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.

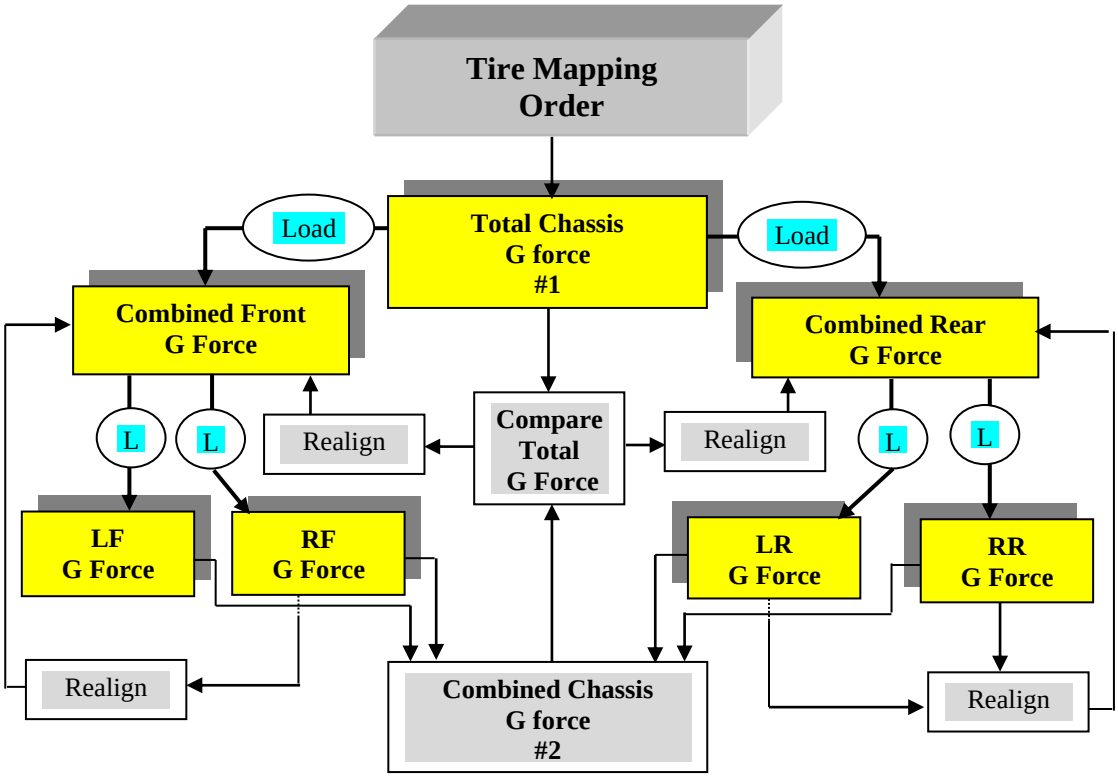
- The resultant front and rear g forces are added together and compared to the total chassis g force. If these two numbers are not the same, the front and rear g forces are realigned.

- 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.

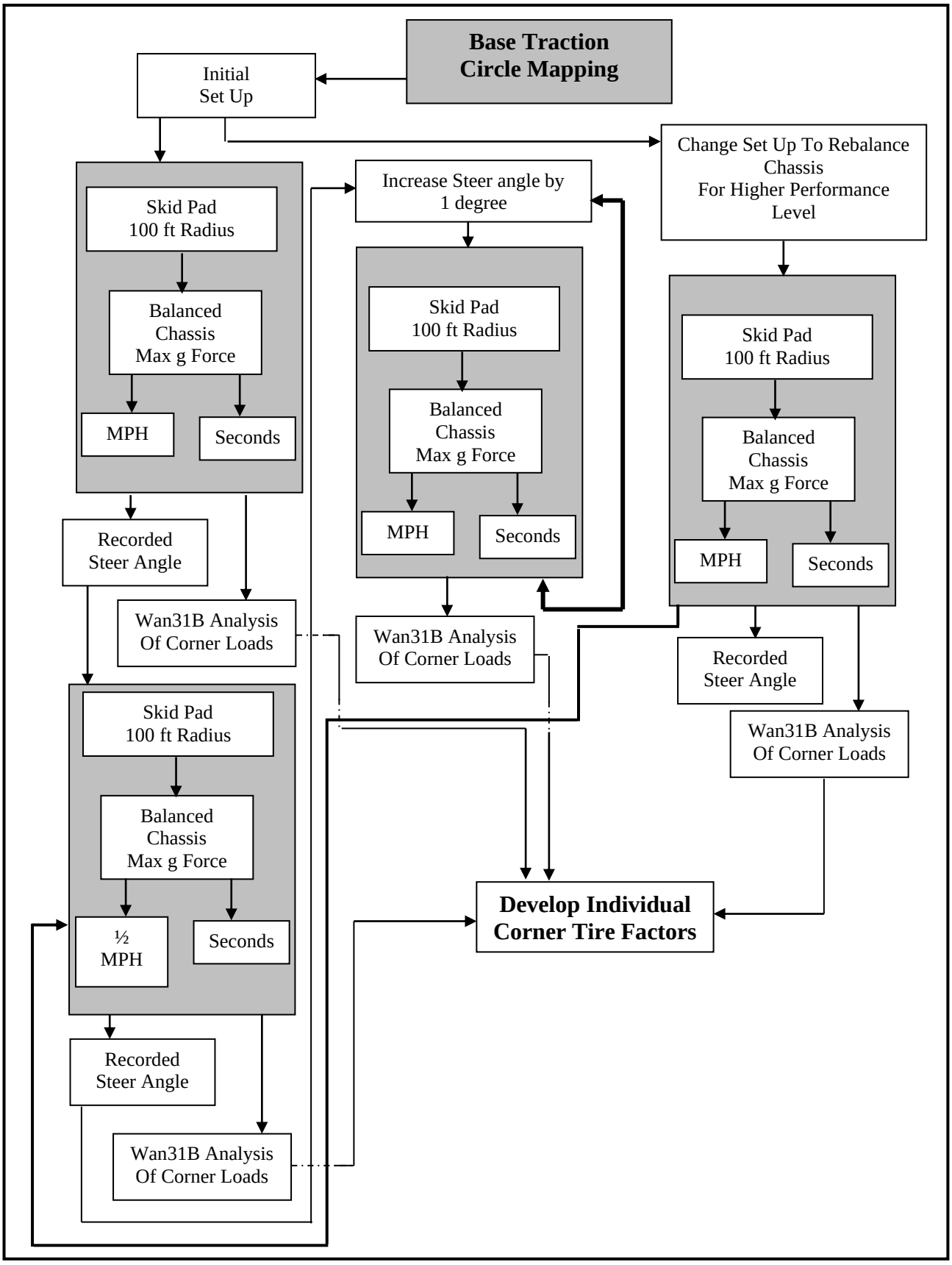
- Rebalancing the Chassis - After the initial run is completed and analyzed, a series of balance changes are made until the chassis steps outside the circle radius without exhibiting a yaw in or yaw out condition i.e. the chassis remains balanced. At this point, the chassis has reached its maximum velocity 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.

