12

Tires as Springs

(*It's just not this simple!)*

Pneumatic Tires - Tires used on race cars are capable of deforming/squishing in response to load. The rate of deformation depends upon the construction of the tire and the air pressure inside the tire. Tire deflection changes the chassis' clearances and ride heights, which, in turn, change the **aero balance** and the **suspension kinematics** (camber, toe etc.). On aero driven cars, a change in aero component clearance (change in the platform) can have a major effect on the chassis performance envelope.

Tire Performance Changes Due to a Change in Tire Pressure - Besides the previously stated kinematic and aero considerations, there are three primary reasons why a change in tire psi affects chassis performance:

- Change in amount of suspension motion due to tire squish
- Change due to tire spring rate
- Change due to contact patch size

All three are closely interconnected in that a change in tire pressure changes all three components. An increase in air pressure increases the spring rate while decreasing the amount of tire deflection/squish and the contact patch size per applied load. A decrease in psi causes an increase in contact patch size and amount of squish with a decrease in spring rate.

Tire Spring Rates - A tire's spring rate for any given load and psi setting can vary quite dramatically as the result of how the tire is constructed particularly between bias ply and radial construction. As discussed in the previous tire chapters, a bias ply tire changes in circumference, sidewall width and contact patch size with a change in psi far more dramatically than a radial tire. The bias ply tire is normally far more pliable than a radial tire. As a result, a bias ply tire's spring rate is generally much lower than a radial tire for any given load and air pressure setting (there are exceptions).

The tire spring rates presented in the following section are static spring rates as opposed to dynamic spring rates which are calculated with the tire rotating at various speeds. As a general rule, a tire's spring rate will increase with rotational speed; however, without test data from the tire manufacturer to use as a base, it is very difficult to develop a general formula to accurately correct the static load rates. Besides the increase in centrifugal loading, much of a tire's increased spring rate and subsequent decrease in squish is the result of impact loading as discussed in the tire chapters. Tested impact loading rates are often two to four times lower than many of the published formulas calculate. Radial tires generally have a much smaller tested increase in dynamic tire rate than a bias ply tire. Data from dynamic testing tends to be rather more linear in nature than from static tests, due, in part, to friction and stiction between the tire contact patch and the load cell plate.

Definitions - Up to this point in the book, we have been referring to wheel rate as the amount of force/load it takes to bump a wheel as the result of the various spring and bar forces. This definition is correct if the tires are infinitely stiff, which, of course, is never the case. Tires also have a spring rate which must be factored into the overall wheel rate. When only considering the rate resulting from springs and anti roll bars, we refer to this rate as the **hub center rate** i.e. the rate required to move the hub center in bump. Later in the book we will also include the damper velocity versus force rates in these calculations. **True Wheel rate** is the rate seen at the tire contact patch, which includes both the spring and bar rates as well as the tire spring rate. It is the rate/force required to lift the tire at the contact patch in bump.

- **Hub Center Rate** is the combined spring, bar and damper rates times the distance the components compress/deflect times the appropriate motion ratio - H_{CR}. This rate tells us the incremental amount of force/load needed to move the center of the hub in bump from a static load condition.

- **Combined Rate/Wheel Rate** is the combined hub center rate and tire spring rate in series. The formula used to find the rate of two springs in series is $S^1*S^2/(S^1+S^2)$. In our case it would be $H_{CR}*T_R/(H_{CR}+T_R)$ where T_R = the spring rate of the tire. This rate tells us the amount of force/load needed to move the wheel in bump when a force/load is applied at the tire contact patch. Wheel rate will always be less than hub center rate as two springs in series always have a smaller rate than the spring with the lowest rate. Spring, bar and damper rates are calculated in parallel while tire spring rate is calculated in series.

- **Vertical Load/Wheel Load** is the total or actual load the tire contact patch sees which is the combined static and dynamic load/weight as the result of ride and roll forces.

As previously stated, if we put two springs in series, their combined rate is $S^1*S^2/(S^1+S^2)$ i.e. the force needed to push the springs down one inch is the result of the combined rates of the two springs - Figure 12-1. This is true whether motion ratios are involved or not. A formula known as the reciprocal of reciprocals can also be used to find the rate of combined springs in series. 1/(1/500+1/2000) = 1/(0.002+0.0005) = 1/0.0025 = 400 lb.

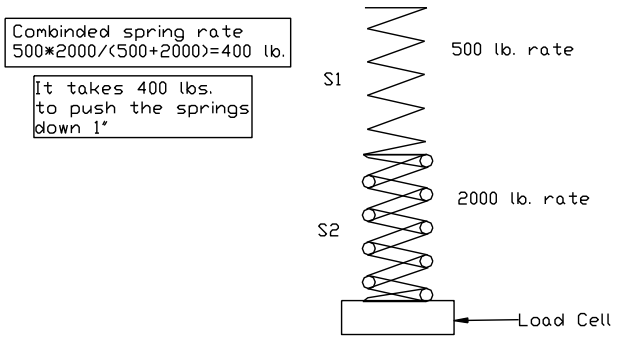


Figure 12-1

Tire Squish Versus Wheel Rate - Because the tire is compliant under load, it will see a certain amount of deflection/squish. The lower the tire's psi, the more squish it will see for a given load. There is a direct relationship between the amount of tire squish and resultant change in suspension motion. As the amount of tire squish increases, the suspension motion decreases proportionally.

