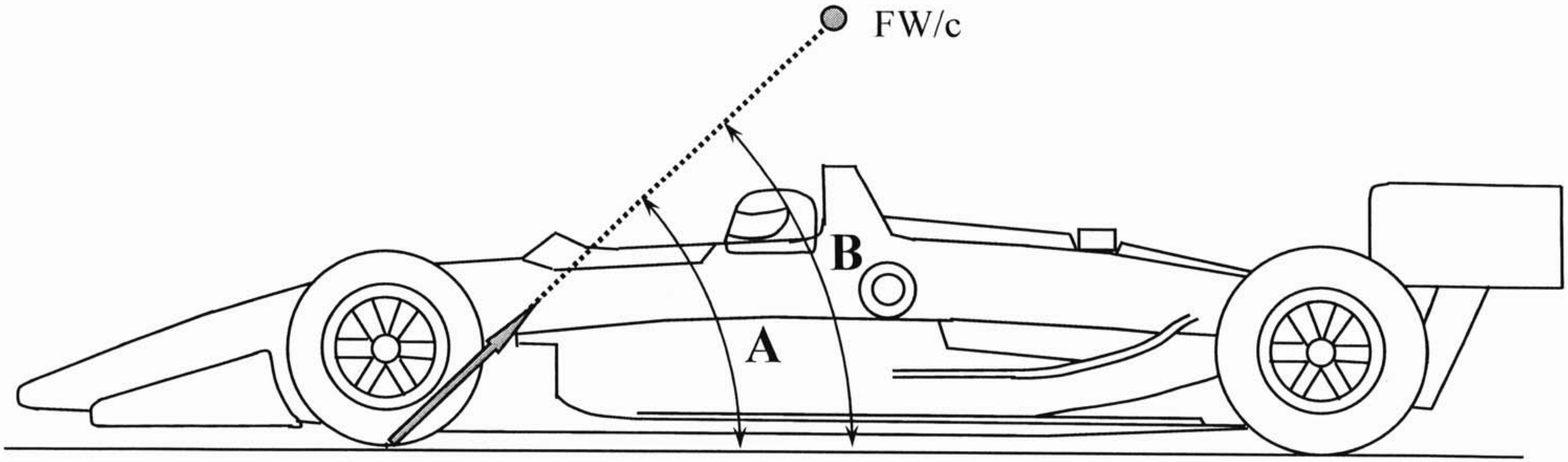


Antidive (%) = 100 * Tan A / Tan B

Angle A = Fn (Instant suspension geometry)

Angle B = Fn (Inline Weight Transfer, Brake balance)

Front Antidive and Inline Braking

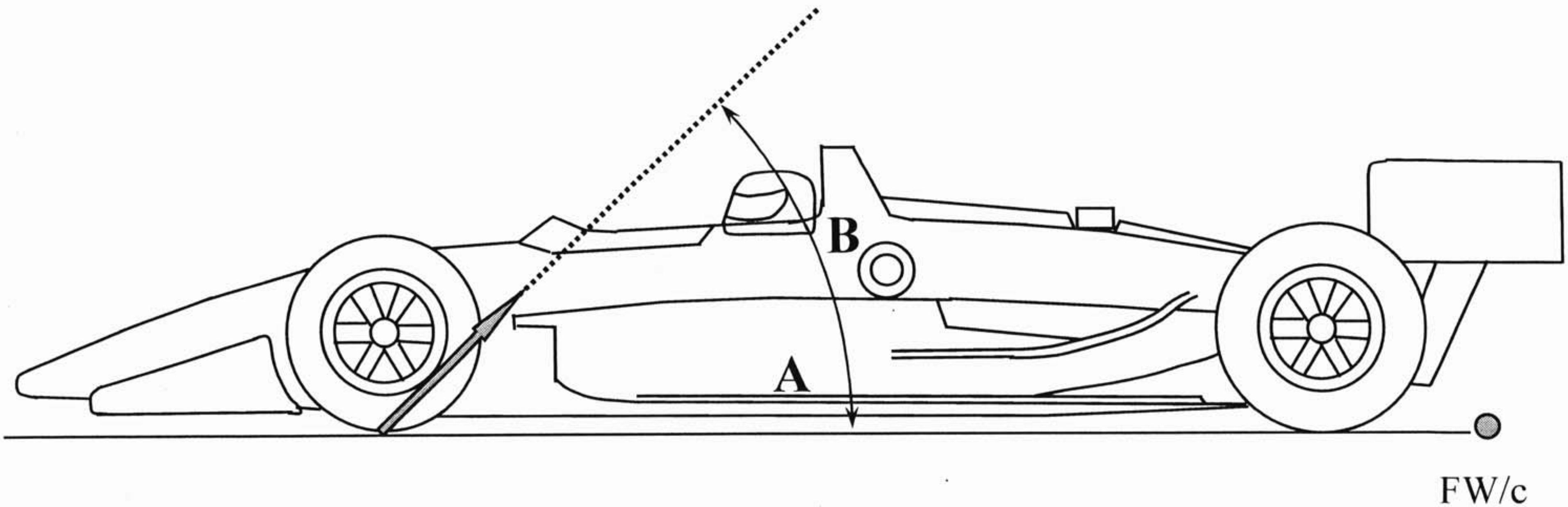


Tan A = Tan B   Antidive = 100 %

Inline Suspended Weight Transfer could create Pitch movement (depending of rear suspension geometry) but there is no front suspension deflection.

All the Inline Suspended Weight Transfer Forces will go through the wishbones. This is 100 % of in line "geometric" weight transfer. No forces are measured on the front pushrod strain gauges.

Front Antidive and Inline Braking

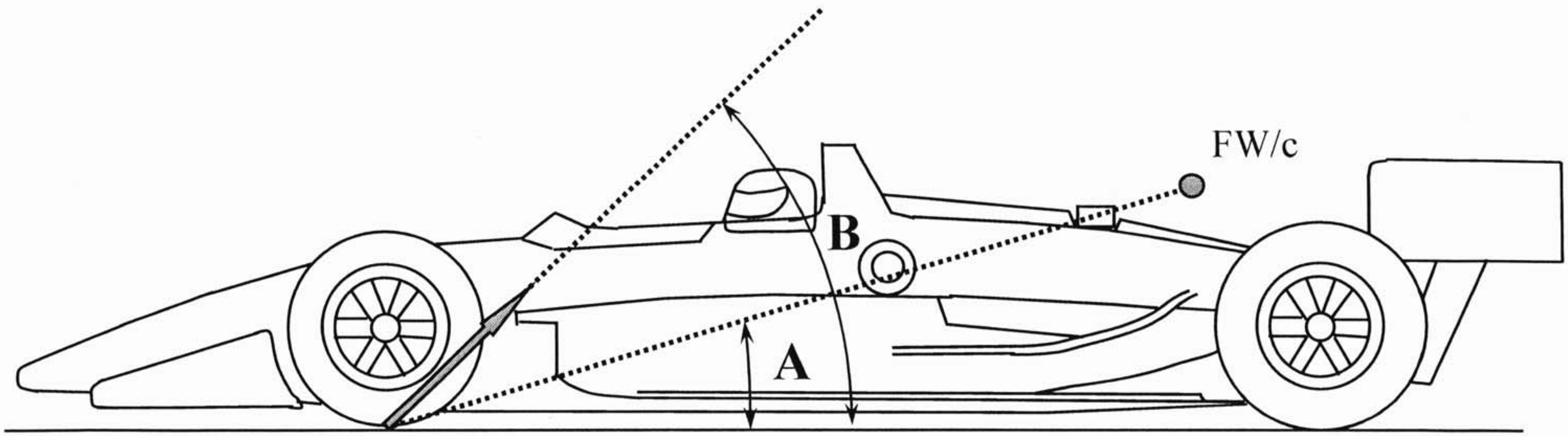


Tan A = 0   Antidive = 0 %

Inline Suspended Weight Transfer creates Pitch movement (depending on rear suspension geometry) and Front Suspension deflection.

All the Inline Suspended Weight Transfer Forces will go through the springs. This is 100 % of "elastic" weight transfer.
All forces are measured on the Front pushrod strain gauges.

Front Antidive and Inline Braking



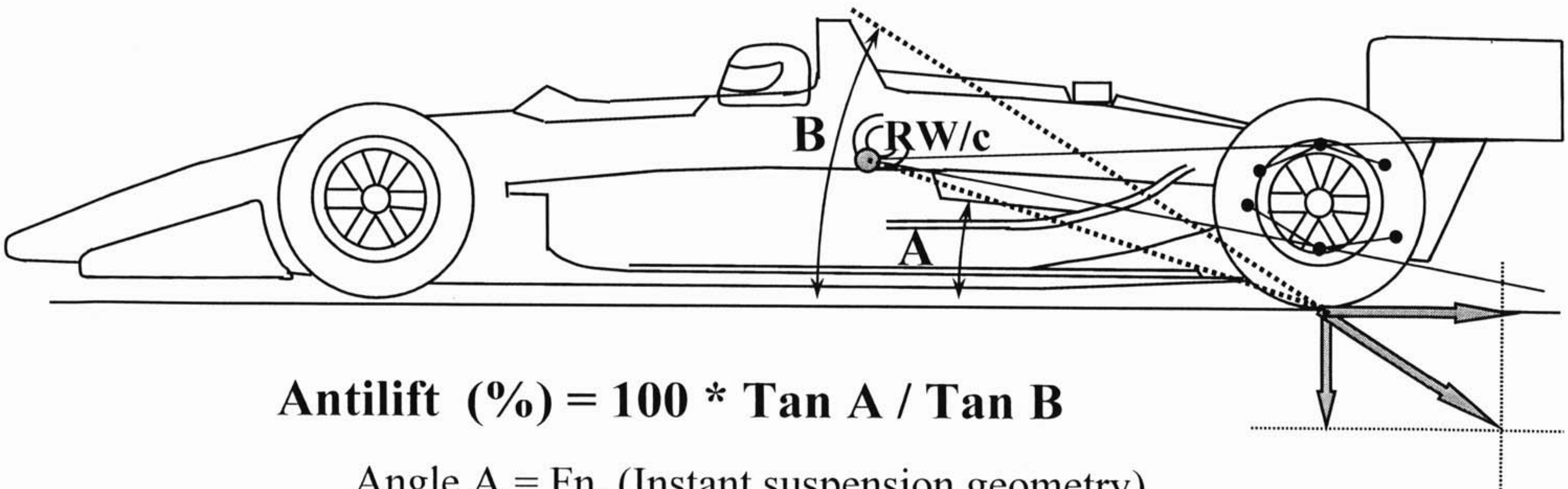
Antidive = 30 %

Inline Suspended Weight Transfer creates Pitch movement (depending on rear suspension geometry) and Front Suspension deflection.

30 % of the Inline Suspended Weight Transfer Forces will go through the wishbones ("geometric" weight transfer) and 70 % through the springs ("elastic "weight transfer). Only 70 % of these forces will be measured on the Front pushrod strain gauges.

To calculate the front suspension deflection we will only take into account 70 % of the Inline Suspended Weight Transfer forces.

Rear Antilift and Inline Braking



Antilift (%) = 100 * Tan A / Tan B

Angle A = Fn. (Instant suspension geometry)

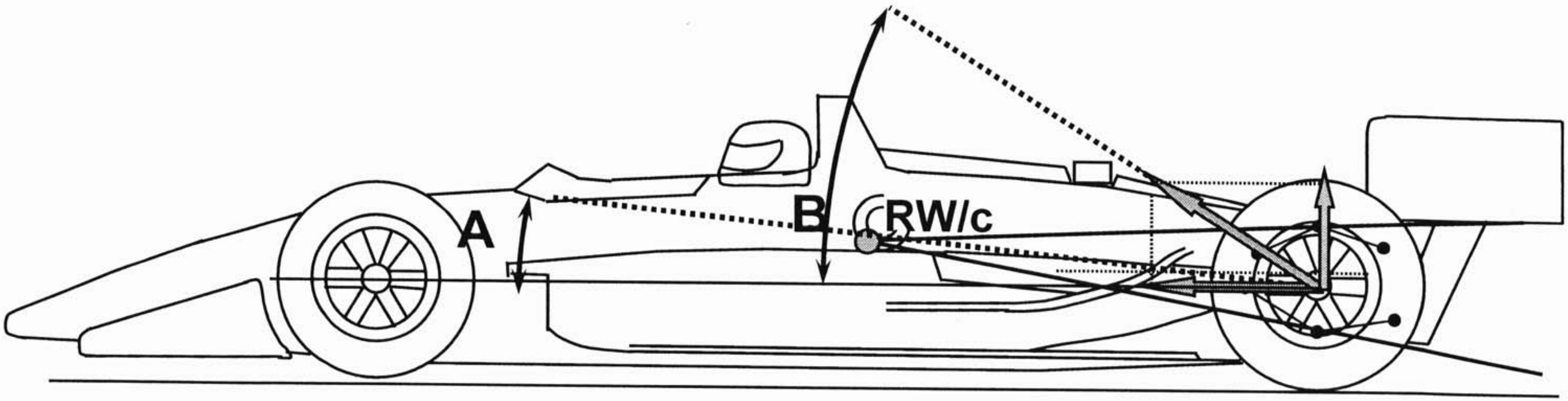
Angle B = Fn. (Inline Weight Transfer, Brake balance)

Forces are applied at the front tire contact patch center if brakes are outboard (in the wheel).

Forces would be applied at the wheel center if brakes were inboard (in the chassis).

Considerations about pitch, suspension deflection and strain gauges are similar to the one made for Antidive.

Rear Antisquat and Inline Acceleration

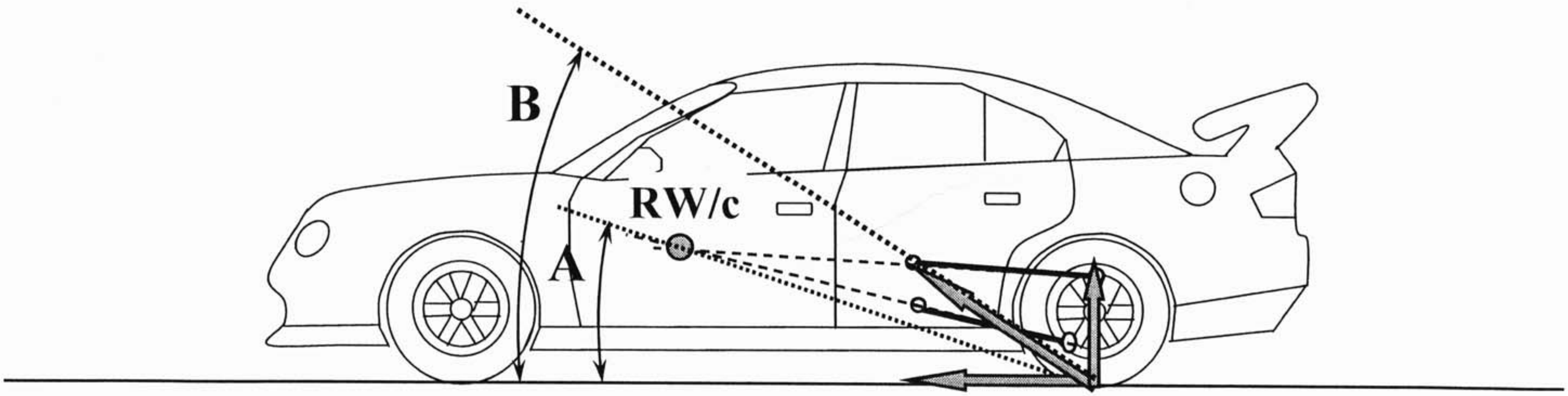


Antisquat (%) = 100 * Tan A / Tan B

Angle A = Fn. (Instant suspension geometry, *wheel radius*)
Angle B = Fn. (Inline Weight Transfer)

Forces are applied at the wheel center in the case of an independent suspension.
Forces would be applied at the tire contact patch center in case of a solid axle.
Considerations about pitch, suspension deflection and strain gauges are similar to the one made for Antilift.

Rear Antisquat and Inline Acceleration

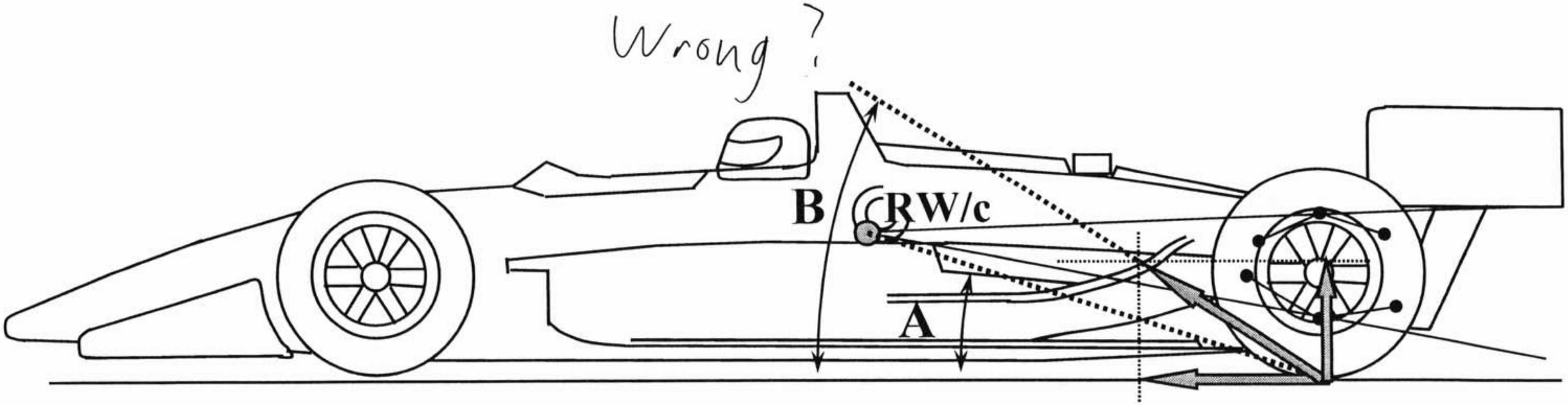


Antisquat (%) = 100 * Tan A / Tan B

Angle A = Fn. (Instant suspension geometry, *wheel radius*)
Angle B = Fn. (Inline Weight Transfer)

Forces are applied at the wheel center in the case of an independent suspension.
Forces would be applied at the tire contact patch center in case of a solid axle.
Considerations about pitch, suspension deflection and strain gauges are similar to the ones made for Antilift.
The angle B is going to be a function of the differential ratio.

Rear Antisquat and Inline Acceleration



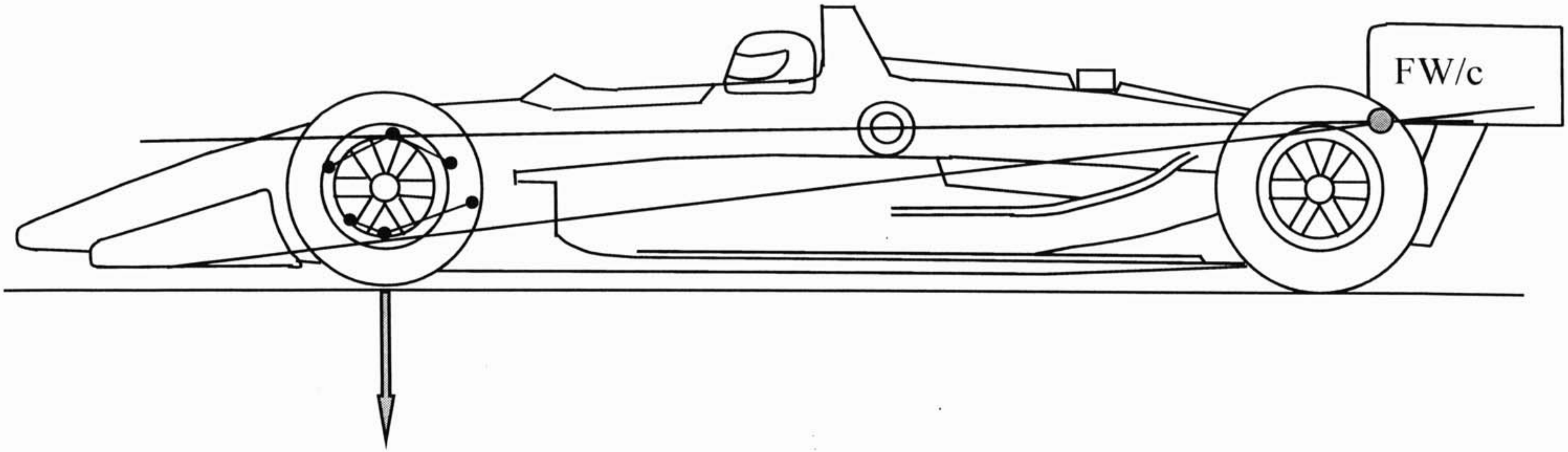
Antisquat (%) = 100 * Tan A / Tan B

Angle A = Fn. (Instant suspension geometry, *wheel radius*)
Angle B = Fn. (Inline Weight Transfer)

Forces are applied at the wheel center in the case of an independent suspension.
Forces would be applied at the tire contact patch center in case of a solid axle.
Considerations about pitch, suspension deflection and strain gauges are similar to the one made for Antilift.

See 140

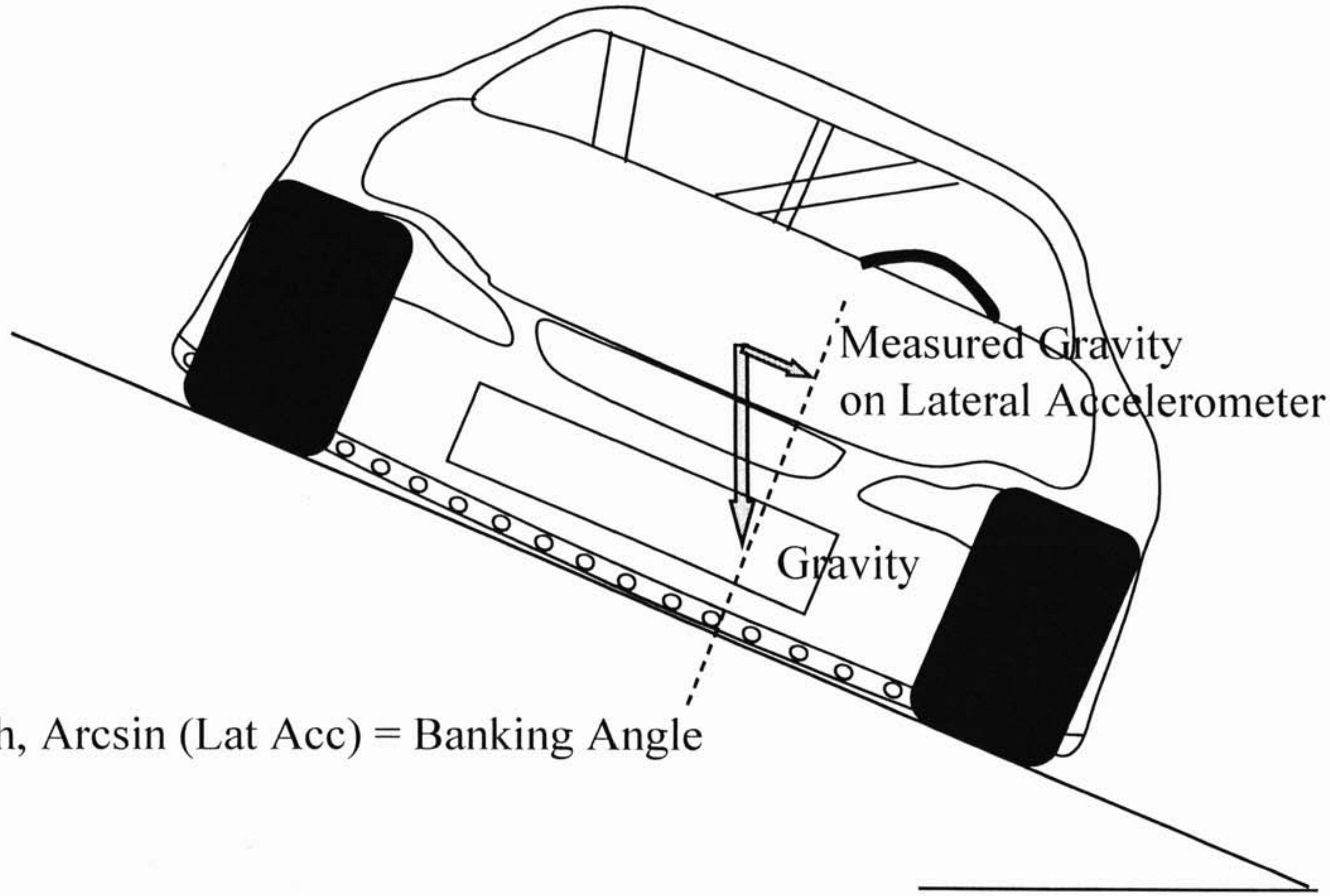
Front Antilift and Inline Acceleration



In the case of rear wheel drive there is no in line force applied at the front wheel center nor at the front wheel contact patch as there would be for a front wheel drive or a 4 wheel drive car.

Suspended weight pitch, front suspended weight ride height changes and front suspension deflection will be 100 % function of the inline weight transfer.

Vertical Acceleration (Banking)



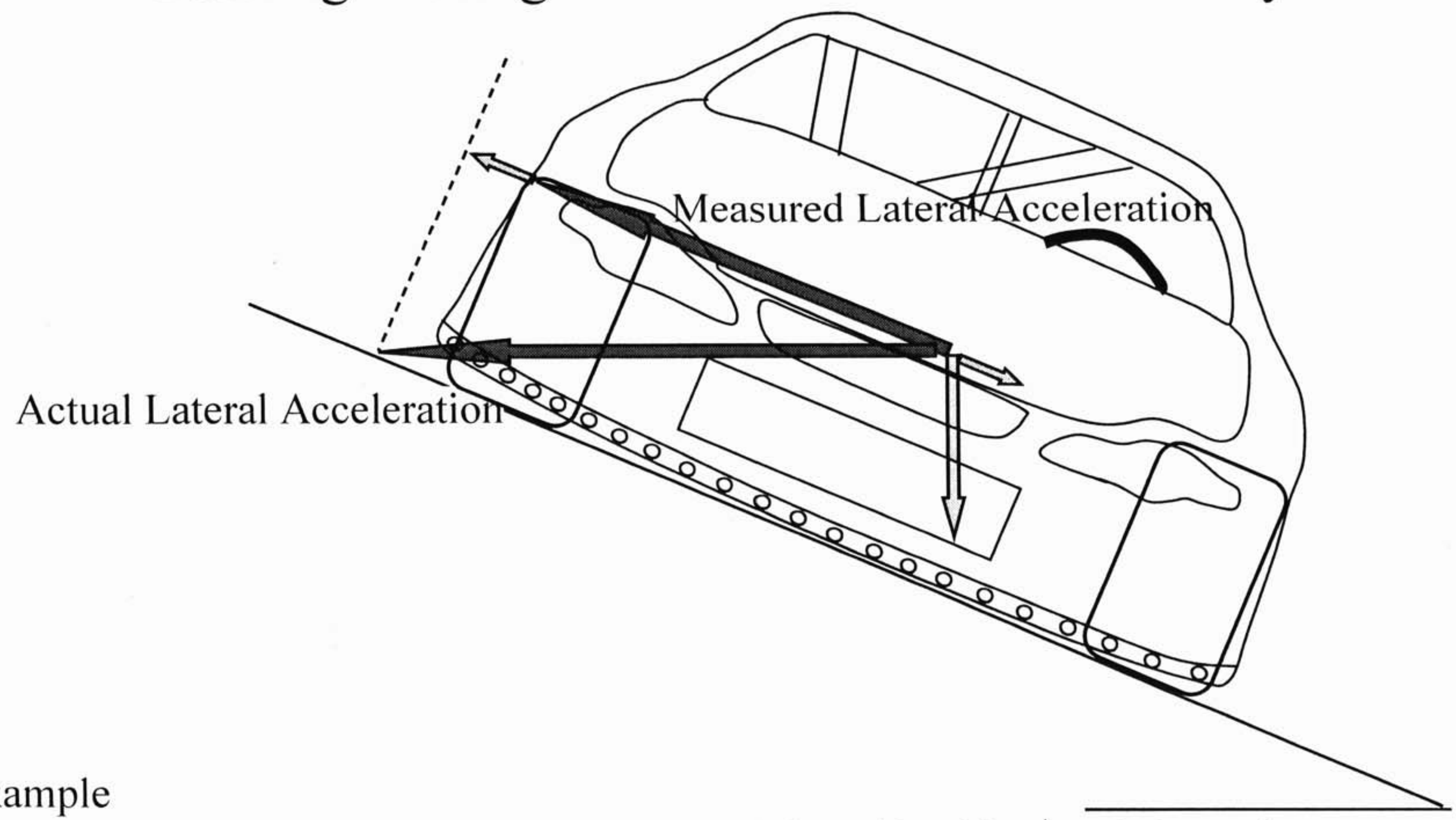
At 0 mph, Arcsin (Lat Acc) = Banking Angle

Example

If Lat Acc measured is - 0.259 G

Banking Angle = Arcsin (0.259) = 15 deg.

Banking / Using the Lateral Accelerometer only

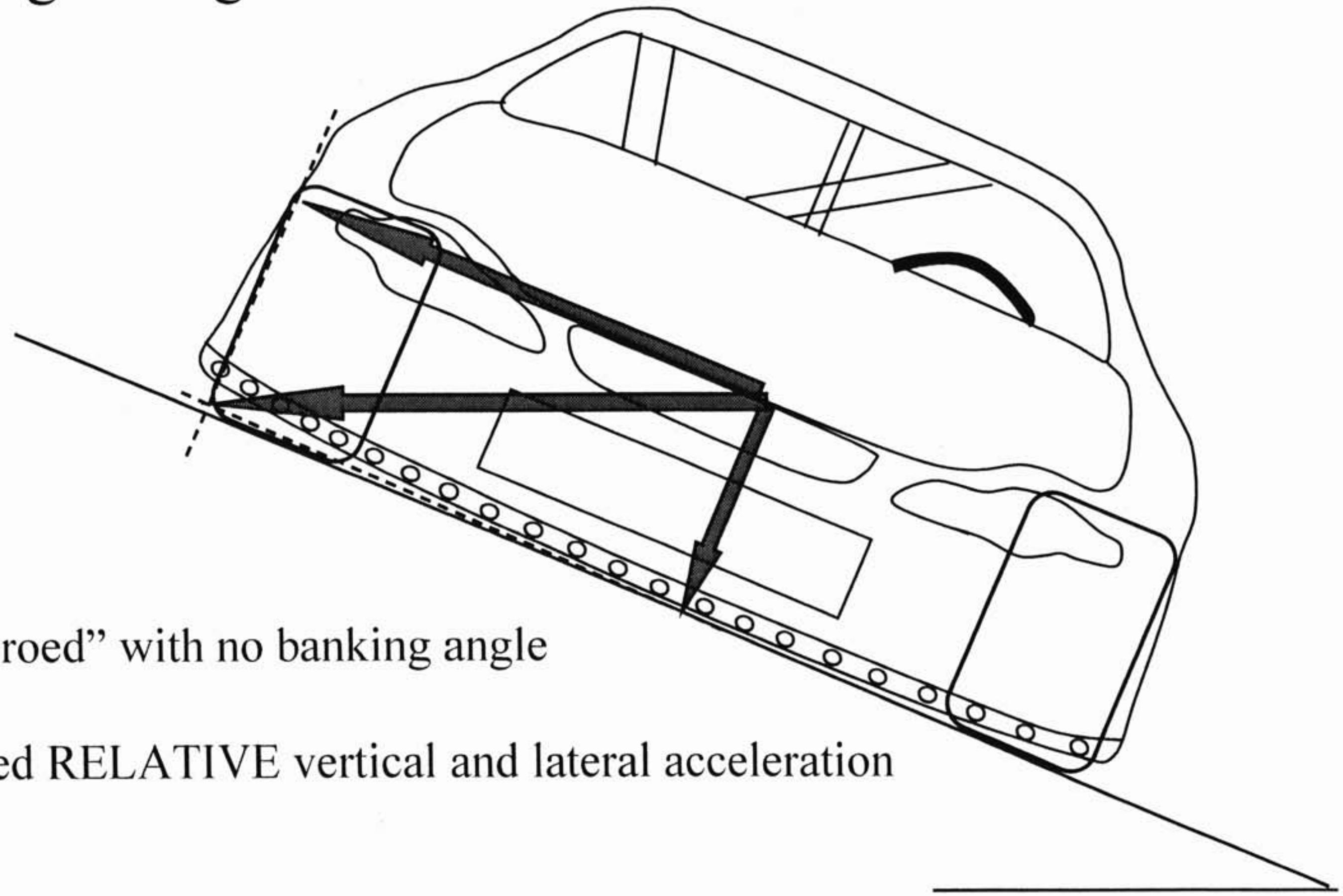


Example
If Lat Acc measured is 2.500 G, Mass = 3,600 lb and banking angle is 15 deg.

Actual Lat Acc = (2.500 + 0.259) / Cos 15 deg = 2.856 G
Vertical Acc = 2.856 * Sin 15 = 0.739

Lateral Force = 3,600 * 2.856 = 10,282 lbs

Banking: Using Lat *and* Vert Accelerometers



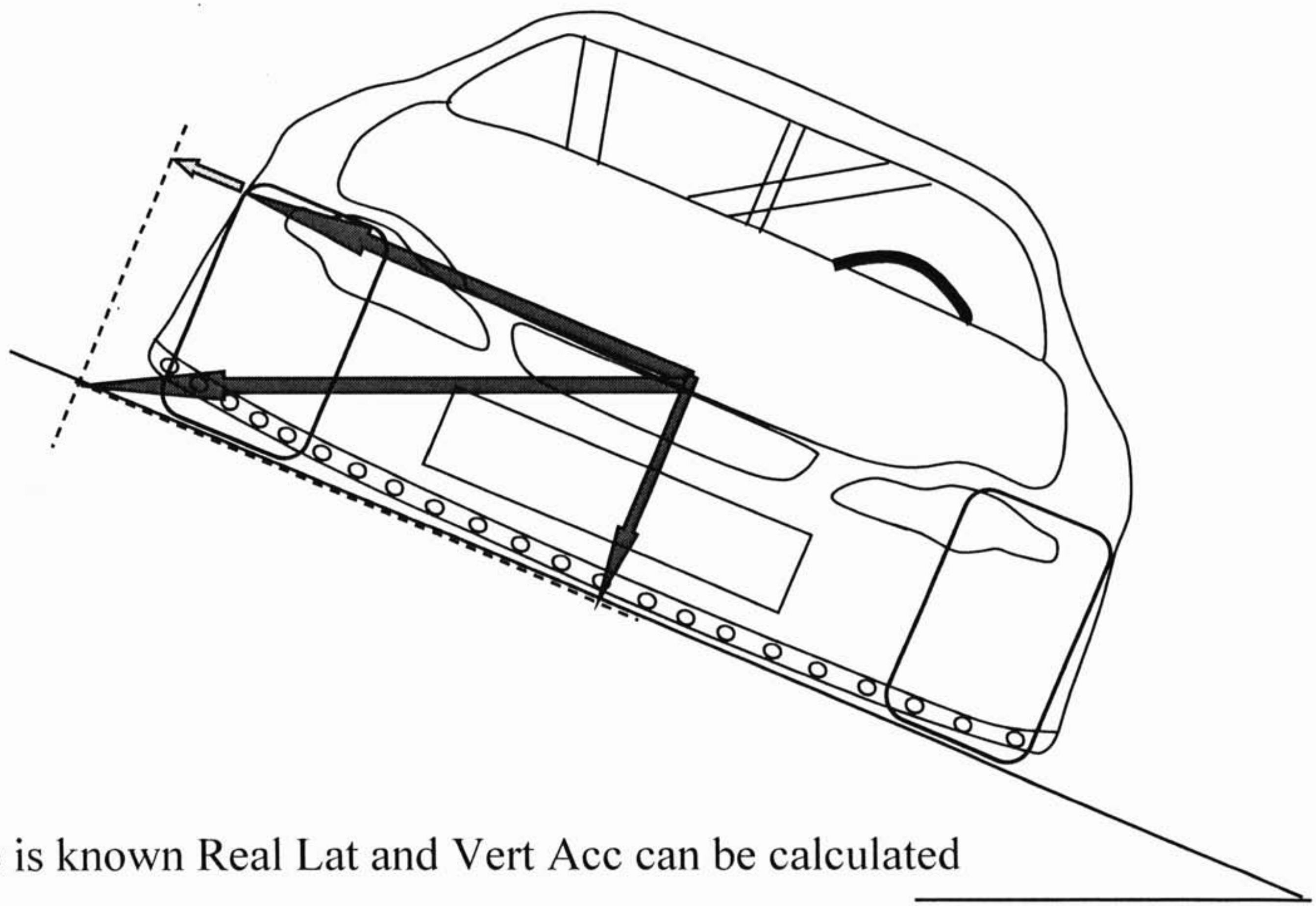
Vertical accelerometer "zeroed" with no banking angle

The knowledge of measured RELATIVE vertical and lateral acceleration gives the banking angle

Banking Angle = Arctan (meas. Vert Acc / meas. Lat Acc)
(Considering roll negligible)

If Meas Lat Acc = 2.500 G and Meas Vert. Acc = 1.670 G
Banking Angle = Atan (*0.670* / 2.500) = 15 deg

Banking / Real Lat and Vert Accelerations



Once the banking angle is known Real Lat and Vert Acc can be calculated

Real Lat Acc = (Meas. Lat Acc + Sin Banking) / Cos Banking
= (2.500 + 0.259) / 0.966
= 2.856

5. Dampers

- Shock
- Damping Shims Principles
- Influence of Shim Stack Preload
- Influence of the Low Speed Adjusters
- How to choose your springs
- How to choose your schocks
- Damping Ratio
- Working with shocks : Example of front setting influence

Shock

Low speed

Around 1 in / sec

Weight transfer

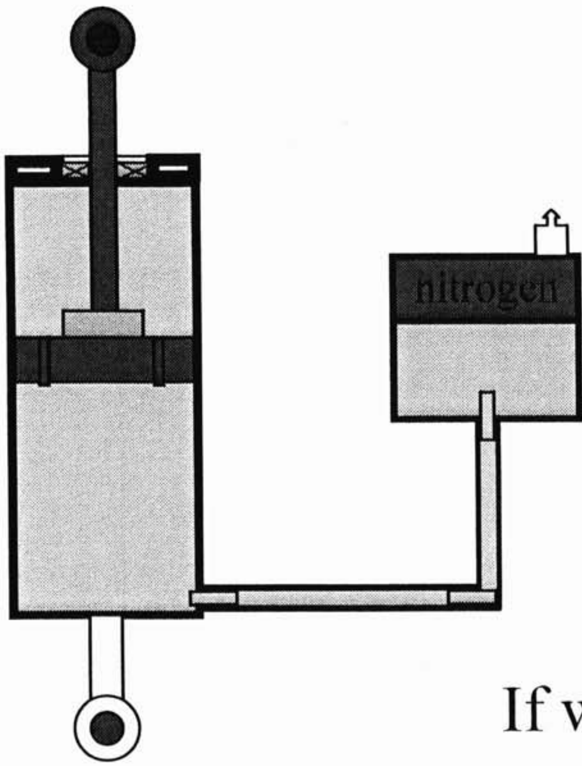
Control transition phases

High speed

5 in / sec and over

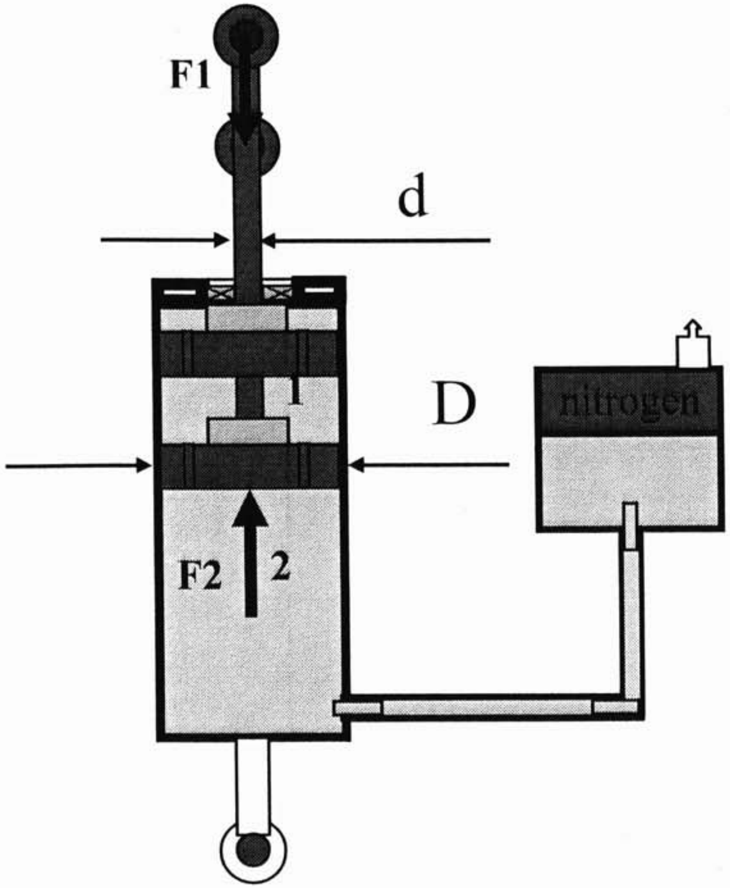
Track surfaces bump / Curbs

Control Tire Contact Patch Surface Consistency



In this case, shock absorber is locked

If we add a reservoir, the piston can move



$$P1 = P2 = P\ nitro$$

$$F1 = P1 * \pi * (D^2 - d^2) / 4$$

$$F2 = P2 * \pi * D^2 / 4$$

$$\Rightarrow \boxed{F1 < F2}$$

This explains why the shock is always extended while not installed on the car

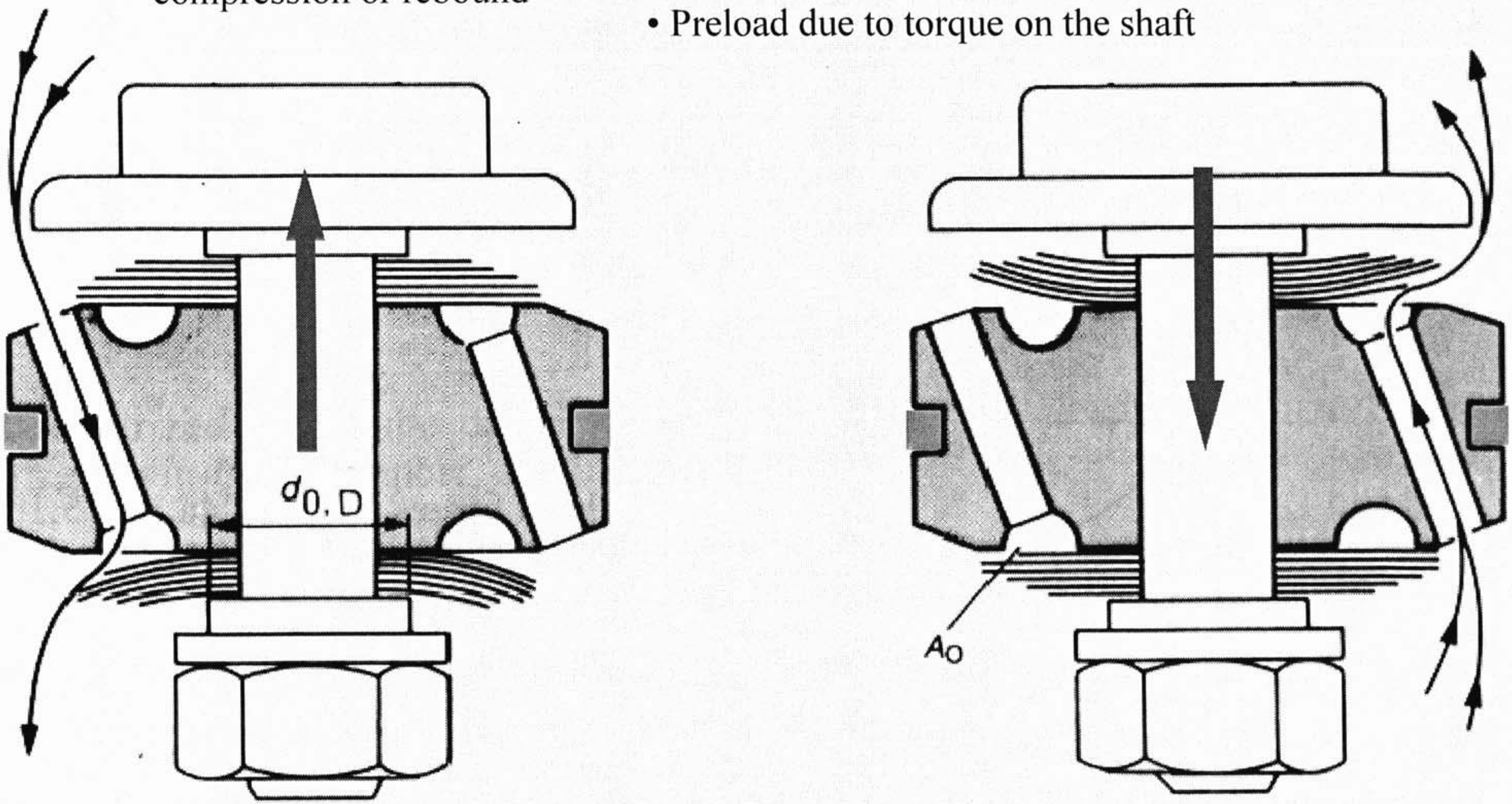
To move, we will first have to fight a force due to the gas pressure.