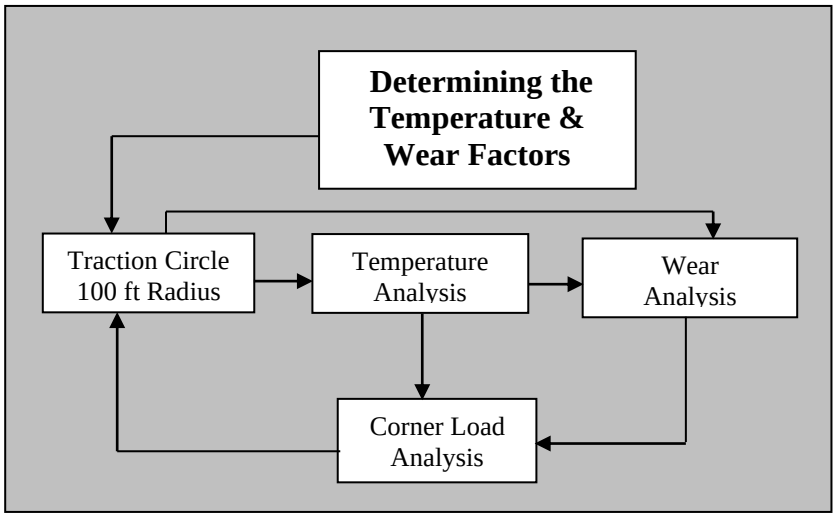
Note: The most difficult part of any test is understanding and controlling all of the contributing factors. To be able to say that an increase or decrease in chassis performance is the result of only one factor just isn't realistic.

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

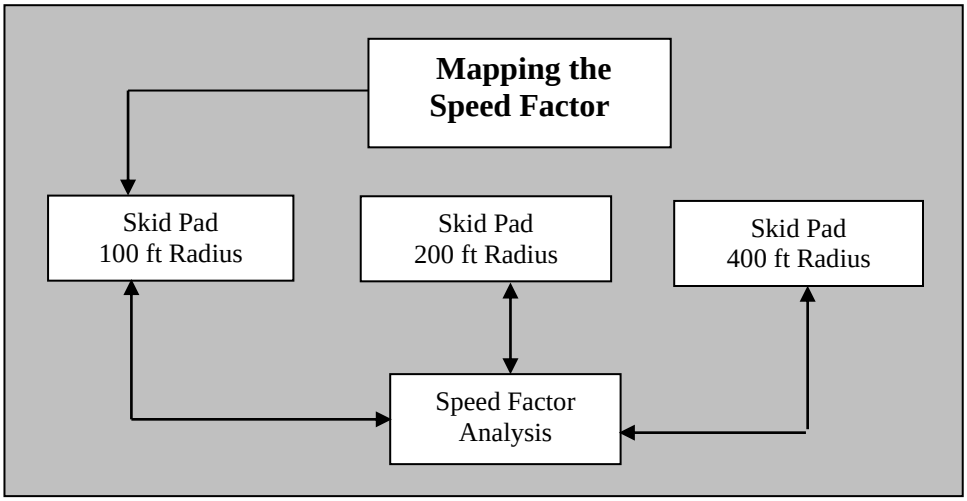
There is a direct relationship between speed and a tire's performance level. Like temperature, an increase in speed results in a decrease in acceleration/adhesion force. Though each tire design and build will have a different secondary factor, the tire's performance will always be degraded by speed (no 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:

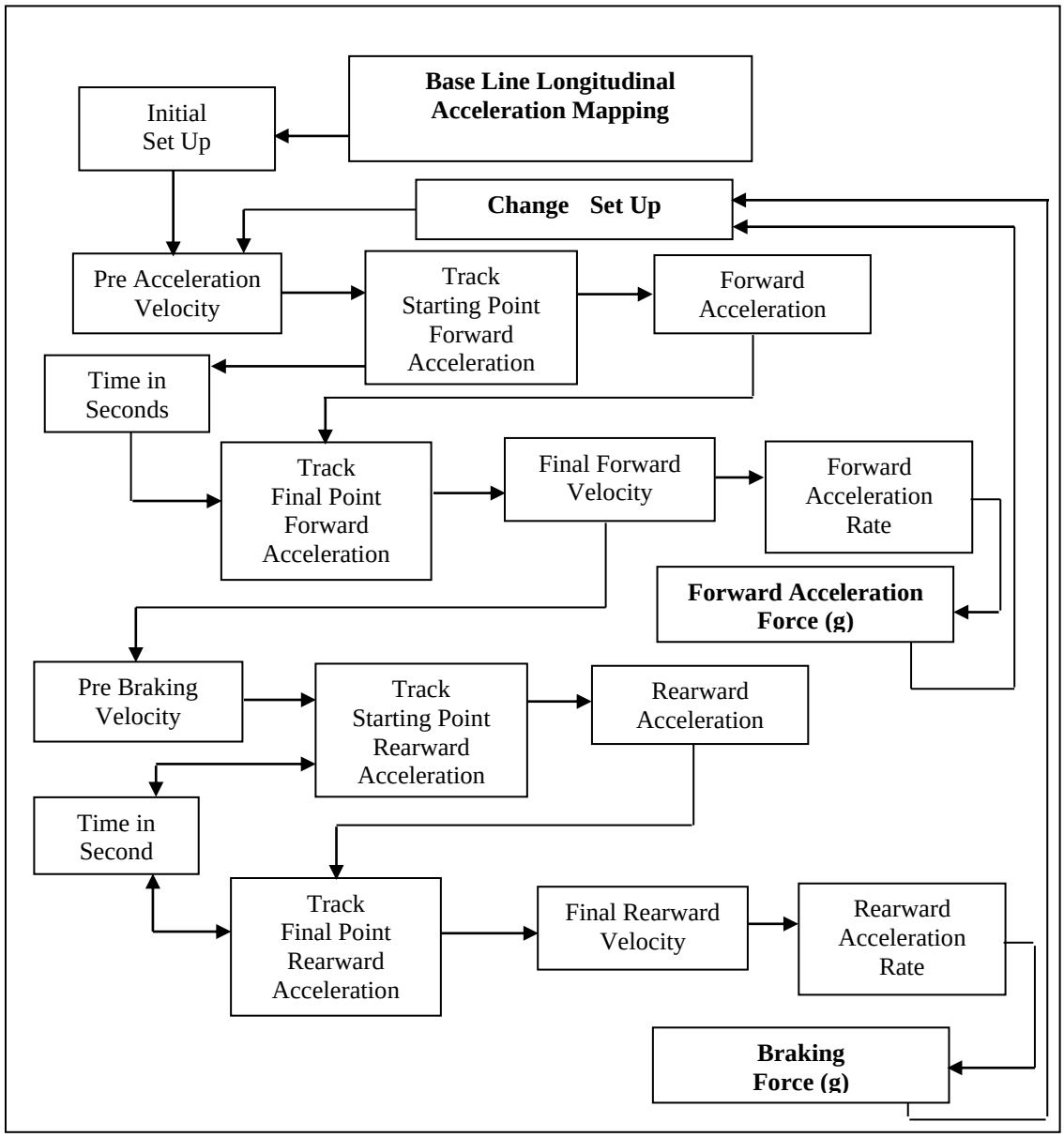
- Camber
- Front tire shear angle
- Rear tire shear angle
- Tire pressure
- Tire type (design and construction)
- Individual corner loads

