# The Dynamics Chapters

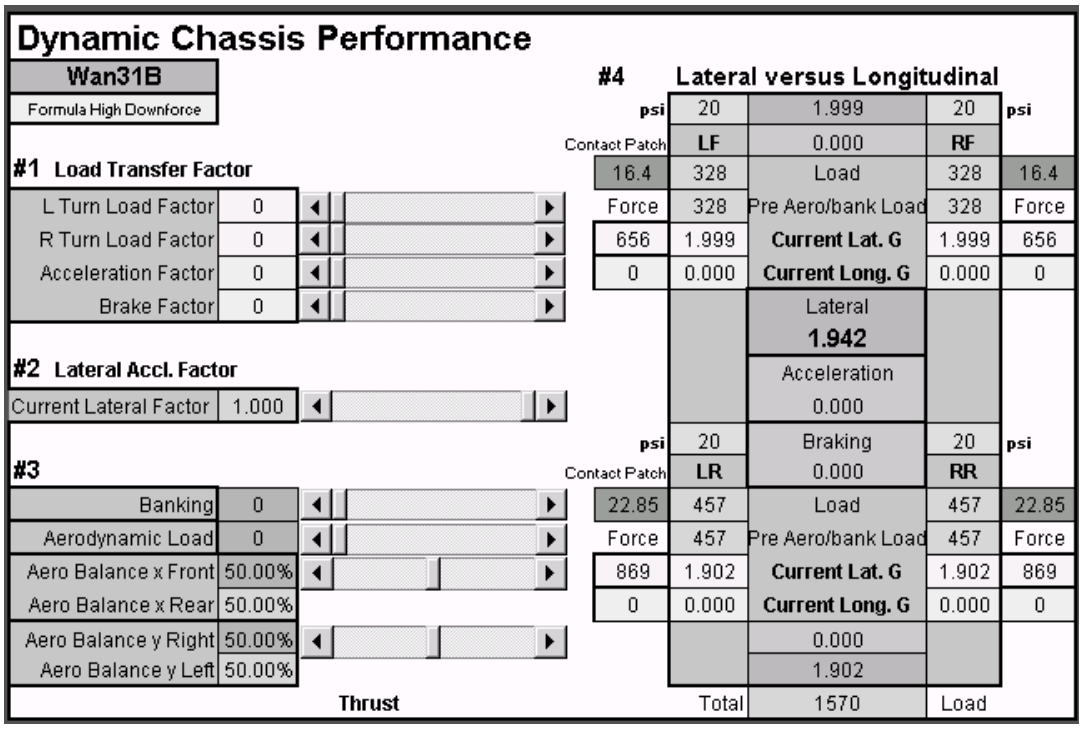
## Understanding Dynamic Performance

This portion of the book is concerned with the understanding of:

- the how's and why's of load transferred during dynamic chassis conditions
- the why's and how's of combined acceleration performance

## Dynamic Simulation Models

The various **Wan31** simulation models that have been incorporated into the dynamic chapters can be found on the accompanying CD ROM. The Wan 31 models were originally developed by Juan Salinas and the author and then reworked with the help of Wm. C. Mitchell.



## Important Note

Within the confines of the simulation design used in this publication, Dr. Juan Salinas, W. C. Mitchell and the author have spent many, many hundreds of hours trying to ensure that the Wan31 models are as accurate as possible. However, the reader should never lose sight of the fact that these models are first, and foremost, educational tools. They are a starting point, not an end in themselves. If you thought you were going to get a full-fledged vehicle dynamics simulation model for the price of the book, dream on.

Since the first printing, Wm. C. Mitchell, Dr. Juan Salinas and the author have collectively spent well over a thousand hours, nearly three inches of emails and accumulated many astronomical phone bills refining the original Wan31 model. At first we were only going to fix several cells within Wan31 whose data strings became corrupted during the compiling of the final model. However, as we were already working on a considerably more advanced simulation model for several professional race teams, we decided to have another look at the Wan31 model as well. This became an outrageous marathon. The deeper we looked, the more we realized we needed to learn, particularly in the area of the live axle. I don't believe any of us realized just how complex the analysis of the live axle would turn out to be.

Wm. C. Mitchell, Dr Juan Salinas and the author are extremely proud of the correlation level we have been able to achieve between the models we are currently developing (including the basic Wan31 model) and recorded on track performance. Having said that, comparing mathematical results with on track data acquisition results is, in itself, extremely difficult. Despite the inordinate amounts of money race teams love to spent on data acquisition, deadly accurate on track dynamic results are at least as difficult to come by (someone should write a book on the problems involved in obtaining **accurate** and **usable** results from on track chassis performance). Further to this, it is my humble opinion that most teams, even many highly funded teams, use their expensive data acquisition systems more like a toy than as a well-defined scientific tool.

One of the many problems we have had in developing our simulation models is this inability to record repeatable, to the second decimal point, on track data. Many times we may have two slightly different theories regarding some aspect of the model, which, in turn, may well result in exactly the same corner loads but with a slightly different suspension motion, for example, 0.008" compared to 0.015" i.e. **repeatable**, on track data isn't always readily attainable to definitively determine which theory is correct.

**The good news is that race engineers don't need perfect simulation models and data acquisition systems to go fast. What racers do need are tools that accurately predict precise trends, and, to that end, the Wan31 models are very useful educational, set up and race tools.**

Wm. C. Mitchell is currently taking the information we have gleaned over the past year to develop a **far** more extensive software package for commercial sale. The new program will probably be called "WinGeo3 - Vehicle Dynamics Model". Two of the three components are nearing completion (2004). This new program will allow the race engineer to use on track data to run various simulation set up scenarios. A team will be able to carefully study the effects an endless number of set up changes have on a chassis performance level (very exciting).

# 14

# Load Transfer - Part One

## Load Transfer 101- The First Basic Look

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

Chapter 14 is a **very** simplistic overview of load transfer and its effect on chassis performance. It is presented in this form to simplify the individual concepts; however, the reader should never lose sight of the fact that *it's just not this simple*. Each subsequent load transfer section and chapter will introduce and discuss additional factors involved in load transfer. How each of these factors interact, and, in turn, affect chassis performance quickly becomes quite complex.

*Though this chapter, for the sake of clarity, uses steady state examples, one must never forget that a race car, except when at rest, hardly ever operates in a* ***purely*** *steady state condition.*

*When trying to analyze vehicle dynamics through data acquisition, the lines between static and dynamic information become somewhat blurred. Obviously, analyzing only one instant in time will be seen as a steady state observation but if a vehicle's loads and kinematics are observed and analyzed from anywhere between ten to four hundred times a second, strung together in a ribbon of time and then carefully compared, the results will more closely represent the dynamic state, even though they are technically still a series of single snapshots in time.*

As previously discussed in the tire chapters, a race car's ultimate performance level is a result of the four tire contact patch loads and forces operating in as **balanced** a manner **as possible** - equal acceleration forces between left and right side tires. Everything a race engineer does is done to develop optimum side to side and front to rear tire balance, including kinematic design and the initial set up of the car. The resultant loads seen at each corner play a major role in developing this optimum tire performance. Having said that, how loads are transferred during both static and dynamic conditions are arguably the least understood aspect of vehicle dynamics (*excluding aero effects*). Dynamic loads transferred from the chassis to the tire contact patches are seldom, if ever, seen by the contact patch as purely normal load and as we will see in Book Two, dynamic loads that are presented at the contact patch with a shearing component do nothing to improve performance.

If you fully and truly understand how spring, damper, bar and kinematic changes affect the four corner loads, you are in a very elite group. Most racers think they understand load transfer, but, unfortunately, or fortunately, depending on how you look at it, very few actually do.

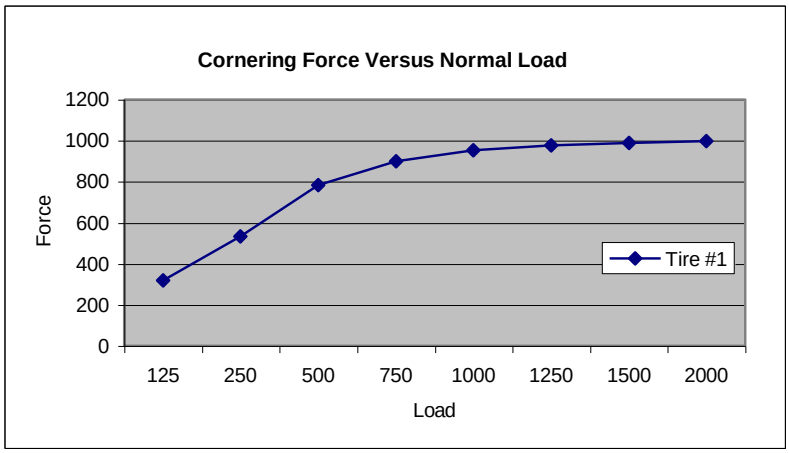
Kinetic Center Co-ordinates: The kinetic center is the **theoretical** mass center when dynamic acceleration forces are applied to the chassis. The center of mass co-ordinates of an object do not move when affected by inertial acceleration forces but the **kinetic center** co-ordinates do change as indicated by the changes in load at the four contact patches. A dynamic change in roll and/or pitch can also change the vertical component of the kinetic center.

Lateral Load Transfer versus Chassis Performance - The Primary Concept: As was previously discussed in the three tire chapters, each tire type will have an individual coefficient of friction factor (traction force divided by normal load). Though, as with all tire data within this book, the numbers used in Table 14-1 and its accompanying graph have been modified somewhat, the overall profile is quite close to a spec tire used in a major racing series (proprietary sensitivities and all). **All** tires under **extended** steady state conditions lose efficiency as the normal load increases but few to the extent of this first example. This particular tire was used because it so graphically illustrates the loss of efficiency versus increased normal load. At a load of 500 lb., the efficiency is 157% while at 1250 lb., the efficiency has dropped to 78%. This

drop in tire efficiency is the key factor in determining a chassis' performance envelope. At a load of 125 lb., Tire #1 is theoretically capable of producing 2.54 g of cornering force while at a load of 2000 lb., it can only produce 0.5 g of cornering force. Balanced side to side loads will almost always produce a higher combined lateral g force than unbalanced loads as seen when comparing a chassis with a LF load of 250 lb. and a RF load of 750 and a chassis with both front loads at 500 lb. The first chassis produces a total load of 534 + 899 = 1443 while the second chassis produces a total load of 783 + 783 = 1566 or an increase of 123 lb. of cornering force.

Table (14-1) See "Base Tire Map" tab

| **Normal Load** | 125 | 250 | 500 | 750 | 1000 | 1250 | 1500 | 2000 |
|---|---|---|---|---|---|---|---|---|
| **Lateral Force** | 317 | 534 | 783 | 899 | 953 | 978 | 990 | 998 |
| **Factor in g's** | 2.54 | 2.14 | 1.57 | 1.20 | 0.95 | 0.78 | 0.66 | 0.50 |
| **Efficiency in %** | 254% | 214% | 157% | 120% | 95% | 78% | 66% | 50% |




**Gravitational Forces**: One g is the force equal to earth's gravity. If an at rest chassis while sitting on a flat surface weighs 1500 lb., then the gravitational force acting on the chassis is 1500 lb. If an additional lateral acceleration force of 1500 lb. is applied to the chassis, it is said to have a lateral acceleration force of 1.00 g. If the acceleration force was reduced to 1000 lb., then the chassis will see an acceleration force of 0.67 g (1000/1500 = 0.67).