Approximate Wheel Rate Calculations - Because of the variance in motion ratios, the following calculations are only approximate and are simply intended to help the reader understand how these calculations are developed. WinGeo3 calculates motion ratios through very small iterations rather than using instantaneous motion ratios as explained in Chapter 10 and is, therefore, far more accurate.

- To calculate the amount of tire squish if the suspension system was locked in place, you divide the hub center rate by the tire spring rate .... (325.219/2000 = 0.163377).

- To calculate the actual amount of tire squish (suspension is not locked), add the locked tire squish number to the amount of ride travel (in this case 1" of ride - 1"+0.163377" = 1.16337") and divide that number into the ride travel .... (1/1.16337 = 0.85956). Now multiple this last number by the locked tire squish number (0.163377*0.859567 = 0.140433).

- To calculate the suspension and tire combined rate\wheel rate, when you have a hub center rate of 325.219 and a tire spring rate of 2000, you can use the springs in series formula .... (325.219*2000)/(325.219+2000) = 279.7319.

- 0.140 is the actual amount of tire squish when suspension motion is taken into consideration while the wheel rate/load is 279.7319.

William C. Mitchell, clever man that he is, discovered that the combined wheel load can be calculated by multiplying the hub center rate by the amount of tire squish and then subtracting that number from the hub center rate:

- 325.219*0.140433 = 45.67161
- 325.219-45.67161 = 279.5474 lb. The actual number is slightly different because of motion ratio variances.

When the suspension is in pure ride, the wheel rate and wheel load/vertical load will be the same. This is not the case when the chassis sees both ride and roll iterations.

Tables 12-1 & 12-2 show the differences in wheel loads as the result of changes in tire spring rate. The example is from a WinGeo3 asymmetric stock car chassis - both the left and right springs are 1000 lb./in. and no anti roll bar is used. The **no tire squish** numbers are calculated using an infinitely stiff tire i.e. only the spring rates and suspension geometry determine the loads seen at the contact patches for a given ride/roll iteration. For the squish calculations, a variety of tire spring rate combinations are used ranging from 1000 lb. 1500 lb. and 2000 lb. Notice how much lower the wheel rates are when the tire spring rates are 1000 lb. compared to 2000 lb.

Table 12-1

Tire Squish Versus Wheel rate - Stock Car # 1209						**Asymmetric Chassis**			
*Change in wheel rate due to a change in tire deflection and suspension motion Coil springs used in all tests have a 1000 lb. rate									
Tire#	Test#	Date							
						Wheel Rate			Wheel Rate
InsideTire	OutsideTire	Ride	Roll	No Squish	Squish	Inside	No Squish	Squish	Outside
Spring Rate	Spring Rate			inside Load	inside	Load	Outside Load	Outside	Load
1000	1000	-1	\	483.828	-0.331	331.124	502.347	-0.344	344.127
1500	1500	-1	\	483.828	-0.247	370.603	502.347	-0.257	385.054
2000	2000	-1	\	483.828	-0.197	393.912	502.347	-0.205	409.21
1000	1000	\	2	-616.178	0.393	-393.206	571.591	-0.744	744.295
1500	1500	\	2	-616.178	0.298	-446.686	571.591	-0.469	703.488
2000	2000	\	2	-616.178	0.24	-479.42	571.591	-0.339	678.314
1000	1000	-1	2	-64.119	0.042	-42.077	988.003	-1.004	1003.619
1500	1500	-1	2	-64.119	0.032	-47.516	988.003	-0.667	999.773
2000	2000	-1	2	-64.119	0.025	-50.802	988.003	-0.499	997.448

Table 12-2 shows the change in wheel rate for 100 and 1 lb. changes in tire spring rate (two left hand columns).

Table 12-2

Stock Car #1209				Wheel Rate	Change in	Change per
OutsideTire	Ride	No Squish	Squish	Outside	Wheel Rate	lb. tire rate
Spring Rate		Outside Load	Outside	Load	Load	Change
2000	-1	988.003	-0.205	409.21		
1900	-1	988.003	-0.213	405.206	-4.004	-0.04004
1800	-1	988.003	-0.223	400.844	-4.362	-0.04362
1700	-1	988.003	-0.233	396.073	-4.771	-0.04771
1600	-1	988.003	-0.244	390.834	-5.239	-0.05239
1500	-1	988.003	-0.257	385.05	-5.784	-0.05784

Table 12-3 gives an indication of the type of kinematic changes seen by a stock car as the result of 1000 and 2000 lb. tire spring rates and their related amounts of squish.