Damping Shims Principles

Force due to shims depends on :

- Shims flexion inertia (number, thickness, diameter)
- Holes diameters in the piston
- Preload due to torque on the shaft

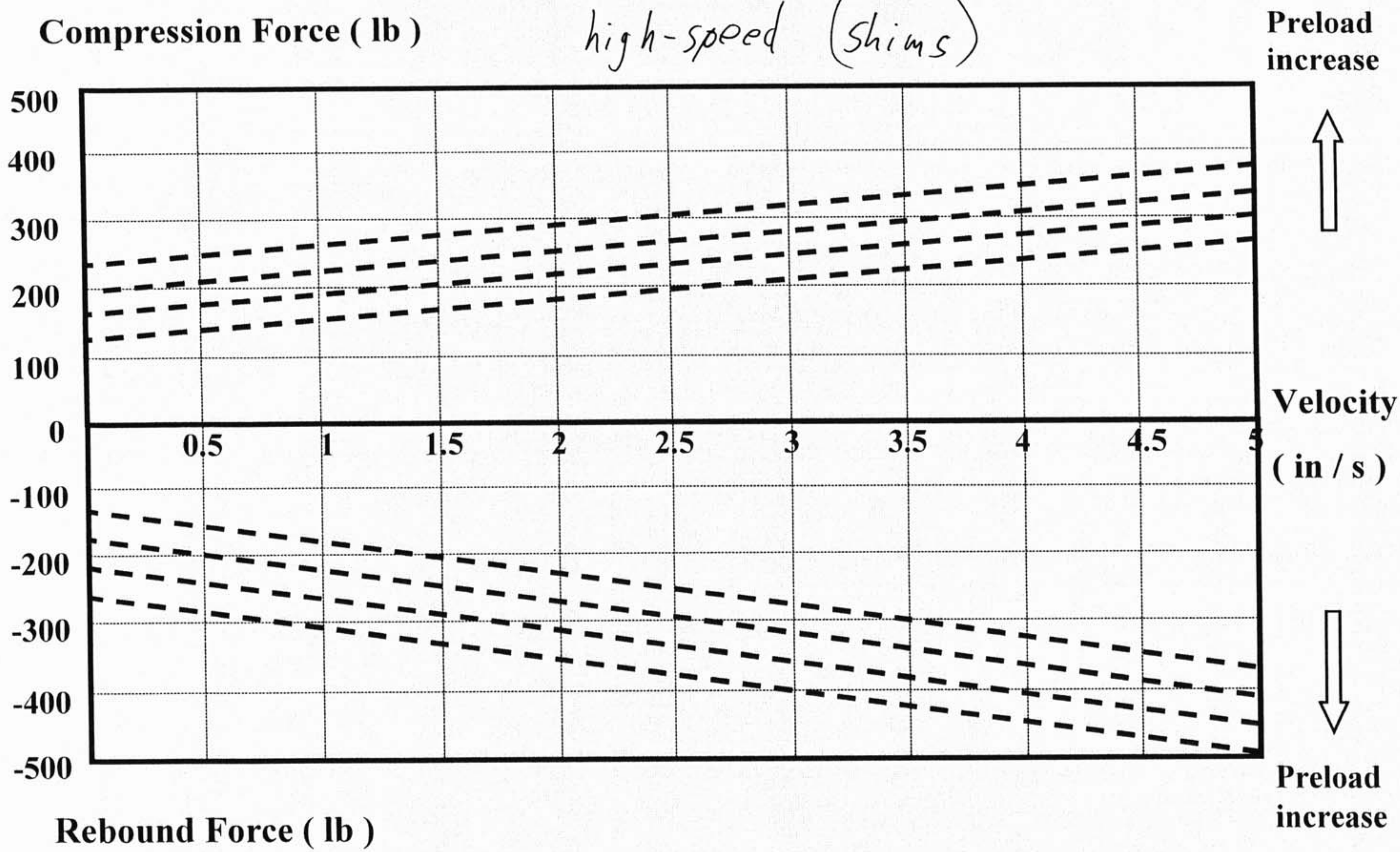
For high speed of compression or rebound

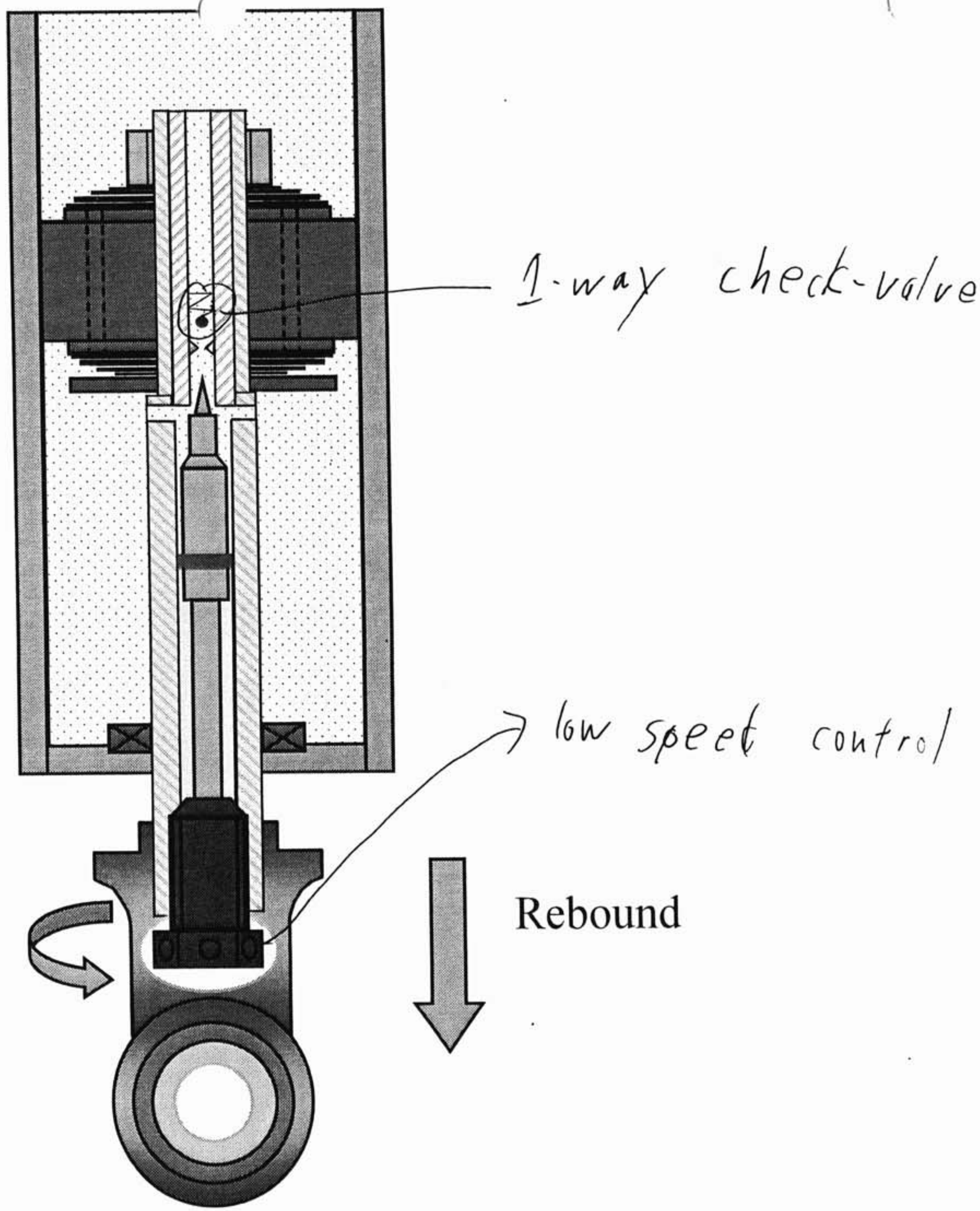


Rebound *Compression*

Influence of Shim Stack Preload

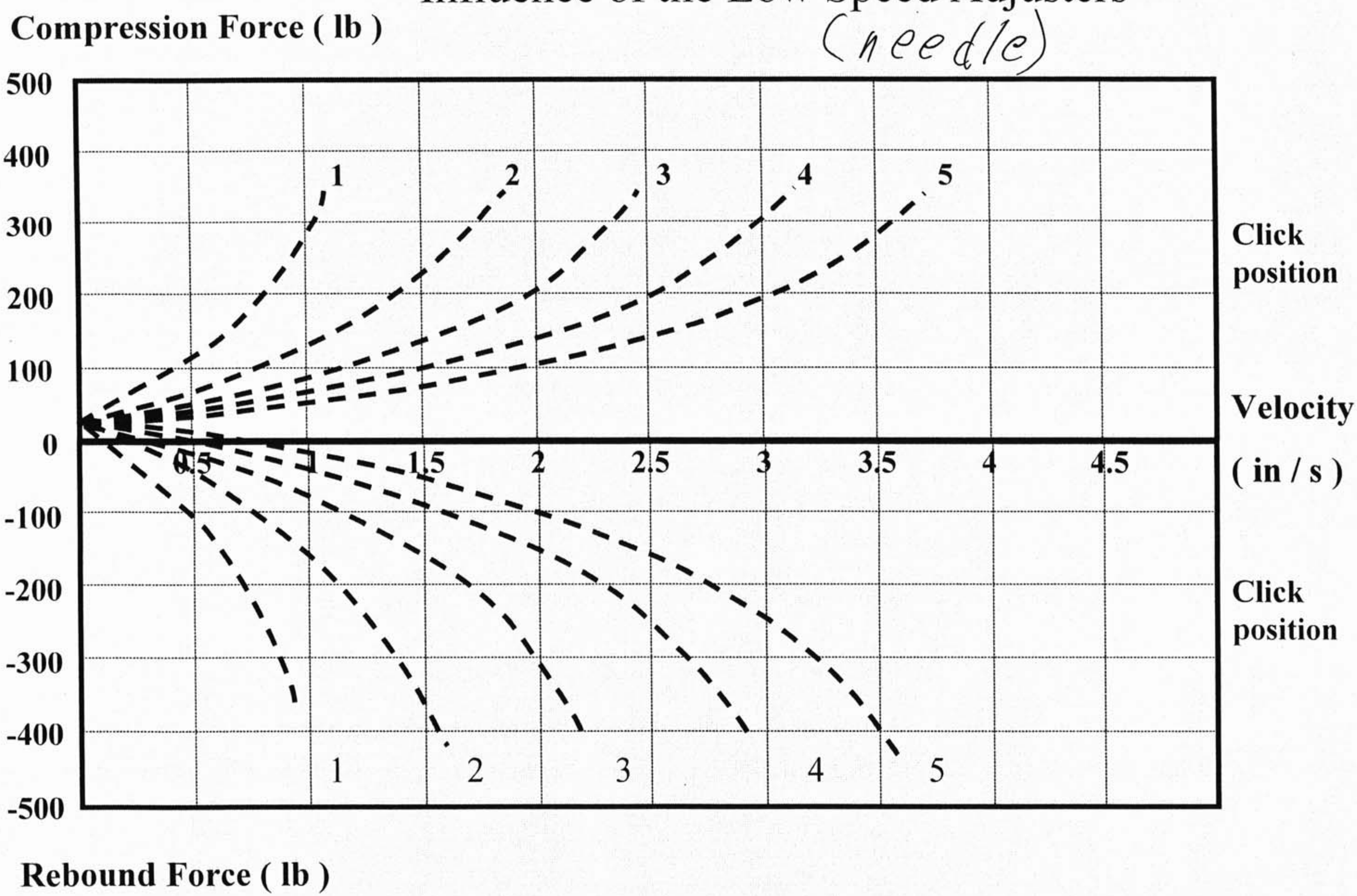
high-speed (shims)

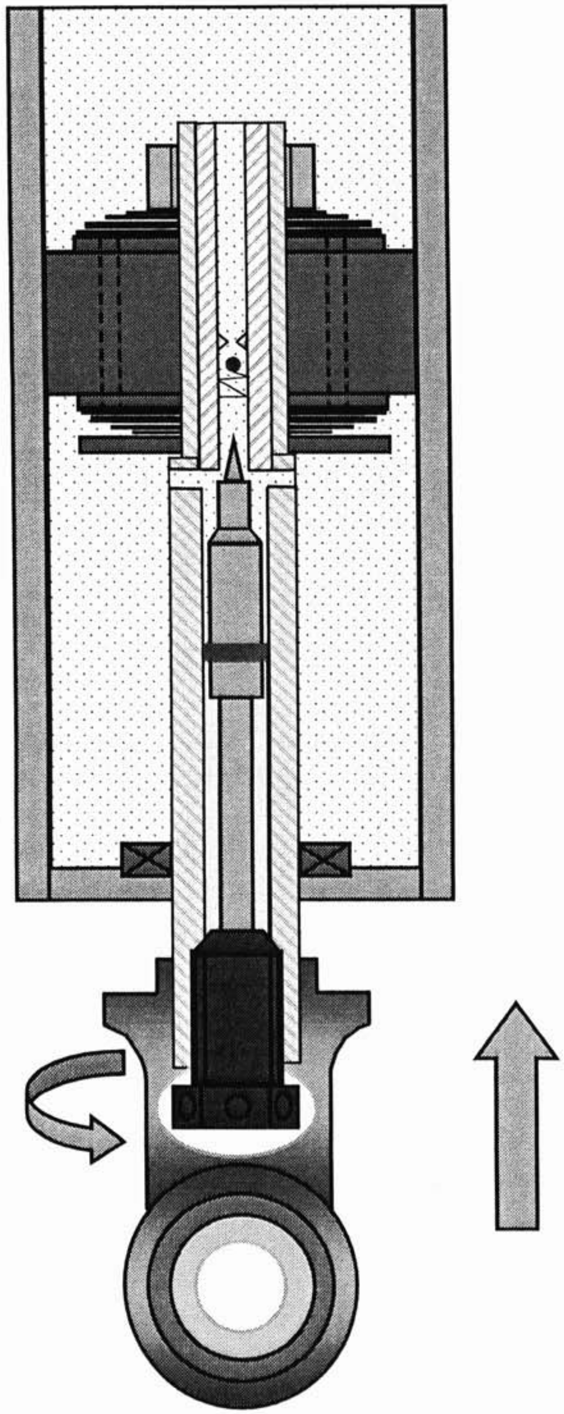


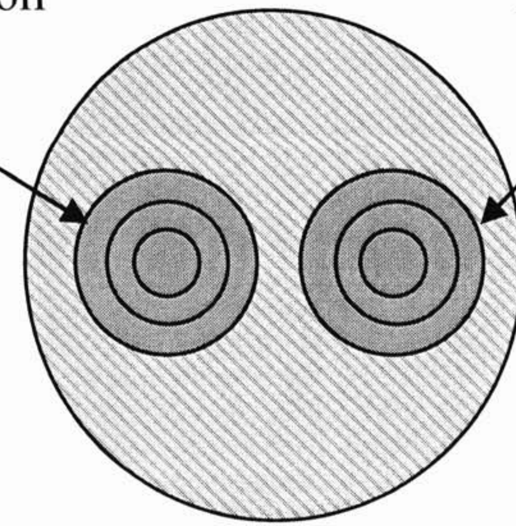

1-way check-valve
low speet control
Rebound

Influence of the Low Speed Adjusters

(needle)

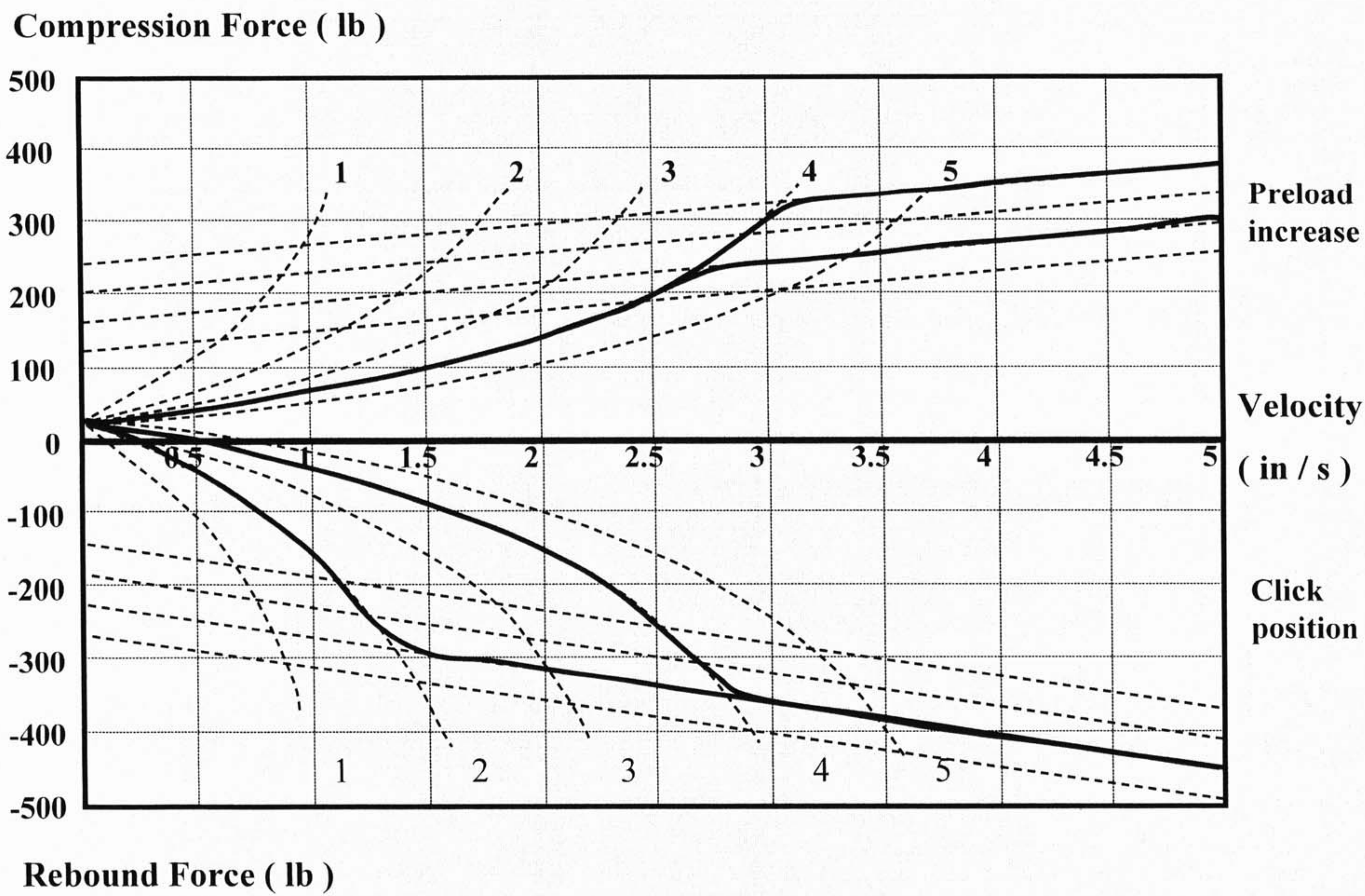


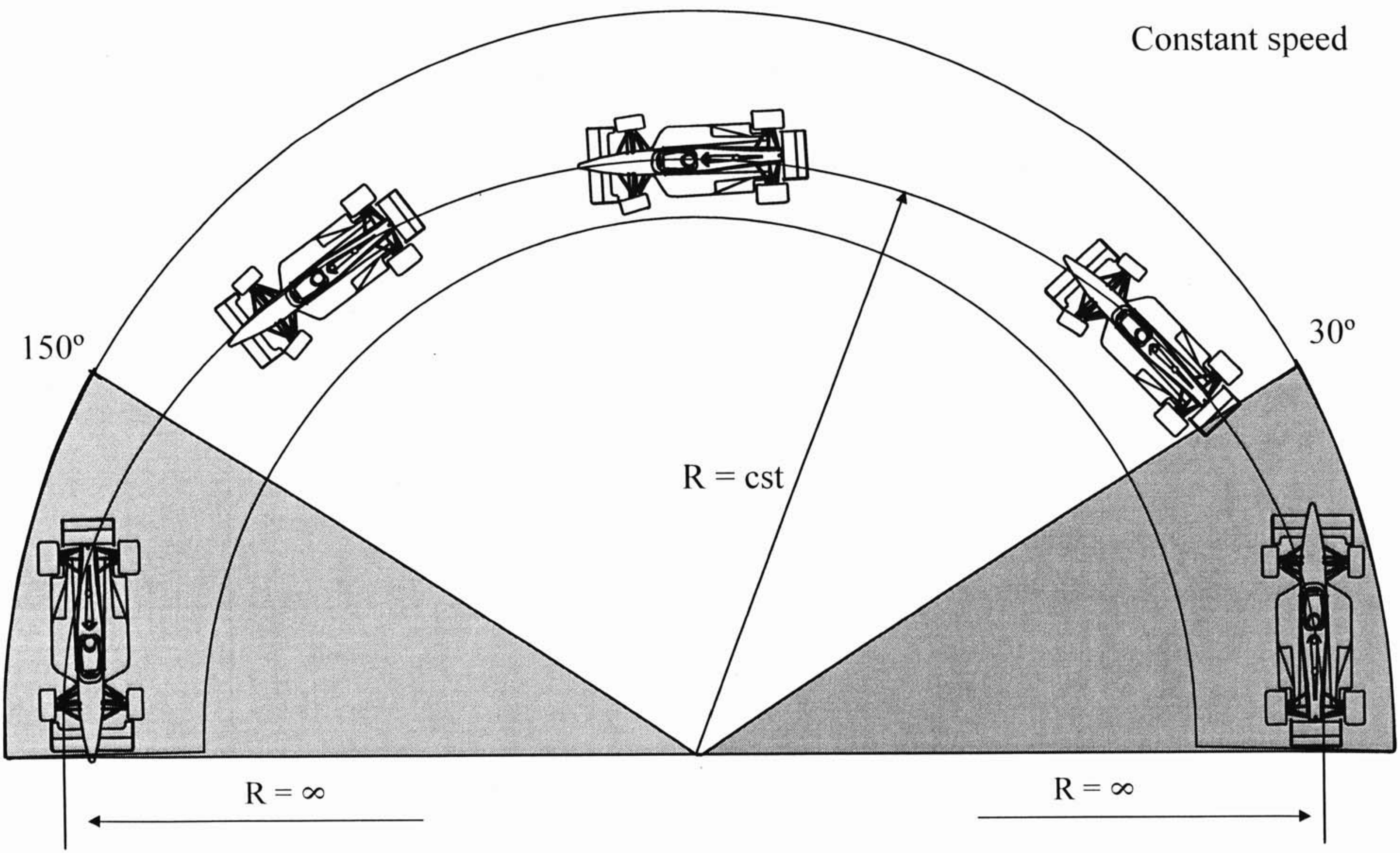


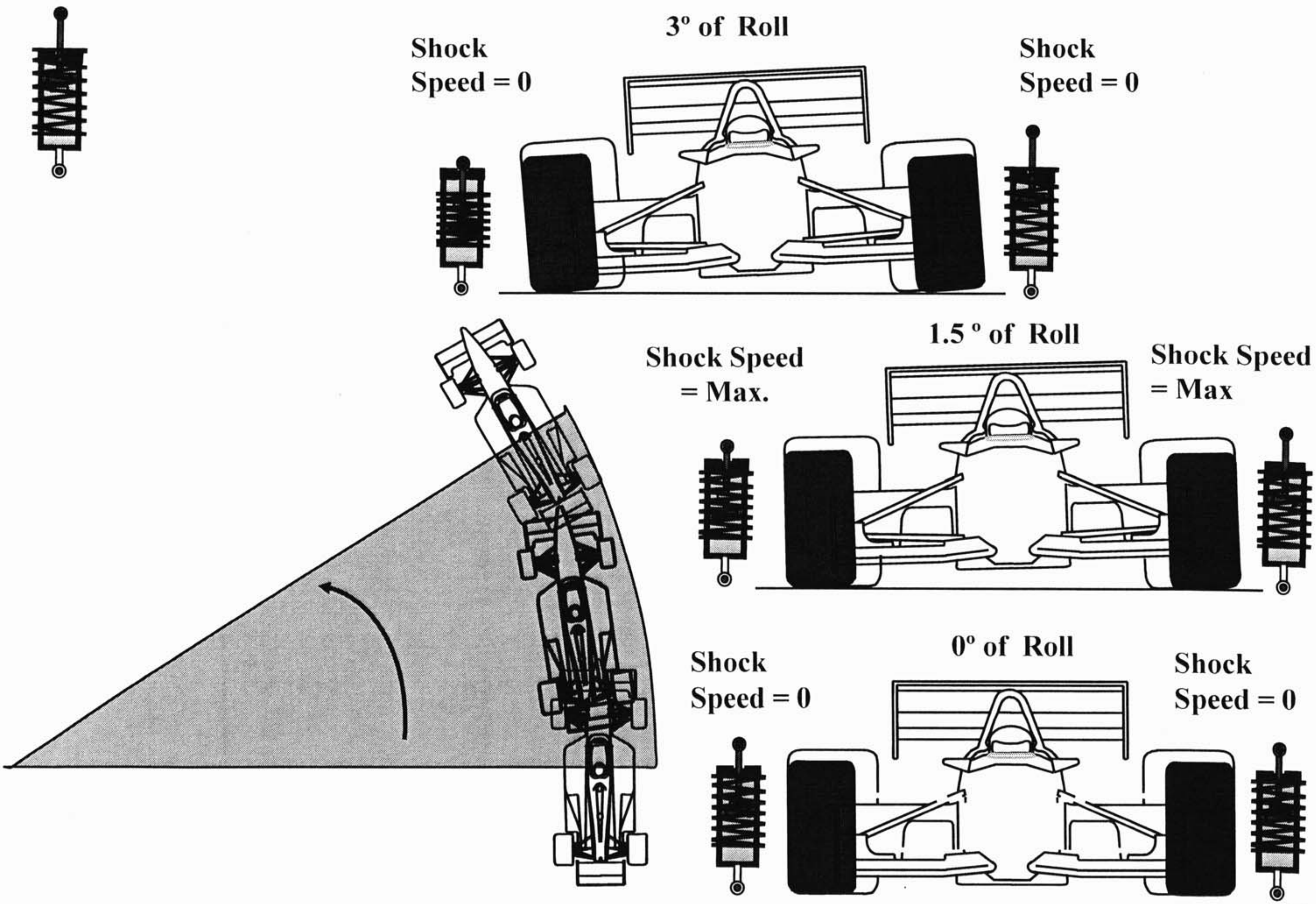


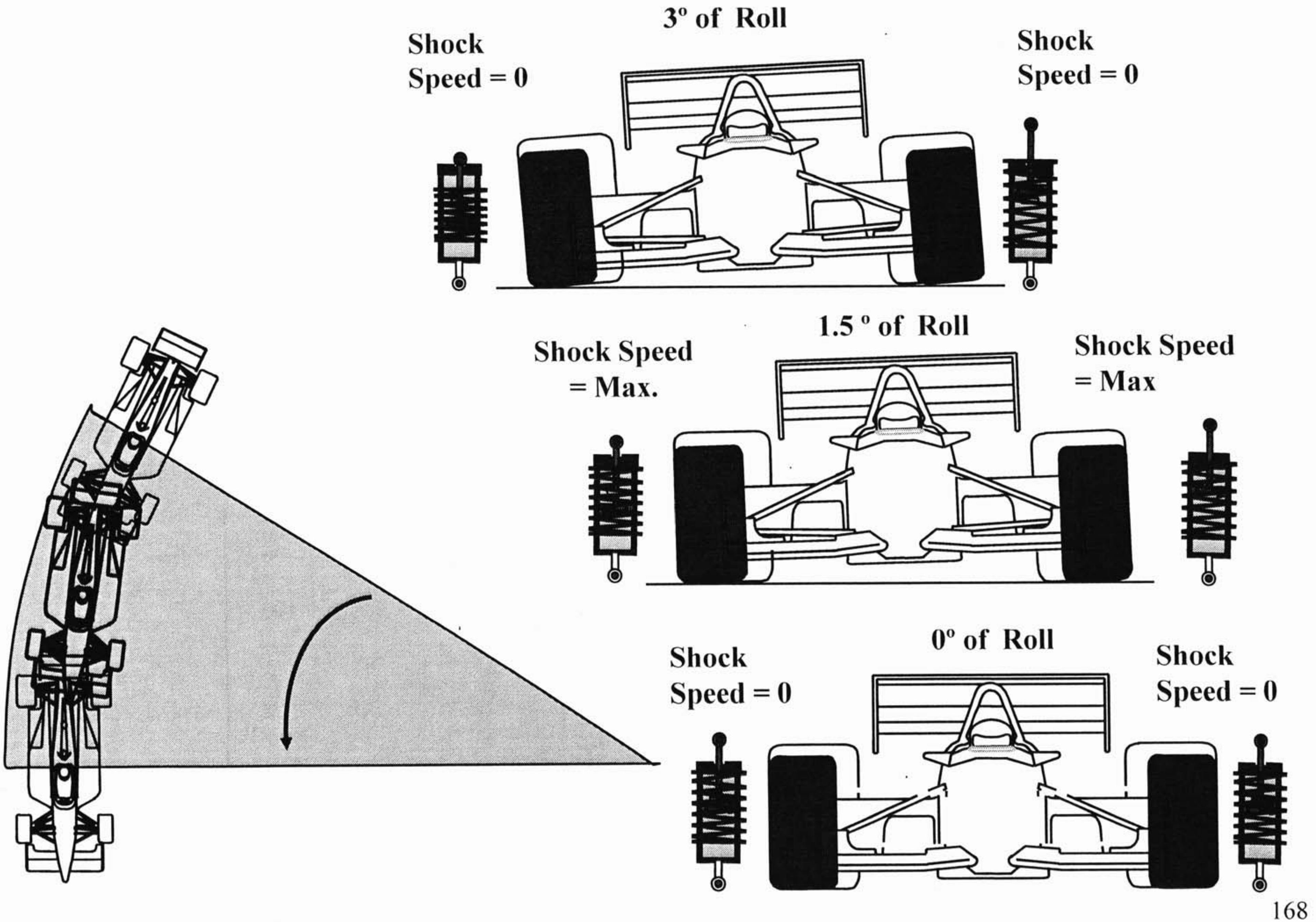
Shaft

Influence of Low and High Speed Adjustments



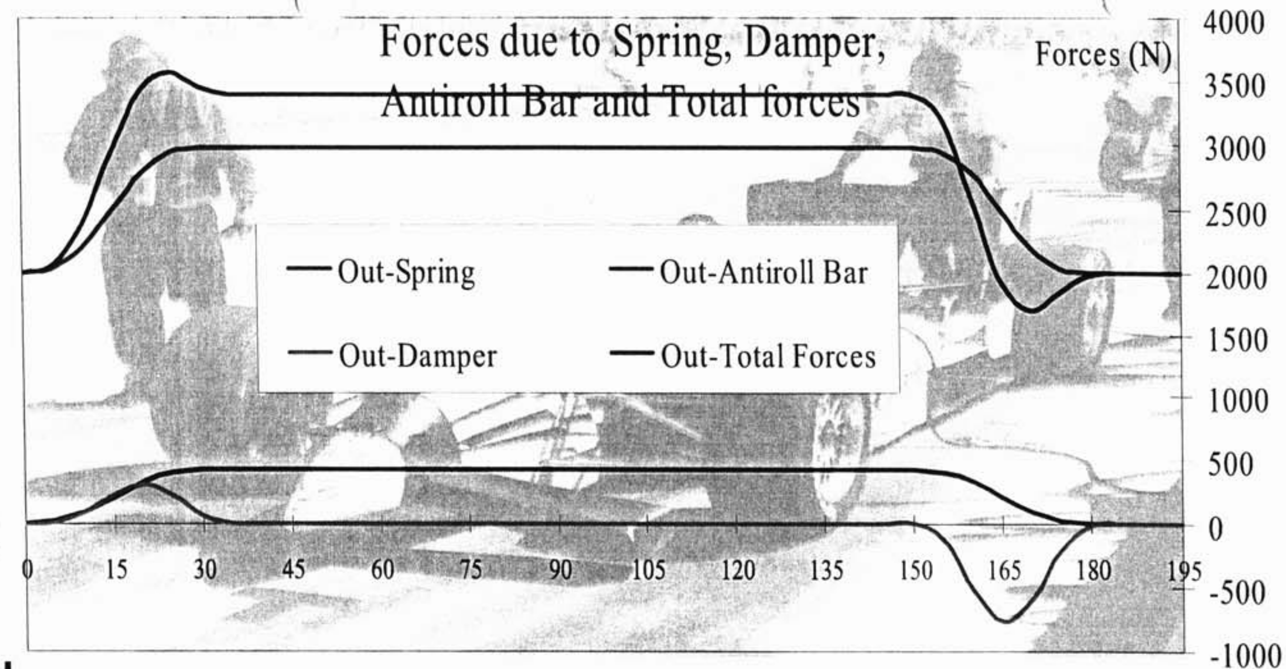

No aero
No braking
Constant speed
150º
30º
R = cst
R = ∞
R = ∞

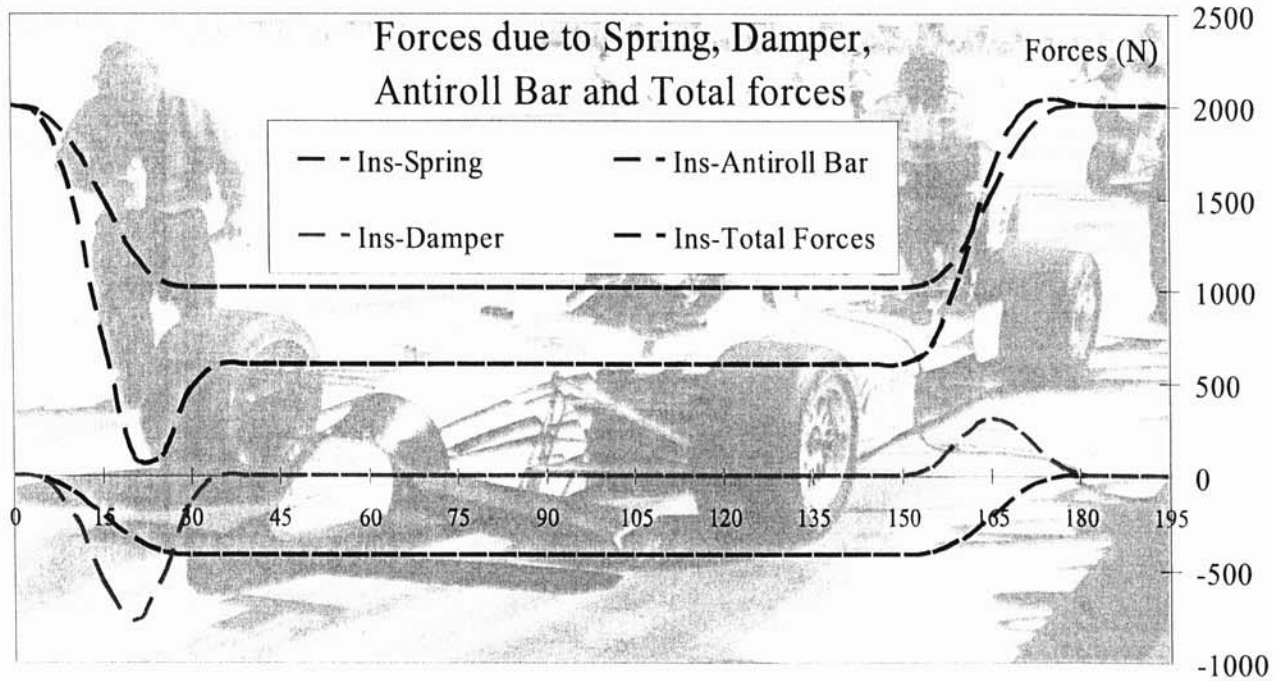

3° of Roll
Shock
Speed = 0
Shock
Speed = 0
1.5 ° of Roll
Shock Speed
= Max.
Shock Speed
= Max
0° of Roll
Shock
Speed = 0
Shock
Speed = 0


3° of Roll
Shock Speed = 0
Shock Speed = 0
1.5 ° of Roll
Shock Speed = Max.
Shock Speed = Max
0° of Roll
Shock Speed = 0
Shock Speed = 0

Working with shocks :

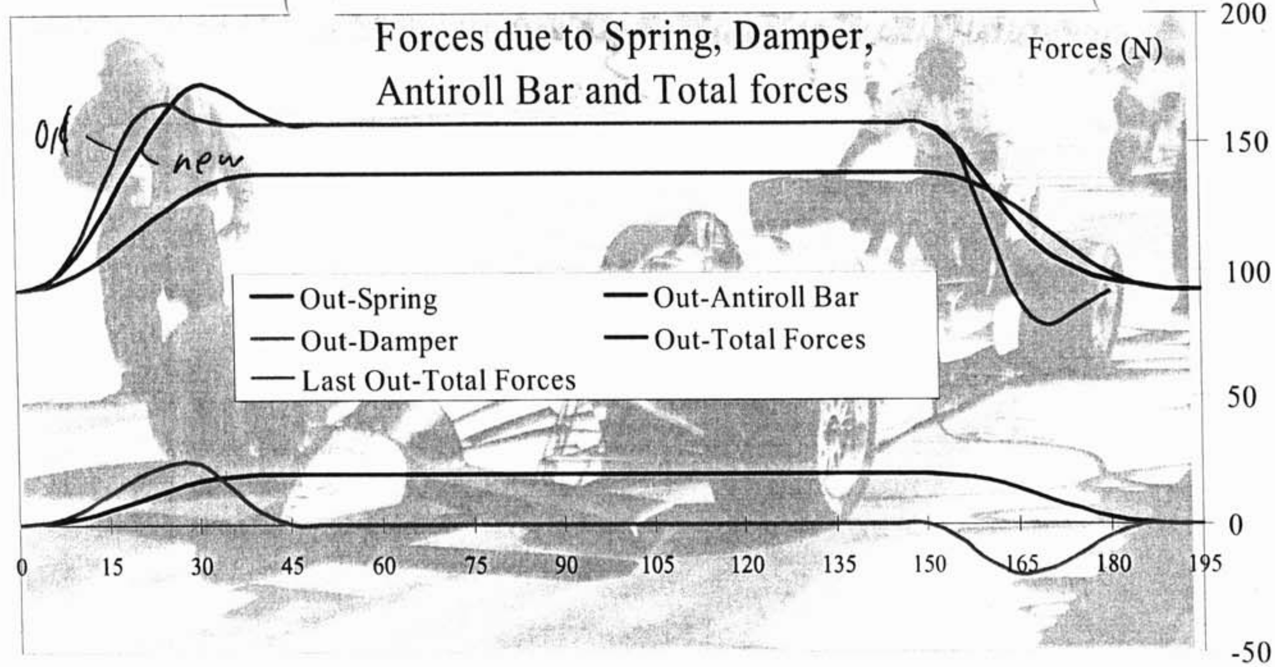
Damping outside and inside are equal.

