16

Load Transfer – Stock Car

Asymmetric Load Transfer

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

Despite its title, Chapter 16 is just as important for **road course** only race engineers as it is for oval track racers. All information in Book 1 is sequential i.e. you can't skip over any part of any chapter. Just because we are looking at a stock car chassis does not mean all of the asymmetric information is not just as important for road racers. As previously stated, under any time of dynamic acceleration, a road course chassis becomes asymmetric. Additionally, information presented in this chapter about how to work with Wan31 is not presented in any other chapter.

3rd Addition Note: The first two editions deliberately left out any type of calculator which would recalculate preloads after spring changes have been made. This was done so the user would have to think about what type of preload changes would be needed. However, because of popular demand, Claude R. Fortier has now included such a calculator within the "Spring Pairs Rate" calculator.

In Chapter 16 we will be looking at a three link live axle stockcar. The three-link suspension system is also used on many live axle GT type road course chassis. The chassis are found in the WinGeo3 software as Short Track Front, Short Track Rear. In Wan31A, the chassis is found under Short Track Stock Car in the Wan31A files.

Oval track cars, in theory, only have to turn left and therefore are set up with a number of static and dynamic asymmetries that will help balance the dynamic left turn corner loads. Oval track cars are not necessarily more difficult than road course cars to set up but they certainly have considerably more set up possibilities.

Throughout Chapters 16 through 21 we will look at a number of different corner entry, apex and exit scenarios. The ten **generic** phases used in this chapter are as follows:

- **Corner Entry**
  - Phase One – Hard Braking and Rapidly Decreasing Throttle – B = 1.00 g - T_L = 0.0
  - Phase Two – Hard Braking, No Throttle and Slowly Increasing Steer Angle – B = 1.25 - T_L = 0.5 g
  - Phase Three – Moderate Braking with Rapidly Increasing Steer Angle – B = 0.6 - T_L = 1.0 g
  - Phase Four – No Braking with Slowly Increasing Steer Angle – B = 0.15 - T_L = 1.25 g
- **Corner Apex**
  - Phase Five – Constant Steer Angle with No Throttle – B = 0.05 - T_L = 1.53 g

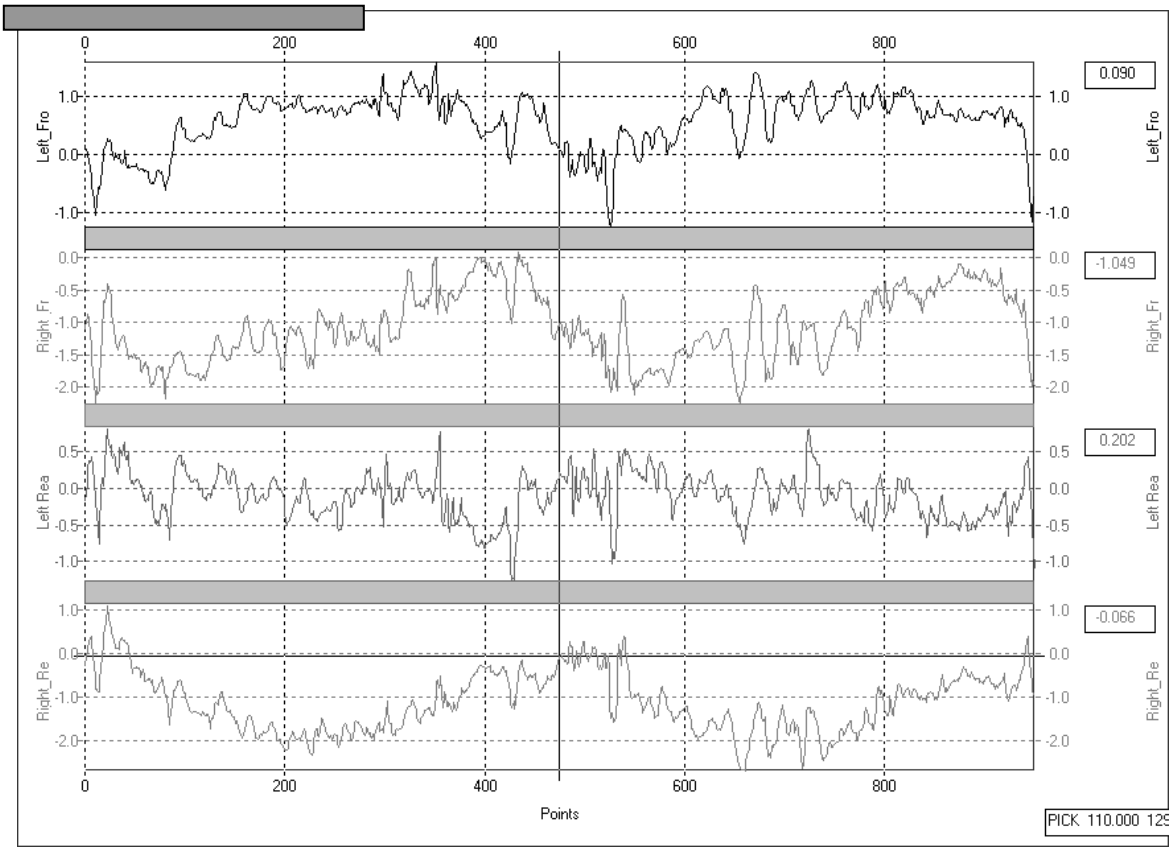
- Phase Six – Constant or Slowly Decreasing Steer Angle with Modulating Throttle – A = 0 - T_L = 1.37g

- Phase Seven – Slowly Decreasing Steer Angle with Slow Pick Up on Throttle – A = 0.3 - T_L = 1.0 g

- **Corner Exit**
  - Phase Eight – Rapidly Decreasing Steer Angle with Slow Pick Up on Throttle – A = 0.4 - T_L = 0.7 g
  - Phase Nine – Slowly Decreasing Steer Angle with Rapid Pick Up on Throttle – A = 0.65 g - T_L = 0.5 g

  - Phase Ten – Full Throttle with No Steer Angle – A = 0.85 g - T_L = 0.0 g

Note: As shown below, in the four suspension graphs, actual on track suspension motion is mind bogglingly complex even if only measured every twentieth of a second i.e. actual chassis performance is a **great** deal more complex than the simplified examples used in Book One. However, when using on track data, I still normally break the corners into approximately ten phases were each phase contains multiple data points. Each lap will result in slightly different phase entry and exit points for each portion of the track (no two laps will ever be precisely the same). *It's just not that simple.*



Note: It has been a somewhat daunting exercise to determine what needed to be included and what could be left for the readers to ferret out for themselves in Chapters 16 through 21. Remember that just because a reader has carefully read through and understood the contents of a chapter, as well as having made the prescribed changes in the Wan31A model, it **does not**, in any way, mean they have gained all of the needed load transfer knowledge. In fact, these chapters barely introduce the static and dynamic set up possibilities. If we were going to cover each chassis type in detail, it would take ten thousand pages and probably that wouldn't even cover it ("*say it ain't so*"). I know this has already been stated ad infinitum, but becoming a knowledgeable race engineer takes a considerable amount of intestinal fortitude.

As the authors assume the reader possesses a modicum of intelligence, diligence and conviction to acquire the prerequisite knowledge, a great deal is left for the reader to discover on his/her own. In this regard, the reader will need to develop a great number of charts, graphs and tables on his/her own in order to understand the myriad of set up, static and dynamic load transfer combinations.

Wan31A – Short Track Stock Car

1) **Wan31A – Short Track Stock Car (Ride Height and Balance)**: Load the Wan31A Short Track Stock Car. **IMPORTANT**: Turn off all green anti/jacking cells and reset the LR spring preload to 1.373 and RR spring preload to 0.810. The change in rear preload is required to zero the Solutions Load Changes so the Solutions Corner Loads and Initial Loads match. The reason the preload needs to be changed when the anti/jacking forces are turned off is to compensate for a small amount of static track bar forces. The spring preload as the model is loaded is set for the anti/jacking forces engaged. Notice the initial corner loads, left side/rear bias and the wedge. As previously discussed, there is a very important relationship between the spring rates, corner loads, wedge and ride heights. Before the user starts working with this model, he/she should take time to look at all of the model's cells.

    - The left front wheelbase is 0.5" shorter than the other three wheelbases.
    - The tracks, as measured from the hub face, are LF = 32.50", RF = 33", LR & RR = 32.75". Even though the front and rear tracks are offset, they are both 65.5" in width.
    - The tire radii as measured on the set up pad are LF = 13.47", RF = 13.645", LR = 13.36" and RR = 13.853".
    - Spring motion ratios are LF = 0.473". RF = 0.455", LR &RR = 1.0"
    - Spring Rates are LF = 850 lb./in, RF = 900 lb./in, LR = 225 lb./in and RR = 200 lb./in.
    - Once the corner loads and spring rates have been determined, the spring preload is adjusted in **A1** to rebalance the chassis loads in **A6** while also setting the static ride heights as close as possible to the designed heights. There are always a number of different ride height combinations that will balance the **A6** corner loads while also maintaining the wedge percentage. The **#4 Differences in Ride Height** calculator found on the **Splits and Changes** worksheet shows the relationships between the individual corner ride heights. For example, as the ride height is set when the model is first opened the difference between LF - RF is the same as LR - RR. If the RR preload is increased by 1" the chassis can be rebalanced by adjusting the preload at any of the other corners or at a combination of corners. Each type of adjustment will result in a ride height, pitch and roll change but LF-RF and LR-RR will still be equal. Adjusting preload is an extremely important tuning tool.
    - The original ride height is LF = 4.255", RF = 4.506", LR = 4.783" and RR = 5.034". The original static pitch is 0.680 degrees nose down while the original static roll angle is 0.257 degrees down to the left.

- If the RR preload is changed from 0.810” to 1.810”, the chassis can be rebalanced by one of the following:

  - Raising the LR preload to 2.368”. The new ride heights are LF = 4.566”, RF = 4.822”, LR = 5.509” and RR = 5.764”. The new static pitch is 1.213 degrees down and the new static roll is 0.261 degrees to the left. *Reset LR to 1.373*.

  - Raising the RF from 0.240” to 0.695”. The new ride heights are LF = 4.324”, RF = 5.431”, LR = 4.855” and RR = 5.961”. The new pitch is 0.683 degrees down and the new roll angle is 1.132 left. *Reset RF to 0.240*.

  - Lowering the LF from 0.17” To –0.300”. The new ride heights are LF = 3.642”, RF = 4.747”, LR = 4.585” and RR = 5.691”. The new pitch is 1.215 degrees and the new roll angle is 1.131 degrees. *Reset LF to 0.17*.

- Notice that in all three cases, the difference between the side to side splits (LF - RF) and (LR – RR) remains equal. When working with an infinitely rigid body with equal spring rates and motion ratios, as in the previous Chapter 14 **symmetrical model**, an increase of preload at the RR of 1” can be balanced by raising either the LR or RF by 1” or lowering the LF by 1”. This is a constant relationship even when working with a chassis having different spring rates and/or motion ratios. However, in this latter case, the different rates and ratios also need to be taken into consideration.

- In some cases, all four preloads will need to be changed a small amount, but, in most cases, the needed ride height ratios can be maintained by changing only the diagonal corners. However, you can seldom adjust the preloads to the exact prescribed ride heights while also maintaining the **A6** Solutions load balance (equilibrium of a rigid body). As chassis balance almost always takes precedence over small ride height irregularities, the static set up often ends up with the ride heights off a few thousandths. Nonetheless, if a stock car ride height setting is off more than 0.050”, a different set of preload combinations need to be tried unless, of course, the designated ride heights are completely incorrect in which case they need to be reconsidered.

- For many oval track races, the sanctioning body will require a minimum LF ride height and often a minimum RR ride height. Therefore, for oval track cars, the ride height relationship between the LF and the RR is the most important one. However, great care still needs to be taken not to unduly change the RF/LR balance, particularly with an aero sensitive chassis.

- The reader has no doubt already realized just how small a change in preload can be before it can alter the chassis balance. Racing is a rather exacting business when you consider a change of one or two pounds in corner load can move the balance from a loose to tight condition or vice versa.

2) **Wan31A – Short Track Stock Car (Wedge and Balance):** Changing the wedge percentage with preload while closely maintaining the ride height balance is an important shop set up procedure. Teams need to leave the shop already knowing how to change the various wedge percentages without upsetting the ride height balance, particularly with an aero sensitive chassis which is just about every modern chassis. Changing the static wedge percentage changes both the static loads and ride heights. Adjusting the wedge percentage, which, in turn, changes the ride heights, also results in a kinematic change. As we will discover shortly, a change in the kinematic IC co-ordinates can have a considerable effect on the anti and jacking forces.

- Static wedge can be increased by adding preload to the RF and/or LR or by decreasing preload at the LF and/or RR. Decreasing wedge is just the opposite. No matter what corner or combination of corners from which the preload is adjusted, a given change in wedge percentage will always result

in the same amount of static load transfer. The ride heights will change depending on where the preload change(s) are made but the corner loads will not change for **any given wedge percentage**. Adding preload at one corner will increase the ride height at that corner and that corner's two opposite corners while decreasing the ride height at its diagonal corner. The opposite happens if the preload is decreased.

Reload Wan31 Short Track

- Changing the **Static** wedge from 53.6% to 55.8%: At 53.6% the ride heights are LF = 4.255", RF = 4.506", LR = 4.783" and RR = 5.034". Chassis pitch is 0.680 degrees nose down and the roll is 0.257 degrees to the left.

- Increase the LR preload from 1.373" to 2.020". Wedge has changed to 55.8% and the resultant change in load transfer is approximately 32.3 lb. per corner. The new ride heights are LF = 4.505", RF = 4.464", LR = 5.171" and RR = 5.131". Chassis pitch is 0.858 degrees nose down and the roll is 0.042 degrees to the left. *Reset to base*

- Increase the RF preload from 0.240" to 0.541". Wedge has changed to 55.8% and the resultant change in load transfer is plus approximately 32.9 lb. per corner. The new ride heights are LF = 4.349", RF = 4.866", LR = 4.745" and RR = 5.262". Chassis pitch is 0.510 degrees noise down and the roll is 0.529 degrees to the left. *Reset to base.*

- Decrease the RR preload from 0.810" to 0.150". Wedge has changed to 55.8% and the resultant change in load transfer is approximately 32.9 lb. per corner. The new ride heights are LF = 4.303", RF = 4.255", LR = 4.698" and RR = 4.650". Chassis pitch is 0.509 degrees nose down and the roll is - 0.049degrees to the left. *Reset to base.*

- Decrease the LF preload from 0.17" to –0.140". Wedge has changed to 55.8% and the resultant change in load transfer is approximately 32.8 lb. per corner. The new ride heights are LF = 3.899", RF = 4.414", LR = 4.568" and RR = 5.084". Chassis pitch is 0.862 degrees nose down and the roll is 0.528 degrees to the left. *Reset to base.*

- Take time to explore the relationships as the result of a wedge change, between the changes in ride height, pitch and roll. Remember changing the wedge **does not** change the left side and rear bias.

3) **Wan31A – Short Track Stock Car (Spring Changes)**: As with the symmetric chassis, any time a spring change is made, a preload change will also have to be made in order to reset the corner load balance and ride heights. As with a road course car, spring changes are made to change the roll, dive, squat and ride height balance in addition to the load transfer balance. Unlike a road course car, these changes are normally asymmetric in nature to help left turn performance. More on this shortly.

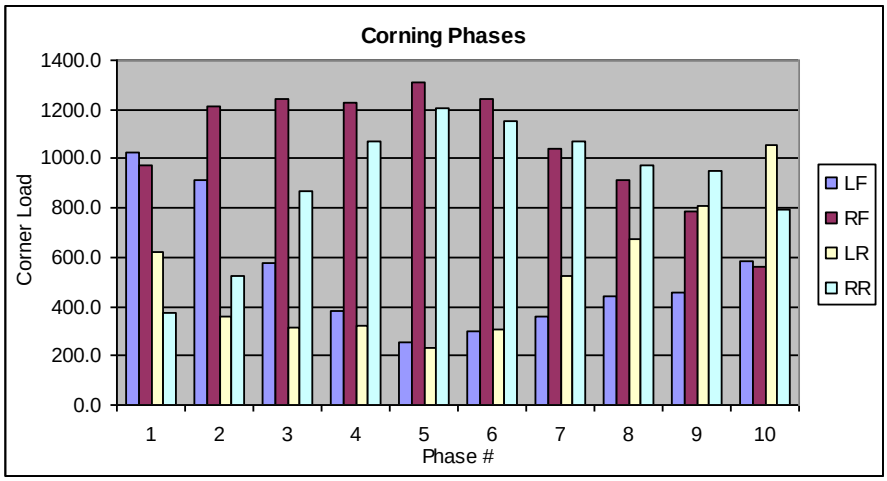
Load Transfer through the Ten Cornering Phases (Springs)

Table 16-1 and its accompanying graph represents a generic left turn scenario. It shows the dynamic corner loads as a result of ten base cornering phases. There are many different types of cornering scenarios but even the classic, get all the braking done in a straight line, late apex line is never that cut and dried.

Corner Loads with Base Spring Rates:

	Load	Load	Load	Load
	LF	RF	LR	RR
#1 B = 1.0g - T_L = 0.0g	1028.8	977.0	618.0	377.3
#2 B = 1.25g - T_L = 0.5g	910.2	1210.2	359.0	521.6
#3 B = 0.6g - T_L = 1.0g	576.7	1242.7	313.4	868.2
#4 B = 0.15g - T_L = 1.25g	380.1	1231.1	320.2	1069.6
#5 B = 0.05g - T_L = 1.53g	256.3	1308.2	232.1	1204.4
#6 A= 0.0g - T_L =1.37g	301.4	1240.3	307.9	1151.4
#7 A =0.3g - T_L =1.0g	361.7	1042.1	526.7	1070.4
#8 A = 0.4g - T_L = 0.7g	444.8	913.3	670.3	972.6
#9 A = 0.65g - T_L = 0.5g	456.5	786.6	809.4	948.5
#10 A =0.85g - T_L =0.0g	587	564.5	1056.5	793

Table 16-1



The above table and graph of the ten cornering phases gives us an overview of how much the loads shift between each phase. The fastest car, all other things being equal, will have the best dynamic set up compromises through each phase. Mess up one phase and it doesn't matter how good the next ones might have been. Likewise, a killer set up through the first two phases doesn't help at all if it results in the third stage set up being all wrong. **There is no perfect set up, only compromises**.

Note: Chapters 16 & 17 look at corner loads, amounts of load transfer plus side to side and front to rear load splits. Until the tire models are added in Chapters 20 & 21, we won't really know whether a change in balance will help or degrade the chassis' ultimate performance. Further to this, a balance change for any given tire map may help one driver's performance while hurting a less talented driver's performance.

The Four Corner Entry Phases

1) **Phase One – Corner Entry - Hard Braking and Rapidly Decreasing Throttle (B = 1.0g – T_L = 0.0g)**: This first set of corner phases sees all of the load transfer passing through the **springs**. For this example there is still no anti roll bar, damper or anti/jacking force reaction to the load transfer.

- Load the Short Track Stock Car, zero all of the green anti/jacking cells and reset the LR spring preload to 1.373 and the RR spring preload to 0.810. The static corner loads are LF = 790 lb., RF = 754 lb., LR = 855 lb. and RR = 602 lb. Load transfer is zero. Ride heights are LF = 4.255", RF = 4.506", LR = 4.783" and RR = 5.034".

- Enter 1g of braking.

  - The new Phase One base set up loads are LF = 1032.2 lb., RF = 973.5 lb., LR = 614.6 lb. and RR = 380.7 lb.

    - Notice that the percentage increase in LF load is slightly higher than the percentage increase in RF load. At first glance this may not make sense because, as we learned while working with the symmetrical chassis in Chapter 14, the stiffest spring will receive the highest percentage of load transfer. However, we also learned that a stiffer spring will also **lose** a higher percentage of load transfer in rebound. What this tells us is, when looking at load transfer, we always need to look at all four corner wheel rates, or, in this case, spring rates and motion ratios. We can't just look at one end of the chassis.

      <u>A quick load transfer review (Pure Braking)</u>:
      - A stiffer RF wheel rate during braking will see a higher load at the RF and LR and a lower load at the LF and RR.

      - A stiffer RR wheel rate during braking will see a lower load at the RR than the LR and a lower load at the LF than the RF.

      - The reader may want to review the spring versus load transfer tables presented in Chapter 14.

