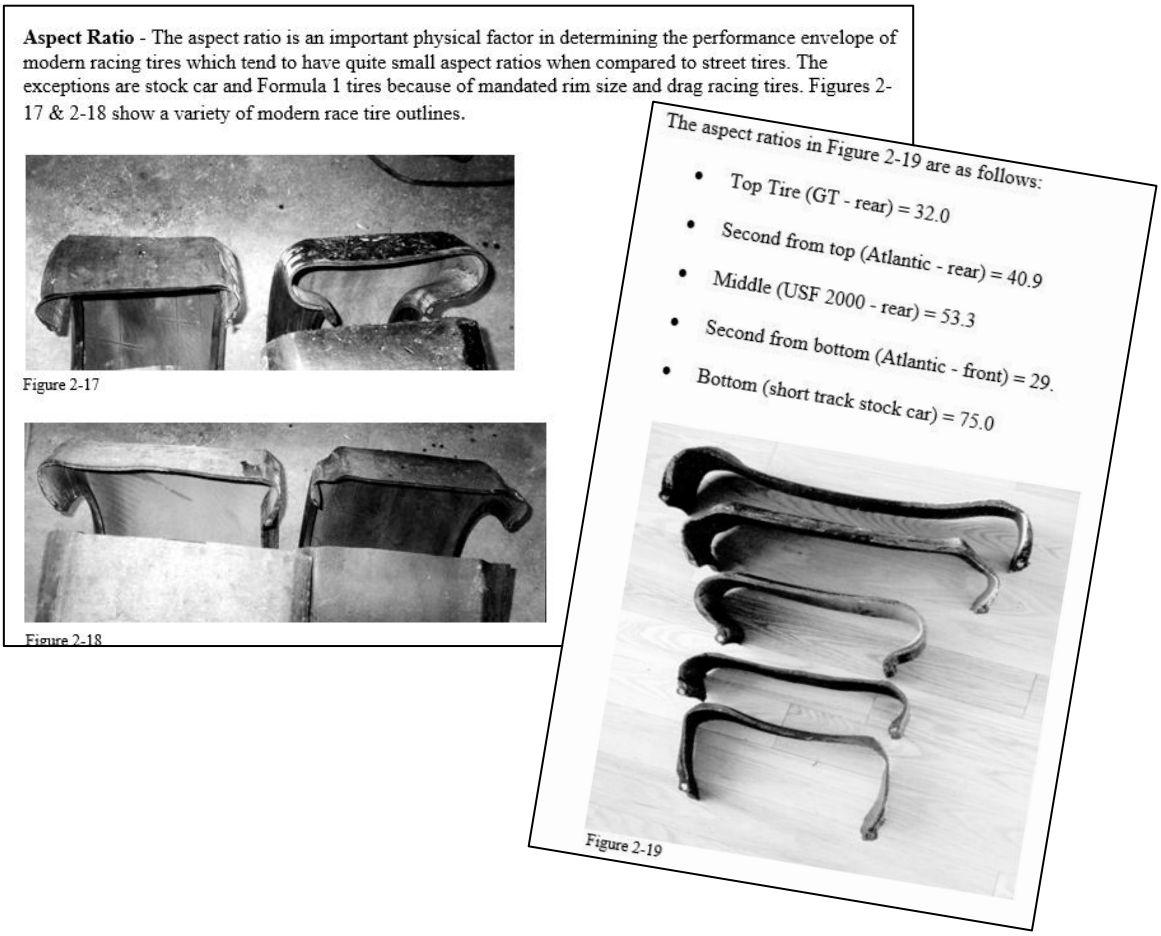
RowleyRaceDynamics

Book 1 Examples

Book 1 looks at both oval-track cars and circuit-type cars (open-wheel and sports cars) - symmetric and asymmetric setups.

Book 1 is divided into three primary components

- The basics of tire performance
- An extensive look at suspension kinematics in consort with Wm. C. Mitchell's WinGeo3. These chapters cover virtually every component and theory of use for all types of modern race cars. The Kinematic chapters carefully walk the user through each step of using WinGeo3.
- The basics of vehicle dynamic performance. These chapters cover the base setup and the resultant on-track performance of various oval-track and circuit-type cars. The authors have developed a series of Excel-based software tools to help explain each component of the book's vehicle dynamics examples and to allow users to further expand on the book's initial theories and examples. All the math used in the book's vehicle dynamic chapters is carefully developed and explained in Chapter 15.



Aspect Ratio - The aspect ratio is an important physical factor in determining the performance envelope of modern racing tires which tend to have quite small aspect ratios when compared to street tires. The exceptions are stock car and Formula 1 tires because of mandated rim size and drag racing tires. Figures 2-17 & 2-18 show a variety of modern race tire outlines.

Figure 2-17

Figure 2-18

The aspect ratios in Figure 2-19 are as follows:

- Top Tire (GT - rear) = 32.0
- Second from top (Atlantic - rear) = 40.9
- Middle (USF 2000 - rear) = 53.3
- Second from bottom (Atlantic - front) = 29.
- Bottom (short track stock car) = 75.0

Figure 2-19

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longer than it is wide while the sports car tire will normally be just the opposite. The height and width of the tire design is always a compromise between longitudinal and lateral acceleration performance i.e. **tread surface cooling rates**. Though the load on the tire and the pressure within the tire are the two primary factors determining the size of the resultant contact patch, the tire side wall and carcass design also play a small role in determining the contact patch, size. If the tires' sidewalls are sufficiently stiff to support a portion of the load on their own, this formula would need a correction factor added to compensate for the sidewall support. The (A=L/P) calculation is only true when the tire is entirely reliant on air pressure to maintain its shape. Though not completely accurate for **dynamic** conditions, static prints as shown in Figures 2-26 & 2-27 are quite revealing.

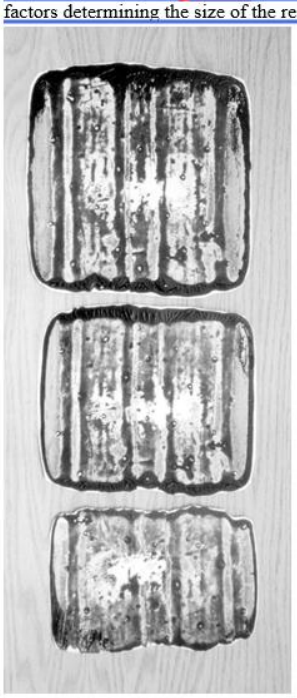


Figure 2-26 - The three contact patches are from the same tire at 35psi but with 500, 1000, and 1500 lb. load respectively.



Figure 2-27 - The three contact patches are from the same tire at 35 psi, with -5 degrees of camber but with 500, 1000, and 1500 lb. load respectively.

Total Shear Angle - The combined tread and sidewall/carcass angle of shear - Figure 2-35.

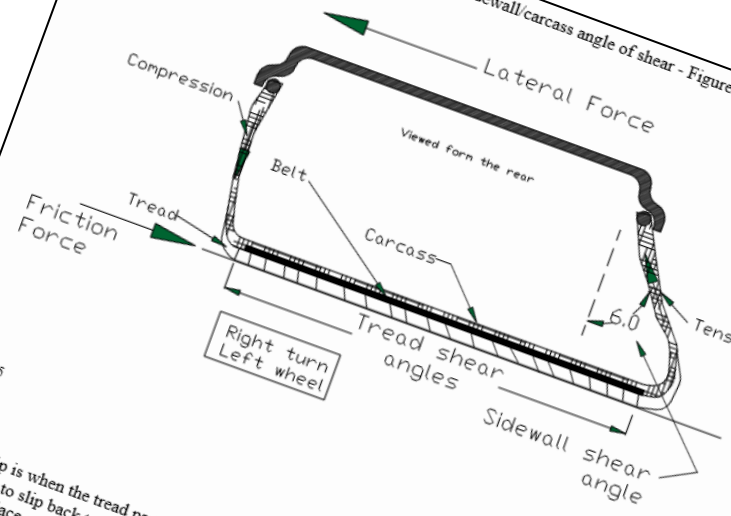


Figure 2-35

Slip - Slip is when the tread particles have stretched past the point of maximum deflection, are losing grip and begin to slip back to their original at rest position. At or near the peak of tire performance, this process is taking place on a continuous basis.

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Vertical Loads On The Sidewall Cords - Action and reaction vertical loads are transferred through the tire sidewalls via the cords from the tread to the rim and from the rim to the tread. The sidewall design significantly contributes to the tire's load carrying capacity. As previously discussed, the tire's design, to a great extent, determines how and when the loads are transferred. The cords act as a series of springs compressing and extending under the combinations of vertical and resultant loads. This spring effect helps prevent abrupt shock loading by slowing the load transfer - Figure 3-18.