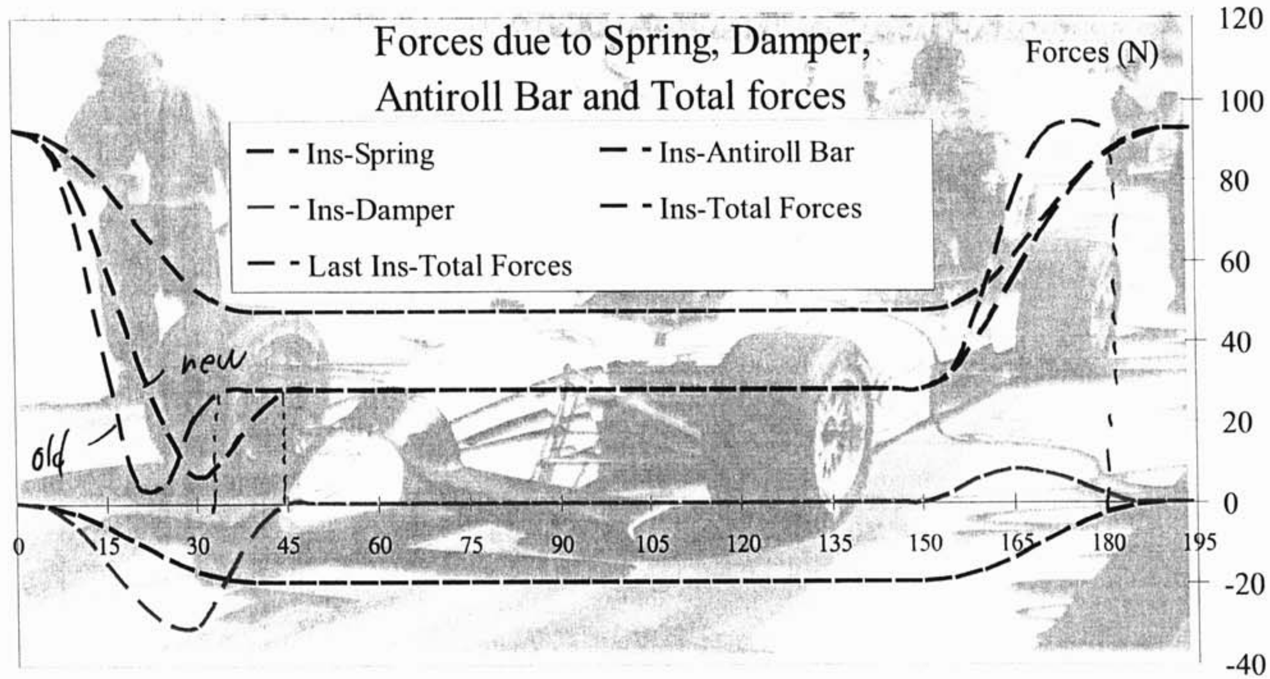


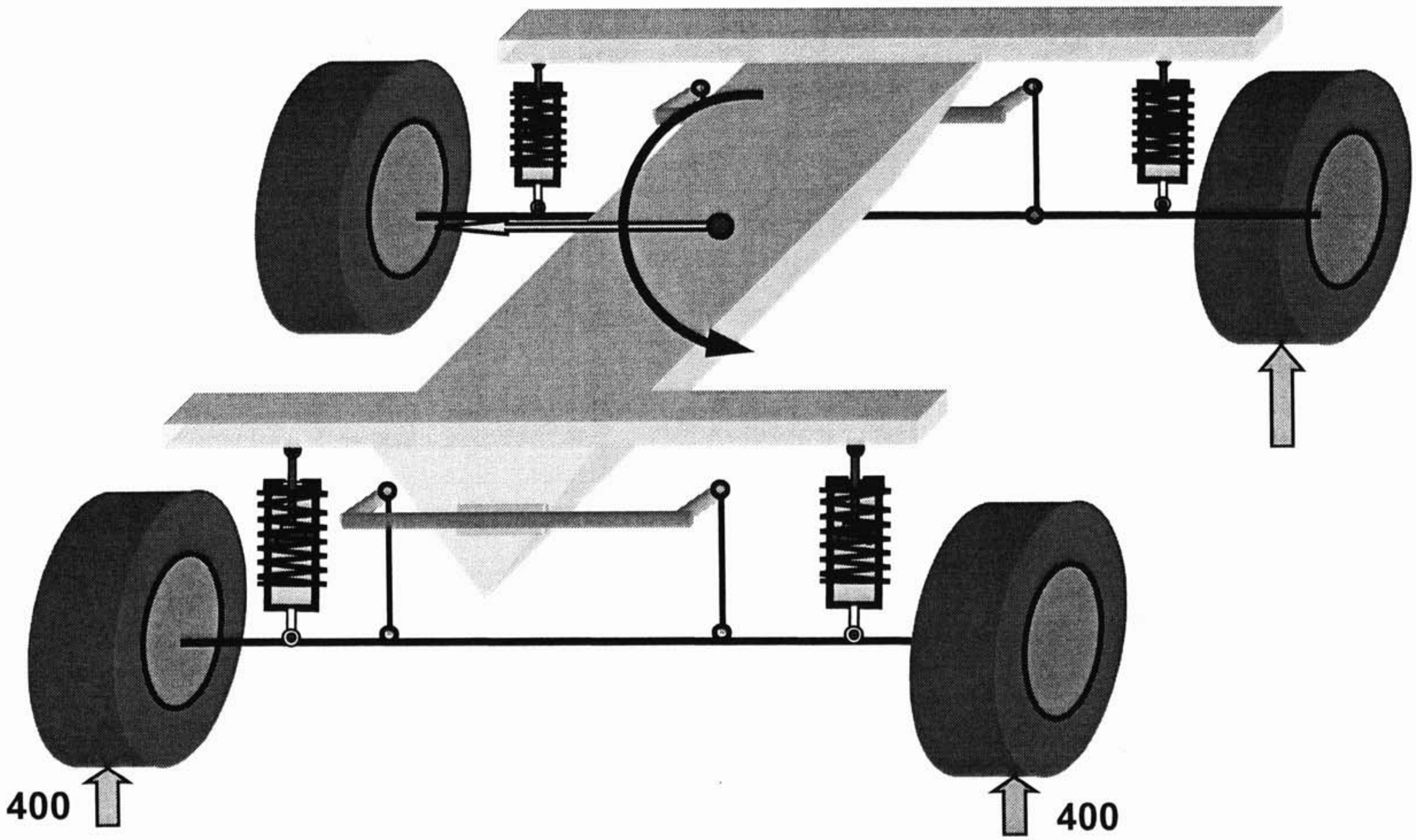


Working with shocks :

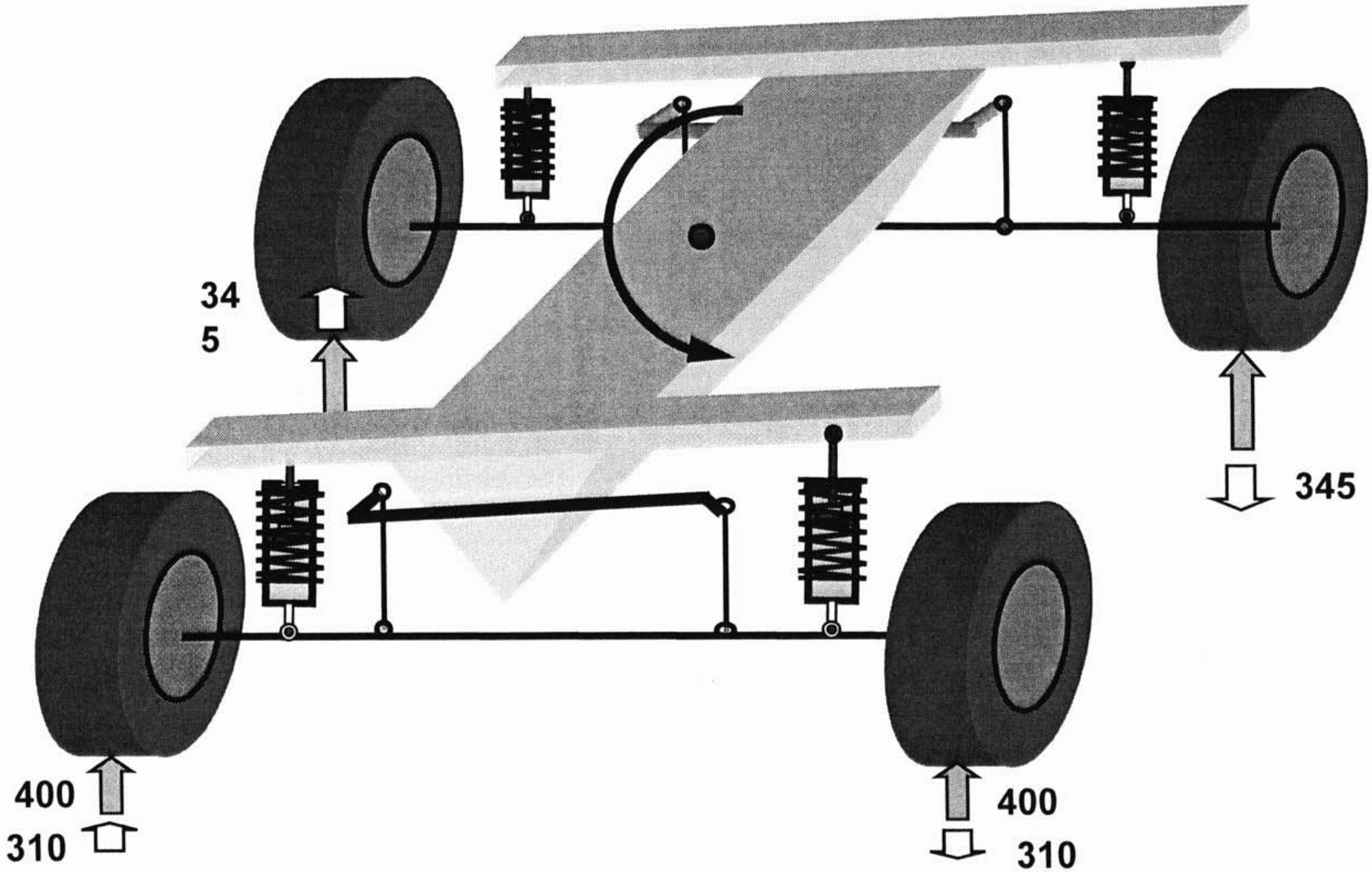
50% increase of Outside Front Bump only

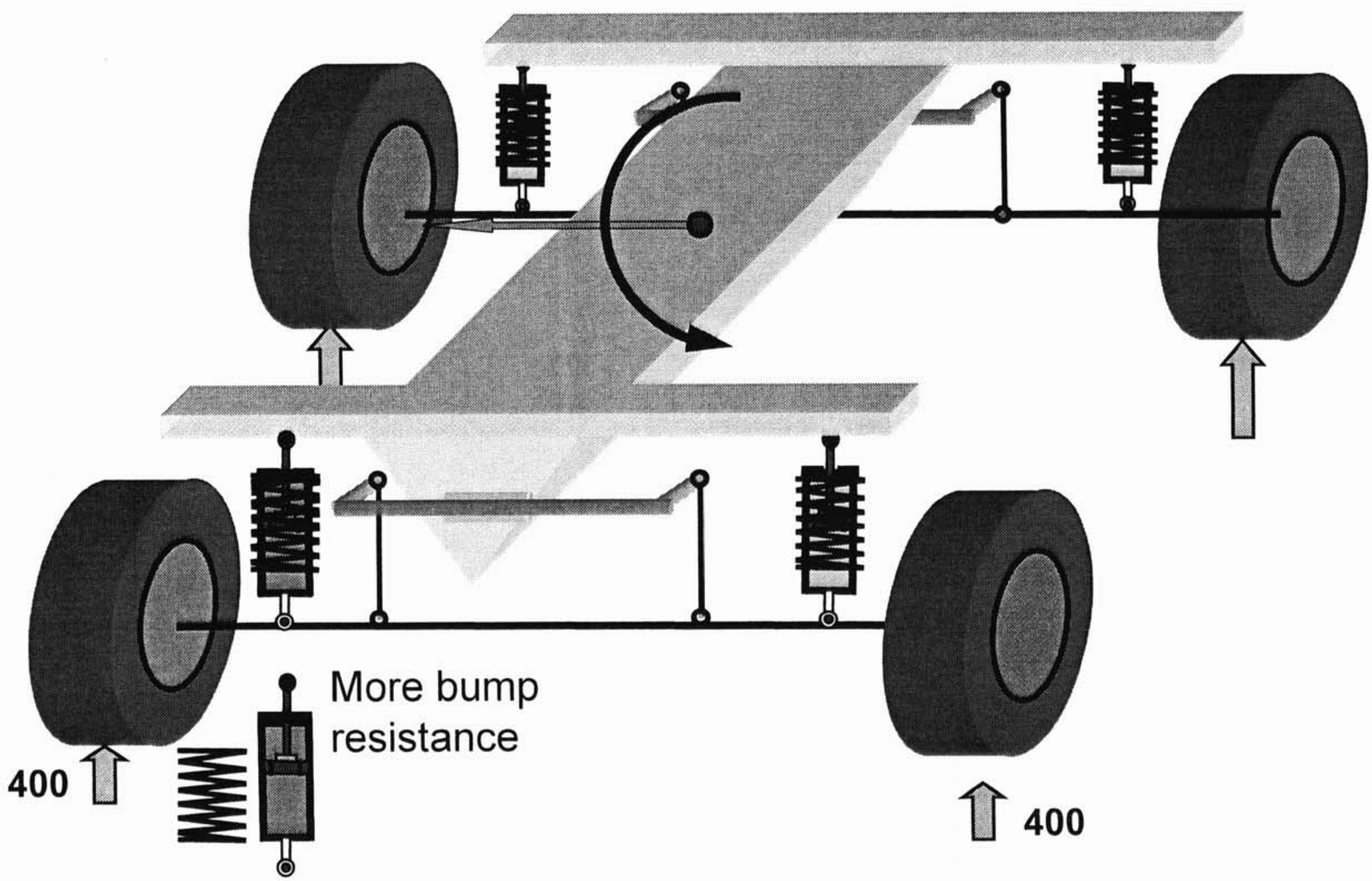





400
400

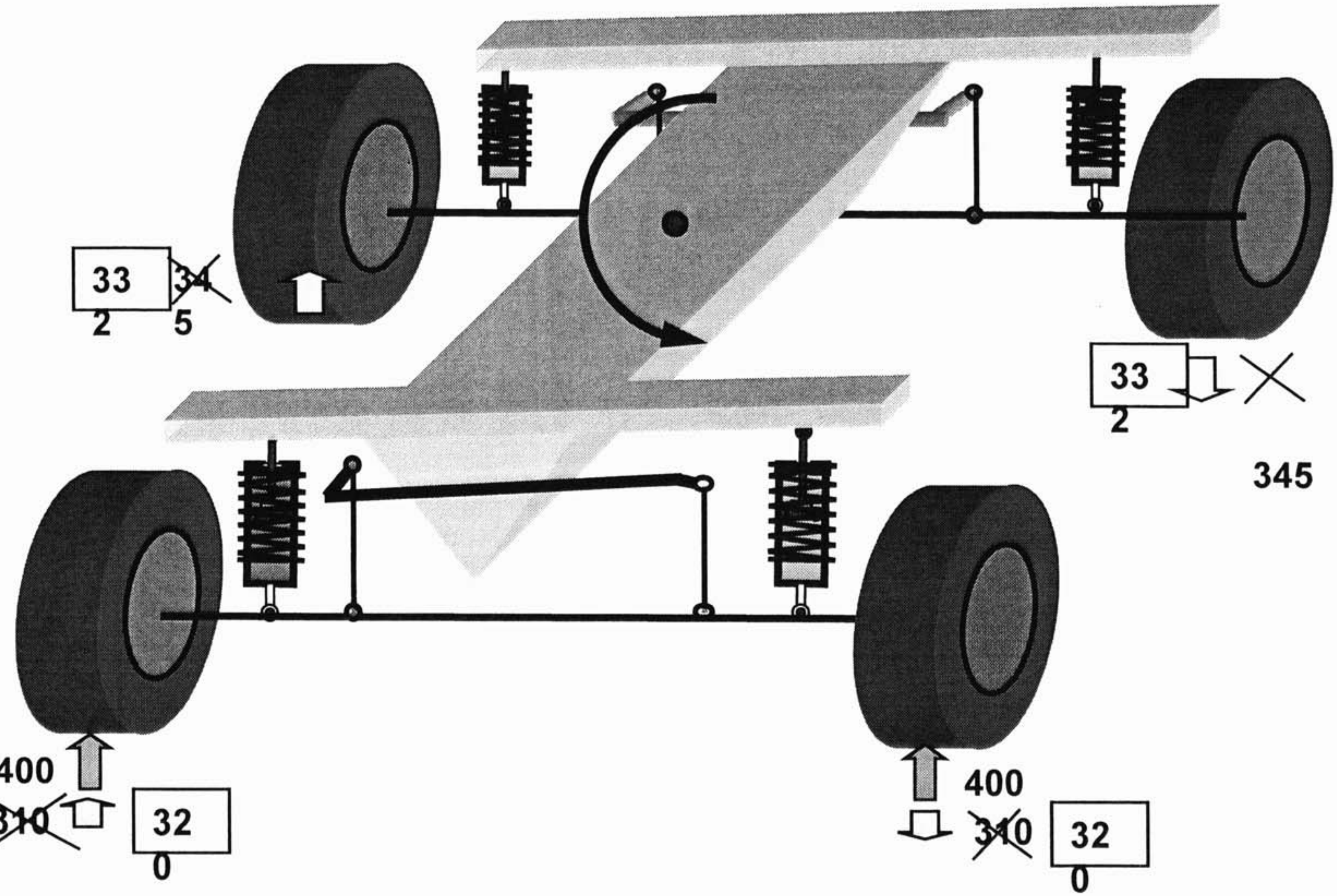
0.463 º of Roll




More bump resistance
400
400

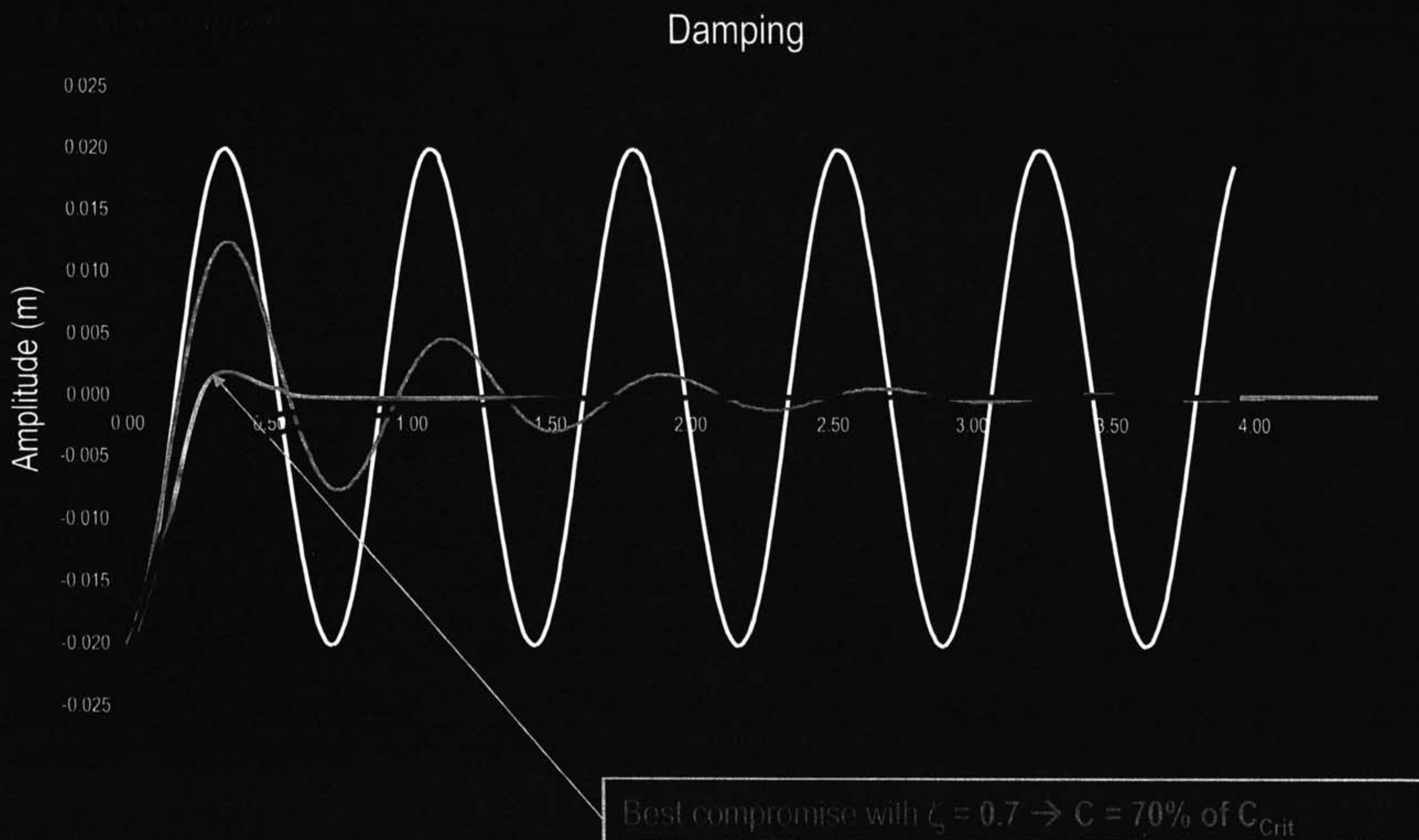
~~0.463º of Roll at a given position~~ of the track

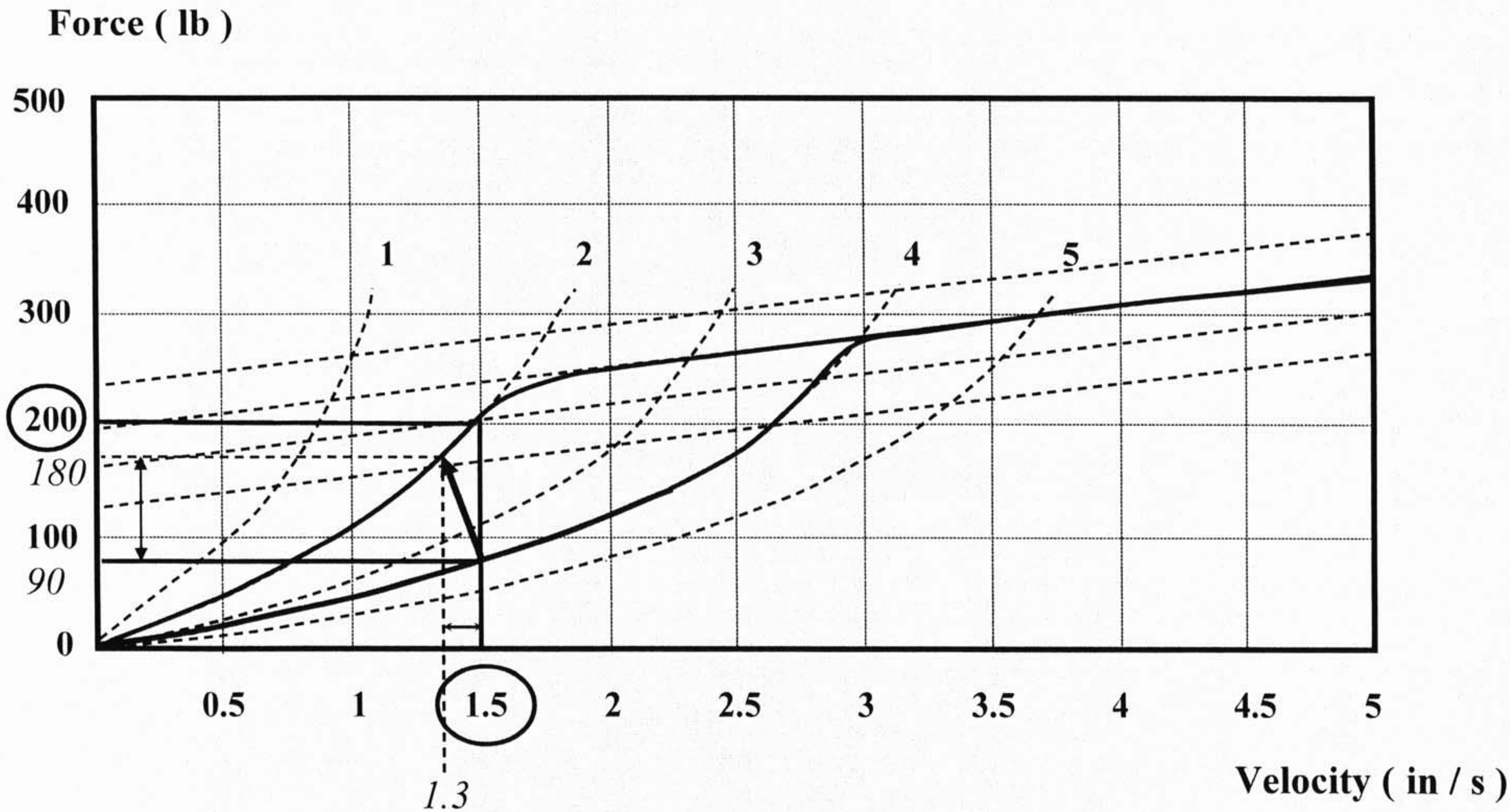
0.389 º of Roll at the same given position of the track



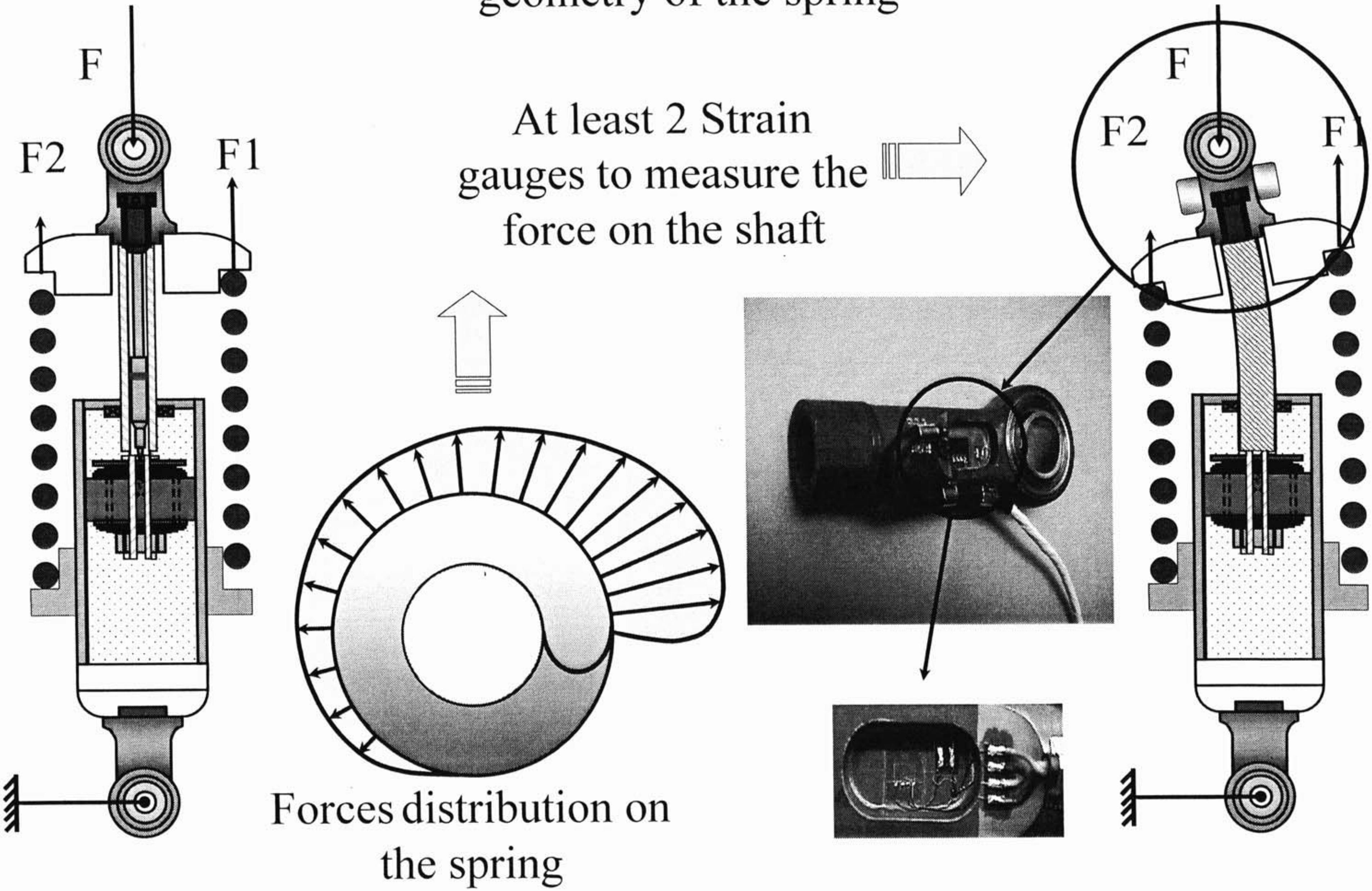
Speed Damper Histogram: 1.Study of the damped free vibration

- No damping
- ζ = 0.1 Underdamped
- ζ = 0.7 Underdamped

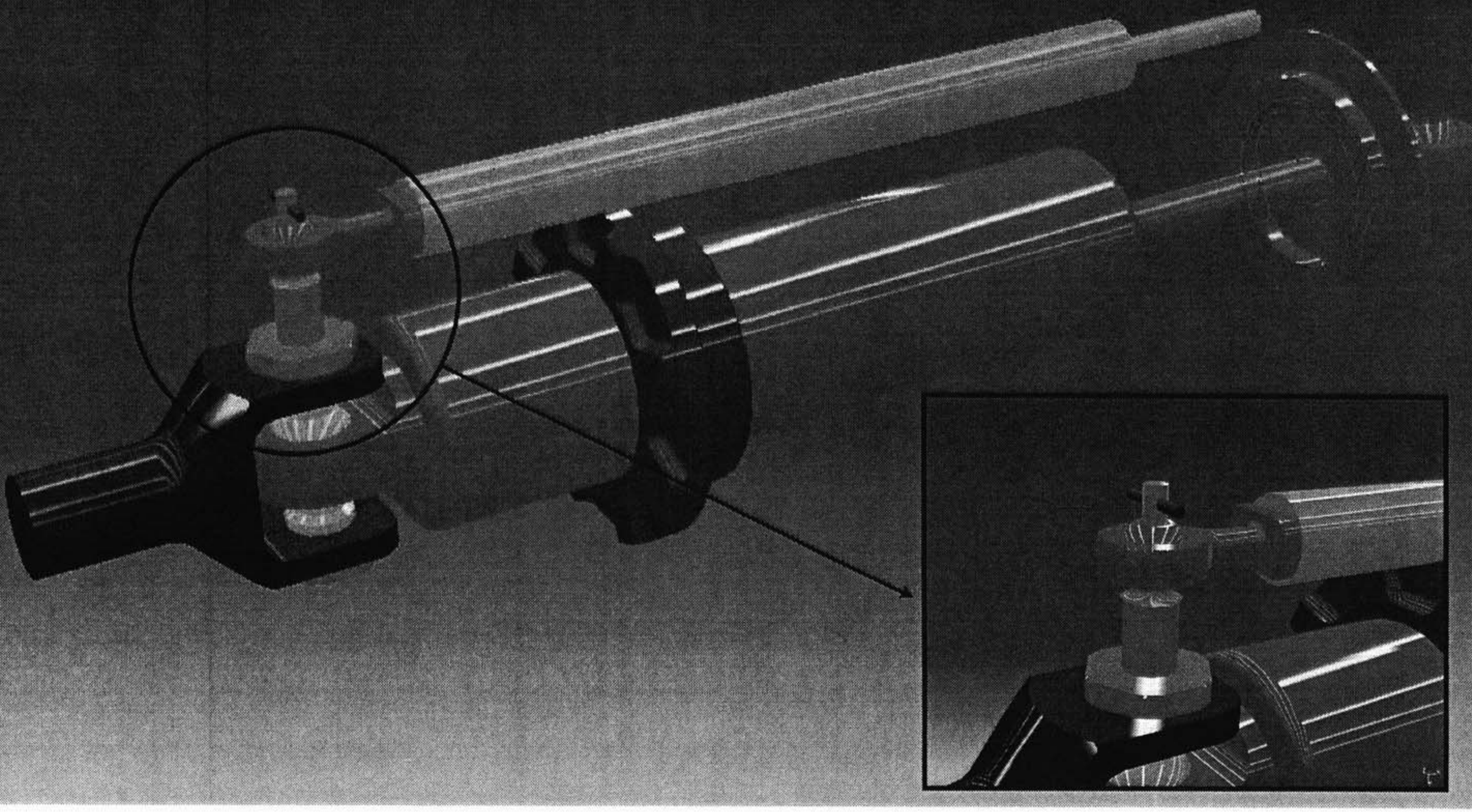



Force (lb)
500
400
300
200
180
100
90
0
1
2
3
4
5
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1.3
Velocity (in / s)

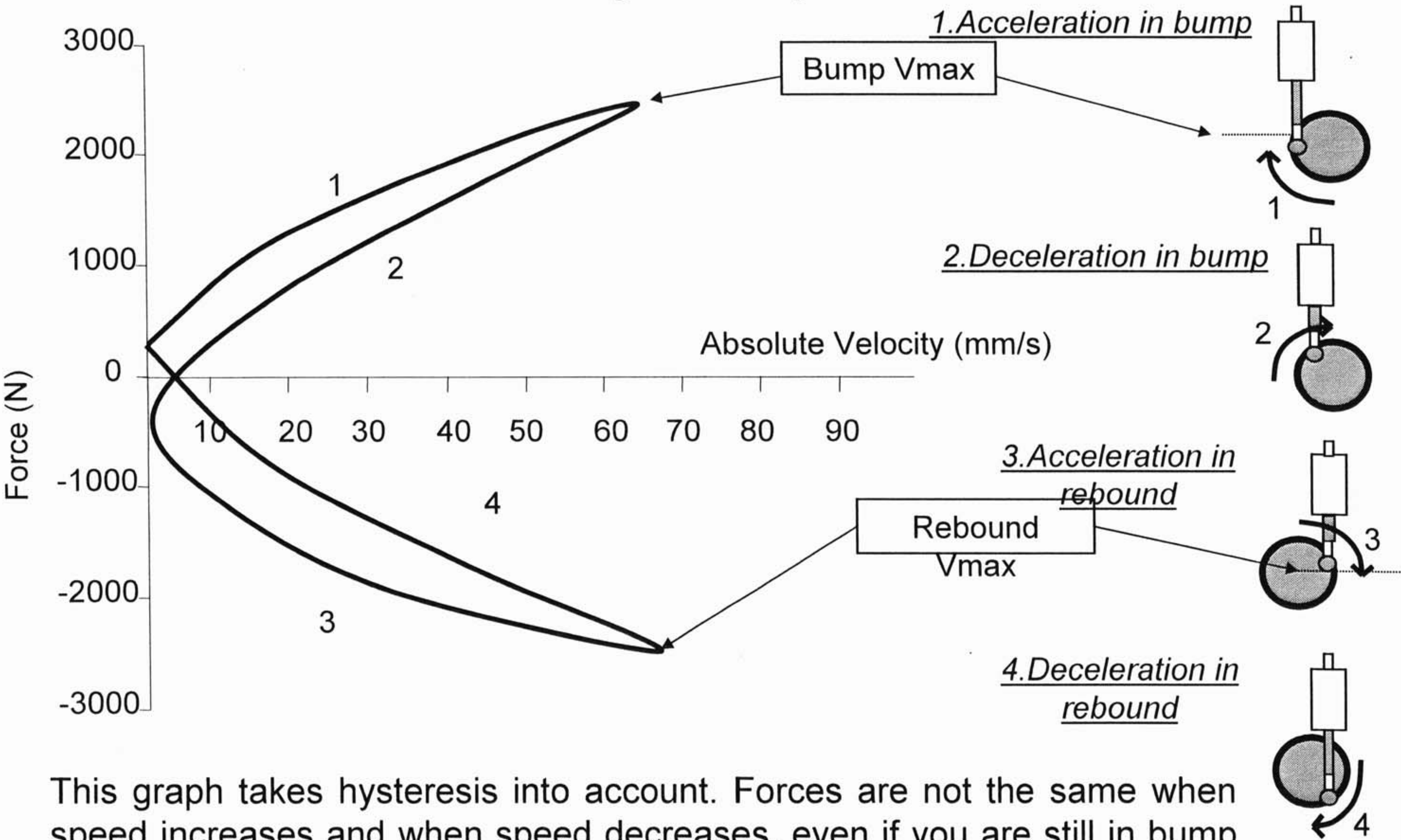
Bending of the shaft of the damper due to the dissymmetrical geometry of the spring



Smart way to install a linear potentiometer

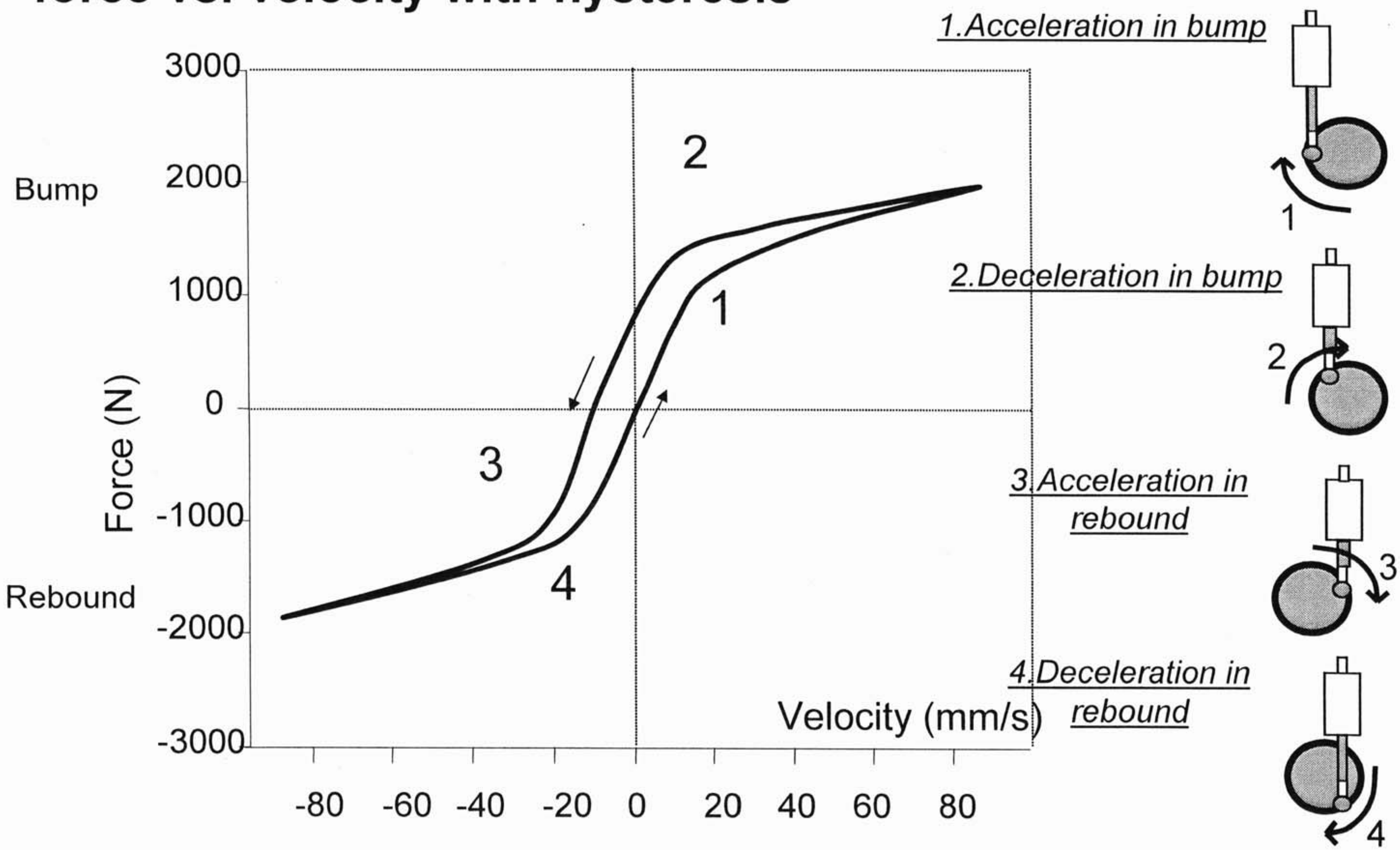


Using different types of damper curves: force vs. absolute velocity with hysteresis



This graph takes hysteresis into account. Forces are not the same when speed increases and when speed decreases, even if you are still in bump or rebound. We still have an absolute velocity for the X axis and gas preload effect.

Using different types of damper curves: force vs. velocity with hysteresis



Here, negative velocity is used for bump and positive velocity for rebound.