  - Some of the increased load seen at the LF is a result of the narrower LF track and shorter LF wheelbase but the majority of the increase, beyond the static bias offset, is the result of the spring rates and motion ratios.

    - The static wheel rates are LF 850 * 0.473^2 = 190.2 lb./in, RF 900 * 0.455^2 = 186.3 lb./in. **Surprise**, **surprise!** The LF wheel rate is actually higher than the RF with its higher spring rate but lower motion ratio. The rear corners have a 1/1 ratio so the spring rate and wheel rate will both be the same. This tells us that making a rear spring change, for any given rate change, will have a larger influence over load transfer than the front springs with their much lower motion ratios. Further to this, the LF, with its slightly higher motion ratio, will influence load transfer more than for the same change at the RF.

  - <u>Changing Spring Rates</u>: With 1g of inertial braking forces, the base load transfer is LF = 238.8 lb., RF = 223.0 lb., LR = -237.0 lb. and RR = -224.7 lb. Notice that the LF has gained more than the RF while the RR sees less load loss than the LR. If one corner sees a higher load transfer percentage than its opposite corner, its diagonal corner will, in turn, see less load transfer than its opposite corner. Increasing the LF corner load percentage will also increase the RR corner load percentage.

Note: Fundamental Truth – As previously discussed, stiffening a corner in compression will result in a load increase at that corner and its diagonal corner in addition to a load decrease at the opposite diagonal corners. The opposite is true when the corner is softened. Stiffening a corner in extension/rebound will result in a load decrease at that corner and its diagonal corner in addition to a load increase at the opposite diagonal corners. The opposite is true when the corner is softened.

- Increase the LR spring from 225 to 250 and rebalance the chassis by changing the preload to 1.045. The new load transfer is LF = 244.2 lb., RF = 217.5 lb., LR = -242.5 lb. and RR = -219.3 lb. The LR saw a larger amount of load transfer than the RR while the RF saw less load transfer than the LF. Using a stiffer LR spring resulted in a higher load at the LF and RR as seen in the corner loads. Corner loads are LF = 1034.2 lb., RF = 971.5 lb., LR = 612.5 lb. and RR = 382.7 lb. The dynamic wedge is decreased from 53.6% to 52.8%.

    - Base set up ride heights at 1g braking were LF = 4.255", RF = 4.506", LR = 4.783" and RR = 5.034".

    - The new ride heights are LF = 3.684", RF = 4.045", LR = 5.150" and RR = 5.511".

    - *Reset the springs and preloads to the base set up*.

- Decrease the LR from 225 to 200 lb. and rebalance the chassis by changing the preload to 1.780. The new load transfer is LF = 232.4 lb., RF = 229.3 lb., LR = -230.6 lb. and RR = -231.1 lb. Notice that the amount of load transfer is quite balanced with this spring combination. Corner loads are LF = 1022.4 lb., RF = 983.3 lb., LR = 624.4 lb. and RR = 370.9 lb. The dynamic wedge is 53.6%, the same as the static wedge percentage. Using a softer LR spring decreases the dynamic LF and RR loads while increasing the dynamic RF and LR loads.

    - Ride heights are LF = 3.776", RF = 4.030", LR = 5.292" and RR = 5.546".

    - *Reset the springs and preloads to the base set up*.

- Decrease the RR spring from 200 lb. to175 lb. and rebalance the chassis by changing the preload to 1.155. The new load transfer is LF = 246.5 lb., RF = 215.3 lb., LR = -244.8 and RR = -217.0 lb. Corner loads are LF = 1036.5 lb., RF = 969.3 lb., LR = 610.2 lb. and RR = 385.0 lb. The dynamic wedge has moved from 53.6% to 52.6%. Decreasing the RR spring rate has increased the LF and RR corner loads while decreasing the RF and LR loads.

- *Reset the springs and preloads to the base set up.*

- Increase the RR spring from 200 to 225 and rebalance the chassis by changing the preload to 0.543. The new load transfer is LF = 232.4 lb., RF = 229.3 lb., LR = -230.6 lb. and RR = -231.1 lb. Corner loads are LF = 1022.4 lb., RF = 983.3 lb., LR = 624.4 lb. and RR = 370.9 lb. The dynamic wedge is the same as the static wedge of 53.6%. Decreasing the RR spring rate has increased the LF and RR corners while decreasing the RF and LR loads.

- *Reset the springs and preloads to the base set up*

- Table 16-2 illustrate the changes in corner load at 1g of braking as the result of rear spring changes. The base springs are LF = 850, RF = 900, LR = 225 and RR = 200. Notice the relationships between the diagonal corners.

Short Track Stock Car 1g Brake

Spring Changes	Load LF	Load RF	Load LR	Load RR
Base	1028.8	977.0	618.0	377.3
LR 250	1034.2	971.5	612.5	382.7
LR 200	1022.4	983.3	624.4	370.9
RR 175	1036.5	969.3	610.2	385.0
RR 225	1022.4	983.3	624.4	370.9

Short Track Stock Car 1g Brake

Spring Changes	Load LF	Load RF	Load LR	Load RR
Base	Base	Base	Base	Base
LR 250	Increase	Decrease	Decrease	Increase
LR 200	Decrease	Increase	Increase	Decrease
RR 175	Increase	Decrease	Decrease	Increase
RR 225	Decrease	Increase	Increase	Decrease

Table 16-2

Set Up Scenarios: There are two primary reasons why a chassis would be set up to have higher left side loads under pure braking:

- A higher LF load would tend to bias the braking force to the left front over the right front, thereby producing a tendency for the chassis to begin to turn left before a steer angle is introduced.

- To help balance the left to right lateral acceleration load transfer as the chassis begins to turn left. Because the side to side balance during a turn is so important, teams take every opportunity to add as much **static** and **dynamic** left side bias as they can. Getting the right amount of dynamic bias is the tricky bit.

2) **Phase Two – Corner Entry - Hard Braking, No Throttle and Slowly Increasing Steer Angle (B = 1.25g – T_L = 0.5g)**: This first set of corner phases sees all of the load transfer passing through the springs. There is no anti roll bar, damper or kinematic reaction to the load transfer.

- Enter 1.25g of braking and 0.5g of left turn acceleration.

- The new base set up corner loads are LF = 910.2 lb., RF = 1210.2 lb., LR = 359.0 lb. and RR = 521.6 lb. The load transfer is LF = 120.2 lb., RF = 456.2 lb., LR = -496.0 lb. and RR = -80.4 lb.

- This first stage of corner turn in sees some of the most abrupt changes in side to side corner loads - it all happens quite quickly. If the chassis doesn't get through this phase well, the rest of the corner is pretty well downhill from this point. If the chassis takes a set and stays balanced front to rear, there is much time to be saved in this phase. If the **chassis** or **driver** has trouble taking or keeping a set through this stage, the lost time can never be made up throughout the rest of the corner even if the driver is able to regain chassis balance later in the turn.

- From the time steer angle is introduced, it should only take about one and a half to four revolutions of the tires for the load transfer to settle in (find its balance), depending on how stiff the chassis is (roll and pitch rate). As previously discussed, load transfer is pretty well instantaneous, but, depending on the spring, bar and damper rates, it takes a certain amount of time for the chassis to find its state of equilibrium. As we will discover shortly, the build and shaft velocity of the shocks

play a major role in how long it takes for the load transfer to balance (reach equilibrium).

- The stiffer the chassis is, the faster the chassis will pass through this first stage. However, for a heavy stock car, even for an extremely talented driver, slowing the transitions down slightly in this phase can help set up the rest of the corner. As long as the ride heights are changing, be it ever so slightly, the race engineer can exert a modicum of dynamic control through the set up options. More on this later in the chapter.

- The Phase Two ride heights are LF = 4.384", RF = 3.095", LR = 6.090" and RR = 4.800". How quickly the ride heights change over a given time determines the shaft speed and rate of acceleration of the shock. When we add the shocks into the load transfer calculations, we find many more ways in which the race engineer can control the chassis dynamic load transfer and balance. Of course, that also gives us many more ways to go astray.

- If the RF ride height changes more than the LR ride height for a given amount of time, then the RF shaft velocity will be higher than the LR. *It's just not that simple*.

- Notice that the wedge has moved from 53.1% during Phase One to 52.3% in Phase Two. The chassis has dewedged, which, in turn, will help the front balance and degrade the rear balance. This is confirmed by looking at the front and rear load splits where in Phase One they were front = 51.8 and rear = 240.7 while in Phase Two the splits are front = -300.0 and rear = -162.6.

Making Changes

- As in Phase One, we can change the static wedge (preload changes) and/or dynamic wedge change (changing spring rates) to adjust the front to rear balance. We can also change the actual amount of load transfer by changing the tracks, wheelbases and/or the CG.

    - <u>CG Height</u>: We can change the CG height by changing the static and/or dynamic ride heights. If we soften the right side springs, the chassis will roll down, thereby slightly lowering the CG (the right side ride heights move down more than the left side ride heights move up). If we stiffen the right side springs, the chassis will roll up, thereby slightly raising the CG (the left side ride heights will move up more than the right side ride heights move down). Once we introduce the shocks into the calculation, we are able to further exaggerate the extent of roll up or roll down.

Figures 16-1 through 16-3 show the resultant change in CG height as the result of roll up or roll down. The chassis is viewed from the rear with the left front static ride height at 4.262” while the right front static ride height is at 4.510. Its CG height is 18.0”.

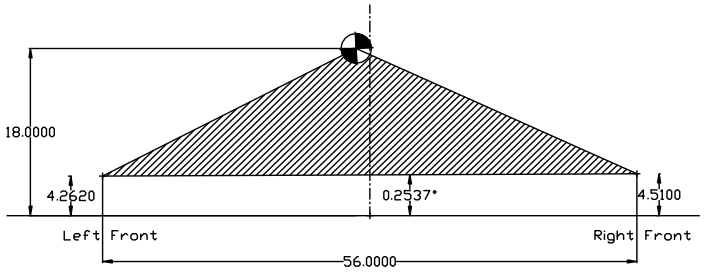


Figure 16-1

Figure 16-2 shows the same chassis as in the previous example but with a change in roll angle of 3 degrees as the result of a change in LF and RF dynamic ride height. This is a roll up example as a result of the datum roll center being positioned to the right of the chassis centerline. Notice that the CG height in this roll up example is now 19.5216.

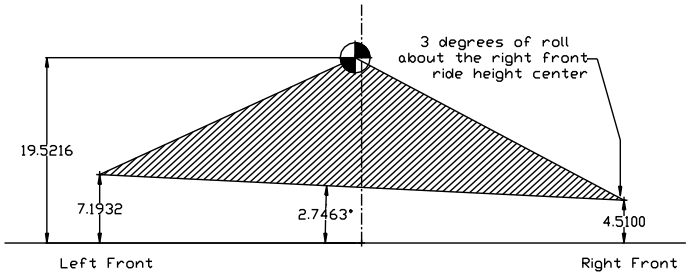


Figure 16-2

Figure 16-3 shows the same chassis as in the previous two examples with a roll angle of 3 degrees as the result of the change in the LF and RF dynamic ride heights. This is a roll down example as a result of the datum roll center being positioned to the left of the chassis centerline. Notice that the CG height in this roll down example is now 16.5905.

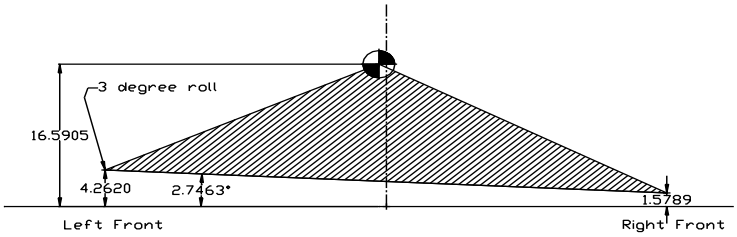


Figure 16-3

Note: We are about to look at a number of CG heights versus dynamic corner load distribution examples.

This, as it turns out, is another one of those chicken and egg calculations where the program requires a series of closed loop iterations. We will once again bypass the need for an iterative solver by manually entering the new CG height in the **A2** CG z cell.

- The CG height is obtained by first entering the front dynamic Wan31A ride heights (clearance heights) into the appropriate WinGeo3 model (Short Track Front).
    - (Compute) – (Solve for clearance) – enter clearance/ride height numbers
    - Calculate the new ride heights by clicking on the [**compute**] box located on the second line of boxes and to the right of the screen between animate and ride and roll.
    - Click on (Analysis) –(Anti Dive – Anti Squat) – This box gives the static and dynamic CG height.

Short Track CG Height Examples – Load Transfer Changes:

- With the base set up, add 1g of left turn acceleration. The total lateral load transfer is 756.0 lb. The new front ride heights are LF = 5.834" and RF = 2.853". Using WinGeo3, click on (Edit) – (Clearance) and make sure the CG is set at 16.5". Enter the new ride height numbers in WinGeo3 under (Compute) – (Solve for Clearance) and click on [**Compute**]. Go to (Analysis) and click on (Anti Dive – Anti Squat). The new CG height is 16.612".
    - Enter the new CG height in the appropriate **A2** cell (H 32).
    - This particular set up results in a small load change due to the change in dynamic CG height. The resultant change in corner loads are LF = -2.4 lb., RF = 2.4 lb., LR = -2.7 lb. and RR = 2.7 lb. (LF – less, RF – more, LR – less and RR – more). The amount of total lateral load transfer has increased to 761.1 lb., a change of 5.1 lb. This may seem like an extremely trivial amount but on track data shows us it is not.
- Change the RF spring from 900 lb. to 450 lb. and reset the preload to 1.7881". Enter the new front ride heights in WinGeo3. The new CG height is 16.118".
    - Enter the new CG height in the appropriate A2 cell. The resultant change in corner loads as a result of changing the CG from 16.5" to 16.118" are LF = 81.5 lb., RF = -81.2 lb., LR = -64.0 lb. and RR = 63.7 lb. (LF – more, RF – less, LR – less and RR – more). The total amount of lateral load transfer = 738.5 lb., a decrease of 17.5 lb. from the base set up at 1g left turn acceleration.
- Change the RF spring from 900 lb. to 1150 lb. and reset the preload to –0.097" and the RR from 200 lb. to 450 lb. and reset its preload to -0.529". Enter the new front ride heights in WinGeo3. The new CG height is 16.895".
    - Enter the new CG height in the appropriate A2 cell. The resultant change in corner loads as a result of changing the CG from 16.5" to 16.895" are LF = 35.9 lb., RF = -35.8 lb., LF = -54.0 lb. and RR = 54.0 lb. The total amount of lateral load transfer = 774.1 lb., an increase of 18.1 lb. from the 16.5" CG set up at 1g left turn acceleration.
- Track and Wheelbase Change: Widening the tracks and/or wheelbases decreases the amount of load transfer while narrowing the tracks and/or wheelbases does just the opposite.
- *Reset the CG to 16.5"*

- Changing the Static Wedge Percentage: Reload Wan31A Short Track Chassis. Adding or decreasing the amount of **static** wedge (RF to LR diagonal percentage) is one of the most useful tools oval track racers have to change the front to rear chassis balance. Like everything else in racing, too much of a good thing **is** too much of a good thing. Changing the wedge percentage much past the baseline set up generally means that either the base set up was wrong or something else within the base set up is not right. Wedge, like a shock change, is a fine adjustment tool.
    - In our short track example, Phase Two sees the chassis extremely unbalanced at the front but with a much better rear balance. As is often the case, we will need to degrade the rear balance to improve the front balance.
        - Reset the left turn and braking acceleration to zero and then change the wedge from 53.6% to 57.9% by adjusting the preloads to LF = 0.016, RF = 0.420, LR = 1.620 and RR = 0.474. Notice that we adjusted the preloads so that we ended up with the same static LF = 4.255" and RR = 5.036" ride heights. The RF = 4.532" while the LR = 4.759". There are an infinite number of preload and ride height possibilities that will result in the static wedge changing from 53.6% to 57.9% while maintaining any two combinations of ride heights.
        - Enter 1.25g braking and 0.5g left turn acceleration.
        - **Whoops!** We went the wrong way. The front split now has the LF corner 430.0 lb. lighter than the RF while the LR is only 32.6 lb. lighter than the RR. The dynamic wedge has dropped to 56.6% as seen in the splits and changes worksheet.
        - *Reset to base setting*.
    - Okay, let's try this again. Reload Wan31A Short Track Chassis. In the previous example we increased the wedge by 4.4% (a rather large amount) so this time we will decrease the wedge by 4.3% to 49.2%. Change the preloads to LF = 0.458, RF = 0.406, LR = 0.406 and RR = 0.918. The static wedge is now set at 49.2% and the LF and RR ride heights remain the same as with the base set up.
        - Enter 1.25g braking and 0.5g left turn acceleration.
        - The corner loads are now LF = 976.3 lb., RF = 1144.4 lb., LR = 292.9 lb. and RR = 587.4 lb. The front load split at –168.1 lb. is now less than the rear load split at –294.5 lb. Though slightly on the loose side, the chassis is far more balanced than the previous examples. The dynamic wedge has moved to 47.9%.
        - The primary reason for using such a large increase and decrease in wedge (4.4%) was to show the reader that virtually any change in wedge can be accomplished while maintaining the LF and RR ride heights. We could have also made the wedge change while maintaining the RF and LR ride heights or closely maintained the overall ride height balance at all four corners to accommodate an aero sensitive chassis. Maintaining the overall ride height balance requires a small change at all four corners (maintaining the sweet spots).
        - If we change the static wedge to 50.5% by adjusting the preloads to LF = 0.306, RF = 0 496, LR = 0.490 and RR = 1.144, we now find that during

Phase Two (1.25g braking and 0.5g left turn), the dynamic wedge moves to 49.2%. The front split is -205.8 lb. while the rear split is -256.8 lb.

- In order to balance out the front and rear splits requires 50.0% dynamic wedge, which, under the Phase Two conditions, begins as 51.3% static wedge. Preloads of LF = 0.387, RF = 0 508, LR = 0.500 and RR = 0.746 will get you very close. This is an excellent exercise for the user to see just how precise one needs to be when adjusting spring preload. A change of 0.002" can result in a significant change in front and rear splits. As we will discover shortly, running with 51.3% static wedge is not the fastest set up for all cornering phases. Everything is a compromise.

Note: Balancing corner loads is only one part of chassis performance. In Chapters 20 & 21 we will also look at the effect of various tire maps in regards to load versus force, steer angle, shear angle, type of load transfer, camber change, static and dynamic toe, longitudinal tire torque (including stagger torque tire), tire pressure, tire temperature, tire wear, etc.

- Combining Static and Dynamic Wedge: Reload Wan31A Short Track Chassis. Race engineers are always looking for ways to produce dynamic wedge changes that help balance the chassis. As in the previous examples, we are not going to be all that subtle with our changes. That will come later. At this point we are only looking at the possibilities.

  - The preload examples showed us that we need the chassis to be dewedged for optimum Phase Two performance. We have also learned that if we want the chassis to dewedge under dynamic conditions, we can, for Phase Two load transfer, increase the LF and RR spring rate and/or decrease the RF and LR spring rate.

    - Change the LF spring from 850 lb. to 1100 lb. and reset the LF preload to –0.208. The front split under Phase Two conditions has decreased from -300.0 lb. to –284.6 lb. and the rear split has increased from –162.6 lb. to -178.0 lb. This change did not change static ride heights but did change the dynamic ride heights.

    - Maintaining the previous change, also change the RF spring from 900 lb. to 700 lb. and reset the RF preload to 0.683. The front split has further decreased to –217.4 lb. and the rear split has further increased to –245.2 lb. The static ride heights have not changed. At this point, the front load split is less than the rear load split. The chassis **may** show a slight loose condition.

    - Maintaining the previous change, also change the LR spring from 225 lb. to 350 lb. and reset the LR preload to 0.205. The front split has decreased considerably to –126.3 lb. and the rear split has increased considerably to –336.3 lb. The static ride heights have not changed.

    - Maintaining the previous change, also change the RR from 200 lb. to 150 lb. and reset the RR preload to 1.613. The front split has slightly increased to –127.4 lb. while the rear split has slightly decreased to -335.2 lb.

    - Rather than change the RR from 200 lb. to 150 lb, change it to 100 lb. and reset the RR preload to 3.220. Notice that even a 100 lb. change in the RR spring rate under Phase Two conditions showed very little

effect on the front and rear splits. It also showed very little change in the side splits (LF-LR and RF-RR). In combination with all the other spring and preload changes, a change to the RR showed the least effect on the side to side splits. However, under higher lateral acceleration, a RR change would result in a much larger change. Further to this, if the chassis was under forward acceleration rather than braking, the RR change would result in an even greater change.