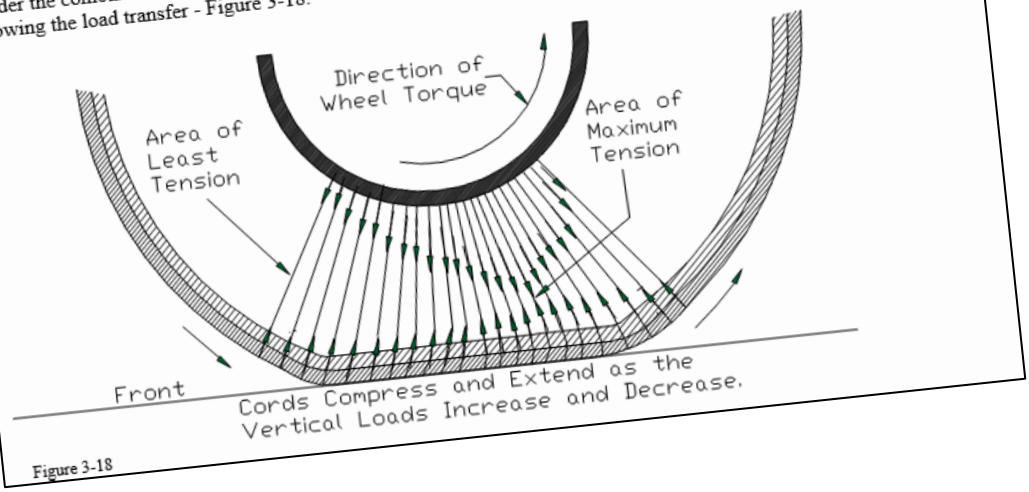


Figure 3-18

Vertical Loads On The Sidewall Cords - Action and reaction vertical loads are transferred through the tire sidewalls via the cords from the tread to the rim and from the rim to the tread. The sidewall design significantly contributes to the tire's load carrying capacity. As previously discussed, the tire's design, to a great extent, determines how and when the loads are transferred. The cords act as a series of springs compressing and extending under the combinations of vertical and resultant loads. This spring effect helps prevent abrupt shock loading by slowing the load transfer - Figure 3-18.

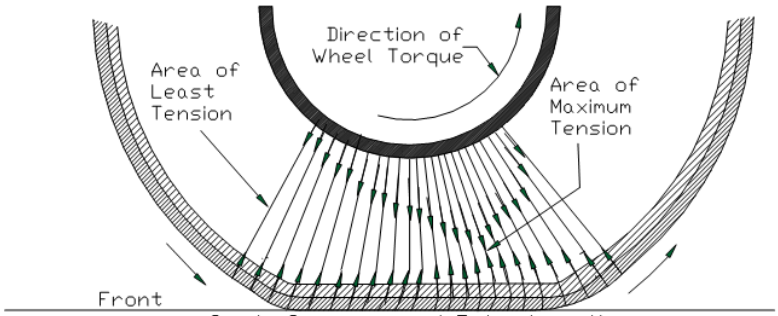
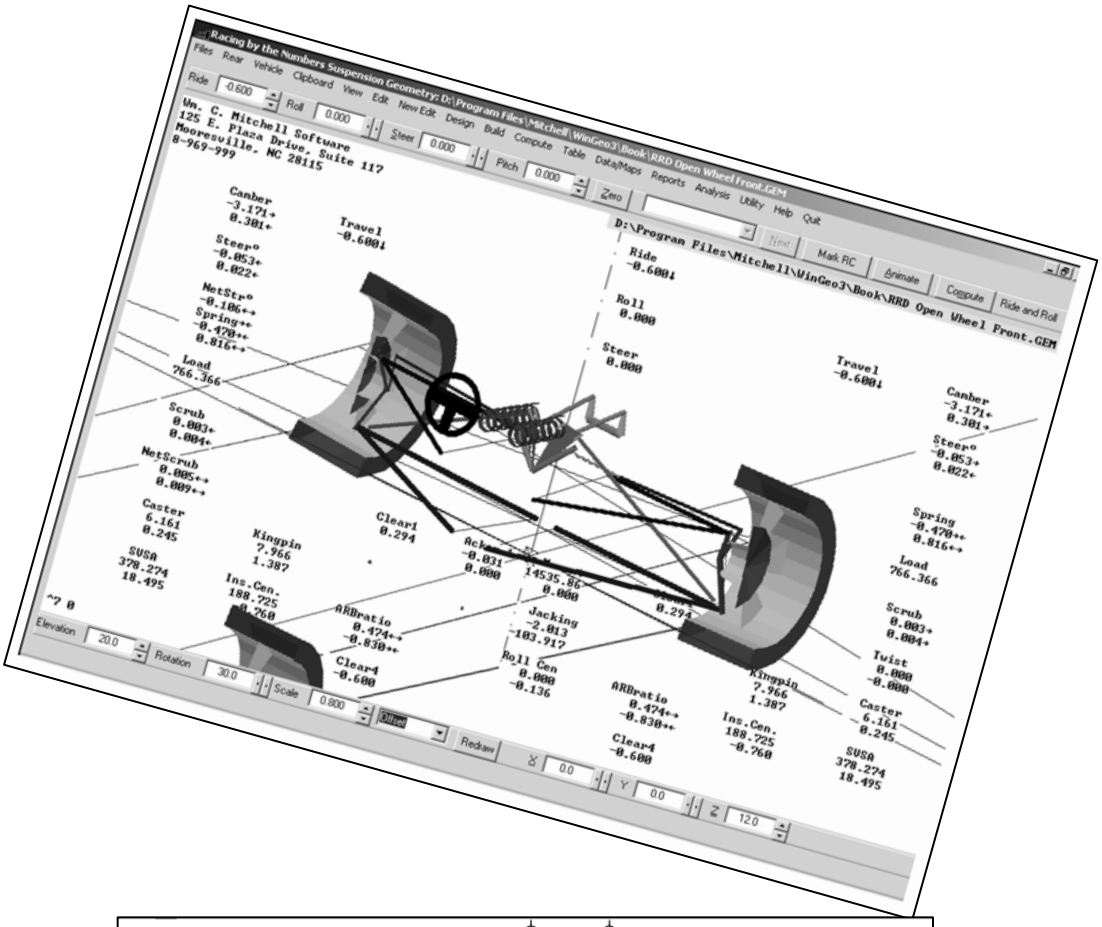
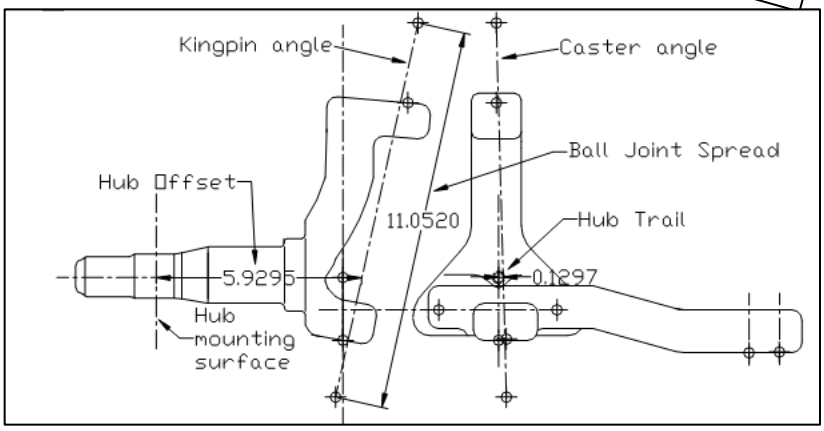


Figure 3-18

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Book 1 Examples





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Rotate about Hub center – This mode rotates the suspension assembly about the h
primarily used to redesign both the upper and lower control arms to fit a particular s
and setting. When the suspension assembly is rotated about the hub center, both the
control arm lengths change.

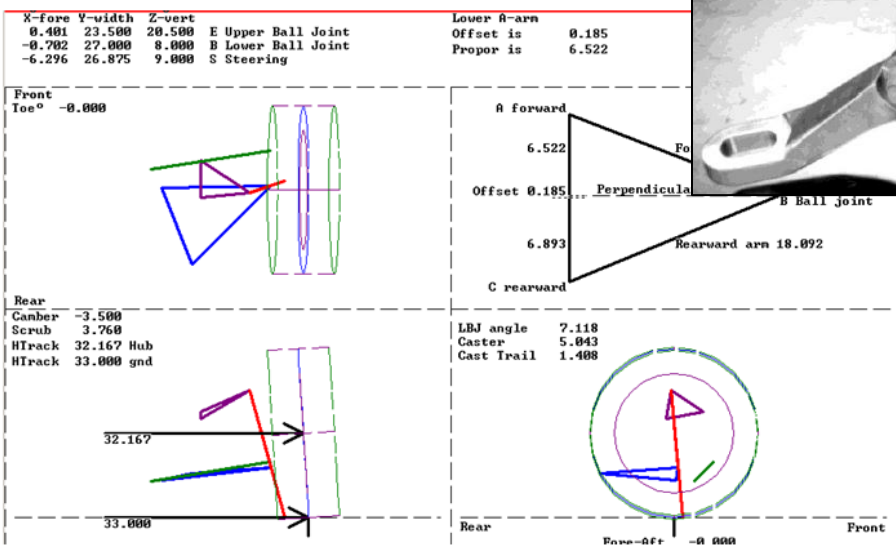


Figure 5-11

This form shows three views of the upright/spindle as well as a detail of the fixture points. The upright/spindle, A arms and tire are shown from the top (upper-left), rear (lower-left) and side (lower right). The upper right panel shows the lower control arm dimensions.

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Before beginning the kinematic chapters I would highly recommend that anyone who is not thoroughly familiar with all aspects of racecar vehicle dynamics take time to build a series of models such as the spindle/upright model shown in Figures (6-1 & 6-2). They don't have to be pieces of artwork as long as they are closely representative of what you are studying and can have their various co-ordinates quickly changed. An accurately working model is worth its weight in gold. The hardest thing about building both representational and to-scale models is not creating unwanted moments - (Book Two).