Longitudinal Acceleration

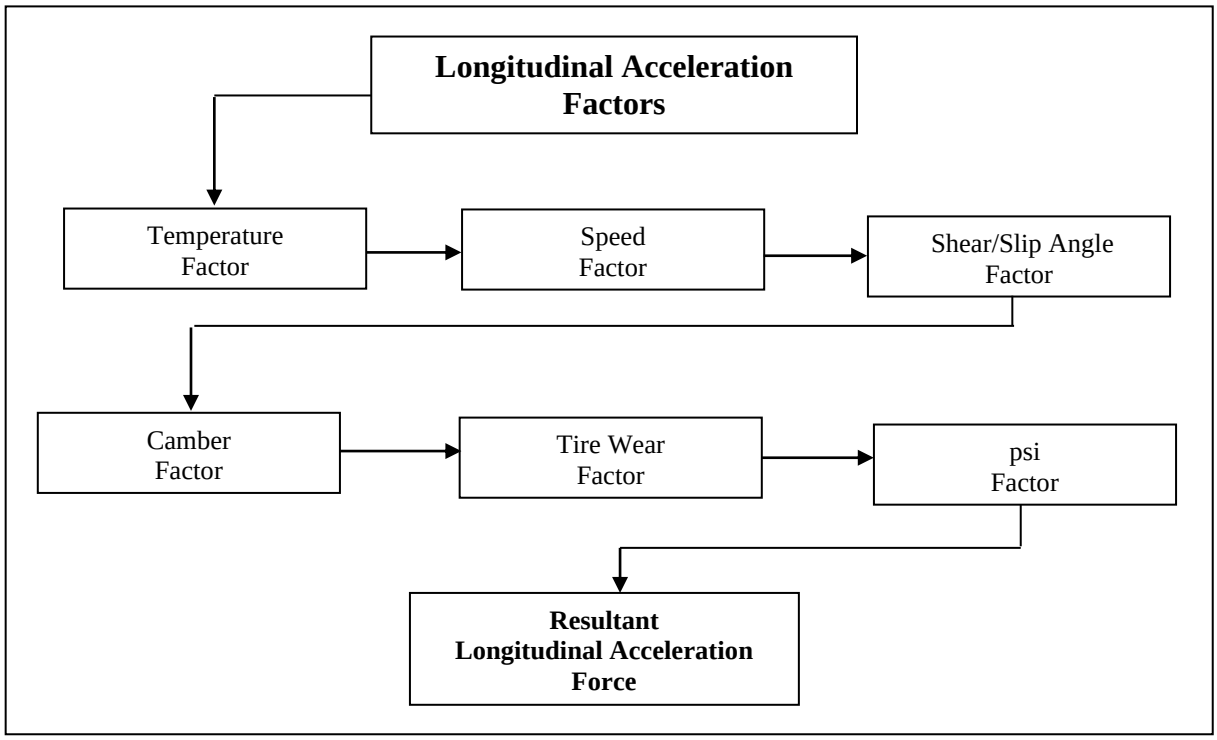
Base Line Longitudinal Testing

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 braking 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 braking 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 **Base Tire Force Calculators**, 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	600.04895

#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 – 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

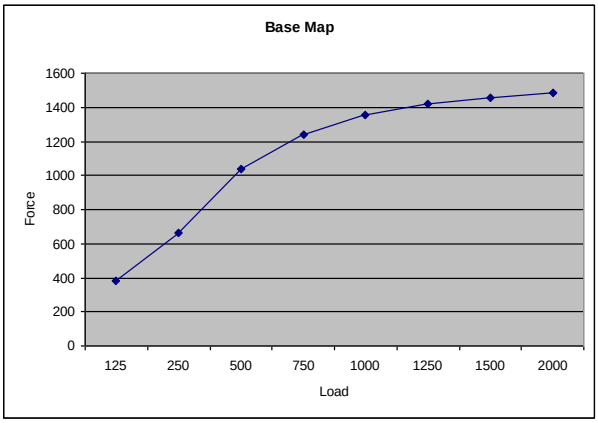


Figure 19-6

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

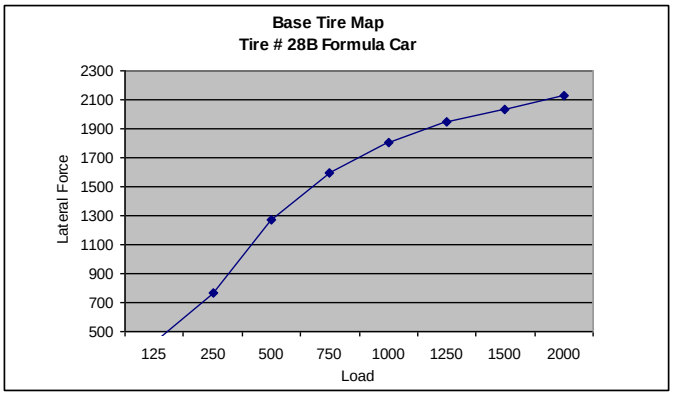


Figure 19-7

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 "**Lateral Factor**s" 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