- At this point in the corner we have the chassis on the loose side but don't worry because here comes Phase Three and Four.

- Reset the spring rates and preloads to the base setting.

- Changing only the RR to 150 lb. and resetting the preload to 1.6133 changes the front and rear side to side splits from -300.0 to -287.7 lb. at the front and from -162.6 to -174.9 at the rear. Changing just the RR from 200 to 150 results in a larger change in side to side splits than when that same change was made in combination with the LF, RF and LR changes.

Set Up Scenarios:

- Load transfer can be decreased by increasing the tracks and/or wheelbases in addition to lowering the CG height.

- Changing the static wedge percentage can change load transfer balance.

- Changing the dynamic wedge percentage can change load transfer balance.

    - Changing the spring rates can change the load transfer balance.

3) **Phase Three – Corner Entry - Moderate Braking with Rapidly Increasing Steer Angle (B = 0.6g – T_L = 1.0g)**: This first set of corner phases sees all of the load transfer passing through the spring. There is no anti roll bar, damper or kinematic reaction to the load transfer. Reload Wan31A Short Track Chassis.

    - Load the Wan31A Short Track Model, place zeros in all of the anti/jacking cells and recalibrate the LR spring preload to 1.373 and the RR spring preload to 0.810. Enter 0.6g braking and 1.0g left turn acceleration.

    - The base set up loads during Phase Three conditions are LF = 576.7 lb., RF = 1242.7 lb., LR = 313.4 lb. and RR = 868.2 lb.

        - The load transfer is LF = -213.3 lb., RF = 488.7 lb., LR = -541.6 lb. and RR = 266.2 lb.

        - The side to side corner load splits are front –666.1 and rear –554.8 while the rear to front splits are left –-263.2 and right –374.5.

        - The ride heights are LF = 5.517", RF = 2.573", LR = 6.575" and RR = 3.630". Compared to the static rides of LF = 4.255", RF = 4.506", LR = 4.783" and RR = 5.034", the LF has moved up 1.262", the RF down 1.933", the LR up 1.792" and the RR down 1.404". Though the shocks will not be introduced until later in this chapter and aero loads in Chapter 18, the reader should begin looking at the ride height changes in relation to the shock shaft velocity and the proximity of the chassis' four corners to the track surface. For any given dynamic change, the corner which sees the largest change in ride height would also see the highest

damper shaft velocity. Comparing the various ride height changes, the LR would have the highest rebound velocity while the RF would have the highest bump velocity. The RF sees the lowest ride height change while the LR sees the highest ride height change. Take note of the relationship between shaft velocity and corner proximity to the track surface.

It is pretty clear that we have a preponderance of load on the RF compared to the LF. The problem is how to find a better front balance. The first thing we want to look at is whether we can change the **amount** of load transfer. As previously discussed, the only way we can decrease the **amount** of load transfer is by decreasing the chassis' total weight, increasing the track and/or wheelbase and/or by lowering the CG. In our case the rules dictate that the car must have a minimum weight without the driver of 2850 lb., and, as our driver weighs 151 lb., we are already at minimum weight. The rules allow the chassis to have a left side bias of 55% (which is great compared to the approximate 53% we are allowed to run with our NASCAR chassis). We have chosen to run at 54.8% left side bias.

- Lowering the CG by 1" is by no means simple but any CG decrease is worth the time, effort and often the money. With the CG at 16.5", the load transfer in Phase Three is y = 754.9 lb. and x = 275.4 lb. The percentage of load at each corner as seen in the **Splits and Changes** worksheet are LF = 19.2%, RF = 41.4%, LR = 10.4% and RR = 28.9%. The front split is –666.1 lb. and the rear split is –554.8 lb. while the left rear to front split is –263.2 lb. and the right rear to front split is –374.5 lb.

    - If the CG was lowered to 15.5", the load transfer in Phase Three is y = 709.2 lb., a decrease of 45.7 lb. and x = 258.7 lb., a decrease of 16.7 lb. The percentage of load at each corner as seen in the **Splits and Changes** worksheet are LF = 19.6%, RF = 40.4%, LR = 11.5% and RR = 28.4%. The front split is –623.5 lb. and the rear split is –505.8 lb. while the left rear to front split is –243.3 lb. and the right rear to front split is –361.0 lb.

    - *Reset the CG height to 16.5*.

- The way the rules are written, the maximum track is 65.5" from hub face to hub face. Because the rear tracks must be symmetrical, they are both set at 32.75". The front tracks can be offset to a maximum of ¾". Our front track is offset ½". We shortened our LF track because it was the easiest why to help achieve the left side bias. This can be seen by experimenting with the Track-**Wheelbase vs Load** calculator -* **Remember the static load change from shortening the LF track has already been taken into consideration when entering the initial loads in A2**.

    - Under Phase Three cornering conditions, the base model has a load transfer of y = 754.9 and x = 275.4

        - The corner loads are LF = 576.7 lb., RF = 1242.7 lb., LR = 313.4 lb. and RR = 868.2 lb.

        - The splits are Front = -666.1, Rear = -554.8, Left = -263.2 and Right = -374.5.

Note: When changing a track and/or wheelbase in this section, we are only looking at the resultant changes in dynamic load transfer. We are assuming that when a track and/or wheelbase change was made that various component and ballast bits were moved around in order to achieve the chassis initial scale pad loads as seen in the A2 initial load cells i.e. the changes were made before the chassis was lowered onto the scale pads.

Changes

- Load the Wan31A Short Track Model, place zeros in all of the green anti/jacking cells and recalibrate the LR spring preload to 1.373 and the RR spring preload to 0.810. Enter 0.6g braking and 1.0g left turn acceleration.

CASE 1

- Change all wheelbases to 53.75 and all tracks to 32.75. **Recalibrate** the x and y **pink cells** in A2. The pink x cell is changed from 1.722 to 1.855 and the pink y cell is changed from 3.625 to 3.754.

    - The load transfer is now y = 756.0 and x = 276.4. Compared to the base set up, the lateral load transfer increased by 1.1 lb. and the longitudinal load transfer increased by 1.0 lb.

        - The corner loads are LF = 577.3 lb., RF = 1243.1 lb., LR = 311.7 lb. and RR = 868.9 lb. Notice that the LF, RF and RR have gained load while the LR has lost load – the load transfer change is not directly coupled to the diagonal corners, since the CG has now been moved.

        - The splits are Front = -665.8, Rear = -557.1, Left = -265.5 and Right = -374.2. During Phase Three, the **symmetrical** tracks and wheelbases set up improved lateral balance while longitudinal balance was degraded (depending on the tire map).

CASE 2

- Reverse the original front tracks so that the LF = 33” and the RF = 32.5” and leave all wheelbase at 53.75. **Recalibrate** the **A2** x and y **pink** cell.

    - The load transfer is now y = 757.0 and x = 276.4. Compared to the base set up, the longitudinal load increased by 1.0 lb. while the lateral load transfer increased by 2.1 lb.

        - The corner loads are LF = 576.8 lb., RF = 1243.6 lb., LR = 311.3 lb. and RR = 869.4 lb. Compared to the base set up the RF and RR have gained load while the LF and LR have lost load – the load transfer change is not directly coupled to the diagonal corners.

        - The splits are Front = -666.8, Rear = -558.2, Left = -265.6 and Right = -374.2. During Phase Three, the LF = 33” and RF = 32.5” track setting very slightly improved the overall cornering balance.

CASE 3

- Set all track widths at 32.75” while changing the LF wheelbase to 53.25”. **Recalibrate** the **A2** x and y **pink** cells.

    - The load transfer is now y = 756.0 and x = 275.4. Compared to the base set up, the lateral load transfer increased by 1.1 lb. and the longitudinal load transfer stayed the same.

        - The corner loads are LF = 576.2 lb., RF = 1243.2 lb., LR = 312.9 lb. and RR = 868.8 lb. The LF and LR have lost load while the RF and RR have gained load – the load transfer change is not directly coupled to the diagonal corners.

        - The splits are Front = -667.1 lb., Rear = -555.9 lb., Left = -263.3 lb. and Right = -374.5 lb.

CASE 4

- Set all track widths at 32.75" while changing the front wheelbases to LF = 53.75" and RF = 53.25". **Recalibrate** the **A2** x **pink** cell.

    - The load transfer is now y = 756.0 and x = 278.6. Compared to the base set up the lateral load transfer increased by 1.1 lb. and the longitudinal load transfer increased by 3.2 lb.

        - The corner loads are LF = 579.0 lb., RF = 1243.6 lb., LR = 310.0 lb. and RR = 868.4 lb.

        - The splits are Front = -664.6 lb., Rear = -558.4 lb., Left = -269.1 lb. and Right = -375.2 lb.

4) **Phase Four – Corner Entry - No Braking with Slowly Increasing Steer Angle (B = 0.15g – T_L = 1.25g).** From this point on, we will often include a front and/or rear anti roll bar. The load transfer will pass through both the springs and roll bars. There is no damper or kinematic reaction to the load transfer.
    - Load the Wan31A Short Track Model, place zeros in all of the anti/jacking cells and recalibrate the LR spring preload to 1.373 and the RR spring preload to 0.810. Enter 1.25g of left turn and 0.15g braking acceleration.

        - The base set up corner loads are LF = 380.1 lb., RF = 1231.1 lb., LR = 320.2 lb. and RR = 1069.6 lb. The splits are front = -851.1 lb. and rear = -749.4 lb. and the total lateral load transfer is 944.7 lb. The dynamic wedge is 51.7%. As we will discover when working with the tire maps in Chapters 20 and 21, the total chassis performance can only be as strong as the least balanced end. In this case, it is the front end of the chassis that will restrict the chassis' ultimate performance. *It's not that simple*.

        - At this point in our analysis, it would appear that we need to start with less static wedge in the chassis, which is true, until we also introduce the rear jacking forces transferred through the track bar. We will look at jacking forces shortly.

        - Anti Roll Bars: Roll bars are used for two primary reasons: to decrease the amount of body roll and to balance the opposite end of the chassis. If a **front** bar is used, it will degrade the front balance by adding weight to the outside corner and decreasing weight at the inside corner. On the other hand, a **front** bar will improve the rear balance by adding weight at the rear inside corner while reducing weight at the rear outside corner. A rear bar improves/decreases the front load balance/split while increasing the rear outside to inside split.

            - Add a 200 lb. bar at the front of the chassis. The wedge increases to 63.3% while the roll angle decreases from –3.867 to –2.4353 degrees. Notice that adding the front bar increases the RF and LR corner loads while decreasing the LF and RR corner loads, thereby further degrading the front balance but improving the rear balance. The front split has increased from –851.1 lb. to –1197.9 lb. and the rear split has decreased from –749.4 lb. to –402.5 lb., not a good thing for overall chassis balance and performance. Looking at the **Split & Changes** worksheet, notice that the total front weight to total rear weight percentage is still the same as with the base set up – Front = 53.7% and rear = 46.3%.

            - Remove the front bar and add a 200 lb. rear bar. The dynamic wedge percentage decrease from 51.7% to 36.9%, and, as a result, the front balance improved considerably. The front split is now –407.1 lb. while the rear split has increased to –1193.3 lb. Notice that the rear 200 lb./in bar results in a larger change in wedge as the result of the rear1:1 motion ratio. The total front and rear load percentages are still the same as the base set up. The amount of roll has decreased to –1.804 degrees.

Anti and Jacking Forces – The First Four Cornering Phases Revisited

- Jack Forces: Unlike the front and rear independent suspension system we looked at in Chapter 14, when running a **live axle** rear suspension using a track bar, we **only** place ones in the LF and RF **A4.1** cells while leaving the LR and RR cells set at zero. In order to activate the rear **live axle** track bar system, we need to place a one in the **A4.2** green cell. Under bar geometry, the track bar y and z co-ordinates are entered as:

    - Axle y = Lateral distance from the track bar **Axle mount** to the center line of the chassis

    - Axle z = Vertical distance from the track bar **Axle mount** to the track surface

    - Frame y = Lateral distance from the track bar **Frame mount** to the center line of the chassis

    - Frame z = Vertical distance from the track bar **Frame mount** to the track surface

A Pure Lateral Acceleration Side Bar

- Load Wan31A Short Track – Check to see that the appropriate green Anti/Jacking cells are set at 1 and the spring preloads are LF = 0.170, RF = 0.240, LR = 1.600 and RR = 0.470.

- Turn off the Anti/Jacking green cells and reset the rear preload to LR = 1.373 and RR = 0.810.

- Enter 1g of left turn acceleration. The 1g left turn base set up loads are LF = 433.4 lb., RF = 1109.0 lb., LR = 455.6 lb. and RR = 1003.0 lb. The wedge is 52.1% and the front split is –675.6 lb. while the rear split is –547.4 lb.

- Place a 1 in the LF and RF **A4.1** cells. Do not change the **A4.2** track bar cell from its zero setting. The new corner loads are LF = 395.3 lb., RF = 1146.9 lb., LR = 493.8 lb. and RR = 965.1 lb. The new wedge is 54.7% and the front split is –751.7 lb. while the rear split is –471.3 lb. Including the front jacking forces in the load transfer calculation clearly shows an additional loss in the front balance with an improvement in the rear balance.

- Place a 1 in the LF and RF **A4.1** cells and the **A4.2** track bar cell and change the rear spring preload to LR = 1.600 and RR = 0.470. The new corner loads are LF = 445.1 lb., RF = 1097.3 lb., LR = 444.0 lb. and RR = 1014.6 lb. The new wedge is 51.4% and the front split is –652.3 lb. while the rear split is –570.7 lb. The lateral jacking forces are LF = -30.176 lb., RF = 111.14 lb., LR = -270 lb. and RR = 243.5 lb as seen in A4.5 cells.

    - Including the track bar jacking force in the lateral load transfer calculations **dramatically** improves the front balance while **dramatically** degrading the rear balance.

- Lower the track bar axle mount 1” from 10.860” to 9.860” in the **Axle Z** cell. The corner loads are now LF = 436.6 lb., RF = 1105.7 lb., LR = 452.4 lb. and RR = 1006.2 lb. The wedge is now 51.9% and the front split is –669.1 lb. while the rear split is –553.8 lb. Lowering the track bar axle mount 1” while maintaining the frame mount height increased the bar angle to 2.463 degrees up

towards the frame mount. This helped the rear balance while degrading the front balance. The jacking forces are LR = -277 lb. and RR = 211.9. Back to Base Set Up

- Lower both the track bar axle mount and frame mount 1" from their base setting. The corner loads are now LF = 430.3 lb., RF = 1112.0 lb., LR = 458.7 lb. and RR = 1000.0 lb. The wedge is now 52.3% and the front split is –681.7 lb. while the rear split is –541.3 lb. Moving both mounts down 1" improved the rear balance more than just moving the axle mount down 1". The rear jacking forces are LR = -246.8 lb. and RR = 220.5. Back to Base Set Up

- Lower the track bar frame mount 1" from 11.543" to 10.543" and reset track bar to 10.86. The corner loads are now LF = 438.7 lb., RF = 1103.6 lb., LR = 450.3 lb. and RR = 1008.4 lb. The wedge is now 51.8% and the front split is –664.9 lb. while the rear split is –558.1 lb. The bar angle is 0.464 down towards the frame mount. The rear jacking forces are LR = -239.9 lb. and RR = 252.1. Moving the frame mount down 1" rather than the axle mount down 1" showed slightly less improvement to the rear balance. Back to Base Set Up

- Raise the track bar axle mount 1" to 11.86. Frame Z remains at 11.543. The corner loads are now LF = 453.5 lb., RF = 1088.9 lb., LR = 435.5 lb. and RR = 1023.1 lb. The wedge is now 50.8% and the front split is – 635.4 lb. while the rear split is –587.5 lb. The rear jacking forces are LR = -262.9lb. and RR = 275.1. Raising the track bar axle mount helped the front balance while degrading the rear balance. The track bar angle is 0.646 down towards the frame mount. Back to Base Set U

- Raise the track bar axle and frame mount 1" to 11.860 & 12.543. The corner loads are now LF = 459.8 lb., RF = 1082.7 lb., LR = 429.2 lb. and RR = 1029.3 lb. The wedge is now 50.4% and the front split is – 622.8 lb. while the rear split is –600.1 lb. The rear jacking forces are LR = -292.7 lb. and RR = 266.4. Raising both track bar axle mounts helped the front balance more than raising only the axle mount. The track bar angle is 1.00 degrees up towards the frame mount.

- From the base setting, raise the track bar frame mount 1". The corner loads are now LF = 451.4 lb., RF = 1091.1 lb., LR = 437.7 lb. and RR = 1020.9 lb. The wedge is now 50.9% and the front split is – 639.7 lb. while the rear split is –583.3 lb. The rear jacking forces are LR = -299.6 lb. and RR = 234.9. Raising the track bar axle mount helped the front balance while degrading the rear balance. The track bar angle is 2.463 up towards the frame mount.

    - As we will soon discover, a dynamic change in the track bar angle as the chassis rolls can play a significant role in chassis balance.

- Starting from the base set up, shorten the track bar length by moving the frame mount in towards the center line of the chassis from 21.063" to 19.063". Notice that with 1g left turn acceleration, the corner loads showed very little change. The length of the bar by itself has little effect on the track bar jacking forces **except** for the fact that the shorter the bar, the more pronounced the angle change will be for any given amount of body roll and/or suspension motion. With 1g left turn lateral acceleration shortening the track bar by 2", change the bar angle from 1 degree to 1.054 degrees up towards the frame mount.

The Four Corner Entry Phases With Anti and Jacking Forces

1) **Phase One – Corner Entry - Hard Braking and Rapidly Decreasing Throttle (B = 1.0g – T_L = 0.0g)**: All load transfer forces pass through a combination of the springs, anti roll bars and the anti and jacking components.

    - Load Wan31A Short Track Stock Car. Enter 1g braking and 0.0g of lateral acceleration.

- Check to see that a 1 is placed in the LF and RF **A4.1** cells, the **A4.2** track bar cell, the LR and RR **A4.3** acceleration cells and the four **A4.4** braking cells.

    - The corner loads are quite similar to the loads before the Anti forces were included in the calculations - LF = 1028.9 lb., RF = 976.9 lb., LR = 617.9 lb. and RR = 377.4 lb. but the amount of load traveling through the springs as opposed to the suspension bits is quite different. As seen in A6.1, the no anti/jacking forces base set up spring loads were LF = 1921.3 lb., RF = 1883.5 lb., LR = 498.0 lb. and RR = 257.3 lb. compared to the new spring loads of LF = 1644.0 lb., RF = 1660.5 lb., LR = 590.1 lb. and RR = 268.0 lb. The front springs see less load while the rear springs see an increased load.

    - The loads passing through the suspension bits as seen in A4.4 are LF = 131.273 lb., RF = 101.322 lb., LR = - 45.822 lb. and RR = -57.055 lb. **A positive number indicates the suspension is pushing up on the sprung mass while a negative number indicates the suspension is pulling down on the sprung mass**. A positive number will decrease the load seen at the spring while a negative number will see an increased load at the spring.

- Increase the front brake percentage to 65%. The corner loads only change a small amount but the loads seen at the springs have changed considerably. The 65% spring loads are LF = 1567.1 lb., RF = 1587.1 lb., LR = 572.8 lb. and RR = 254.4 lb. while the anti forces are LF = 170.655 lb., RF = 131.718 lb., LR = -32.075 lb. and RR = -39.938 lb.

- Changing the Front IC - As we learned in Chapter 14, changing the suspension co-ordinates allow the race engineer to alter the dynamic corner loads by proportioning the amount of load passing through the springy bits compared to the suspension bits. If, for example, the engineer wanted to shift weight from the LF to the RF during Phase One braking he/she could lower the RF rearward upper control arm mount by 1". Using WinGeo3 when the aforementioned mount is lowered 1", the new RF side view IC co-ordinates become e = 10.777 and ax = 48.060.

    - Entering these new IC co-ordinates in the Wan31A model (O29 & O30) with 65% front brake bias, the corner loads are now LF = 1019.9 lb., RF = 985.8 lb., LR = 626.8 lb. and RR = 368.5 lb. compared to LF = 1031.9 lb., RF = 973.9 lb., LR = 614.9 lb. and RR = 380.4 lb. before the IC change. LF went down while RF went up.