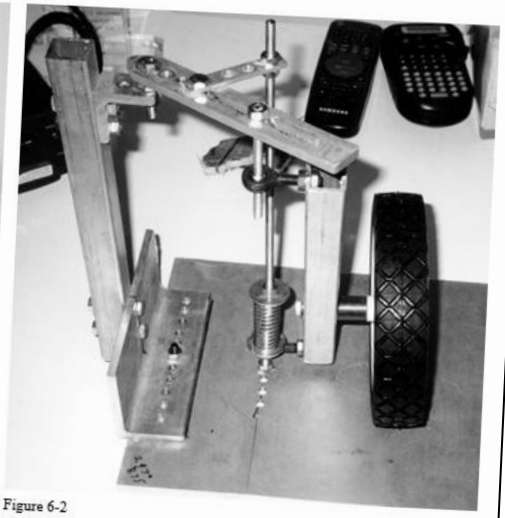
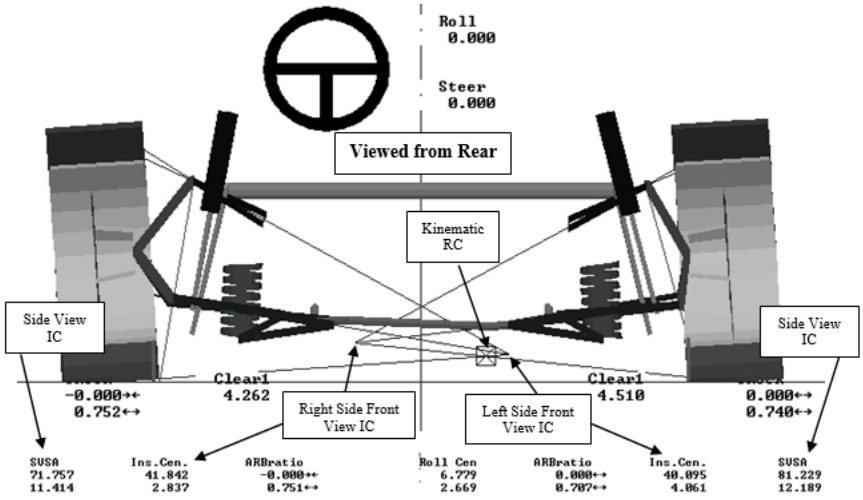


Figure 6-2

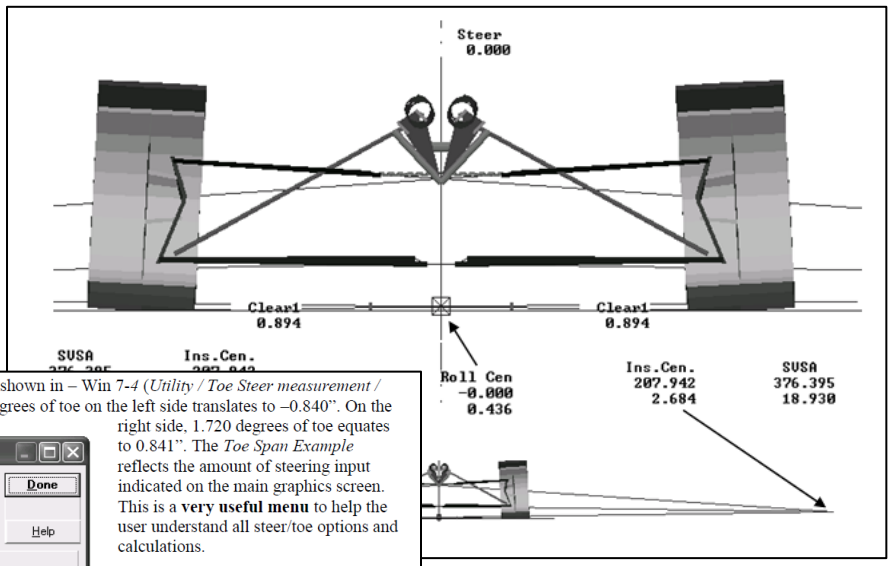
**** Begin WinGeo3 Example****

Win 6-22 / 6-25 illustrate the differences between the kinematic roll centers, front view instant centers and side view centers of a stock car and an open wheel car. The front view and side view instant center co-ordinates are shown with the IC height above the IC length. The Dynamics chapters use the IC co-ordinates to calculate jacking and anti forces.

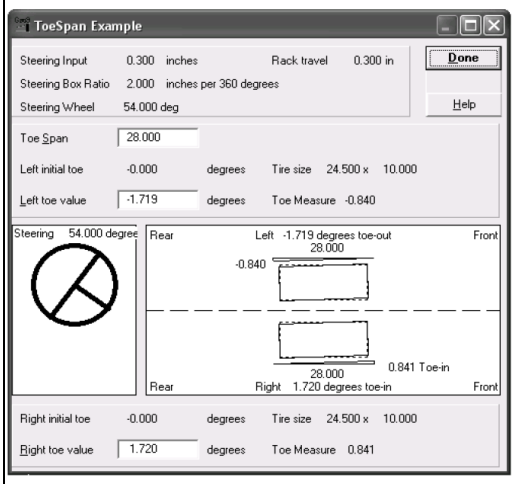


Win 6-22 Stock Car - Viewed from the rear

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The *Utility* menu also includes an example of *Toe Span* as shown in – Win 7-*4* (*Utility / Toe Steer measurement / Example of Toe Span*). The example shows how –1.719 degrees of toe on the left side translates to –0.840". On the right side, 1.720 degrees of toe equates to 0.841". The *Toe Span Example* reflects the amount of steering input indicated on the main graphics screen. This is a **very useful menu** to help the user understand all steer/toe options and calculations.



Win 7-4

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Roll Rate

Wm. C. Mitchell

When a car is subjected to a lateral force, there is a resulting torque about the center of gravity. This torque is resisted by the springs (and swaybars, which we are going to ignore for now). This torque (let's call it overturning torque) is resisted by the torques generated by the two springs. These torques are the moment arm (distance from CG to an extension of the spring axis) multiplied by the spring force, which is proportional to the displacement of the spring.

The chassis does not care whether these resisting torques are generated by the outside spring in compression or the inside spring in extension. The effect on the chassis is the same whether it is being pushed or pulled.

Let us assume the two springs have the same moment arm. The combined effective spring rate is K1*K2/(K1+K2). The following pairs of springs have the same roll rate:

Left:	Right:	Roll Rate:
200	400	133.33
300	239	133.33
267	267	133.33
239	300	133.33
400	200	133.33
500	181	133.33
600	171	133.33
800	160	133.33
1000	153	133.33
infinite	133	133.33

All of these spring combinations produce the same roll resistance. They will produce the same amount of roll and the same load transfer. It matters not one bit which pair of springs you select.

But the spring choice does affect the resulting ride height. If you put the stiffer spring on the outside, then the chassis will be higher than if you put the stiffer spring on the inside. If you are concerned about keeping the right front corner of the car from hitting the track while on a high-banked oval (turning left), then placing the stiffer spring on the right side will help to support the right side of the car and keep it from hitting the track. Placing the stiffer spring on the inside or left side will produce the same roll angle but the chassis will be lower.

If you are not concerned about hitting the track but want to minimize ground clearance for aerodynamic effects, then put the stiffer spring on the inside and the chassis will ride lower.

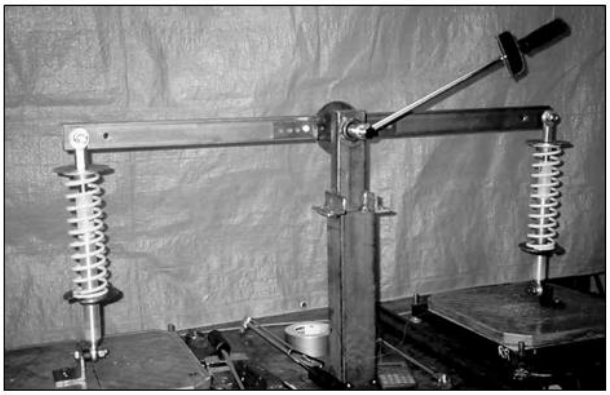
Spring Center:

The process just described is called a spring center. If two ends of a beam are supported by springs at either end and we apply a torque to the beam, the spring center is the point that will remain stationary as the beam rotates. If the beam is 100 inches long and we measure the spring center from the left end:

Left:	Right:	Spring Center	R side Drop	
133	infinite	100	0.000	Beam rotates about right end
200	400	66.7	0.333	
301	239	44.3	0.557	
267	267	50	0.500	
239		55.7	0.443	
		33.3	0.667	
		26.6	0.734	
		22.2	0.777	
		16.7	0.833	
		13.3	0.867	
		0	1.000	Beam rotates about left end

= 100 * R / (L + R)

If you have trouble digesting the above phenomenon, you might want to build a test jig as shown below. However, as in the case of all mechanical test apparatus, one needs to be very careful that they don't bias the outcome. This concept will be much easier to understand once we begin using the Wan31 software beginning in Chapter 14.



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A Mathematical Look at Vehicle Dynamics

Dr. J. J. Salinas and W. J. Rowley
With Second Printing Additions by **Wm. C. Mitchell**

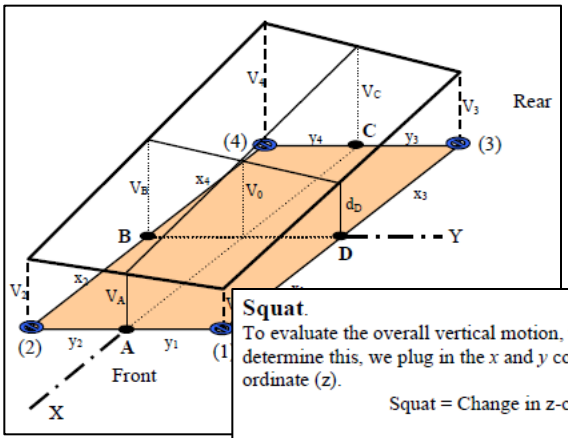
(It's just not this simple!)

About Juan Salinas

Dr. Juan Salinas – Juan is a brilliant engineer, mathematician and engineering professor (his office walls are covered with teaching awards). He is also one of the **most** modest and nicest people I have ever met. He is a true renaissance man whose range of experiences and expertise continually dumbfound me – from nuclear power plants to satellite global positioning to consulting for the United Nations. Juan has a **great** mixture of theoretical and hands-on experience.