WHAT IS REQUIRED TO CALCULATE WEIGHT TRANSFER

	LATERAL WEIGHT TRANSFER		
	Front & Rear Sprung "Elastic" W.T	Front & Rear Sprung "Geometric" W.T	Front & Rear Unsprung W.T
F&R Sprung Mass	X	X	
F&R Unsprung Mass			X
F&R Lateral Acceleration	X	X	X
F&R Roll Centre (Height)	X	X	
Sprung CG Height	X		
F&R Unsprung CG Height			X
F&R Distance [CG - Roll Centre]	X		
F&R Track	X	X	X
Wheelbase		X	
a' and 'b' Length		X	
F&R Anti-Roll Torque distribution	X		

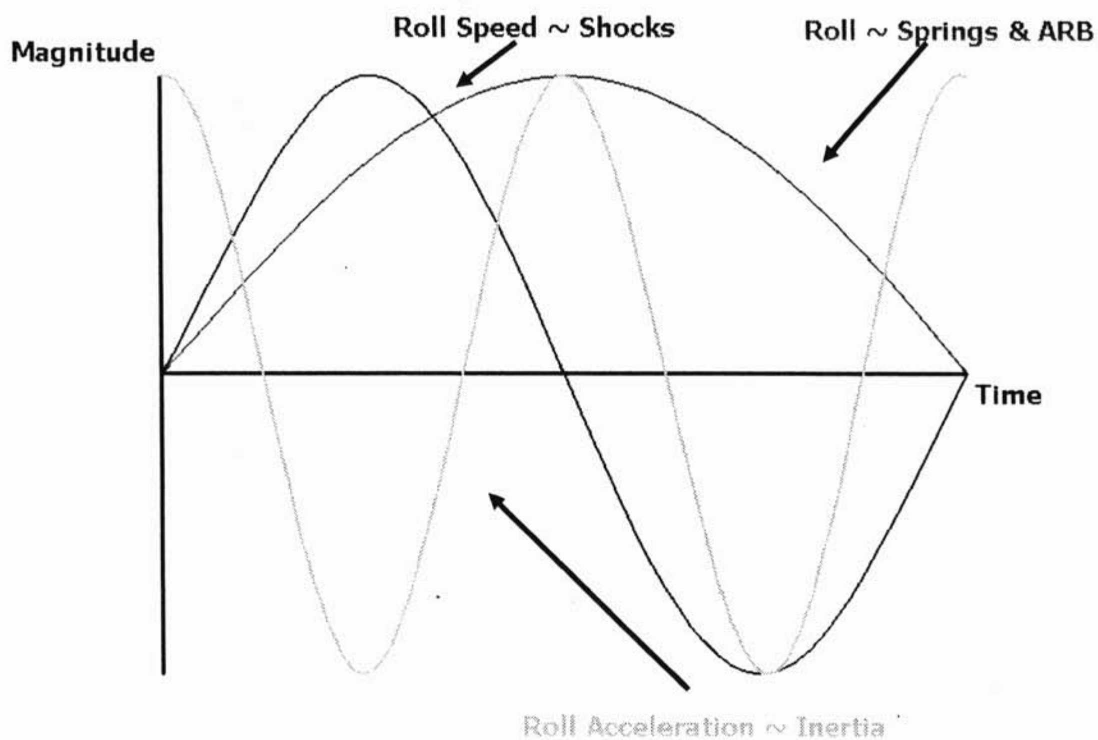
Note: *For F & R Anti Roll Torque*

Steady State - Springs, ARB, MR & Track

Transient - Springs, ARB, MR , Track, Roll Inertia & F & R Shocks

CORNERING CHARACTERISTICS

		Roll	Roll Speed	Roll Acceleration
	Units	deg	deg/sec	deg/sec^2
Spring/ARB	lb / in	X	X	X
Shocks	lb / in/sec		X	X
Roll Inertia	lb.in^2			X



CORNERING CHARACTERISTICS

- The same also holds true for both the pitch and yaw of the car.

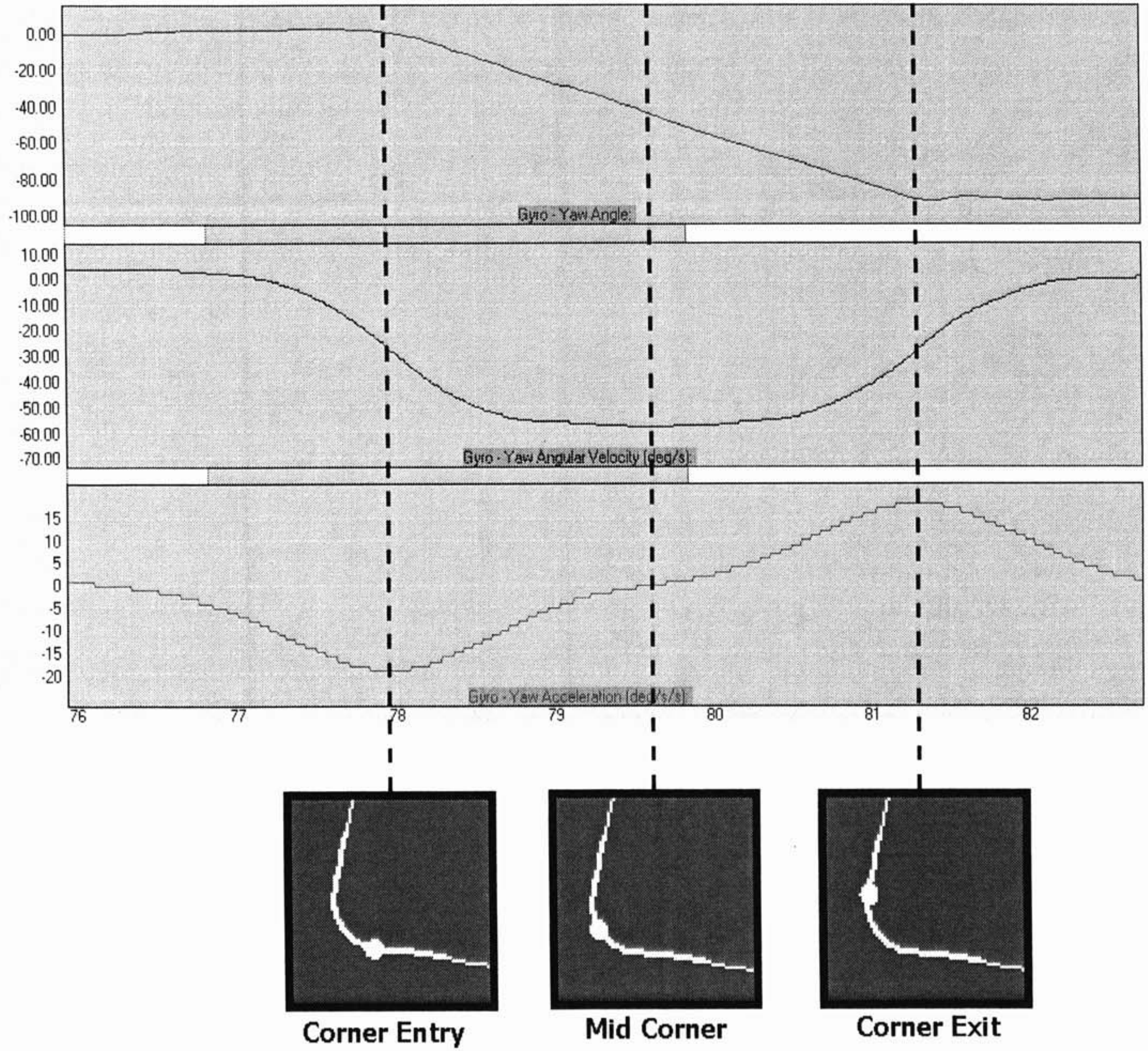
PITCH

		Pitch	Pitch Speed	Pitch Acceleration
	Units	deg	deg/sec	deg/sec^2
Spring/ARB	lb / in	X	X	X
Shocks	lb / in/sec		X	X
Pitch Inertia	lb.in^2			X

YAW

		Yaw	Yaw Speed	Yaw Acceleration
	Units	deg	deg/sec	deg/sec^2
Tire cornering stiffness	lb /deg	X	X	X
Tire cornering damping	Lb /deg/sec		X	X
Yaw Inertia	lb.in^2			X

Example Of Using A Yaw Gyro Sensor in A Corner



Yaw Angle

$$\int Yaw\ Velocity\ dt$$

Yaw Velocity

Yaw Acceleration

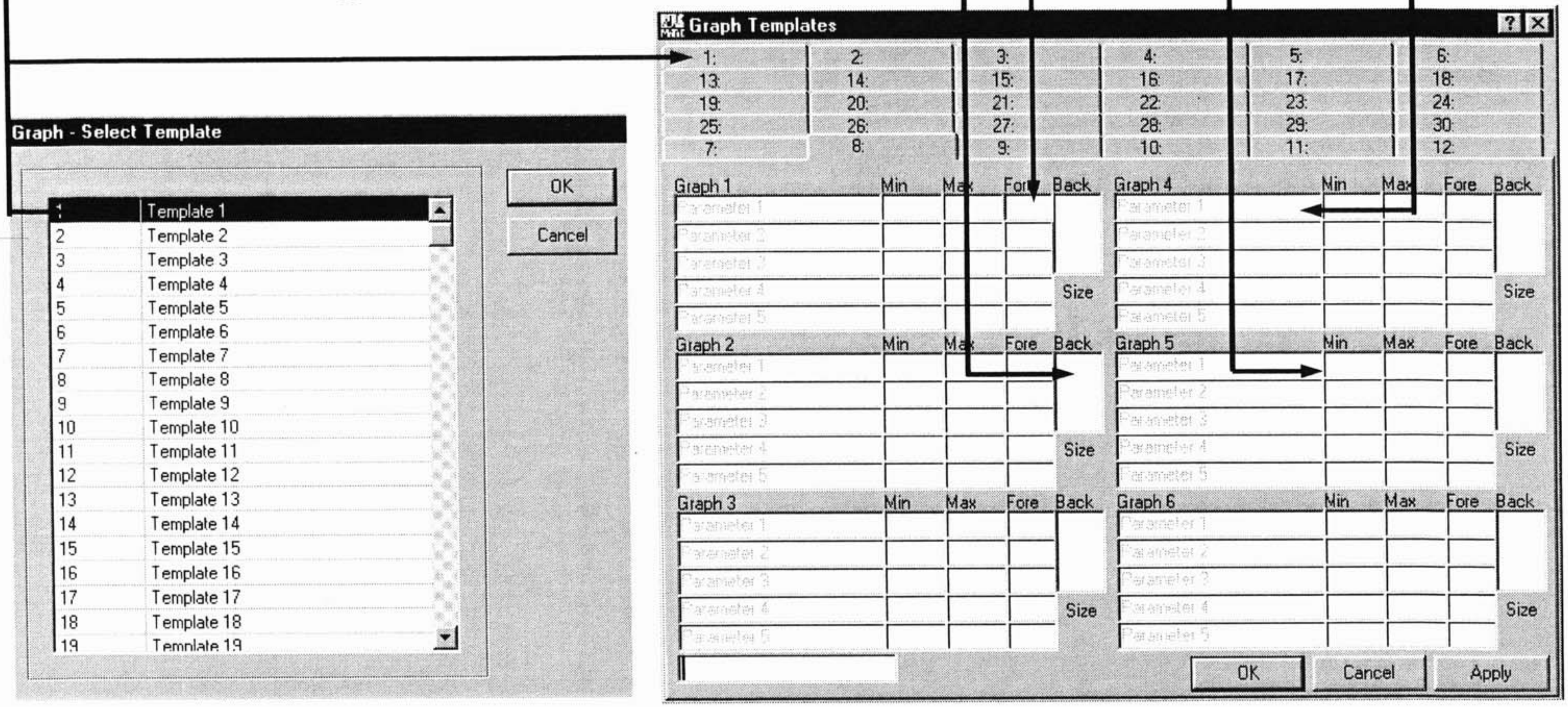
$$\frac{d(Yaw\ Velocity)}{dt}$$

6. Organizing the Data Work

- Templates Organization
- Writing Math Functions
- Things to Set Before Leaving the Shop
- Things to Set During the Test or Race
- Influence of Filter, Logging Rate and Zoom on Match Functions Accuracy
- What we can learn from shock's linear potentiometers
- Wheel Speed Sensors and Diff Work

Template Organization

- Give a name to each template
- Inside each template, for each graph, select a channel out of the logged or defined math functions
- Select Auto scale or a Min and Max for each channel
- Select a color for each channel
- Select a background color for each graph



Template Organization Examples and Advices

<u>Template 1</u>: Engine
- Water temperature
- Oil Temperature
- Oil Pressure
- Fuel pressure
- Battery voltage

<u>Template 2</u>: Driver
- Throttle
- Speed
- Lateral Acceleration
- Steering

<u>Template 3</u>: Dampers
- LF Damper
- RF Damper
- LR Damper
- RR Damper

<u>Template 4</u>: Damper Vel.
- LF Damper Vel.
- RF Damper Vel.
- LR Damper Vel.
- RR Damper Vel.

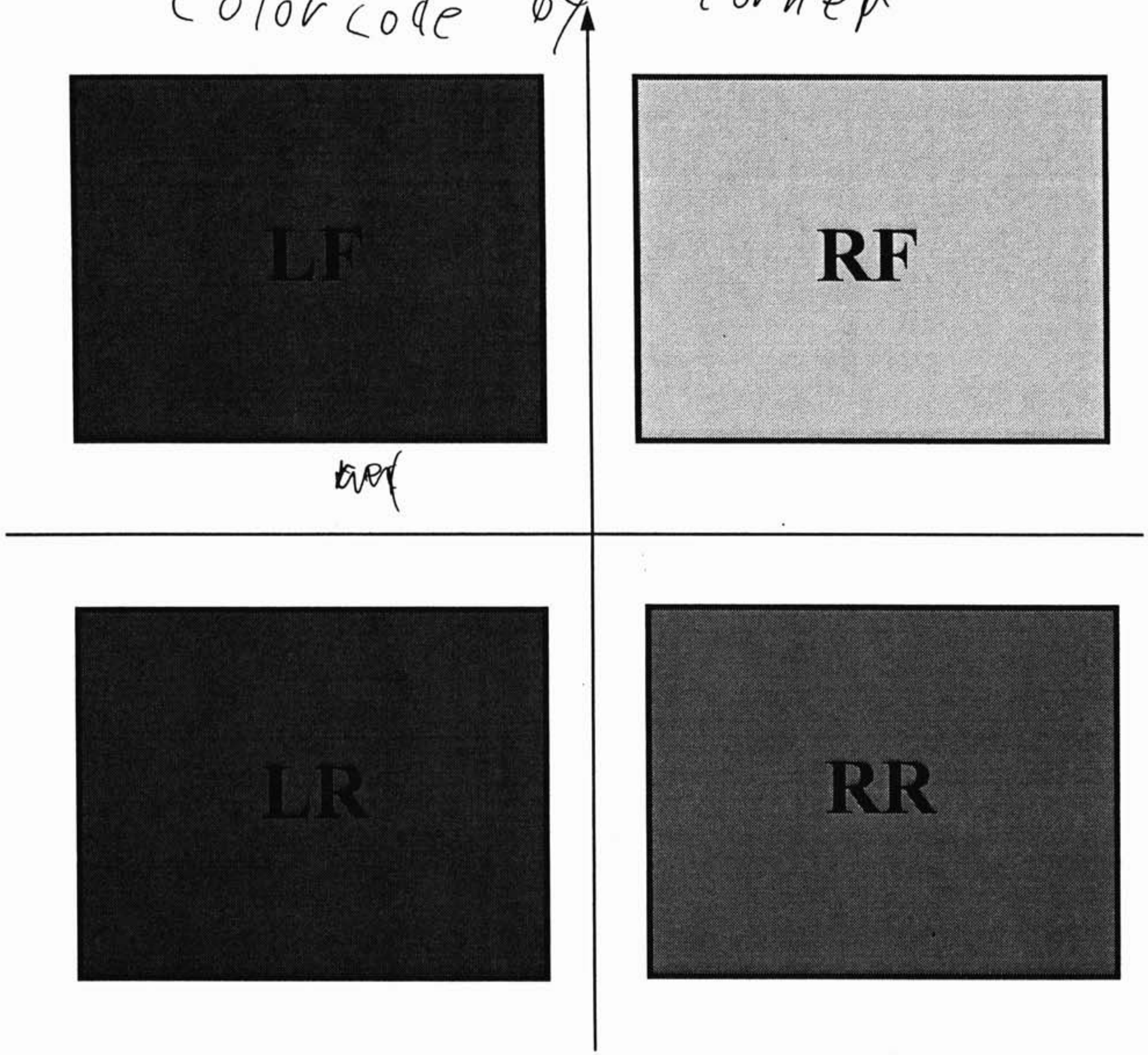
<u>Template 5</u>: Roll and Pitch
- Front Roll
- Rear Roll
- Left Pitch
- Right Pitch

<u>Template 6</u>: Strain Gauges
- LF Strain
- RF Strain
- LR Strain
- RR Strain

Group in a given template all channels subject to the same type of analysis

Attach Specific Colors to Specific Channels. Example

Color code by corner

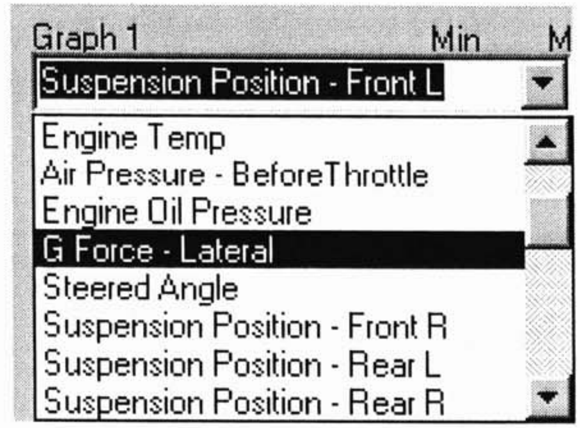


Attach Specific Colors to Specific Channels. Example

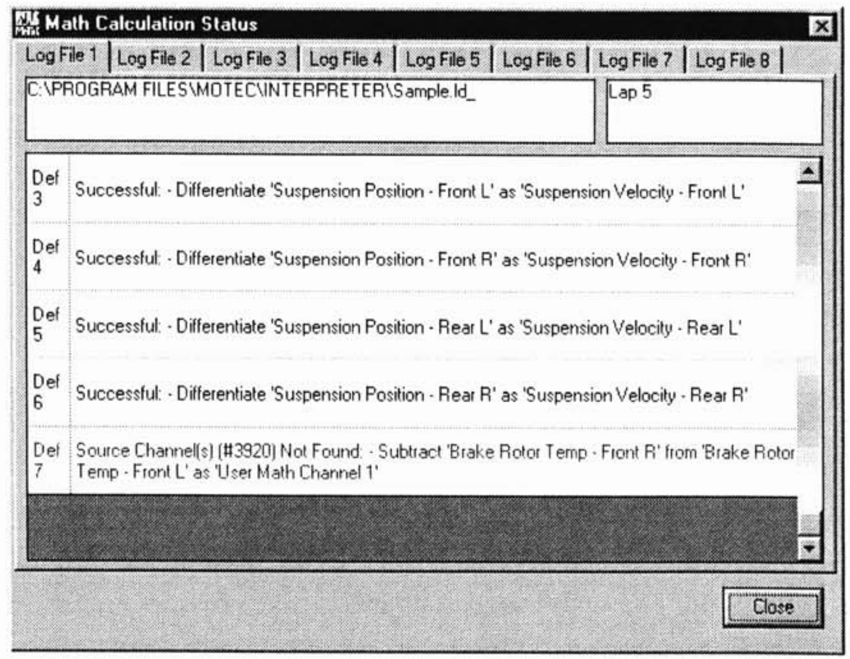
- Throttle
- Speed
- RPM
- Steering
- Lateral Acceleration
- Inline Acceleration
- Front
  (roll, load, brake pressure…)
- Rear
  (roll, load, brake pressure…)
- Water Temperature
- Oil Temperature
- Oil Pressure
- Battery Voltage
- Fuel Pressure

Setting up the Templates

- Always use the same name for a given data. Choose the data to be displayed in the graph in the channel window list.



- If the data you want to display does not appear in this list, it means that this particular data has not been logged.

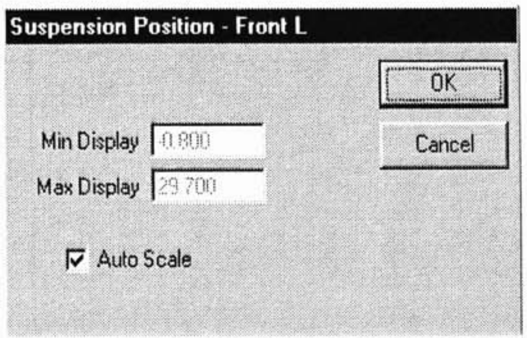


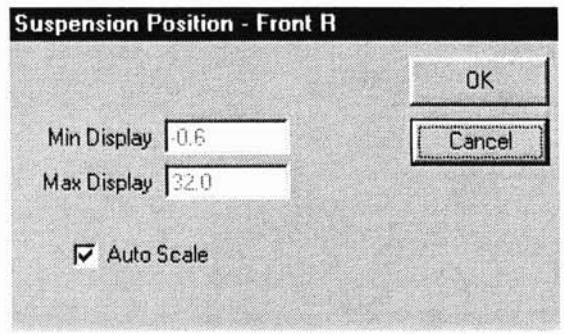
- If the data you want to display is a math function and it does not appear in the graph template displayable channels list, it means it has been created with at least one data which has not been logged. To check this, go to View / Math Status. Any unsuccessful math function will be written in red.

Setting up the Templates

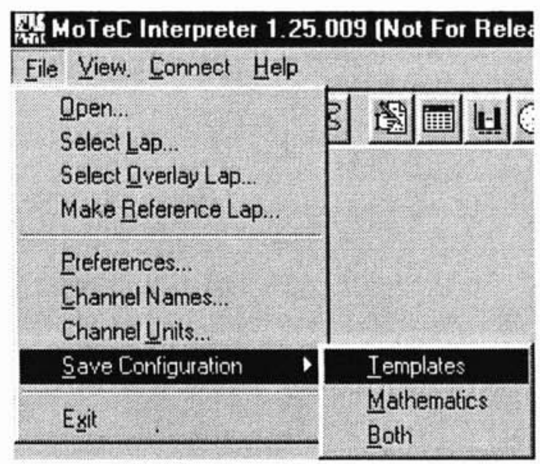
- Maximum and Minimum according to the circuit you use (Speed, Lateral Acceleration, etc …).

- Note the min and max in the auto scale mode to choose the min and max of each particular channel or group of similar channels.





- Use the same min and max for all comparable channels (like all the dampers).
- Use a smart color for each graph background (light gray is a good choice).
- <u>Save the templates configuration !</u>



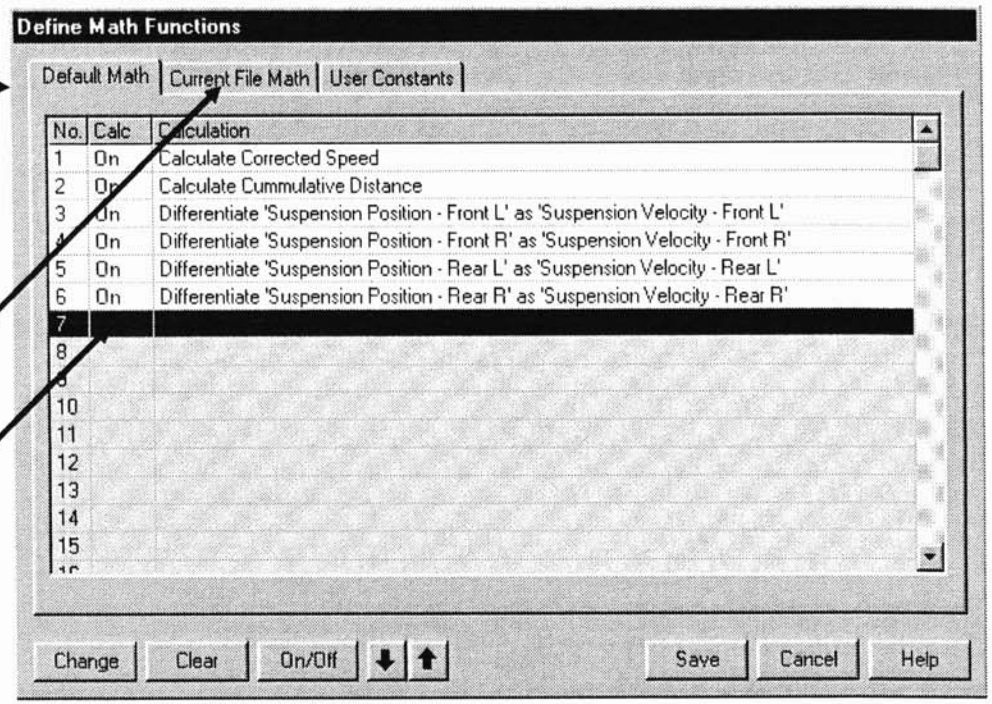
Math Functions Creations

To create a new math function, go to View / Math.

Choose Default Math to create math functions which will work for any series of laps analyzed.

Choose Current File Math to create math functions which will work only for the particular outing just opened.

Highlight a new line and click on Change.



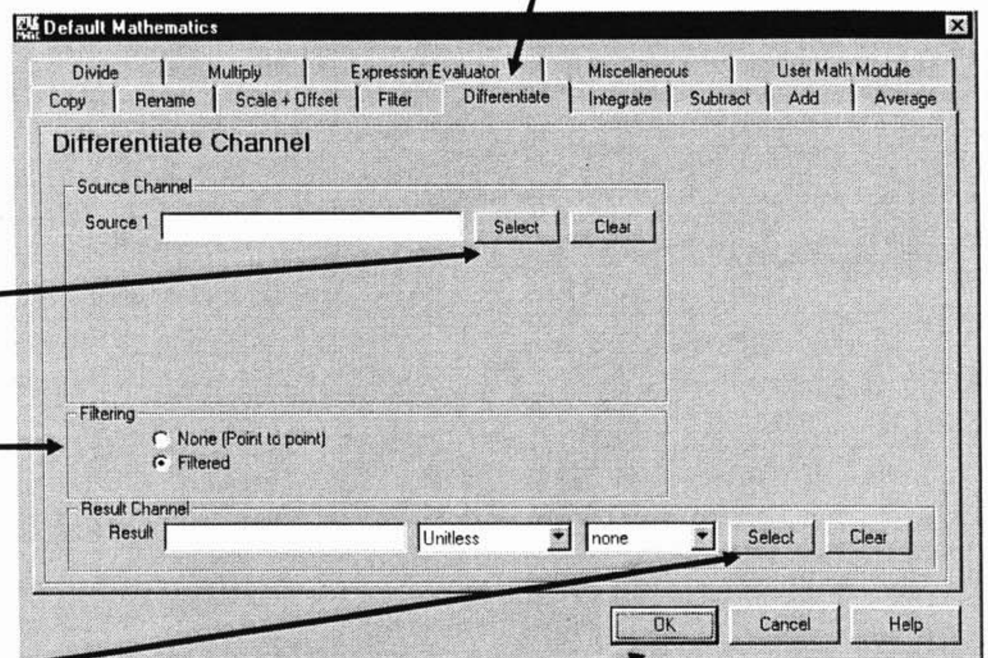
Math Functions Creations

Choose the tab of the operation you want to do.

Click on Select. The *Select from All Channels* window appears. Choose the source(s) you need to create the math channel.

Select a filter.

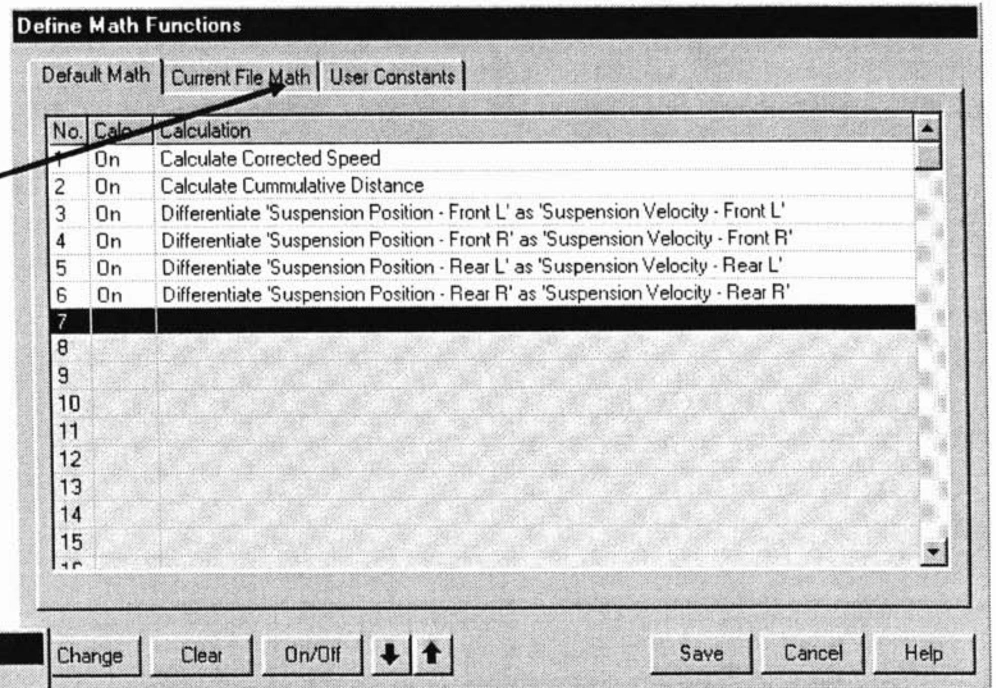
Select the source(s) of the result channel and its units form the appearing *Select from All Channels* window.



Click OK.

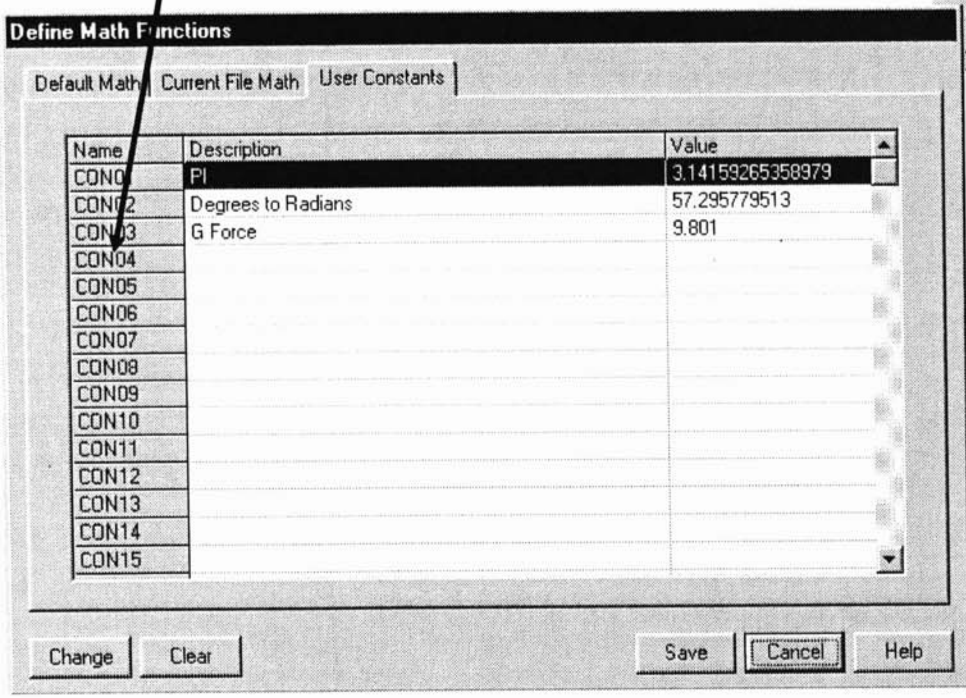
Math Functions Creations

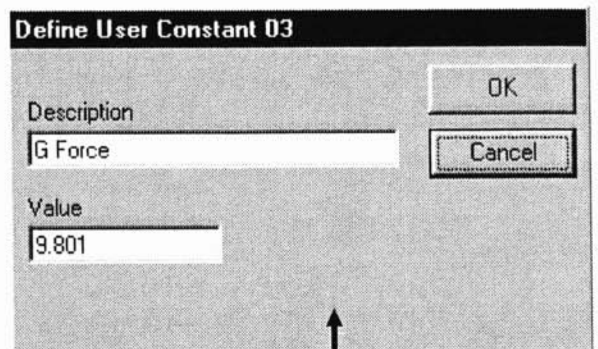
If the match function involves constant which are often the same, select User Constant.



Highlight an existing line to modify an existing constant or a new line to create a new constant.

Click on Change.



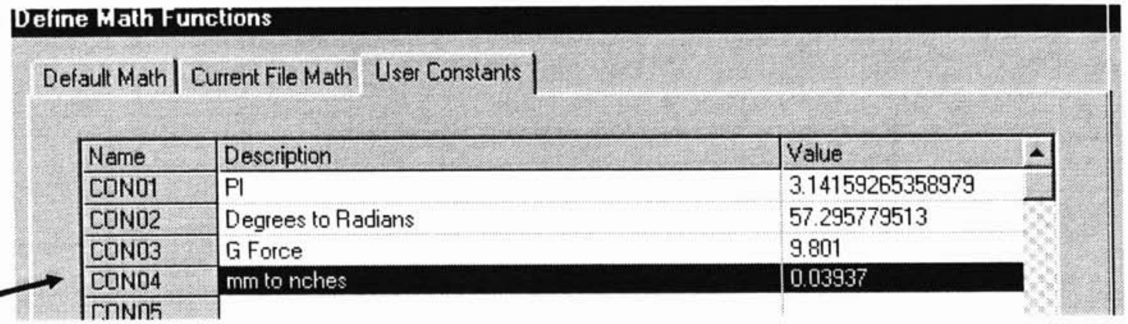


Highlight the name and / or the value to be changed.

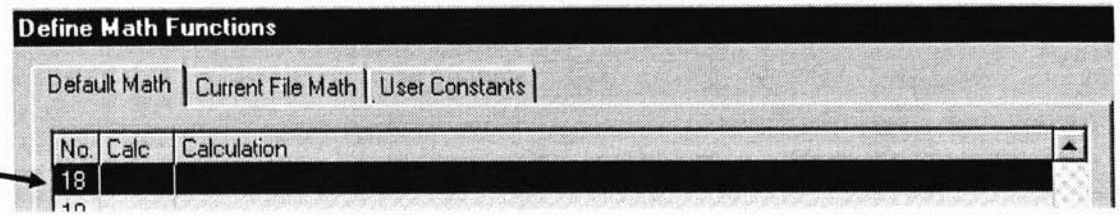
Click on OK.

Math Functions Creations

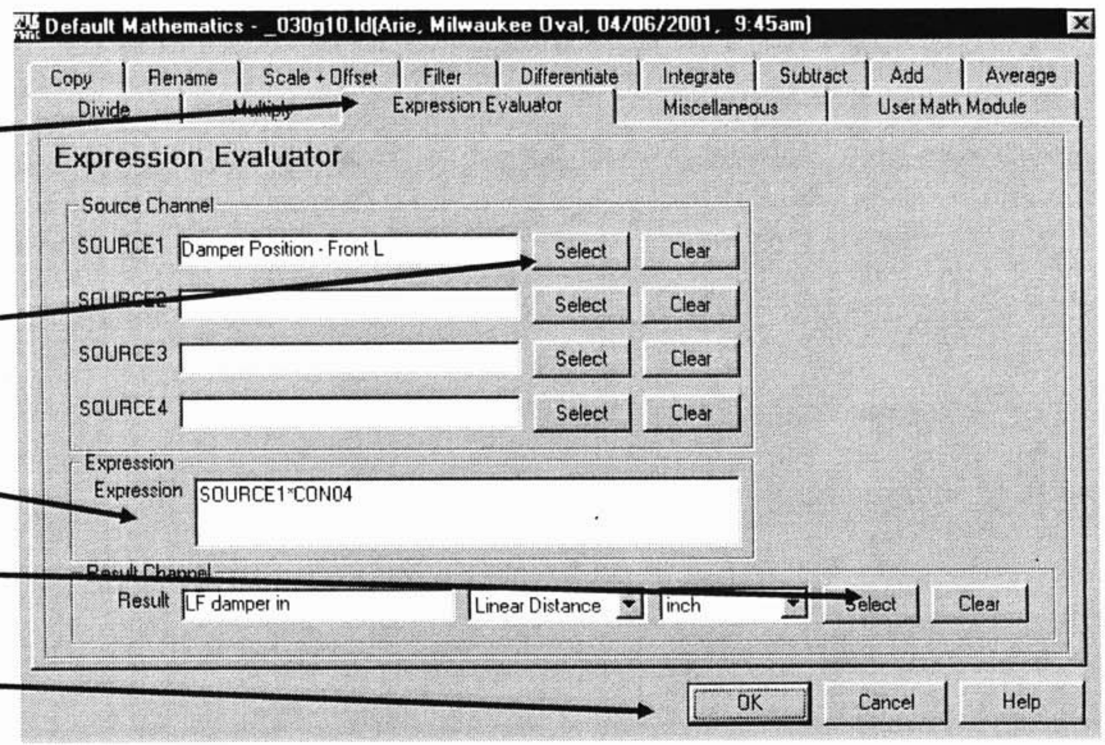
Math Functions with a constant



Once a new constant created, <u>remember</u> the name of the constant.



Go to define math functions, highlight a new line and click on Change.



The Defaults Mathematics window appears. Click on Expression Evaluator.

Choose the source(s) by clicking on Select.

Write the expression containing the Constant.

Select the result channel and its units.

Click OK.

Math Function Creations

The components (SOURCE) of a new math function are :

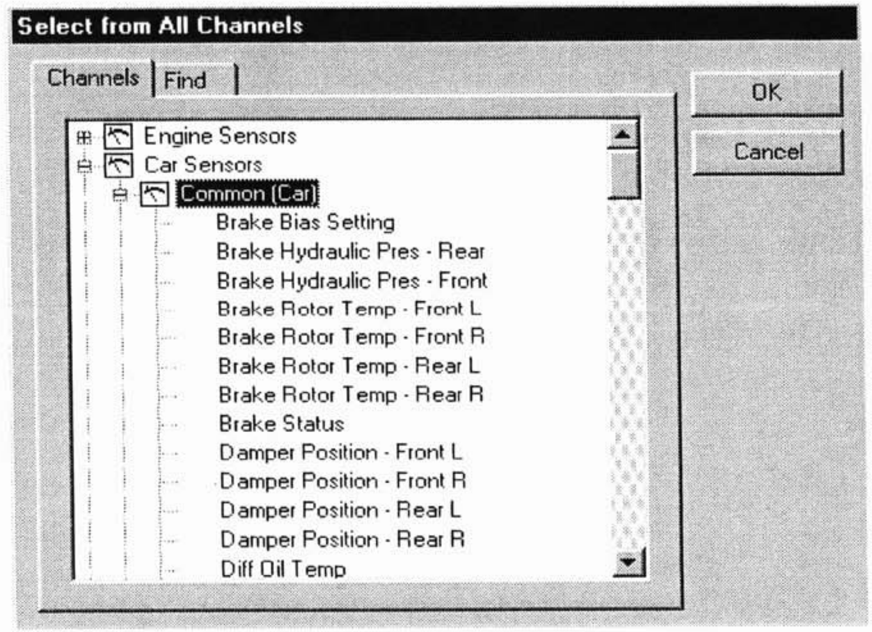
- either an existing logged data chosen out of the *Select from All Channels* window.

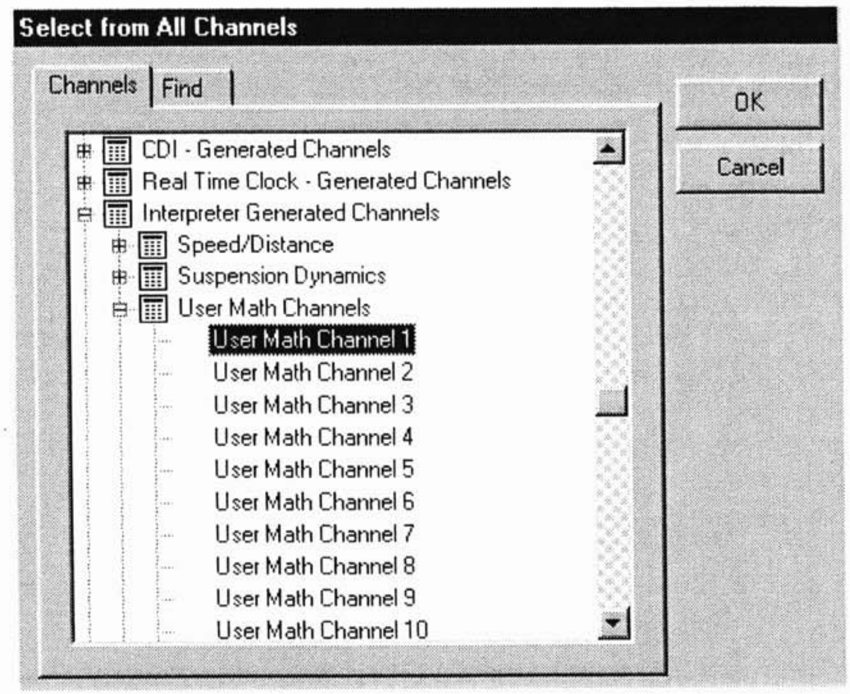
- and /or existing math function(s) previously created and found in the *Select from All Channels* window.

- either a constant.

If you create a brand new math function with a name which doesn't exist in any of the already  or  files,

in the *Select form All Channels* window, go to a  file at the bottom of the same *Select from All Channels* window and click on *User Math Channel x.*

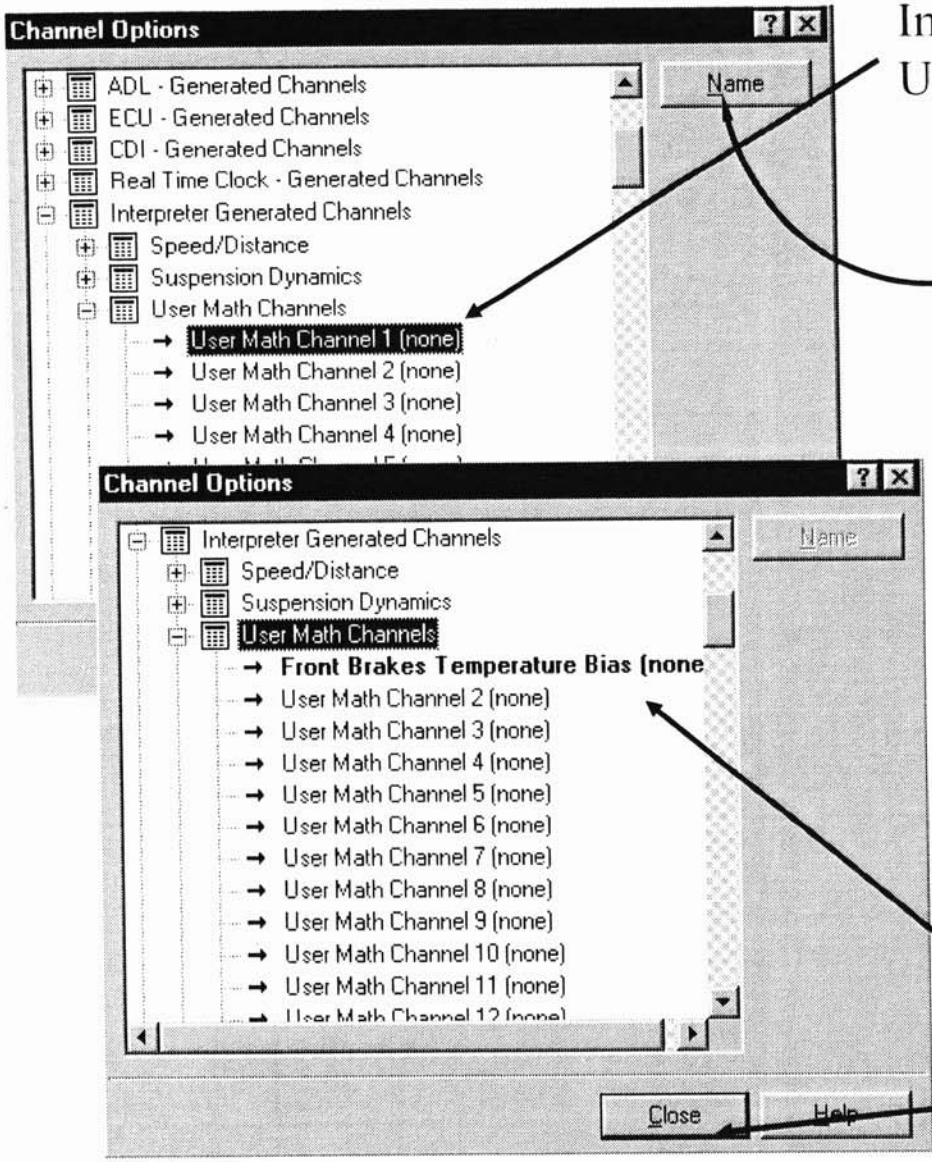




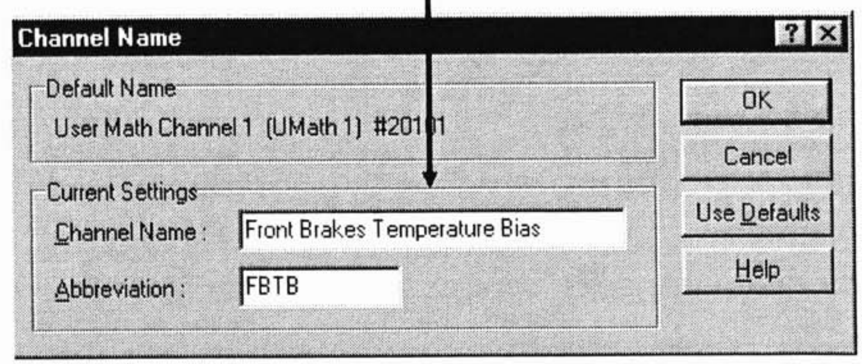
Math Function Creations

Giving a name to a brand new math function

In File / Channel Name, choose one of the User Math Channels.



