19

Developing The Tire Maps

An Absurdly Basic Overview
(*It's just not this simple!*)

Up to this point, we have only been looking at how load is transferred during static and dynamic conditions. Other than believing a balanced left to right load is better than an unbalanced load, we really haven't been able to tell how much acceleration force each particular corner is able to produce. To determine that type of information, we need to have a complete and accurate set of tire maps. The accuracy of any simulation program depends primarily upon how accurate the tire maps are, and, as we have discussed numerous times throughout Book One, the design, build and performance of race tires is still very much a developing science. Compared to the understanding of mechanical and aerodynamic performance, understanding tire performance, testing and mapping is still very much a black art. Having said that, there is still much to be gained through laboratory and track tire testing and mapping, particularly when looking for/at trends.

Note: Book One, as always, is simply laying the groundwork for a more detailed look at racecar dynamics in Books Two through Five. While working through Chapters 19 through 21, it is extremely important that the reader does not lose sight of the fact that we are only looking at how this type of map may be used. However, even though the information gleaned from these chapters may not be 100% accurate, it will still give the race engineer a very **good** set up **starting point**.

Developing the Tire Maps

As previously discussed, tire maps are developed using a combination of data from the tire manufacturer and on track testing – a lot of on track testing.

As in the case of aerodynamic mapping, a base map is first developed using manufacturer and/or track test data. Track testing is divided into three types: skid pad, inline and circuit/race track. As discussed shortly, these tests are further broken into a number of different components. Base line mapping is never a matter of just taking the manufacturer's data and using that as the base map; however, laboratory testing is still extremely useful because each parameter of a test can be more closely controlled and repeated. What laboratory testing can not do is introduce the myriad of conditions and parameters under which a tire must operate on track. Between the controlled data from laboratory testing and the diverse but less controlled data from on track testing, the race engineer is able to slowly build a **fairly** accurate base map.

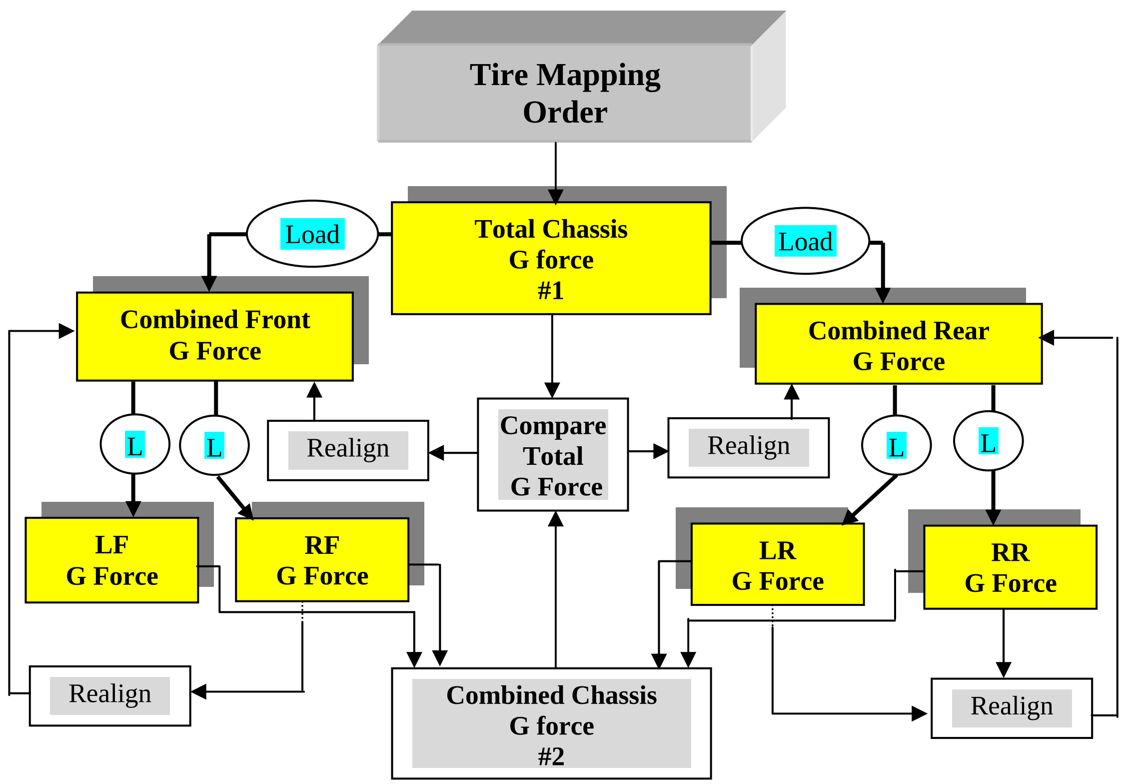
Note: Several chapters in Book Two are devoted to how teams gather and use tire data to develop their tire maps and tire performance algorithms. As always, Book One will simply introduce the concepts.