I first met Juan when he was doing postdoctoral work in engineering while I was doing research into brain sense stimulation and deprivation (controlling three dimensional environments through the use of various brain frequencies). Juan often volunteered as a guinea pig for some of the more bizarre experiments. However, after one particularly outlandish test, we had great difficulty coaxing Juan back to the real world. Some say he has never been the same since, though I like to think he just got better! Sorry about that, Juan.



Squat.
To evaluate the overall vertical motion, we will consider the change in vertical co-ordinate of the origin (V_0). To determine this, we plug in the *x* and *y* co-ordinates of the origin into the equation of the plane and find the third co-ordinate (z).

Squat = Change in z-co-ordinate of the origin = V_0

Co-ordinates of the origin:

$x = 0, \qquad y = 0 \qquad z = V_0$

Equation of the plane:

$$AA\,(0) + BB\,(0) + CC\,(V_0) - DD = 0$$

Solving for V_0

$$V_0 = \frac{-DD - AA(0) - BB(0)}{CC} = \frac{+DD}{CC} \rightarrow \text{Squat}$$

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Analysis

The overall analysis of the system follows the same concepts presented before. First, we establish the conditions for equilibrium: Vertical forces (Z), Moments about the X−axis and Moments about the Y−axis, equations [1], [2] and [3]. Second, we write the equations describing the behaviour of the suspension components, equations [4], [5], [6] and [7]. For this case equations [4] and [5] are the same as for the previous one because the front remains as an independent suspension system. Equations [6] and [7] for the rear axle are the ones developed for a track bar suspension. Third, we write the equation of compatibility of deformations, equation [8]. Then we write the equation establishing the compliance of the roll bar to the deformations of the springs, Equation [9]. Equations [1], [2], [3] and [8] involve the overall behaviour of the system and are the same as for the General Case with independent suspension in all corners. Equations [4] and [5], as indicated above, are also the same. Equations [6] and [7] involve the behaviour of the solid axle suspension in the rear and will be different from those developed for the previous case.

Equations

[1] $$P_1 + P_2 + P_3 + P_4 = W_T \cos\alpha + (T_L + T_R)\sin\alpha + (Ba + Dr + Fu)\cos\alpha + Ae$$

[2] $$P_1t_1 - P_2t_2 + P_3t_3 - P_4t_4 = [-R]\{ (W_T \sin\alpha - (T_L + T_R)\cos\alpha)\, z_T - (W_T \cos\alpha + (T_L + T_R)\sin\alpha)\, y_T$$
$$(Ba\, z_B + Dr\, z_D + Fu\, z_F)\sin\alpha - (Ba\, y_B + Dr\, y_D + Fu\, y_F)\cos\alpha + Ae\, y_A \}$$

[3] $$P_1l_1 + P_2l_2 - P_3l_3 - P_4l_4 = (W_T \cos\alpha + (T_L + T_R)\sin\alpha)\, x_T$$
$$+ (B-A)\, z_T + (Ba\, x_B + Dr\, x_D + Fu\, x_F)\cos\alpha + Ae\, x_A$$

[4] $$P_1\left[1 + \frac{T_L+T_R}{W_T}\left(\frac{e}{a_y}\right)_1\right] - K_1V_1 - m_{R1}k_{RF}d_R =$$
$$q_1B\left(\frac{e}{a_x}\right)_1 + m_1k_1\,(D_1 + m_1R_{C1}) + m_{R1}k_{RF}\,(D_{R1} + m_{R1}R_{C1}) + m_{S1}F_{S1} + w_{u1}$$

[5] $$P_2\left[1 - \frac{T_L+T_R}{W_T}\left(\frac{e}{a_y}\right)_2\right] - K_2V_2 + m_{R2}k_{RF}d_R =$$
$$q_2B\left(\frac{e}{a_x}\right)_2 + m_2k_2\,(D_2 + m_2R_{C2}) + m_{R2}k_{RF}\,(D_{R2} + m_{R2}R_{C2}) + m_{S2}F_{S2} + w_{u2}$$

[6] $$P_3 - L_3V_3 - L_{3opp}V_4 = m_3k_3D_3\frac{t_4+s_3}{t_3+t_4} + m_{s3}F_{s3}\frac{t_4+y_{S3}}{t_3+t_4} + m_4k_4D_4\frac{-s_4+t_4}{t_3+t_4} + m_{s4}F_{s4}\frac{-y_{S4}+t_4}{t_3+t_4} -$$
$$r_TT_L\frac{h_4}{t_3+t_4} + w_{u3}$$

[7] $$P_4 - L_4V_4 - L_{4opp}V_3 = m_4k_4D_4\frac{t_3+s_4}{t_3+t_4} + m_{s4}F_{s4}\frac{t_3+y_{S4}}{t_3+t_4} + m_3k_3d_3\frac{t_3-s_3}{t_3+t_4} + m_{s3}F_{s3}\frac{t_3-y_{S3}}{t_3+t_4} + r_TT_L$$
$$\frac{h3}{t_3+t_4} + w_{u4}$$

Matrix Formulation

This system of 9 equations and 9 unknowns can be formulated using matrix notation.

$$A\,X = B \quad \rightarrow \quad X = A^{-1}\,B$$

Where

A = Matrix of stiffness and geometry coefficients
$\mathbf{A^{-1}}$ = Inverse of matrix A
X = Vector of unknown variables (Four wheel loads, P, and four spring deformations, d)
B = Vector of constant coefficients

$$A = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ t_1 & -t_2 & t_3 & -t_4 & 0 & 0 & 0 & 0 & 0 \\ l_1 & l_2 & -l_3 & -l_4 & 0 & 0 & 0 & 0 & 0 \\ E_1 & 0 & 0 & 0 & -K_1 & 0 & 0 & 0 & K_{R1} \\ 0 & E_2 & 0 & 0 & 0 & -K_2 & 0 & 0 & K_{R2} \\ 0 & 0 & E_3 & 0 & 0 & 0 & -L_3 & -L_{3opp} & K_{R3} \\ 0 & 0 & 0 & E_4 & 0 & 0 & -L_{4opp} & -L_4 & K_{R4} \\ 0 & 0 & 0 & 0 & C_1 & C_2 & C_3 & C_4 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & -G \end{bmatrix}$$

$E_1 = 1 + \frac{T_L+T_R}{W_T}\left(\frac{e}{a_y}\right)_1$ $\quad E_2 = 1 - \frac{T_L+T_R}{W_T}\left(\frac{e}{a_y}\right)_2$

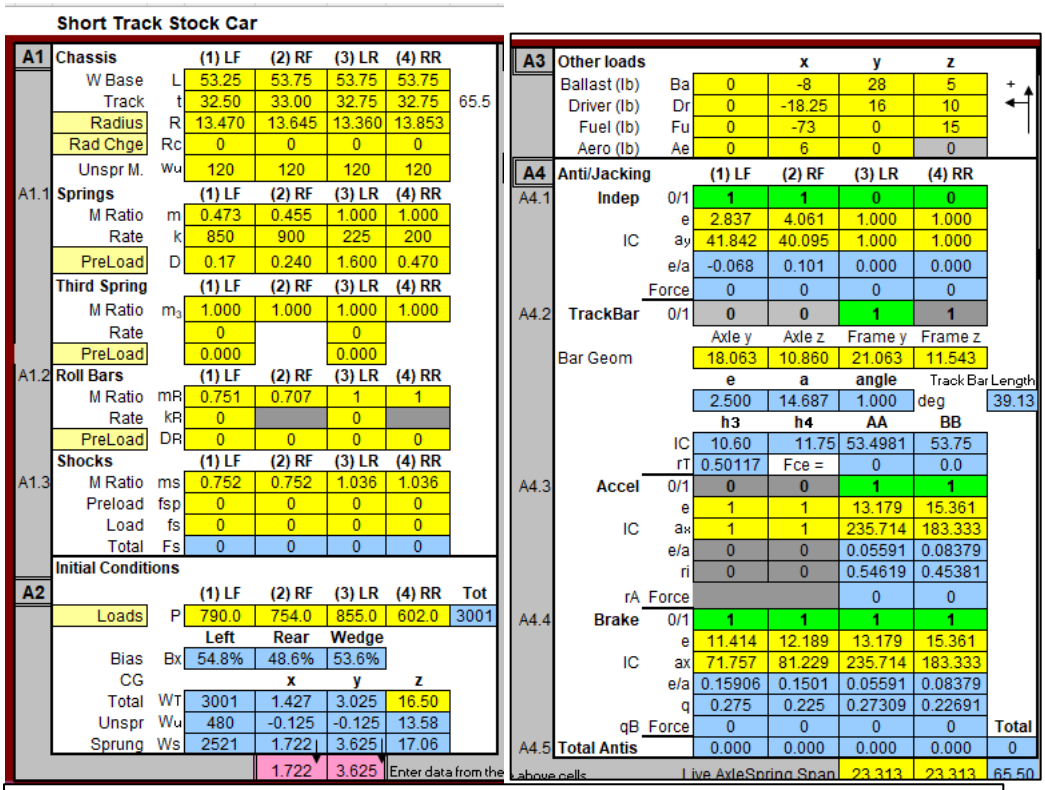
$K_i = m_i^2\,k_I$ for i = 1 … 4

$K_{R1} = -m_{R1}k_{RF}$ $\quad K_{R2} = m_{R2}k_{RF}$ $\quad K_{R3} = -m_{R3}k_{RR}$ $\quad K_{R4} = m_{R4}k_{RR}$

C_i = Compatibility coefficients $\quad G = \frac{y_1 + y_2}{y_{R1} + y_{R2}}$

$$X = \begin{Bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \\ V_1 \\ V_2 \\ V_3 \\ V_4 \\ d_R \end{Bmatrix} \quad \text{and} \quad B = \begin{Bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \\ B_6 \\ B_7 \\ B_8 \\ B_9 \end{Bmatrix}$$