Click on Name and choose a new name and abbreviation for this new math function. Click OK.



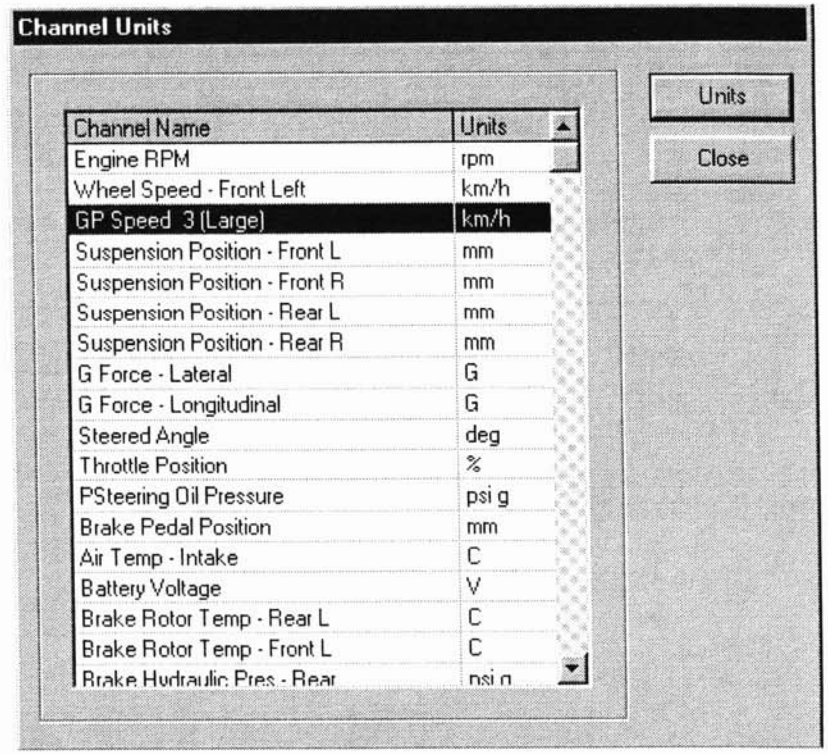
The new name appears as the new Math Channel.

Remember its location.

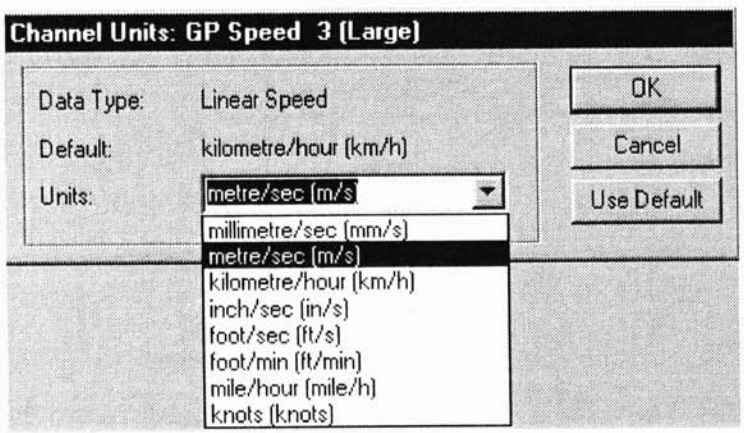
Click Close.

Changing the math function units

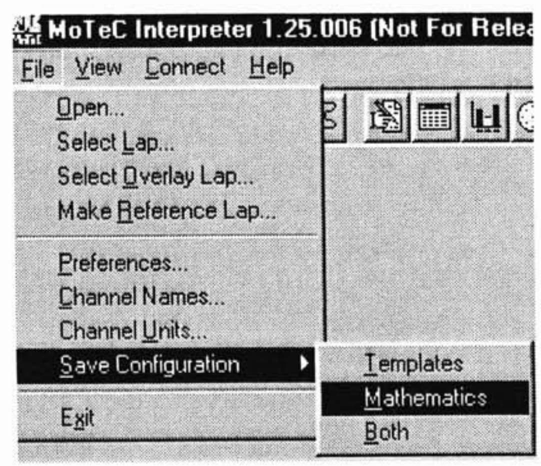
Once a file is open, right click the mouse, or go on File / Channels Units and click on Units.



Change the units and click OK.



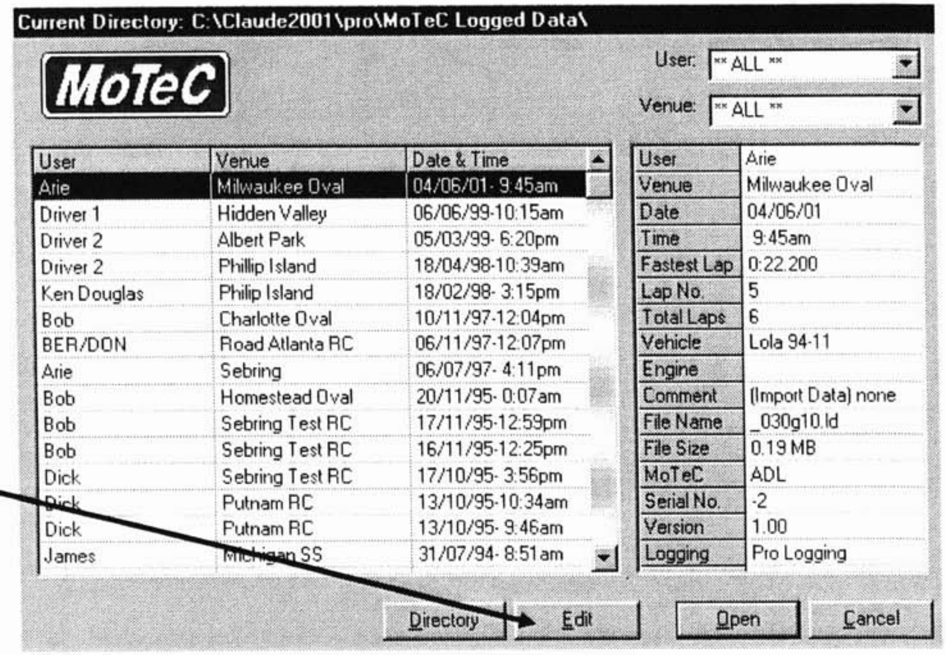
Do not forget to go on File / Save Configuration and Save the Mathematics.



Things to Set During the Test or Race

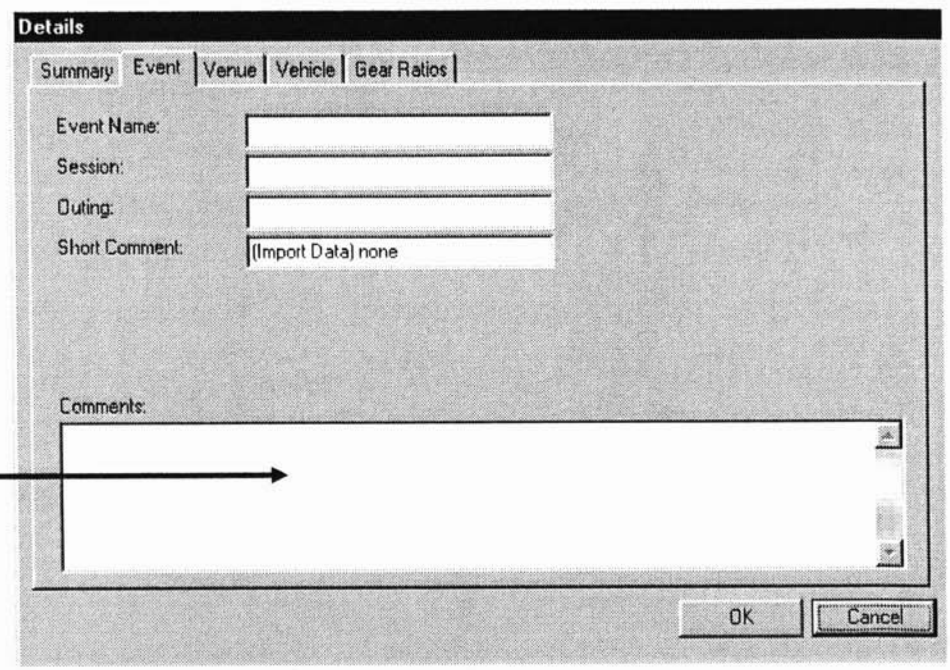
In the File/ Open window, highlight the series of lap you want to analyze.

Click on Edit.



Consider the importance to fill in the information and the comments for each tab (Event, Venue, Vehicle and Gear Ratios). Write the correct local time so that it corresponds to the time of the test or race described in any other team documents (engineer test sheet, official race or QF results etc...).

The information written here will help to remember what was changed in the car setup and WHY the data and the car behavior are different.



Using the MoTeC system before the set up pad (car still on stands)

To be checked

- Beacon / Transmitter
- Wheel speed sensors
- All connections
- Any left hand sensors not connected with any right hand cable and vice versa.
- Signal from all sensors (chassis and engine)

To be set or / and adjusted

- Dashboard (to do on all pages with the driver in the car with seat belt and helmet)
- Brake Balance. Example: for a 500 psi front brake pressure the brake balance should be set so that the rear brake pressure is at 375 psi
- Check there is no brake pressure at any throttle position (brakes should be disengaged)
- Throttle Potentiometer
- Etc …

Logging Frequencies

- Depend of Memory Size
- Test (a few laps) or Race (as long as 2 hours)
- To be taken into account: downloading time

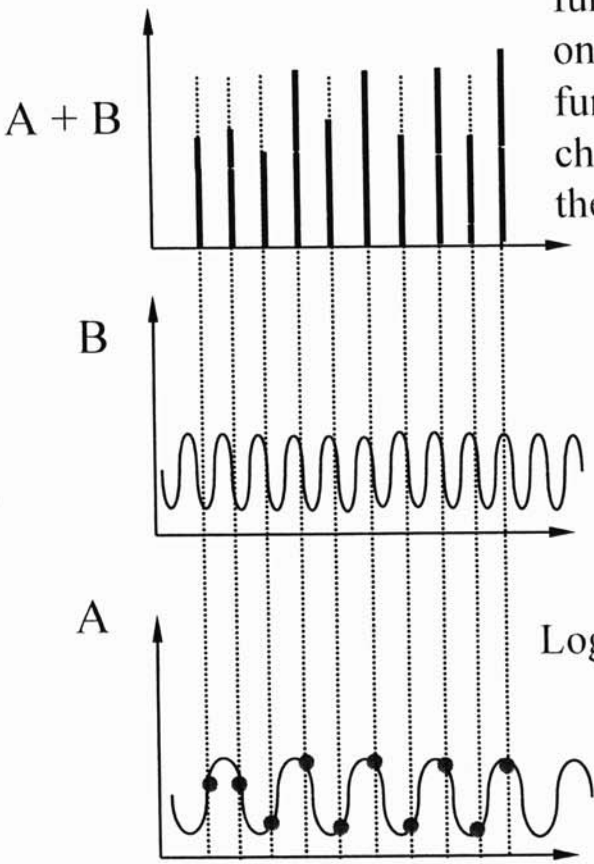
<u>Examples</u>

■ Oil and water temperatures	1 Hz
■ Oil and fuel pressure	2 Hz
■ Brake pressure	10 Hz
■ Voltage	5 Hz
■ Steering, Gear	10 to 50 Hz
■ Accelerometers	50 to 200 Hz
■ Shocks and strain gauges	20 to 500 Hz

Math Functions, Logging Frequencies and Filter

- Be sure all inputs of a given equation have a nearly similar logging rate
- Filter choice depends on logging rate.

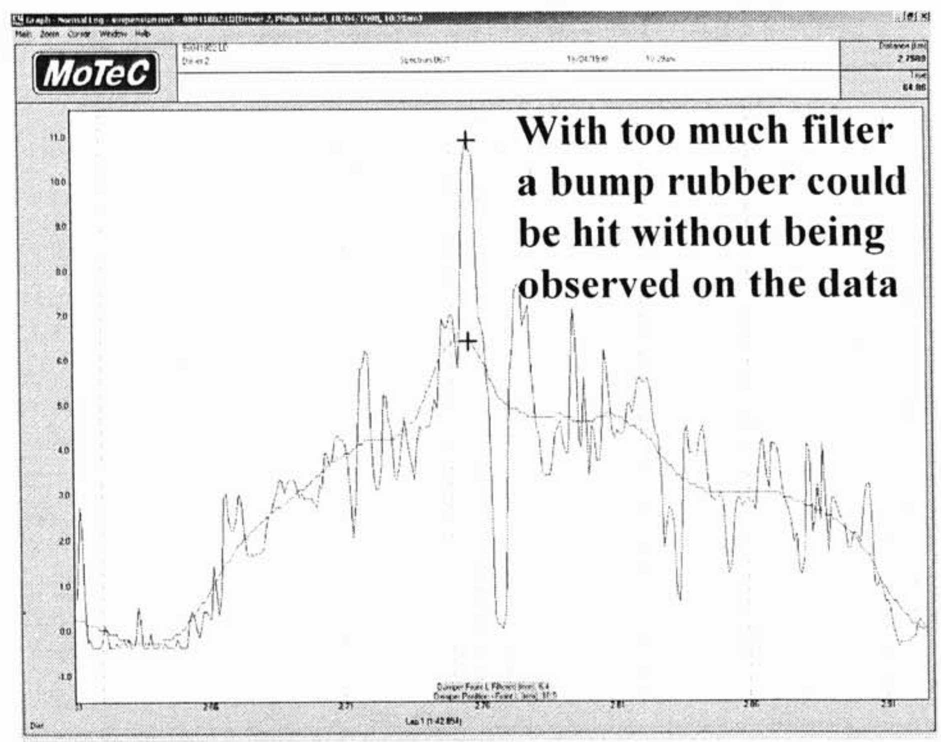
The result of a math function will be the one similar to a math function of both channels logged at the lowest of the rates



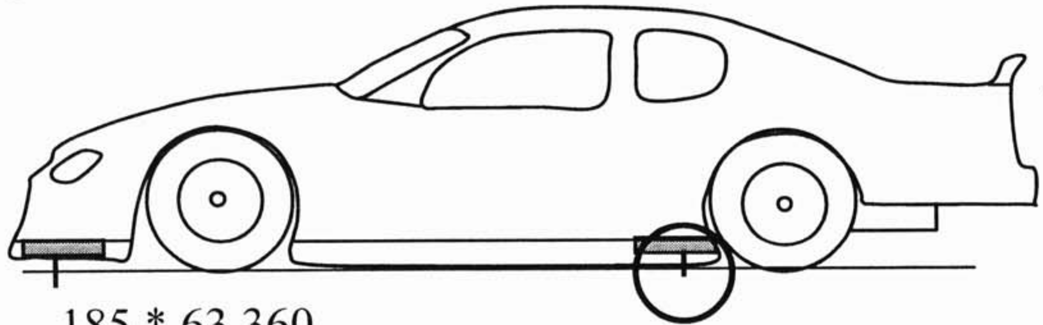
Logged at 200 Hz
Every single point of the represented curve

Logged at 10 Hz

Example of a filtered and non filtered shock data



Importance of High Logging Rate for some Data

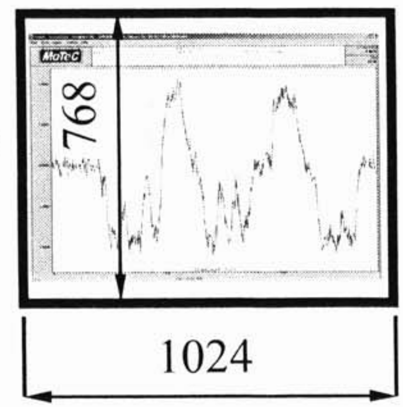


Example with laser sensors logging at 500 Hz

Car at 185 mph

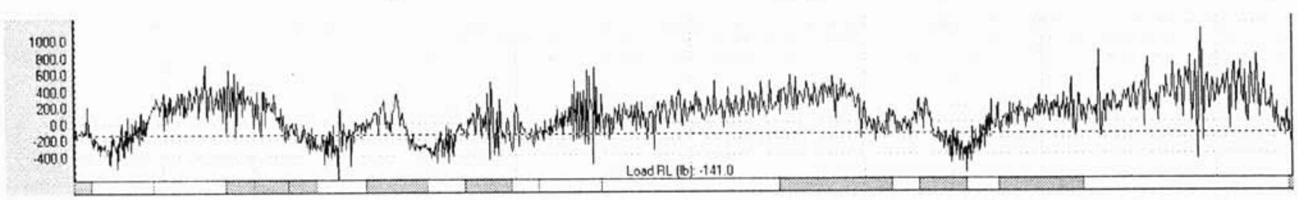
Space between each logging = $\dfrac{185 * 63{,}360}{3{,}600 * 500}$ = 6,512 in

Unzooming is Filtering !

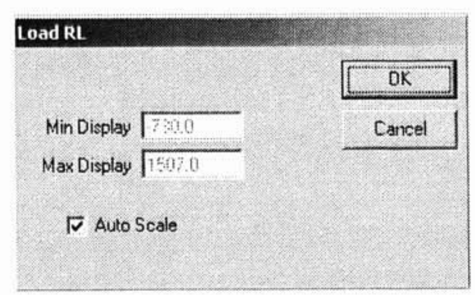


If the computer resolution is for example 1024 x 768. At best you will se only 1024 / 500 = 2.04 seconds of the data without any filtering. If you look at the all lap you are necessarily filtering. If you want to see the extremes you need to zoom on just a segment equal or smaller to 2.04 seconds.

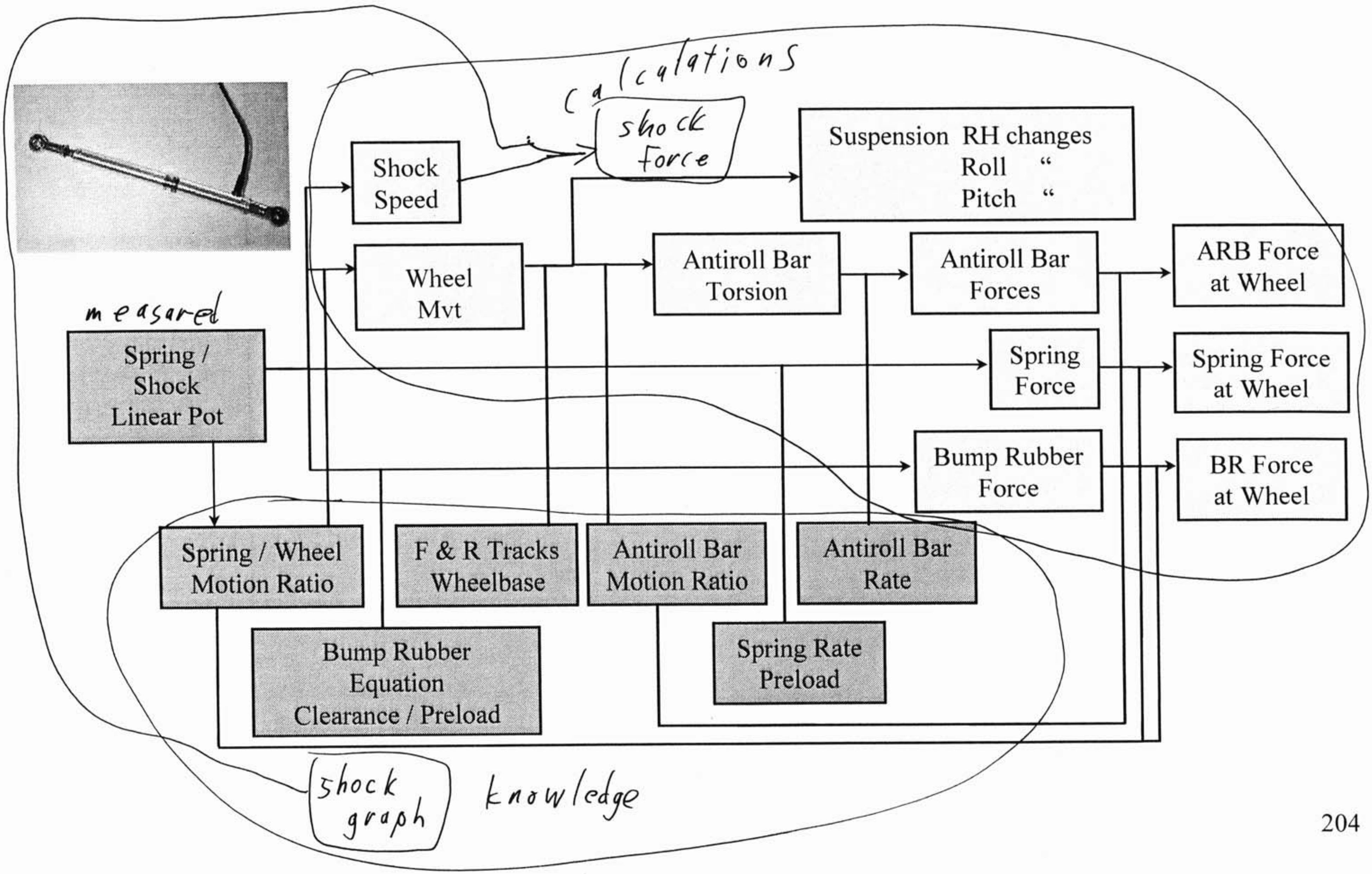
That is the reason why the min and max apparently visible on this graph



are smaller than the one seen on the auto scale min and max numbers.



Principles behind Mathematics Functions
What we can learn from shock's linear potentiometers



Wheel Speed Sensors and Diff Work

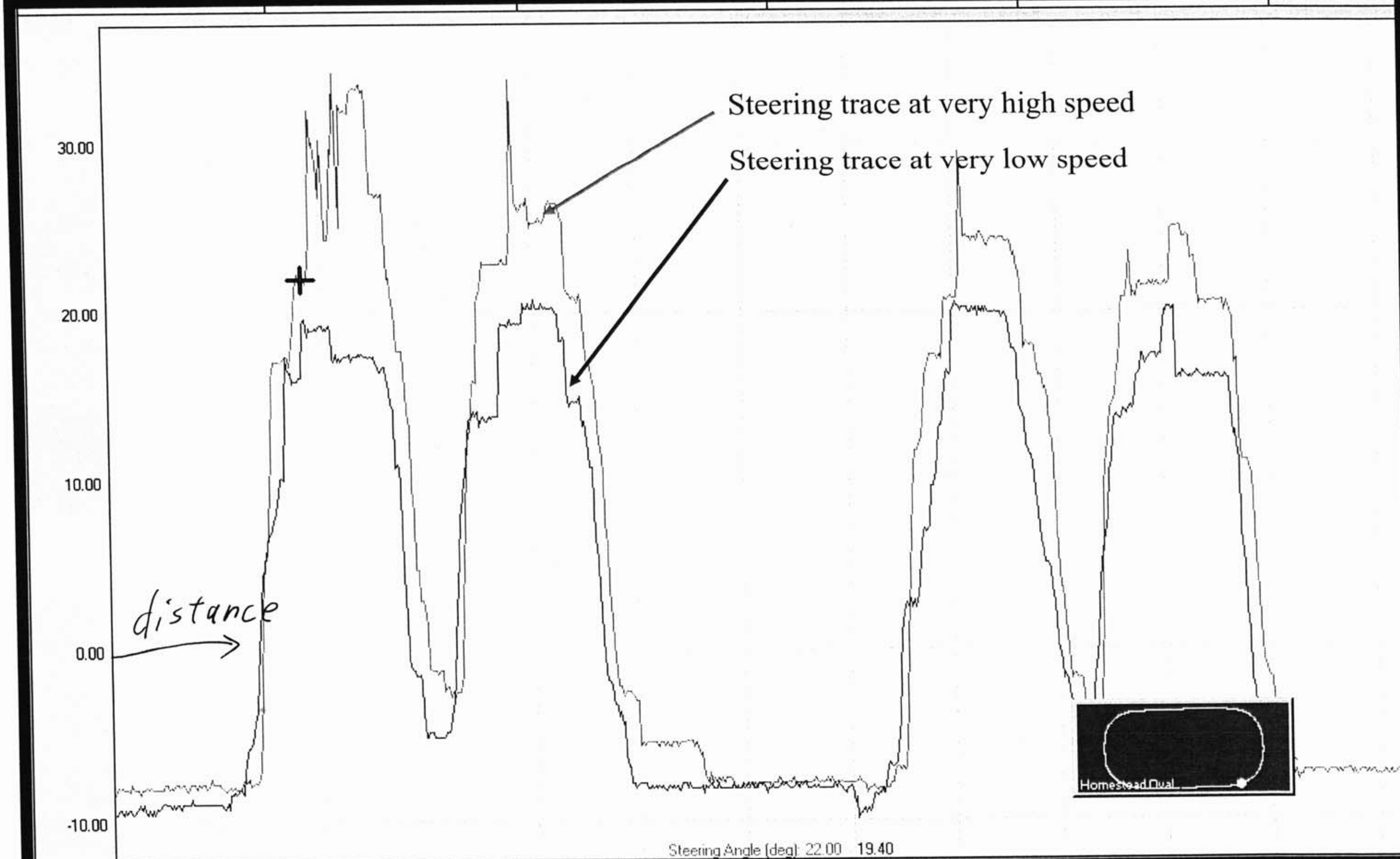
Adjust tire rolling radius diameter to get:

- Same 4 wheels speed in straight away
- Same speed as speed trap. Use medium to high straight speed as a reference (taking into account tire deflection due to high downforce)
- Check wheel locking
- Measure diff work
- Comparison to front wheel speed to measure rear wheels spin
- If no rear wheel speed sensors, calculate average rear speed from RPM, final drive and gear ratios; then, compare them to front speed

7. Measuring and Comparing Performance

- Evaluating under and over steer with the steering trace
- Evaluating under and over steer with the steering and the throttle data
- Evaluating under and over steer with the gyro
- Evaluating under and over steer with a front and a rear lateral accelerometers
- Evaluating performances and driving style with the speed, steering, lateral acceleration and throttle data
- Comparing performance with inline, lateral and total acceleration
- Analyzing shock data
- Shock speed histogram
- Track Map
- Dash Setup
- Magic numbers

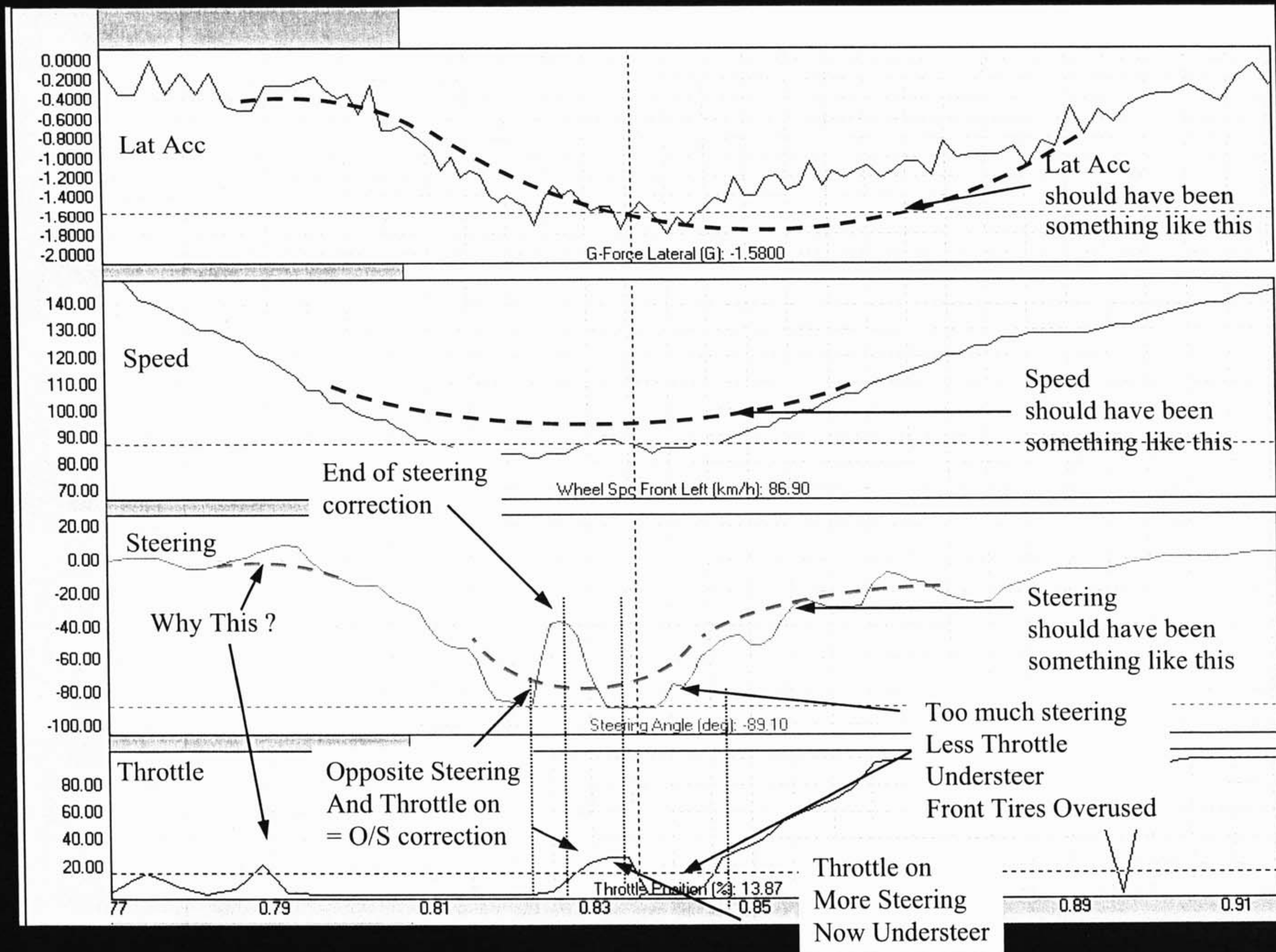
Analyzing the Steering Data



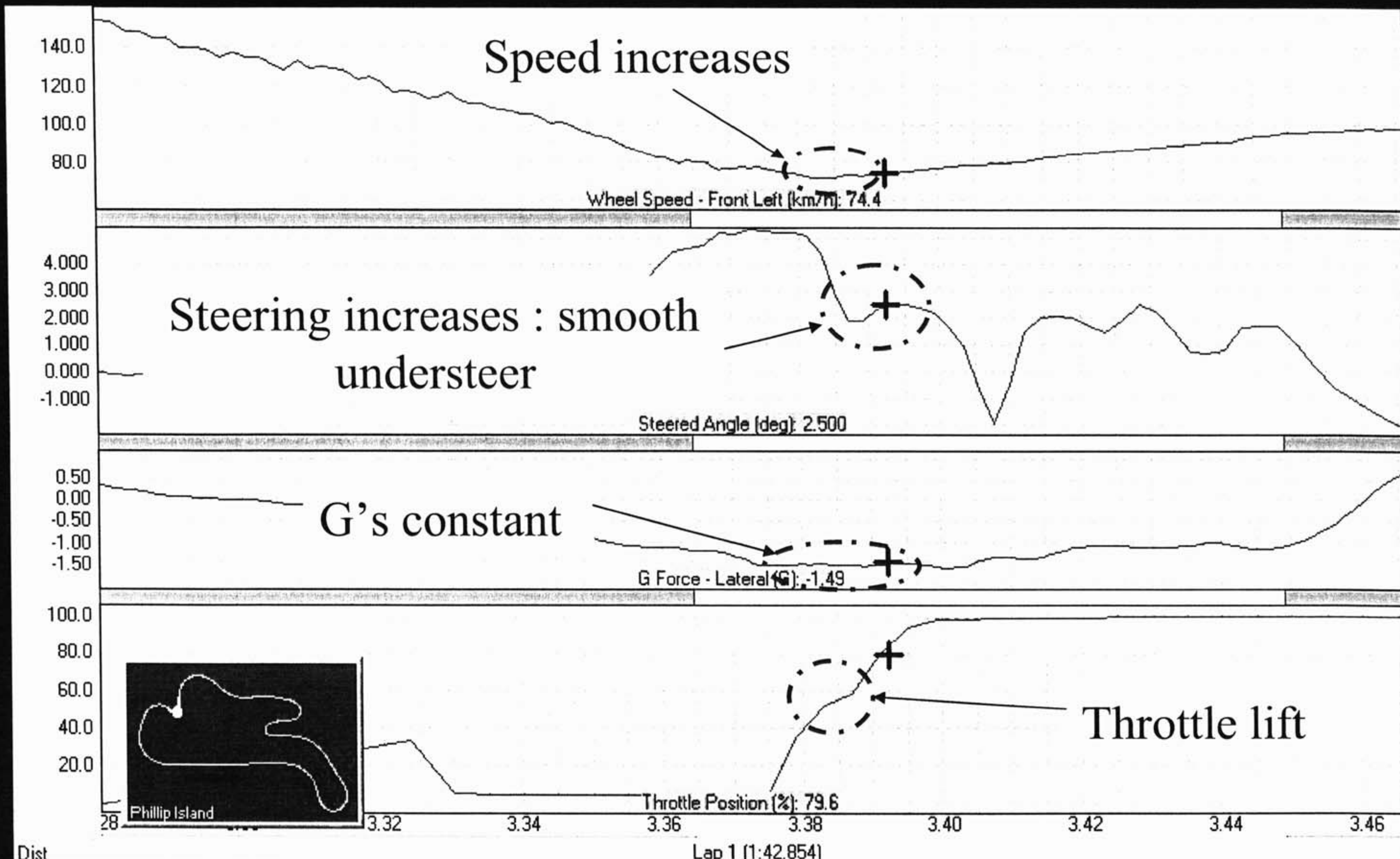
Analyzing the Steering Data

- Let's ask the driver to go alone (and safely !) on the circuit at very low and very constant speed (6 to 12 mph) *on the exact same trajectory he has at high speed* and let's record the steering data.
- We can consider that at very low and constant speed, without any lateral acceleration, none of the tires is under big lateral or vertical loads. The slip angles are negligible. They probably are equal to the wheels toe in and toe out.
- Consequently, the difference between the front and rear slip angles can be considered negligible too.
- That means we can consider the car as neutral.
- If, at high speed, we get lateral acceleration because of we get tire lateral forces tire lateral forces appear … because of tires slip angles.
- We know that bigger slip angles on the front means understeer. To keep the car on the same trajectory the driver will have to steer more. Vice versa if it is oversteer.
- Comparing the steering trace at high and low speed will help us to quantify the understeer or oversteer *only if the driver is as exactly as possible on the same trajectory.*
- Caution: the steering trace at high speed should not be exactly comparable to the one at low speed : slip angle implies yaw angle as we have seen previously. To keep the same trajectory the driver will have to steer a bit less to compensate the smaller turn radius due to the slip angle.