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 for parts: "Base Map", "Lateral Factors", Longitudinal 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	
1^o	0.9962
2^o	1
4^o	1.0028
6^o	1.00108
8^o	0.989

Camber Factor	
1^o	0.9922
2^o	1
4^o	1.0041
6^o	1.0012
8^o	0.9948

Temp. Factor	
Constant	1
Below Con.	0.98929
Above Con.	0.9846

psi Factor	
Constant	1
Below Con.	1.0012
Above Con.	0.99891

Speed Factor	
Slow	1.0021
Medium	1
Fast	0.989771

Wear Factor	
Sticker	1.0026
Scuffed	1
Worn	0.99437
Done	0.9799

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 examples of 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

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.

Longitudinal Acceleration

As previously discussed, tread realignment during longitudinal acceleration is measured as percentage of shear. The "**Longitudinal Acc**." calculator used with Wan31B works in the same manner as the lateral calculator except with different secondary factors.

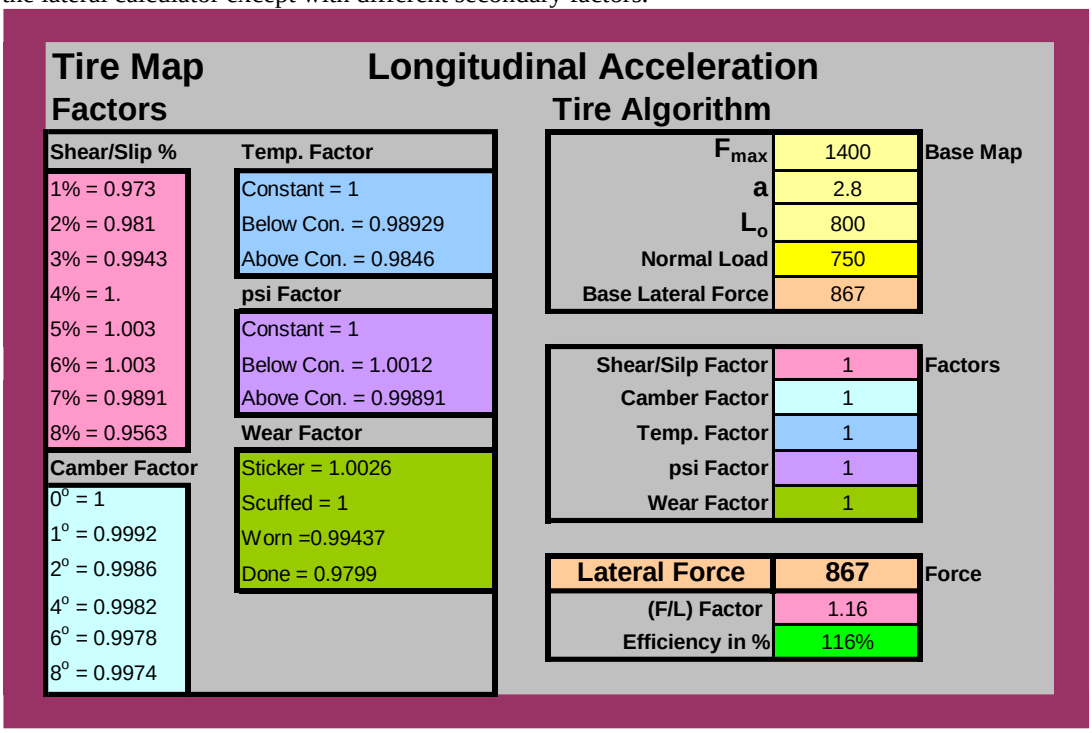


Table 19-12 and Figure 19-8 show the changes in longitudinal acceleration forces for 1% to 8% shear percent while Figure 19-9 shows the change in longitudinal acceleration for shear percentages of 1% through 8% at 750 lb. of normal load. Notice how quickly the acceleration force drops between 5 and 6 percent of shear.

Longitudinal Acceleration vs Shear/Slip Percentage

Normal Load	125	250	500	750	1000	1250	1500	2000
1%	229	396	623	760	843	894	925	956
2%	239	416	657	802	891	945	978	1011
3%	258	451	717	878	977	1037	1074	1110
Base 4%	266	467	745	913	1016	1079	1118	1156
5%	270	476	760	932	1037	1102	1142	1181
6%	259	453	721	882	981	1042	1079	1116
7%	250	437	693	848	942	1000	1036	1070
8%	226	391	615	749	831	881	912	942