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Short Track Stock Car

A1 Chassis		(1) LF	(2) RF	(3) LR	(4) RR	
W Base	L	53.25	53.75	53.75	53.75	
Track	t	32.50	33.00	32.75	32.75	65.5
Radius	R	13.470	13.645	13.360	13.853	
Rad Chge	Rc	0	0	0	0	
Unspr M.	w_u	120	120	120	120	

A1.1 Springs		(1) LF	(2) RF	(3) LR	(4) RR
M Ratio	m	0.473	0.455	1.000	1.000
Rate	k	850	900	225	200
PreLoad	D	0.17	0.240	1.600	0.470

Third Spring		(1) LF	(2) RF	(3) LR	(4) RR
M Ratio	m_3	1.000	1.000	1.000	1.000
Rate		0		0	
PreLoad		0.000		0.000	

A1.2 Roll Bars		(1) LF	(2) RF	(3) LR	(4) RR
M Ratio	mR	0.751	0.707	1	1
Rate	kR	0		0	
PreLoad	DR	0	0	0	0

A1.3 Shocks		(1) LF	(2) RF	(3) LR	(4) RR
M Ratio	ms	0.752	0.752	1.036	1.036
Preload	fsp	0	0	0	0
Load	fs	0	0	0	0
Total	Fs	0	0	0	0

A2 Initial Conditions

		(1) LF	(2) RF	(3) LR	(4) RR	Tot
Loads	P	790.0	754.0	855.0	602.0	3001

		Left	Rear	Wedge
Bias	Bx	54.8%	48.6%	53.6%

CG		x	y	z
Total	WT	3001	1.427	3.025	16.50
Unspr	W_u	480	-0.125	-0.125	13.58
Sprung	Ws	2521	1.722	3.625	17.06
		1.722	3.625	Enter data from the above cells	

A3 Other loads		x	y	z
Ballast (lb)	Ba	0	-8	28	5
Driver (lb)	Dr	0	-18.25	16	10
Fuel (lb)	Fu	0	-73	0	15
Aero (lb)	Ae	0	6	0	0

A4 Anti/Jacking		(1) LF	(2) RF	(3) LR	(4) RR
A4.1 Indep	0/1	1	1	0	0
	e	2.837	4.061	1.000	1.000
IC	a_y	41.842	40.095	1.000	1.000
	e/a	-0.068	0.101	0.000	0.000
	Force	0	0	0	0
A4.2 TrackBar	0/1	0	0	1	1

Bar Geom	Axle y	Axle z	Frame y	Frame z
	18.063	10.860	21.063	11.543

e	a	angle	Track Bar Length
2.500	14.687	1.000	deg	39.13

	h3	h4	AA	BB
IC	10.60	11.75	53.4981	53.75
rT	0.50117	Fce =	0	0.0

A4.3 Accel	0/1	0	0	1	1
	e	1	1	13.179	15.361
IC	a_x	1	1	235.714	183.333
	e/a	0	0	0.05591	0.08379
	ri	0	0	0.54619	0.45381
	rA Force			0	0
A4.4 Brake	0/1	1	1	1	1
	e	11.414	12.189	13.179	15.361
IC	ax	71.757	81.229	235.714	183.333
	e/a	0.15906	0.1501	0.05591	0.08379
	q	0.275	0.225	0.27309	0.22691
	qB Force	0	0	0	0	Total
A4.5 Total Antis		0.000	0.000	0.000	0.000	0
		Live AxleSpring Span		23.313	23.313	65.50

Wan31A – The Quick Overview:

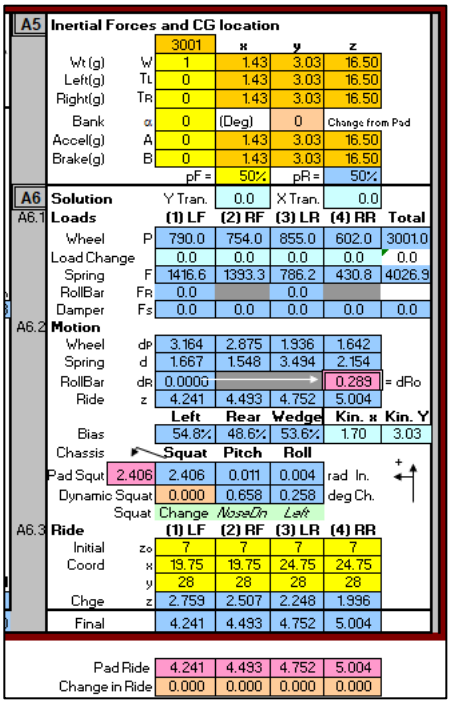
Wan31A Cars

- There are four Wan31A models presented on CD-ROM. All four models match the cars used in the accompanying WinGeo3 demo files.
  - Short Track
  - Open Wheel
  - Truck Arm
  - Symmetrical chassis

Screen Format

- The main screen is separated into six **Component Boxes**:
  - **A1** Chassis
  - **A2** Initial Conditions
  - **A3** Other Loads
  - **A4** Anti/Jacking
  - **A5** Inertial Forces and CG Location
  - **A6** Solutions

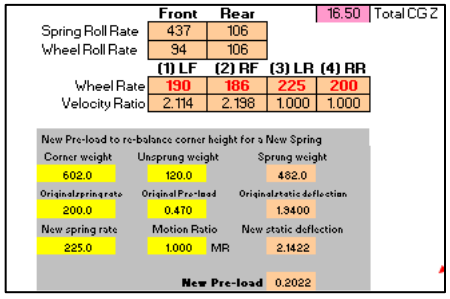
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A5	Inertial Forces and CG location					
		3001	x	y	z	
	Wt (g) W	1	1.43	3.03	16.50	
	Left(g) TL	0	1.43	3.03	16.50	
	Right(g) TR	0	1.43	3.03	16.50	
	Bank α	0	(Deg)	0	Change from Pad	
	Accel(g) A	0	1.43	3.03	16.50	
	Brake(g) B	0	1.43	3.03	16.50	
		pF =	50%	pR =	50%	
A6	Solution	Y Tran.	0.0	X Tran.	0.0	
A6.1	Loads	(1) LF	(2) RF	(3) LR	(4) RR	Total
	Wheel P	790.0	754.0	855.0	602.0	3001.0
	Load Change	0.0	0.0	0.0	0.0	0.0
	Spring F	1416.6	1393.3	786.2	430.8	4026.9
	RollBar FR	0.0		0.0		
	Damper FS	0.0	0.0	0.0	0.0	0.0
A6.2	Motion					
	Wheel dP	3.164	2.875	1.936	1.642	
	Spring d	1.667	1.548	3.494	2.154	
	RollBar dR	0.0000			0.289	= dRo
	Ride z	4.241	4.493	4.752	5.004	
		Left	Rear	Wedge	Kin. x	Kin. Y
	Bias	54.8%	48.6%	53.6%	1.70	3.03
	Chassis	Squat	Pitch	Roll		
	Pad Squt 2.406	2.406	0.011	0.004	rad In.	
	Dynamic Squat	0.000	0.658	0.258	deg Ch.	
	Squat	Change	NoseDn	Left		
A6.3	Ride	(1) LF	(2) RF	(3) LR	(4) RR	
	Initial z0	7	7	7	7	
	Coord x	19.75	19.75	24.75	24.75	
	y	28	28	28	28	
	Chge z	2.759	2.507	2.248	1.996	
	Final	4.241	4.493	4.752	5.004	
	Pad Ride	4.241	4.493	4.752	5.004	
	Change in Ride	0.000	0.000	0.000	0.000	

Other Loads: - A3

- Ballast lb. (Ba) – Allows the user to add ballast to the chassis. Adding ballast offset from the CG will change the final bias numbers as indicated in cells O4, P4 & Q4.
- Driver lb. (Dr) – Allows the user to show differences in driver's weight. Changing a driver's weight, if offset from the CG, will change the final bias numbers as indicated in cells O5, P5 & Q5.
- Fuel lb. (Fu) – Allows the user to look at fuel load changes. Changing fuel loads offset from the CG will change the final bias numbers as indicated in cells O6, P6 & Q6.
- Aero lb. (Ae) – Allows the user to change aero load forces and pressure centers. Changes in aero loads and pressure centers are determined by consulting the team's aero maps or directly from the data acquisition system. The x, y & z co-ordinates (cells O7, P7 & Q7) indicate the aero pressure center.