- Changing the Front IC - To further balance the front corner loads under braking, raise the LF rearward upper control arm mount 1" in WinGeo3. This results in a LF (N29) side view IC of e = 16.444" and (N30) ax = 304.154".

    - Entering the new IC co-ordinates in Wan31A the resultant corner loads are LF = 999.6 lb., RF = 1006.0 lb., LR = 647.2 lb. and RR = 348.2 lb. while the spring loads have changed to LF = 1737.0 lb., RF = 1514.7 lb., LR = 618.2 lb. and RR = 209.3 lb. The anti forces are LF = 58.0041 lb., RF = 196.835 lb., LR = -32.075 lb. and RR = -39.938 lb. While the LF and RF upper control arm changes helped balance the front corners, the change also resulted in the rear corners becoming less balanced even though the rear anti forces did not change. There is no free lunch!

- Changing the Rear IC – Keeping the previous LF and RF changes, balance the rear lower control arm co-ordinates by raising the LR forward (frame) control arm mount from 9.75" to 10.250" to match the RR setting. WinGeo3 indicates that the new left and right rear side view IC co-ordinates are both e = 15.361 and ax = 183.333.

    - Entering the new IC co-ordinates in Wan311A and with 65% front brake bias, the corner loads are LF = 1004.5", RF = 1001.1", LR = 642.3" and RR = 353.1" while the spring loads have change to LF = 1747.3 lb., RF = 1503.9 lb., LR = 630.5 lb. and RR = 212.9 lb. The anti forces are LF = 58.004 lb., RF = 196.835 lb., LR = -48.068 lb. and RR = -39.938 lb.

- Dive, Pitch and Roll:

    - Load Wan31 Stock Car Chassis

    - The ride heights at 1g of braking forces (50% front brake bias) with the anti calculators turned **off** are LF = 3.714", RF = 4.024", LR = 5.185" and RR = 5.495". **Pitch** is **1.894** degrees - nose down.

    - The ride heights at 1g of braking force with **50%** front brake bias and the anti calculators turned **on** are LF = 4.123", RF = 4.307", LR = 5.236" and RR = 5.420". **Pitch** is **1.433** degrees – nose down. Notice that the L F, RF and LR ride heights are higher while the RR ride height is lower and the pitch angle has decreased.
        - At **65%** front brake, the ride heights are LF = 4.278", RF = 4.451", LR = 5.345" and RR = 5.517". **Pitch** is **1.373** degrees. Notice that compared to the 50% front brake example, all of the ride heights are higher. The pitch angle has also decreased from the previous example.

Note: The authors will assume that from this point on the reader knows how to move back and forth between Wan31A and WinGeo3 in order to determine the new IC co-ordinates.

- Changing the Front IC - The ride height at 1g of braking force with **50%** front brake bias, the RF rearward upper control arm mount lowered 1" (10.777/48.068) and the LF rearward upper control arm mount raised 1" (16.444/304.154) are LF = 3.863", RF = 4.441", LR = 5.020" and RR = 5.598". **Pitch** is **1.490** degrees. Notice that the LF and LR ride heights are considerably lower than in the base 50% brake bias example while the RF and RR ride heights have both increased. The roll angle is 0.591 degrees to the left compared to 0.188 degrees to the left in the base model.

    - At **65%** front brake, the ride heights are LF = 3.940", RF = 4.626", LR = 5.063" and RR = 5.749". **Pitch** is **1.446** degrees. Notice that all of the ride heights have increased from the previous example.

- Changing the Rear IC – Keeping the previous LF and RF changes balance the rear lower control arm co-ordinates by raising the LR forward (frame) control arm mount from 9.75" to 10.250" to match the RR setting. WinGeo3 indicates that the new left and right rear side view IC co-ordinates are both e = 15.361 and ax = 183.333. At **50%** front brake bias, the ride heights are LF = 3.815", RF = 4.456", LR = 4.950" and RR = 5.592". **Pitch** is **1.462** degrees.

    - At **65%** front brake bias, the ride heights are LF = 3.906", RF = 4.636", LR = 5.014" and RR = 5.744". **Pitch** is **1.427** degrees.

Set Up Scenarios: We have just begun to look at the role suspension kinematics play in dynamic load transfer and balance. If, for example, the race engineer had installed a higher LF than RF spring rate in order to help left turn lateral load transfer, he/she, could, in turn, rebalance the LF/RF braking load transfer by changing the dynamic suspension kinematics i.e. IC co-ordinates. As is so often stated throughout the book, never lose sight of the fact that each on track corner, will, in actuality, contain thousands of phases, not just ten.

- Any type of asymmetrical change will introduce additional asymmetries. Everything affects everything else.

- Under pure braking only the side view IC forces affect the load transfer loads and kinematics

Oval Track Asymmetries

Working with asymmetries to enhance dynamic left turn performance is an extremely difficult proposition. There are thousands of set up iterations but only one of those iterations will contain the ultimate compromise.
Type of Asymmetries:

- Wheelbase
- Track
- Tire Radius
- Biases
- Corner Loads
- Springs
- Shocks
- Bars
- Motion Ratios
- Wheel Rates
- Kinematics
  - Front View IC's
  - Side View IC's
  - Camber Gain
  - Caster Gain
  - Toe
  - Etc.

2) **Phase Two – Corner Entry - Hard Braking, No Throttle and Slowly Increasing Steer Angle (B = -1.25g – T_L = 0.5g)**: All load transfer forces pass through a combination of the springs, anti roll bars and the anti and jacking components.

- Both anti (longitudinal) and jacking (lateral) forces will affect this cornering phase.

The reader has no doubt noticed that up to this point we have been using the chassis static kinematics to determine the IC co-ordinates. Once again, we are faced with a closed loop iterative problem where the IC co-ordinates need to be calculated from the dynamic kinematic positions, including how the anti and jacking forces calculations affect the kinematics, which, in turn, affect the anti and jacking forces, etc. As the IC co-ordinates need to be obtained from the WinGeo3 software either by combining the two programs through ASCII or Matlab or by simply entering the data manually, we are going to do the latter throughout Book One for a number of reasons, not the least of which is that the real time WinGeo3 ASCII data is **not free**. Once it has been thoroughly tested, we are going to sell a software package geared towards professional race teams that will combine the WinGeo3 software with a new vehicle dynamic software package. This new software will allow the user to download on track data in order to run both the WinGeo3 and vehicle dynamics software in combination with each other (very exciting). A third dynamic software simulation package can be added in order to determine chassis performance envelopes. This third package will include dynamic tire performance algorithms, aero load algorithms as well as a considerably more sophisticated damper algorithms. Though this commercial software package has its basic vehicle dynamics engine based on the algorithms found in Chapter 15, it is many, many times more complex.

Important Note: The following procedures will be used to set the IC co-ordinates throughout the rest of the book.

- With all appropriate **A4** green cells turned **on,** add the **A5** acceleration forces.
- Enter the resulting ride heights (clearances) in the appropriate WinGeo3 model.
- Change the appropriate Wan31A height (e) and length (a_x) co-ordinates to those shown in WinGeo3.

- Load Wan31A Short Track Stock Car. Turn on all the appropriate **A4** green cells and enter 1.25g of braking and 0.5g of left turn acceleration.

- The base set up loads including the anti/jacking forces are LF = 912.2 lb., RF = 1208.1 lb., LR = 357.0 lb. and RR = 523.6 lb. The front split is –296.0 and rear –166.6 while the rear to front left split is = –555.2 and right side split = -684.5.

- We now have a number of ways to change the chassis static and dynamic balance including:

    - Bias - Static
    - Wedge – Static and Dynamic
    - Preload – Static
    - Spring Rate – Static and Dynamic
    - Bar Rate - Static and Dynamic
    - Motion Ratio - Static and Dynamic
    - Suspension Kinematics (IC Co-ordinates) – Dynamic

Balancing the Braking

- Setting the Brake Bias: A first step in setting the brake bias is to set the bias in relation to the front to rear dynamic loads. At 1.25g of braking, the front load percentage is just over 70%. As long as we maintain 1.25g of braking that will not change appreciably unless we also change the wheelbase and/or dynamic CG height.

    - Set the front brake bias at 65%. The corner loads are now LF = 916.0 lb., RF = 1204.4 lb., LR = 353.2 lb. and RR = 527.4 lb. The front split is –288.4 lb. and rear –174.2 lb. while the rear to front split is left = –562.7 and right = -677.0. The wedge is at 51.9 %.

        - The final brake bias will depend on the tire coefficients. As a general rule, when the chassis is required to begin lateral acceleration while braking, the front brake balance will need to decrease slightly in order to accommodate the lateral turn in. Increasing the front brake bias degrades the front turn in balance while helping the rear turn in balance. Setting the front brake bias at 70% may help pure braking performance but it would most likely reduce the overall Phase Two performance level.

Note: Each chassis, track condition and driving style **will** require a **completely** different set up scenario. When a suggested set up change is made in this book, it is presented strictly to present some aspect of load transfer dynamics. Each performance problem will require its own set of solutions. As always, what this book is attempting to do is to help the race engineer understand the basics of chassis dynamics. There are **no** generic answers. As discussed in Chapter One, if the reader is looking for the quick answers to all his/her handling problems, they should probably take up some other profession – "Paint by the Numbers" would be good.

- Adjusting the Corner Loads: With 70% of the dynamic load at the front, one of our first concerns will be to rebalance the LF/RF load percentages in order to help both the braking and turn in performance. Even though the wedge is at 51.9%, the front split is –288.4 lb. compared to the rear split of – 174.2 lb.

    - We now need to decide what kind of change will best help Phase Two performance without unduly degrading performance in the other nine phases. The good news is that increasing the load on the LF will generally help both braking and left turn performance.

        - Several Important Relationships -(Increase LF & RR load and decreased RF & LR load under braking)

            1. Increase the LF spring rate
            2. Decrease the RF spring rate
            3. Increase the LR spring rate
            4. Decrease the RR spring rate
            5. Raise the LF side view IC
            6. Lower the RF side view IC
            7. Add a rear anti roll bar or increase its rate if one is already being used
            8. Decrease the front bar rate if one is being used
            9. Reduce the percentage of static wedge
            10. Raise the track bar and/or
            11. Tire radius change.

        - Selecting the Options:

            1. Static or dynamic change
            2. Single change or a combination of changes
            3. A change that primarily affects braking and/or braking and turn in or a change that will affect a larger number of cornering phases.

- Raising the LF side view IC or lowering the RF side view IC only affects the corner loading when a braking force is applied at the front wheels. This works fine for turn in under braking but its effect diminishes in direct proportion to the front braking force. Once the brakes are released there is no further corner load balancing effect.

- Adding or stiffening a rear anti roll bar will have little effect on corner balance until the chassis exhibits some form of asymmetrical rear suspension motion and/or roll. A rear roll bar improves front corner balance by degrading rear corner balance. A rear bar tends to loosen up the chassis **particularly** under left turn acceleration – it de-wedges the chassis. The good news is that as the chassis roll angle is decreased coming out of the corner, the chassis will begin to re-wedge.

- Changing the static wedge affects the corner balance during all ten cornering phases. Decreasing the static wedge percentage will improve the front balance while degrading the rear balance. The correct amount of static wedge for the first six phases may well be too little wedge for peak performance from Phase Seven on.

- Raising the track bar and/or the track bar angle will improve the front balance while degrading the rear balance during left turn lateral acceleration. The track bar's effect on the corner loads is directly related to the amount of lateral force seen at the rear tires.

- Increasing the amount of rear stagger split will help the chassis turn in and roll through the center of the turn but will tend to loosen up the chassis during turn exit.

- The correct balance normally requires a number of small combined changes rather than changing just one thing. This is what separates the constant front runners from the once in awhile front runners.

Shocks and Their Effect on Corner Balance

A Brief Shock Precursor

The design, build and/or adjustment of the shocks/dampers are not covered in this book other than through the most cursory of introductions. If the reader has no working knowledge of the modern shock, they **need to** familiarize themselves with the suggested reading material presented in Chapter 1.

When working with the Wan31A and B models we are assuming that the race engineer is able to build and adjust for any shock profile they may require. This, of course, is a somewhat naive approach, but even a basic introduction to shock types and adjustment philosophies as included in Book Two covers several hundred pages and Book One just doesn't have the space to do so. The design and use of shocks is still **very** much a developing science.

What we are attempting to show with the use of the Wan31A model is how shocks affect load transfer and for that we do not **immediatel**y need to know the theory behind the design, build and adjustment of the modern shock. The word **immediately** is used because any race engineer working in the field most definitely needs to thoroughly understand the ins and outs of shocks (pun intended).

Note: During this first look at shocks we are primarily concerned with the low speed transitional functions of a shock.

Shocks, as used on asymmetric cars, have a number of equally important roles:

- **Mechanical Grip**
  - Load Transfer Management
    - Corner load distribution
    - Rate of load transfer change
    - Balance rate of change
  - Controlling Spring Motion
    - In compression controlling movement
    - In rebound absorbing stored spring energy
  - Keeping the tire on the track over bumps (high speed)
  - Ride Height Management
    - Individual Corner Ride Heights
    - Rate of Ride Height Change
- **Aero Management**
  - Aero Load Management
    - Aero pressure center
      - Corner load disbursement
      - Rate of load transfer change
    - Rate of balance change
  - Ride Height Management
    - Individual corner ride heights
    - Rate of ride height change

- **Driver Feel**
    - How quickly the driver feels a change in chassis balance (Book Two)

In Chapter 16 we are only looking at shocks in relation to the management of mechanical grip as it pertains to load transfer while Chapter 17 will include the use of shocks in managing aero loads. Driver feel requires a different type of mathematical model as used in Book Two, and as a result will only be covered with anecdotal comments throughout Chapters 16 through 21.

Mechanical Grip: A shock needs to work in consort with the springs, anti roll bars and anti/jacking forces. None of these components can be completely separated from each other but they all have different levels of activation and control.

Types and Rates of Load Transfer

Note: Before we continue with our brief introduction of shocks, a quick **review** of the **four load transfer components** is in order.

- Springs- Force versus Deflection: As previously discussed, springs are force versus deflection components. If a spring's deflection (distance between the upper and lower perch) is changed, the load the spring sees will change.
    - The higher the spring load is, the higher the resultant wheel load will be.
    - The greater the spring motion ratio is, the greater the resultant wheel load.
    - Spring loads are changed through any type of suspension motion whether it is due to **sprung** mass motion or **unsprung** mass motion and whether the motion is symmetrical or asymmetrical.
    - The more a spring is compressed, the more force it will exert against both the suspension components (the lower spring perch) and sprung mass (the upper spring perch). Spring extension works in the opposite manner.
    - As the amount the spring is extended or compressed is varied, the load change it sees will be in direct relation to the spring's rate. A stiffer spring gains more load for any given amount of spring motion in compression while losing more load for any given amount of extension.
    - Unlike a solid link which transfers a load change instantly, when a load is applied at one end of a spring it takes a prescribed amount of time for that load to balance out at each end to the spring. The softer the spring rate is, the further the spring will have to move before the loads are balanced. **Spring rate controls the rate of load transfer through motion**. A spring's motion ratio also controls the rate of load transfer. The higher a spring's rate and/or motion ratio, the faster it will transfer load – see balanced loads at each end of the spring. An infinitely stiff spring will transfer a load change instantly.
    - In relation to the springs during load transfer, the **less** a corner is moving, the **greater** the percentage of load it will see.
    - The stiffest corner sees the highest percentage of load.
    - The softest corner sees the lowest percentage of load.

- Anti Roll Bars - Force versus Deflection: As previously discussed, bars, like springs, are motion actuated but unlike springs, they are only actuated when the left to right side suspension motion is asymmetric – one side's suspension moves more than the other side. Though the amount of twist a roll bar sees is normally equated to sprung mass roll, in fact, any type of asymmetric suspension motion will result in some amount of roll bar twist. For example under braking with asymmetric left to right suspension, a chassis pitch change will result in a small amount of bar twist.

    - The more a roll bar is twisted, the more force it will exert. A roll bar directly ties the left side and right side suspensions together. Whatever load the bar applies to the outside corner, it removes from the inside corner and vise versa. In actuality, even though the springs are **not** directly connected, the resultant load transfer is much the same. The primary difference between the spring versus bar right to left load change is in the **amount** of resultant change.

        - Load Wan31 Symmetrical Chassis

            - Going back to the Symmetrical Chassis with the base set up and1g of left turn acceleration, we see the addition of 201.8 lb. of load at the right side corners and a similar decrease at the left side corners.

            - If the front spring rates are both increased to 500 lb.(no per-load change), the RF gains 224.2 lb. while the LF loses 224.2 lb. The RR tire gains 179.4 lb. while the LR tire loses 179.4 lb. When the front springs are returned to 400 lb. and a front bar is added, it only takes a 50.0 lb. bar to accomplish the same change. The amount of roll along with the LF, LR and RR ride heights are the same in both cases, however, the pitch and RF ride heights are slightly different.

    - The more the bar twists, the greater the force it will exhibit.

    - The stiffest corner sees the highest percentage of load.

- Shocks – Force versus Velocity: Unlike springs and bars, shocks, except for their gas preload, only affect corner load when in motion. As a result, the shock's effect on load transfer is far more transient than for the springs and bars – the shock force can vary considerably over a one second period.

    - Low speed shock set ups are used to help control transitional conditions such as corner entry and corner exit. Shocks have no effect during static conditions except for the gas preload.

    - Low speed shock settings are used to help control spring motion – dampen the spring oscillation. In bump/compression springs and shocks work in parallel to control motion while in rebound/extension, the shock works to control the spring's release of stored energy.

        - If the chassis is balanced, adding a stiffer spring will require a lower compression and higher rebound setting.

    - High speed shock settings are primarily used to help keep the tire in contact with the track over bumps.

    - The greater the shaft velocity, the greater the shock's force. As velocity slows, the force the shock exhibits is reduced. For example, under braking and with equal front spring rates, if the RF shock has a higher compression/bump setting than the LF, as the front suspension compresses the RF will see a higher percentage of the longitudinal load

transfer but as the motion slows the RF and LF loads will begin to balance out. A stiffer spring during compression results in less suspension motion, which, in turn, decreases the time the shock is in motion.

- In relation to the shocks, the **slower** a corner is moving, the **smaller** the percentage of load it will see.

- The stiffest corner sees the highest percentage of load.

- Anti/Jacking Forces: Unlike the springs, bars and dampers, anti and jacking forces only affect dynamic load transfer when subjected to a force running from the tires/track through the suspension bits into the sprung mass and/or from the sprung mass through the suspension bits to the tire/track. Anti and jacking forces affect load transfer in direct relation to the amount of combined acceleration.

    - Pure **longitudinal** acceleration affects **anti longitudinal** forces while pure **lateral** forces affect **lateral jacking** forces.

    - Like springs and bars, anti and jacking forces can affect load transfer during both transitional and steady state conditions. The amount of anti and jacking force is **directly** related to the amount of acceleration force seen at the contact patch and the IC co-ordinates. Raising and/or shortening the IC co-ordinates increase the anti and jacking forces for any given amount of acceleration.

    - Anti and jacking forces are not affected by motion other than through a change in IC co-ordinates.

    - The stiffest corner sees the highest percentage of load. *It's not that simple*.

Shocks 101

Modern shocks can be built and adjusted to virtually any velocity versus force profile. There are four primary shock/damper stages though often only three are shown in the velocity versus force dyno graph. We are only concerned with the first three stages in Book One.

Gas Preload/Breakaway: Gas preload, also called breakaway, is the force that needs to be applied to a shock before the shaft will begin to move (dyno test). It is primarily the result of the internal gas pressure's resistance against the diameter of the shock shaft. The higher the gas pressure, the higher the breakaway preload. *It's not that simple*. Dyno software often doesn't show this initial stage. Gas preload is **not** the same as shim stack preload.

Nose (Low Speed or Bleed):

- The low speed valve adjuster primarily controls this part of the curve. The valve adjuster can be made to show various ranges of amplitude change per click of the adjuster. The rate of bleed through the low speed valve can be used to control the rate of change, which, in turn, controls the rate of load transfer (tire loading). Many of the new piston designs use multiple shim stacks that can affect the nose.

Knee (Transition):

- The knee is the transitional point between the nose and the straight line of the slope. It is controlled through a combination of the low speed adjuster and the initial opening of the piston shim stack. This section is adjusted through the type of bleed valve used and the positioning of the valve (number of clicks) in conjunction with the piston design, shim stack used and the amount

and type of shim stack preload. Many of the new piston designs use multiple shim stacks that can affect the knee.