Load Transfer - The Basic Formula (Symmetrical Tracks and Wheelbases) - Total lateral load transfer is calculated as:

$$L_T = \frac{W_T * g * CG_Z}{t}$$

Where:
$L_T$ = load transfer
$W_T$ = total chassis weight
g = lateral acceleration force
$CG_Z$ = center of gravity height of the total chassis
t = track

**The complete asymmetrical formula can be found in Chapter 15**

Calculating load transfer and acceleration forces present a bit of a chicken and egg problem. Load transfer is dependent upon acceleration forces while acceleration forces are dependent on load transfer. Dynamic conditions involve an endless number of closed loop iterations.

Modeling Chassis Performance: Before the race engineer can understand how loads and load transfer affect tire and chassis performance, he/she must first understand the ins and outs of load transfer itself. The underlying principles of load transfer are contained in any high school physics text. The problem race engineers have in analyzing chassis performance is not particularly due to any one aspect of load transfer, but, is, instead, the fact that there are so many factors and they are all interconnected. It is easy to understand that we need the four tires to be as balanced as possible. It is not so easy to accomplish this balance under so many different dynamic conditions. There are quite literally thousands of interconnected factors affecting chassis performance, which, in turn result in tens of millions of possible iterations. It's a bit daunting to realize, that, despite the fact this first book only looks at a few of these factors, the mathematical model we have developed to help explain how load transfer works still ends up growing to a rather considerable size. The fact is, even the simplest of performance simulation programs will require at least one thousand separate inputs in order to produce any type of usable lap simulation. I have experienced several in house programs that require over fifteen hundred inputs. This is incredible when you consider these load simulation programs are capable of running millions of iterations at close to real lap times on your basic lap top.

Mathematical modeling of this type is, of course, extremely useful if accurate, but there is no substitute for testing with a physical model when one is first learning about the basic laws of load transfer. I believe **all** race engineers should build and spend time experimenting with these types of models so they can actually see, measure and feel the changes. Mathematical modeling should come only after the race engineer has a good theoretical grasp of the basic **hands-on** load transfer trends. You don't learn about the inner workings of stiction, friction, compliance and torsional rigidity from mathematical models even if they are factored into the model. *There is no substitute for this type of empirical knowledge*. Of course I also believe that **all** race engineers should have had experience machining, welding, fabricating, working as a race mechanic and setting up the chassis, but, after all, as stated in Chapter 1, I'm just a simple farm boy.

"Everyone believes the data from a mathematical model except the person who developed it while no one believes the data from a empirical prototype model test except the person who designed and ran it". Dr. J. J. Salinas

The aforementioned quote was in no way intended to infer that empirical testing is without its faults. There are as many ways to screw up an empirical test as there are grains of sand on a nice Mediterranean beach. Always remember the 3/2 rule from Chapter 1: test everything three times in at least two different ways and then continue to remain skeptical about the resulting data.

## Important Explanatory Note:

When this book was first started some years ago now we had planned to write it using both Standard (Customary) units and Metric (SI – International System) units. However, we soon realized that combining both systems would become not only extremely cumbersome but expensive to produce, considering the additional text required. An additional problem was whether to remain true to Mr. Newton and clearly delineate between "*mass*" and "*weight*". Obviously, if this book was to be used strictly by university trained engineers, mathematicians and physicists, we would have delineated between the two, but, as we hope the book will be used by both the aforementioned as well as racers in general, this became a rather perplexing problem. After a great deal of consideration and consultation with both racers and academics, in addition to reviewing my rather tattered copy of the Milliken and Milliken "Race Car Vehicle Dynamics" bible, we decided to use standard (Customary) units as well as combining both mass and weight as "weight". This was done for purely practical reasons and not because we do not realize that there is a clearly delineated difference. There are different fields of study, for example, space travel, where this approach would clearly not work, but in the design and set up of race cars, being off by 1 to the $15^{th}$ decimal point probably won't mean the difference between winning and finishing second. In reality, most racers in today's world use a rather mind-boggling combination of both metric and standard language – I know I certainly do. However, if I were writing the book today I would clearly use …….

Load Transfer Model B28-8: - This test model (nicknamed “The Thing”) was designed and used to explain a number of load transfer scenarios including how the addition of a anti roll bar affects load transfer. The model has a simple suspension system with a front anti roll bar - Figure 14.1. It uses a coil over configuration with the springs placed over sliders The tire contact patches have roller balls at each corner to reduce friction and stiction. A data acquisition system is used to measure motion change and load transfer. It only took a few hours to build from materials on hand in the R & D shop but the results were worth their weight in gold.

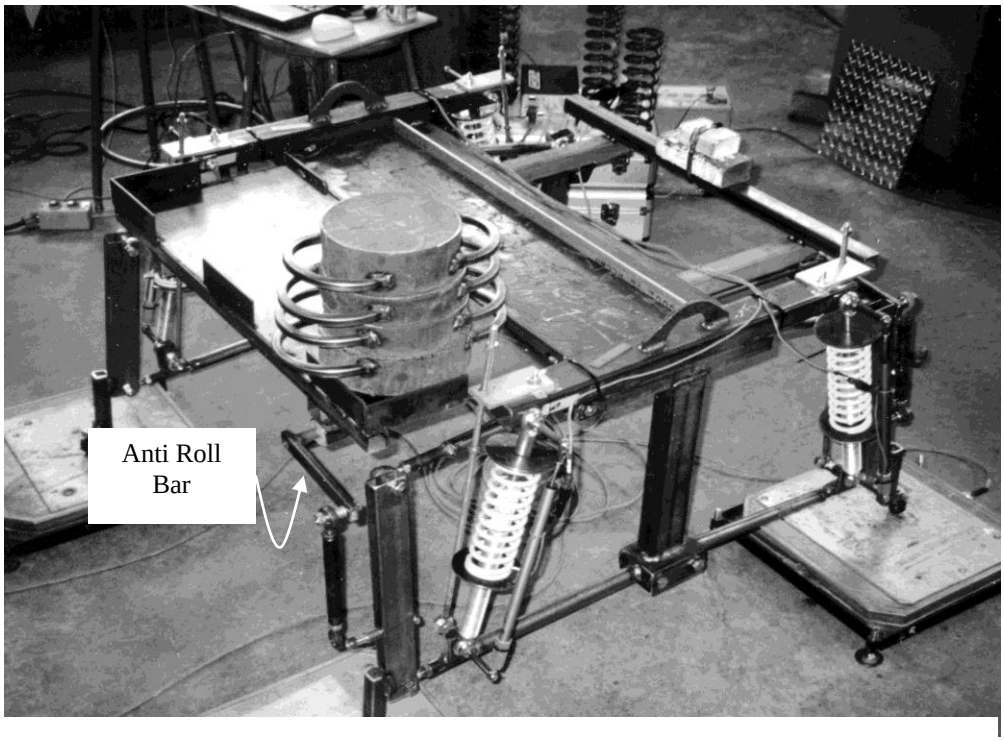



Figure 14-1

The movement of the inertial load-simulating weight stack is assisted by the use of four roller balls. The stack locks into six predetermined places - Figure 14-2.

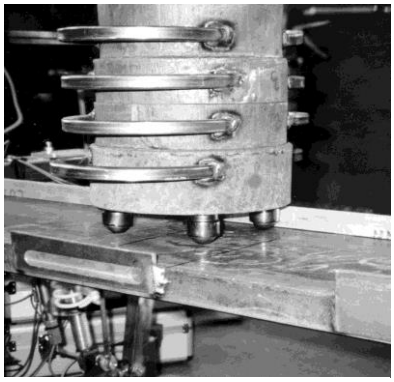


Figure 14-2

Elements of Chassis Performance: Chassis performance can be broken down into three basic elements:

- Static Set Up (Model Wan31A)
- Dynamic Load Transfer (Model Wan31A)
- Tire Acceleration Coefficients Versus Normal Loads (Model Wan31B)

Each of these elements is knowledge compounding. The race engineer must fully understand static set up before he/she will be able to understand load transfer etc. At the same time, the three elements must also be seen as a closed loop. The final set up cannot be determined until the best load transfer combinations are known, but the best load transfer combinations can not be worked out until they are combined with all the tire data iterations. This all leads to an endless chicken and egg problem, or, in computer terms, closed loop calculations.

Running the three elements back and forth in a closed loop never results in **the** one perfect scenario. As we will soon discover, every aspect of every element ends in a series of compromises and all of this before we even begin to consider chassis performance through all the combined turn and straight line scenarios. This is not a simple business.

Each element contains a series of **General Truths.** These general truths are compounding in nature i.e. they just keep getting more and more complex. If the race engineer fully understands these General Truths, he/she will be well on his/her way to acquiring the skills needed to successfully determine the best static and dynamic set up **compromises** for any particular on track scenario. *Right! It's just not that simple.*

The Initial or Shop Set Up: The first step in on track performance involves the shop set up. It is at this point that the race engineer needs to decide on what springs, bars and dampers will be used in conjunction with the preloads and ride height settings. As just discussed, how well these components and settings will work under dynamic conditions is dependent on the amount of dynamic load transfer but that is dependent on the shop set up and the tires load versus acceleration force factors. The tire force factors are dependent on the amount of load transfer, how it is transferred and the kinematics of the tires, which, in turn, are dependent on the dynamic ride heights and steering input. The amount of steering input is dependent on the tire performance factors, turn radius, chassis balance and track conditions.

The Closed Loop: In order for the chassis to be set up properly the race engineer needs to have a considerable amount of information about the dynamic conditions to follow. The first big question is what are the expected lateral, longitudinal and combined acceleration forces? The shop set up will only be as good as the accuracy of the acceleration data. This data is used to calculate the ride and roll forces i.e. loads at the tire contact patches, spring deflection and suspension motion. Acceleration data is developed using load transfer and performance models as presented in this book and from on track data. The on track data will only be as accurate as previous track performance. If previous shop and track set ups did not allow for maximum on track performance, then the track data will not accurately show the maximum acceleration forces, which, in turn, will mean the engineer is not developing the shop set up for the highest possible load transfer numbers. If the models the race engineer is using are flawed or too basic, this will also lead to a less than optimum shop set up. The race engineer should always develop a statistical model in order to compare the on track data with the mathematical model.

As we will discuss to some extent later in Book One, and, to a much greater extent in Book Two, the acquiring of accurate data and being able to analyze and use that data most effectively is one of the race engineer's primary jobs. Miss the initial shop set up and everything else is downhill from there. The set up is used to put in place the best **rate** (spring, bars and damper rates and motion ratios), **kinematic** (camber gain, jacking and anti geometry, etc.) and **ride height** compromises for optimum on track chassis performance. A chassis is designed to run at a prescribed ride height under dynamic conditions, which, in turn, affects pitch, roll and ride. The amounts of ride, roll and pitch under dynamic conditions affect suspension motion, clearances and aerodynamics. Suspension motion affects camber gain/loss, bump and roll steer, etc. Changes in camber angle, steering input etc., in turn, affect tire performance.