Table 12-3

Changes to right side kinematics					Spring = 1000 lb.		Stock Car				
Tire	Ride	Camber	Camber	Caster	Caster	Caster trail	Caster trail	Kingpin	Kingpin	Steer	Steer
rate	Roll	No squish	With squish	No squish	With squish	No squish	With squish	No squish	With squish	No squish	With squish
1000	(-1/0)	-4.465	-4.112	5.665	5.457	1.128	1.044	7.993	7.631	-0.348	-0.288
1000	(0/1)	-3.027	-2.837	5.390	5.260	1.076	1.023	6.544	6.349	-0.270	-0.226
1000	(-1/1)	-4.129	-3.521	5.970	5.682	1.215	1.079	7.667	7.049	-0.416	-0.356
2000	(-1/0)	-4.465	-4.251	5.665	5.542	1.128	1.078	7.993	7.773	-0.348	-0.314
2000	(0/1)	-3.027	-2.912	5.390	5.313	1.076	1.044	6.544	6.426	-0.270	-0.244
2000	(-1/1)	-4.129	-3.76	5.970	5.803	1.215	1.147	7.667	7.293	-0.416	-0.901

Table 12-4 illustrates the differences in tire squish versus wheel rate for a Formula car using a bell crank push rod system.

Table 12-4

Tire Squish Versus Wheel rate - Bell Crank #A-12c						**Asymmetric Chassis**			
*Change in wheel rate due to a change in suspension motion as the result of tire deflection Coil springs used in all tests have a 1000 lb. rate									
Tire#	Test#	Date							
						Wheel Rate			Wheel Rate
InsideTire	OutsideTire	Ride	Roll	No Squish	Squish	Inside	No Squish	Squish	Outside
Spring Rate	Spring Rate			inside Load	inside	Load	Outside Load	Outside	Load
1000	1000	-1	\	900.202	-0.565	345.884	900.202	-0.582	331.455
1500	1500	-1	\	900.202	-0.357	534.427	900.202	-0.357	534.398
2000	2000	-1	\	900.202	-0.296	592.518	900.202	-0.296	592.518
1000	1000	\	2	-678.298	0.449	-448.886	1076.023	-0.784	288.619
1500	1500	\	2	-678.298	0.339	-508.571	1076.023	-0.417	623.433
2000	2000	\	2	-678.298	0.272	-543.852	1076.023	-0.347	693.688
1000	1000	-1	2	-107.612			2683.06		
1500	1500	-1	2	-107.612	0.49	-73.735	2683.06	-0.957	1129.133
2000	2000	-1	2	-107.612	0.04	-80.07	2683.06	-0.722	1433.265

Table 12-5 shows the change in wheel rate for 100 and 1 lb. changes in tire spring rate (two left hand columns).

Table 12-5

Bell Crank #A-12c				Center Rate	Change in	Change per
OutsideTire	Ride	No Squish	Squish	Outside	center rate	lb. tire rate
Spring Rate		Outside Load	Outside	Load	Load	Change
2000	-1	900.202	-0.296	592.518		
1900	-1	900.202	-0.307	582.505	-10.013	-0.10013
1800	-1	900.202	-0.318	571.795	-10.71	-0.1071
1700	-1	900.202	-0.33	560.298	-11.497	-0.11497
1600	-1	900.202	-0.343	547.896	-12.402	-0.12402
1500	-1	900.202	-0.357	534.398	-13.498	-0.13498

Table 12-6 gives an indication of the type of kinematic changes seen by a Formula car as the result of 1000 and 2000 lb. tire spring rates and their related amounts of squish.

Table 12-6

Changes to right side kinematics					Spring = 1000 lb.		Formula Car				
Tire	Ride	Camber	Camber	Caster	Caster	Caster trail	Caster trail	Kingpin	Kingpin	Steer	Steer
rate	Roll	No squish	With squish	No squish	With squish	No squish	With squish	No squish	With squish	No squish	With squish
1000	(-1/0)	-3.348	-3.186	6.919	6.830	0.587	0.518	7.536	7.375	0.027	0.012
1000	(0/1)	-2.194	-2.107	6.821	6.771	0.576	0.538	6.383	6.297	0.013	0.006
1000	(-1/1)	-2.571	-2.290	7.018	6.873	0.611	0.498	6.757	6.479	0.054	0.021
2000	(-1/0)	-3.348	-3.240	6.919	6.680	0.587	0.542	7.536	7.428	0.027	0.017
2000	(0/1)	-2.194	-2.138	6.821	6.789	0.576	0.551	6.383	6.327	0.013	0.008
2000	(-1/1)	-2.571	-2.378	7.018	6.920	0.611	0.534	6.757	6.566	0.054	0.030

Table 12-7 illustrates the differences in tire squish versus wheel rate for a symmetric GT coil over chassis.

Table 12-7

Tire Squish Versus Wheel rate - Coil Over #743						**Symmetric Chassis**			
*Change in wheel rate due to a change in suspension motion as the result of tire deflection Coil springs used in all tests have a 1000 lb. rate									
Tire#	Test#	Date							
						Wheel Rate			Wheel Rate
InsideTire	OutsideTire	Ride	Roll	No Squish	Squish	Inside	No Squish	Squish	Outside
Spring Rate	Spring Rate			inside Load	Outside	Load	Outside Load	Outside	Load
1000	1000	-1	\	558.224	-0.360	359.502	558.224	-0.360	359.499
1500	1500	-1	\	558.224	-0.272	408.101	558.224	-0.272	408.101
2000	2000	-1	\	558.224	-0.219	437.608	558.224	-0.219	437.608
1000	1000	\	2	-542.153	0.346	-345.936	540.524	-0.347	346.873
1500	1500	\	2	-542.153	0.262	-393.355	540.524	-0.263	394.099
2000	2000	\	2	-542.153	0.211	-422.295	540.524	-0.211	422.81
1000	1000	-1	2	22.571	-0.014	14.473	1084.021	-0.704	704.177
1500	1500	-1	2	22.571	-0.011	16.44	1084.021	-0.532	798.317
2000	2000	-1	2	22.571	-0.009	17.638	1084.021	-0.428	855.166

Table 12-8 gives an indication of the type of kinematic changes seen by a GT car as the result of 1000 and 2000 lb. tire spring rates and their related amounts of squish.