Table 19-12

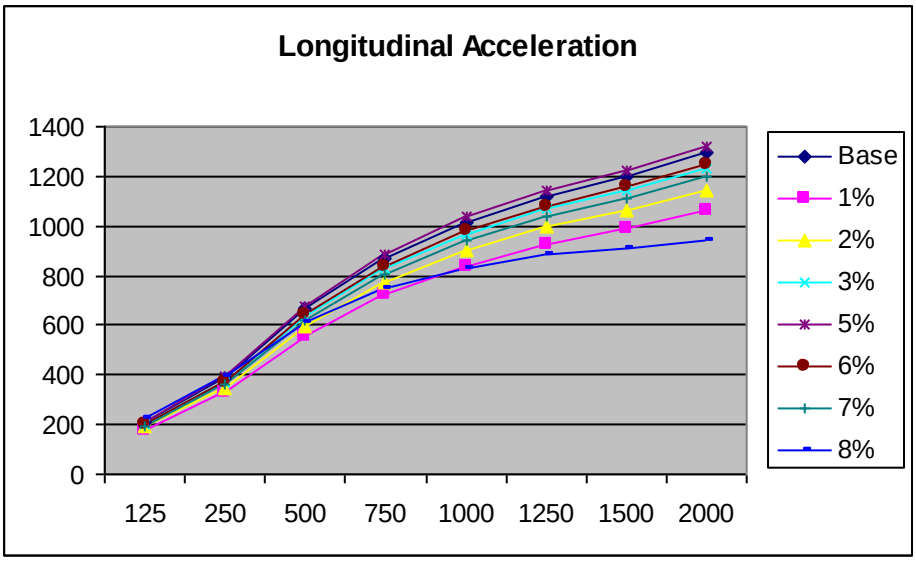


Figure 19-8

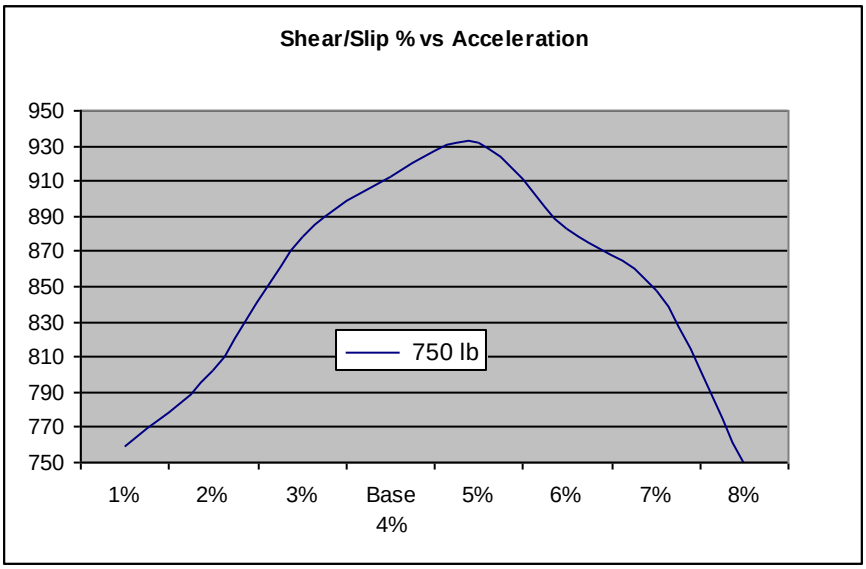


Figure 19-9

On Track Testing

As difficult as it may be to develop good individual lateral and longitudinal tire maps, those tasks pale in comparison to developing **combined** acceleration.

Traction Circles

Traction circles are simply a way to graphically represent a chassis' performance envelope under lateral and longitudinal acceleration. Virtually all data acquisition systems allow the user to look at on track performance via traction circle graphics. The user can break the view down from a complete lap, one corner, or only a few milliseconds of time. The user can also indicate how many samples a second they want and what degree and type of filtering they wish to use. While developing tire maps, the traction circles are normally broken down into the various corner phases. Careful study of each phase allows the race engineer to slowly refine the tire maps though it is always extremely difficult to separate ultimate tire performance parameters from set up anomalies and driver error. Data from repeated laps needs to be overlaid for each corner and corner section. *It's far from this simple*.

Though a tire's performance level in turning, braking and acceleration are theoretically all the same, in practice this is seldom the case due to a myriad of kinematic, aero and load type and rate iterations. As a result, an individual tire's traction circle will almost always end up being slightly elliptical.

Because of the differences in the turning, braking and forward acceleration performance levels of each chassis type, the chassis traction circles are often anything but a circle. A two wheel drive forward acceleration g level is seldom, if ever, as high as its four wheel braking g level, and, depending on the aerodynamic forces, a chassis' lateral acceleration g levels are often greater than its braking g level. For an oval track car, the left turn g level will be considerably higher than its right turn g level. The circle in Figure 19-10 has an ultimate lateral performance level of 4 g, an ultimate braking performance level of 3 g and an ultimate forward acceleration level of 2 g. Figure 19-10 represents the classic traction circle model. Actual traction circle maps are nowhere near as nicely defined as the examples used in this chapter.

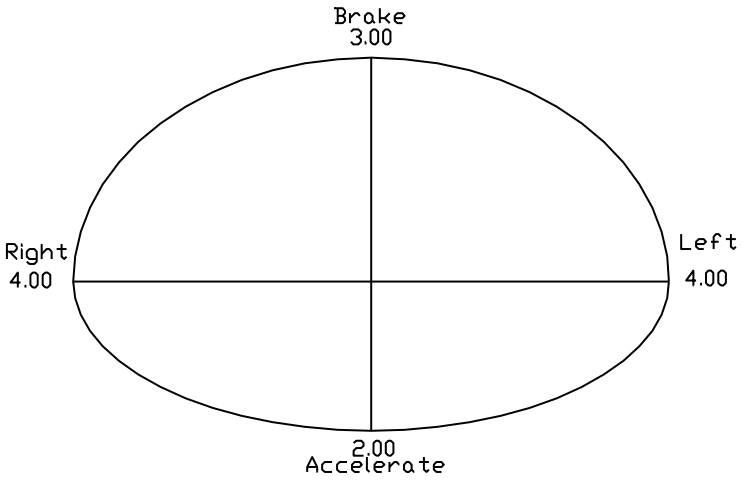


Figure 19-10

As previously discussed, when lateral and longitudinal acceleration are combined, the individual acceleration forces will never be as high as they would be if the chassis was only accelerating in one direction. On the other hand, the combined acceleration force will always be equal to or greater than either of the individual lateral or longitudinal forces – Figure 19-11.