Spring, bar and damper rates in conjunction with their respective motion ratios and the various lateral and longitudinal jacking/anti forces can affect both the static and dynamic contact patch loads. Replacing a spring with a stiffer spring and then readjusting the chassis balance and adjusting the preload will not change the static loads but will affect the dynamic loads at all four corners. Changing the preload at one corner will effect static loads at all four corners but not necessarily dynamic loads. Changing anti/jacking kinematics will not affect the static set up very much but it may well have a considerable affect on dynamic load transfer and subsequent corner loads. Dynamic corner load equals static corner load plus inertial forces i.e. dynamic load transfer always begins at the static setting.

## The Load Transfer Model – Wan31A

Wan31A is the thirty-first load transfer model of this type that Dr. Juan Salinas and the author have written (Juan did 95% of the work on this model). The model was developed to run using the Excel format and is the first part of a two-part model. Both the A and B models require Excel 98 or newer to run. Though the model is basic in nature, it is definitely not trivial in its construction. It was developed specifically as an educational tool to accompany the first book in the "Introduction to Race Car Engineering" series. Wan31A can be found on the "Formulas and Models" CD located at the back of the book. We have tried to develop the model in a way that the race engineer will find the most useful but that does not necessarily mean it is confusion proof. There are so many different approaches we could have taken so the user needs to have a good long look at the Wna31 Symmetrical Chassis outline before wandering off too far on his/her own.

The Excel format was chosen for this model because virtually everyone that has access to a computer will also have access to Excel. A second reason for using Excel was to allow the user unfettered access to the program itself and to allow the user, if he/she so desires, to get in and rewrite parts of the code. Because this program was developed as a teaching tool, we wanted the user to be able to look at the process as well as the outcomes. The working part of the program can be found to the right of the primary screen. In addition, all seventeen formula components of the model and their accompanying analyses are included in Chapter 15. Wan31B introduces a number of tire models, and, when plugged into Wan31A, helps to predict chassis performance and balance. Wan31A & B are just the first two algorithms in a series of algorithms used to develop a track simulation program.

If the user does not have at least a basic working knowledge of Excel, it is highly recommended that he/she spend some time with one or two Excel - *How to books*. My favorite is "Excel In A Nutshell" written by Jinjer Simon and published by Reilly. The Internet is also a good source for how to information about Excel.

Excel is a very powerful tool that virtually all race teams use. However, it is not particularly well-suited for this type of calculation, particularly when closed loop iterative types of calculations are required. Excel does have a circular iterative solver but if the user accidentally moves one closed loop cell to the wrong place, the entire program will crash. For this reason, moving Wan31 into the Excel format while keeping it user friendly was not particularly easy – some small iterative compromises were made. It is also quite difficult and exasperating to enter large sets of algorithms/formulas into Excel because the programmer is only able to see small parts of the code at any one time.

The program format was not designed to win any ergonomic beauty contests, but, instead, was designed to allow the race engineer constant access to as big a picture as possible rather than having to constantly flip back and forth between screens. Each iteration within Wan31A involves the calculation of approximately 350 factors and though not presented this way in the book, the program can be set up to run real time data streams (ASCII or Matlab) from data acquisition systems plugged into WinGeo3.

Wan31A allows the user to examine **corner load** changes as the result of various combinations of lateral and longitudinal acceleration in conjunction with various spring, damper and anti roll bar rates, their individual motion ratios and preloads as well as the various side and front view kinematic anti/jacking forces.

# Wan31A – The Quick Overview:

## Wan31A Cars

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

## Screen Format

- The main screen is separated into six **Component Boxes**:
    - **A1** Chassis
    - **A2** Initial Conditions
    - **A3** Other Loads
    - **A4** Anti/Jacking
    - **A5** Inertial Forces and CG Location
    - **A6** Solutions
- All three Wan31A models are saved with the Excel screen set at 84%. If you are using a smaller monitor, you may have to decrease the screen size by 1 or 2 % in order to see the whole screen. The user should be able to just see the dark brown border surrounding the six component boxes.

**Yellow Input Cells**

- The user enters data **only** in the bright yellow cells and three pink cells as will be explained shortly.
- **All** kinematic data should be entered from WinGeo3 including the front view and side view instant center co-ordinates, tire radius, lower spring/pushrod and anti roll bar link co-ordinates and all spring, damper and anti roll bar motion ratios. In the case of push rod and bell crank suspension systems where both the dampers and anti roll bars are attached to a bell crank, the bottom spring and bottom shock co-ordinates are entered as the bottom push rod co-ordinates as shown in WinGeo3.

**Blue and Brown Cells**

- All blue and brown cells are program-calculated cells. They are not used for data entry. If the user accidentally enters data in a blue or brown cell, the safest thing to do is close the program without saving and then reload it. The user is encouraged to always burn a non-rewriteable CD of his/her chassis' base model.

**Pink Cells**

- The pink cells are used to avoid closed loop iterative calculations. The user manually enters data in the pink cells from the appropriate companion cells. There are two pink cells in **A2** and one pink cell in **A6**. The when and how the user enters data in these cells will be explained shortly.

**Gray Cells**

- Gray cells are currently unused program cells. They are primarily included in Wan31A for ergonomic reasons but will be used in a later version to implement front and four wheel drive forward acceleration.

**Green Cells**

- All green cells are switches used to turn anti/jacking kinematic force calculators on and off. The number 1 turns the anti calculator on while the number 0 turns the anti calculator off.

## Chassis: - A1

- W Base (L) – Each wheelbase co-ordinate represents the distance from the lateral center of the chassis to the centerline of the hub. As is often the case with oval track cars, the left side wheel base may be shorter than the right side wheel base. Normally, this is accomplished by moving the left front hub/wheel back towards the longitudinal centerline of the chassis.

- Track (t) – Each track co-ordinate represents the distance from the longitudinal centerline of the chassis to the rim-mounting surface on the hub.

- Radius, (R) – This is the tire's loaded radii as entered in WinGeo3 (distance from the track surface to the center of the hub). WinGeo3 has the user input the tire's diameter so these numbers will need to be divided by 2.

- Rad Chge (Rc) – These cells represent the change in tire radius due to tire squish/deflection and stagger changes at each corner.

- Unspr m (Wu) – These cells allow the user to enter each corner's unsprung weight.

**Springs** A1.1

- M Ratio (m) – Allows the user to enter spring motion ratio as shown in WinGeo3.

- Rate (k) – Allows the user to enter the spring rate.

- Preload (D) – Allows the user to change the amount of initial preload on the spring. A minus number removes preload while a positive number adds preload. The initial preload on the springs is the result of the sprung mass weight being placed on the springs, bars and dampers in relation to their respective motion ratios. Changing the distance between the upper and lower spring perch (the spring's upper and lower mounting surface) changes preload. For a coil over system this is a matter of turning the adjuster ring in or out while on a stock car the upper spring perch is moved by turning the load bolt in or out.

- Bottom (X/Y) – These are the X and Y co-ordinates for a system that has its springs and /or springs/dampers attached directly to the lower A-arms. The X co-ordinates represent distances measured from the chassis's longitudinal centerline towards the left and right side wheels. The Y co-ordinates represent distances measured from the chassis's lateral centerline out towards the

front and rear of the chassis. For a push rod system, the bottom x and y co-ordinates are where the bottom of the push rod affixes to the lower A-arm.

**Roll Bars** A1.2

- M Ratio (mR) – Bar motion ratio as shown in WinGeo3.
- Rate (KR) – Roll Bar Linear rate (Force in pounds per inch of total linear arm motion – combined left and right arm linear motion).
- Preload (DR) - Allows the user to change the amount of preload on the bar. Except when using a Howe bar, this is accomplished by lengthening or shortening the adjuster link.
- Bottom (X/Y) – These are the X and Y co-ordinates for a system that has its roll bar links attached directly to the lower A-arms.

  For a push rod system, the bottom x and y co-ordinates are where the bottom of the push rod affixes to the lower A-arm.

**Shocks** A1.3

- M Ratio (ms) – Shock motion ratio as shown in WinGeo3.
- Preload (fsp) – Shock preload represents force produced by internal gas pressure. In most cases the higher the shock's nitrogen pressure, the greater the applied load will need to be before the shock's shaft will begin to move.
- Load (fs) – Shock loads are a function of shaft velocity (force vs velocity). To determine shock forces, the user must compare shaft velocity from the data acquisition system to the shock dyno read outs. A positive number represents shock forces in bump while a negative number represents shock forces in rebound.
- Total (Fs) – This is a calculated number adding the shock preload and load forces together (no user input).

**Initial Conditions: - A2**

- Loads (P) – The user enters the initial wheel loads as seen on the set up scales.
- Bias ($B_X$) – The model calculates the bias and wedge percentages.
- Total ($W_T$) – The model shows the total weight of the car plus the total weight x, y & z co-ordinates.
- Unspr (Wu) – The model shows the total unsprung weight of the car plus the total unsprung weight x, y & z co-ordinates.
- Sprung (Ws) – The model shows the total sprung weight of the car plus the total sprung weight x, y & z co-ordinates.
- **A2** Pink Cells – In order to avoid the need for a series of circular iterations, the user needs to enter the data from the blue cell directly above the pink cells. This is done after all **A1** data and **A2** initial loads have been entered. If the user links these cells rather than manually entering the data, load transfer changes resulting from a track or wheelbase change will be incorrect. The appropriate

numbers have already been **programmed** into all Wan31A models included on the CD. The user will only have to change these numbers if he/she changes the base track and/or wheelbase.

**Other Loads: - A3**

- Ballast lb. (Ba) – Allows the user to add ballast to the chassis. Adding ballast offset from the CG will change the final bias numbers as indicated in cells O4, P4 & Q4.

- Driver lb. (Dr) – Allows the user to show differences in driver's weight. Changing a driver's weight, if offset from the CG, will change the final bias numbers as indicated in cells O5, P5 & Q5.

- Fuel lb. (Fu) – Allows the user to look at fuel load changes. Changing fuel loads offset from the CG will change the final bias numbers as indicated in cells O6, P6 & Q6.

- Aero lb. (Ae) – Allows the user to change aero load forces and pressure centers. Changes in aero loads and pressure centers are determined by consulting the team's aero maps or directly from the data acquisition system. The x, y & z co-ordinates (cells O7, P7 & Q7) indicate the aero pressure center.

## Anti/Jacking: - A4

### **Indep** A4.1

- 0/1 - The green switching cells allow the user to turn the kinematic anti/jacking forces on and off for each individual corner. 0 indicates the calculator is turned off for that particular corner while a 1 indicates the calculator is turned on for that particular corner. When running an independent rear suspension system, the **track bar** calculator (green cell P15) needs to be **turned off**.

- IC (e) – Allows the user to input the front view instant center height for each corner as calculated by WinGeo3.

- IC (ay) – Allows the user to input the front view instant center length for each corner as calculated by WinGeo3.

- (e/a) – Calculates the IC slope.

- Force – Calculates the Anti/jacking forces at each corner.

**Track Bar** A4.2

- 0/1 - * When using a live axle rear suspension system in conjunction with a track bar, the track bar calculator needs to be turned **on** (green cell P15) while the rear **independent** LR & RR calculators need to be turned **off** (green cells P10 & Q10). The calculator is currently set up for a track bar system that has its axle mount on the left side and its frame mount on the right side. The user would need to do a little reprogramming to change the track bar mounting positions.