When developing a complete tire map, there may well be sixty or more secondary factors tied to the base map. Book One will only look at six. It is important to remember that none of the correction factors function independently of one another. A change in one factor will result in a change in all of the factors. *It's not that simple*.

Important Note: Tire testing is often done in consort with set up testing.

Tire Mapping as a Circular Process

- The total g force the chassis can produce is broken into front and rear g force components by comparing the percentage of front and rear normal load in relation to actual chassis performance and balance.
- The resultant front and rear g forces are added together and compared to the total chassis g force. If these two numbers are not the same, the front and rear g forces are realigned.
- These front and rear g force components are then further broken into the individual corner g forces by comparing the left/right load splits.
    - The LF and RF corner g forces are added together and compared to the previously calculated front g force. If necessary, the left and right g forces are realigned.
    - The LR and RR corner g forces are added together and compared to the previously calculated rear g force. If necessary, the left and right g forces are realigned.
- The individual corner g forces are added together and compared to the initial performance level the total chassis produced. If the numbers don't match the whole process begins again.



The Primary Tire Factor - Normal Load versus Force

The primary factor in all tire maps is the relationship between normal load and the tire's acceleration potential (force). Though a tire's performance envelope is changed by the secondary factors, sometimes dramatically, the primary factor controlling a tire's performance level, beyond the tire's design and build, is load. In Book Two we will discover that once again it's not that simple. Dynamic load transfer, as it moves from corner to corner, is not always **instantly** seen by the tire as normal load. During the transitional stage of load transfer, there will always be some percentage of the load transfer which will be horizontal in nature (shearing force). In other words, the resultant angle of the combined moment arm is seldom at a 90 degree angle to the tire's contact patch.

Book One - Secondary Tire Factors:

(a) Temperature
(b) Speed
(c) Shear Angle, or, in some cases, steer angle
(d) Camber
(e) Tire internal pressure - psi
(f) Tire wear

Both temperature and speed dramatically affect a tire's base load vs force coefficient.

Temperature

Because tire data from the manufacturers is often recorded at one steady state tire temperature, it is important that through track testing a correction factor is developed for temperatures above and below the equalized manufacturer's test data. Not compensating for tread temperature will lead to considerable problems when trying to match on track performance with simulation programs. Tire tread temperature plays a major role in determining the tire's performance envelope.

Tire tread temperature is controlled by:

(a) Normal load – As the normal load increases under dynamic conditions, the tread temperature increases while the friction coefficient goes down.

(b) As speed increases, the tread temperature increases while the friction coefficient goes down.

(c) As the g force increases, the tread temperature increases while the friction coefficient decreases.

(d) The narrower the tire's tread width, the higher the tread temperature and the lower the friction coefficient. The wider the tread width is, the better the surface cooling will be (a major reason why a wider tire can maintain a higher level of lateral acceleration).

Though it is possible to develop a tire map without a number of infrared sensors to measure real time tread temperatures, the use of infrared sensors **dramatically** improves both the accuracy and speed of developing a tire map.

Lateral Acceleration

Base Line Lateral Testing

The Base Map – Base load versus cornering force maps are, when possible, developed on three different sizes of skid pads. The three sizes are used to develop both the speed and temperature factors.

Base Line Skid Pad Test – Developing the Traction Circle

If the team has three different skid pad sizes available to them they will normally begin the testing on the smallest of the three. Basic tire maps can be developed without the use of a data acquisition system but it is much more difficult, time consuming and many times less accurate.

100 ft Radius Circle

- Initial set up – The test begins with the best guess set up. The driver drives around the circle slowly increasing his/her speed until the chassis wants to step away from the radius of the circle. If the front end steps out first, then the car is showing a tendency towards a push/understeer condition. If the rear steps out first, then the chassis is showing a tendency towards a loose/oversteer condition.