	Front	Rear	16.50	Total CG Z
Spring Roll Rate	437	106		
Wheel Roll Rate	94	106		
	(1) LF	(2) RF	(3) LR	(4) RR
Wheel Rate	190	186	225	200
Velocity Ratio	2.114	2.198	1.000	1.000

New Pre-load to re-balance corner height for a New Spring

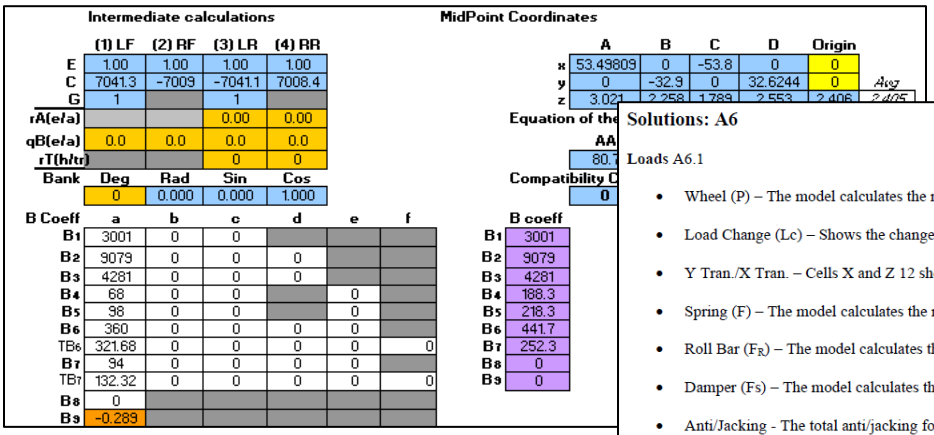
Corner weight	Unsprung weight	Sprung weight
602.0	120.0	482.0
Original spring rate	Original Pre-load	Original static deflection
200.0	0.470	1.3400
New spring rate	Motion Ratio	New static deflection
225.0	1.000 MR	2.1422
	New Pre-load	0.2022

Anti/Jacking: - A4

Indep A4.1

- 0/1 - The green switching cells allow the user to turn the kinematic anti/jacking forces on and off for each individual corner. 0 indicates the calculator is turned off for that particular corner while a 1 indicates the calculator is turned on for that particular corner. When running an independent rear suspension system, the **track bar** calculator (green cell P15) needs to be **turned off**.
- IC (e) – Allows the user to input the front view instant center height for each corner as calculated by WinGeo3.
- IC (ay) – Allows the user to input the front view instant center length for each corner as calculated by WinGeo3.
- (e/a) – Calculates the IC slope.
- Force – Calculates the Anti/jacking forces at each corner.

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Intermediate calculations

	(1) LF	(2) RF	(3) LR	(4) RR
E	1.00	1.00	1.00	1.00
C	7041.3	-7009	-7041.1	7008.4
G	1		1	
rA(e/a)			0.00	0.00
qB(e/a)	0.0	0.0	0.0	0.0
rT(h/tr)			0	0

Bank	Deg	Rad	Sin	Cos
	0	0.000	0.000	1.000

MidPoint Coordinates

	A	B	C	D	Origin
x	53.49809	0	-53.8	0	0
y	0	-32.9	0	32.6244	0
z	3.021	2.258	1.789	2.553	2.406

Avg 2.405

Equation of the

AA

80.7

Compatibility C

0

B Coeff	a	b	c	d	e	f
B1	3001	0	0			
B2	9079	0	0	0		
B3	4281	0	0	0		
B4	68	0	0		0	
B5	98	0	0		0	
B6	360	0	0	0	0	
TB6	321.68	0	0	0	0	0
B7	94	0	0	0	0	
TB7	132.32	0	0	0	0	0
B8	0					
B9	-0.289					

B coeff	
B1	3001
B2	9079
B3	4281
B4	188.3
B5	218.3
B6	441.7
B7	252.3
B8	0
B9	0

Matrix A

	P1	P2	P3	P4	V1	V2	V3	V4	dR
[1]	1	1	1	1	0	0	0	0	0
[2]	32.50	-33.00	32.75	-32.75	0	0	0	0	0
[3]	53.25	53.75	-53.75	-53.75	0	0	0	0	0
[4]	1.00	0	0	0	-190.2	0	0	0	0
[5]	0	1.00	0	0	0	-186.3	0	0	0
[6]	0	0	1.00	0	0	0	-169.0	-52.41	0
[7]	0	0	0	1.00	0	0	-52.4103	-151.2	0
[8]	0	0	0	0	7041.3	######	-7041.1	7008.4	0
[9]	0	0	0	0	-1	1	0	0	1

Inverse of A

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
P1	0.246	0.010	0.005	0.181	-0.183	-0.306	0.332	0.005	0.000
P2	0.255	-0.010	0.005	-0.180	0.183	0.305	-0.331	-0.005	0.000
P3	0.256	0.006	-0.005	-0.181	0.183	0.306	-0.332	-0.005	0.000
P4	0.243	-0.006	-0.005	0.180	-0.183	-0.305	0.331	0.005	0.000
d1	0.001	0.000	0.000	-0.004	-0.001	-0.002	0.002	0.000	0.000
d2	0.001	0.000	0.000	-0.001	-0.004	0.002	-0.002	0.000	0.000
d3	0.001	0.000	0.000	-0.002	0.002	-0.004	-0.001	0.000	0.000
d4	0.001	0.000	0.000	0.002	-0.002	-0.001	-0.004	0.000	0.000
dR	0.000	0.000	0.000	-0.003	0.003	-0.003	0.004	0.000	1.000

ion

Solutions: A6

Loads A6.1

- Wheel (P) – The model calculates the resultant wheel loads at each corner.
- Load Change (Lc) – Shows the change in load at each corner – the amount of load transfer.
- Y Tran./X Tran. – Cells X and Z 12 show the amount of total lateral and longitudinal load transfer.
- Spring (F) – The model calculates the resultant spring loads at each corner.
- Roll Bar (F_R) – The model calculates the resultant roll bar forces at the front and rear.
- Damper (Fs) – The model calculates the resultant shock forces at each corner.
- Anti/Jacking - The total anti/jacking forces are shown under **A4.5.**

Motion A6.2

- Wheel (dP) – The model calculates the resultant wheel motion at each corner.
- Spring (d) - The model calculates the resultant spring motion at each corner.
- RollBar (dR) - The model calculates the resultant roll bar motion at each corner.

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Wan31 A Static Set Up Precursor

Static Set Up: The race engineer needs to spend an inordinate amount of time working first with the static set up portion of the model. Even if the reader will only be working with road course chassis, he/she still needs to work through and understand all of the asymmetrical scenarios because as we will soon discover, under dynamic conditions, even a symmetrical chassis will exhibit asymmetrical factors.

The static set up consists of finding the correct corner loads versus ride heights versus diagonal % (wedge) for any given combination of wheel rates. It sounds easy enough but it isn't. Each car has a very specific relation between the ride heights, loads and diagonal cross weight. There is a very small window within this relationship where the chassis will operate at its maximum performance level. This small window is referred to as the sweet spot.

First Order Static Relationships - Changing a corner load will also result in a change in ride height unless the wheel rate and tire rate is infinitely stiff:

- Replacing a spring with a spring of a different rate or free height will change that corner's static and/or dynamic wheel rate, which, in turn, will change the corner load and ride height at all four corners. In order to reset the static corner loads and ride heights, the static loads need to be adjusted back to their original rate. For all types of chassis, except push rod/bell crank systems, this is accomplished by increasing or decreasing the spring preload – changing the distance between the upper and lower spring perches.

- Changing the static preload at just **one** spring will result in a change in static load at that corner, and, subsequently, a load and ride height change at **all** four corners. It can also result in a spring preload change at the other three corners.

Take time to explore several hundred **Bias-Load-Split Calculators** and **Pad Load Calculator** iterations in conjunction with the Wan31 symmetrical chassis.

4) **A1 Chassis - Springs**: Notice that changing a single spring rate, spring motion ratio and/or preload setting in the **A1** Chassis box results in both static load transfer and static wedge change as indicated in the **A6** Solution Box.

   - Check to see that all **A2** loads are 370 lb and the pink F35 and G35 cells are returned to 0.

   - Changing the LF spring from 400 to 300 without changing the preload results in a load transfer of 19.2 pounds per corner – the LF and RR diagonal corners lose 19.2 lb. while the RF and LR diagonal corners gain 19.2 lb. The wedge changes 2.6% from 50% to 52.6%. Take note of the changes in spring motion, ride height change and final ride heights.

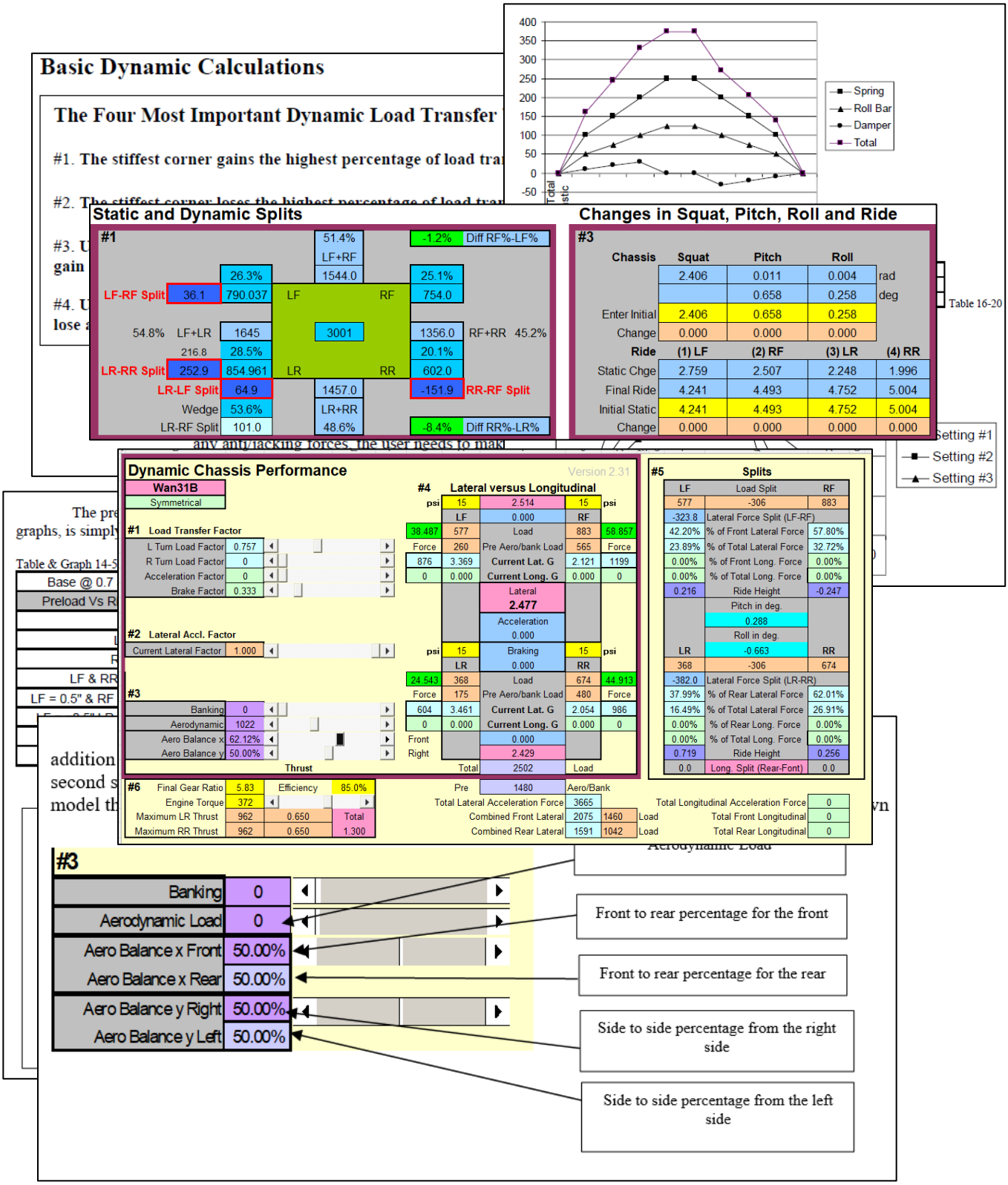
   - With all spring rates at 400 lb., the ride height at all four corners was 0.875". When the left front spring was changed from a 400 to 300 lb. spring, the ride heights changed to LF = 0.752", RF = 0.810", LR = 0.844" and RR = 0.902". The LF, RF and LR corner ride heights all decreased in different amounts from the base setting while the RR corner ride height increased. It is presumed that all the springs had the same free height and the chassis was not rebalanced after the spring change.