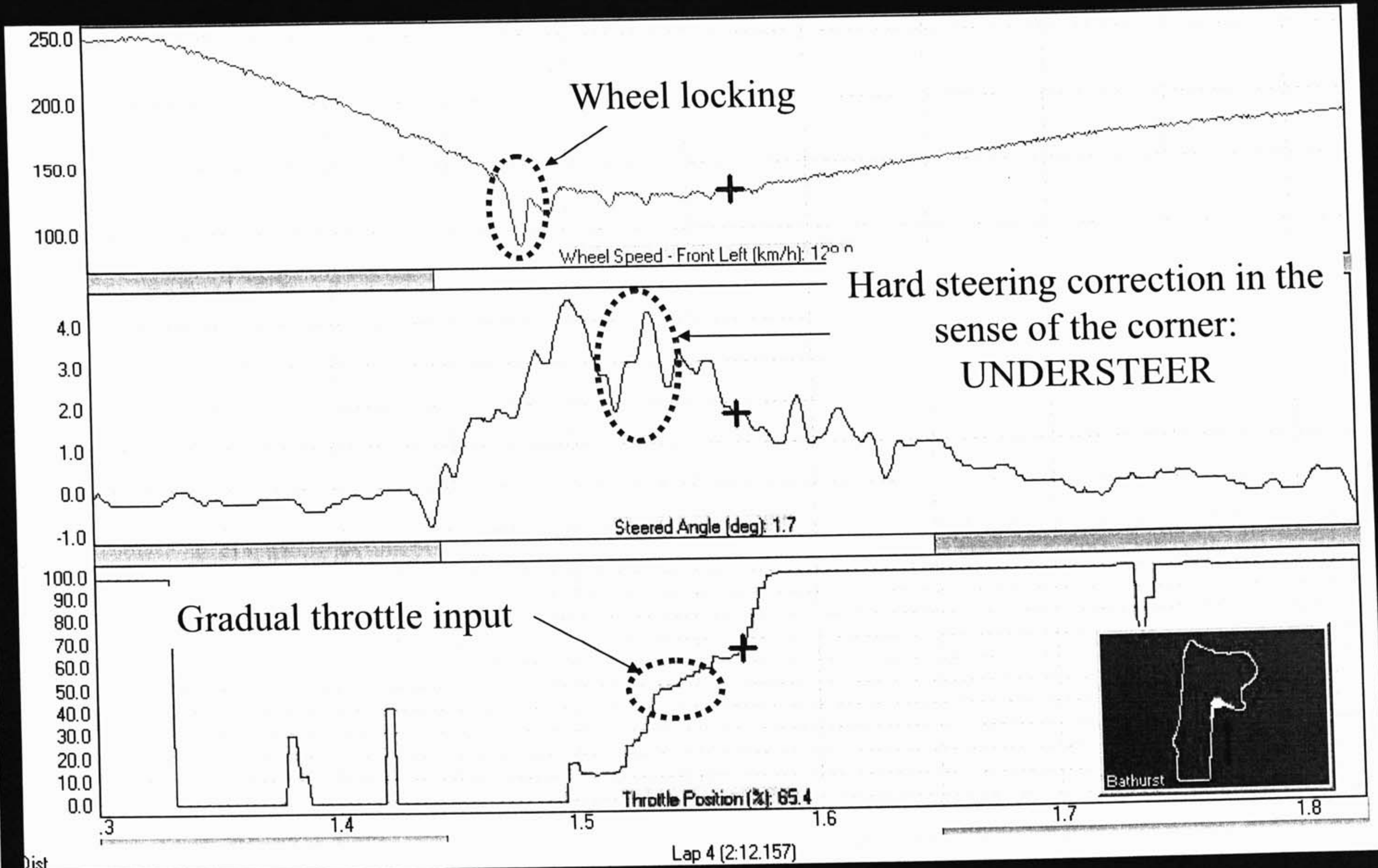
Analyzing the Steering and the Throttle Data



Detecting understeer (1)

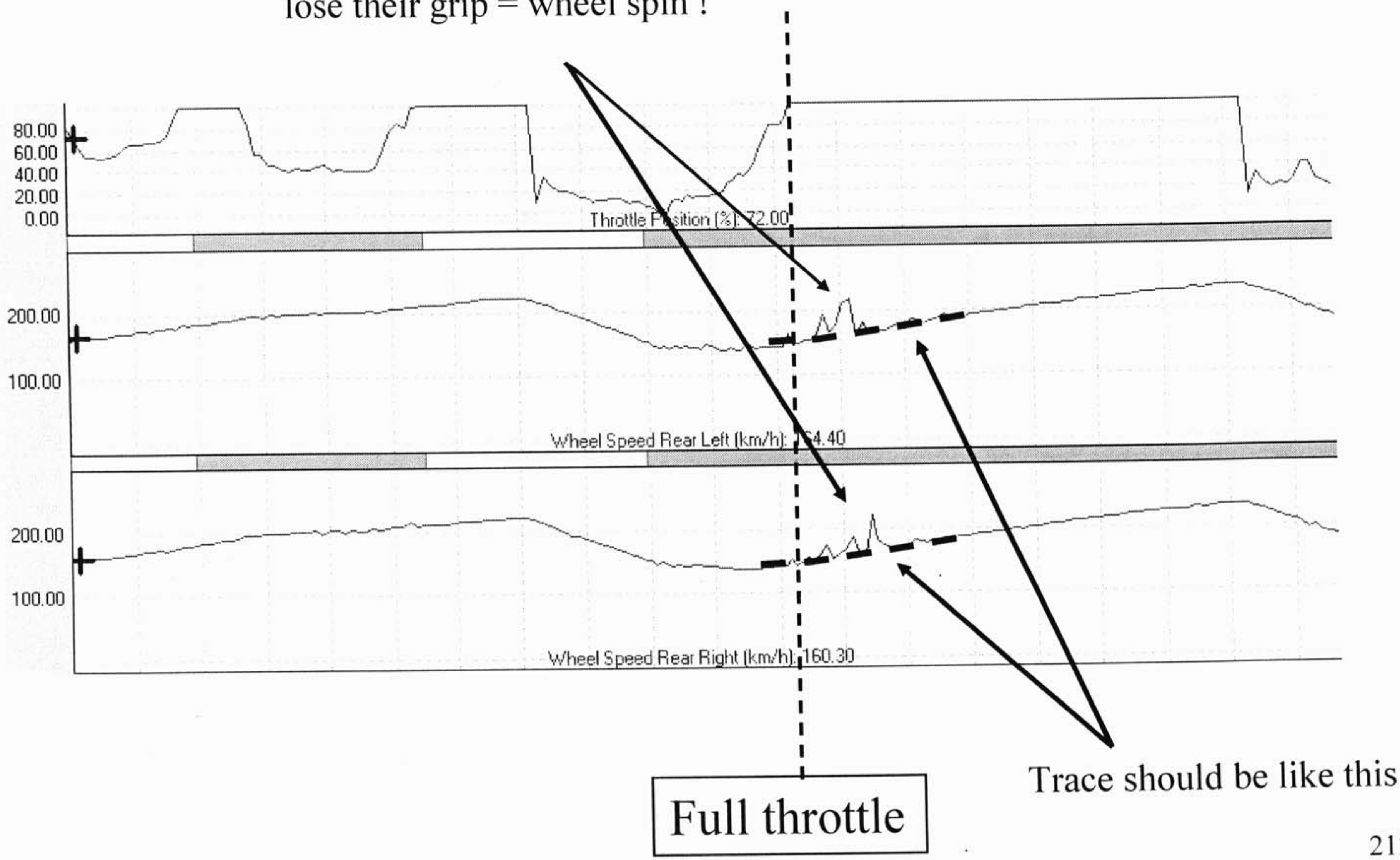


Detecting understeer (2)

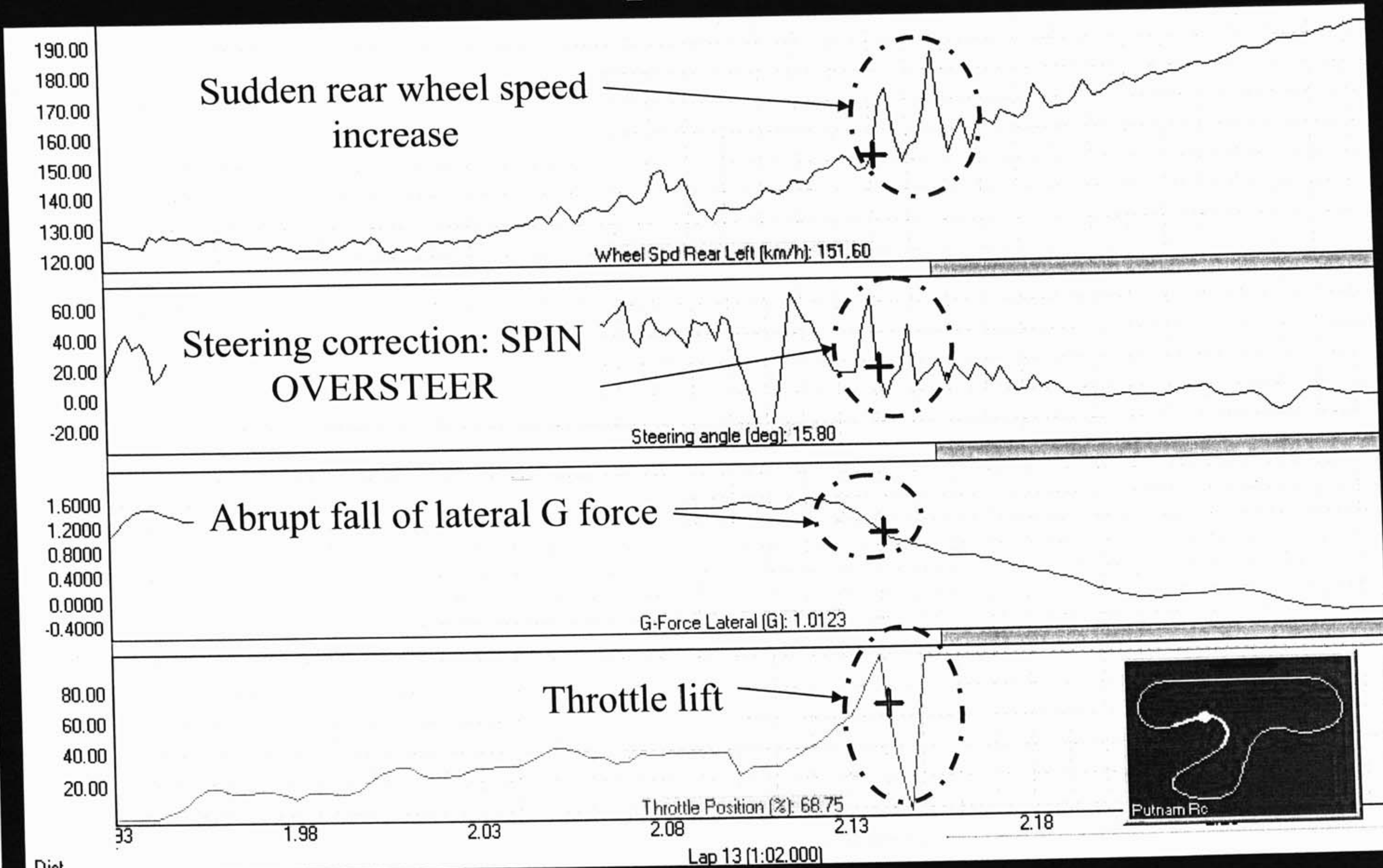


Detecting traction problem

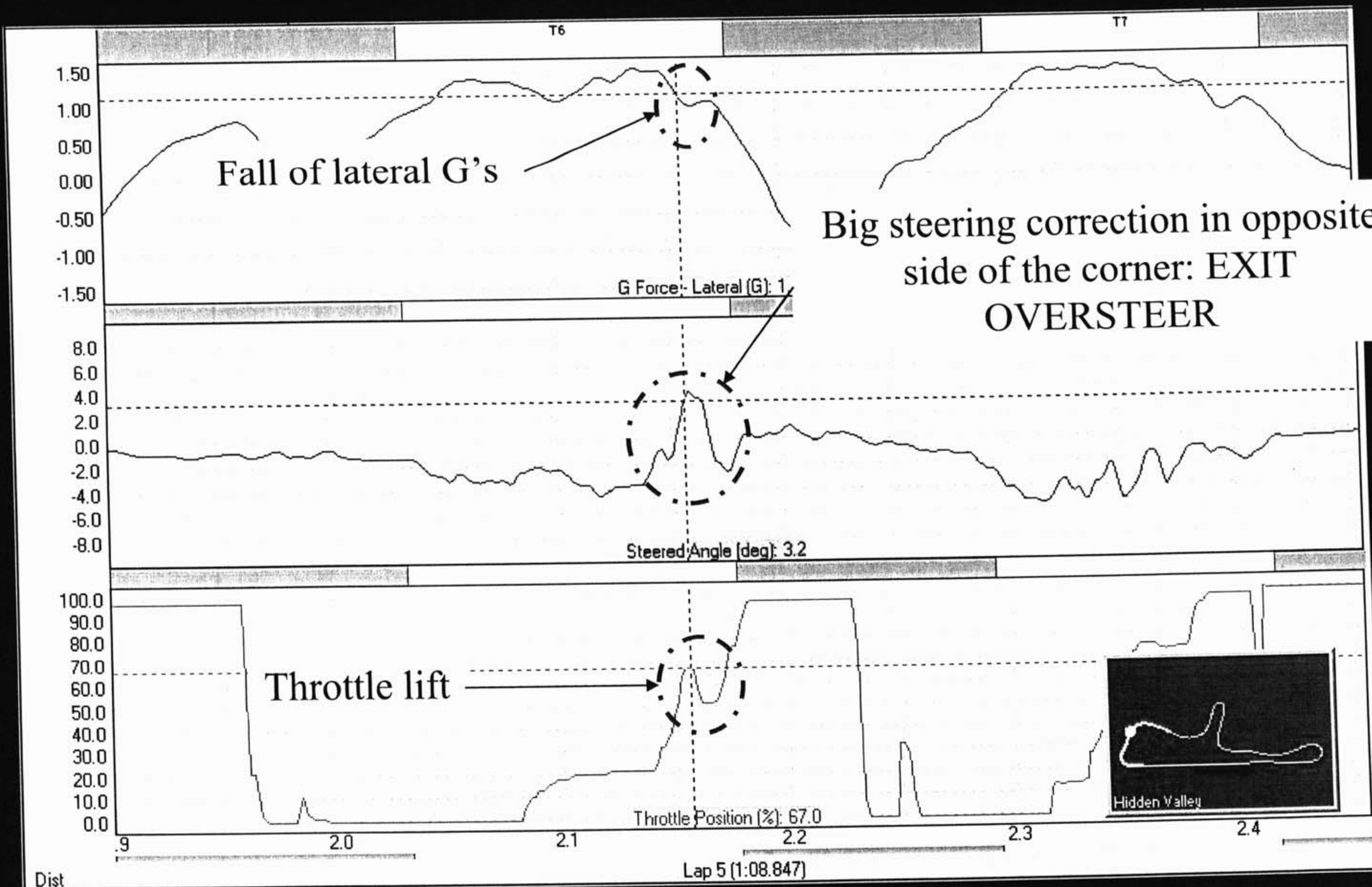
On power, sudden increase of rear wheels speeds: rear tires lose their grip = wheel spin !



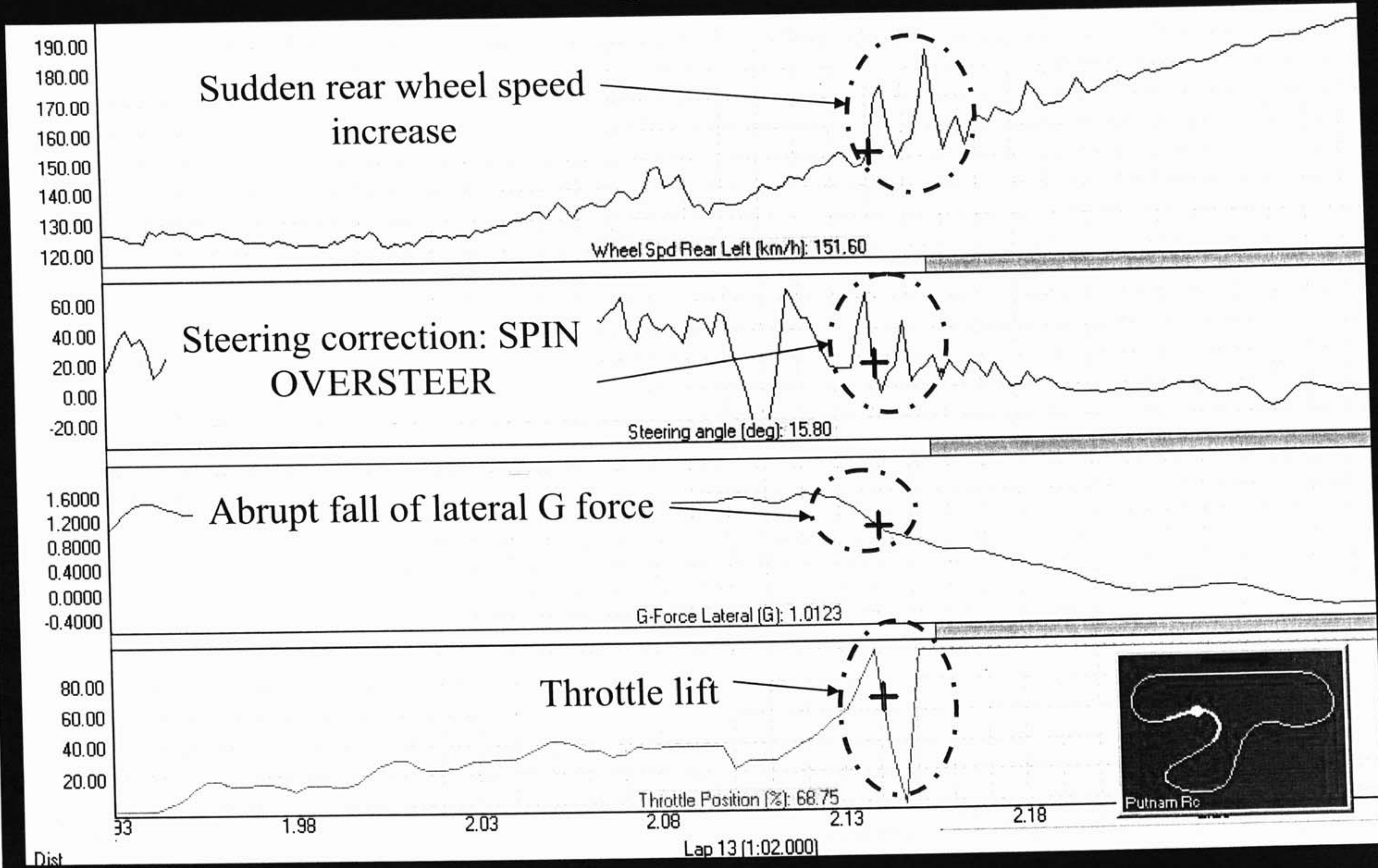
Wheel spin oversteer



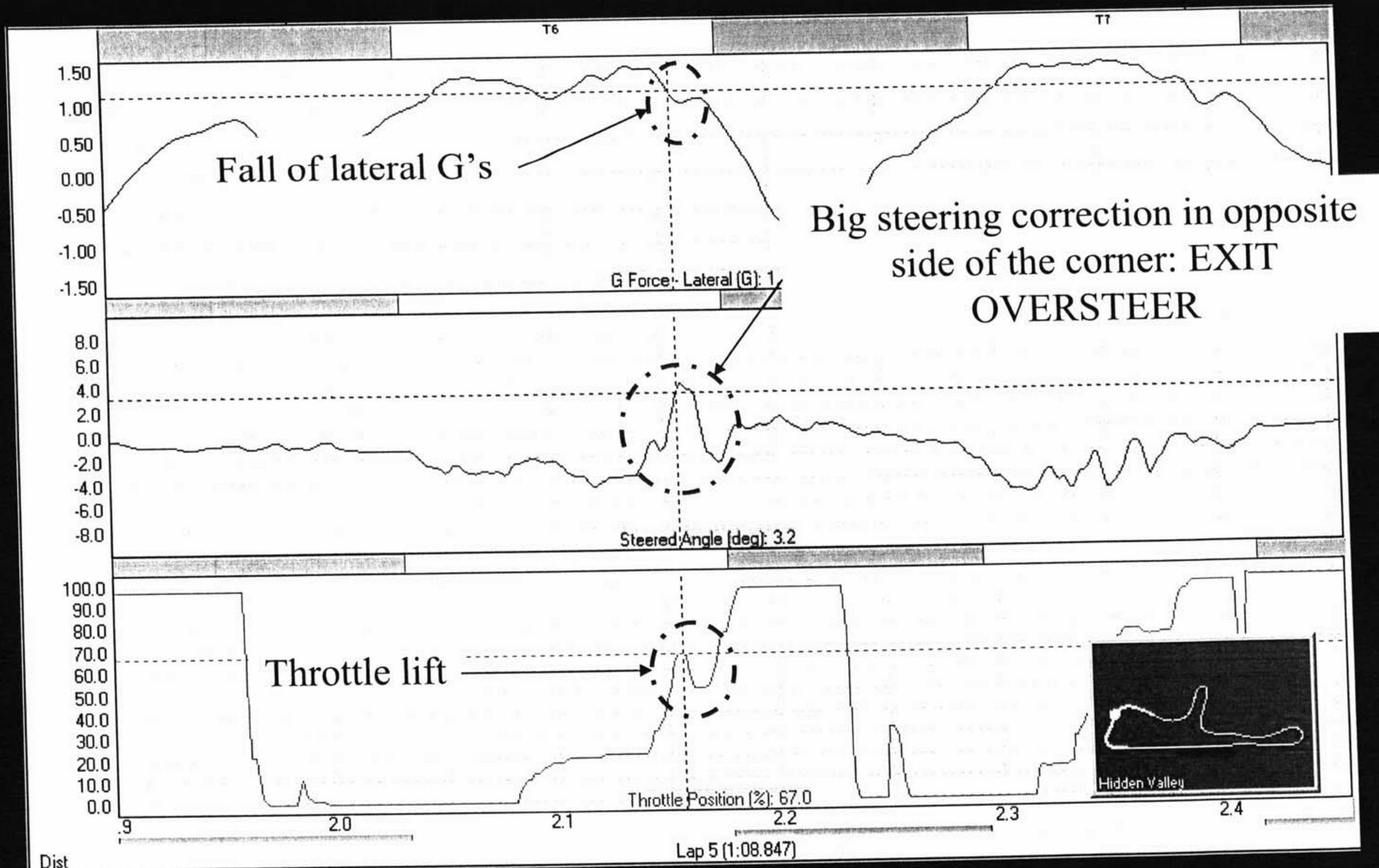
Exit oversteer



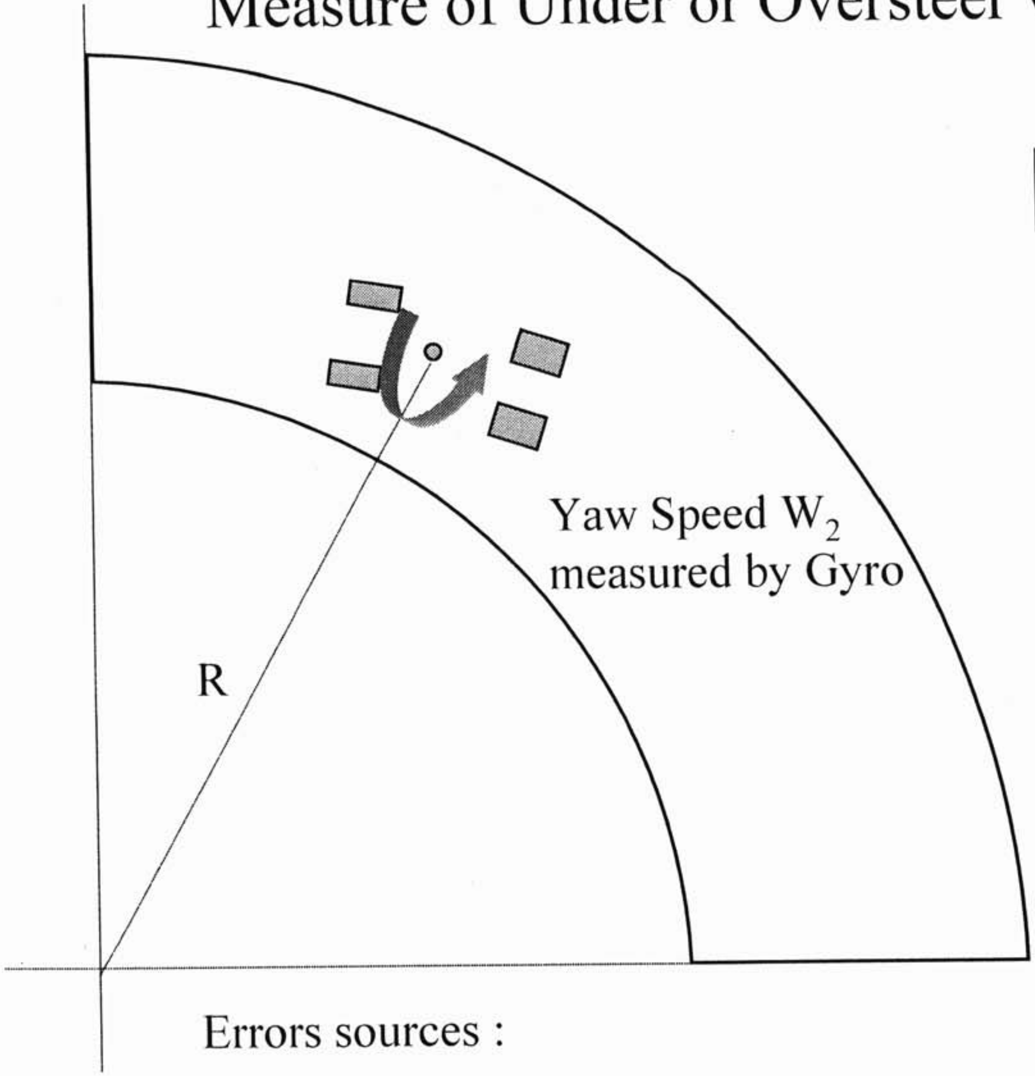
Wheel spin oversteer



Exit oversteer



Measure of Under or Oversteer with Gyroscope Data



Acceleration a

$a = S^2 / R \leftrightarrow R = S^2 / a$

Radius R

$W = S / R$

Car Rotation Speed W

If $W_2 > W$: Over Steer
If $W_2 < W$: Under Steer

Errors sources :

- Wheel Speed $S \neq$ Car Speed
- This doesn't take care of Slip Angles
- Numerical approximations from data system

Used for relative comparison

Using a Gyro

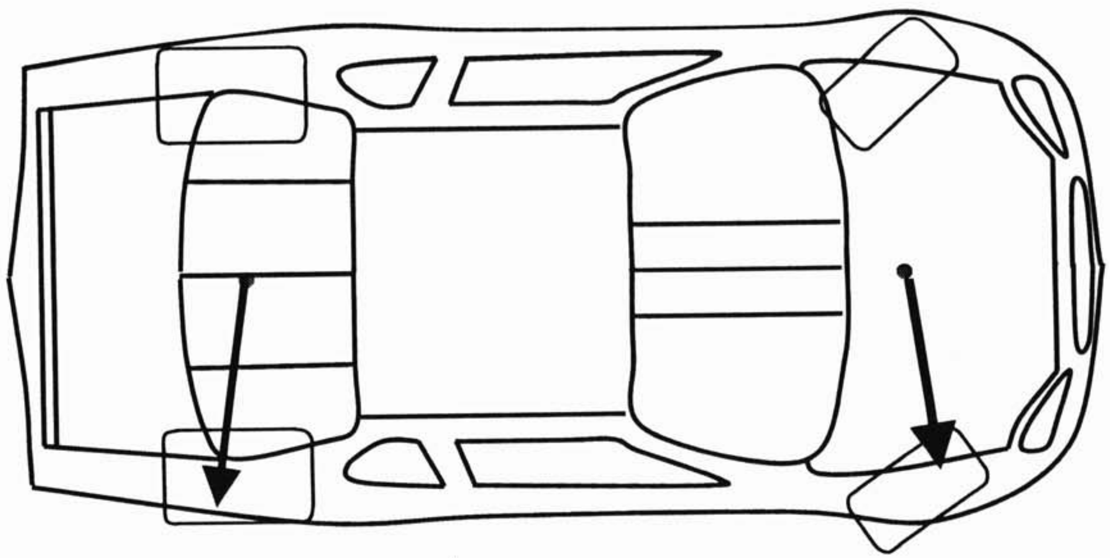
- Lat Acc = Speed^2 / Radius
- Speed = Angular velocity * Radius
- Angular velocity = Lat Acc / Speed
- Lat Acc = 37.2 * G (ft/sec^2)
- Speed (ft/sec) = Speed (mph) * 5,280 / 3,600
- Angular velocity (rad/sec) = 22 * G / mph
- Angular velocity (deg/sec) = 1,260 * G / mph
- Difference between Angular velocity and Yaw rate shows amount of U/S or O/S
- Attitude velocity = Angular Velocity - Yaw rate
- > 0 value shows U/S tendency
- It is useful to calculate the integration of the yaw rotational speed which will give the yaw angle

<u>Limitations</u>

- Does not take into account slip angles
- Lateral acceleration need to be corrected with banking angle
- Difficulty placing the Gyro at the exact Cg
- Chicane (some gyro inertia)

<u>Still and excellent relative comparison</u>

Evaluating Under and Oversteer with a Front and a Rear Lateral Accelerometers

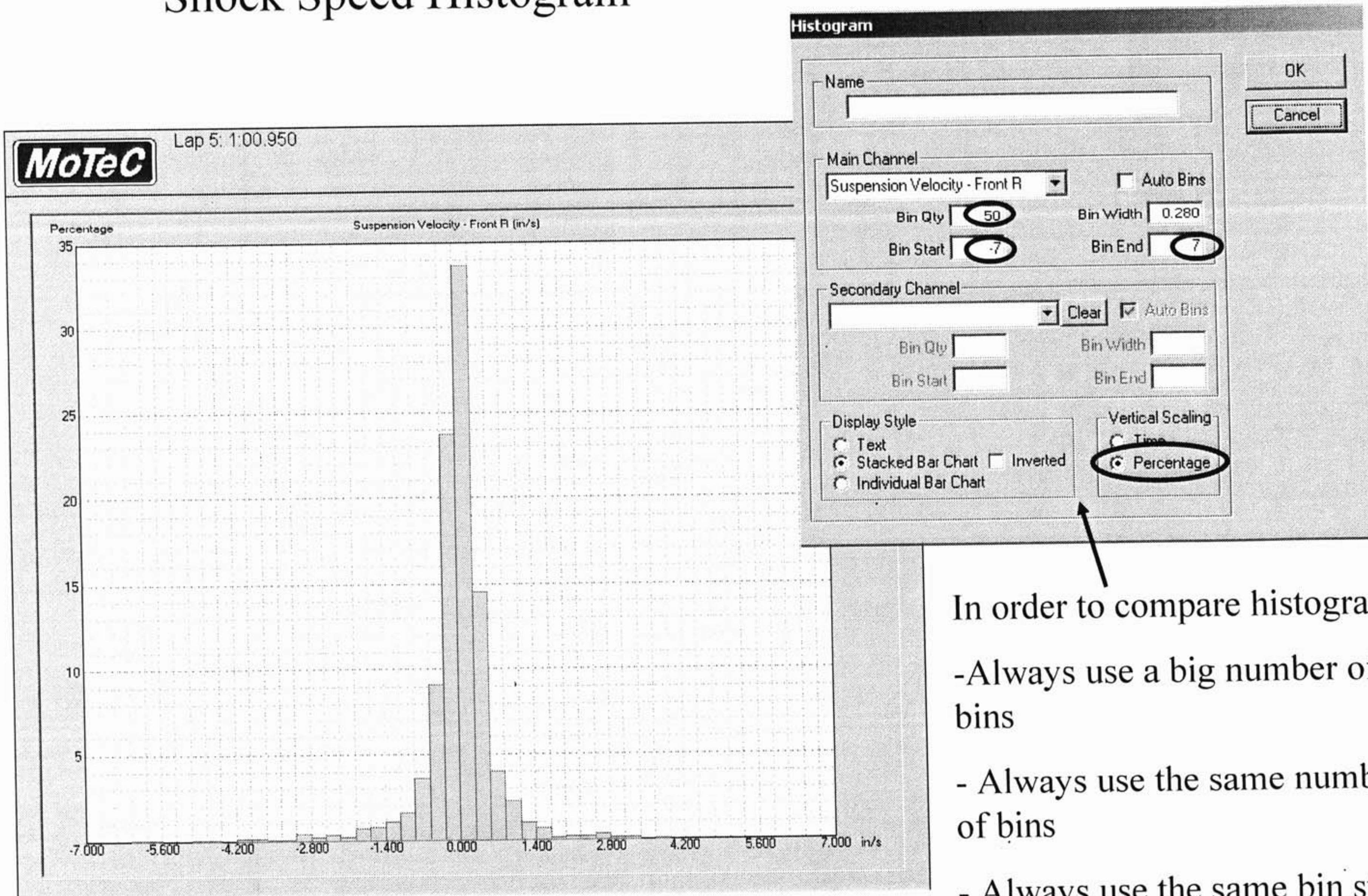


If Rear Lateral Acceleration > Front Lateral Acceleration : Understeer

If Front Lateral Acceleration > Rear Lateral Acceleration : Oversteer

Very useful to analyze the car handling in transients : corner entry and exit

Shock Speed Histogram



In order to compare histograms.

-Always use a big number of bins

- Always use the same number of bins

- Always use the same bin start and bin end

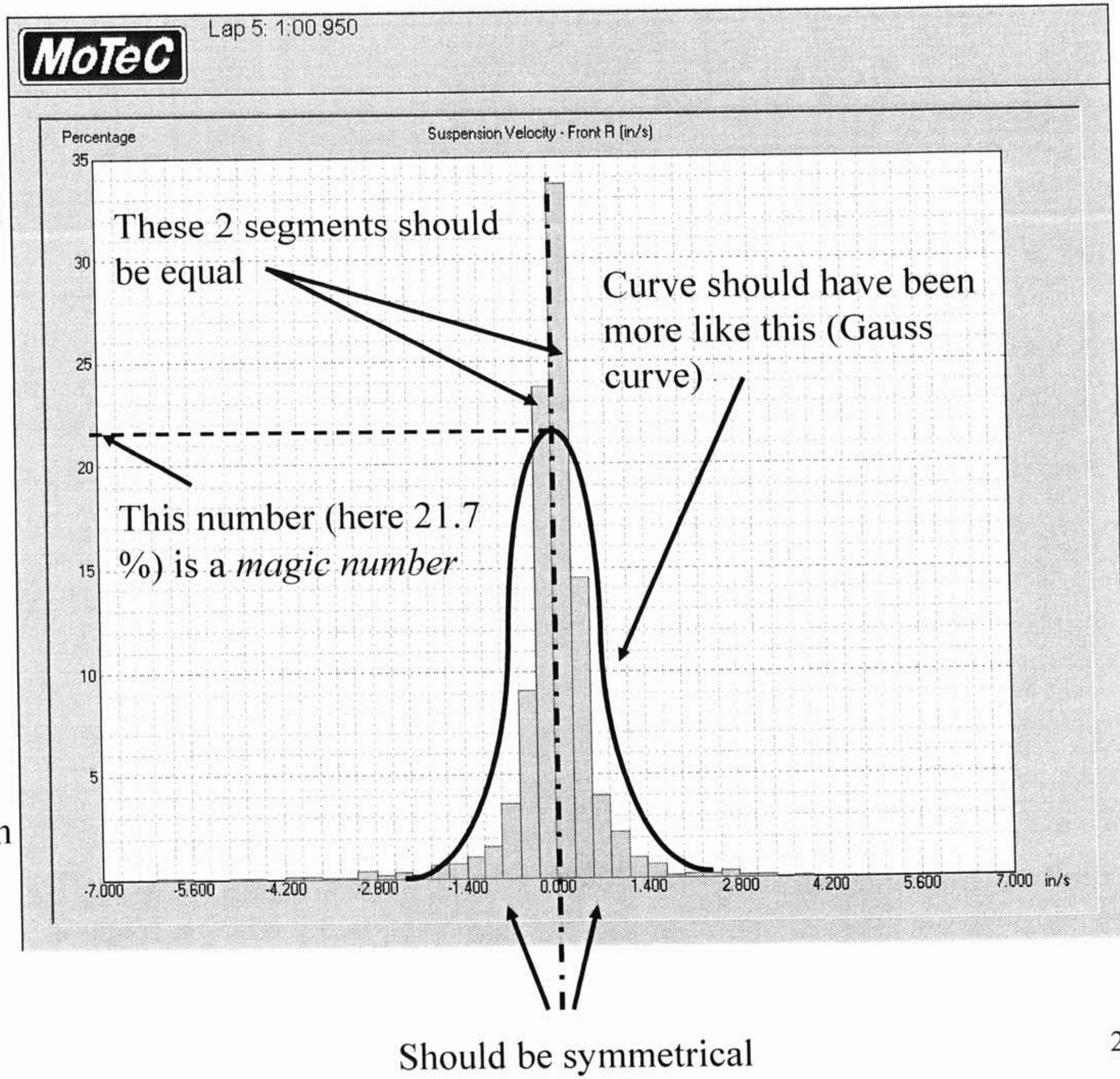
Ideal Histogram

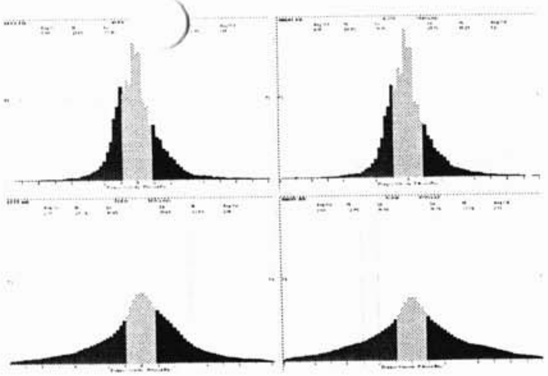
In this example we have too much low speed and not enough high speed.

Both low speed bump and rebound flow need to be increased.

The bump speed is negative here. (In this case, that is the way shock has been calibrated).

It shows the need to release more flow in rebound (>0 speed) than in bump (<0 speed).





How to get four dampers histograms (1)

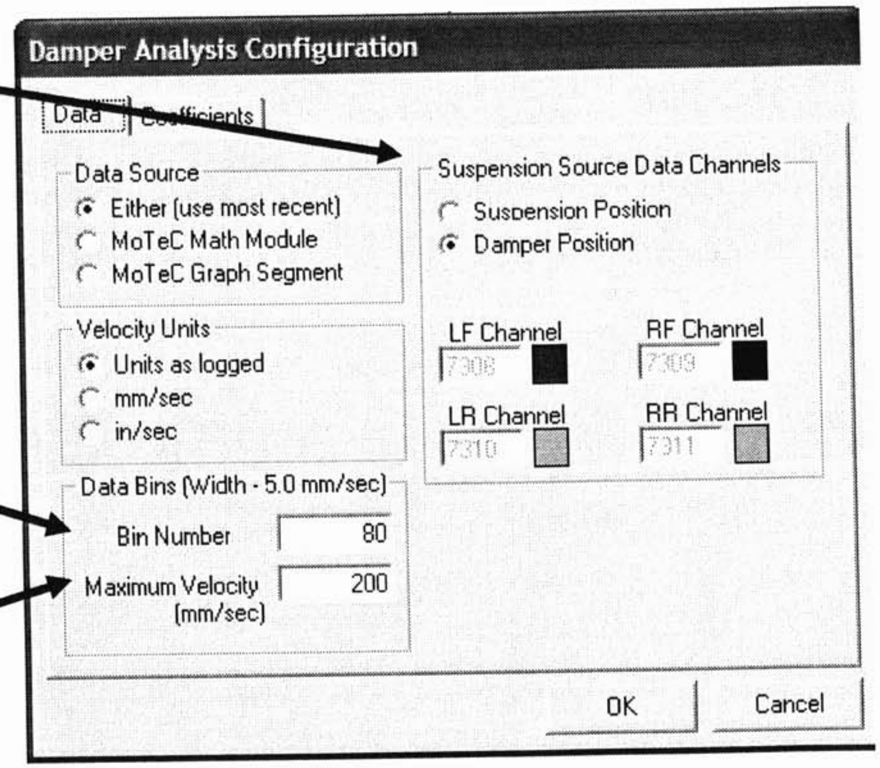
Shortcut to MoTeC damper.lnk

1. Double click on "Motec damper" → Configure

2. Choose the name you gave to your dampers channel

3. Choose your number of bins (mini 50)

4. Choose your maximum damper velocity



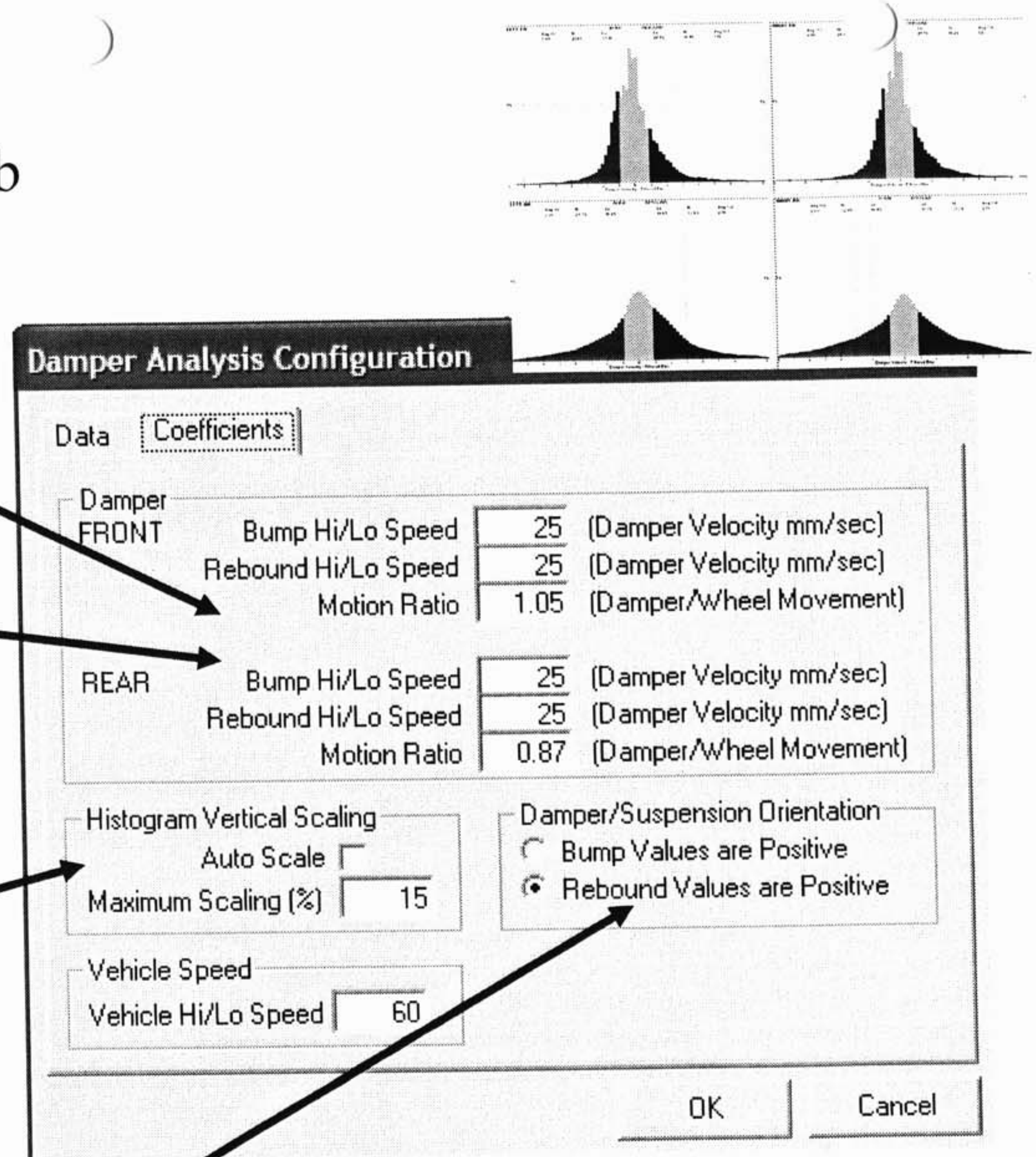
4. Click on “Coefficients” tab

5. Choose front and rear MR

6. Choose what you consider as Low/High speed

7. Choose manual scale in order to always compare histograms with the same scale

8. Check if bump is positive or negative



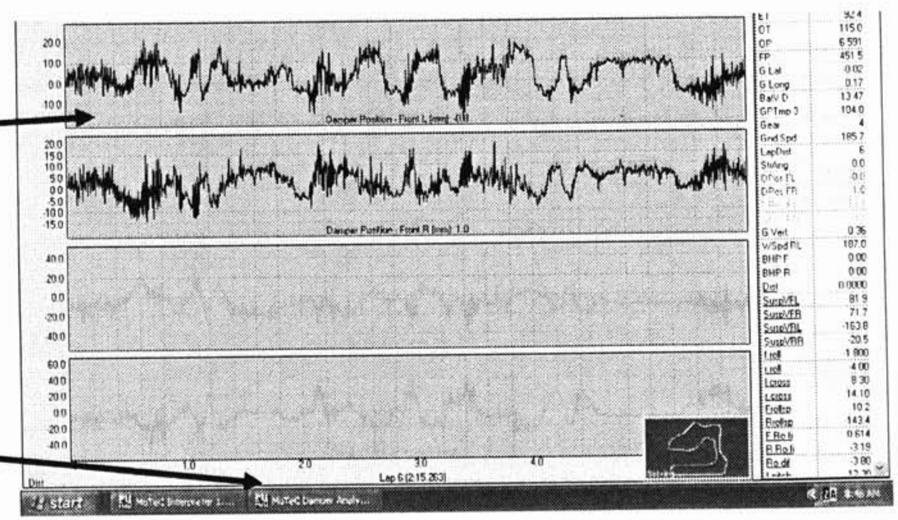
9. Open an Interpreter template with damper or suspension position. Be careful, damper position acquisition frequency should be at least 100 Hz

10. Press both "Shift" and "Alt"

11. Select the entire lap:

Highlight in blue

MoTeC Damper must be opened in the tool bar

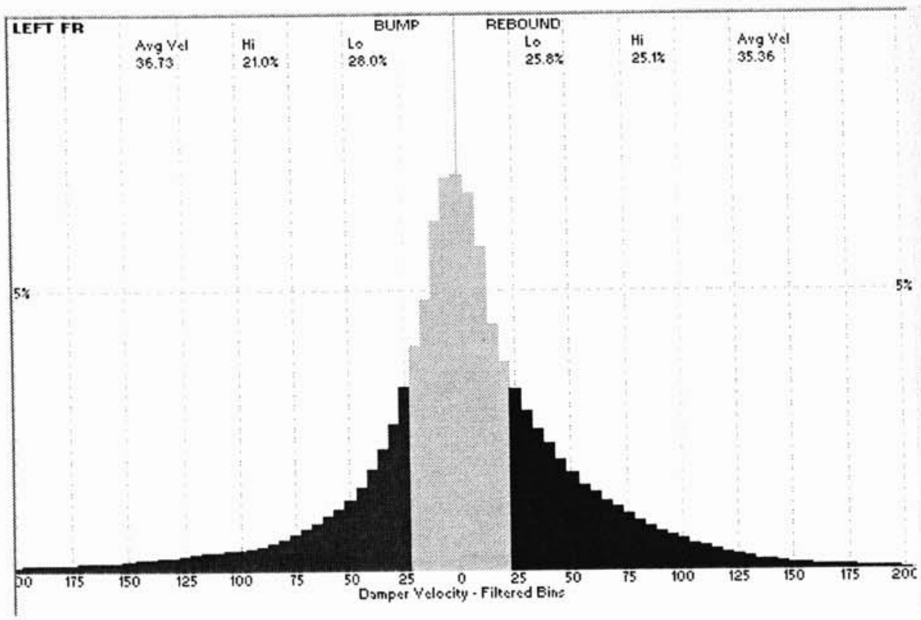


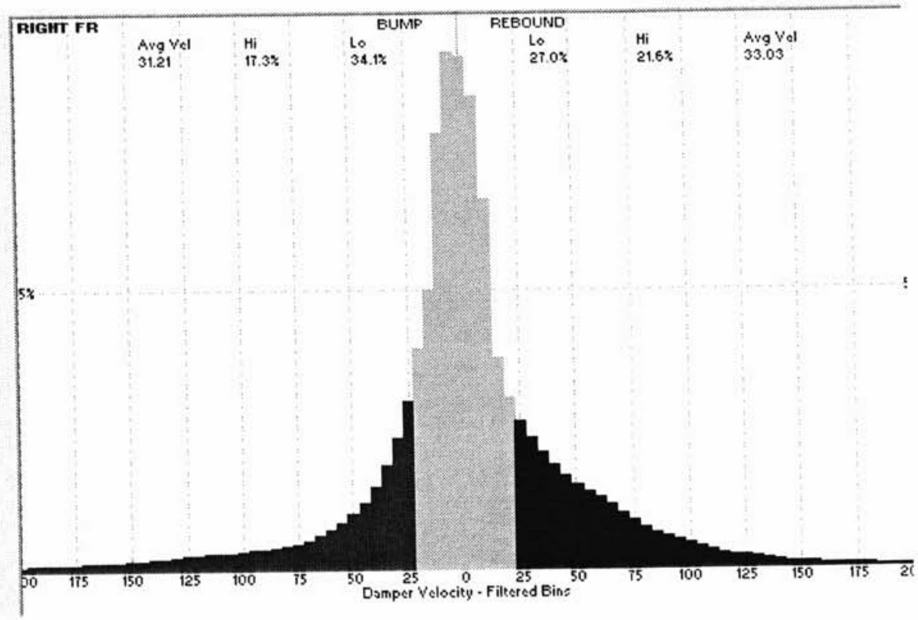
12. Double click when selection is finished