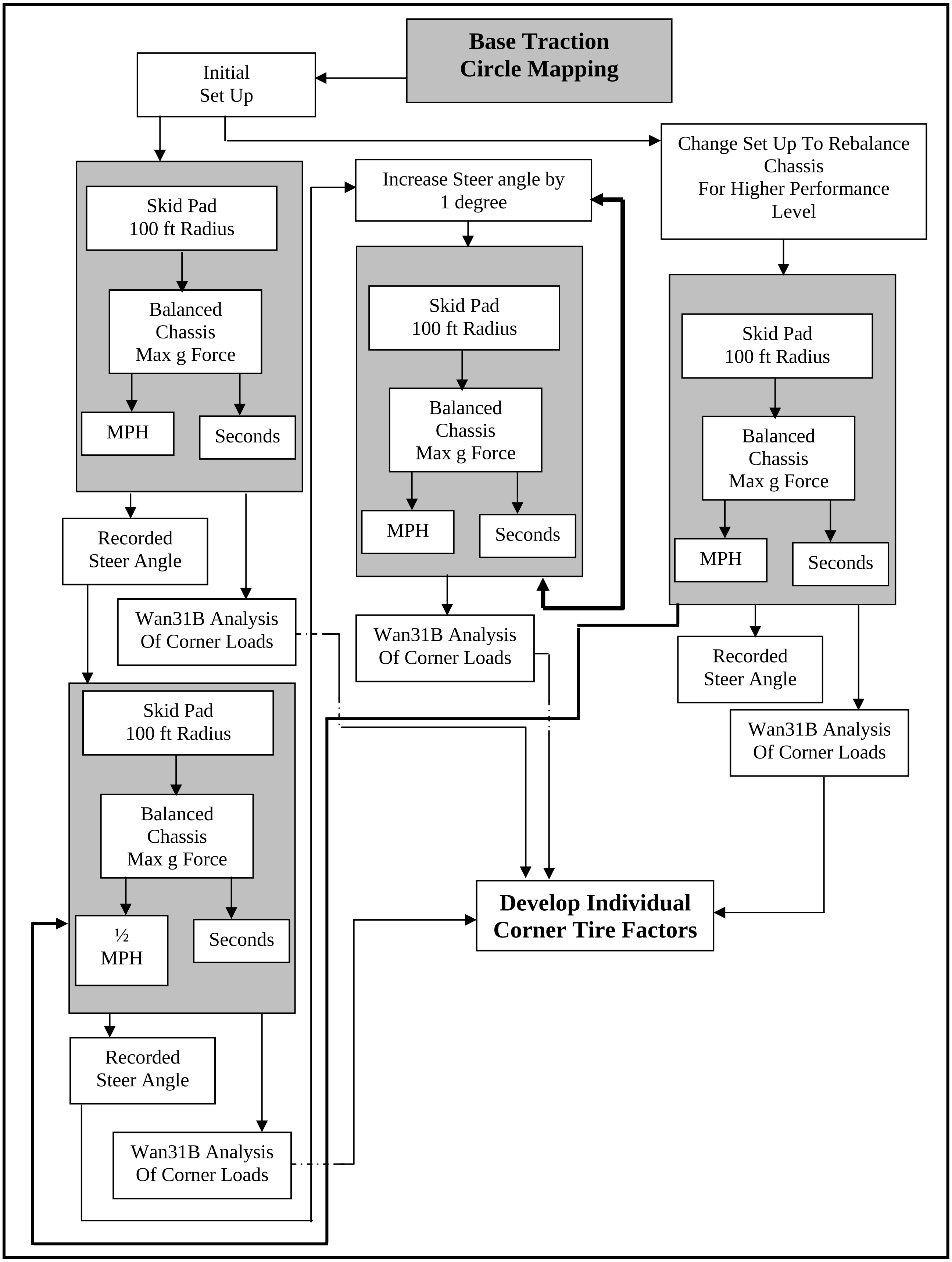
- Rebalancing the Chassis - After the initial run is completed and analyzed, a series of balance changes are made until the chassis steps outside the circle radius without exhibiting a yaw in or yaw out condition i.e. the chassis remains balanced. At this point, the chassis has reached its maximum velocity for that particular set up configuration. *It's never that cut and dried*.

- Changing the Steer Angle – Once a balanced set up is obtained, the chassis is run at approximately one half the speed obtained in the previous run. The steer angle needed to maintain the circle's radius is recorded. Successive runs are then made while the steer angle is increased in one degree steps (below the optimum speed the turn radius will be smaller than the prescribed radius). Each time the steer angle is increased, the chassis is run up to the point where it begins to step away from the circle's radius. The steer angle is increased up to and then several increments past the best case steer angle versus speed increment. Beyond the best case steer angle, the chassis will see a slower speed at the point of step out than the best case steer angle versus speed configuration. It's ***FAR*** *from this simple.*

- Calculating the Front and Rear Shear Angles – The exact amount of tread and sidewall shear a tire is experiencing at any particular moment in time is very difficult to **accurately** calculate even for the tire manufacturers. For this reason, the shear angles for the front tires are often shown the same as the steer input angle. A secondary factor is then added that combines the steer angle with the laboratory tested shear angle per amount of applied lateral force to determine the final amount of front tire shear. The rear tire shear angle is then calculated comparing each tire's rear lateral force with the front tire force versus shear angle map. *It's* ***far*** *from this simple.*