   - This type of load transfer changes the chassis diagonal cross weights (wedge) but **does not change** the left side and rear bias. This last point is very important to remember. As discussed in the spring chapter it takes a very small variant in one spring rate, preload or free height to produce a significant change in static corner loads.

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RowleyRaceDynamics

Book 1 Examples



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Note: Remember not to readjust the Box #1 sliders after the initial mechanical loads are fixed.

- **Add** 500 lb. aero load
  - The front lateral acceleration rate is 1.846g while the rear is 1.881g
  - The left turn acceleration is 1.846g (**front** maximum capacity). The lateral acceleration rate at the **front** of the chassis is **now** the controlling factor in the chassis ultimate lateral performance i.e. the front has a lower lateral acceleration rate than the rear.
  - The braking capacity is 1.396g
  - The corner loads are LF = 344lb., RF = 765 lb., LR = 144 lb. and RR = 817 lb.
  - The ride heights are LF = 0.663", RF = 0.584", LR = 0.806" and RR = 0.735"
- **Maintaining** the 500 lb. aero load, move the aero pressure center forward to 52.22% front. This moves the y co-ordinate in Wan31A forward 2.797".

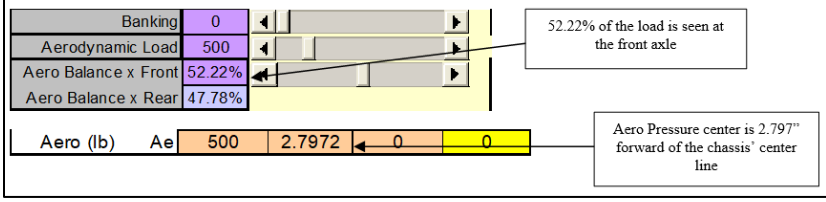


Table	Front View LF - Height	Front View LF - Length	Side View LF - Height	Side View LF - Length	Front View RF - Height	Front View RF - Length	Side View RF - Height	Side View RF - Length	Track Bar Angle	Side View LR - Height	Side View LR - Length	Side View RR - Height	Side View RR - Length	Lg	Rg	Ag	Bg
0	2.837	41.842	11.414	71.757	4.061	40.061	12.189	81.229	1	13.179	235.714	15.361	183.333	0	0	0	0
1	2.823	41.291	11.325	72.451	4.008	40.048	12.182	81.382	1.958	18.790	262.275	19.878	194.477	0	0	0	1
2	2.380	46.874	12.093	66.726	3.984	36.721	11.323	91.749	1.456	20.840	199.204	20.145	263.226	0.5	0	0	1.25
3	1.889	55.186	12.783	61.076	4.038	33.891	10.193	104.620	0.091	18.650	150.555	12.485	363.893	1	0	0	0.6
4	1.614	60.595	13.071	58.489	4.074	32.626	9.497	112.340	-0.716	17.458	133.246	4.849	436.362	1.25	0	0	0.15
5	1.258	67.519	13.332	55.950	4.101	31.296	8.573	122.459	-1.228	17.548	120.296	-4.575	608.375	1.53	0	0	0.05
6	1.470	63.508	13.193	57.332	4.090	32.049	9.124	116.435	-1.038	17.183	126.653	0.575	488.195	1.37	0	0	0
7	1.907	56.052	12.833	60.601	4.078	33.923	10.207	104.401	-0.776	15.566	142.403	5.875	328.006	1	0	0.3	0
8	2.217	51.048	12.483	63.541	4.071	35.590	10.924	96.249	-0.426	14.410	159.714	8.932	261.577	0.7	0	0.4	0
9	2.412	48.313	12.236	65.508	4.081	36.796	11.341	91.394	-0.367	12.795	171.290	9.464	227.189	0.5	0	0.65	0
10	2.630	42.317	11.487	71.178	4.106	40.136	12.194	81.096	0.182	9.228	216.805	11.909	174.614	0	0	0.85	0

LF Front	RF Front	Track Bar
1.258	4.101	-1.228
67.519	31.296	

LF Side	RF Side	LR Side	RR Side
13.332	8.573	17.548	-4.575
55.95	122.459	120.296	608.375

T_L	1.53
T_R	0
A	0
B	0.05

Table	(1) LF	(2) RF	(3) LR	(4) RR
0	0	0	0	0
1	30.9	43.1	-118.2	-106.0
2	-169.6	158.0	-182.2	145.3
3	-246.5	99.9	-129.4	217.0
4	-138.6	43.4	-61.8	120.3
5	-139.9	45.9	-108.0	77.8
6	75.4	-25.5	71.6	-29.2
7	98.2	-97.7	131.9	-63.9
8	120.0	-91.9	125.5	-86.3
9	42.2	-90.3	84.4	-48.1
10	195.2	-216.7	224.3	-187.6
	-139.9	45.9	-108.0	77.8

Calculating dynamic damper forces

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Developing The Tire Maps

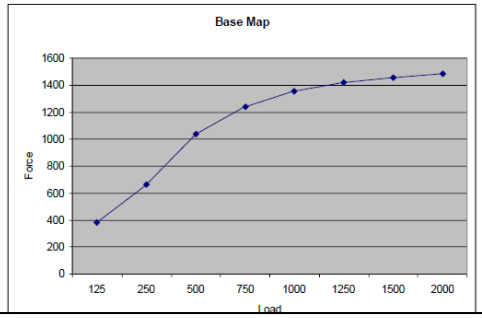
Tire maps are often broken into three parts: initial slope, knee and final slope. The steeper the slopes and the less curved the knee, the better the tire's performance will be under higher loads – see "**Base Tire Map**" in all **Wan31B** programs.

Base Tire Map

F_{max}	1500
a	1.8
L_o	250

Normal Load	125	250	500	750	1000	1250	1500	2000
Lateral Force	382	667	1037	1243	1357	1421	1456	1486
(F/L) Factor	3.06	2.67	2.07	1.66	1.36	1.14	0.97	0.74
Efficiency in %	306%	267%	207%	166%	136%	114%	97%	74%

Table 19-2



#5 Burrell

$F=F_{max}(1-a^{-L/Lo})$

3 parameters: F_{max}, a, L_o

F_{max} = constant

a = constant

L= load seen at contact patch

L_o= reference load

F reference $(a-1/a)F_{max}$

Normal Load (L)	500
F_{max}	2000
a	2.3
L_o	1100
Force	630.3543

Tested Tire Data

Once the initial base map has been developed, the various secondary factors are compiled. The following tables show the assorted acceleration forces for a variety of normal loads – Tables 19-4 through 19-9. The second row in each table is the base map. Developing a good base map is child's play compared to accurately predicting the various secondary factors. A "**Lateral Factors**" calculator can be found as part of the **Tire Calculator** program.