- Bar Geom (e) – Allows the user to input the distance from the center of the axle track bar mount to the center line of the axle as indicated in WinGeo3 (a vertical distance).

- Bar Geom (a) - Allows the user to input the distance from the center of the axle track bar mount to the centerline of the left side hub-mounting surface as indicated in WinGeo3 (a horizontal distance). This distance is calculated as the left side track minus the distance the track bar axle mount is from the center line of the chassis (assuming the wheel has zero offset).

- Bar Geom (angle) – Allows the user to enter the angle in degrees of the track bar. A minus number indicates the track bar is angled down towards the frame mount.

- Fce (AA) – Calculates the anti/jacking force at the LR.

- Fce (BB) – Calculates the anti/jacking force at the RR.

**Accel** A4.3

- 0/1 – The Wan31 demonstration model is currently set up for rear wheel drive vehicles. The green cells are used to turn the LR and RR anti/jacking calculators on and off. The LF and RF cells are **not** used in this configuration of the model.

- IC (e) – Allows the user to input the side view instant center height for each corner as calculated by WinGeo3.

- IC (ax) – Allows the user to input the side view instant center length for each corner as calculated by WinGeo3.

- (e/a) – Calculates the IC slope.

- Force (rA) – Calculates the anti/jacking forces at each corner

**Brake** A4.4

- 0/1 – Allows the user to turn the brake anti/jacking calculators on and off for each corner.

- IC (e) – Allows the user to input the side view instant center height for each corner as calculated by WinGeo3.

- IC (ax) – Allows the user to input the side view instant center length for each corner as calculated by WinGeo3.

- (e/a) – Calculates the IC slope

- Force (qB) – Calculates the Anti/jacking forces at each corner

**Total Antis** A4.5

- Calculates the total anti/jacking forces at each corner.

## Inertial Forces and CG Location – A5

- Wt g (W) – For **normal** operations, the user should have the number 1 placed in the yellow cell at **all** times. When a 0 is placed in the cell, the loads as entered in "A2 Loads" are removed from the springs, bars and dampers. If the chassis is symmetrical the load cells "A6 Loads" will read zero. If these cells don't read zero they are indicating the chassis is asymmetrical.

- Left g ($T_L$) – Allows the user to input left turn acceleration forces expressed in g's.

- Right g ($T_R$) - Allows the user to input right turn acceleration forces expressed in g's.

- Bank (alpha) – Allows the user to input a track-banking angle expressed in degrees.

- Accel g (A) – Allows the user to input inline acceleration forces expressed in g's.

- Brake g (B) - Allows the user to input inline-braking forces expressed in g's.
  pF – Allows the user to input the percentage of front brake force. Rear brake force percentage is calculated.

## Solutions: A6

**Loads** A6.1

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

**Motion** A6.2

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

**Important Note**:

- **Before** entering a roll bar rate (A.1), place a zero (0) in the teal cell Z22.
- After the initial loads have been placed in cells E29 through to H29, **all** acceleration forces at zero, **no** roll bar rate entered in cells E17 and G 17 and **no** Other Loads entered, enter the number seen in cell W22 into cell Z22.
- Cell W22 should now show 0.000. If not, check to see that all the above conditions have been met.
- The roll bar rates can now be entered.
- Ride (z) - The model calculates the final ride height at each individual corner.

**Bias**

- Left - The model calculates the resultant left side bias.
- Rear - The model calculates the resultant rear bias.
- Wedge - The model calculates the resultant RF to LR diagonal percentage (wedge).
- Kin. x – The model calculates the lateral (x) kinetic mass center.
- Kin. y – The model calculates the longitudinal (y) kinetic mass center.

**Chassis**

- Squat - The model calculates the resultant **over all** change in chassis ride.
- Pitch - The model calculates the resultant chassis pitch angle given in degrees.
- Roll - The model calculates the resultant chassis roll angle given in degrees.

**Ride** A6.3

- Initial (zo) – The user enters a factor into these cells to correct initial ride height. These factors are required to accommodate different spring free heights, push rod lengths, different ride height measuring points, etc.
- Coord (x) – User entered longitudinal ride height measuring points.
- Coord (y) – User entered lateral ride height measuring points.
- Chge (z) – The model calculates changes in ride heights due to **Acceleration Forces** and **Other Loads.**
- Final – The model calculates the final ride heights.

**Note**: Because we wanted the main program to fit onto a single page (for educational purposes), we unfortunately had to leave some of our original components out. These include:

- Droop/no droop push rod changes
- Combining tire spring rate with the total wheel rate
- Showing ride height change due to tire squish
- A considerable number of incidental calculators

Most of the information from these types of components can still be obtained but it is just not as convenient. The primary calculator in Book Two includes all of the above and considerably more but the downside is that the calculator needs to use a number of secondary pages.

# Wan31A Layout

**A1 Chassis**

| A1 | Chassis | | (1) LF | (2) RF | (3) LR | (4) RR |
|---|---|---|---|---|---|---|
| | W Base | L | 53.26 | 53.75 | 53.75 | 53.75 |
| | Track | t | 32.50 | 33.00 | 32.75 | 32.75 |
| | Radius | R | 13.470 | 13.647 | 13.360 | 13.853 |
| | Rad Chge | Rc | 0 | 0 | 0 | 0 |
| | Unspr M. | wu | 120 | 120 | 120 | 120 |
| A1.1 | **Springs** | | **(1) LF** | **(2) RF** | **(3) LR** | **(4) RR** |
| | M Ratio | m | 0.494 | 0.460 | 1 | 1 |
| | Rate | k | 850 | 900 | 225 | 200 |
| | PreLoad | D | -0.1 | 0 | 2 | 1.35 |
| | BOTTOM | x | 52.706 | 52.706 | 53.750 | 53.750 |
| | | y | 19.044 | 19.044 | 23.313 | 23.313 |
| A1.2 | **Roll Bars** | | **(1) LF** | **(2) RF** | **(3) LR** | **(4) RR** |
| | M Ratio | mR | 0.5 | 0.5 | 1 | 1 |
| | Rate | kR | 0 | | 0 | |
| | PreLoad | DR | 0 | 0 | 0 | 0 |
| | BOTTOM | xR | 54.062 | 54.062 | 53.750 | 53.750 |
| | | yR | 23.405 | 23.405 | 23.313 | 23.313 |
| A1.3 | **Shocks** | | **(1) LF** | **(2) RF** | **(3) LR** | **(4) RR** |
| | M Ratio | ms | 1 | 1 | 1 | 1 |
| | Preload | fsp | 0 | 0 | 0 | 0 |
| | Load | fs | 0 | 0 | 0 | 0 |
| | Total | Fs | 0 | 0 | 0 | 0 |

A2 Initial Conditions

| A2 | Initial Conditions | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | (1) LF | (2) RF | (3) LR | (4) RR | Tot |
| | Loads | P | 790.0 | 754.0 | 855.0 | 602.0 | 3001 |
| | | | **Left** | **Rear** | **Wedge** | | |
| | Bias | Bx | 54.8% | 48.6% | 53.6% | | |
| | CG | | | **x** | **y** | **z** | |
| | Total | WT | 3001 | 1.429 | 3.025 | 18.00 | |
| | Unspr | Wu | 480 | -0.122 | -0.125 | 13.58 | |
| | Sprung | Ws | 2521 | 1.725 | 3.625 | 18.84 | |

A3 Other Loads

| A3 | Other loads | | x | y | z |
|---|---|---|---|---|---|
| | Ballast (lb) | Ba | 0 | -8 | 28 | 5 |
| | Driver (lb) | Dr | 0 | -3 | -1 | 10 |
| | Fuel (lb) | Fu | 0 | -40 | 0 | 10 |
| | Aero (lb) | Ae | 0 | 6 | 0 | 20 |

A4 Antis/Jacking

| A4 | Antis/Jacking | | (1) LF | (2) RF | (3) LR | (4) RR | |
|---|---|---|---|---|---|---|---|
| A4.1 | **Indep** | 0/1 | **1** | **1** | **0** | **0** | |
| | | e | 2.837 | 4.06 | 1 | 1 | |
| | IC | ay | 40.1 | 38.9 | 1 | 1 | |
| | | e/a | -0.07 | 0.10 | 0.00 | 0.00 | |
| | | Force | 0 | 0 | 0 | 0 | |
| A4.2 | **TrackBar** | 0/1 | **0** | **0** | **1** | **1** | |
| | | | **e** | **a** | **angle** | | |
| | Bar Geom | | 2.5 | 16 | 1 | deg | |
| | | | **$h_3$** | **$h_4$** | **AA** | **BB** | |
| | | IC | 10.58 | 11.72 | 53.503 | 53.75 | |
| | | rT | 0.501 | Fce = | 0 | 0 | |
| A4.3 | **Accel** | 0/1 | **0** | **0** | **1** | **1** | |
| | | e | 11.05 | 11.9 | 9.25 | 9.25 | |
| | IC | ax | 68.75 | 78.7 | 330.0 | 330.0 | |
| | | e/a | 0 | 0 | 0.028 | 0.028 | |
| | | ri | 0 | 0 | 0.5462 | 0.454 | |
| | rA | Force | | | 0 | 0 | |
| A4.4 | **Brake** | 0/1 | **1** | **1** | **1** | **1** | |
| | | e | 11.05 | 11.9 | 13.179 | 15.37 | |
| | IC | ax | 68.75 | 78.7 | 235.71 | 183.3 | |
| | | e/a | 0.161 | 0.15 | 0.0559 | 0.084 | |
| | | q | 0.275 | 0.22 | 0.2731 | 0.227 | |
| | qB | Force | 0 | 0 | 0 | 0 | **Total** |
| A4.5 | **Total Antis** | | 0 | 0 | 0 | 0 | 0 |

A5 Inertial Forces and CG Location

| A5 | Inertial Forces and CG location | | | | | |
|---|---|---|---|---|---|---|
| | | | 3001 | x | y | z |
| | Wt (g) | W | 1 | 1.43 | 3.03 | 18.00 |
| | Left(g) | TL | 0 | 1.43 | 3.03 | 18.00 |
| | Right(g) | TR | 0 | 1.43 | 3.03 | 18.00 |
| | Bank | alfa | 0 | (Degrees) | | |
| | Accel(g) | A | 0 | 1.43 | 3.03 | 18.00 |
| | Brake(g) | B | 0 | 1.43 | 3.03 | 18.00 |
| | | | pF = | 50% | pR = | 50% |

## Don't Forget the Pink Cells

A6 Solutions

| A6 | Solution | | | | | | |
|---|---|---|---|---|---|---|---|
| A6.1 | **Loads** | | **(1) LF** | **(2) RF** | **(3) LR** | **(4) RR** | **Total** |
| | Wheel | P | 790.4 | 753.6 | 854.6 | 602.4 | 3001.0 |
| | Spring | F | 670.4 | 633.6 | 734.6 | 482.4 | 2521.0 |
| | RollBar | $F_R$ | 0.0 | | 0.0 | | |
| | Damper | Fs | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| A6.2 | **Motion** | | | | | | |
| | Wheel | $d_P$ | 3.232 | 3.327 | 3.265 | 2.412 | |
| | Spring | d | 1.596 | 1.531 | 3.265 | 2.412 | |
| | RollBar | $d_R$ | 0.000 | → | | 0.204 | = dRo |
| | Ride | z | 4.304 | 4.469 | 4.735 | | |
| | | | **Left** | **Rear** | **Wedge** | **Kin. x** | **Kin. Y** |
| | Bias | | 54.8% | 48.6% | 53.6% | 1.429 | 3.0252 |
| | Chassis | | **Squat** | **Pitch** | **Roll** | | |
| | | | 1.391 | 0.004 | 0.004 | rad | |
| | | | | 0.242 | 0.250 | deg | |
| | | | | *NoseDn* | *Left* | | |
| | **Ride** | | **(1) LF** | **(2) RF** | **(3) LR** | **(4) RR** | |
| A6.3 | Initial | $z_o$ | 6 | 6 | 6 | 6 | |
| | Coord | x | 52.71 | 52.706 | 53.75 | 53.75 | |
| | | y | 19.04 | 19.044 | 23.313 | 23.31 | |
| | Chge | z | 1.70 | 1.531 | 1.265 | 1.062 | |
| | Final | | 4.304 | 4.469 | 4.735 | 4.938 | |

# The Symmetrical Chassis

## - A First Look at How the Wan31A Model Works

**Important Note**: After entering data in a Excel cell, the user must click on another cell or press the enter key in order to activate the change.