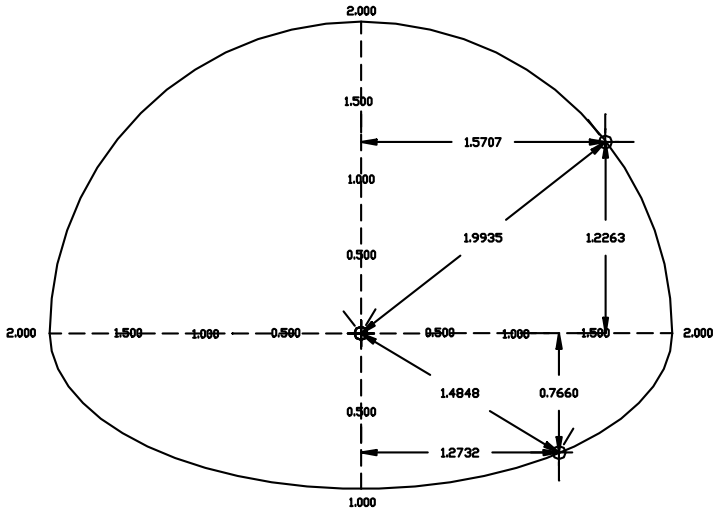


Figure 19-11

Note: The following traction circle examples are extremely simplified. They only represent a data rate of 0.5 of a second and are highly filtered. As in all cases with Book One, the traction circles are only used to introduce concepts. Analyzing actual traction circle data is slow, laborious, frustrating and worth its weight in gold. Remember, traction data is almost always broken into total chassis performance, front and rear end performance and individual corner performance.

As previously discussed, traction circles are very useful when analyzing combined acceleration forces. Although much more complex than the provided examples, if carefully dissected, they can tell the race engineer a great deal about how the tires are working in **combined** acceleration. It takes a considerable amount of time for the race engineer to discern why one type of acceleration takes **precedence** over another acceleration type. These types of answers are often found in the amount and type of corner loads and rate of corner load change.

Note: When first starting to work with traction circle data, break down the components into **very** small parts.

Important Note: Determining the maximum lateral and longitudinal acceleration forces under combined conditions is the key to developing accurate tire maps. The race engineer must understand why under one combined acceleration condition, the tire(s) will produce a higher longitudinal than lateral acceleration force ratio, while, under a slightly different condition, they produce a higher lateral than longitudinal acceleration force ratio. This type of knowledge will separate the consistent winners from the sometime front runners.

The following two examples represent a left turn of constant radius. The circle begins at the zero g braking mark and ends when the forward acceleration rate nears zero g.

- Figure 19-12:
  - a – Shows trail braking
  - b – Peak braking force at 1.59 g
  - c – As braking initially tapers off, a marked increase in lateral forces is shown

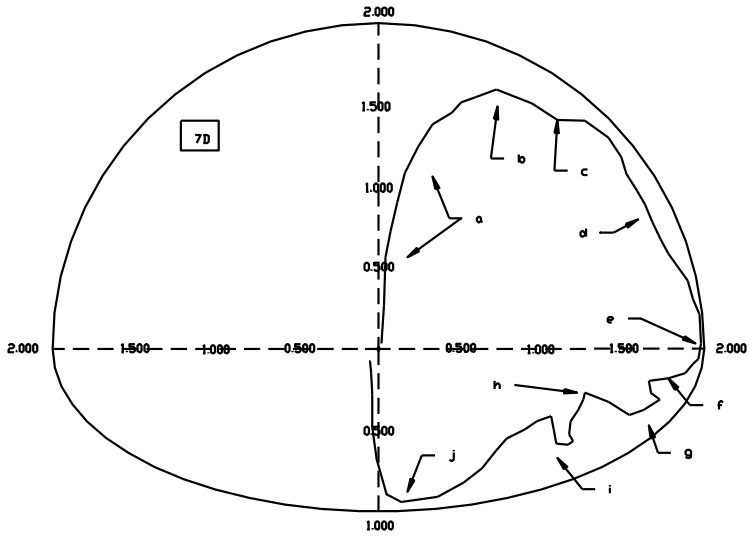
- d – Lateral forces increase in a more or less linear manner with the decrease in braking force.
- e - Maximum lateral force of 1.98 g.

- f – As forward acceleration is initially added and load is removed from the front tires, the chassis develops a push.

- g – As the driver adds more forward acceleration while adding more left steer to counteract the power on push, the chassis goes snap loose.

- h – To counteract the snap loose condition, the driver lets off the power while also adding rightward steer angle.

- i - As the driver adds power, the car once again snaps loose. The driver momentarily lets off the power before adding power at a lower rate.



- j – Maximum forward acceleration of 0.94 g.

Figure 19-12

The example in Figure 19-13 is the same corner as in the previous example but with a much less talented driver. Drivers with a talent level as shown in the following example make it next to impossible to develop accurate tire maps and do nothing for the race engineer's career. Tire mapping requires both a talented and **consistent** driver. If the driver is unable to consistently duplicate the line and performance level for each section of the track, it will take much longer to develop accurate tire maps.

- a – Maximum braking force of 1.09 g - - at this point, the car is turning in well.

- b – The driver momentarily eases off the brake pedal which does nothing for chassis performance.

- c – Brake pressure is increased, but, in a very erratic manner.

- d – Both braking and lateral acceleration performance is well below the chassis' and tire ultimate performance level.

- e – The driver, for whatever reason, makes a small steer correction to the right.

- f - A small amount of forward acceleration is applied before the apex of the corner which causes the chassis to push/understeer.
- g – The driver abruptly adds left steer angle while continuing to add a small amount of forward acceleration. This is the point of maximum lateral acceleration of 1.87 g.

- h - Fearing too much left steer angle has been applied, the driver quickly lets off the power and steers to the right.

- i – Forward acceleration is momentarily decreased for no apparent reason.

- j – Point of maximum forward acceleration of 0.83 g.

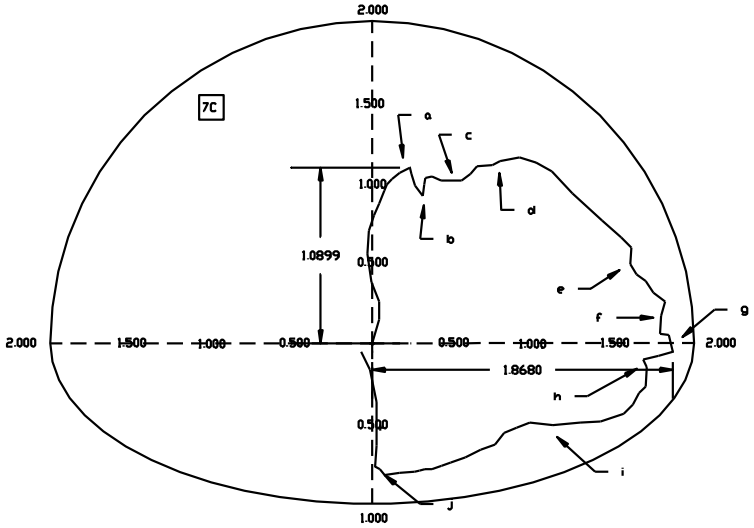


Figure 19-13

Traction circles are useful tools for developing tire maps, analyzing chassis performance, and, dare we say it, analyzing driver performance. Once the race engineer has developed the initial chassis and **tire** performance maps, a series of best case traction circles are developed. From this point, actual performance circles can be compared and analyzed in relation to the best case circles.