Steer

Normal Load	125	250	500	750	1000	1250	1500	2000
Base 2°	304	542	874	1078	1203	1279	1326	1372
Steer 1°	306	529	852	1050	1171	1245	1290	1335
Steer4°	309	552	891	1099	1227	1305	1353	1400
Steer6°	306	546	881	1086	1212	1289	1336	1383
Steer 8°	286	506	812	998	1112	1182	1225	1267

Table 19-4

Camber

Normal Load	125	250	500	750	1000	1250	1500	2000
Base 2 °	304	542	874	1078	1203	1279	1326	1372
Camber = 1°	291	516	829	1021	1138	1210	1254	1297
Camber = 4°	311	556	899	1109	1238	1317	1366	1413
Camber = 6°	306	546	882	1087	1213	1290	1337	1384
Camber =8°	295	525	844	1039	1159	1232	1277	1322

Table 19-5

Temperature

Normal Load	125	250	500	750	1000	1250	1500	2000
Constant	304	542	874	1078	1203	1279	1326	1372
Below constant	286	507	813	1000	1115	1185	1228	1270
Above Constant	278	492	788	968	1078	1146	1187	1228

Table 19-6

Wear

Normal Load	125	250	500	750	1000	1250	1500	2000
Scuffed	304	542	874	1078	1203	1279	1326	1372
Sticker	309	551	890	1098	1225	1303	1351	1398
Worn	294	523	842	1036	1156	1229	1273	1317
Done	271	478	763	937	1043	1108	1147	1187

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Book 1 Examples

LF Tire - Lateral	
F_{max}	1400
a	1.8
L_o	300
Normal Load	250
Base Lateral Force	542
ShearSilp Factor	1.0028
Camber Factor	1.0041
Temp. Factor	1
psi Factor	1.0012
Speed Factor	1
Wear Factor	1.0026
Lateral Force	**580**
(F/L) Factor g	2.320
Efficiency in %	232%
#1 Lateral vs Longitudinal	
A_{max} =	2.169
T_{max} =	2.320
T =	1.549
A =	1.615
G_A =	2.238

LF Tire - Longitudinal	
F_{max}	1400
a	1.8
L_o	300
Normal Load	250
Base Longitudinal	542
ShearSilp %	1
Camber Factor	1
Temp. Factor	1
psi Factor	1
Wear Factor	1
Longitudinal	**542**
(F/L) Factor g	2.169
Efficiency in %	217%
#2 Longitudinal vs Lateral	
A_{max} =	2.169
T_{max} =	2.320
A =	1.240
T_A =	1.904
G_A =	2.272

RF Tire - Lateral	
F_{max}	1400
a	1.8
L_o	300
Normal Load	1000
Base Lateral Force	1203
ShearSilp Factor	1.0028
Camber Factor	1.0041
Temp. Factor	1
psi Factor	1.0012
Speed Factor	1
Wear Factor	1.0026
Lateral Force	**1298**
(F/L) Factor g	1.298
Efficiency in %	130%
#1 Lateral vs Longitudinal	
A_{max} =	1.203
T_{max} =	1.298
T =	1.549
A =	0.000
G_A =	1.549

RF Tire - Longitudinal	
F_{max}	1400
a	1.8
L_o	300
Normal Load	1000
Base Longitudinal	1203
ShearSilp %	1
Camber Factor	1
Temp. Factor	1
psi Factor	1
Wear Factor	1
Longitudinal	**1203**
(F/L) Factor g	1.203
Efficiency in %	120%
#2 Longitudinal vs Lateral	
A_{max} =	1.203
T_{max} =	1.298
A =	1.240
T_A =	0.000
G_A =	1.240

LR Tire - Lateral	
F_{max}	1400
a	1.8
L_o	300
Normal Load	350
Base Lateral Force	695
ShearSilp Factor	1.0028
Camber Factor	1.0041
Temp. Factor	1
psi Factor	1.0012
Speed Factor	1
Wear Factor	1.0026
Lateral Force	**745**
(F/L) Factor g	2.130
Efficiency in %	213%
#1 Lateral vs Longitudinal	
A_{max} =	1.985
T_{max} =	2.130
T =	1.549
A =	1.362
G_A =	2.063

LR Tire - Longitudinal	
F_{max}	1400
a	1.8
L_o	300
Normal Load	350
Base Longitudinal	695
ShearSilp %	1
Camber Factor	1
Temp. Factor	1
psi Factor	1
Wear Factor	1
Longitudinal	**695**
(F/L) Factor g	1.985
Efficiency in %	199%
#2 Longitudinal vs Lateral	
A_{max} =	1.985
T_{max} =	2.130
A =	1.240
T_A =	1.663
G_A =	2.074

RR Tire - Lateral	
F_{max}	1400
a	1.8
L_o	300
Normal Load	850
Base Lateral Force	1135
ShearSilp Factor	1.0028
Camber Factor	1.0041
Temp. Factor	1
psi Factor	1.0012
Speed Factor	1
Wear Factor	1.0026
Lateral Force	**1224**
(F/L) Factor g	1.440
Efficiency in %	144%
#1 Lateral vs Longitudinal	
A_{max} =	1.336
T_{max} =	1.440
T =	1.549
A =	0.000
G_A =	1.549

RR Tire - Longitudinal	
F_{max}	1400
a	1.8
L_o	300
Normal Load	850
Base Longitudinal	1135
ShearSilp %	1
Camber Factor	1
Temp. Factor	1
psi Factor	1
Wear Factor	1
Longitudinal	**1135**
(F/L) Factor g	1.336
Efficiency in %	134%
#2 Longitudinal vs Lateral	
A_{max} =	1.336
T_{max} =	1.440
A =	1.240
T_A =	0.535
G_A =	1.351

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RowleyRaceDynamics

Book 1 Examples

The spinner moves the car through a 10-point dynamic cornering stage. Each click changes the lateral and longitudinal forces, aero forces, damper forces, and instant center heights and lengths, which, in turn, calculates the jacking and anti-forces.

Acceleration, Aero and IC Input Through Spinner

A5 Inertial Forces and CG location Version 2.31

		1570	x	y	z	
Wt (g)	W	1	-10.35	0.00	15.00	
Left(g)	TL	0	-10.35	0.00	15.00	
Right(g)	TR	0	-10.35	0.00	15.00	
Bank	α	0	(Degrees)			
Accel(g)	A	0	-10.35	0.00	15.00	
Brake(g)	B	0	-10.35	0.00	15.00	0
		pF =	65%	pR =	35%	

A6 Solution Y Tran. 0.0 X Tran. 0.0

		(1) LF	(2) RF	(3) LR	(4) RR	Total
A6.1 Loads						
Wheel	P	328.0	328.0	457.0	457.0	1570.0
Load Change		0.0	0.0	0.0	0.0	0.0
Spring	F	392.0	392.0	461.7	461.7	1707.4
RollBar	FR	0.0		0.0		
Damper	Fs	0.0	0.0	0.0	0.0	0.0
A6.2 Motion						
Wheel	dP	0.254	0.254	0.202	0.202	
Spring	d	0.196	0.196	0.185	0.185	
RollBar	dR	0.000			0.000	= dRo
Ride	z	0.758	0.758	0.795	0.795	

	Left	Rear	Wedge	Kin. x	Kin. Y
Bias	50.0%	58.2%	50.0%	-10.35	0.00

Chassis		Squat	Pitch	Roll		
Pad Squt	0.228	0.228	0.000	0.000	rad	In.
Dynamic Squat		0.000	0.023	0.000	deg	Ch.
Squat		Change	*NoseDn*	*Even*		

		(1) LF	(2) RF	(3) LR	(4) RR
A6.3 Ride					
Initial	Zo	1	1	1	1
Coord	x	34.992	34.992	56.11	56.11
	y	7.969	7.969	7.125	7.125
Chge	z	0.242	0.242	0.205	0.205
Final		0.758	0.758	0.795	0.795

Total: 0 / 61.76

Table	Front View LF - Height	Front View LF - Length	Side View LF - Height	Side View LF - Length	Front View RF - Height	Front View RF - Length	Side View RF - Height	Side View RF - Length	Track Bar Angle	Side View LR - Height	Side View LR - Length	Side View RR - Height	Side View RR - Length	Lg	Rg	Ag	Bg
0	2.837	41.842	11.414	71.757	4.061	40.061	12.189	81.229	1	13.179	235.714	15.361	183.333	0	0	0	0
1	2.823	41.291	11.325	72.451	4.008	40.048	12.182	81.382	1.958	18.790	262.275	19.878	194.477	0	0	0	1
2	2.380	46.874	12.093	66.726	3.984	35.721	11.323	91.749	1.456	20.840	199.204	20.145	263.226	0.5	0	0	1.25
3	1.889	55.186	12.783	61.076	4.038	33.891	10.193	104.620	0.091	18.650	150.555	12.485	363.893	1	0	0	0.6
4	1.614	60.595	13.071	58.489	4.074	32.626	9.497	112.340	-0.716	17.458	133.246	4.849	436.362	1.25	0	0	0.15
5	1.258	67.519	13.332	55.950	4.101	31.296	8.573	122.459	-1.228	17.548	120.296	-4.575	608.375	1.53	0	0	0.05
6	1.470	63.508	13.193	57.332	4.090	32.049	9.124	116.435	-1.038	17.183	126.653	0.575	488.195	1.37	0	0	0
7	1.907	56.052	12.833	60.601	4.078	33.923	10.207	104.401	-0.776	15.566	142.403	5.875	328.006	1	0	0.3	0
8	2.217	51.048	12.483	63.541	4.071	35.590	10.924	96.249	-0.426	14.410	159.714	8.932	261.577	0.7	0	0.4	0
9	2.413	48.313	12.236	65.508	4.081	36.796	11.341	91.394	-0.367	12.795	171.290	9.464	227.189	0.5	0	0.65	0
10	2.586	46.347	11.487	71.178	4.106	40.136	12.194	81.096	0.182	9.228	216.805	11.909	174.614	0	0	0.85	0

LF Front	RF Front	Track Bar
1.258	4.101	-1.228
67.519	31.296	

TL	1.53
TR	0
A	0
B	0.05

LF Side	RF Side	LR Side	RR Side
13.332	8.573	17.548	-4.575
55.95	122.459	120.296	608.375

Table	(1) LF	(2) RF	(3) LR	(4) RR
0	0	0	0	0
1	30.9	43.1	-118.2	-106.0
2	-169.6	158.0	-182.2	145.3
3	-246.5	99.9	-129.4	217.0
4	-138.6	43.4	-61.8	120.3
5	-139.9	45.9	-108.0	77.8
6	75.4	-25.5	71.6	-29.2
7	98.2	-97.7	131.9	-63.9
8	120.0	-91.9	125.5	-86.3
9	42.2	-90.3	84.4	-48.1
10	195.2	-216.7	224.3	-187.6
	-139.9	45.9	-108.0	77.8

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