Slope (We are only interested in the first part of the slope):

- The slope, normally, but not always, a straight line, is controlled by the shim stack and piston design. The slope is the high speed portion of the graph. When looking at load transfer, we are interested in shock velocities up to approximately 6" per second. The new velocity dependent, multiple stack, pistons can move from digressive to linear to progressive.

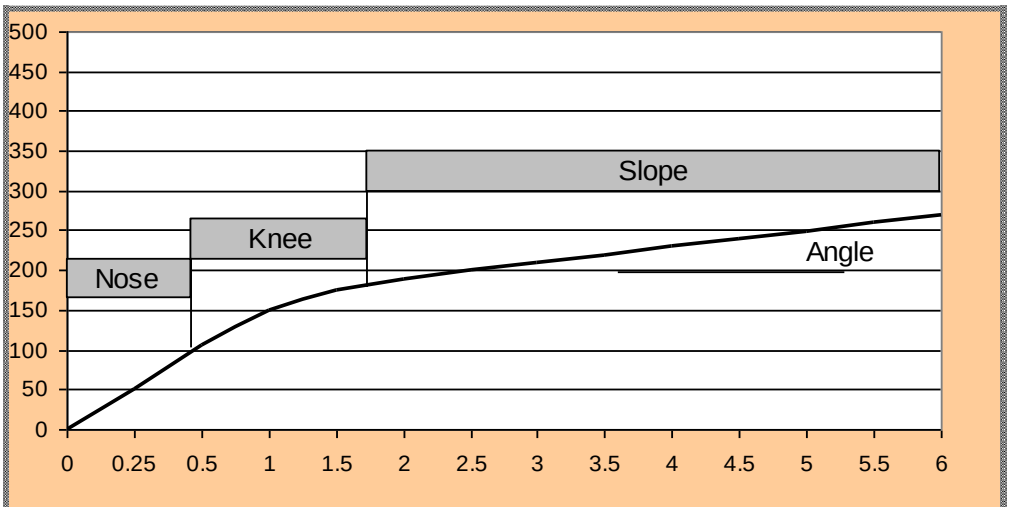


Figure 16-4 When looking at a shock dyno graph, we are only interested in velocities from 0" to approximately 6" per second when studying the transitional load transfer component.

As previously discussed, the shock's force profile can be set up through design, build and adjustment to fit just about any requirement, though not always with just one shock make. For example, because Penske and Ohlins shocks use a slightly different design philosophy, most teams will carry both types. That way the shock engineer is able to supply the race engineer with a wider variety of shock profiles. Though not covered until Book Two, the reader needs to at least familiarize himself with the effects of acceleration rate, hysteresis and jerk when it comes to the shock's force profiles. A Penske versus Ohlins shock can look similar when run on a traditional electric dyno but still yield different results on the track. Often this difference is the result of how the shock reacts to acceleration rate, hysteresis and jerk. To analyze these differences, teams are now moving to far more expensive hydraulic dynos that can mirror on track shock motion data.

The following graphs illustrate two different shock profiles. In both cases, the rebound side has a considerably higher force from the nose through to the slope.

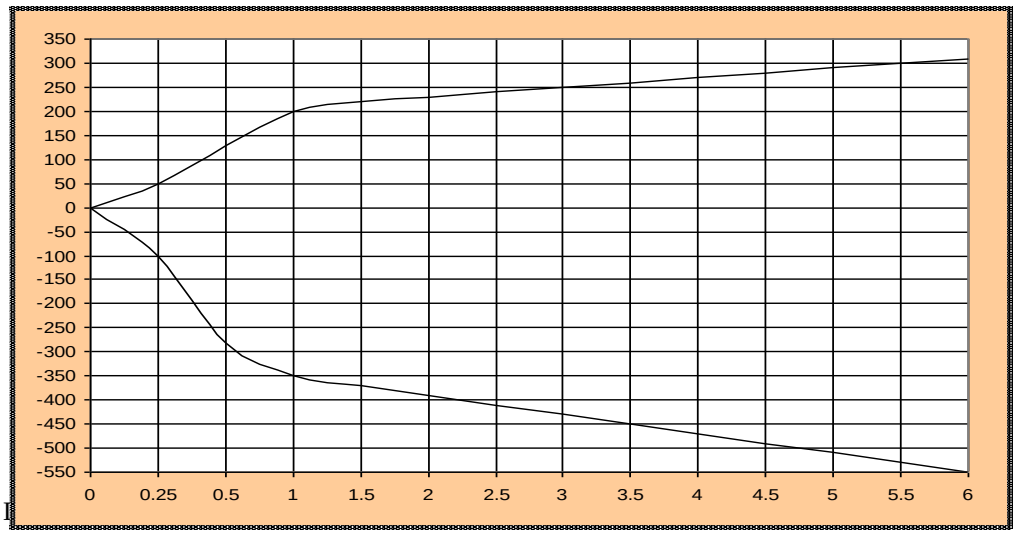


Figure 16-5

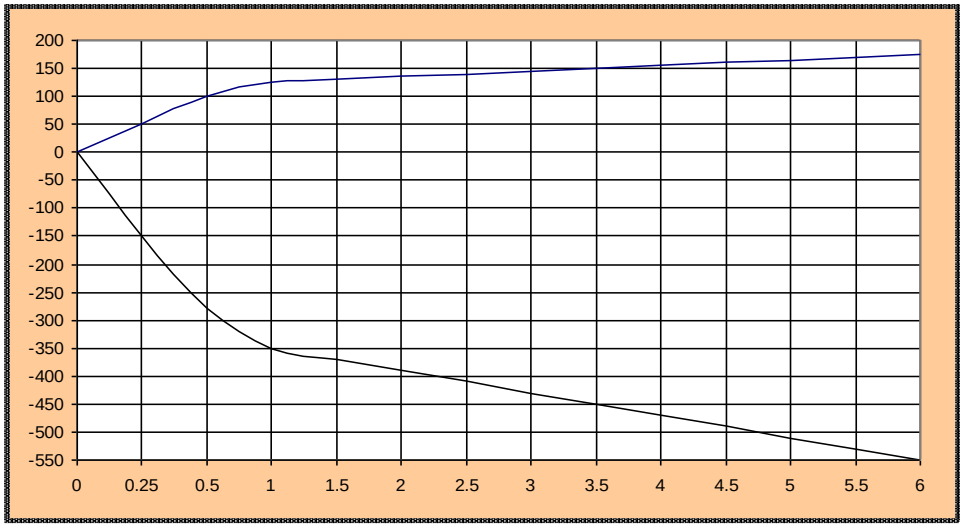


Figure 16-6

Two primary functions of a damper are to dampen chassis oscillation due to dynamic chassis forces such as roll and pitch and to dampen suspension oscillation when moving over track surface irregularities such as bumps and curbs – the first mode is considered low speed while the second mode is considered high speed. During low speed damping, the damper can help control the rate and amount of dynamic load transfer throughout the various transitional phases. During high speed suspension motion, the damper's primary function is to keep the tire contact patch loads from abruptly changing. The damper is often required to function at the same time and equally as well for both high and low speed conditions. For example, during braking, the change in chassis pitch is a low speed function. In this case, the race engineer is concerned about where and how fast the chassis loads are transferred. The prevention of wheel patter during braking is primarily a function of high speed damper set up.

How much and how quickly the chassis and/or suspension components return to their static position are controlled by the damper build and settings. When designing a damper build, one must first determine the dampers primary direction of motion during each corner phase - bump or rebound. An overview of how dampers are operating can be accomplished by using a dynamics model such as Wan31. However, for any sort of accuracy, one needs to incorporate data from the team's acquisition system. When designing a build for chassis motion, slow speed damping, a sampling rate in the proximity of 40 samples per second is normally used to study both the damper's rate and direction of motion. Even though the data is sampled at 40 samples per second, the actual slow speed damper velocity during these samples will be much slower, generally in the 0" to 6" per second range.

It can be quite astounding how often race engineers are wrong when asked about the damper's direction of motion for any given moment in time. For example, during a combination of bump and roll, all four dampers can be compressing even though the outer dampers will be compressed more and at a faster rate. Each corner, as shown in Figure 16-4, will have a completely different bump and rebound profile.

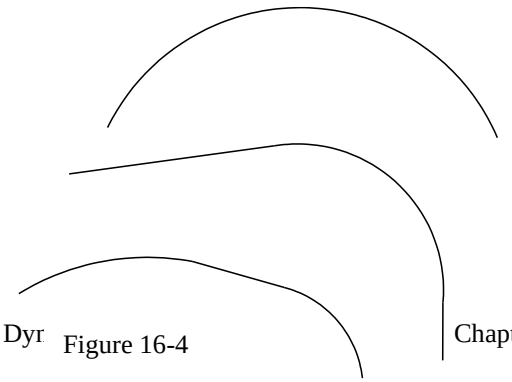


Figure 16-4

Damper Rate of Motion – Depending on whether the damper is set to underdamp, overdamp or critically damp will affect how quickly that corner will move back to its static position. The damper setting will determine if the corner will oscillate about the static position, return to the static position with little or no overshoot or return to the static position at a rate slower than the spring's/chassis' natural frequency. If underdamped, the corner will see less load transfer and initially return to the static position in less than one natural cycle, but, in turn, will oscillate several times above and below that corner's static position. If overdamped, that corner will see a higher rate of load transfer, the corner will move slower, and, depending on the dynamic conditions, it may never return to its static position before seeing a new dynamic event.

Damping Calculators – A number of basic calculators used when working with dampers are included with the accompanying CD. Please note that these calculators are extremely rudimental in nature.

Natural Frequency – Using Wan31 to determine wheel motion, a chassis' natural frequency in ride can be found through the following formula. A wheel deflection of 2.5" results in a natural frequency of 1.98 cycles per second (Hz), a wheel motion of 0.25 results in 6.27Hz while a wheel motion of 6" sees a ride rate of 1.28Hz – Calculator #1.

#1. Ride Natural Frequency vs Static Wheel Deflection

$$\omega = \frac{188}{\sqrt{x}}$$

x = Static Deflection in inches

ω = Frequency Hz (Cycles per second)

x	2.5	
ω	1.98	Hz
ω	118.9	Cycles/min

The undamped natural frequency can also be determined using the following formula. With a spring wheel rate of 50 lb. (spring rate * MR^2) and a vertical force at the tire of 125 lb., the natural frequency is 1.89 Hz – Calculator #2.

#2. Undamped Natural Frequency

$$\omega_n = \sqrt{K'/F_1}$$ In radians/sec

Divide by 2*Pi to convert to Hz

ω_n = Undamped Natural Frequency

K'= Spring Rate (lb) @ the wheel

F_1 = Force on mass

K'	50	
F_1	125	
ω_h	1.98	Hz

Critical Damping (Co) – As previously stated, a damper can be built to provide varying amounts of damping. Critical damping is referred to as the smallest value of damping required for the chassis and/or suspension to return to its position of equilibrium (static position) without overshooting or oscillating about that position - Figure 16-5. Figure 16-6 shows an underdamped system while Figure 16-7 shows an overdamped system. It is generally considered that a sub-critical damping rate of 70% is near the optimum rate for many modern race cars – Figure 16-8. Of course, it is far from that simple. In fact, Book Two will require something in the order of one hundred pages to merely introduce damping and damping rates.

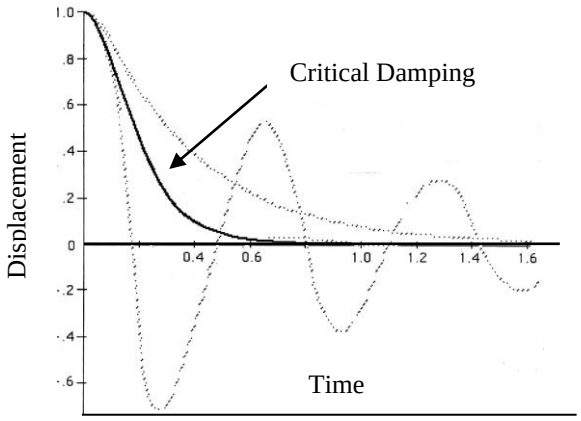


Figure 16-5

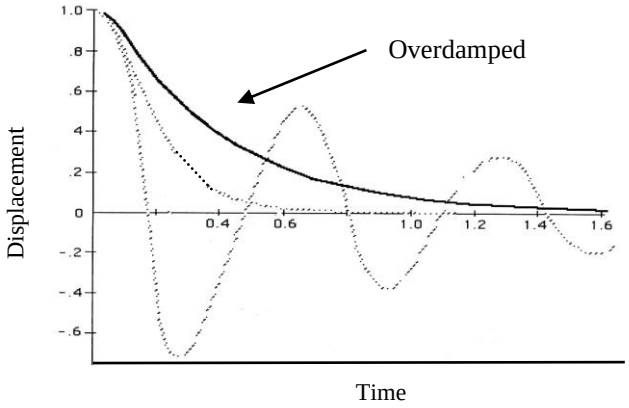


Figure 16-6

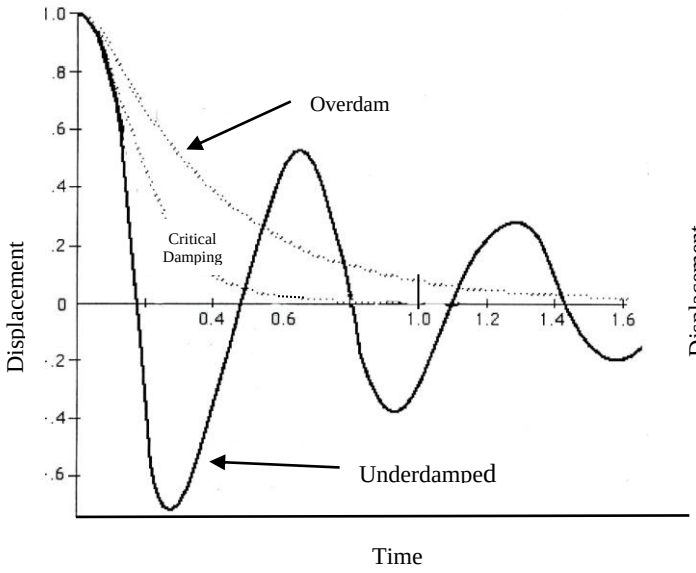


Figure 16-7

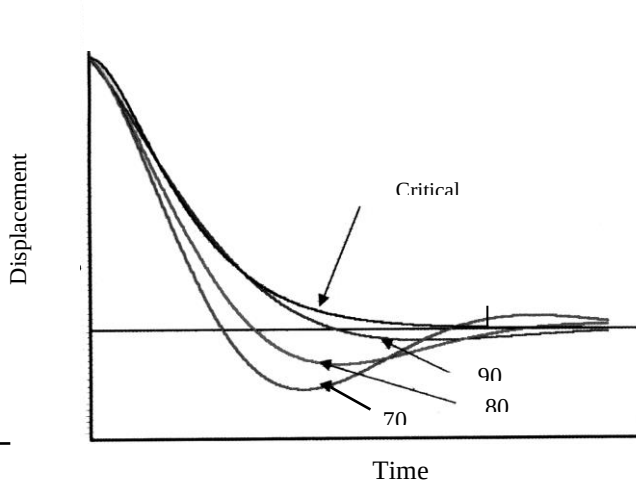


Figure 16-8

Calculator #3 allows the user to quickly calculate the required damping rate for any given percentage of critical damping.

#3. Critical Damping Ratio

$$C_0 = 2 * \sqrt{\frac{K'}{12} * \frac{m}{32.2}}$$

C_0 = Critical Damping Ratio	K'	300	lb/in
K'= Spring Rate (lb) @ the wheel	m	220	lb
m = mass (lb)	%	70%	
	C_0	18	lb/sec
	MR	0.8	
	C_0 @ Damper	29	

Damper Settings – Fortunately for the race engineer, most modern dampers can be set to dampen at different rates during both high and low speed damping as well as in bump versus rebound. High speed damping is primarily controlled through the design and setting of the dampers shim stacks. Changing the shim configuration will change the damping force the damper will produce for any given damper velocity. Figure 16-9 shows the change in damping force for three different shim stack configurations.

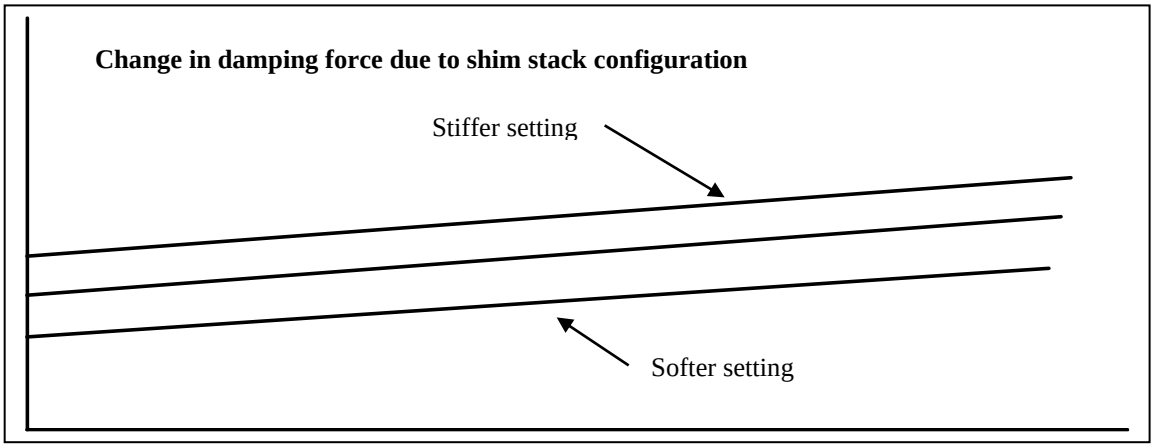


Figure 16-9

Figure 16-10 shows the changes in low speed damper force due to changes in the dampers low speed settings – normally through changes in the valving system.

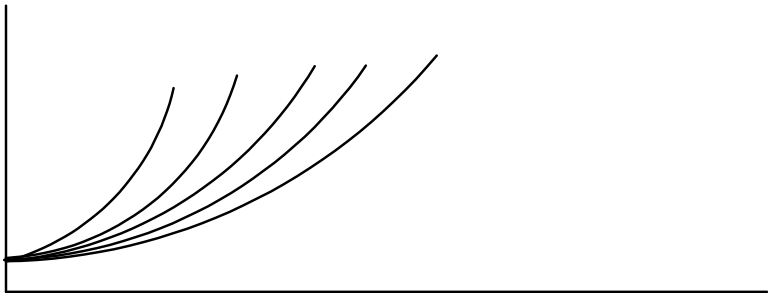


Figure 16-10

Figure 16-11 illustrates the changes in damping with a single valve setting in conjunction with three shim stack configurations.

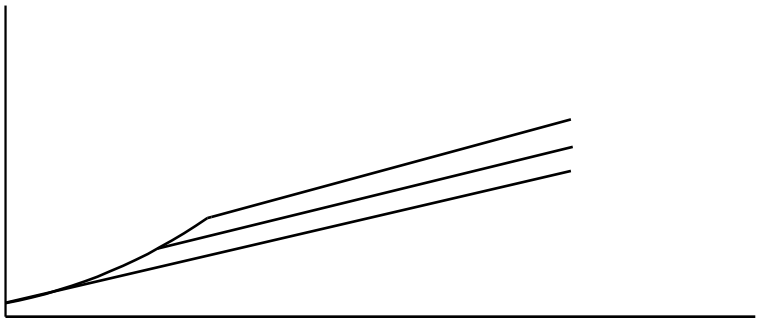


Figure 16-11

Figure 16-12 shows corner movement for one possible scenario of over and underdamping. Remember that a damper's setting can change corner motion in both bump and rebound. Figure 16-13 shows chassis motion resulting from zero damping.