- Developing the Individual Corner Load versus Tire Coefficient of Friction Factors – At some point after the test sessions are completed, the results of each run will be analyzed in order to begin developing a corner by corner map showing each tire's lateral force contribution. This is done by first matching the individual corner loads as indicated in a load transfer model such as Wan31 and the loads obtained from the data acquisition system (obtaining the same load numbers from a load transfer model and a data system is an **extremely** difficult task in itself). These loads are then compared to the base tire map load versus lateral force numbers. It is at this point that the race engineer will begin to develop primary and secondary factors that will bring the tire map coefficients in line with actual chassis performance data. This is a continuous process of map versus on track performance refinement. *It is* ***far*** *from this simple.*

The Base Lateral Acceleration Procedural Algorithm



Note: In order to maintain a high level of tire wear consistency at least three sets of tires need to be cycled back and forth throughout the tests.

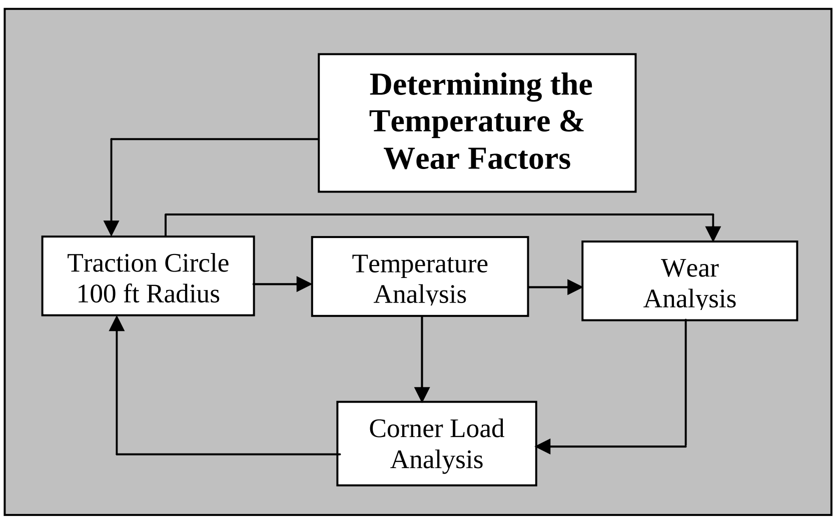
Note: The most difficult part of any test is understanding and controlling all of the contributing factors. To be able to say that an increase or decrease in chassis performance is the result of only one factor just isn't realistic.

Temperature and Wear Factors

Once the highest base level set up and steer angle performance have been achieved, either a set of stickers or slightly scrubbed tires are run in order to determine the wear and temperature factors.

- Temperature – A number of circles at maximum speed are run until the tire temperatures have reached and then passed their predicated optimum running temperatures. Next, a number of much slower circles are run, allowing the tires to cool before they are run again to and then past their optimum temperatures. Analyzing the speed and g forces versus the tire temperatures allows the race engineer to begin developing a tire temperature factor. A tire's performance factor drops off both below and above its optimum operating temperature.

- Wear – Tires of various levels of wear are run. Each tire in a set is analyzed from its initial performance level to a point of dramatic performance drop off. This type of test also requires various temperature factors.



Speed Factor

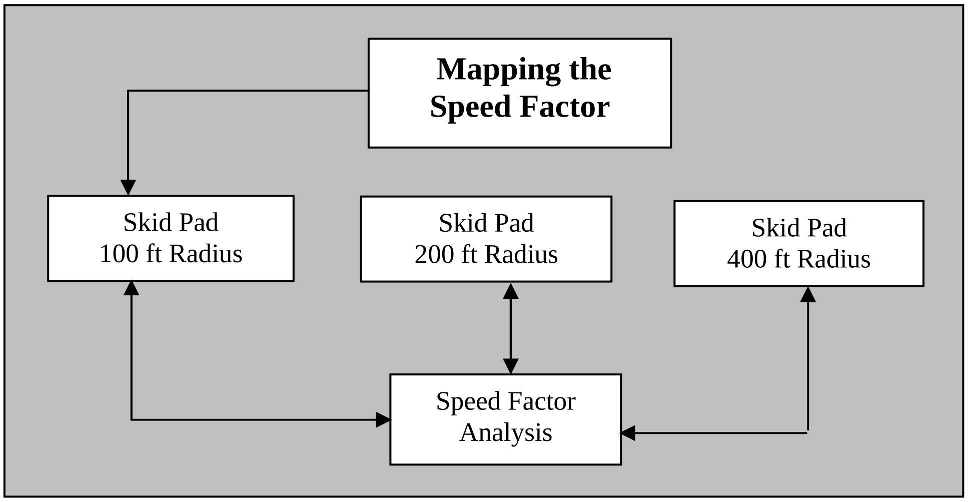
There is a direct relationship between speed and a tire's performance level. Like temperature, an increase in speed results in a decrease in acceleration/adhesion force. Though each tire design and build will have a different secondary factor, the tire's performance will always be degraded by speed (no increased aero loads). One of the simplest ways of determining a tire's speed factor is to run on three different sizes of skid pads.