Table 12-8

Changes to right side kinematics					Spring = 1000 lb.		GT Car				
Tire	Ride	Camber	Camber	Caster	Caster	Caster trail	Caster trail	Kingpin	Kingpin	Steer	Steer
rate	Roll	No squish	With squish	No squish	With squish	No squish	With squish	No squish	With squish	No squish	With squish
1000	(-1/0)	-2.947	-2.395	1.910	1.772	0.234	0.210	13.283	12.737	0.538	0.339
1000	(0/1)	-1.161	-0.915	1.704	1.638	0.216	0.203	11.506	11.262	0.253	0.160
1000	(-1/1)	-2.748	-1.868	2.087	1.884	0.254	0.218	13.074	12.205	0.813	0.510
2000	(-1/0)	-2.947	-2.606	1.910	1.826	0.234	0.219	13.283	12.946	0.538	0.416
2000	(0/1)	-1.161	-1.010	1.704	1.664	0.216	0.208	11.506	11.356	0.253	0.196
2000	(-1/1)	-2.748	-2.203	2.087	1.963	0.254	0.232	13.074	12.536	0.813	0.627

Tire Data

About the data presented in the following tables - Data is seldom, if ever, what you expect and the material in the following tables is no exception. All tests were conducted at least three times. If the tested data for all three tests were within a few pounds, the numbers were averaged before being entered into the tables. The data in these tables has not been doctored to fit some presupposed norm.

Contact Patch Load Rate and Tire Spring Rate - If we place a helical spring on a scale and preload the spring by placing an appropriate weight on it, measure the preloaded height and then add weight until the spring compresses an additional 1", the scale reading will give us both the spring rate (pounds per one inch deflection) and the load the spring is exerting on the scale surface (lb.). The same thing takes place when we load a pneumatic tire as it sits on the road. If we place a vertical force of 100 lb. (weight) at the tire hub center, and, as a result, the radius of the tire changes 1/8", we can say that the tire has a spring rate of 100 lb. per 1/8" deflection or 800 lb. per 1" deflection/radius change. We can also say that the tire, at the contact patch, is exerting a load of 100 lb. on the road.

Table 12-9 illustrates the changes in spring rate through 1/4" deflection/squish increments at various psi settings for a bias ply tire. Notice that the amount of additional load increase seen for each 1/4" deflection increment **decreases** as deflection increases - *** Load Rate = Spring Rate.**

Table 12-9

Tire Spring Rate	Tire # 3238-d		Bias ply - RF			
Load change per 1/4" change in radius @ 5 psi increments						
Tire is preloaded to 500 lb. - load cell is zeroed and zeroed again after each test iteration						
psi	#1-1/4" Load	#2-1/2" Load	1/2" Total	#3-3/4" Load	3/4" Total	#4-1" Load	1" Total
15	250	218	468	211	779	198	977
20	320	231	551	225	812	218	1030
25	400	314	714	272	959	267	1226
30	412	339	751	320	1092	289	1381
35	440	352	792	340	1150	331	1481
40	466	366	832	348	1180	336	1516

Table 12-10 extrapolates the average change in contact patch load per pound of tire pressure change i.e. within the first 1/4" of tire deflection the average change in load between 15 psi and 16 psi . . . . . 19 psi and 20 psi is 14 lb.

Table 12-10

Average load change per 1 psi change							
psi	#1-1/4" Load	#2-1/2" Load	1/2" Total	#3-3/4" Load	3/4" Total	#4-1" Load	1" Total
15	1 psi average	1 psi average	1 psi average	1 psi average	1 psi average	1 psi average	1 psi average
20	14	2.6	16.6	2.8	6.6	4	10.6
25	16	16.6	32.6	9.4	29.4	9.8	39.2
30	2.4	5	7.4	9.6	26.6	4.4	31
35	5.6	2.6	8.2	4	11.6	8.4	20
40	5.2	2.8	8	1.6	6	1	7

Table 12-11 illustrates the changes in spring rate through 1/4" squish increments at various psi settings for a RF oval track radial tire with no inner liner. Notice, as with the bias ply example, the amount of additional load seen for each 1/4" deflection increment **decreases** as deflection increases. The load rates for this radial tire are much higher than in the previous bias ply example.