For the initial discussions regarding the use of Wan31, the various boxes and cell co-ordinates will often be referred to when describing an operation. This is done in order to help the novice Excel user navigate through the program. This first section is, by necessity, somewhat belabored, but, take heart because the redundant use of cell location co-ordinates pretty well stops after the first five paragraphs.

After the first few examples, only the operation and box numbers will be referenced. Shortly thereafter, only the operation will be referenced. Hopefully, by this time, the user will be able to freely navigate through the program on his/her own.

The user, no matter what his/her racing experience is, **should take the time** to carefully go through **all** of the Wan31 examples.

### Checking for Asymmetries - Switching Cell (*W5*) in Box **A5** between 1 and 0:

1) **Load** the Wan31 **Symmetrical Chassis** found on the "Formulas and Models" CD. This base chassis is completely symmetrical left to right and front to rear. It's the first model to examine when exploring static set up and dynamic load transfer basics. Any type of asymmetry will change part(s) of the static and/or dynamic results.

2) To make sure the model contains no spring, bar, shock or initial load asymmetries, go to the **A5** Inertial Forces Box and place a 0 in the Wt (g) cell (*W5*). If the model contains no asymmetries, the wheel loads shown in the **A6** wheel load will all be zero. Placing a 0 in the Wt (g) cell removes the chassis initial corner loads from the **A6** wheel load cells but does not remove the initial corner loads from the Wan31 internal calculator.

3) While keeping the 0 in the Wt (g) cell (*W5*), place a 1 in the Left (g) cell (*W6*) found in Box **A5**. The 1 in this cell represents one g of left turn lateral acceleration. Notice that the blue load cells (*W14/Z14*) in the **A6** Solution box now show the **amount** of left turn load transfer i.e.201.8 pounds are removed from the left side corners and 201.8 pounds are added to the right side tires. If the left turn g force is reduced to 0.5, then the load transfer becomes 100.9 removed from the left side corners and 100.9 added to the right side corners.

4) If the Initial Loads (*E28/H28*) in the **A2** Initial Conditions box are increased from 370 lb. to 500 lb. and with left turn acceleration set at 1 g, the wheel loads in Box **A6** also change. In this case 272.7 lb. are removed from the left side corners and 272.7 lb. are added to the right side corners.

5) When the user wants to see the **actual** corner loads rather than just the amount of load transfer, he/she simply places a 1 rather than a 0 in the **A5** Wt (g) cell. With the initial loads each set at 370 pounds, 1 g of left turn lateral acceleration and a 1 placed in the **A5** Wt (g) cell, the **A6** corner loads show 168.2 lb. at the left side corners and 571.8 lb. at the right side corners.

**Note**: Except when trouble shooting, the 1 is **always** left in the **A5** Wt (g) cell.

## Wan31 A Static Set Up Precursor

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

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

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

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

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

- Finding the initial static wheel rate versus load versus ride combination can be quite time consuming as we will soon discover. Solver types of software can be written to help in this process, but, to begin with, we are going to use the solver between our ears.

By design, each chassis has a particular ride height configuration needed to meet the chassis kinematic and aero requirements for each race track configuration - the ride height sweet spot. This sweet spot is the one set of static ride heights that allows the chassis to operate within the appropriate kinematic and aero range during on track dynamic conditions. As previously discussed, dynamic motion controls camber gain, caster gain, bump and roll steer, etc. as well as the front and side view anti/jacking forces. If the dynamic ride heights are not within the required kinematics range, the chassis performance envelope will be degraded. Dynamic ride heights working outside the aero requirements will similarly degrade the chassis' performance envelope. The aerodynamic sweet spot window can be surprisingly small, even with a stock car, and incredibly small on a formula car. One of the primary problems with the chassis operating with dynamic ride heights outside its design parameters is having the various suspension bits moving beyond the center of their arcs. For example, having camber gain moving from increasing to suddenly decreasing or having a wheel quickly move from toe out to toe in. These types of sudden changes can make both the chassis and driver rather nervous. Changes that move beyond the center of their arc can drastically change the overall chassis balance.

Every time a spring rate is changed, a new dynamic sweet spot combination needs to be found, which, in turn, requires a change to the static ride height set up. For example, when a spring is replaced with a stiffer one, all other things being equal, the dynamic ride height at that corner will change less for the same amount of applied dynamic load and that always needs to be considered when designing the static ride heights. Additionally, when a stiffer spring is installed at one corner, it often results in one or more of the other corners seeing a larger ride height change under dynamic conditions.

Changing Static Corner Load:

- When working with a stock car, changing the static corner load is normally a matter of turning the load bolts in or out to adjust the spring preloads. Turning the load bolt in shortens the distance between the upper and lower spring perches, increases the static corner load. When using a load bolt system, the static corner load and ride height can be adjusted back to the original settings no matter what spring rate is used. If a higher rate spring is used, preload will need to be decreased in order to get back to the original setting. If a lower rate spring is used, preload will need to be increased in order to get back to the original setting.

- When working with a coil over system, as found on a GT car, the preload is increased or decreased by turning the spring perch (adjuster ring) in or out the appropriate amount. If a higher rate spring is used, preload will need to be decreased in order to get back to the original setting. If a lower rate spring is used, preload will need to be increased in order to get back to the original setting.

## Don't Forget the Pink Cells

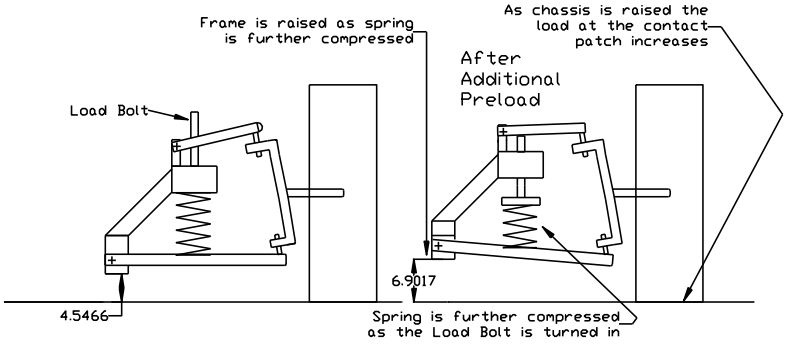



Figure 14-3 With a stock car or traditional coilover spring system, any additional corner load and/or preload change via the load bolt/ring adjuster will result in a change in spring compression unless a stop is built in or the spring becomes completely coil bound i.e. infinitely stiff.

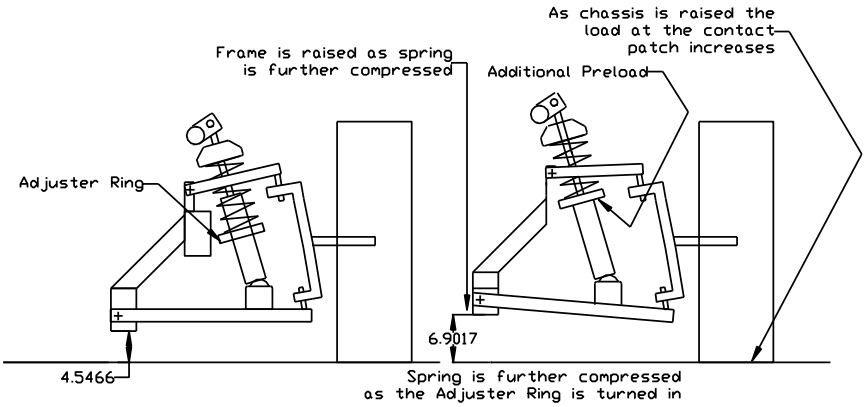



Figure 14-4

- Changing the corner loads and ride heights when working with a bell crank and pushrod system is not as straight forward as the previous two examples. **If** the spring preload is set for zero droop, the damper's piston will be fully extended as seen in Figure 14-5. Any further preload on the spring will not change the **static** corner load or ride height. It does, however, change the dynamic wheel loads and the amount of dynamic load the spring needs to see before it begins to further compress. In order to change the corner load and ride height when the damper/spring is set for no droop, (damper shaft fully extended) the pushrod will need to be shortened or lengthened.

    - Changing the preload on a spring whose damper is not already fully extended will further extend the damper shaft and increase the corner load and ride height just as in the stock car and GT examples.

    - Changing the spring preload on a damper whose piston is already fully extended **will** change the **dynamic** corner loads and ride heights but **not** the **static** corner loads and ride heights.

    - Changing the push rod length on a system whose damper is already fully extended will change the static corner loads and ride heights but will **not** alter corner load and ride height change due to dynamic conditions (conditions where lengthening the pushrod does not further compress the spring).

- Changing the push rod length **will** increase the amount of spring deflection only if the pushrod load exceeds the spring preload.

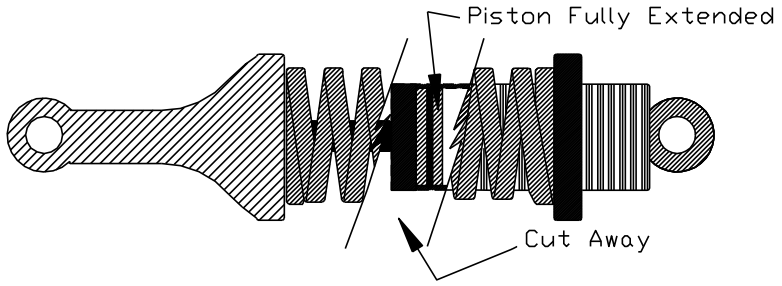



Figure 14-5

Figure (14-6) illustrates how a preloaded spring/ damper system works.