Using the **MPH** worksheet provided with all Wan31 models, the engineer can find at what times and speeds the chassis would have to run in order to maintain a particular lateral acceleration rate for any skid pad circumference. Figure 19-1 shows the required speeds and times to maintain a lateral acceleration rate of 1.45g for the four different corner radius. However, under on track conditions, if a chassis' maximum performance level was at 1.45 g on a skid pad with a100 ft radius, it would be unlikely that the chassis could duplicate that same level of lateral acceleration while running on a skid pad with a 200 ft radius.

Skid Pad Analysis

Radius	Seconds	MPH	g Force
100	9.22	46.44	1.45
200	13.04	65.67	1.45
300	15.971	80.43	1.45
400	18.44	92.88	1.45

Figure 19-1



Note: Each skid pad test is run in accordance with the **Base Map Algorithm**.

Additional Factors

Once the team has established its initial Base Map plus the temperature, wear and speed factors, they will repeat all previous tests while developing additional tire factors such as:

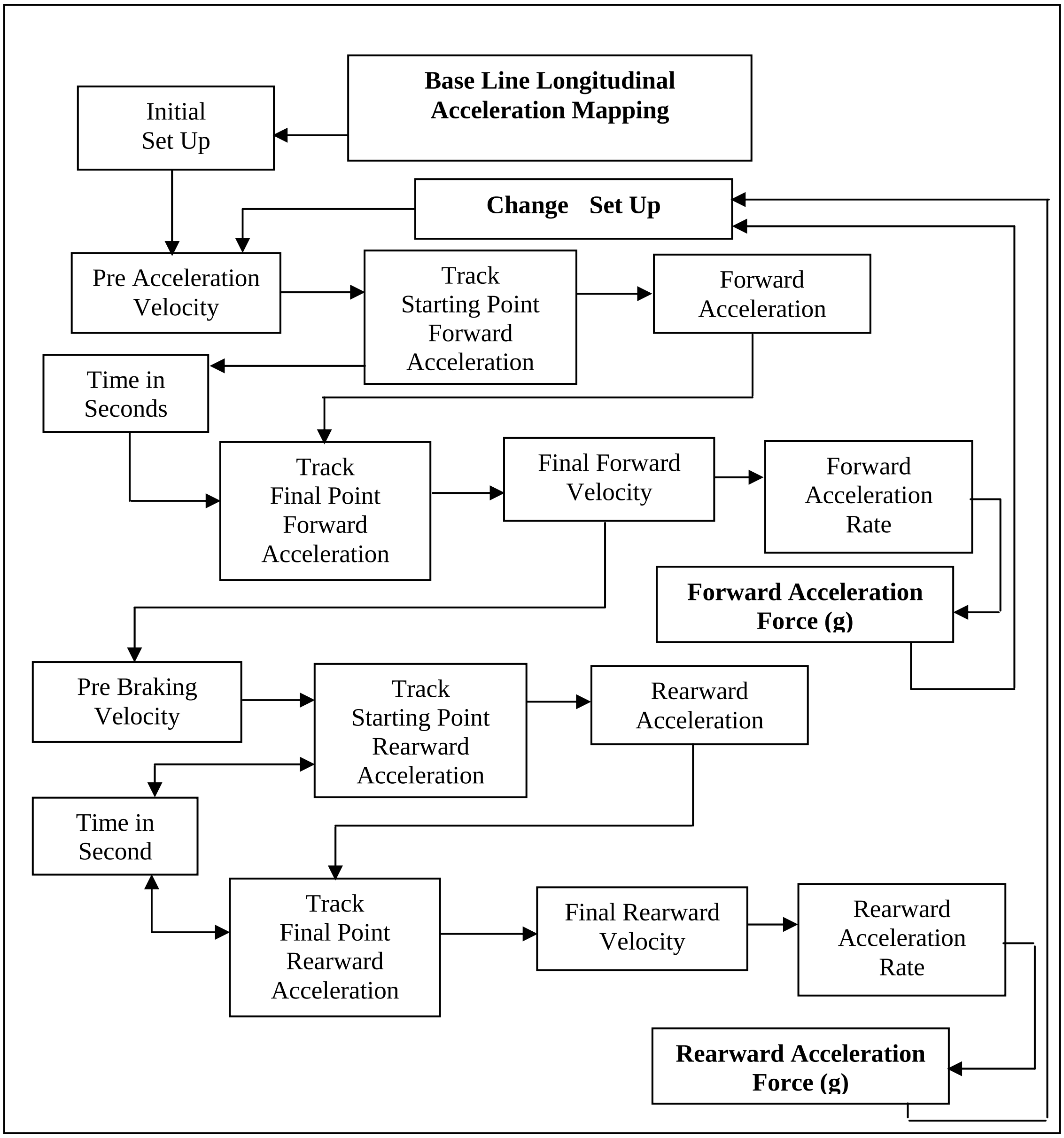
- Camber
- Front tire shear angle
- Rear tire shear angle
- Tire pressure
- Tire type (design and construction)
- Individual corner loads