Table 12-11

Tire Spring Rate			**RF** G #32755 - a		Track #3438				
Test#	Static A27		Date						
Note: Tire preload is 500 lb. Load cell was then zeroed and zeroed again after each test segment.									
* No inner liner									
psi	Base radius	500 lb. radius	#1. - 1/4" deflection load	#2. - 1/4" load	1/2" total load	#3. - 1/4" load	3/4" total load	#4. - 1/4" load	1" total load
15	13.83	13.634	566	530	1096	504	1600	423	2023
20	13.85	13.673	740	575	1315	562	1877	552	2429
25	13.854	13.714	810	711	1521	684	2205	613	2818
30	13.864	13.719	910	820	1730	798	2528	706	3234
35	13.897	13.75	1072	935	2007	816	2823	710	3533
40	13.939	13.825	1361	964	2325	956	3281	806	4087
45	13.894	13.791	1408	1134	2542	972	3514	865	4379

Tire spring rate (pounds per inch of deflection) is normally calculated within the dynamic range of squish/deflection because the spring rate of a tire is not linear as is the case of high quality springs. As shown in Table 12-12, if the operating rate of dynamic tire squish/deflection is within a 1/4", then the spring (lb./in) rate of the tire would be load divided by deflection. For the 15 psi example, it would be 566/0.250 = 2264 lb. Notice the dynamic 1/4" deflection spring rate **2264** is higher than the combined one inch rate **2023**. To keep the tables smaller for this book, 1/4" deflection increments were used. Actual rates are normally worked out in 0.040" increments. This same method is also used to work out biscuit and bump stop rates. *1" total load = tire spring rate.*

Table 12-12

Tire Spring Rate		**RF** G #32755 - a		Track #3438		**Radial**		
Test#	Static A27	Date						
Note: Tire preload is 500 lb. Load cell was then zeroed and zeroed again after each test segment.								
* no inner liner								
psi	#1. - 1/4" deflection load	#1. - 1/4" **lb./in** Load / 0.25	#2. - 1/4" load	#2. - 1/4" **lb./in** Load / 0.25	#3. - 1/4" load	#3. - 1/4" **lb./in** Load / 0.25	#4. - 1/4" load	#4. - 1/4" **lb./in** Load / 0.25	1" total load
15	566	2264	530	2120	504	2016	423	1692	2023
20	740	2960	575	2300	562	2248	552	2208	2429
25	810	3240	711	2844	684	2736	613	2452	2818
30	910	3640	820	3280	798	3192	706	2824	3234
35	1072	4288	935	3740	816	3264	710	2840	3533
40	1361	5444	964	3856	956	3824	806	3224	4087
45	1408	5632	1134	4536	972	3888	865	3460	4379

Table 12-13 shows the average load changes per 1 pound of tire pressure change. Notice that the rate changes are far from linear. This non-linearity tends to make the accurate tuning of the chassis through tire pressure changes rather more difficult. Even tires made from the same manufacturer can change quite considerably from track to track. *1" total load = tire spring rate*

Table 12-13

Load change per 1 psi change					
psi	#1. - 1/4"	#2. - 1/4"	#3. - 1/4"	#4. - 1/4"	1" total
	per 1 psi	per 1 psi	per 1 psi	per 1 psi	per 1 psi
20	34.8	9	11.6	25.8	81.2
25	14	27.2	24.4	12.2	77.8
30	20	21.8	22.8	18.6	83.2
35	32.4	23	3.6	0.8	59.8
40	57.8	5.8	28	19.2	110.8
45	9.4	34	3.2	11.8	58.4

Table 12-14 illustrates the difference between zero and negative 4.4 degrees of camber at 40 psi. Notice the lack of linearity. Test data, as previously stated, is never nice and neat. This test, as all tests in this section, was run three times to make sure there were no erroneous readings.
1" total load = tire spring rate

Table 12-14

4.4 negative camber									
psi	Camber	500 lb.	#1. - 1/4"	#2. - 1/4"	1/2"	#3. - 1/4"	3/4"	#4. - 1/4"	1"
		radius	deflection		total		total		total
		outside	load	load	load	load	load	load	load
40	0	13.825	1361	964	2325	956	3281	806	4087
40	4.4	14.664	1059	1026	2085	941	3026	714	3740
	Change	0.839	-302	62	-240	-15	-255	-92	-347

Tables 12-15 illustrates the changes in spring rate through 1/4" deflection/squish increments at various psi settings for a RF oval track radial tire running an **inner liner**. *1" total load = tire spring rate*

Table 12-15

Tire Spring Rate **RF** Tire # DH - 2312 Radial

Test# Static A14 Date Track #8772

Note: Tire preload is 500 lb. Load cell was then zeroed and zeroed again after each test segment.

*** Inner liner set @ 60 psi**

psi	Base	500 lb.	#1. - 1/4"	#2. - 1/4"	1/2"	#3. - 1/4"	3/4"	#4. - 1/4"	1"
	radius	radius	deflection		total		total		total
			load	load	load	load	load	load	load
20	13.830	13.664	738	661	1399	584	1983	536	2519
25	13.839	13.699	935	827	1762	721	2483	612	3095
30	13.878	13.738	938	928	1866	815	2681	707	3388
35	13.879	13.747	986	1067	2053	1010	3063	820	3883
40	13.902	13.779	1153	1105	2258	1034	3292	883	4175
45	13.914	13.743	1209	1194	2403	1090	3493	980	4473
50	13.904	13.734	1278	1198	2476	1156	3632	1010	4642
At outer 20 psi inner liner pressure is down to 57 psi									
20 lb. Difference on the outside makes 3 lb. difference on the inside									

Table 12-16 shows the actual or dynamic spring rate within the active range of tire squish (lb./in.)