13. Reopen "Motec Damper"

14. Choose display preferences

Setting dampers with histograms (1)





Left front	Low speed	High speed
Bump	28.0 %	21.0 %
Rebound	25.8 %	25.1 %

Right front	Low speed	High speed
Bump	34.1 %	17.3 %
Rebound	27.0 %	21.6 %

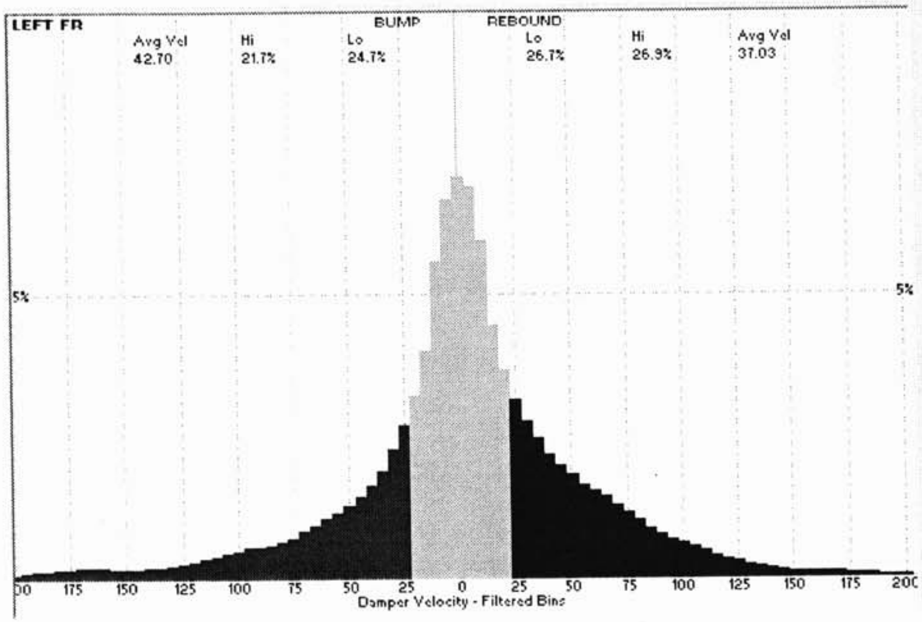
Left bump low speed is too stiff

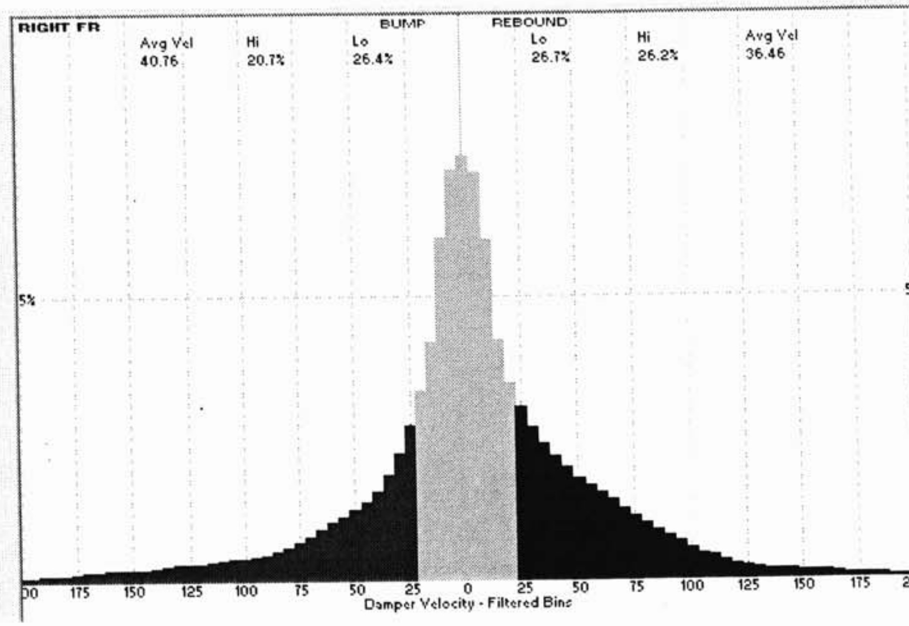
Right low speed bump is too stiff

Right damper is stiffer than left damper

Setting dampers with histograms (2)

<u>Set-up modification :</u> 2 clicks softer in right low speed bump
1 click softer in left low speed bump



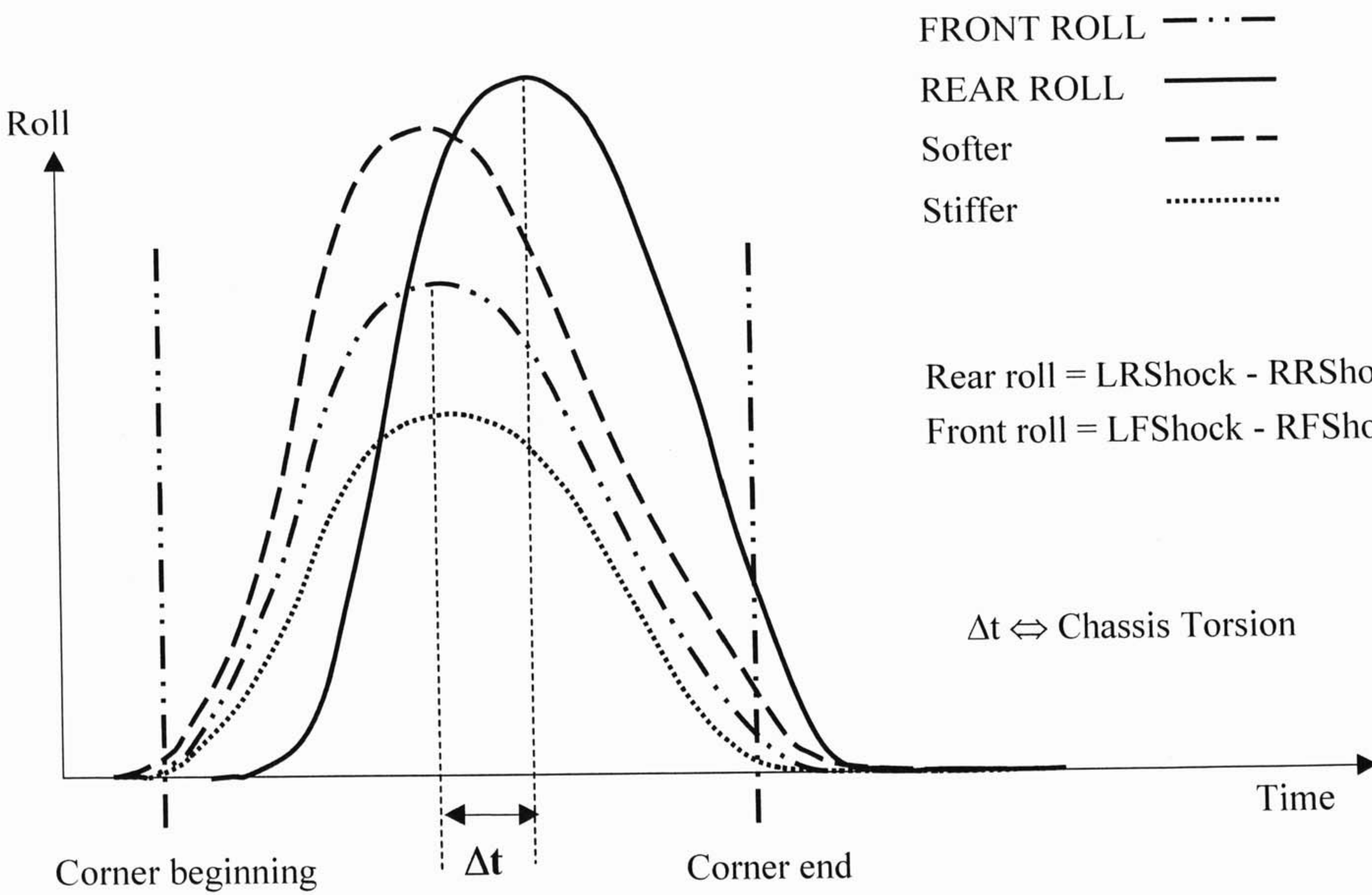


Left front	Low speed	High speed
Bump	24.7 %	21.7 %
Rebound	26.7 %	26.9 %

<u>3/10 sec. Gain with this setting!!</u>

Right front	Low speed	High speed
Bump	26.4 %	20.7 %
Rebound	26.7 %	26.2 %

Difference of Time Between Maximum Value of Front and Rear Roll



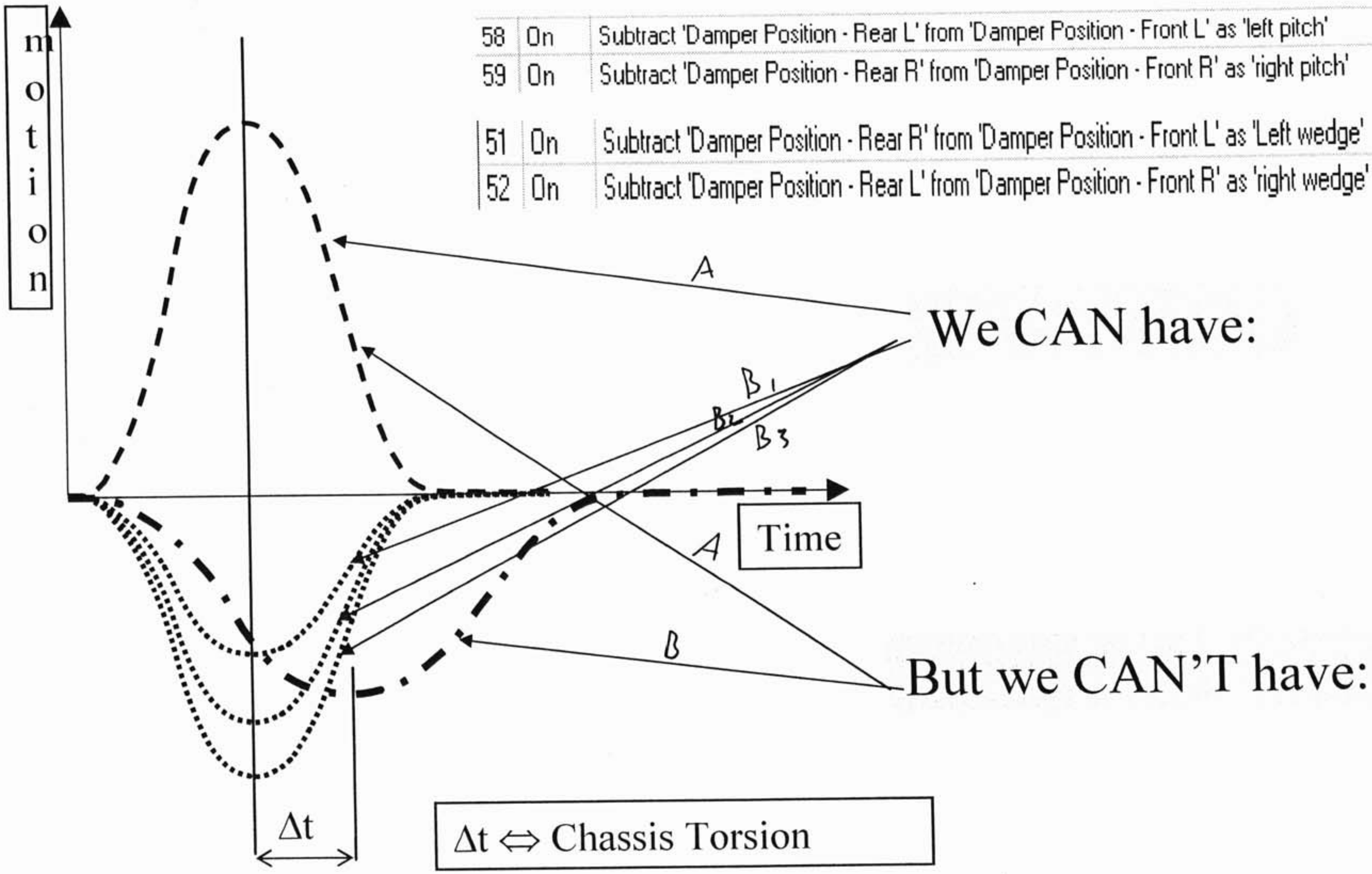
Rear roll = LRShock - RRShock

Front roll = LFShock - RFShock

Δt ⇔ Chassis Torsion

Difference of Time Between Maximum Value of Front and Rear Roll, Left and Right Pitch and Left and Right Wedge

56	On	Subtract 'Damper Position - Front R' from 'Damper Position - Front L' as 'Front roll'
57	On	Subtract 'Damper Position - Rear R' from 'Damper Position - Rear L' as 'Rear roll'
58	On	Subtract 'Damper Position - Rear L' from 'Damper Position - Front L' as 'left pitch'
59	On	Subtract 'Damper Position - Rear R' from 'Damper Position - Front R' as 'right pitch'
51	On	Subtract 'Damper Position - Rear R' from 'Damper Position - Front L' as 'Left wedge'
52	On	Subtract 'Damper Position - Rear L' from 'Damper Position - Front R' as 'right wedge'



Front and rear roll

2 ways to find it:

56	On	Subtract 'Damper Position - Front R' from 'Damper Position - Front L' as 'Front roll'
57	On	Subtract 'Damper Position - Rear R' from 'Damper Position - Rear L' as 'Rear roll'

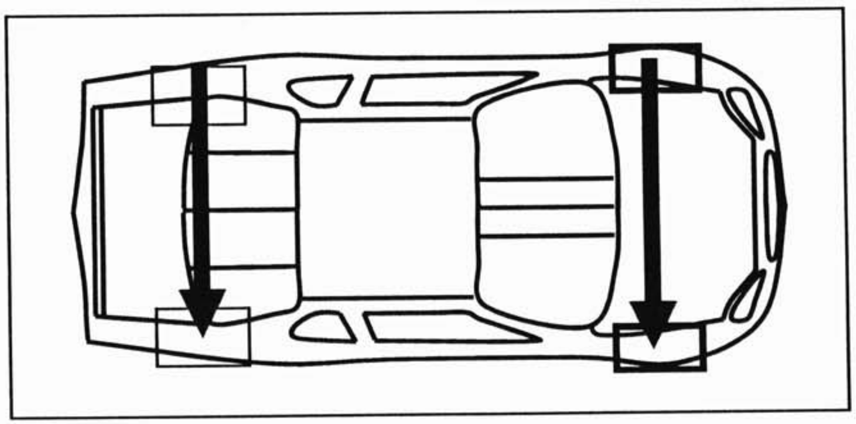
This is more a difference of position between right and left side

Or:

29	On	Expression (ATN('Damper Position - Front L'-'Damper Position - Front R')/FRONTTRACK*Constant - Radians to degrees) as 'real front roll'

Where 57.3 is the conversion in radians to degree. This is the real front roll of the car.

Rear roll



Front roll

When analyzing the front and rear roll traces, prioritize the shape and the relative symmetry of the curves more than the amplitude.

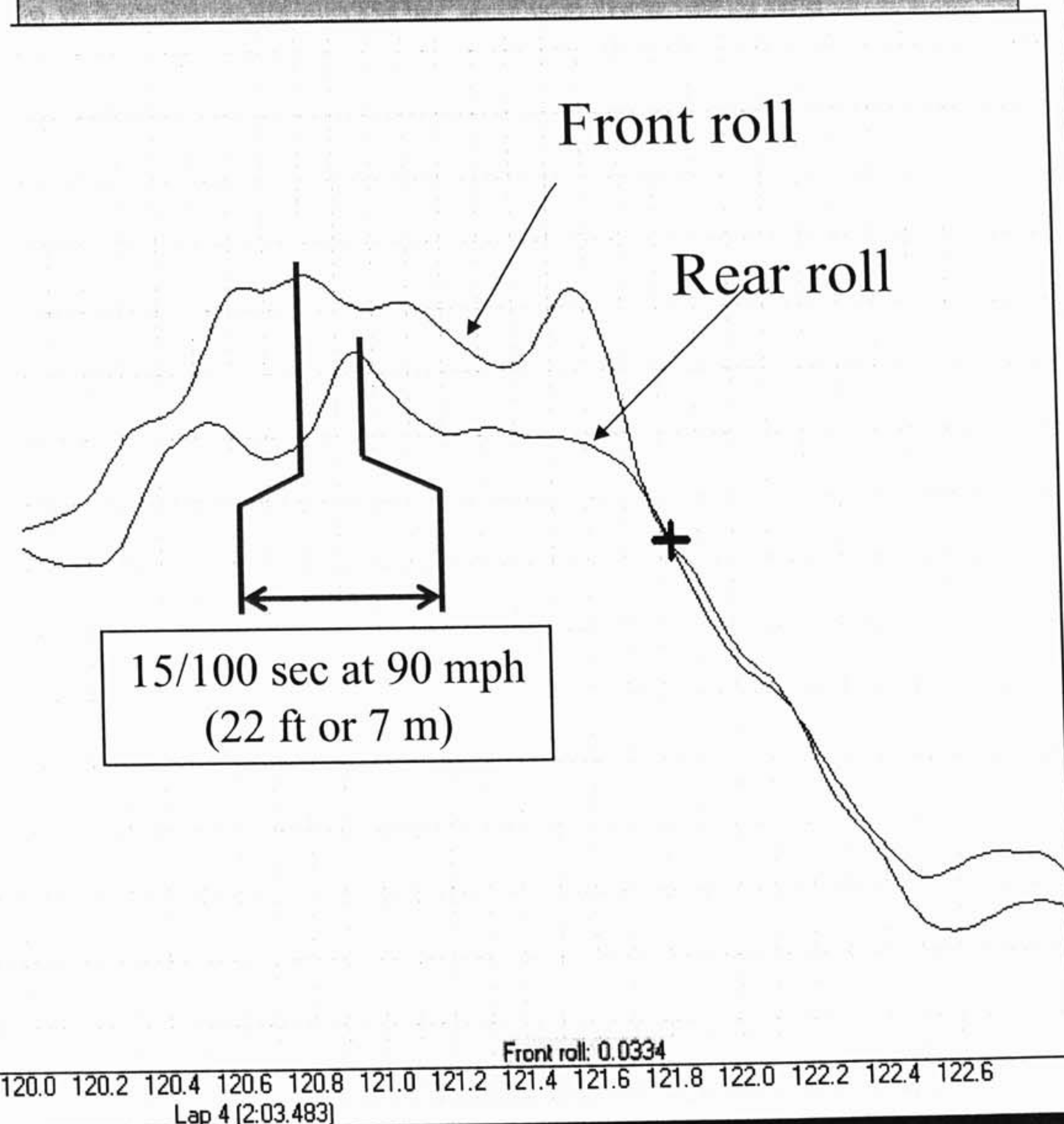
Example of front and rear roll difference

2 solutions for this case of corner exit:

- Front roll arrives too soon: stiffen front bump and/or rebound

-Rear roll arrives too late: soften rear bump and/or rebound

Be careful! Before making the final decision, look at the damper histogram on this area in order to decide if you want to work on high or low speed settings…



Working with damper histogram to control motion on this area

Steps of reasoning:

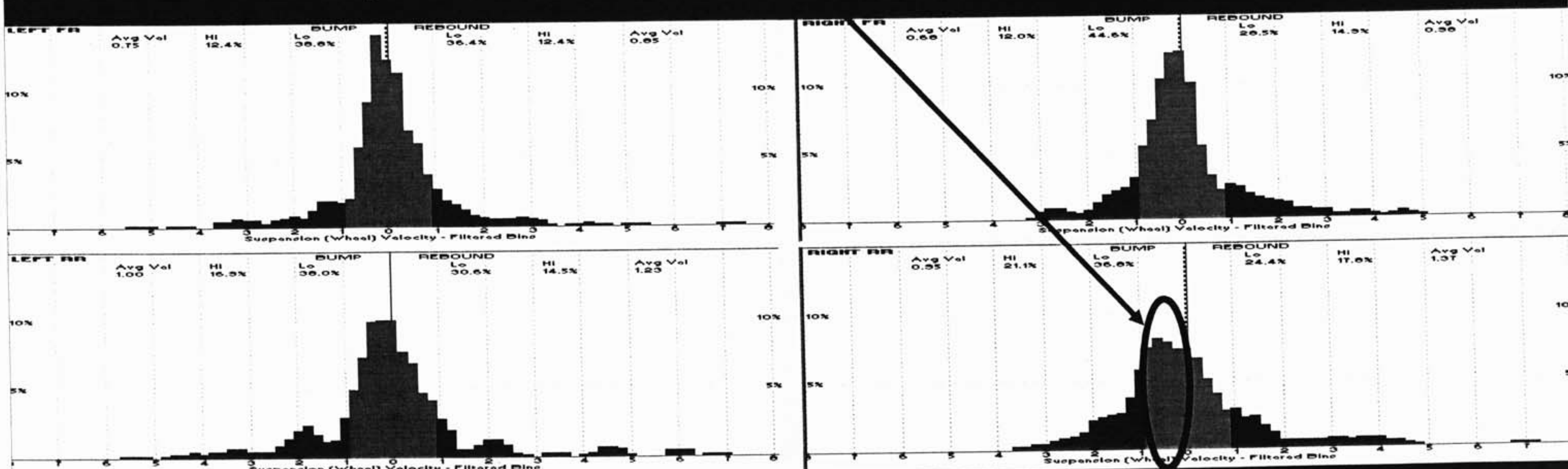
1) Which extremity do we have to stiffen or soften, front or rear?

2) On which side do we have to work first, right or left?

3) Which Gauss curve do I expect?

It is almost always better to first have a look on the symmetry of the histogram than on the Gauss curve expected.

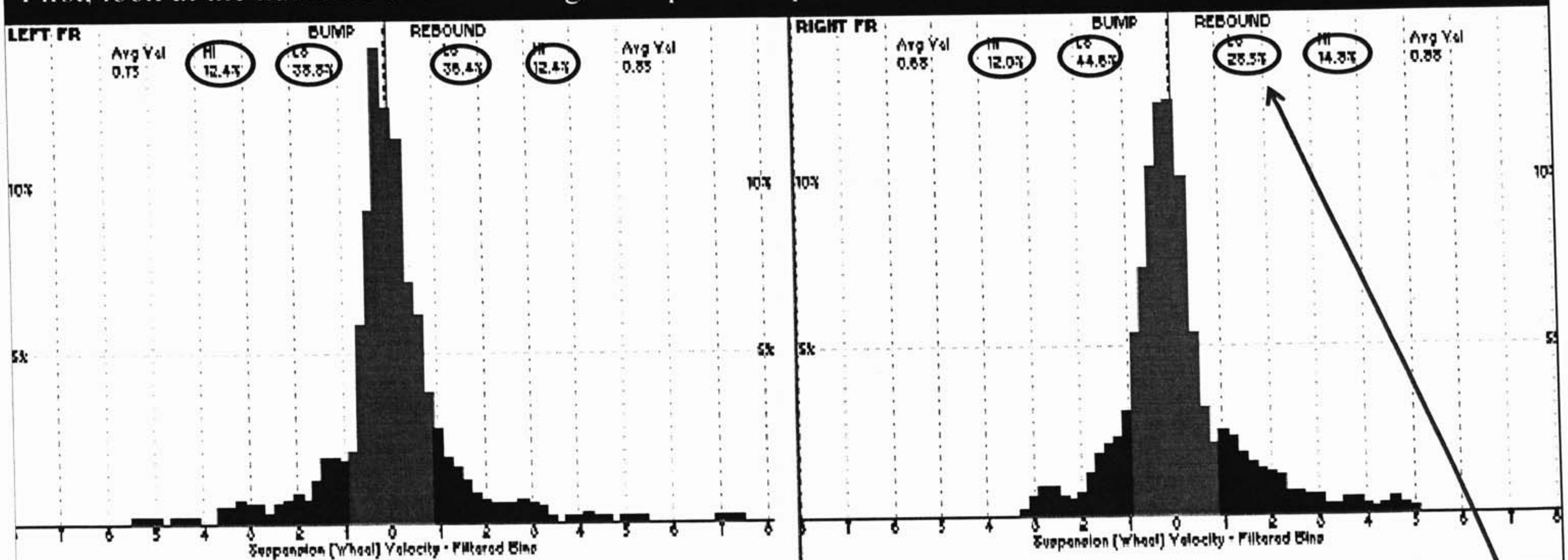
In this particular case, the first thing to do will be to soften the right rear low bump rebound which is the most dissymmetrical histogram.



Damper histogram on this area

We need to stiffer front bump and/or rebound to delay front roll

First, look at the numbers of low and high bump in bump and rebound of the front end.



After subtractions of each low speed and high speed values between bump and rebound, we find:

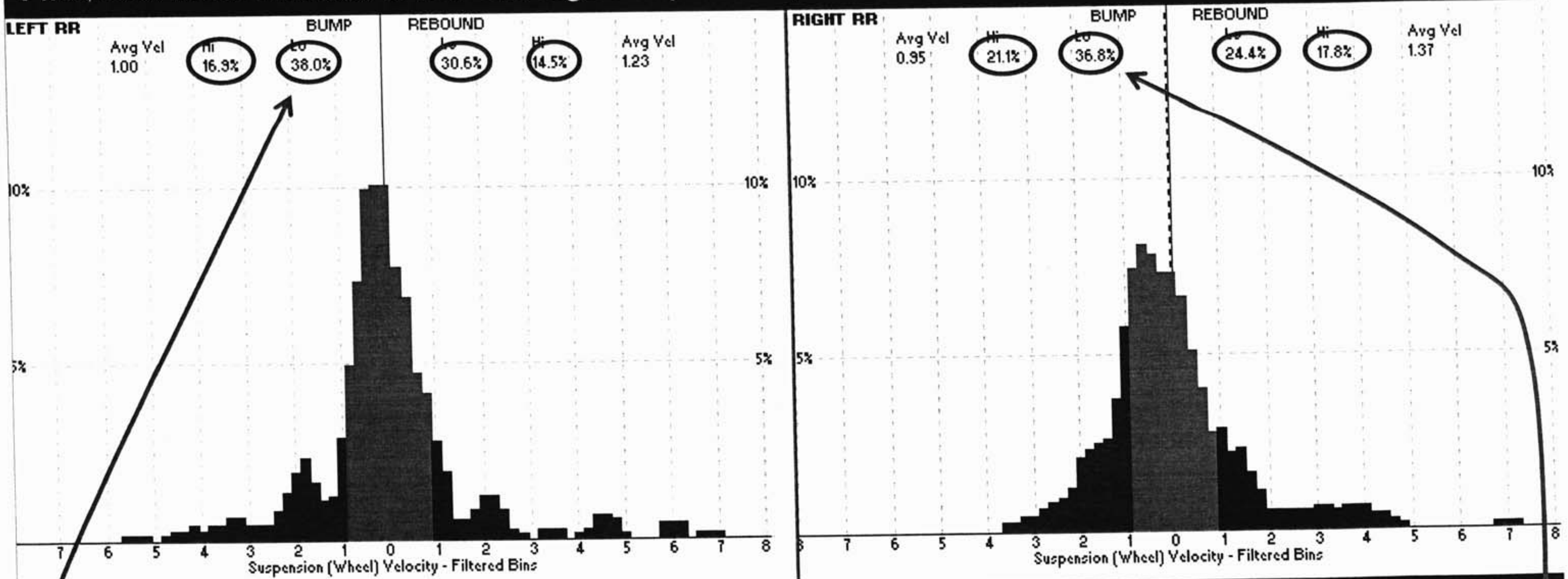
(Bump-Rebound) Low speed	38.8 -36.4 = 2.4	44.6 -28.5 = 16.1
(Bump-Rebound) High speed	12.4 -12.4 = 0	12 -14.9 = -2.9

Here, we have the biggest difference so let's work on this side

In this case, it will be better to stiffen right front low speed rebound

We need to softer rear bump and/or rebound to advance rear roll

First, look at the numbers of low and high bump in bump and rebound of the rear end.



After subtractions of each low speed and high speed values between bump and rebound, we find:

(Bump-Rebound) Low speed 38 – 30.6 = 7.4 36.8 – 24.4 = 12.4

(Bump-Rebound) High speed 16.9 – 14.5 = 2.4 21.1 – 17.8 = 3.3

Here, we have the biggest difference so let's work on both side

In this case, it will be better to soften right and left front low speed bump: 3 clicks on the right and 1 click on the left for example.

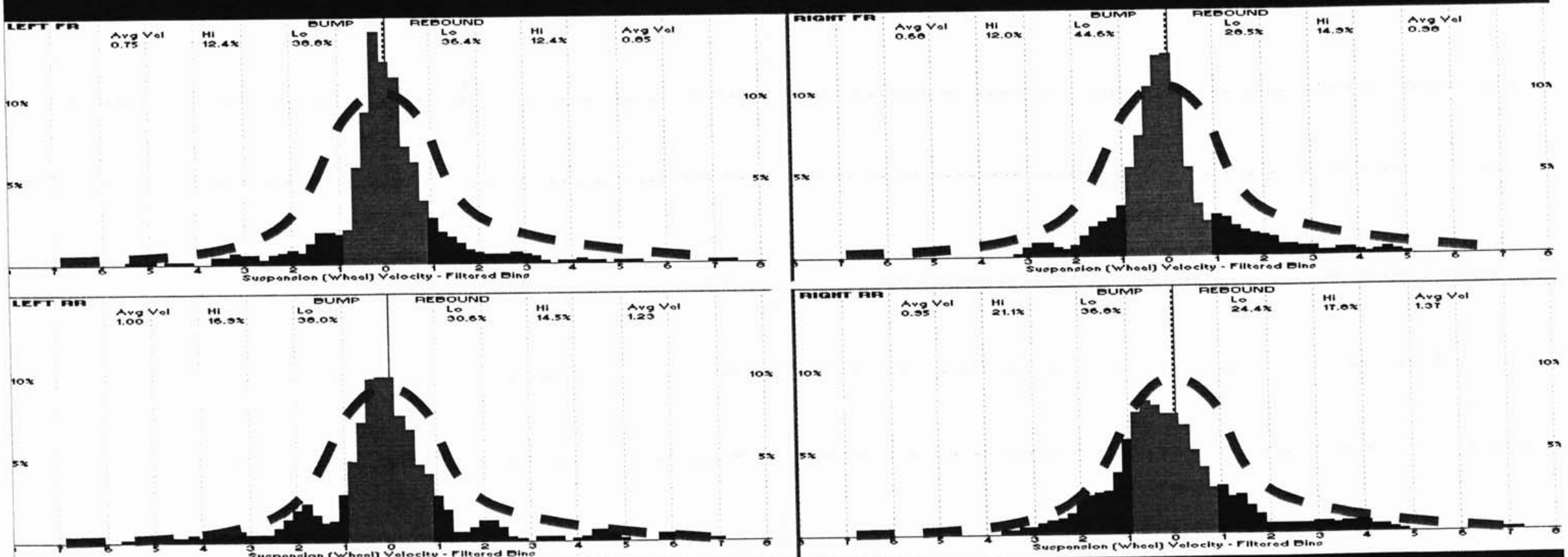
Damper histogram on this area: regarding the ideal Gauss curve

We need to stiffer front bump and/or rebound to delay front roll

Front low bump and rebound already are very stiff

So it is better to stiffer high speed bump and rebound

By experience, we know that the ideal Gauss curve for this track is:



We need to softer rear bump and/or rebound to advance rear roll

Rear high speed bump and rebound already are soft

So it is better to soften low speed bump and rebound

G-G Diagram

The G-G diagram is a conceptual way of showing driver and vehicle performance. In theory, the driver should try to operate as close to the boundary of the circle as possible. In reality, physical limitations prevent a vehicle reaching the theoretical boundary like changes in suspension geometry, brake balance, tire grip, etc.

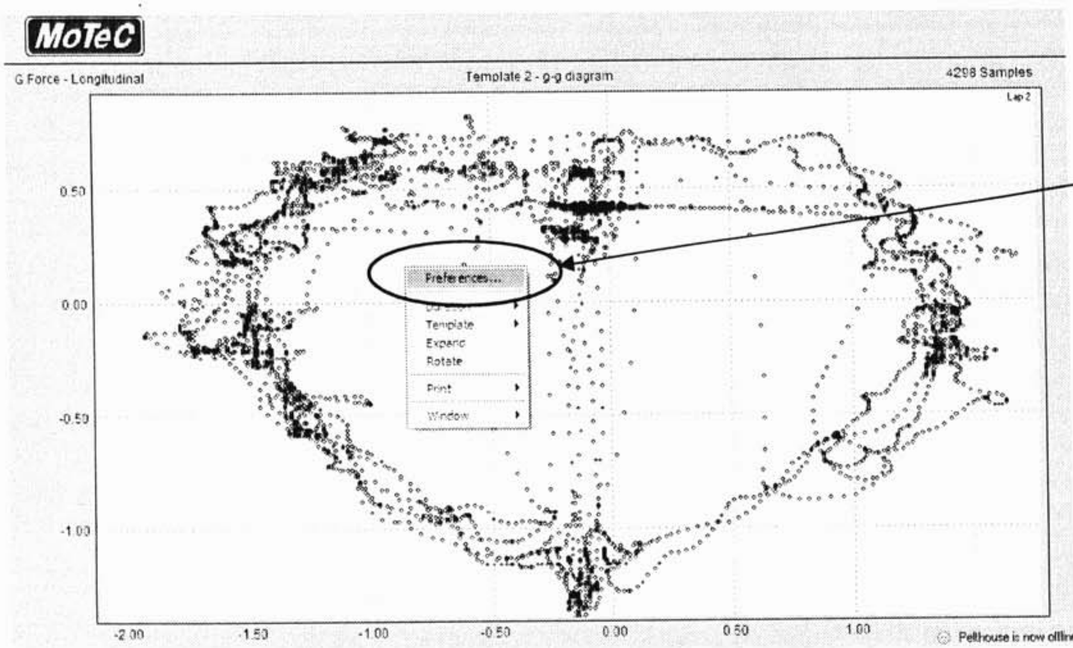
The best way to obtain high quality data is to use a 3-axis accelerometer mounted at or below the center of gravity.

<u>Some advise for G-G diagram:</u>

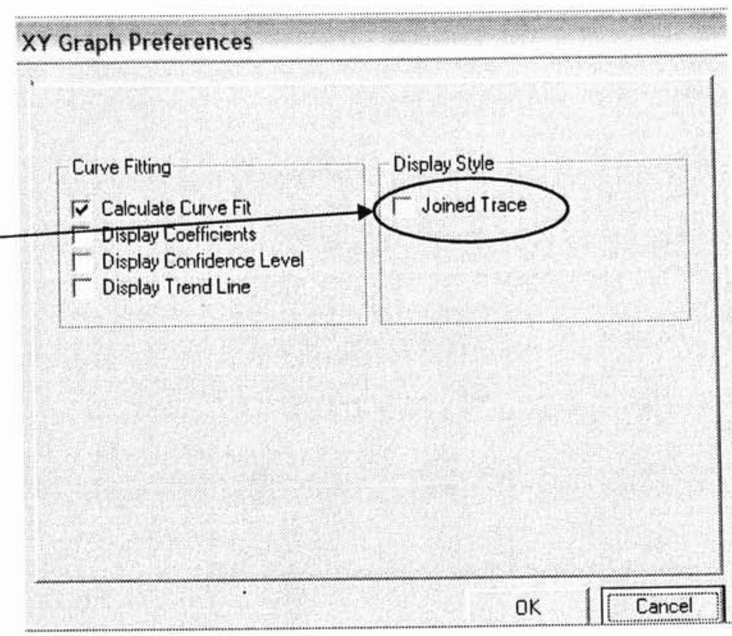
- It look best when data are displayed as dots rather than lines

- Scales should be chosen so that the points are reasonably spread

Display of dots or lines curves for X-Y graph in Interpreter



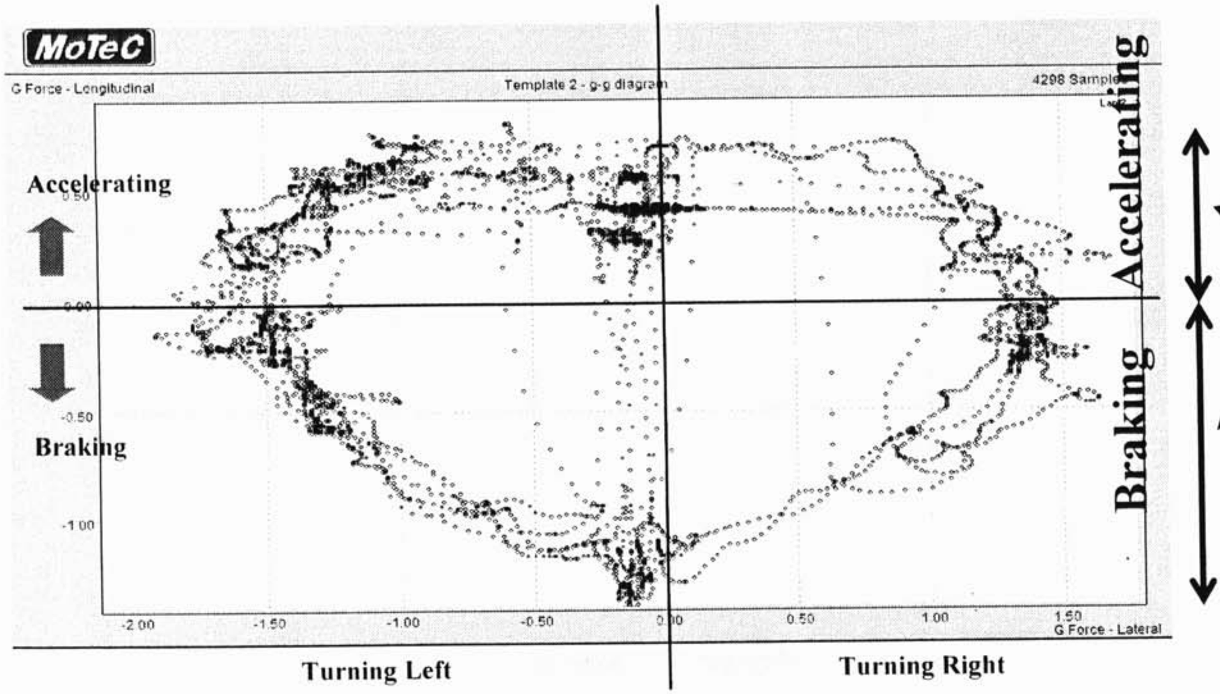
Right click on the graph, than select "Preference"



Check or uncheck "joined trace" square for lines or dots trace.

G-G Diagram: Example of use

The different plots provide good comparisons of different tires, brakes, setups and driving style



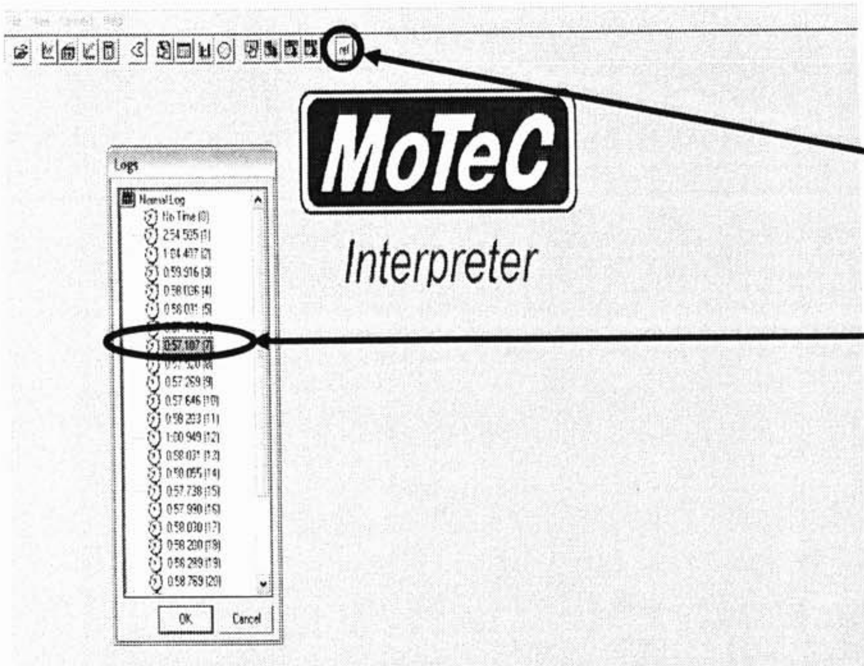
Braking area are always much greater than acceleration under power

Along the orthogonal axes the plots give details of maximum acceleration achieved. This gives a direct comparison of braking and cornering ability in the steady state.

The area between the axes is the most interesting. This represents the transition area as longitudinal acceleration of the car changes to lateral acceleration associated with cornering. This is when the driver is trail braking or getting the power down early on the exit.