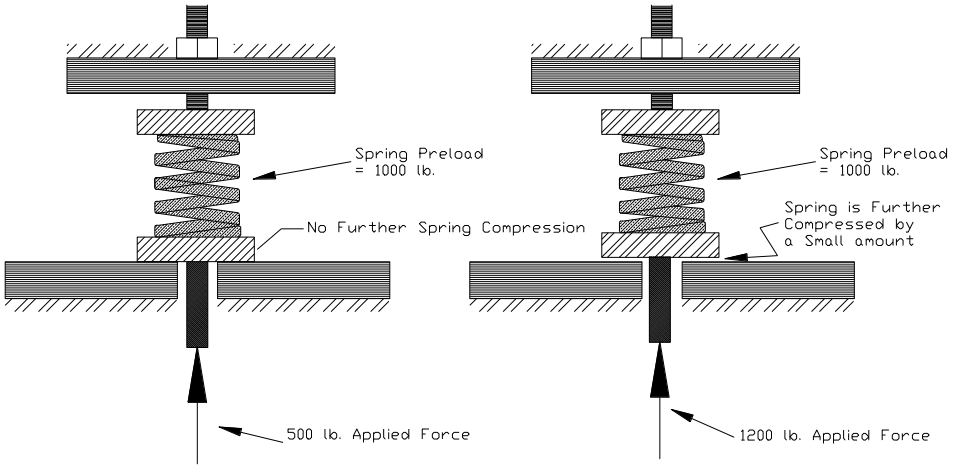



Table 14 – 2 outlines two scenarios that will and will not see additional spring compression versus applied load at the pushrod:

- Case 1, 3, 4 & 6 – Until load at the wheel is greater than the spring preload including the motion ratios, the spring will not see any further deflection. Lengthening the pushrod will increase the corner load and the ride height in direct relation to the pushrod motion ratio.

- Case 2, 5 & 7 – When the load at the wheel is greater than the spring preload including the motion ratio, the spring will see further deflection. Lengthening the pushrod will increase the corner load and the ride height in direct relation to the pushrod, bell crank and spring motion ratio. A lower spring rate will result in a smaller ride height and corner load change in relation to the amount the pushrod length is changed just as in the stock car and GT examples.

Table 14 – 2

**Spring Compression Beyond the Initial Spring/Damper Preload**

| Case | K | Spring Preload | Load on Pushrod | Addition Compression |
|---|---|---|---|---|
| 1 | 100 | 100 | 100 | No |
| 2 | 100 | 50 | 100 | Yes |
| 3 | 100 | 400 | 100 | No |
| 4 | 100 | 400 | 375 | No |
| 5 | 8000 | 75 | 100 | Yes |
| 6 | 2000 | 1000 | 100 | No |
| 7 | 2000 | 100 | 200 | Yes |

Figure 14 – 7 illustrates a pushrod/bell crank system with the pushrod adjuster at the point where the pushrod affixes to the bell crank.

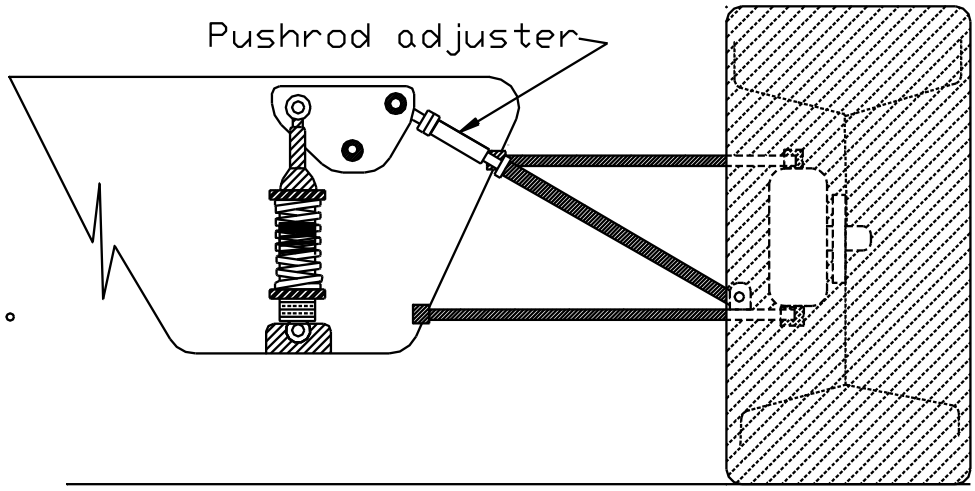



Figure 14-7

## **Basic Static Calculations** – (Take a Deep Breath)

1) **Load** the Wan31 **Symmetrical Chassis**. Check to see that there is a 1 in the **A5** Wt (g) Cell so that the **A6** Box shows corner loads. Cells (*W14/Z14*) should all show 370 pounds.

2) **A6.3 Ride**: The yellow X and Y coordinate cells are used to input the lateral and longitudinal co-ordinates from which the chassis ride height points are measured. The Initial (zo) is a factor used to index the height of the initial static ride height. The height at which the ride height is measured is often simply a reference number measured at some point on the chassis and not the actual distance the chassis or tub is from the track surface. For example, on a aero driven formula car, the ride height, for convenience reasons, is often taken from an inner suspension tab. This measurement is then entered into a spreadsheet, which, in turn, recalculates the actual ride height of the tub and aero bits in relation to their proximity to the track. This static ride height factor needs to be calculated with the chassis sitting on the set up pad. Determining what (zo) factors to use depends on what points are picked to measure the ride height, what the spring free heights are, etc. The four factors may not all have the same numbers. When validating the model with an actual chassis, take great care that the (zo) factors are correct.

The blue **A6.3** Ride cells show the calculated change in ride heights and the final ride heights. When developing the initial static set up, the final ride heights are an extremely important number to get right because the static ride height, in turn, affects many of the kinematic and aerodynamic factors.

3) **A2 Initial Conditions**: It is in this box that the user enters the initial corner loads as seen at the scale pads and the CG total height as previously calculated (see Chapter 13). If all the corner loads are entered as the same number, in this case 370 lb., the left side bias, rear bias and wedge percentages will all show 50%. This does not necessarily indicate that the chassis kinematics are all symmetrical but only that the static corner loads are symmetrical. A change in static bias can be accomplished by moving either ballast and/or chassis components.

   - Take time to experiment with both the **Bias-Load-Split** calculators and **the Pad Load** calculator (included on separate worksheets). Enter the calculator numbers into the load cells in Box **A2** and observe the various load, bias and ride height changes in Box **A6**. The race engineer **needs** to spend inordinate amounts of time looking at the myriad of interactions between static corner loads, bias, wedge and ride height. It can not be **overly** emphasized how important this is.

   - The calculators can easily be linked to the **A2** load cells by clicking on one **A2** cell at a time, enter an = sign and then going to the calculator and click on the appropriate box.

   - Using the **Bias-Load-Split Calculators** and while keeping the total load, left side bias and rear bias constant, experiment with changing the yellow corner load numbers. As discussed in Chapter13, by increasing a load at one corner, using this type of calculator will result in a similar increase at the diagonal corner and a similar decrease at the opposite diagonal corners. It is important to observe the change in static ride height in relation to a change in corner load.

**Important Note**: Once the initial loads are entered in Box **A2**, enter the sprung weight x and y numbers into the pink cells. The pink cells are found directly below the sprung weight x and y blue cells. They are outlined by a black arrow running from the blue cell to the pink cell.

- Differences between **A2** Initial loads and **A6** Calculated loads: The reader has no doubt noticed by now that even when the chassis is symmetrical in all ways, except for the initial loads, the **A2** loads and bias often end up being different than the **A6** loads and bias. In order to bring these two loads back into line, we need to adjust the spring preload. This is done in the A1.1 preload cells (*E12/H12*). This is exactly what happens on an actual chassis when we make a spring rate change and then have to change the preload at that corner in order to rebalance the chassis to its original corner loads.

    - #1. Using the first **Bias-Load-Split Calculator,** set the left and rear bias to 50% and the total load to 1480 lb. and change the LF yellow cell load to 380 lb. Now enter these values from the calculator such that the **A2** corner loads are LF = 380 lb., RF = 360 lb., LR = 360 lb. and RR = 380 lb. The left and rear biases are still at 50% but the wedge (diagonal cross weight between the RF and LR) has changed to 48.6%. Enter theses loads in A2 cells.

        - Notice that the **A6** loads are still equal (370 lb) and the left, rear and wedge are all still 50%. In order to bring the **A6** loads and wedge back into line with the **A2** loads and wedge, the LF spring preload needs to be changed. Because the load change in **A6** only shows a difference of 10 lb. we know that the needed LF preload change will be very small, which, in this case, is 0.1. Remember that the number entered in a preload cell represents a change in distance between the upper and lower spring perches.

        - All the springs showed a compression/motion of 0.625" in Box **A6** before the preload was adjusted. After the preload adjustment, they were LF = 0.550", RF = 0.600", LR = 0.600" and RR = 0.650".

        - Any time a wedge (diagonal cross weight) change is required, all other things remaining the same, a change in preload will need to be made.

            - Unless of course component weight and/or ballast is moved around within the chassis.

    - Reload Wan31A.

    - #2. A change in left side and/or rear bias will not change the cross weight (wedge) because the two left side or right side corners are being changed by the same amount. The same is true for a rear bias change.

    - Using the **Pad Load Calculator** with the total load set at 1480 lb., change the left side bias to 55% and the rear bias to 48%. We now have **A2** initial condition loads of LR = 421.8 lb., RF = 347.8 lb., LR = 392.2 lb. and RR = 318.2 lb.

        - ** **Change the pink A2 cells to the appropriate numbers found in the blue x & y A2 sprung weight cells directly above them** **.

    - In this case, the **A6** loads match the initial loads in **A2**. There was no bias change. Take note of the changes in spring motion, ride height change and

final ride heights. If the A2 and A6 loads don't match, check to see that the spring preloads are all zero.

- *Reload Wan31A*

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

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

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

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

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

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

    - Experiment with changing an individual corner spring rate and then rebalancing the static set up by changing the spring preload.

        - Change the LF spring rate from 400 to 500 lb. The wedge as shown in the **A6** Solution Box has moved from 50.0% to 48.2%.

        - Notice that the change in corner loads is 13.2 lb. rather than 19.2 lb. when the LF spring rate was increased from the base spring by 100 lb. rather than decreased by 100 lb. When the spring rate was reduced, the ride height at that corner reduced more than that same corner gained when a stiffer spring was added.

        - The ride heights are now LF = 0.959", RF = 0.920", LR = 0.896" and RR = 0.856". The LF, RF and LR corner ride heights all increased from the base setting with the LF increasing the most and the LR the least. The RR corner ride height decreased.

        - The relationships between changes in static corner loads versus changes in static ride heights are important when working out static set up. In this case the LF load increased and the ride height increased, the RF

and LR loads decreased but the ride height increased and the RR load increased while its ride height decreased.

- The **A6** Solution Loads and ride heights can be rebalanced by changing any or all of the corner preloads.

- To return to the original corner loads and ride heights, the LF preload needs to be changed. In this case, the preload will need to be decreased by –0.125". Looking at the **Thread Calculator** (separate worksheet) for a damper adjuster ring having a thread count of 32 threads per inch, it would take 4 turns out to unload the LF spring by -0.125".

- Experiment with changing the spring rate at one corner and then rebalancing the wedge by adjusting the spring preload at a different corner.

- By removing –0.125" of preload from the RR rather than the LF, all the corner loads return to 370 lb. but the ride heights are LF = 0.973", RF = 0.897", LR = 0.853" and RR = 0.777". Compared to the LF 500 lb. spring rate scenario with no preload, the LF ride height has increased while the RF, LR and RR ride heights have all decreased.