Table 12-16

Tire Spring Rate			**RF** Tire #		DH - 2312		Radial		
Test# Static A14			Date		Track #8772				
Note: Tire preload is 500 lb. Load cell was then zeroed and zeroed again after each test segment.									
*** Inner liner set @ 60 psi**									
psi	#1. - 1/4"	#1. - 1/4"	#2. - 1/4"	#2. - 1/4"	#3. - 1/4"	#3. - 1/4"	#4. - 1/4"	#4. - 1/4"	1"
	deflection	**lb./in**	deflection	**lb./in**	deflection	**lb./in**	deflection	**lb./in**	total
	load	Load / 0.25	load	Load / 0.25	load	Load / 0.25	load	Load / 0.25	load
20	738	2952	661	2644	584	2336	536	2144	2519
25	935	3740	827	3308	721	2884	612	2448	3095
30	938	3752	928	3712	815	3260	707	2828	3388
35	986	3944	1067	4268	1010	4040	820	3280	3883
40	1153	4612	1105	4420	1034	4136	883	3532	4175
45	1209	4836	1194	4776	1090	4360	980	3920	4473
50	1278	5112	1198	4792	1156	4624	1010	4040	4642

Table 12-17 presents the difference in load rate per a change of 1 psi for the above tire. *1" total load = tire spring rate*

Table 12-17

RF Tire #	DH - 2312		Track #8772		
Load change per 1 psi change					
psi	#1. - 1/4"	#2. - 1/4"	#3. - 1/4"	#4. - 1/4"	1"
	1 psi	1 psi	1 psi	1 psi	1 psi
25	39.4	33.2	27.4	15.2	115.2
30	0.6	20.2	18.8	19	58.6
35	9.6	27.8	39	22.6	99
40	33.4	7.6	4.8	12.6	58.4
45	11.2	17.8	11.2	19.4	59.6
50	13.8	0.8	13.2	6	33.8

Table 12-18 illustrates the change in spring rate with 10 pound changes in inner liner pressure. *1" total load = tire spring rate*

Table 12-18

Changes in inner liner psi with constant 40 outer psi									
psi	Base	500 lb.	#1. - 1/4"	#2. - 1/4"	1/2"	#3. - 1/4"	3/4"	#4. - 1/4"	1"
	radius	radius	deflection	deflection	total	deflection	total	deflection	total
			load	load	load	load	load	load	load
40/70	13.945	13.798	1021	993	2014	865	2879	736	3615
40/60	13.922	13.771	1114	1000	2114	862	2976	767	3743
40/50	13.869	13.746	1120	1060	2180	1011	3191	781	3972

Table 12-19 illustrates the changes in load rate through 1/4" squish increments at various psi settings for a LF oval track radial tire running an inner liner. *1" total load = tire spring rate*.

Table 12-19

Tire Spring Rate			**LF** Tire #		DH - 2454		Track #8772		
Test#	Static B14		Date						
Note: Tire preload is 500 lb. Load cell was then zeroed and zeroed again after each test segment.									
* Inner liner set @ 45 psi - kept constant throughout test									
psi	Base	500 lb.	#1. - 1/4"	#2. - 1/4"	1/2"	#3. - 1/4"	3/4"	#4. - 1/4"	1"
	radius	radius	deflection		total		total		total
			load	load	load	load	load	load	load
20	13.637	13.476	855	665	1520	617	2137	545	2682
25	13.654	13.511	1010	813	1823	752	2575	640	3215
30	13.694	13.587	1001	1022	2023	901	2924	668	3592
35	13.679	13.564	1177	1039	2216	927	3143	765	3908
40	13.664	13.554	1263	1111	2374	1099	3473	799	4272

Table 12-20 shows the actual or dynamic spring rate within the active range of tire squish (lb./in.)

Table 12-20

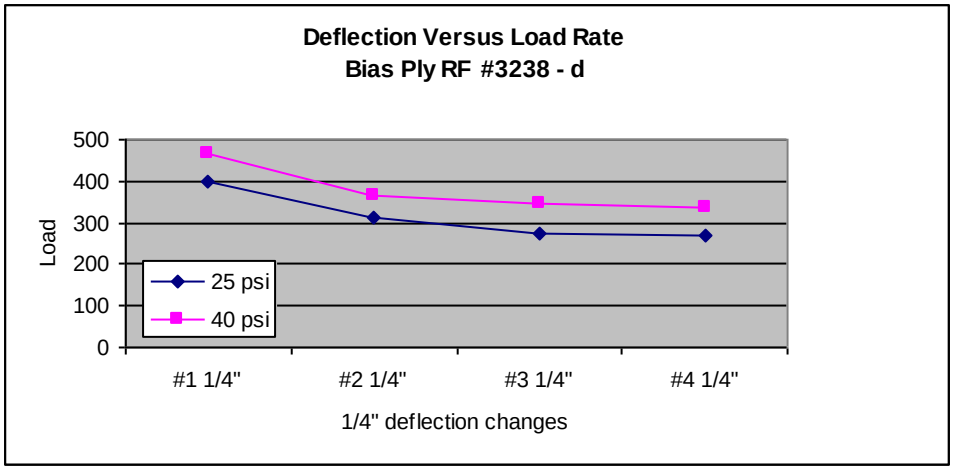
Tire Spring Rate			**LF** Tire #	DH - 2454				Track #8772	
Test#	Static B14		Date						
Note: Tire preload is 500 lb. Load cell was then zeroed and zeroed again after each test segment.									
* Inner liner set @ 45 psi - kept constant throughout test									
psi	#1. - 1/4"	#1. - 1/4"	#2. - 1/4"	#2. - 1/4"	#3. - 1/4"	#3. - 1/4"	#4. - 1/4"	#4. - 1/4"	1"
	deflection	**lb./in**		**lb./in**		**lb./in**		**lb./in**	total
	load	Load / 0.25	load	Load / 0.25	load	Load / 0.25	load	Load / 0.25	load
20	855	3420	665	2660	617	2468	545	2180	2682
25	1010	4040	813	3252	752	3008	640	2560	3215
30	1001	4004	1022	4088	901	3604	668	2672	3592
35	1177	4708	1039	4156	927	3708	765	3060	3908
40	1263	5052	1111	4444	1099	4396	799	3196	4272