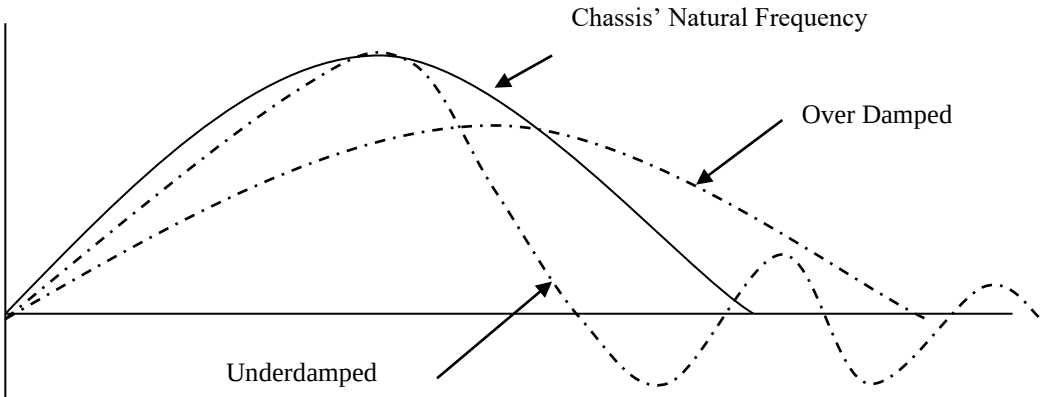


Figure 16-12

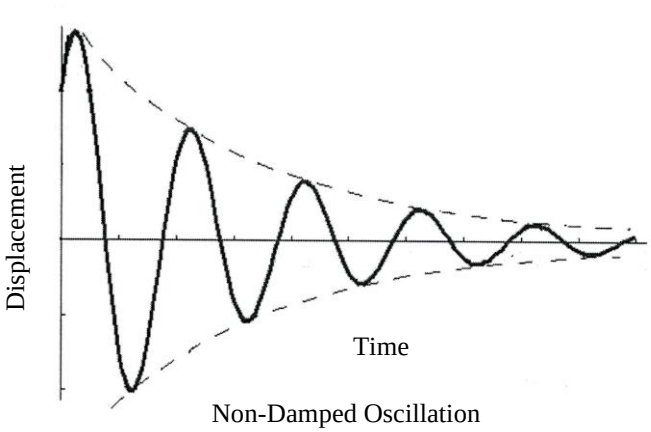


Figure 16-13

Hysteresis – A damper's force profile can and normally does change when comparing acceleration in bump versus deceleration in bump as well as acceleration in rebound versus deceleration in rebound – Figure 16-14.

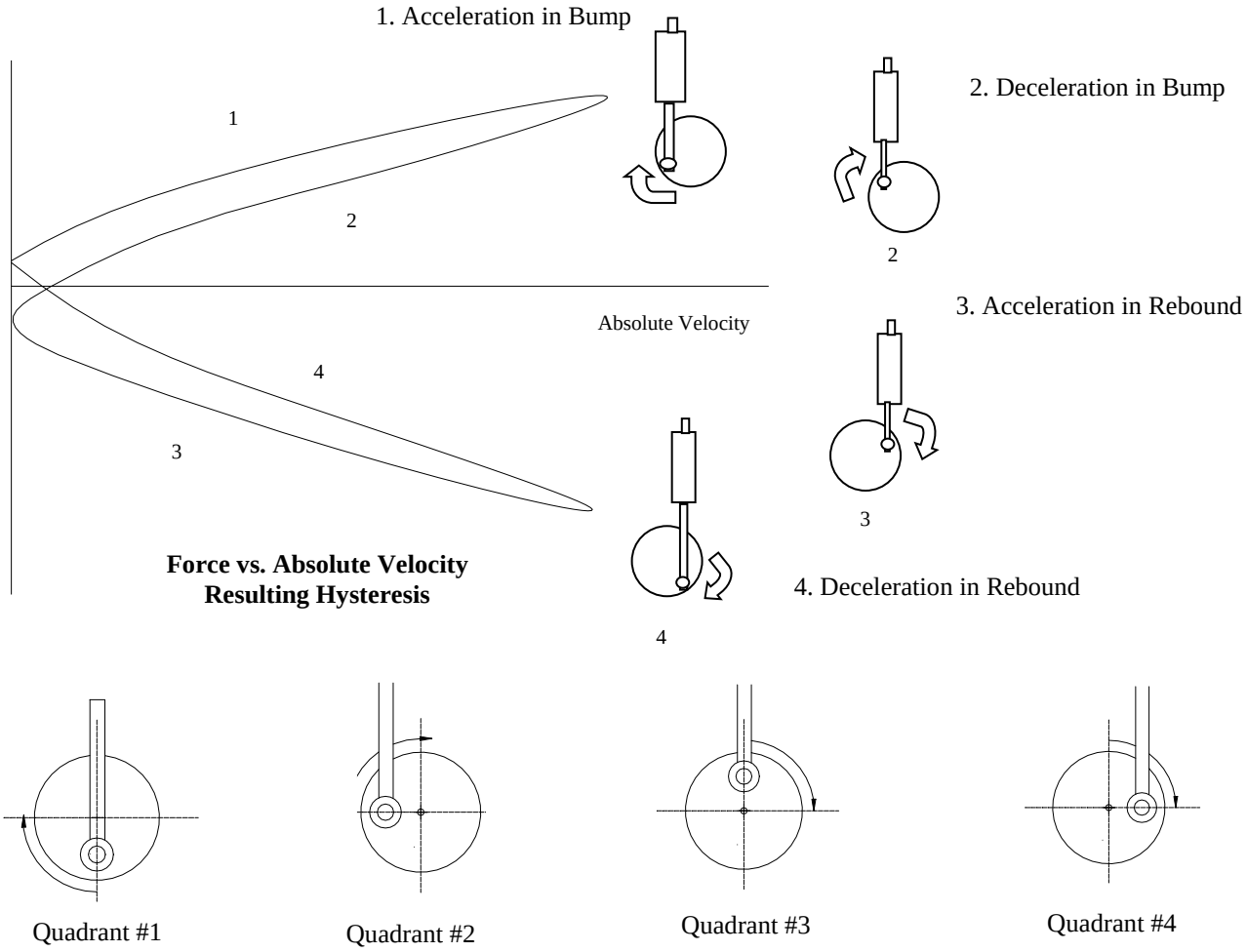


Figure 16-14

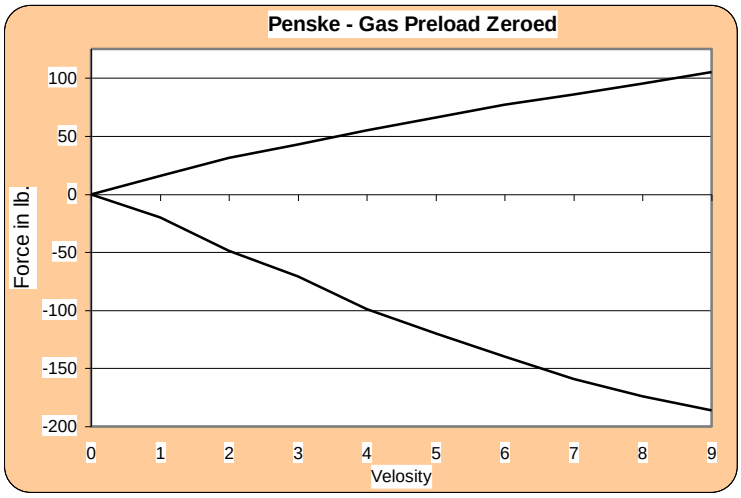
Damper Forces and Preload

As previously stated, damper preload is the extension force applied to the damper shaft as the result of nitrogen gas pressure. This damper gas pressure can affect the static set up. In the case of Wan31, entering a static preload in the preload cell represents the installed shaft force. If the shaft force is changed due to a change in gas pressure, the resultant change in static force would be entered in the preload cells. The damper preload forces are included in the static calculations while the dynamic damper forces are only calculated under dynamic acceleration.

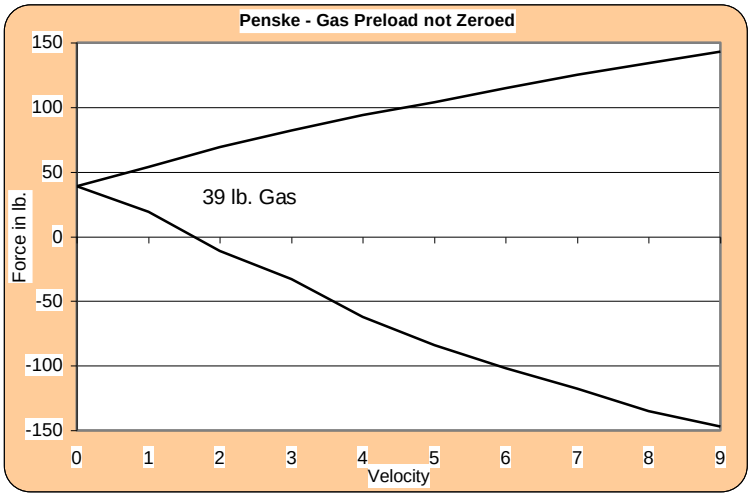
Normally when a damper is first placed in the dyno, the load cell is zeroed before it is run. Doing this removes the preload force from the dyno run. If the dyno is run without zeroing the gas forces, we see the damper velocity versus force numbers plus the preload forces. These combined forces are **somewhat** more representative of the actual damper forces seen by the chassis. ***Of course it is not nearly that simple***.

Changing the **static** gas pressure changes everything from **static** corner loads, suspension motions and ride heights so we need to take this into account.
Figure 16-15 shows the gas preload zeroed while Figure 16-16 shows damper velocities versus forces without the gas preload removed.

	Bump	Rebound
0	0	0
1	16	-20
2	31	-49
3	43	-71
4	55	-99
5	66	-120
6	77	-140
7	86	-159
8	95	-174
9	105	-186



	Bump	Rebound
0	39	39
1	54	19
2	69	-11
3	82	-33
4	94	-62
5	104	-84
6	115	-102
7	125	-118
8	134	-135
9	143	-147

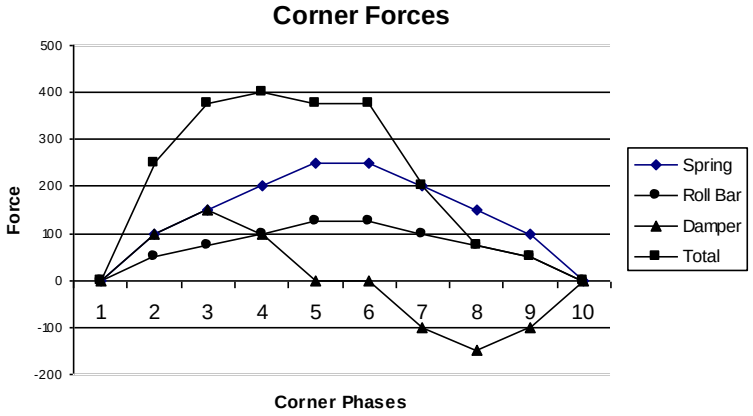


How much the dampers affect the dynamic loads at all four corners is dependent upon the dampers force versus velocity configurations. Table 16-17 to Figure 16-19 and their accompanying graphs illustrate how a damper can affect corner load configurations for three different damper settings in both bump and rebound. Table 16-20 shows the resulting changes in total corner loads for the previous three damper settings. In this particular set of examples, the damper has a much larger effect on the rebound stage than the bump stage even though the damping rates are the same. Notice that during the steady state condition at the center of the corner, the damper has no effect on the final load.

#1. Total Elastic Force During Cornering Phases

Phase	1	2	3	4	5	6	7	8	9	10
Spring	0	100	150	200	250	250	200	150	100	0
Roll Bar	0	50	75	100	125	125	100	75	50	0
Damper	0	100	150	100	0	0	-100	-150	-100	0
Total	0	250	375	400	375	375	200	75	50	0

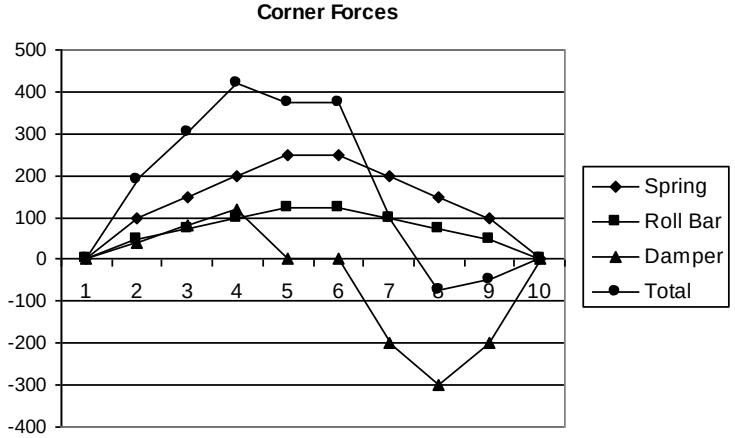
Table 16-17



#2. Total Elastic Force During Cornering Phases

Phase	1	2	3	4	5	6	7	8	9	10
Spring	0	100	150	200	250	250	200	150	100	0
Roll Bar	0	50	75	100	125	125	100	75	50	0
Damper	0	40	80	120	0	0	-200	-300	-200	0
Total	0	190	305	420	375	375	100	-75	-50	0

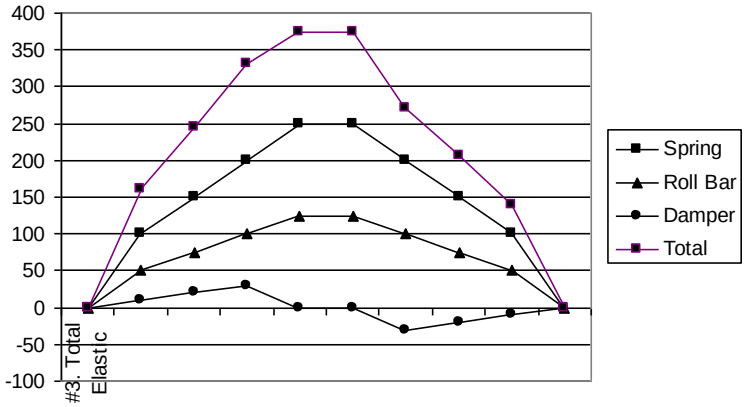
Table 16-18



#3. Total Elastic Force During Cornering Phases

Phase	1	2	3	4	5	6	7	8	9	10
Spring	0	100	150	200	250	250	200	150	100	0
Roll Bar	0	50	75	100	125	125	100	75	50	0
Damper	0	10	20	30	0	0	-30	-20	-10	0
Total	0	160	245	330	375	375	270	205	140	0

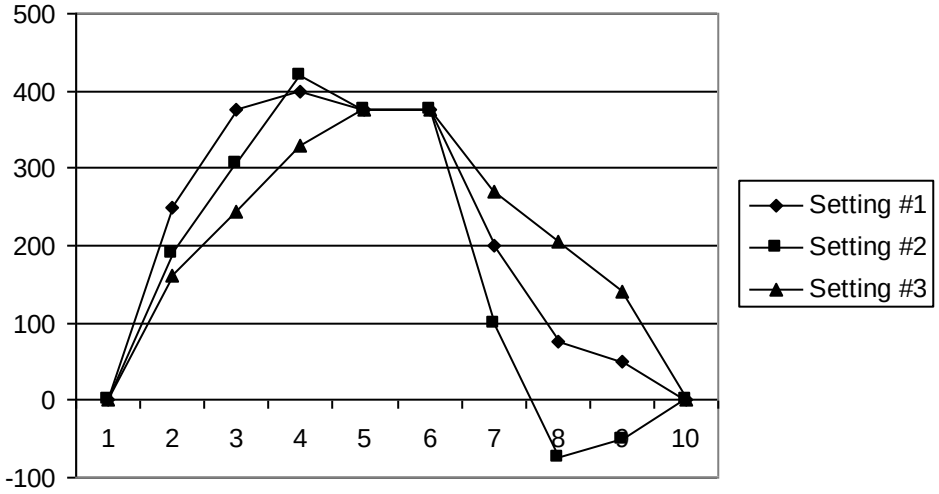
Table 16-19



Total loads for the three different damper settings

Phase	1	2	3	4	5	6	7	8	9	10
Total #1	0	250	375	400	375	375	200	75	50	0
Total #2	0	190	305	420	375	375	100	-75	-50	0
Total #3	0	160	245	330	375	375	270	205	140	0

Table 16-20



Back to the Cornering Phases

This time we will actually make it all the way through the corner. During the first four phases, we will primarily work with the shock settings. From Phase Five on, we may work with any or all of the load transfer components.

Corner Entry

1) **Phase One – Corner Entry - Hard Braking and Rapidly Decreasing Throttle (B = 1.0g – T_L = 0.0g)**:

- Reload Wan31A Short Track Stock Car and make sure all of the appropriate **A4** green cells are turned on. Enter 1.0g braking and 0.0 of left turn acceleration.

- The base corner loads are LF = 1028.9 lb., RF = 976.9 lb., LR = 617.9 lb. and RR = 377.4 lb. while the ride heights are LF = 4.123", RF = 4.307", LR = 5.236" and RR = 5.420" as opposed to the base set up with no anti forces of LF = 4.234", RF = 4.191", LR = 5.345" and RR = 5.302"

Shock Forces - It is **important** to remember that when looking at shock forces, we are observing a snap shot in time. Shock travel can change direction and/or velocity very quickly. In Chapters 16,17, 20 and 21 we are simply looking at the effects and trends of shock forces for moments in time. Only on track data will give the race engineer a **somewhat** accurate idea of how the shocks have, or can affect the chassis balance for any particular cornering phase. *It's just not that simple*.

Note: Entering Shock Forces – When entering shock forces in Wan31A, a positive number indicates a bump or compression force while a negative number indicates a rebound or extension force.

Note: Adjusting the shock forces is usually the **last** part of the tuning procedure.

- If we entered shock forces of LF = 100 lb., RF = 100 lb., LR –100 lb. and RR = -100 lb. in the **symmetrical** chassis, the ride heights would be changed but loads would remain the same. Such is **not** the case with an **asymmetrical** chassis.

- Enter shock forces LF = 100 lb., RF = 100 lb., LR –100 lb. and RR = -100 lb. Notice that even with the shocks balanced left to right, the shock forces still **result** in a **change** in the corner **loads** as well as a change in the ride heights.

    - Corner loads are LF = 1026.0 lb., RF = 979.7 lb., LR = 620.7 lb. and RR = 374.6 lb. while ride heights are LF = 4.260", RF = 4.421", LR = 5.012" and RR = 5.173".

Note: Remember that the wheel rate is a **combination** of the spring rates, roll bar rates, anti/jacking rates and the shock rates plus all the accompanying motion ratios. Far too many teams forget about this little fact when designing their shock builds and adjustments. Adding balanced shock forces on an asymmetrical chassis will not result in symmetrical load transfer. In fact, one component's asymmetries will often be exaggerated with the inclusion of an additional component, even if that component is symmetrical. This is a good thing for teams that understand how to work with transient shock forces but not so good for the rest.

    - If the race engineer wanted to keep the same corner loads as seen with the base set up, he/she could change the RR rebound force to –92.3 lb. Remember these are simply snap shot examples and do not represent transient forces. When a team changes the shock splits, it will affect every single cornering phase, often many times a second. Man, I love racing.

- Transient Forces: In order to transiently balance the front corner loads under pure braking, the team can change the anti dive geometry as described earlier in this chapter or through shock settings. The effects from anti dive forces are reduced when the braking force is reduced while the effect of the shock setting is reduced as the suspension motion slows. Once the brakes are released, there are no further front anti dive forces but the shocks will still exert force on the corners as long as there is shaft velocity. Once the brakes are released, the shock's **direction** of motion will often reverse.

- Increasing the shock's rear rebound forces will tend to keep the ride height tied down. This may be done to keep the CG down and/or to help the rear aero balance.

    - Keep the 100 lb. bump setting at the front and increase rear rebound to –400 lb. Corner loads are LF = 1018.3 lb., RF = 987.4 lb., LR = 628.5 lb. and RR = 366.8 lb. while ride heights are now LF = 3.853", RF = 3.938", LR = 4.018" and RR = 4.103". Notice that **all** of the ride heights are lower, not just the rear ones. Also notice that the shocks have exaggerated the effect of the spring asymmetries.

- Remember rebound setting on a shock will pull load off that corner and its diagonal.

- Keep the front 100.0 lb. bump settings while changing the LR rebound to –100.0 lb. and the RR rebound to –1000 lb. The new corner loads are LF = 706.4 lb., RF = 1297.8 lb., LR = 940.4 lb. and RR = 56.4 lb.

    - This is, of course, a rather exaggerated example, but notice how the chassis roll angle has changed from 0.188 degrees to the **left** with no shocks to 2.808 degrees to the **right** with this last setting. The new ride heights are LF = 5.023", RF = 2.278", LR = 4.865" and RR = 2.121".