Longitudinal Acceleration

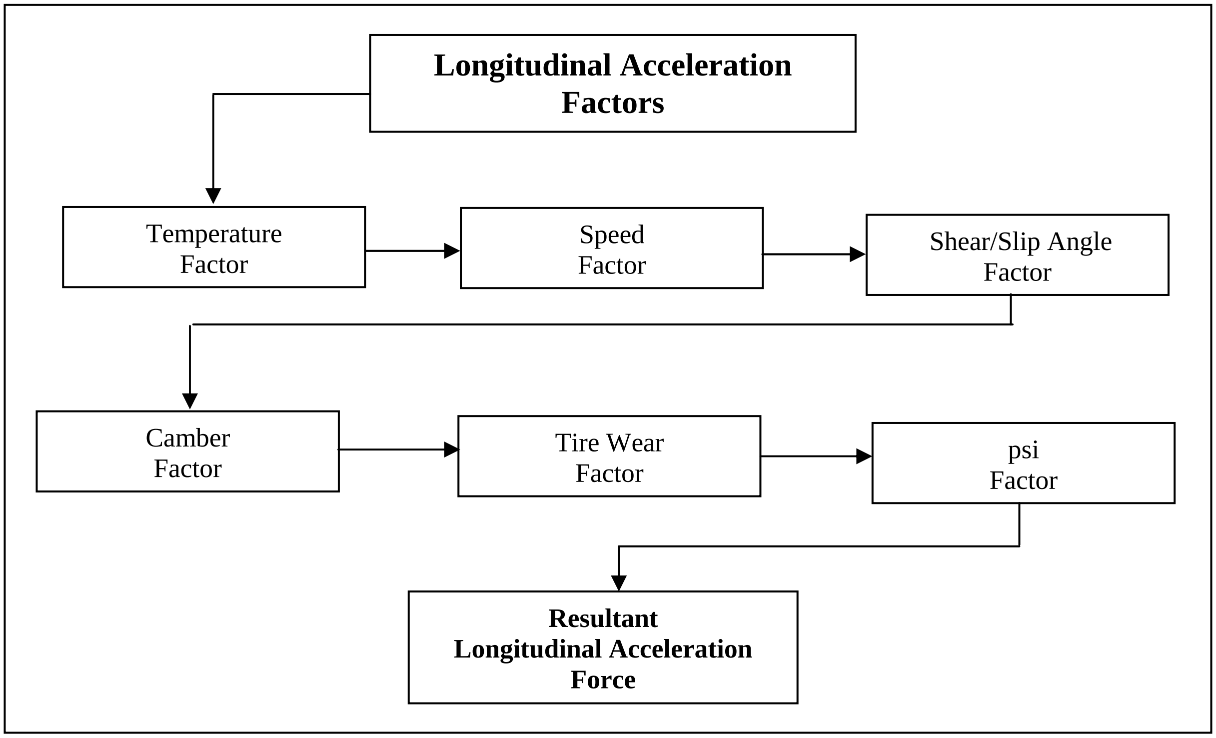
Base Line Longitudinal Testing

Unlike aero mapping which is often performed on a closed runway, tire longitudinal testing must be run on the same track medium on which the chassis will be raced. The most common **initial** inline test facility is on a drag strip. If the facility is of sufficient length, both forward and rearward acceleration testing is run at one time. The percent of tire shear under forward acceleration is determined by comparing the driven tire's individual loaded radius velocities, torque at the axle and the final gear ratio. *It's not that simple*. The amount of rearward shear percentage is determined by comparing each tire's load and axle torque in conjunction with the chassis rearward acceleration rate. *It's definitely not that simple*.

The Base Longitudinal Acceleration Algorithm



As in the case of the lateral acceleration maps, once the initial base line map is developed, a series of factors are tested and added to the map. Each new factor is tested using the base line algorithm. These tests are often run on circuits rather than drag strips in order to facilitate the testing of the temperature and speed factors.



Circuit/Race Track Testing

Though initial, non-laboratory tire testing is normally run on skid pads, the map refinements can really only be developed while running on an actual race track. Development can range from specific tire test sessions, chassis testing sessions to actual race weekends. The refinement of the tire maps never ends.