The more the driver can push out the envelope of the plot to the ideal circle, the better use he is making of the available grip of the tires.

Install reference lap in Dash Manager

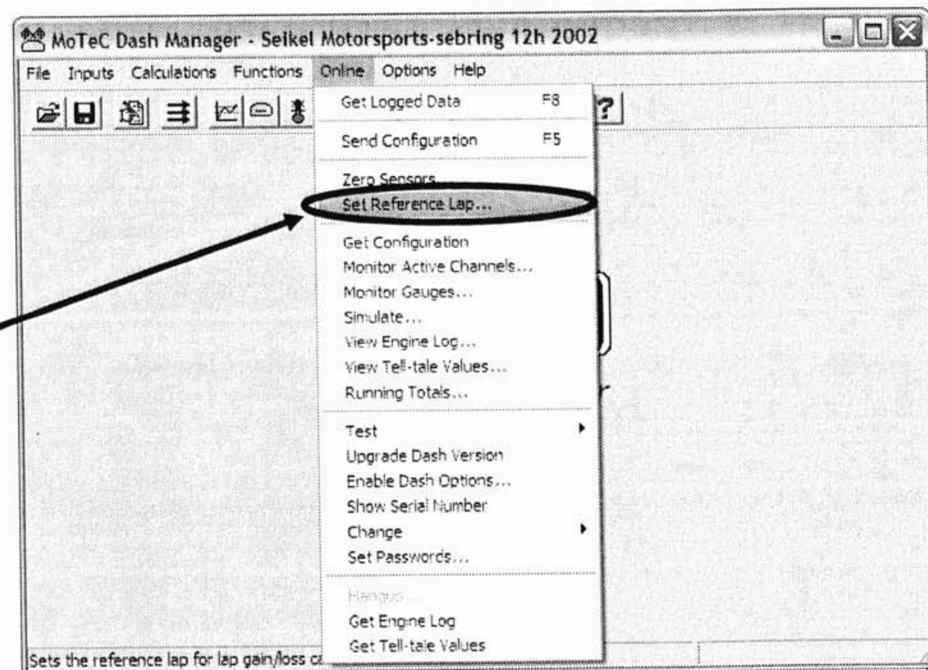


Select first the reference lap in Interpreter

Click on "Ref"

Select your reference lap

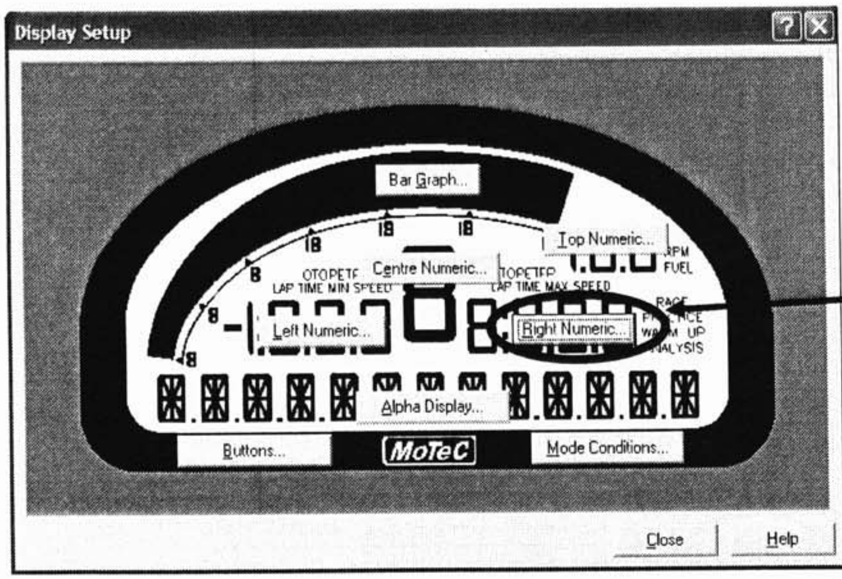
Save your reference lap



In Dash Manager, select "Online" than "set reference lap" and open the saved file before.

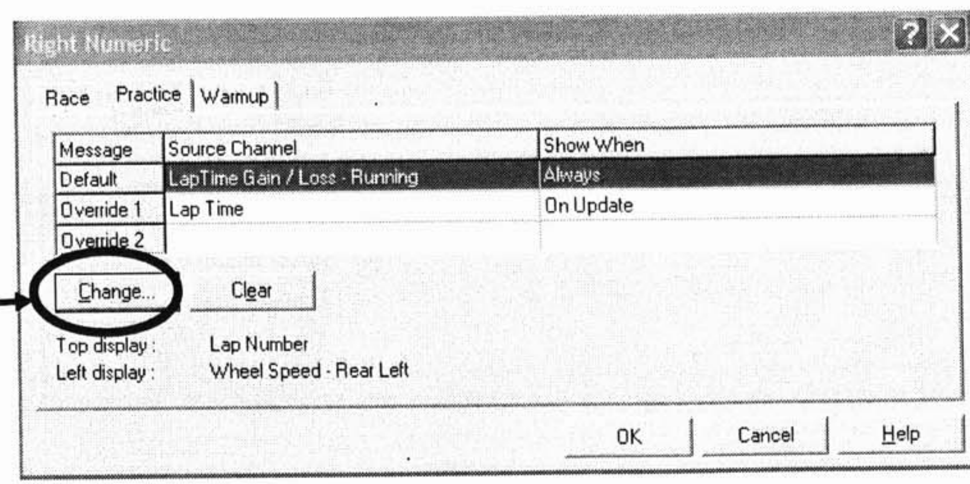
Install Lap Time Gain/Loss Running in Dash Manager

The Lap Gain/Loss system calculates a Running Time Gain or Loss compared to a reference lap, i.e. how far ahead or behind the vehicle is compared to the reference lap, this is continuously updated as the vehicle proceeds around the track. The Running Gain/Loss is zeroed each time the vehicle passes the beacon.

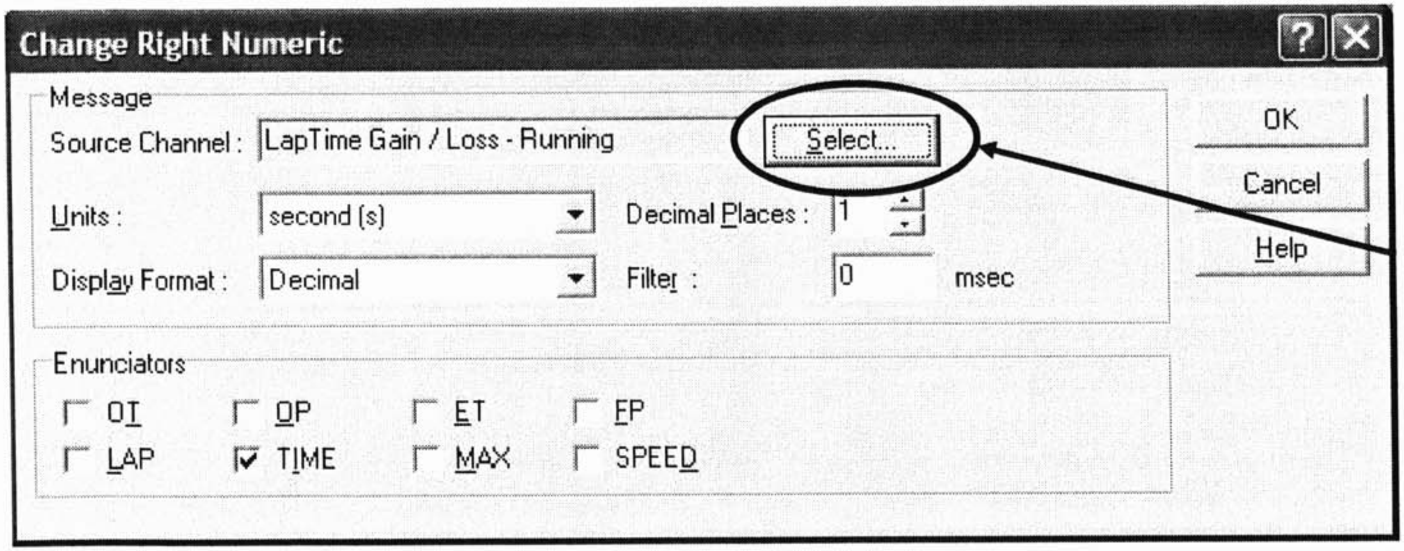


Now your reference lap is installed, so you can install Lap Time gain/loss running

Click on "Right Numeric"

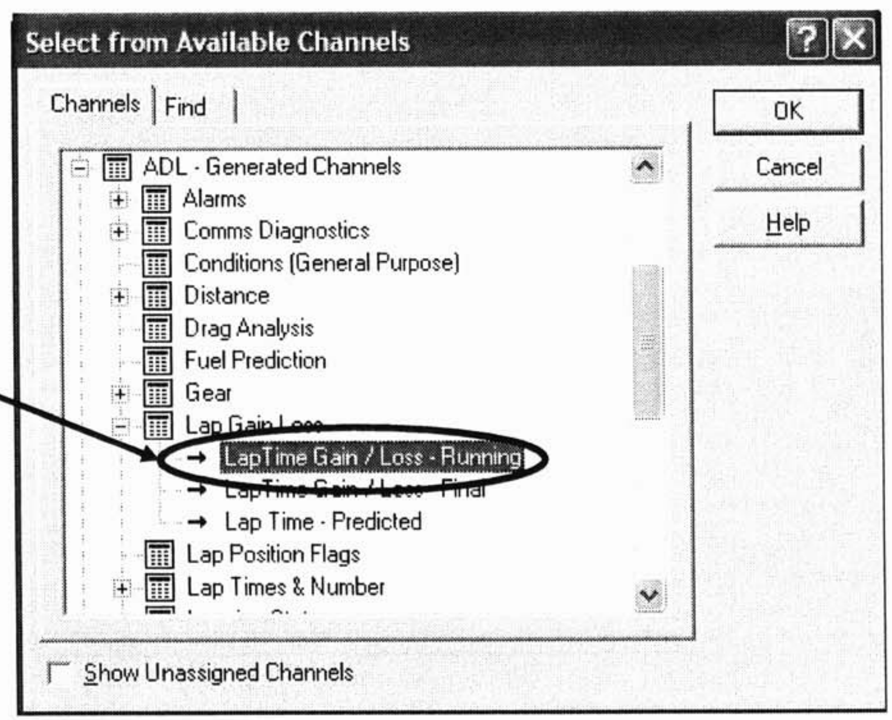


Click on "change"



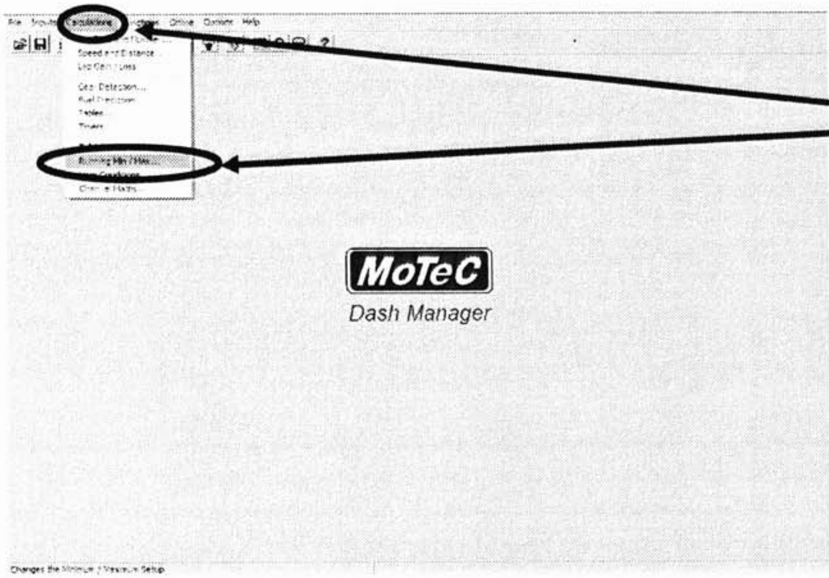
Click on "select"

Select Lap time gain/loss - running

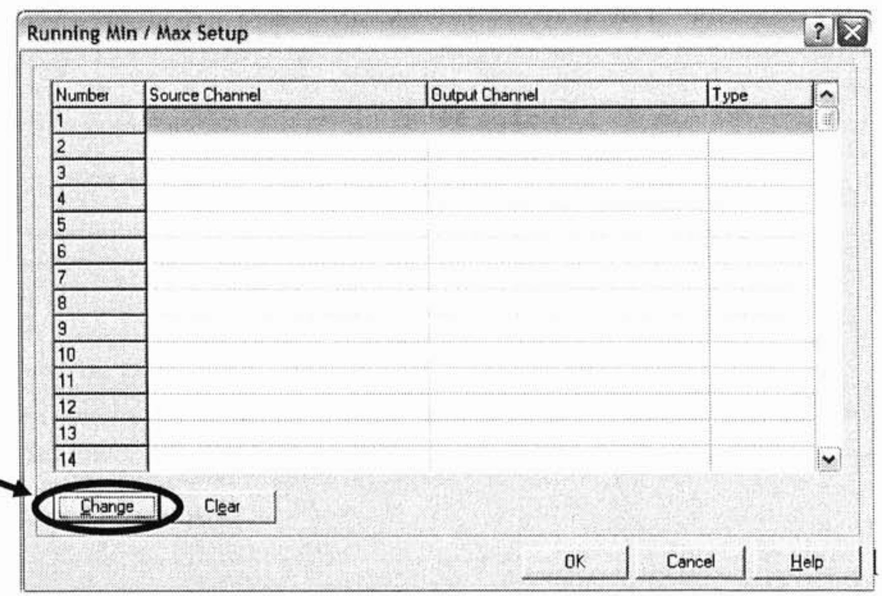


Install Minimum Corner Speed and Maximum Straight Speed in Dash Manager.

A Running Min / Max continuously detects the Peak (Maximum) or Trough (Minimum) of a channel, depending whether Minimum or Maximum is selected. The result is fed to the output channel which is updated each time a new peak (or trough) is detected.



Click on "Calculation", then "Running Min/Max"



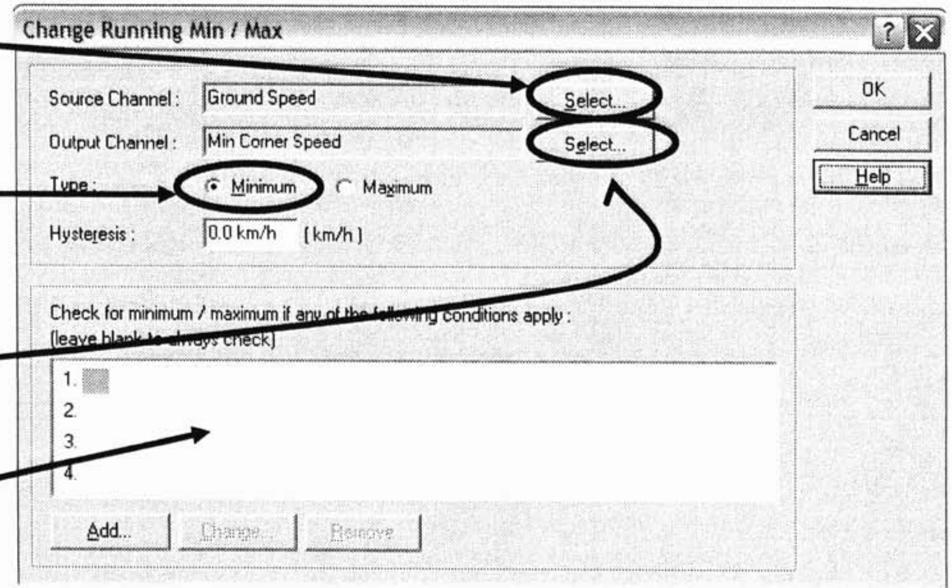
Click on "Change"

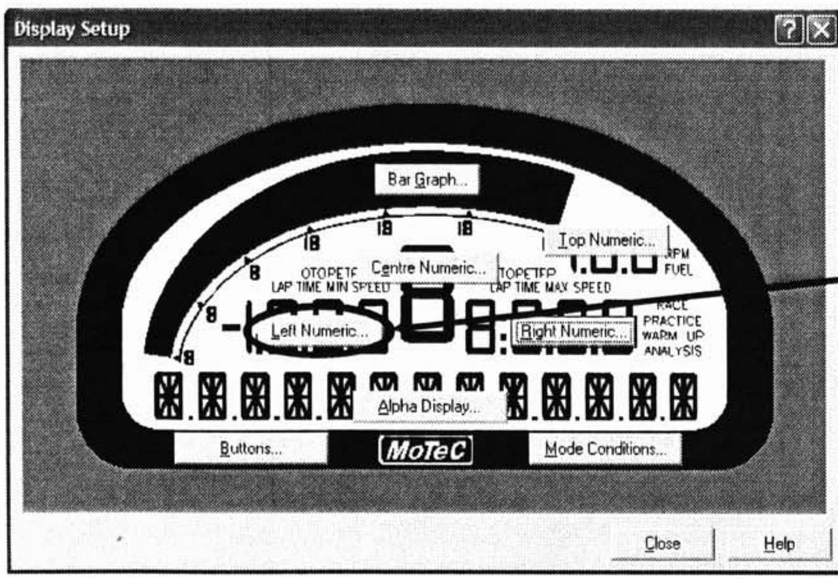
Select your Source Channel: wheel speed

Select your type of channel: minimum corner speed or maximum straight speed

Then, your "Output channel"

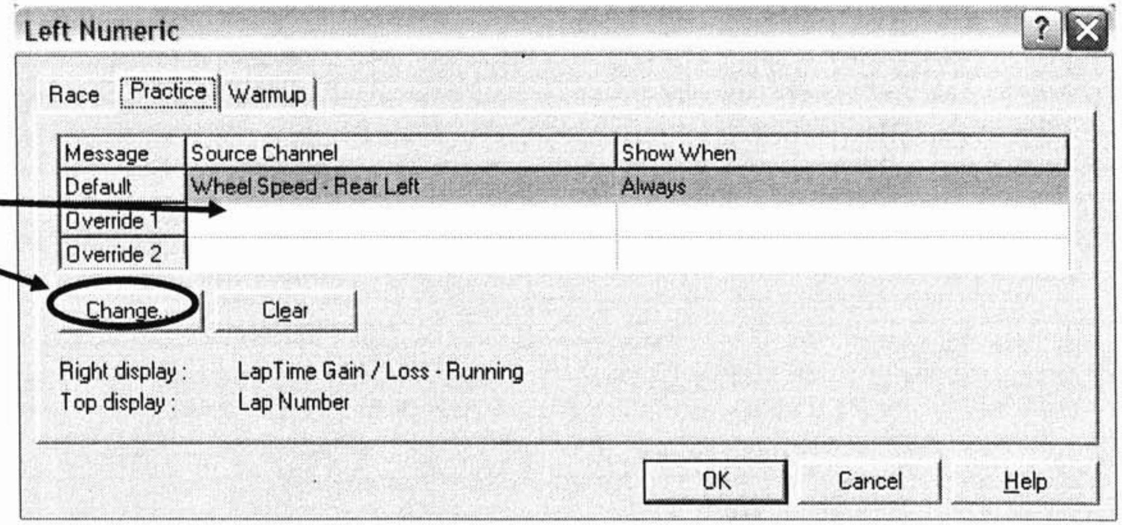
You can add a condition to apply the Running Min/Max

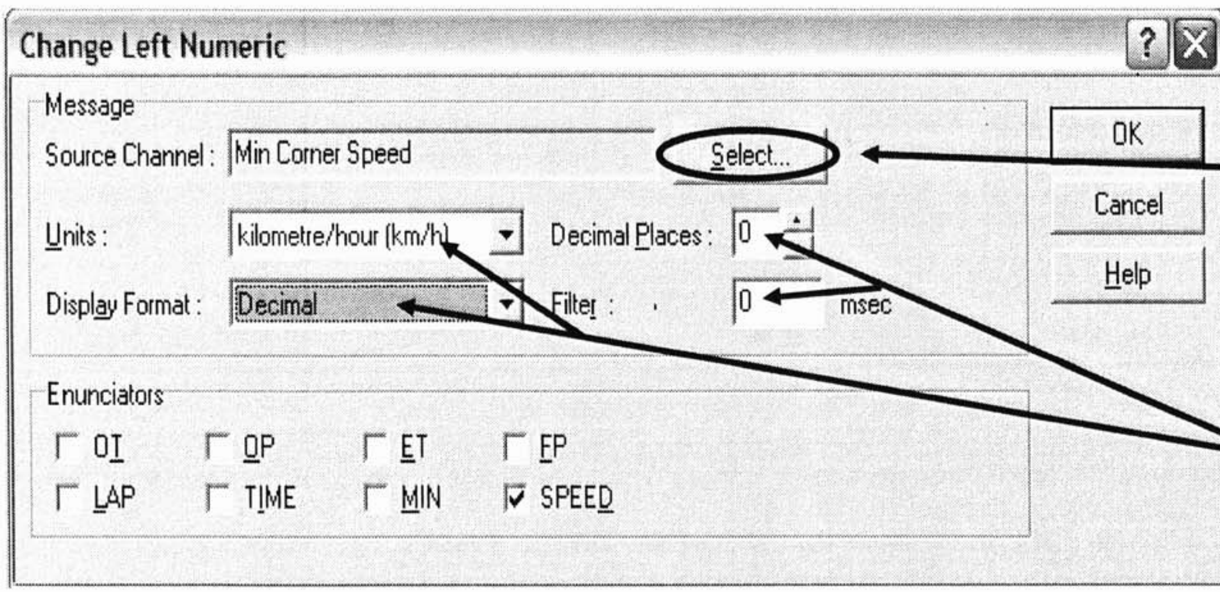




Then click for example on "Left Numeric": generally where you put the display of the speed

Select “Override”, then click on “Change”

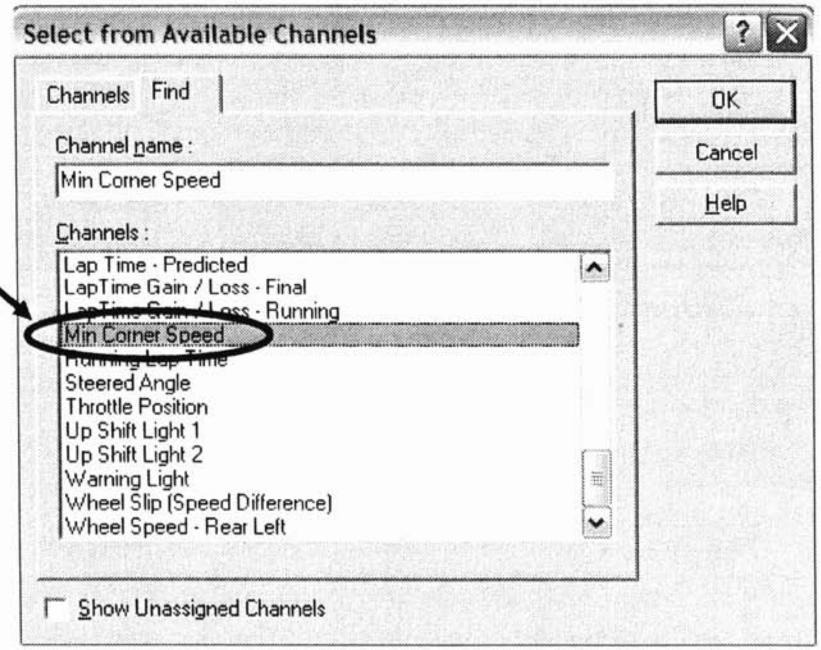




Select your source channel

You can specify units, display format, decimal places and filters

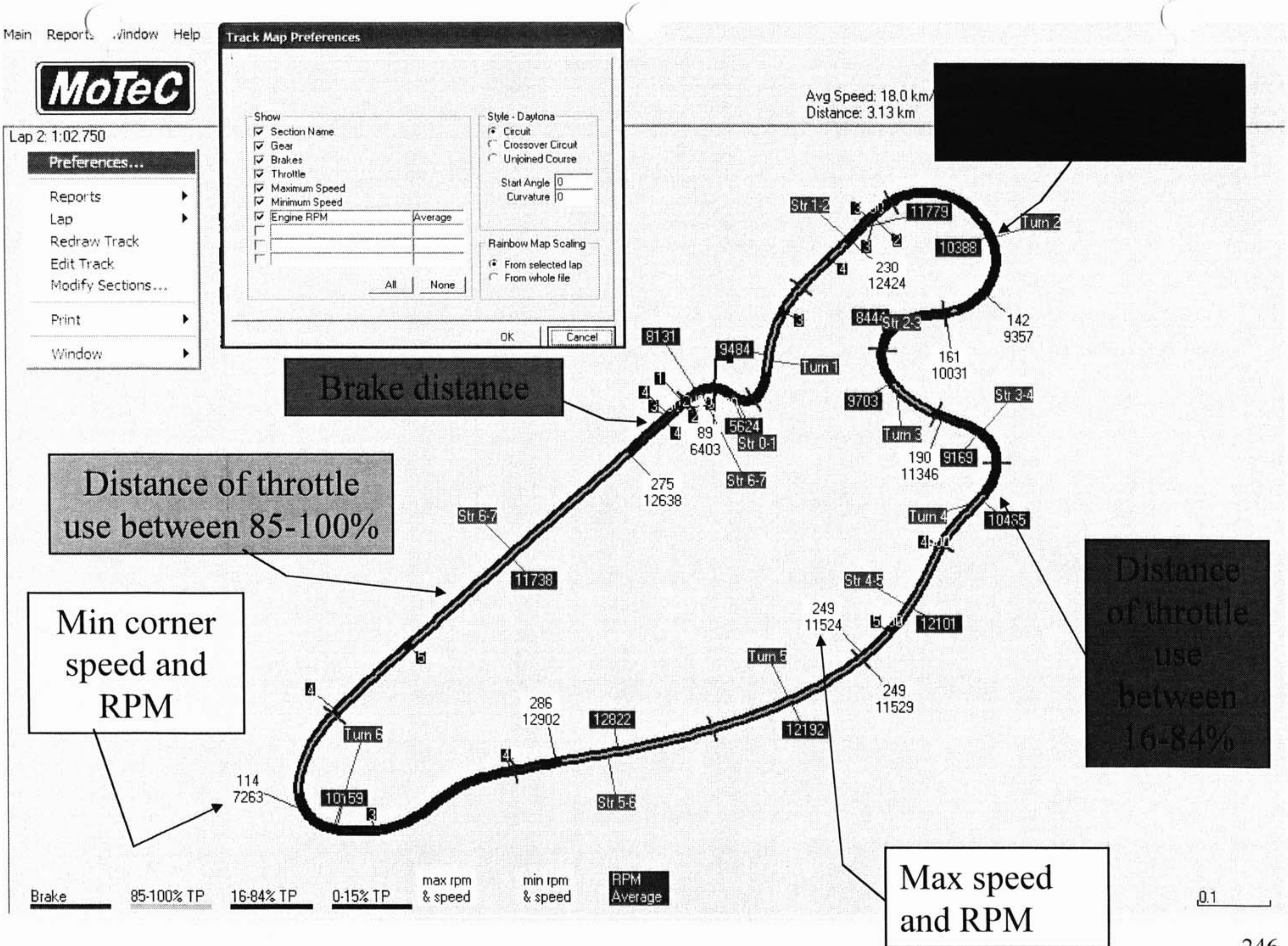
Select Min Corner speed: here for our example



Now the minimum Corner Speed is overriding with Wheel Speed. To display the value, the driver will have to push on his command button on the Dash. For qualify, you can decide to display this value continually. For that, you just have to select your Minimum Corner speed as the default value in the "Left Numeric" display

Use track map

- To compare minimum speed in the corner and maximum speed of two drivers, two laps.
- To compare RPM in the corner or in the straight to see under or over revs between two laps or two drivers
- To compare brake distance and % of throttle of two drivers, two laps
- To compare speed at maximum throttle at the end of each curve between two drivers or laps (to do yourself).
- To compare the channel you want (suspension position, fuel pressure, yaw rate,…) for different laps or drivers


Main Reports Window Help
MoTeC
Lap 2: 1:02.750
Preferences...
Reports
Lap
Redraw Track
Edit Track
Modify Sections...
Print
Window
Track Map Preferences
Show
Section Name
Gear
Brakes
Throttle
Maximum Speed
Minimum Speed
Engine RPM
Average
All
None
Style - Daytona
Circuit
Crossover Circuit
Unjoined Course
Start Angle 0
Curvature 0
Rainbow Map Scaling
From selected lap
From whole file
OK
Cancel
Avg Speed: 18.0 km/
Distance: 3.13 km
[redacted]
Brake distance
Distance of throttle use between 85-100%
Min corner speed and RPM
Max speed and RPM
Distance of throttle use between 16-84%
Turn 1
Turn 2
Turn 3
Turn 4
Turn 5
Turn 6
Str 0-1
Str 1-2
Str 2-3
Str 3-4
Str 4-5
Str 5-6
Str 6-7
230
12424
142
9357
161
10031
89
6403
275
12638
190
11346
249
11524
249
11529
286
12902
114
7263
11779
10388
8131
9484
9703
5624
9169
10465
11738
12101
12192
12822
10159
Brake
85-100% TP
16-84% TP
0-15% TP
max rpm & speed
min rpm & speed
RPM Average
0.1

Magic Numbers

- The concept of magic numbers : Along a racing season, there are times the car works very well and the driver is happy with the handling. There are times the car is not working as well…. Or not at all. In the first case they are some specific numbers and equations you can deduct form the setup sheet. There are also raw data and math functions you can see on the data acquisition system. When the car is working these number and math function are *always* within a very small window.

- When you are lost you need map and you need to know where you are and where to go. Set up numbers analysis and data analysis show you were you are. Observations of these numbers from successful race and testing will tell you where to go.

- Caution : These numbers are circuit type dependant. Don't compare a specific magic number from a one mile oval to a street course of a supper speedway.

- These magic numbers are also driver style. Every time the car is working well on a road course you always will see the same magic numbers form driver A. But these magic numbers could be slightly different for driver B.

6 Magic Numbers

- % Front weight distribution
- % Front wheel rate =

  100 * (LFWR + RFWR) / (LFWR + RFWR +LRWR +LRWR)

  Wheel rate = Spring Rate / Motion Ratio^2
- % Front aerobalance
- % Front elastic weight transfer =

  100 * (RFST - LFST) / [(RFST - LFST) + (RRST – LRST)]

  ST = Strain Gauge
- Minimum time delay between front and rear maximum roll (or/and left and right maximum pitch)
- Shock speed histogram shape and first segment % of bump and rebound low shock speed.

8. Car set up

- Setup procedure
- Set down and tear down sheets
- Racing with and without data acquisition
- Setup parameters influence on handling
- Driver testing, practicing and racing habits
- Racing as a team

Set up procedure

1. Are your chassis and suspensions straight ? Symmetrical ?
2. Dummy shocks
3. Fuel and driver ballast. Same corner weights
4. Tire hot pressure
5. Disconnect ARB
6. Min Shock setting
7. Ride Height
8. Caster
9. Camber
10. Toe
11. Go to 7
12. Corner Weight
13. Go to 7
14. Bump Steer
15. Reconnect ARB and adjust droop link for same corner weight
16. Place shock and adjust length with spring platform until same as dummy shocks length (if using dummy shocks)
17. Shock setting
18. Wings setting

Racing with and without data acquisition

Beware of *the monkey see monkey do!*

Lack of education is the #1 reason for lack of data acquisition efficient use

The 8 essentials sensors besides engine sensors

- Lateral acceleration and speed

(comes with a any good data acquisition system)

- Steering
- Throttle (could come as a signal from the ECU)
- 4 suspension linear or rotary potentiometers

The extras

- Brake pressure
- 2 (inside of 1) lateral or 3way accelerometer (front and rear)
- Gyro
- Rules, budget and imagination are the limits….

Set up Parameters Influence on Handling

Setup Parameters	Car Behavior	Comments
Weight Distribution	More weight on one end = More in line grip on that end More weight on one end = Better lateral grip on that end	More rear load on rear wheel drive = better traction More front load on front wheel drive = better traction More Rear Load = Less O/S More Front Load = Less U/S BUT THE CHANGES OF GRIP WILL BE MORE SUDDEN ! Beware of the changes of the Moment of Inertia in Yaw
Tire Pressure	Too low = "mushy" car, high rolling resistance Too high = bouncy car, lower rolling resistance Increase tire pressure on one end reduce lateral and longitudinal grip on that end	Consider the influence on the static and dynamic ride heights. Qualify "cold" pressures are higher than "cold" race pressures " Cold" Pressures are lower in winter than summer PV = nRT

Setup Parameters	Car Behavior	Comments
Tire Temperature	Nominal temp (NT) found by experience and tire manufacturer info U/S if F > R and F > NT U/S if F < R and F < NT O/S if R > F and R > NT O/S if R < F and R < NT Too high in tire middle = too much pressure and /or too much wheel spin Too low middle = Pressure too low Too high inside = too much camber and/or too much toe in Too high outside = not enough camber and/or too much outside	The # 1 tool to set up a car! Tire temperatures in the pits are not the one while on the race track Tire temperatures in the corner is what matters! Tire temperature at the end of the pit lane are different that the one at the beginning of the pit lane! Tire temperatures are depending on cool down lap speed Each heat cycle wears the tires out
Camber	More < 0 camber = worse braking = worse traction More < 0 camber = more grip on outside unless tire too hot = less grip on inside	Try different camber for qualify: it's all temperature related. More camber = lower vertical tire stiffness

Setup Parameters	Car Behavior	Comments
Toe	More toe in on outside = more grip unless tire too hot More toe out on inside = more grip unless tire too hot	Only way to know: test it ! (unless sophisticated tire model and simulation software)
Springs	Stiffer shocks = Less Roll and Less Pitch Stiffer = harsher = more responsive = more difficult to drive, less forgiven Softer = absorb bumps better = less info to the driver = lazier Stiffer on one end = More lateral weight transfer on that end = less grip on that end, more grip on the other (unless very dissymmetrical tires)	Stiffer = more responsive BUT DOESN'T NECESSARILY MEAN QUICKER !
Anti Roll Bar	Stiffer on one end = More lateral weight transfer on that end = less grip on that end, more grip on the other (unless very dissymmetrical tires)	Stiffer ARB could make the car more unstable on bumpy circuits

Setup Parameters	Car Behavior	Comments
Ride Height	Lower front = more grip (if not less than 1/8 ") Higher Rear A) = More Front *and* Rear downforce .... until too much pitch angle B) = More front downforce distribution Higher Ride heights = Higher center of gravity = Less grip (except Go Kart) = Lazier car	LOWER IS NOT NECESSARILY BETTER Ride height changes = (sometime huge) kinematics change Extremely critical on open wheel with wings Even more critical with flat bottom car Static Ride Height (setup pad) are NOT dynamic ride heights (corner and straights) Sometimes ideal ride heights in corner means bottoming in the straights Inexperienced drivers are less sensitive to aerodynamics effects to to wings settings and/or ride height changes Lower ride height request stiffer springs Downforce is a function of the air density! Rule of thumb: +/- 0.010 " Front = +/- 0.030 to 0.050" Rear

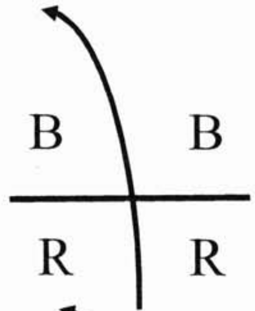
Setup Parameters	Car Behavior	Comments
Caster	More caster = More camber variation in steering = more < 0 camber variation on outside = more > 0 camber variation on inside = stiffer steering (most of the time) = more grip on front end until front "tire washes out" (major variation of steering torque)	Caster angle is not caster trail!
KPI	Increase negative camber in steering on the outside Increase negative camber on the inside Stiffer steering	KPI Angle is not KPI trail
Wings	More wing on one end = more grip on that end and not necessarily less grip on the other But changes aerobalance Efficiency / degree diminishes with high angle and suddenly disappears.	Wings Effect = Function of the speed^2 Beware of stickers! Consider yaw and wing end plate length Front = nearly FOC in drag Rear = Very costly in drag

Setup Parameters	Car Behavior	Comments
Gurney	More wing on one end = more grip on that end and not necessarily less grip on the other But changes aerobalance	Works mostly at low speed
Shocks	Stiffer shocks = Less Roll and Less Pitch Stiffer shocks on one end = less grip on that end = more grip on the other end	Stiffer = more responsive BUT DOESN'T NECESSARILY MEAN QUICKER because *less sensitive* OptimumG experience with customers: Most of the time shocks are twice too stiff in bump and 3 times too stiff and rebound. Softening them makes them car quicker but the driver prefers the previous feeling Consider shocks as and ARB working mainly in transient

Shock Setting

B = Bump   R = Rebound

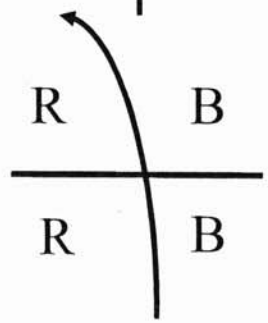
Entry on Brake



U/S: Softer Front B or Stiffer Rear R

O/S: Stiffer Front B or Softer Rear R

Entry



U/S Softer Outside Front B

Softer Inside Front R

Stiffer Outside Rear B

Stiffer Inside Rear R

O/S Softer Outside Rear B

Softer Inside Rear R

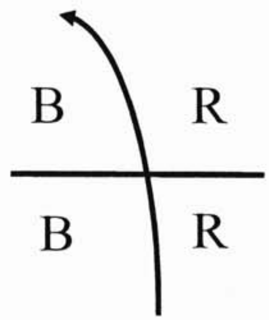
Stiffer Outside Front B

Stiffer Inside Front R

Shock Setting

B = Bump   R = Rebound

Exit



U/S Softer Outside Front R

Softer Inside Front B

Stiffer Outside Rear R

Stiffer Inside Rear B

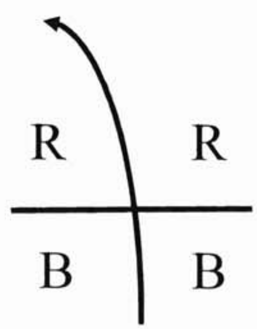
O/S Softer Outside Rear R

Softer Inside Rear B

Stiffer Outside Front R

Stiffer Inside Front B

Exit on Throttle



U/S: Softer Front R or Stiffer Rear B

O/S: Stiffer Front R or Softer Rear B

ONLY DATA ACQUISITION WITH SHOCK LINEAR POTENTIOMETERS

CAN HELP YOU IN PRECISE SHOCK SETTING

Setup Parameters	Car Behavior	Comments
Roll Center	Higher Roll Center on one end = Less Roll = Less moment of inertia = More immediate weight transfer on that end = More responsive car on entry = More grip on entry on that end = Less grip in corner middle on that end = Give less room for shock adjustment in corners Roll Center moving towards one wheel = like stiffer spring on that wheel = like softer spring on the other = quicker loading on that wheel on entry = worse grip on that end in corner middle	Static roll centers position (setup pad) is NOT the dynamic roll centers position (in the corners) Change of ride heights could considerably position and movements of roll centers! Consider influence of compliance on kinematics.

Interesting Race Car Engineering Books

General

- ❑ Automotive Handbook (Bosch)
- ❑ Inside Racing Technology (Paul Haney & Jeff Braun)
- ❑ SAE Motor sports CD Rom (all US SAE papers for the last 35 years)
- ❑ Race Car Engineering and Mechanics (Paul Van Valkenburg)

Aerodynamics

- ❑ Aerodynamics of Road Vehicles (Wolf Heinrich Hocho)
- ❑ Race Car Aerodynamics, designing for speed (Joseph Katz)
- ❑ Road Vehicle Aerodynamics (A.J. Scibor-Rylski)
- ❑ Competition Car Aerodynamics (Simon Mcbeath)
- ❑ Theory of Wing Sections (Abbot and Doenhoff)

Data Acquisition

- ❑ Data Power (Budy Fey)
- ❑ Competition Car Data logging (Simon Mcbeath)

Vehicle Dynamics, Chassis and Suspension

- Engineer to win (Carroll Smith)
- Prepare to Win (Carroll Smith)
- Race to Win (Carroll Smith)
- Tune to win (Carroll Smith)
- Fundamentals of Vehicle Dynamics (Thomas D. Gillepsie)
- Race Car Vehicle Dynamics (Milliken & Milliken)
- Car Suspension and Handling (Donald Bastow)
- New Directions in Suspension Design (Colin Campbell)
- Motor Vehicle Dynamics Modeling and Simulation (Giancarlo Genta)
- The Automotive Chassis (J Reimplell & H Stoll)
- The Shock Absorber Handbook (John C. Dixon)
- Tires, Suspension and Handling (John C. Dixon)
- An Introduction To Race Car Engineering (Warren J Rowley)

Powertrain

- ❑ Design and Simulation of 2 stroke engines (Gordon P Blair)
- ❑ Design and Simulation of 2 stroke engines (Gordon P Blair)
- ❑ Four Stroke Performance Tuning (graham Bell)
- ❑ Two Stroke Performance Tuning (graham Bell)
- ❑ Design of racing and high performance engines PT-53 (Collection of SAE Papers)
- ❑ Design of racing and high performance engines PT-100 (Collection of SAE Papers)

Periodicals

- ❑ Race car Engineering
- ❑ Race Tech Magazine
- ❑Grassroots Motor sports Magazine

MoTeC
& G

Race Car Engineering & Data Acquisition System Seminar

Seminar Venue & Date :	*Team :*
First Name : *Last Name :* *Age :* | *E-mail :*	*Team Address :*
Position : *Ambitions :*	*Team E-mail :* *Team Website :*

Experience :
Race cars you have worked on :
In your opinion, what are the needs in race car engineering ?
How did you hear about the seminar ?

	Sensors you have used before	*Sensors used now*	*Sensors you would like to use*
Suspension Lin. or Rot. potentiometer			
Steering Rot. potentiometer			
Accelerometer (precise 1/2/3 Ways)			
Gyro :			
Ride height Laser Sensor			
Strain Gauges			
Pitot Tube			

MoTeC

& G

Evaluation

Please help me strengthen this program for others, by evaluating these 3 days and offering suggestions.

Scale :	Poor	Meager	Average	Good	Excellent
General					
Overall evaluation					
Learning objectives satisfied					
Quantity of new information gained					
Need scale of this seminar in racing					
Communication					
Program content					
Overall Quality					
Rigor					
Complexity					
Relevance					

Information density / day (too much, good ratio, not enough):

Seminar length (too long, good length, not enough) :

Comments / Suggestions :

Topics to introduce in this seminar :