2) **Phase Two – Corner Entry - Hard Braking, No Throttle and Slowly Increasing Steer Angle (B = 1.25g – T_L = 0.5g)**:

- Reload Wan31A Short Track Stock Car and enter 1.25g of braking and 0.5g of left turn acceleration.

- The base corner loads are LF = 912.2 lb., RF = 1208.1 lb., LR = 357.0 lb. and RR = 523.6 lb. while the ride heights are LF = 4.719", RF = 3.706", LR = 5.924" and RR = 4.911".

- As is so often the case, balancing the front and rear corners is a compromise. Helping the front balance degrades the rear balance and vices versa. The splits are front = -296.0 lb., rear = -166.6 lb. left = -555.2 lb. and right = -684.5 lb.

- As the front split is the largest, we will begin by looking at some transitional shock settings. Make the following shock changes one at a time while observing the resultant corner load changes.

    - We need to look at the difference between Phase One and Phase Two ride heights to determine whether each shock will be in bump or rebound. In this case, looking at the non-shock set ups, the LF extends 0.596", RF compresses 0.601", LR extends 0.688" and RR compresses 0.509". The LR has the highest velocity while the RR has the lowest velocity.

(1) LF	(2) RF	(3) LR	(4) RR
4.123	4.307	5.236	5.42
4.719	3.706	5.924	4.911
-0.596	0.601	-0.688	0.509
		Max.	Min.

    - **Enter LR 75 lb. rebound**. The new splits are front = -246.5 lb., rear = -216.0 lb. left = -604.7 lb. and right = -635.2 lb. This change helped the front left turn balance and the front braking balance.

    - **While keeping the previous LR damper force, enter RR 50 lb. bump**. The new splits are front = -211.0 lb., rear = -251.6 lb. left = -640.3 lb. and right = -599.7 lb. This change helps the front left turn balance and the front braking balance compared to the no damper set up. The front split is now better than the rear split so at this point the chassis may have a tendency to be a little loose but in a moment we will be into Phase Three where we will need all the front balance we can get. *Reset dampers to zero base setting.*

3) **Phase Three – Corner Entry - Moderate Braking with Rapidly Increasing Steer Angle (B = 0.6g – T_L = 1.0g)**:

- Reload Wan31A Short Track Stock Car and enter 0.6g of braking and 1.0g of left turn acceleration.

- The base corner loads are LF = 584.1 lb., RF = 1235.3 lb., LR = 306.0 lb. and RR = 875.6 lb. while the ride heights are LF = 5.494", RF = 3.291", LR = 6.220" and RR = 4.017".

- The splits are front = -651.2 lb., rear = -569.6 lb. left = -278.1 lb. and right = -359.7 lb. Both the side to side and rear to front splits are reasonably well-balanced but the chassis' overall performance level will be severely degraded because of the preponderance of right side load. Anything we can do to decrease the amount of load transfer will help overall performance – weight, track, CG etc. We need to look at the difference between Phase Two and Phase Three ride heights to determine whether each shock will be in bump or rebound. In this case, looking at the non-shock set ups, the LF extends 0.775", RF compresses 0.415", LR extends 0.296" and RR compresses 0.894". The RR has the highest velocity while the LR has the lowest velocity, just the opposite of the previous example.

    - The good news is that all four shocks are still moving in the same direction as in the previous phase.

Note: To calculate changes in CG height using WinGeo3, please refer to pages 16-11 and 16-12.

- The dynamic CG height for the phase three base set up is 16.627". Entering the new CG in the appropriate **A2** cell, the base corner loads are LF = 581.4 lb., RF = 1240.1 lb., LR = 302.8 lb. and RR = 876.6 lb. Looking at the Y Tran. Cell in **A6**, we see the load transfer is 760.7 lb.

    - Keeping the same general shock settings from Phase Two but compensating for the new shaft velocities, the shock forces are LF = -30 lb., RF = 30 lb., LR = -10 lb. and RR = 100 lb. The CG height is now 16.667 which increases the lateral load transfer from 760.7 lb. to 762.6 lb. This represents only a small amount of change but what there is, is moving in the wrong direction.

    - The splits are front = -599.6 lb., rear = -636.5 lb. left = -340.3 lb. and right = -303.4 lb. The shock settings, as used in Phase Two, helped the front split but degraded the rear split in Phase Three.

- Because of the very slow LR velocity and much higher RR velocity, the shock settings will either need to be changed quite considerably or other component changes will need to be made such as lowering the track bar axle mount and/or lowering the track bar angle. Decreasing the RR spring and/or increasing the LR spring would also help.

    - If the situation requires that the change be made at the shocks, then the following setting would be a place to start. Note that all of the following settings will degrade the front split.

        - LF – Raising the rebound setting will help the rear split.

        - RF – Raising the bump setting will help the rear split.

        - LR – Lowering the rebound setting will help the rear split but keep in mind how low the LR shock velocity will be.
        - RR – Lowering the bump setting will help the rear split but keep in mind how much higher the RR shock velocity is compared to the other shocks during this phase.

4) **Phase Four – Corner Entry - No Braking with Slowly Increasing Steer Angle (B = 0.15g – T_L = 1.25g).**

- Reload Wan31A Short Track Stock Car and enter 0.6g of braking and 1.25g of left turn acceleration.

- The base corner loads are LF = 392.6 lb., RF = 1218.6 lb., LR = 307.7 lb. and RR = 1082.1 lb. while the ride heights are LF = 5.930", RF = 3.101", LR = 6.332" and RR = 3.503".

- The splits are front = -826.0 lb., rear = -774.4 lb. left = -85.0 lb. and right = -136.5 lb.

- It appears that with the present balance, the chassis will have a slight push in this stage and that may well be the case, depending on the tire's coefficient of friction curve, but things are not always as they appear. Because the front tires are carrying slightly more combined load and will have a steer angle etc., the chassis balance may be closer to a higher level of understeer than the load balance would indicate.

- Shock Build and Settings:

    - Comparing the ride height changes from the Phase Three base heights the, LF extends 0.436", RF compresses 0.190", LR extends 0.112" and RR compresses 0.514". The RR shows the highest velocity while the LR shows the lowest velocity.

    - Starting with a base shock set up of LF = -50 lb., RF = 50 lb., LR -25 lb. and RR = 100 lb., the corner loads change to LF = 422.9 lb., RF = 1188.5 lb., LR = 277.4 lb. and RR = 1112.3 lb.

        - The new splits are Front = -765.5., Rear = -834.9 lb. Left = -145.6 lb. and Right = -76.2 lb. compared to the no shock splits. The shock forces have moved the chassis from an understeer condition to an oversteer condition. The no shock splits were = -826.0., Rear = -774.4 lb. Left = -85.0 lb. and Right = -136.5 lb.

Note: The following recommendations only work if the shock is moving in the correct direction. Working with the bump build or setting doesn't help all that much if the shock is rebound!

- Removing RF load:

    - Decrease LF rebound

    - Increase RR bump

    - Decrease RF bump

    - Increase LR rebound

    - Of the four choices, changing the RR because of its higher velocity would be the easiest way to accomplish the load change.

- Removing RR load:

    - Increase LF rebound

    - Increase RF bump

    - Decrease LR rebound
    - Decrease RR bump

    - Of the four choices changing the RR, because of its higher velocity, would be the easiest way to accomplish the load change.

- A combination of shock changes may be a better solution when developing the best compromise for all ten cornering phases.

Note: Once again the race engineer must always know the direction and velocity of the shocks throughout each corner phase. Make a table and chart for final ride height and final ride height changes as shown on pages 46 & 47.

Corner Apex

5) Phase Five – Corner Apex – Constant Steer Angle with No Throttle (B=0.05b – T_L = 1.53g)

- Reload Wan31A Short Track Stock Car and enter 0.05g of braking and 1.53g of left turn acceleration.

- The base corner loads are LF = 271.8 lb., RF = 1292.8 lb., LR = 216.6 lb. and RR = 1219.8 lb. while the ride heights are LF = 6.369", RF = 2.856", LR = 6.640" and RR = 3.128".

- The new splits are front = -1020.9 lb., rear = -1003.2 lb. left = -55.3 lb. and right = -73.0 lb.

    - Now this looks ugly. The rear has a slightly better side split balance than the front but both the front and rear corners have far too much load on the right side corners. The total left side weight is only 16.3% while the total right side weight is 83.7%. The race engineer is able to adjust the percentage of front to rear balance but he/she can not change the amount of load transfer without changing the chassis weight, track/wheelbase and/or the CG height.

    - Also notice the rear to front split change. The LR is now 55.3 lb. lighter than the LF while the RR is 73.0 lb. lighter than the RF.

- Comparing the ride height changes from the Phase Four base heights, the LF extends 0.439", RF compresses 0.245", LR extends 0.308" and RR compresses 0.375".

Note: As discussed earlier, the amount of force exerted by the suspension components is in direct proportion to the forces seen at the contact patch. Race engineers and software programs often under-estimate just how much anti and jacking forces affect the corner load balance. During Phase Five, the corner loads calculated without considering the anti/jacking forces are LF = 228.0 lb, RF = 1336.4 lb., LR = 260.4 lb. and RR = 1176.2 lb. while the spring loads are LF = 228.4 lb., RF = 2673.4 lb., LR = 140.4 lb. and RR = 1056.2 lb. With the anti and jacking forces included in the calculations, the corner loads are = 271.8 lb., RF = 1292.8 lb., LR = 216.6 lb. and RR = 1219.8 lb. while the spring loads are LF = 366.8 lb., RF = 2126.1 lb., LR = 467.3 lb. and RR = 774.4 lb. The difference between these two types of calculations is quite **significant**.

Note: The ten cornering phases are simply generic representations of a corner. The actual changes during a corner may be quite different for any given set up, track condition, driving style etc. Remember, we are only looking at trends at this point and not actual on track data. On track performance **never** breaks down into ten easily defined cornering phases. Now there is an understatement for you. Don't get hung up with the numbers – trends, trends and trends - that is what we are interested in at this point.

- <u>Possible Component Changes to Remove Load From the RF</u>:

    - Changing the front and/or rear spring roll rate
    - Changing the front and/or rear suspension kinematics

    - Changing the front and or rear anti roll bar

    - Changing the shock build and setting (shock roll rate)

    - Changing the static wedge

Note: When making a change in order to help any particular cornering phase, never lose sight of how that change will affect the other cornering phases – compromise, compromise and compromise. Though we will first look at the various changes individually, a combination of smaller changes is more the norm.

Spring Controlled Roll Rate Example: Softening the front roll rate. Using the Wan 31 Short Track chassis and looking at the **Springs Pairs Rate** worksheet, we see that a LF 190.2 lb. and RF 186.3 lb. **wheel** rate combination gives us a **wheel** roll rate of 94.1. Keeping the 190.2 lb. RF wheel rate but raising the front wheel roll rate to 100 requires a RF **wheel** rate of 210.9 lb. and a **spring** rate of 1018.7 lb.

- Change the RF spring rate from 900 lb. to 511 lb. and adjust the RF preload to 1.419" in order to rebalance the chassis. This reduces the front and also the overall wheel rate.
- The corner loads are now LF = 313.8 lb., RF = 1251.0 lb., LR = 174.6 lb. and RR = 1261.6 lb. while the ride heights are LF = 6.264", RF = 2.084", LR = 6.791" and RR = 2.611".

- The new side splits are front = -937.1 lb., rear = -1087.0 lb. Notice that the left and rear bias has not changed from the base set up. The balance has changed considerably with a much lower front split and higher rear split than the base case.

- Roll Rate: As we have previously discovered, you cannot simply switch the springs and preload side to side. If the race engineer wanted to switch the rear springs, simply switching the amount of preload will not rebalance the static chassis.

- Reload Wan31A Short Track Stock Car and enter 0.05g of braking and 1.53g of left turn acceleration.

  - Switch the rear springs and rebalance the chassis by entering 2.0083" of LR preload and 0.2022" of RR preload. The higher rated spring is now at the RR.

  - The corner loads are now LF = 272.5 lb., RF = 1292.1 lb., LR = 215.9 lb. and RR = 1220.4 lb. while the ride heights are LF = 6.424", RF = 2.917", LR = 6.772" and RR = 3.265". The very small changes from the base case are due to differences in jacking forces.

  - The new side splits are front = -1019.6 lb., rear = -1004.5 lb. Notice that the left and rear bias values have barely changed from the base set up.

  - Notice that when swapping the springs, because that maintained the same roll rate, the corner loads and splits are virtually identical to the base loads and splits.

- In order to improve the rear balance using springs, either the front roll rate needs to be increased or the rear roll rate decreased.

  - *Return the springs and preloads to the base set up*.

  - The race engineer can stiffen the front roll rate and/or decrease the rear roll rate while maintaining the right side spring rates:

    - Change the front wheel roll rate from 94.1 to 100.0. Using **the Spring Pairs Rate** worksheet, we find the LF spring rate now needs to be 1042.9 lb.

    - Change the LF Spring to 1042.9 lb. and rebalance the chassis by changing the LF preload to –0.1382".

    - The corner loads are now LF = 255.1 lb., RF = 1309.4 lb., LR = 233.3 lb. and RR = 1203.2 lb.

- The new side splits are front = -1054.3 lb., rear = -969.9 lb. Changing the LF spring to 1042.9 lb. degraded the front balance while improving the rear balance.

- *Return the springs and preloads to the base set up*.

Note: Remember, Wan31A only looks at snapshots in time. This model is used to show how changes in chassis set ups affects the corner loads and overall chassis balance. Performance simulation models, as used in Book Two, use on track data with a large number of closed loop iterative solvers to run the model. When calculating anti and jacking forces, the IC co-ordinates can vary quite considerably between the static and dynamic settings. The user always needs to enter the cornering phase ride heights into WinGeo3 and then enter the resulting changes in the IC co-ordinates into the appropriate Wan31A cells. Without a built-in iterative solver, the resultant calculations will only be close.

- Front and Rear Jacking Forces with Base Suspension Set Up:

  - Enter the Phase Five ride heights into the WinGeo3 short track front and rear programs.

    - The new front IC co-ordinates, as found by using WinGeo3, are LF e = 2.073 ay = 55.793 and RF e = 4.161 ay = 34.627.

    - Enter the new IC co-ordinates in Wan31A.

    - The corner loads are now LF = 267.2 lb., RF = 1297.4 lb., LR = 221.2 lb. and RR = 1215.2 lb. compared to the base IC loads LF = 271.8 lb., RF = 1292.8 lb., LR = 216.6 lb. and RR = 1219.8 lb

    - The new side splits are front = -1030.2 lb., rear = -993.9 lb. compared to base IC side splits of front = -1020.9 lb., rear = -1003.2 lb.

- Changing the Front Jacking Forces: Changing the static front suspension co-ordinates can alter the corner loads on a stock car chassis quite considerably i.e. raising the RF IC height and/or shortening its horizontal distance will increase the RF corner load during dynamic conditions. Lowering and lengthening the RF IC will decrease the RF corner load during dynamic conditions. As previously discussed, the amount of corner load change is directly related to the lateral force seen at the RF contact patch. It's a closed loop process.

  - Reload Wan31A Short Track Stock Car and enter 0.05g of braking and 1.53g of left turn acceleration.

  - Using the WinGeo3 Front Short Track Model, raise each of the RF upper, inner mounting co-ordinates by 1".

  - Enter the Phase Five base ride heights. The new front instant center co-ordinates are LF e = 1.663", ay = 71.078" and RF e = 3.335", ay = 38.710". Enter these new co-ordinates in the Wan31A model.

  - The new corner loads as the result of lowering the RF upper, inner control arm mounts are now LF = 280.8 lb., RF = 1283.8 lb., LR = 207.6 lb. and RR = 1228.7 lb. The side to side splits are now front = -1003.0 lb., rear = -1021.1 lb. Notice that the front and rear splits are virtually reversed from the base splits.

  - Raising the RF upper mounts helped the front balance while degrading the rear balance.

- Rear Jacking Forces: As in the previous front jacking force example, the chassis balance can be altered by changing track bar static height and/or angle.

- Changing Track Bar Height: Using the **WinGeo3** Rear Short Track Model, lower both the axle and frame mounts 2". Make sure that the WinGeo3 ride heights/clearance are set at LR = 4.752" & RR = 5.004". Input the Wan31 LR and RR ride heights into WinGeo3 from 0.05g braking and 1.53g left turn acceleration – LR = 6.641" & RR 3.203". The resulting WinGeo3 track bar heights are axle y = 17.483, Z = 8.847" and frame y = 21.645, Z = 8.409". The track bar angle is now down -0.641 degrees.

    - **Maintaining** the new front IC co-ordinates from the previous front example.

    - Change the appropriate track bar co-ordinates in Wan31A.

    - The new corner loads as the result of lowering the RF upper, inner control arm mounts and the track bar are now LF = 210.1 lb., RF = 1354.2 lb., LR = 278.3 lb. and RR = 1158.3 lb. The side to side splits are now front = -1144.1 lb., rear = -880.0 lb.

    - Lowering both track bar mounts helped the rear balance while degrading the front balance.

- Changing Track Bar Angle: Make sure that the WinGeo3 ride heights/clearance are set at LR = 4.752" & RR = 5.004". From the **base** WinGeo3 settings, lower the track bar axle mount 1/2" and the track bar frame mount 2" in WinGeo3. Using the base Wan31A Phase Five ride heights, the new track bar co-ordinates are axle y = 17.440", z = 10.346" and frame y = 21.645", z = 8.409". The track bar angle is down -2.837 degrees.

    - **Maintain** the front IC co-ordinates from the previous front example.

    - Change the track bar co-ordinates.

    - The new corner loads, as the result of changing the **static** track bar vertical co-ordinates are now LF = 230.3 lb., RF = 1334.1 lb., LR = 258.1 lb. and RR = 1178.5 lb. The side to side splits are now front = -1103.7 lb., rear = -920.4 lb.
    - Lowering the track bar 1/2" at the axle mount and 2" at the frame mount helped the rear balance while degrading the front balance, but, to a lesser extent than when both track bar mounts were each lowered 2".

6) Phase Six – Corner Apex - Slowly Decreasing or Constant Steer Angle with Modulating Throttle (A = 0g – T_L = 1.37g)

- Load Wan31A and enter 0g inline acceleration and 1.37g left turn acceleration.

This is the first and only point in the corner where the chassis sees no forward or rearward longitudinal acceleration. However, the driver will most likely have to apply some throttle during this stage in order to maintain 0.0g longitudinal acceleration. This period of 0.0g of longitudinal acceleration varies in direct relationship with the radius of the corner. On a short track, this phase may only last some portion of a second, if it exists at all, while on a super speedway it may last a number of seconds. In reality, the driver will, in almost all cases, be constantly inputting both small amounts of steer and throttle change throughout this phase. There is no such thing as a perfectly balanced chassis. If the driver is telling the race engineer the chassis is perfectly balanced, he/she is not pushing the performance envelope to the last degree.

The amount of left turn acceleration that can be maintained throughout this phase is seldom as high as the momentary left turn peak seen in Phase Five. Chapter 19 looks at the drop in a tire's cornering performance as its temperature increases. Phase Six is the least active shock phase. The importance of the chassis balance during Phase Six is in direct relationship to the radius of the turn. The larger the turn radius, the more important it is that the chassis is well-balanced in this phase. As always, how well the chassis is set up to get **into** Phase Six has a lot to do with how well it gets through Phase Six. Conversely, if the

chassis is unable to make a smooth transition out of Phase Six, all the time made up in this section may be lost.

The good news is that setting up the chassis balance for only one type of acceleration is always easier than for combined acceleration scenarios.

- The base corner loads are LF = 316.3 lb., RF = 1225.5 lb., LR = 293.0 lb. and RR = 1166.2 lb. The side to side splits are now front = -909.2 lb., rear = -873.2 lb.

- Compare these loads and splits to the base Phase Five loads and splits of LF = 271.8 lb., RF = 1292.8 lb., LR = 216.6 lb. and RR = 1219.8 lb. while the front split = -1020.9 lb. and rear side split = -1003.2 lb.

- The suspension **jacking** forces play a **major** role in the set up for this phase. The nature of the stock car suspension systems tends to magnify the jacking and anti forces compared to an open wheel chassis.

    - Taking **out** the jacking forces by placing zeros in A4.1 and A4.2 cells and rebalancing the preloads, LR = 1.373 & RR = 0.810, results in quite a different set of corner loads and side to side splits - LF = 301.4lb., RF = 1240.3 lb., LR = 307.9 lb. and RR = 1151.4 lb. The side to side splits are now front = -938.9 lb., rear = -843.6 lb.