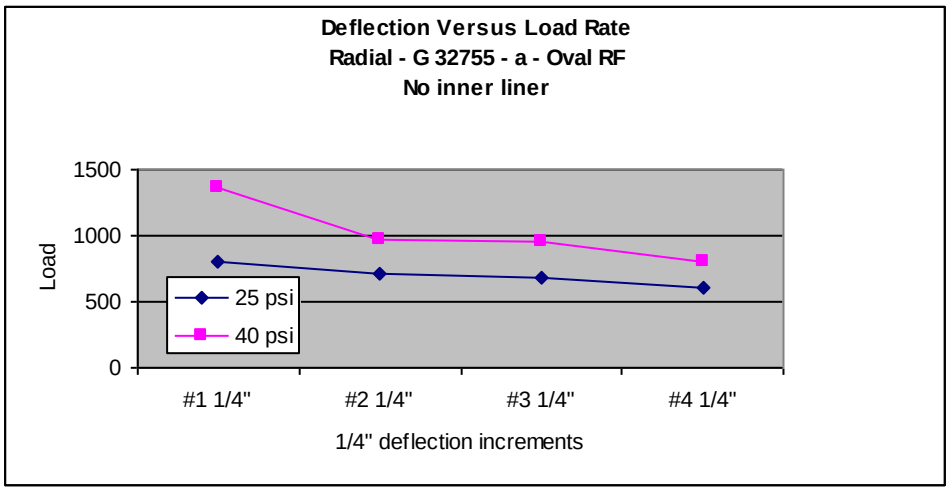
Table 12-21 illustrates the changes in spring rate with 5 pound changes in inner liner pressure. *1" total load = tire spring rate*.

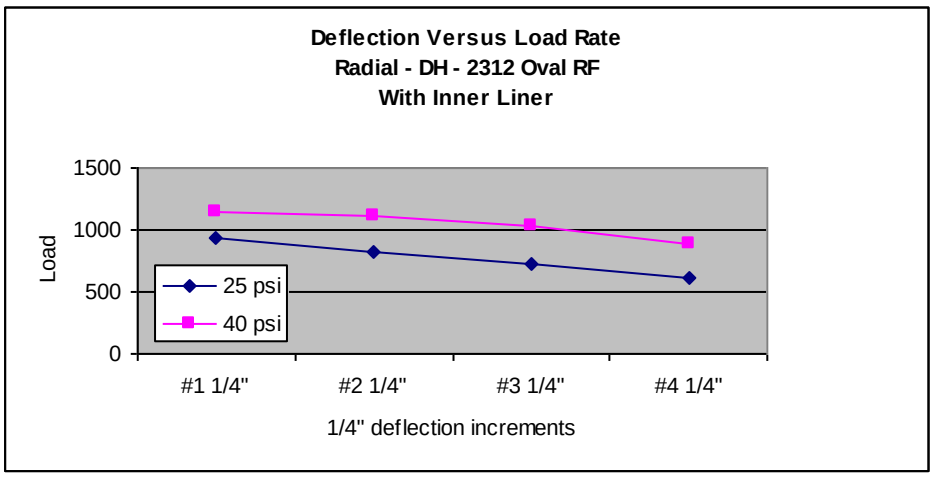
Table 12-21

Changes in inner liner psi with constant 30 outer psi									
30/45	13.657	13.525	1078	892	1970	864	2834	772	3606
30/50	13.653	13.508	1084	933	2017	870	2887	684	3571
30/55	13.639	13.527	1043	937	1980	805	2785	746	3531

The following graphs illustrate the various deflection versus load rates for a bias ply tire and two radial oval track tires, one without an inner liner and one with an inner liner.