Traction Circle Types

Traction circles are broken down into three types:

- Total chassis performance

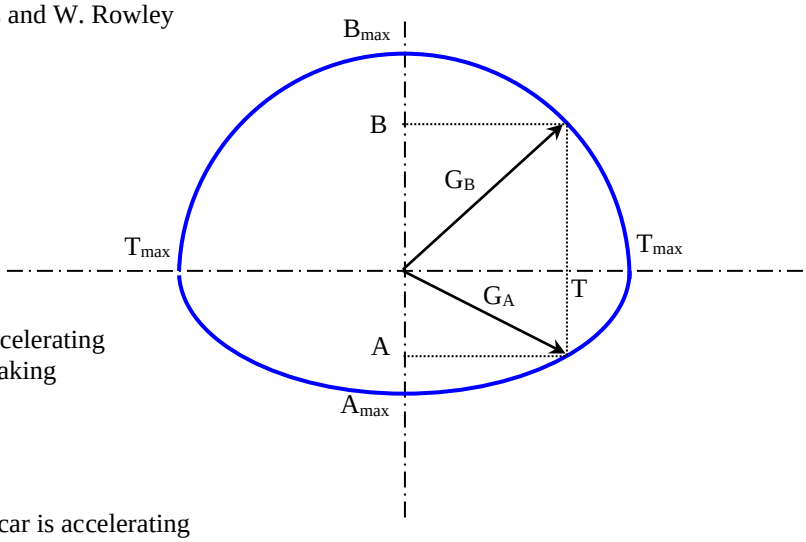
- Front and rear performance

- Individual corner performance

Using the formulas presented on the following page, a series of calculators can be developed to allow the user to enter the amount of current lateral acceleration and see how much tire performance potential is left for braking and forward acceleration. The amount of current braking or forward acceleration can also be given with the calculator showing the remaining amount of turning performance.

Traction Circle Calculations

JJ Salinas and W. Rowley



All accelerations in g's

A = Available longitudinal acceleration
B = Available braking acceleration
T = Available turning acceleration
T_A = Available turning acceleration while car is accelerating
T_B = Available turning acceleration while car is braking
A_{max} = Maximum acceleration capacity
B_{max} = Maximum braking capacity
T_{max} = Maximum turning capacity

G_A = Total combined available acceleration when car is accelerating
G_B = Total combined available acceleration when car is braking

In the figure, both functions are symmetric ellipses with centre at the origin and semi axes as follows:
Semi major axis = T_{max} (Turning)
Semi minor axis = B_{max} (Braking)
Semi minor axis = A_{max} (longitudinal acceleration)

General equation of an ellipse is $\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$

Substitution of limits above yields

$$A = A_{max}\sqrt{1-\left(\frac{T}{T_{max}}\right)^2} \qquad B = B_{max}\sqrt{1-\left(\frac{T}{T_{max}}\right)^2} \qquad T_A = T_{max}\sqrt{1-\left(\frac{A}{A_{max}}\right)^2}$$

$$T_B = T_{max}\sqrt{1-\left(\frac{B}{B_{max}}\right)^2}$$

$$G_A = \sqrt{A^2+T^2} \qquad G_B = \sqrt{B^2+T^2}$$

Example 1
Given: $A_{max} = 1$; $B_{max} = 2$; $T_{max} = 2$ Find: A, B, G_A and G_B for T = 1.2572

$$A = 1\sqrt{1-\left(\frac{1.2572}{2}\right)^2} = 0.778 \qquad B = 2\sqrt{1-\left(\frac{1.2572}{2}\right)^2} = 1.555$$

$$G_A = \sqrt{0.778^2+1.2572^2} = 1.478 \qquad G_B = \sqrt{1.555^2+1.2572^2} = 2.000$$

Example 2
Find G_A for same limits as *Example 1* and T = 0.996

$$A = 1\sqrt{1-\left(\frac{0.9996}{2}\right)^2} = 0.866 \qquad G_A = \sqrt{0.866^2 + 0.9996^2} = 1.322$$

The "**Traction Circle**" calculator, as shown below, can be found in all **Wan31B models**. Using Calculator #1, the user enters the maximum turning, braking and accelerating capacity either from the tire maps or on track chassis data. The user then enters the current turning force to see the available braking and acceleration forces. The calculator also shows the combined available acceleration when the car is braking or forward accelerating. Calculator #2 works the same except the user enters the current level of braking or acceleration to determine the available turning potential. This type of calculator is used to develop and refine the traction circle data and then the tire maps themselves for overall chassis performance, front and rear performance and balance and individual tire performance. Developing and refining data by moving back and forth between the total chassis through to the individual tires is very much an iterative process.

Traction Circle Calculator

#1 Lateral vs Longitudinal

A_{max} =	1	A =	0.778
B_{max} =	2	B =	1.555
T_{max} =	2	G_A =	1.478
T =	1.2572	G_B =	2.000

#2 Longitudinal vs Lateral

A_{max} =	1	T_A =	1.257
B_{max} =	2	T_B =	1.258
T_{max} =	2	G_A =	1.478
A =	0.778	G_B =	2.000
B =	1.555		

A = Available longitudinal acceleration
B = Available braking acceleration
T = Available turning acceleration
TA = Available turning acceleration while car is accelerating
TB = Available turning acceleration while car is braking
Amax = Maximum acceleration capacity
Bmax = Maximum braking capacity
Tmax = Maximum turning capacity
GA = Total combined available acceleration when car is accelerating
GB = Total combined available acceleration when car is braking

Combined Tire Maps

Once all the parts are put in place, a combined tire algorithm, as shown on the following page, is produced which can be used with a simulation model such as Wan31B. In the case of Wan31B, each corner contains both a lateral and longitudinal load versus force calculator. These calculators allow the user to adjust the base map and the appropriate performance factors to match the recorded on track data. The corner loads are entered into this algorithm from the Wan31B worksheet and from this the maximum **individual** lateral and longitudinal forces are calculated. This calculator (lateral versus longitudinal) takes the amount of lateral acceleration as entered from the Wan31B worksheet and calculates the available longitudinal acceleration.