7) **Phase Seven – Corner Apex - Slowly Decreasing Steer Angle with Slow Pickup on Throttle (A = 0.3g – T_L = 1.0g)**

Phase Seven is the last corner apex stage and the **first** stage to see rearward inline acceleration. Remember that spring and wheel **pitch** rate holds the same relationships as the spring and wheel **roll** rates.

- Load Wan31A and enter 0.3g inline acceleration and 1.0g left turn acceleration.

- Using the Spring Pairs Rate worksheet, we see that the left side wheel pitch rate is 103.1 while the right side wheel pitch rate is 96.5.

- The base corner loads are LF = 378.6 lb., RF = 1025.3 lb., LR = 509.9 lb. and RR = 1087.2 lb. The side to side splits are now front = -646.8 lb., rear = -577.3 lb. Notice that the LR has gained a higher percentage of the longitudinal load transfer than the RR which is partly the result of the left side having a **higher** pitch rate. However, the RR is still 577.3 lb. heavier than the LR which does nothing for optimal longitudinal acceleration.

- The rear split for Phase Six was –873.2 lb. while only –577.3 lb. for Phase Seven. The front split has changed from –909.2 lb. in Phase Six to –646.8 lb. in Phase Seven.

- The dynamic wedge is 51.2% compared to 50.6% for Phase Six.

Changing Dynamic Load through Anti Squat Geometry:

Note: Remember that anytime loads are transferred though the suspension arms, the transfer is instantaneous while loads transmitted through the springs, bars, biscuits and shocks are applied in relation to component motion. Loads transferred through the suspension will always have a lateral shear factor which needs to be considered when determining how to adjust the chassis dynamic balance.

- Shortening and/or raising the rear side view IC co-ordinates will increase the amount of load passing through the rear suspension bits under longitudinal acceleration. The base chassis set up

has the right rear IC co-ordinates both shorter and higher than the left side as the result of the right lower control arm being angled up more at the frame mount.

Note: Lowering or raising the third link on a symmetrical chassis will **not** change the amount of longitudinal load transfer seen at the rear wheels but it **will** change the amount of longitudinal load that passes through the suspension bits compared to the springy bits. This, in turn, controls the percentage of longitudinal load transfer seen at the LR compared to the RR corner.

- Load Wan31A and enter 0.3g inline acceleration and 1.0g left turn acceleration.
- Using the WinGeo3 Short Track Rear Model, lower the third mount frame mount by 2" and enter the base Phase Seven rear ride heights. The new IC acceleration co-ordinates are LR e = 13.658" ax = 78.296" and RR e = 9.634" ax = 112.015".
    - The new corner loads are LF = 360.9 lb., a decrease of 84.2 lb. from base, RF = 1042.9 lb., an increase of 54.4 lb., LR = 527.6 lb., an increase of 83.6 lb. and RR = 1069.6 lb., a decrease of 55.0 lb.
    - The side to side splits are now front = -682.0 lb., rear = -542.0 lb. compared to the base set up of –646.8 front and –577.3 rear. More understeer but better inline acceleration.
- Load Wan31A and enter 0.3g inline acceleration and 1.0g left turn acceleration.
- Using the WinGeo3 Short Track Rear Model, raise the left lower control arm frame mount by 2" and enter the base Phase Seven rear ride heights. The new IC co-ordinates are LR e = 19.388" ax = 85.709" and RR e = 8.788" ax = 337.188".
    - Enter the new rear side view IC co-ordinates into Wan31A.
    - The corner loads are now LF = 344.9 lb., RF = 1058.9 lb., LR = 543.6 lb. and RR = 1053.7 lb. The LR and RF corners have gained corner load from the phase six base setting while the RR and LF have lost corner load. The forces running through the springs are LF = 524.9 lb., RF = 1827.7 lb., LR = 562.4 lb. and RR = 699.2 lb. compared to the base set up of LF = 600.9 lb., RF = 1761.5 lb., LR = 620.6 lb. and RR = 701.1 lb. As would be expected, the LR and RR springs see less load while the RF and LF springs see a higher load. The LR anti forces = 111.233 lb. while the RR anti forces = 10.648
    - The side to side splits are now front -714.0 lb., rear = -510.1 lb. compared to the base set up of -647.8 front and -577.3 rear. We now have even more understeer but better inline acceleration than before.
    - Remember that changing the angle of the lower control arms also changes the amount of dynamic rear steer which is the result of the kinematic changes. Also remember that load transfer forces, which run through solid suspension links, transfer instantaneously. *Nothing is for free.*

Corner Exit

8) **Phase Eight – Rapidly Decreasing Steer Angle with Slow Throttle Pick Up (A = 0.4g – T_L = 0.7g)**

If the chassis was tight during the corner apex phases, the dreaded "power on snap loose" may begin in Phase Eight. The snap loose phenomenon is the result of too much steering input during the cornering apex stages. As the load is transferred from right to left and front to rear, the front balance improves, the rear balance degrades and the chassis suddenly has a tendency to turn far too quickly i.e. snap loose. We will look at this in more detail in Chapter 20.

If the chassis is well balanced during the apex phases the driver may be able to apply the throttle much more aggressively than indicated in this phase. The reader should look at various combinations of rearward acceleration.

As previously discussed, using anti squat kinematics to transfer a higher percentage of the rearward load transfer to the LR can lead to the instantaneous load transfer breaking the LR contact patch's bound with the track surface (impact loading). However, as we will discover when looking at rear tire torque when using asymmetric tire circumferences (stagger), the LR can withstand a higher amount of shock loading than the RR tire.

Chassis using a high percentage of anti squat geometry often use some sort of device, such as rubber or phenolic biscuits, to slow down the load transfer through the suspension links. These devices can be used in conjunction with the rear upper and/or lower control arms. When used with a rear lower control arm, the device will also affect rear steer. When used as part of the upper or third link, the device will also affect the amount of pinion angle change during braking and acceleration (a suspension link becomes a springy bit with the addition of a biscuit).

- Load Wan31A, and enter 0.4g inline acceleration and 0.7 left turn acceleration.

- The base set up Phase Eight corner loads are LF = 459.5 lb., RF = 898.7 lb., LR = 655.6 lb. and RR = 987.2 lb. The side to side splits are front = -439.2 and rear = -331.6. There is 107.6 lb. less side to side split at the rear than at the front.

Shocks and Phase Seven Load Transfer: Because shocks, unlike springs, can have different rates in compression and extension, they are often used during a cornering phase to control the rate and amount of load transfer.

- If the chassis is pushing during this and/or Phase Nine try:
    - Decreasing RR rebound or increase RR bump **depending** on the direction of shock travel
    - Increasing LF bump or decreasing LF rebound **depending** on the direction of shock travel
    - Decreasing LR bump or increase LR rebound **depending** on the direction of shock travel
    - Decreasing RF bump or increasing RF rebound **depending** on the direction of shock travel
- Change in shock travel from Phase Seven to Phase Eight:
    - Phase Seven ride heights are LF = 5.792", RF = 3.538", LR = 5.937" and RR = 3.682" while Phase Eight ride heights are LF = 5.432", RF = 3.920", LR = 5.556" and RR = 4.044". The changes are as follows:
        - LF decreases by 0.360" (bump), RF increases by 0.382" (rebound), LR decreases by 0.381" (bump) and the RR actually **increases** by 0.362" (rebound). As long as the decrease in lateral load transfer is greater than the increase in rearward longitudinal acceleration, the RR shock will be in rebound. *It's not that simple*.
            - LF = bump, RF = rebound, LR = bump and RR = rebound
    - Enter 50 lb. of bump at the LF and LR and 50 lb. of rebound at the RF and RR. This will be the base Phase Eight shock setting.

- The corner loads are now LF = 438.9 lb., RF = 919.2 lb., LR = 676.2 lb. and RR = 966.6 lb. The side to side splits are front = -480.4 and rear = -290.4 or 190.0 lb. less split at the rear.
- Enter 25 lb. less rebound at the RR (-25).

    - The corner load changes are LF = 8.9 lb. increase, RF = 8.9 lb. decrease, LR = 8.9 lb. decrease and RR = 8.9 lb. increase. The side to side splits are front = -462.6 and rear = -308.2. There is now 154.4 lb. less side to side split at the rear than at the front.

    - *Reset the shocks to base 50 lb. setting*.

- Increase the LF bump by 25 lb. to 75 lb., increase the RF rebound by 25 lb. to -75 lb. decrease the LR bump by 25 lb. to 25 lb., and decrease the RR rebound by 25 lb. to –25 lb.

    - The corner loads are now LF = 462.9 lb., RF = 895.3 lb., LR = 652.2 lb. and RR = 990.6 lb.

    - The corner load changes from the base shock settings are LF = 23.9 lb. increase, RF = 23.9 lb. decrease, LR = 23.9 lb. decrease and RR = 23.9 lb. increase. The side to side splits are front = -432.2 and rear = -338.4. There is now only 93.8 lb. less side to side split at the rear than at the front.

    - As rear split is increased, rear grip is reduced.

- If the chassis is loose during this and/or Phase Nine try:

    - Increasing RR rebound or decrease RR bump **depending** on the direction of shock travel

    - Decreasing LF bump or increasing LF rebound **depending** on the direction of shock travel

    - Increasing LR bump or decrease LR rebound **depending** on the direction of shock travel

    - Increasing RF bump or decreasing RF rebound **depending** on the direction of shock travel

9) **Phase Nine – Slowly Decreasing Steer Angle with Rapid Throttle Pick Up (A = 0.65g – T_L = 0.5g)**

Note: Rapid throttle pick up is somewhat of a misnomer when working with a low powered chassis.

- Load Wan31A, and enter 0.65g inline acceleration and 0.5g left turn acceleration.

- The base set up Phase Nine corner loads are LF = 471.7 lb., RF = 771.4 lb., LR = 974.2 lb. and RR = 963.7 lb. The side to side splits are front = -299.7 and rear = -169.6. There are 130.1 lb. less side to side split at the rear than at the front.
- Phase Eight ride heights were LF = 5.432", RF = 3.920", LR = 5.556" and RR = 4.044" while Phase Nine ride heights are LF = 5.319", RF = 4.305", LR = 5.285" and RR = 4.271". The changes are as follows:

    - LF = 0.113 bump, RF = 0.385 rebound, LR = 0.271 bump and RR = 0.228 rebound. Despite the fact that the rearward acceleration is now greater than the left turn lateral acceleration all shocks are still moving in the same direction as in Phase Eight – though at different rates.

    - Reenter the Phase Eight shocks while compensating for shock velocity changes – LF = 30 bump, RF = -65 rebound, LR = 50 bump and RR = -40 rebound.

Note: **Remember** the shock forces we are entering into Wan31 are simply representational forces. The only way to actually know what the shock velocities are and therefore the shock forces are is by looking at data from the acquisition system. Book Two uses models specifically designed to run off data from acquisition systems.

- The corner loads are now LF = 454.0 lb., RF = 789.0 lb., LR = 811.8 lb. and RR = 946.1 lb. while the side to side splits are front = -335.0 and rear –134.3. There is 200.7 lb. less split at the rear. The potential for rearward acceleration has improved dramatically.

- Compared to Phase Eight the corner load changes are LF = a decrease of 8.9 lb., RF = a decrease of 106.3 lb., LR = an increase of 159.6 lb. and RR = a decrease of 44.5 lb.

10) **Phase Ten – Full Throttle with No Steer Angle (A = 0.85g – T_L = 0.0g) (**FINALLY!)

- Load Wan31A, and enter 0.85g inline acceleration and 0.0g left turn acceleration.

- The base set up Phase Ten corner loads are LF = 595.6 lb., RF = 556.0 lb., LR = 1047.9 lb. and RR = 801.5 lb. The side to side splits are front = +39.6 and rear = +246.4. The rear dynamic bias is 61.6% while the left bias is 54.8%. The fact that the LR is now 246.4 lb. heavier than the RR will be looked at when we discuss the effects of stagger torque.

- Phase Nine ride heights were LF = 5.319", RF = 4.305", LR = 5.285" and RR = 4.271" while Phase Ten ride heights are LF = 4.781", RF = 5.060", LR = 4.647" and RR = 4.927". The changes are as follows:

  - LF = 0.538 bump, RF = 0.755 rebound, LR = 0.638 bump and RR = 0.656 rebound.

    - Notice that the four shocks direction of motion remained constant from Phase Six through to Phase Ten – through with differing velocities. The four shocks will see a higher shaft velocity in phase Ten than in the previous two phases which, in turn, will result in much higher shock forces both in bump and rebound.

  - Keeping the same shock settings as in the previous phases but adjusting for the higher shaft velocities enter the following shock forces. LF = 75 lb. in bump, RF = -100 lb. in rebound, LR = 85 lb. in bump and RR = -85 lb. in rebound.

    - The new corner loads are LF = 561.4 lb., RF = 590.0 lb., LR = 1082.1 lb. and RR = 767.5 lb. while the side to side splits are front = -28.7 and rear = +314.7 compared to front = +39.6 and rear = +246.4 without the shocks added to the calculations.

Note: The race engineer can often change a corner's direction of motion, or, at least, its rate of motion by changing the spring rates, anti/jacking IC co-ordinates, etc.

- Load Wan31A, and enter 0.85g inline acceleration and 0.0g left turn acceleration

- <u>Changing the Rear IC Co-ordinates</u>: Using the WinGeo3 Rear Short Track Stock Car raise the third link frame mount 1", lower both of the lower control arm frame mounts so they are 1" below the axle mount.

  - The new IC co-ordinates are LR e = 28.420 ax = 443.133, RR e = 28.464 ax = 446.740

  - Enter the new IC co-ordinates in Wan31A (A4.3).

  - The new corner loads are LF = 584.3 lb., RF = 567.2 lb., LR = 1059.2 lb. and RR = 790.3 lb. compared to the base set up (no shock forces) corner loads of LF = 595.6 lb., RF = 556.0 lb., LR = 1047.9 lb. and RR = 801.5 lb.

- The load on the springs are now LF = 981.7 lb., RF = 982.8 lb., LR = 901.1 lb. and RR = 545.3 lb. compared to the base set up (no shock forces) spring loads of LF = 1005.4 lb., RF = 958.2 lb., LR = 903.8 lb. and RR = 530.8 lb.

- The loads passing through the rear suspension links are LR = 89.354 lb. and RR = 73.757 lb. compared to the base set up of LR = 77.897 lb. and RR = 96.993.

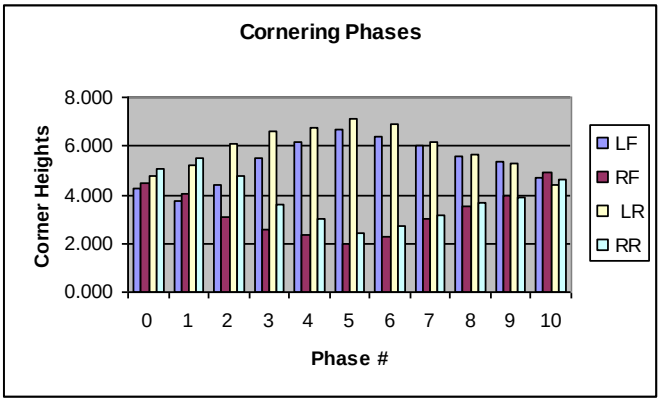
Note: The reader needs to experiment with a large number of different upper and lower suspension setting in order to more clearly understand how the suspension kinematics can be used to change the corner loads. When making a suspension kinematic change the reader also needs to look at all the other kinematic ramifications such as rear steer, scrub, pinion angle change, etc. This is done using WinGeo3.

The Ten Corner Phases

		Phases										
	Case	0	1	2	3	4	5	6	7	8	9	10
Wt (g)	W	1	1	1	1	1	1	1	1	1	1	1
Left(g)	Tl	0	0	0.5	1	1.25	1.53	1.37	1	0.7	0.5	0
Right(g)	Tr	0	0	0	0	0	0	0	0	0	0	0
Bank		0	0	0	0	0	0	0	0	0	0	0
Accel(g)	A	0	0	0	0	0	0	0	0.3	0.4	0.65	0.85
Brake(g)	B	0	1	1.25	0.6	0.15	0.05	0	0	0	0	0

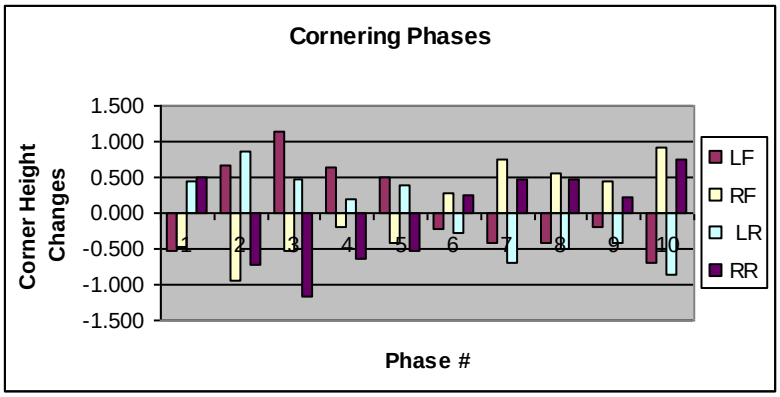
Corner Heights

Case	LF	RF	LR	RR
0	4.255	4.506	4.783	5.034
1	3.727	4.038	5.216	5.527
2	4.384	3.095	6.090	4.800
3	5.517	2.573	6.575	3.630
4	6.150	2.370	6.763	2.983
5	6.645	1.954	7.149	2.458
6	6.418	2.242	6.882	2.705
7	5.992	2.994	6.185	3.187
8	5.571	3.536	5.682	3.647
9	5.387	3.984	5.268	3.864
10	4.703	4.904	4.415	4.616



Corner Height Changes

Case	LF	RF	LR	RR
1	-0.528	-0.468	0.433	0.492
2	0.658	-0.943	0.874	-0.727
3	1.133	-0.522	0.485	-1.170
4	0.632	-0.203	0.188	-0.647
5	0.495	-0.416	0.386	-0.525
6	-0.226	0.288	-0.267	0.247
7	-0.426	0.752	-0.697	0.481
8	-0.421	0.543	-0.503	0.461
9	-0.184	0.448	-0.415	0.217
10	-0.684	0.920	-0.853	0.752



Banking

Track banking increases normal force and improves the side to side balance during lateral acceleration. Table 16- 3 shows the difference in Phase Five corner loads for banking angles from 0.0 to 45 degrees. Banking dramatically improves the chassis performance envelope but the improvement in performance is not linear as seen in Table 16-22. Tables 16-21, 16-22 and 16-23 have a different set of acceleration rates than in the previous examples.

Effects of Track Banking - Base Set Up

Phase Five (B = 0.05g - T_L = 1.53g)

Corner	LF	RF	LR	RR
Flat	374.4	1398.0	114.8	1113.8
5 degrees	524.8	1447.8	247.8	1169.4
10 degrees	673.6	1486.0	376.5	1216.6
15 degrees	819.6	1512.3	500.0	1255.2
20 degrees	961.7	1526.5	617.4	1284.7
25 degrees	1098.9	1528.5	727.8	1305.1
30 degrees	1230.0	1518.3	830.2	1316.1
35 degrees	1354.1	1496.0	924.0	1317.7
40 degrees	1470.3	1461.7	1008.5	1309.9
45 degrees	1577.6	1415.7	1082.9	1292.6

Table 16-21

Corner	LF	Difference
Flat	374.4	
5 degrees	524.8	150.4
10 degrees	673.6	148.8
15 degrees	819.6	146.0
20 degrees	961.7	142.1
25 degrees	1098.9	137.2
30 degrees	1230.0	131.1
35 degrees	1354.1	124.1
40 degrees	1470.3	116.2
45 degrees	1577.6	107.3

Table 16-22

Braking and rearward acceleration are also affected by track banking as seen in tables 16-5.

Effects of Track Banking - Base Set Up

Phase Nine (A =0.65g - T_L = 0.5g)

Corner	LF	RF	LR	RR
Flat	471.7	771.4	794.2	963.7
5 degrees	548.1	756.7	850.6	965.1
10 degrees	619.3	734.8	901.4	960.4
15 degrees	684.9	706	946.3	949.8

Corner	LF	Difference
Flat	471.7	
5 degrees	548.1	76.4
10 degrees	619.3	71.2
15 degrees	684.9	65.6

Figure 16-23



Picture compliments of **Penske Technology Group**