Tables 12-22/12-25 illustrate the spring rate of a tire currently used in a popular GT racing series in North America. Notice how **low** the spring rate is even though the tire uses a **radial** design.
1" total load = tire spring rate

Table 12-22

Tire Spring Rate			Tire #	**Rear**	**Radial**				
Test#			Date						
Note: Tire preload is 500 lb. Load cell was then zeroed and zeroed again after each test segment.									
* no inner liner									
psi	Base	500 lb.	#1. - 1/4"	#2. - 1/4"	1/2"	#3. - 1/4"	3/4"	#4. - 1/4"	1"
	radius	radius	deflection	deflection	total	deflection	total	deflection	total
			load	load	load	load	load	load	load
15	13.457	13.089	364	366	730	412	1142	346	1488
20	13.470	13.128	409	410	819	452	1271	407	1678
25	13.483	13.19	463	469	932	488	1420	450	1870
30	13.491	13.223	502	529	1031	504	1535	515	2050
35	13.496	13.253	562	579	1141	538	1679	535	2214
40	13.502	13.282	604	637	1241	546	1787	585	2372

Table 12-23

psi	#1. - 1/4"	#1. - 1/4"	#2. - 1/4"	#2. - 1/4"	#3. - 1/4"	#3. - 1/4"	#4. - 1/4"	#4. - 1/4"	1"
	deflection	**lb./in**	deflection	**lb./in**	deflection	**lb./in**	deflection	**lb./in**	total
	load	Load / 0.25	load	Load / 0.25	load	Load / 0.25	load	Load / 0.25	load
15	364	1456	366	1464	412	1648	346	1384	1488
20	409	1636	410	1640	452	1808	407	1628	1678
25	463	1852	469	1876	488	1952	450	1800	1870
30	502	2008	529	2116	504	2016	515	2060	2050
35	562	2248	579	2316	538	2152	535	2140	2214
40	604	2416	637	2548	546	2184	585	2340	2372

Tables 12-24 illustrate the spring rate of a front tire from the same series as in the previous example. *1" total load = tire spring rate*

Table 12-24

Tire Spring Rate			Tire #	**Front**	**Radial**				
Test#			Date						
Note: Tire preload is 500 lb. Load cell was then zeroed and zeroed again after each test segment.									
* no inner liner									
psi	Base	500 lb.	#1. - 1/4"	#2. - 1/4"	1/2"	#3. - 1/4"	3/4"	#4. - 1/4"	1"
	radius	radius	deflection	deflection	total	deflection	total	deflection	total
			load	load	load	load	load	load	load
15	12.655	12.26	363	372	735	390	1125	375	1500
20	12.585	12.25	365	432	797	448	1245	409	1654
25	12.580	12.286	441	475	916	499	1415	452	1867
30	12.531	12.274	472	522	994	522	1516	490	2006
35	12.500	12.25	521	536	1057	555	1612	580	2192
40	12.465	12.243	595	636	1231	576	1807	595	2402

Table 12-25

psi	#1. - 1/4"	#1. - 1/4"	#2. - 1/4"	#2. - 1/4"	#3. - 1/4"	#3. - 1/4"	#4. - 1/4"	#4. - 1/4"	1"
	deflection	**lb./in**	deflection	**lb./in**	deflection	**lb./in**	deflection	**lb./in**	total
	load	Load / 0.25	load	Load / 0.25	load	Load / 0.25	load	Load / 0.25	load
15	363	1452	372	1488	390	1560	375	1500	1500
20	365	1460	432	1728	448	1792	409	1636	1654
25	441	1764	475	1900	499	1996	452	1808	1867
30	472	1888	522	2088	522	2088	490	1960	2006
35	521	2084	536	2144	555	2220	580	2320	2192
40	595	2380	636	2544	576	2304	595	2380	2402

The tire illustrated in Tables 12-26 & 12-27 is one formerly used in the same series as the two previous examples. Notice that even though this tire is a bias ply tire, its spring rate is quite similar to the two previous examples. *1" total load = tire spring rate*

Table 12-26

Tire Spring Rate			Tire #	Rear	Older GT Tire		**Bias Ply**		
Test#			Date						
Note: Tire preload is 500 lb. Load cell was then zeroed and zeroed again after each test segment.									
* no inner liner									
psi	Base	500 lb.	#1. - 1/4"	#2. - 1/4"	1/2"	#3. - 1/4"	3/4"	#4. - 1/4"	1"
	radius	radius	deflection	deflection	total	deflection	total	deflection	total
			load	load	load	load	load	load	load
15	13.243	12.861	367	348	715	378	1093	374	1467
20	13.24	12.884	386	402	788	450	1238	401	1639
25	13.239	12.908	453	495	948	495	1443	443	1886
30	13.264	12.959	507	568	1075	540	1615	507	2122
35	13.305	13.012	560	590	1150	565	1715	565	2280
40	13.34	13.082	560	630	1190	590	1780	603	2383

Table 12-27

psi	#1. - 1/4"	#1. - 1/4"	#2. - 1/4"	#2. - 1/4"	#3. - 1/4"	#3. - 1/4"	#4. - 1/4"	#4. - 1/4"	1"
	deflection	**lb./in**	deflection	**lb./in**	deflection	**lb./in**	deflection	**lb./in**	total
	load	Load / 0.25	load	Load / 0.25	load	Load / 0.25	load	Load / 0.25	load
15	367	1468	348	1392	378	1512	374	1496	1467
20	386	1544	402	1608	450	1800	401	1604	1639
25	453	1812	495	1980	495	1980	443	1772	1886
30	507	2028	568	2272	540	2160	507	2028	2122
35	560	2240	590	2360	565	2260	565	2260	2280
40	560	2240	630	2520	590	2360	603	2412	2383