Important Note: The tire calculators as used in the Wan31B models are intended as educational tools, and, therefore, require the user to manually update the various factors. Actual simulation software packages all use some sort of best fit algorithms to automatically update all input cells. After having mastered the basics, users with sufficient programming and mathematical skills are encouraged to experiment with developing far more complex models, including the use of best fit algorithms.

For simulation models running in real time from data acquisition programs, the loads entered into the tire algorithm would be calculated from a combination of suspension motion data, corner load data, ride height data and accelerometer data. The simulated chassis performance, balance and combined lateral and longitudinal acceleration rates could then be compared to the actual track performance as recorded by the

acquisition system. If required the individual tire load versus force algorithm plus the various tire factors could then be adjusted to bring the simulation program in line with the on track performance. Once the on track and simulation programs match, with both the on track and simulation chassis running with the exact same set up, different simulation set ups would then be run to determine whether a higher performance level or better balance could be achieved with a different set up.

In actuality, it is **far** from that cut and dried. Simulation programs **can** be very important tools for the race engineer to use and learn from, particularly to learn from, but they are still far, far from infallible. Wan31B was developed as a teaching tool, and, as such, is extremely useful. Though the Wan31B trends are very accurate, the actual performance levels may be off a few pounds here and there. The basic engines used in all simulation tools are built from well-established physics principles and laws, and, therefore, are very accurate. The problem, as always, is garbage in equals garbage out.

Important Note: **Every race engineer needs to know how a simulation program works as this is the only way for the engineer to truly understand how a chassis works under both static and dynamic conditions as well as knowing what the consequences of a set up change will be. On the other hand, every engineer must also know that a simulation program is just one more tool in his/her bag of tools. *It's just not that simple*.**

Combined Tire Map – Wan31B

LF Tire - Lateral		LF Tire - Longitudinal		RF Tire - Lateral		RF Tire - Longitudinal	
F_{max}	1400	F_{max}	1400	F_{max}	1400	F_{max}	1400
a	1.8	a	1.8	a	1.8	a	1.8
L_o	300	L_o	300	L_o	300	L_o	300
Normal Load	250	Normal Load	250	Normal Load	1000	Normal Load	1000
Base Lateral Force	542	Base Longitudinal	542	Base Lateral Force	1203	Base Longitudinal	1203
Shear/silp Factor	1.0028	Shear/silp %	1	Shear/silp Factor	1.0028	Shear/silp %	1
Camber Factor	1.0041	Camber Factor	1	Camber Factor	1.0041	Camber Factor	1
Temp. Factor	1	Temp. Factor	1	Temp. Factor	1	Temp. Factor	1
psi Factor	1.0012	psi Factor	1	psi Factor	1.0012	psi Factor	1
Speed Factor	1	Wear Factor	1	Speed Factor	1	Wear Factor	1
Wear Factor	1.0026			Wear Factor	1.0026		
Lateral Force	**580**	**Longitudinal**	**542**	**Lateral Force**	**1298**	**Longitudinal**	**1203**
(F/L) Factor g	2.320	(F/L) Factor g	2.169	(F/L) Factor g	1.298	(F/L) Factor g	1.203
Efficiency in %	232%	Efficiency in %	217%	Efficiency in %	130%	Efficiency in %	120%
#1 Lateral vs Longitudinal		#2 Longitudinal vs Lateral		#1 Lateral vs Longitudinal		#2 Longitudinal vs Lateral	
A_{max} =	2.169	A_{max} =	2.169	A_{max} =	1.203	A_{max} =	1.203
T_{max} =	2.320	T_{max} =	2.320	T_{max} =	1.298	T_{max} =	1.298
T =	1.549	A =	1.240	T =	1.549	A =	1.240
A =	1.615	T_A =	1.904	A =	0.000	T_A =	0.000
G_A =	2.238	G_A =	2.272	G_A =	1.549	G_A =	1.240

LR Tire - Lateral		LR Tire - Longitudinal		RR Tire - Lateral		RR Tire - Longitudinal	
F_{max}	1400	F_{max}	1400	F_{max}	1400	F_{max}	1400
a	1.8	a	1.8	a	1.8	a	1.8
L_o	300	L_o	300	L_o	300	L_o	300
Normal Load	350	Normal Load	350	Normal Load	850	Normal Load	850
Base Lateral Force	695	Base Longitudinal	695	Base Lateral Force	1135	Base Longitudinal	1135
Shear/silp Factor	1.0028	Shear/silp %	1	Shear/silp Factor	1.0028	Shear/silp %	1
Camber Factor	1.0041	Camber Factor	1	Camber Factor	1.0041	Camber Factor	1
Temp. Factor	1	Temp. Factor	1	Temp. Factor	1	Temp. Factor	1
psi Factor	1.0012	psi Factor	1	psi Factor	1.0012	psi Factor	1
Speed Factor	1	Wear Factor	1	Speed Factor	1	Wear Factor	1
Wear Factor	1.0026			Wear Factor	1.0026		
Lateral Force	**745**	**Longitudinal**	**695**	**Lateral Force**	**1224**	**Longitudinal**	**1135**
(F/L) Factor g	2.130	(F/L) Factor g	1.985	(F/L) Factor g	1.440	(F/L) Factor g	1.336
Efficiency in %	213%	Efficiency in %	199%	Efficiency in %	144%	Efficiency in %	134%
#1 Lateral vs Longitudinal		#2 Longitudinal vs Lateral		#1 Lateral vs Longitudinal		#2 Longitudinal vs Lateral	
A_{max} =	1.985	A_{max} =	1.985	A_{max} =	1.336	A_{max} =	1.336
T_{max} =	2.130	T_{max} =	2.130	T_{max} =	1.440	T_{max} =	1.440
T =	1.549	A =	1.240	T =	1.549	A =	1.240
A =	1.362	T_A =	1.663	A =	0.000	T_A =	0.535
G_A =	2.063	G_A =	2.074	G_A =	1.549	G_A =	1.351