Combined Acceleration map development is very much the domain of the race track where various types of straights and corners are used to determine the combined acceleration rates. Many of the top teams have at least one race engineer designated specifically to developing the tire profile maps. Combined acceleration corner loads, temperatures and dynamic suspension kinematics and forces seen on a racetrack can not be duplicated on a skid pad. Individual corner loads during combined longitudinal and lateral on track acceleration can be substantially higher than will be seen during skid pad testing.

Best Fit Equations

Once the base tire map profiles are developed, a base equation and its secondary factors need to be developed. The **Best Fit** Calculator, part of the **Tire Calculator** program, is found in all Wan31B models and provides six examples of best fit equations. These are just six of literally hundreds of equations used by race engineers to develop best fit scenarios. Virtually every tire performance profile requires the development of its own formula. The Burrell formula, named after the physicist Dr. Craig Burrell, is an excellent place to start when developing the base map. By manipulating the various constants within the equation, the engineer can fit the equation to the map profile.

Tire Force Calculators

#1 Quadratic

Force = (A*L-B*(L-C)^2+D)

A	0.45376
B	0.00042
C	875
D	430.427
Load	500
Force	598.2445

#2 Linear

Force = A*L+B

Load	500
Base A	0.45375
Base B	292.58
Force	519.455

#3 F = A*Load^B

Load	500
A	83.8
B	0.33
Force	651.48

#4

Load X = Load/100

Cubic = Load X*Cubic Factor

Force = Cubic+A+B+C

Load	500
A	-102.934
B	-58.002
C	672.34
Cubic Factor	17.72899
Load X	5
Cubic	88.64495
Force	600.049

#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

#6

X =	500
A =	-5.20095
B =	6.75
C =	0.365
D =	572.34
E =	1.72899
Force =	563.1009

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.

Base 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

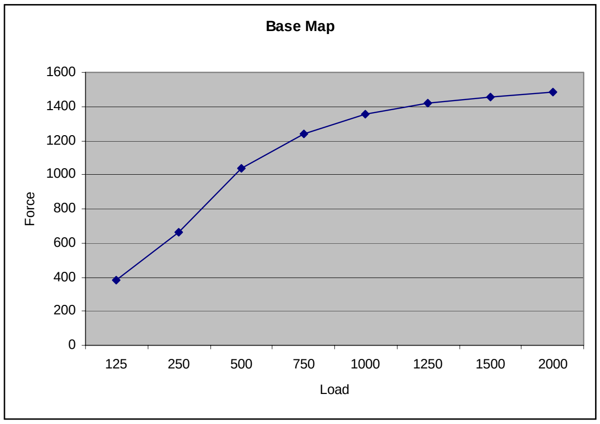


Figure 19-6

The tire shown in Table 19-3 is a serious tire designed for a high downforce aero car. Notice that even at a load of 2000 lb., the tire still has an efficiency of over 100%.

Base Map - Formula Car

F_{max}	2200							
a	2.366							
L_o	500							
Normal Load	125	250	500	750	1000	1250	1500	2000
Lateral Force	426	770	1270	1595	1807	1945	2034	2130
(F/L) Factor	3.41	3.08	2.54	2.13	1.81	1.56	1.36	1.06
Efficiency in %	341%	308%	254%	213%	181%	156%	136%	106%

Table 19-3

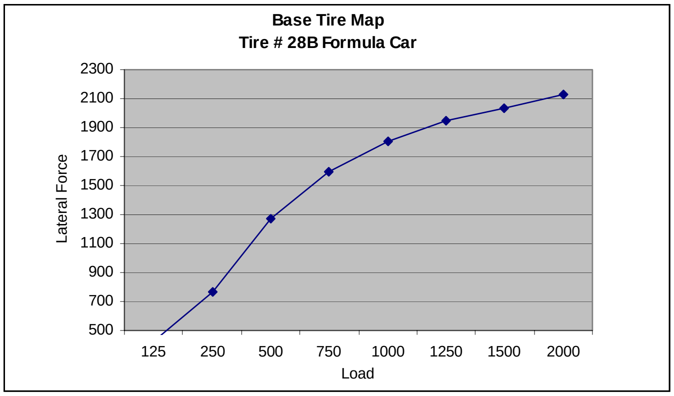


Figure 19-7

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 tire factor calculator can be found as part of the **Tire Calculator** program.