- By adding 0.125" of preload to the RF, all the corner loads return to 370 lb. but the ride heights are LF = 0.998", RF = 0.998", LR = 0.877" and RR = 0.877". Compared to the LF 500 lb. spring rate scenario with no preload, the LF and RF ride heights have increased, the LR ride height has decreased and the RR ride height has increased. Notice that the front ride heights are balanced with each other and the rear ride heights are balanced with each other.

- Though the ride height changes in the above examples are relatively small in stock car terms, it is the general trends in which we are primarily interested. When any type of asymmetries are introduced, these numbers increase significantly i.e. larger spring rates at the rear of a formula car. In formula car terms, a ride height change of 0.040" (forty thousandths of an inch) is huge.

- Changing spring motion ratios affects the static corner wheel rate in the same manner as changing a spring rate and/or spring preload. However, as we will soon discover in the dynamic sections, these three components often produce very different dynamic results.

- Changing the front and/or rear spring rates, preloads or motion ratios by the same amount does not change the static corner loads but it does affect **all** of the spring deflections and static ride heights – actually it does change the corner loads by a very, very small amount but it is not calculated in Wan31A. If the front spring rates are changed from 400 lb. to 200 lb., the corner loads remain at 370 lb. but the ride heights have changed from all being 0.875" to 0.262" front and 0.863" rear. The result is that the chassis has been lowered at both the front and rear (squat has changed from 0.625" to 0.938") and is now pitched down at the front 0.344 degrees.

- As we will see in Chapter17, virtually every spring and bar rate change will affect the aero balance.

5) **A1 Chassis - Wheel Base and Track**: The Wan31 model calculates changes in wheel base and track as dynamic changes rather than static changes i.e. the track and wheel base are already considered when the **A2** static loads are seen at the scale pads. Changing these components will result in a change in **A2** CG co-ordinates, which, in turn, affects the dynamic loads - changing a wheel base and/or track in **A1 does not** change the static loads in **A6** but **does** affect the **A6** dynamic loads. We will look at dynamic conditions shortly. If you want to see what the resultant static scale pad loads would be due to a change in track and/or wheelbase look at the **Track/Wheelbase vs Load** worksheet included in Wan31A.

**Reminder:** The Track/Wheelbase changes are included in the initial **A2** loads.

6) **A1 Chassis - Tire Radius and Radius Change**:
   - Radius - The user enters the tire radius as the chassis sits on the scale pads. The static tire radius does not change the **A6** loads and ride heights.
   - Radius Change – Changing the tire radius in this set of cells will result in a change in the static set up. A change in tire radius also changes **A6** solutions including loads and ride heights.
   - A change in a tire's radius can be the result of a change in air pressure or load seen at the tire contact patch. Tire pressure and load are the two primary factors that control changes in tire radius.
   - Using the **Tire Spring Rate Calculator** (included on a separate worksheet), we see that when a tire with a unload radius of 11.735" and a spring rate of 2000 lb. is subjected to a load of 370 lb., its loaded radius will decrease to 11.55" a radius change of –0.2186". This calculation is a static calculation, which will be slightly different than the dynamic change.
     - We can also use the radius change cells to examine **dynamic** changes in loaded radius due to **dynamic** loads. On track dynamic changes need to be determined through the use of laser ride height data.

7) **A1 Chassis – Roll Bars**: Roll bars can be added to the front and/or rear suspension. However, in order to bypass the need for the program to use iterative calculations in order to zero the initial roll bar preload, the user must **first** make sure that a zero is entered in the pink motion roll bar cell (*Z22*) located in the **A6** Solution Box. The number from the blue motion roll bar cell (*W22*) is then entered into the pink (*Z22*) cell. If the correct number was entered into the (*Z22)* cell, the blue (*W22*) cell will now read zero. Take heart, this is the **most** awkward operation in the entire Wan31 program. When working with a **completely** symmetrical chassis, both cells will already read zero.

**Important Note**: Just as when working with an actual chassis, the roll bar (rate) is the **last** item to be entered into the model before the inertial loads are applied. All A3 **Other Loads** are entered before the W22 cell is zeroed. At this point, the bar rate can be entered.

   - Motion ratio – depending on where the roll bar links are attached to the suspension, the left and right side may have a different motion ratio.
     - The motion ratio affects both the bar rate and preload rate. If one anti roll bar link has a lower motion ratio, the loads the inside and outside corners see will be the same (except the inside corner sees a decrease in

load while the outside corner sees an increase in load) but the overall roll rate will be different than if both links had the same motion ratio.

- Roll Bar Rate – This number represents the roll bar's linear rate (total linear motion of the arms at the link attachments). A roll bar calculator and a roll bar blade calculator are included on separate worksheets; see "Roll Bar Rate" & "Roll Bar Blades" calculators.

  - Entering a roll bar rate under static conditions **will not** change the **A6** Solution loads providing the Initial Loads and Solution Loads are the same (no load or wedge difference).

- Roll Bar Preload – In most cases, the anti roll bar static preload is adjusted to zero preload with the driver in the car. In this case the preload cells would be left at their zero setting.

  - A roll bar rate needs to be entered before entering roll bar preload.

- Reload Wan31 – Symmetrical Chassis

  - Bar preload can be used to change the chassis diagonal percentage (wedge) and static ride height. If the user enters a front bar rate of 200 lb. and then changes the RF preload by 0.5", (lengthening the RF link by 0.5") the RF and LR corners will gain 33.3 lb. and the LF and RR corners will lose 33.3 lb. This also changes the wedge from 50.0% to 54.5%. The ride heights moved from 0.875" at all corners to LF = 0.824", RF = 0.926", LR = 0.824" and RR = 0.926". The relationship between static corner load change and static change in ride height is **very** important.

  - With both the front and rear bar rates set at 200 lb., set both the RF and RR preload at 0.5", the corner loads will return to 370 lb. at each corner but the corner ride heights are now LF = 0.799", RF = 0.951, LR = 0.799" and RR = 0.951". All corner ride heights have increased from the zero preload setting with the right sides increasing more than the left side. Notice that both left side ride heights are equal to each other and both right side ride heights are equal to each other.

  - *Return the roll bar loads and preloads to zero before proceeding to the next step.*

8) **A1 Chassis – Shocks**: Unlike springs and anti roll bars which are force versus deflection/travel components, shocks (dampers) are force versus velocity components. Shock loads are derived from looking at on track data acquisition in order to determine shaft velocity and then comparing this velocity with shock dyno graphs. A positive load number represents the damper in bump (compression) while a negative number produces a rebound (extension) effect. Dampers are an extremely complex component and will not be studied in detail until Book Two. At this point we are only trying to look at the general effects of shock settings.

   - Shock Motion Ratios – As in the case of the springs and bars, the shock motion ratios are defined by their attachment co-ordinates.

   - Shock Preload – Gas dampers normally exhibit a gas pressure preload, which, to a point, can be increased or decreased by changing the gas pressure. Like spring preload, a shock's preload needs to be overcome before the damper shaft will

begin to move. Calculating combined damper and preload forces is far more complex than developed in Book 1. *It's just not that simple*.

- If each damper has a gas preload of 75 lb., the static ride height will increase from 0.875" to 1.063" at each corner. A force of something over 75 lb. is needed before the damper shaft will begin to move. This is often referred to as shock stiction, which, of course, is technically incorrect. Stiction is actually static friction, a very different phenomenon.

- If one damper's nose/preload is different than the other three, the chassis will have an asymmetric static set up.

    - If the RF corner has a gas preload of 25 lb. greater than the other three, the chassis will see a 6.2 lb. diagonal offset at each corner. The wedge changes from 50.0% to 50.8%

- Shocks Total – These cells combine the nose/preload and load values.

- *Return all shock loads and preloads to zero before proceeding to the next step*.

**Note**: Dampers/Shocks are covered in more detail in Chapter 16.

9) **A3 Other Loads**: The user can add or subtract any of the "**Other Loads"** at any x, y and z co-ordinate. These loads are added to the initial loads, and, as a result, will affect all **A6** Solution cells. The **initial** ballast, fuel and driver loads are calculated into the initial static set up as seen in **A2**. The **A3** loads are only used to see what the resultant charge would be if additional weight was added or subtracted.

**Note**: Remember that the A3 **Other Loads** need to entered before the W22 roll bar cell is zeroed and the bar rate is added.

- Ballast – Virtually all racecars are designed to run with some amount of ballast. If the race engineer wants to look at the results of adding or subtracting ballast, it is done in Box **A3**.

    - Add 200 lb. of ballast at x = 0, y = 0 and z = 15". Take note that the z component of all "Other Loads" only results in an **A6** solution change during **dynamic** conditions as a result of the chassis total CG height changing. Looking at the A5 Box we see that the total CG height has decreased from 18" to 17.64". Changing the Ballast, Driver and/or Fuel load will result in a total CG height change as seen in Box A5.

        - Notice that the load change is distributed evenly throughout the four corners in **A6**. The new total weight is 1680 lb. The biases and wedge have not changed.

    - Now change the location of the 200 lb. of ballast to x = 6, y = 0 and z = 15" (the weight is moved forward 6"). In this case, a higher percentage of the added load is seen at the front corners and the rear bias percentage is decreased. To restore the original ride height, the spring preloads would need to be changed at all four corners. Remember, the front to rear bias can not be changed by adjusting the spring rates, preload or motion ratios. Weight must be added, taken away or moved in order to change the left and rear bias percentages.

- Change 200 lb. of ballast location to x = 6, y = 28 and z = 15". Both the left side and rear bias has changed but the diagonal percentage (wedge) has not. The only time the wedge will not change when any type of **other load** is applied is when the chassis is completely symmetrical. If both front springs were changed to 300 lb., the resultant wedge would be 50.7%.
  - *Remove all ballast and return the springs to 400 lb. before proceeding to the next step*.

- Driver – The original driver weight is normally part of the initial static set up loads. If the engineer wants to look at the static set up without the driver's weight, it can be subtracted in the **A3** Other Loads Box.

  - Enter the driver's weight as minus 175 lb. at x = -5, y = 0 and z = 8. We can now look at the changes in **A6**. Changing the driver's weight will affect the total CG height.

  - Conversely, if the chassis was placed on the set up pad without the driver's weight, it can be added later in the **A3** Box.

    - *Remove driver's weight before proceeding to the next step*.

  - Fuel – During the initial set up, the team normally weighs the chassis with no fuel, a minimal amount of fuel, half tank and/or full tank. The **A3** Other Loads Box allows the race engineer to look at the results of different fuel loads. Changing the fuel weight will affect the total CG height.

- Aero – Though the effects of aerodynamic loads are only cursorily introduced in this first book, the **A3** aero cells allow the user to take an initial look at how aero loads affect the chassis dynamic performance and balance. The aerodynamic pressure center is entered as x and y co-ordinates. The z co-ordinate for all aero loads remains at zero. Aero loads are discussed in more detail in Chapter 17.

## Basic Dynamic Calculations

**The Four Most Important Dynamic Load Transfer Truths**:

#1. **The stiffest corner gains the highest percentage of load transfer in Compression**

#2. **The stiffest corner loses the highest percentage of load transfer in Extension**

#3. **Under dynamic load transfer conditions, if a corner gains load, its diagonal corner will also gain a proportional amount of load**

#4. **Under dynamic load transfer conditions, if a corner loses load, its diagonal corner will also lose a proportional amount of load**

1) Load the Wan31 **Symmetrical Chassis**.