Steer

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

Table 19-4

Camber

Normal Load	125	250	500	750	1000	1250	1500	2000
Base 2 ^{o}	304	542	874	1078	1203	1279	1326	1372
Camber = 1^o	291	516	829	1021	1138	1210	1254	1297
Camber = 4^o	311	556	899	1109	1238	1317	1366	1413
Camber = 6^o	306	546	882	1087	1213	1290	1337	1384
Camber =8^o	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
W orn	294	523	842	1036	1156	1229	1273	1317
Done	271	478	763	937	1043	1108	1147	1187

Table 19-7

psi

Normal Load	125	250	500	750	1000	1250	1500	2000
Constant	304	542	874	1078	1203	1279	1326	1372
Below constant	306	546	882	1087	1213	1290	1337	1384
Above Constant	302	538	868	1070	1193	1269	1316	1361

Table 19-8

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

Table 19-9

The Base Tire Calculator

The base Wan31B calculator uses the Burrell formula with different constants entered to fit the various types of tires.

Tire Algorithm

F_{max}	1500
a	1.8
L_o	250
Normal Load	750
Base Lateral Force	1243

Tire Algorithm

F_{max}	2200
a	2.366
L_o	500
Normal Load	750
Base Lateral Force	1595

Important Note: The reader is again reminded that nothing about developing tire maps and tire calculators is as simple as presented in Chapter 19. Tire secondary factors are almost always a series of complex equations, and, unlike the tire calculator used in Book One, the secondary factors are broken down into very small increments.

Lateral Calculators and Performance Factors

Once the race engineer has compiled the initial secondary tables, a series of factors are found that can be tied to the base tire performance calculator. The factors used in Wan31B are shown on the left side of the calculator. The calculator itself is broken into three parts: Base Map, Factors and Force. Once the user enters the load in the Base Map, it then calculates the base lateral acceleration force. The user then enters the appropriate secondary factors in the Factors box. The final force, F/L (force/load) factor and efficiency percentage are then calculated in the Force box.

Tire Map Factors

Shear/Silp Factor	psi Factor
1^o = 0.9962	Constant = 1
2^o = 1	Below Con. = 1.0012
4^o = 1.0028	Above Con. = 0.99891
6^o = 1.00108	**Speed Factor**
8^o = 0.989	Slow = 1.0021
Camber Factor	Medium = 1
1^o = 0.9922	Fast = 0.989771
2^o = 1	**Wear Factor**
4^o = 1.0041	Sticker = 1.0026
6^o = 1.0012	Scuffed = 1
8^o = 0.9948	Worn =0.99437
Temp. Factor	Done = 0.9799
Constant = 1	
Below Con. = 0.98929	
Above Con. = 0.9846	

Lateral Acceleration Tire Algorithm

F_{max}	1400	Base Map
a	1.8	
L_o	300	
Normal Load	750	
Base Lateral Force	1078	
Shear/Silp Factor	1.0028	Factors
Camber Factor	1.0041	
Temp. Factor	0.9846	
psi Factor	0.99891	
Speed Factor	0.99847	
Wear Factor	0.99437	
Lateral Force	**959**	Force
(F/L) Factor	1.28	
Efficiency in %	128%	

Table 19-10 shows three different factored tire performance levels. Factor Set#1 is at the mid point of performance, Factor Set#1 is pretty close to the best case scenario while Factor Set#3 is close to the worst case scenario.

Factor Set #1

		Load	Base Force	Factored F	(F/L) Factor	Efficiency
Shear/Silp Factor	1.0028	Load	Base Force	Factored F	(F/L) Factor	Efficiency
Camber Factor	1.0041	500	874	781	1.56	156%
Temp. Factor	0.9846	750	1078	959	1.28	128%
psi Factor	0.99891	900	1160	1031	1.15	115%
Speed Factor	0.99847	1500	1326	1175	0.78	78%
Wear Factor	0.99437					

Factor Set #2

Shear/Silp Factor	1.0028	Load	Base Force	Factored F	(F/L) Factor	Efficiency
Camber Factor	1.0041	500	874	933	1.87	187%
Temp. Factor	1.0000	750	1078	1152	1.54	154%
psi Factor	1.0000	900	1160	1241	1.38	138%
Speed Factor	1.0000	1500	1326	1420	0.95	95%
Wear Factor	1.0000					

Factor Set #3

Shear/Silp Factor	0.989	Load	Base Force	Factored F	(F/L) Factor	Efficiency
Camber Factor	0.9962	500	874	582	1.16	116%
Temp. Factor	0.9846	750	1078	708	0.94	94%
psi Factor	0.99891	900	1160	759	0.84	84%
Speed Factor	0.989771	1500	1326	860	0.57	57%
Wear Factor	0.9799					

Table 19-10

Table 19-11 shows the differences between the three secondary factor combinations. Notice that there is a 560 lb. difference in acceleration force between #2 and #3 at 1500 lb. of normal load.

Factored Forces

Load	#2-#1	#3-#1	#2-#3
500	152	-199	351
750	193	-251	444
900	210	-272	482
1500	245	-315	560

Table 19-11

Note: Teams with less experience and resources often develop a steer factor rather than developing the shear/slip factor.