2) In order to begin looking at dynamic load transfer scenarios without the influence of any anti/jacking forces, the user needs to make sure **all** of the green **A4** Anti/Jacking cells are zero.

3) **A5 Initial Forces** – Left (g): The user enters lateral acceleration forces as gravitation forces i.e. 1 = 1g.
   - Enter 1 g of left turn lateral acceleration in cell (*W6*). Notice that the left side loads are reduced by 201.8 lb. while the right side loads increased by 201.8 lb. thus reducing the left side bias to 22.7%

4) **A1 Chassis – Rebalanced Spring Changes and load transfer**: Never lose sight of the fact that the stiffer spring will receive the highest percentage of load transfer in compression. If follows that, the stiffer spring will lose the highest percentage of load transfer in extension.

   - Load the Symmetrical Chassis. Increase the RF spring to 500 lb./in and then rebalance the chassis by changing the RF preload to –0.125.

     - Apply 1g braking force. If an inertial braking force is applied to the chassis, we find that the RF will see a higher percentage of the forward load transfer than the LF, and, conversely, the LR will see a higher percentage of the remaining load (less load loss) than the RR. LF = 491.3 lb., RF = 504.8 lb., LR = 248.7 and RR = 235.2 lb.

     - *Remove the 1g of braking force*.

     - Apply 1g forward acceleration force. If an inertial forward acceleration force is applied to the chassis, we find that the RF loses a higher percentage of the load transfer than the LF. The RR will see a higher percentage of the load than the LR. LF = 157.6 lb., RF = 582.4 lb., LR = 178.8 and RR = 561.2 lb.

     - *Remove the 1g of forward acceleration force*.

     - Apply 1g of left turn acceleration. If a left turn inertial force is applied to the chassis, we find that the RF receives a higher percentage of the load transfer than the RR while the LF loses a higher percentage of load than the LR. LF = 201.6 lb., RF = 538.4 lb., LR = 218.4 and RR = 521.6 lb.

     - *Remove the 1g of left turn acceleration force.*

     - Apply 1g of right turn acceleration. If right turn inertial force is applied to the chassis we find that the RF loses a higher percentage of load than the RR while the LF gains a higher percentage of the load transfer than the LR. LF = 582.4 lb., RF = 157.6 lb., LR = 561.2 and RR = 178.8 lb.

**Note**: The following tables illustrate the basics of how changing corner spring rates affect load transfer. If the reader is not **absolutely** sure how all types of spring rate changes work in conjunction with all types of individual and combined inertial forces, he/she should take time to develop a much larger inventory of table entries.

Table 14-3 shows changes in corner loads with an applied inertial braking force of 1g. Notice the relationship between the (a), (b), (c) and (d) examples.

Table 14-3

**Corner Load Versus Spring Rate** (The chassis has been rebalanced after all spring changes)

| **Braking** | Load | Load | Load | Load |
|---|---|---|---|---|
| 1g | LF | RF | LR | RR |
| Base all 400 | 498.1 | 498.1 | 241.9 | 241.9 |
| LF 300 / RF 600 | 476.8 | 519.4 | 263.2 | 220.6 |
| LF 600 / RF 300 | 519.4 | 476.8 | 220.6 | 263.2 |
| (a) LF 500 | 504.8 | 491.3 | 235.2 | 248.7 |
| (b) LF 300 | 488.2 | 508.0 | 251.8 | 232.0 |
| (c) RF 500 | 491.3 | 504.8 | 248.7 | 235.2 |
| (d) RF 300 | 508.0 | 488.2 | 232.0 | 251.8 |
| (a) LR 500 | 504.8 | 491.3 | 235.2 | 248.7 |
| (b) LR 300 | 488.2 | 508.0 | 251.8 | 232.0 |
| (c)RR 500 | 491.3 | 504.8 | 248.7 | 235.2 |
| (d) RR 300 | 508.0 | 488.2 | 232.0 | 251.8 |
| RF 500 / LR 300 | 481.6 | 514.6 | 258.4 | 225.4 |
| RF 500 / RR 300 | 502.2 | 494 | 237.8 | 246 |
| RF 500 / LR 500 | 498.1 | 498.1 | 241.9 | 241.9 |
| RF 500 / RR 500 | 483.8 | 512.3 | 256.2 | 227.7 |
| | LF | RF | LR | RR |

| **Braking** | Load | Load | Load | Load |
|---|---|---|---|---|
| 1g | LF | RF | LR | RR |
| Base | Base | Base | Base | Base |
| LF 300 / RF 600 | Decrease | Increase | Increase | Decrease |
| LF 600 / RF 300 | Increase | Decrease | Decrease | Increase |
| LF Stiffer | Increase | Decrease | Decrease | Increase |
| LF Softer | Decrease | Increase | Increase | Decrease |
| RF Stiffer | Decrease | Increase | Increase | Decrease |
| RF Softer | Increase | Decrease | Decrease | Increase |
| LR Stiffer | Increase | Decrease | Decrease | Increase |
| LR Softer | Decrease | Increase | Increase | Decrease |
| RR Stiffer | Decrease | Increase | Increase | Decrease |
| RR Softer | Increase | Decrease | Decrease | Increase |
| RF St / LR So | Decrease | Increase | Increase | Decrease |
| RF St / RR So | Increase | Decrease | Decrease | Increase |
| RF St / LR St | Same | Same | Same | Same |
| RF St / RR St | Decrease | Increase | Increase | Decrease |
| | LF | RF | LR | RR |

Table 14-4 shows changes in corner loads with an applied left turn inertial force. Notice that when keeping the same roll rate as in the 300/600 spring split, the corner loads do not change from the base set up. Also notice the relationship between the (a), (b), (c) and (d) examples.

Table 14-4

**Corner Load Versus Spring Rate** (The chassis has been rebalanced after all spring changes)

| **Braking 0.0g** | Load | Load | Load | Load |
|---|---|---|---|---|
| **Left Turn 1.0g** | LF | RF | LR | RR |
| Base all 400 | 168.2 | 571.8 | 168.2 | 571.8 |
| LF 300 / RF 600 | 168.2 | 571.8 | 168.2 | 571.8 |
| LF 600 / RF 300 | 168.2 | 571.8 | 168.2 | 571.8 |
| (a) LF 500 | 157.6 | 582.4 | 178.8 | 561.2 |
| (b) LF 300 | 183.7 | 556.3 | 152.7 | 587.3 |
| (a) RF 500 | 157.6 | 582.4 | 178.8 | 561.2 |
| (b) RF 300 | 183.7 | 556.3 | 152.7 | 587.3 |
| (c) LR 500 | 178.8 | 561.2 | 157.6 | 582.4 |
| (d) LR 300 | 152.7 | 587.3 | 183.7 | 556.3 |
| (c) RR 500 | 178.8 | 561.2 | 157.6 | 582.4 |
| (d) RR 300 | 152.7 | 587.3 | 183.7 | 556.3 |

| **Braking 0.0g** | Load | Load | Load | Load |
|---|---|---|---|---|
| **Left Turn 1.0g** | LF | RF | LR | RR |
| Base | Base | Base | Base | Base |
| LF 300 / RF 600 | same | same | same | same |
| LF 600 / RF 300 | same | same | same | same |
| LF Stiffer | Decrease | Increase | Increase | Decrease |
| LF Softer | Increase | Decrease | Decrease | Increase |
| RF Stiffer | Decrease | Increase | Increase | Decrease |
| RF Softer | Increase | Decrease | Decrease | Increase |
| LR Stiffer | Increase | Decrease | Decrease | Increase |
| LR Softer | Decrease | Increase | Increase | Decrease |
| RR Stiffer | Increase | Decrease | Decrease | Increase |
| RR Softer | Decrease | Increase | Increase | Decrease |

Table 14-5 shows changes in corner loads with an applied 1g braking and left turn inertial force.

Table 14-5

**Corner Load Versus Spring Rate** (The chassis has been rebalanced after all spring changes)

| **Braking 1g** | Load | Load | Load | Load | **Braking 1g** | Load | Load | Load | Load |
|---|---|---|---|---|---|---|---|---|---|
| **Left Turn 1g** | LF | RF | LR | RR | **Left Turn 1g** | LF | RF | LR | RR |
| Base all 400 | 296.3 | 699.9 | 40.1 | 443.7 | Base | Base | Base | Base | Base |
| LF 500 | 292.4 | 703.8 | 44.0 | 439.9 | LF Stiffer | Decrease | Increase | Increase | Decrease |
| LF 300 | 301.9 | 694.3 | 34.5 | 449.4 | LF Softer | Increase | Decrease | Decrease | Increase |
| RF 500 | 278.9 | 717.3 | 57.5 | 426.4 | RF Stiffer | Decrease | Increase | Increase | Decrease |
| RF 300 | 321.7 | 674.5 | 14.7 | 469.1 | RF Softer | Increase | Decrease | Decrease | Increase |
| LR 500 | 313.6 | 682.5 | 22.7 | 461.1 | LR Stiffer | Increase | Decrease | Decrease | Increase |
| LR 300 | 270.9 | 725.2 | 65.5 | 418.4 | LR Softer | Decrease | Increase | Increase | Decrease |
| RR 500 | 300.1 | 696.0 | 36.2 | 447.6 | RR Stiffer | Increase | Decrease | Decrease | Increase |
| RR 300 | 290.6 | 705.6 | 45.8 | 438.0 | RR Softer | Decrease | Increase | Increase | Decrease |

When working with the Symmetrical Model, in order to rebalance the chassis after increasing a corner spring rate by 100 requires that the preload be reduced by –0.125". If the spring rate is reduced by 100 lb. the preload will need to be increased by 0.2083" and if the spring rate is increased to 600 the preload will need to be decreased by –0.2083.

**A Quick Load Transfer Review:** The following relationships hold the basis for all dynamic load transfer set ups, **irrespective** of chassis type. Though the following examples use spring rate changes **any** change or combination of changes that alters the wheel rate will give the same results (spring, bar, shock and anti/jacking forces).

LF:

- Increasing the LF spring rate under pure braking will result in a higher dynamic load at the LF and RR while decreasing the RF and LR load.
- Increasing the LF spring rate under pure left turn acceleration will result in a higher dynamic load at the RF and LR while decreasing the LF and RR load.
- Increasing the LF spring rate under pure acceleration will result in a lower dynamic load at the LF and RR while increasing the RF and LR load.

RR:

- Increasing the RR spring rate under pure braking will result in a lower dynamic load at the LF and RR while increasing the RF and LR load.
- Increasing the RR spring rate under pure left turn acceleration will result in a higher dynamic load at the LF and RR while decreasing the RF and LR load.
- Increasing the RR spring rate under pure acceleration will result in a higher dynamic load at the LF and RR while decreasing the RF and LR load.

RF:

- Increasing the RF spring rate under pure braking will result in a higher dynamic load at the RF and LR while decreasing the LF and RR load.
- Increasing the RF spring rate under pure left turn acceleration will result in a higher dynamic load at the RF and LR while decreasing the LF and RR load.
- Increasing the RF spring rate under pure acceleration will result in a lower dynamic load at the RF and LR while increasing the LF and RR load.

LR:

- Increasing the LR spring rate under pure braking will result in a lower dynamic load at the RF and LR while increasing the LF and RR load.

- Increasing the LR spring rate under pure left turn acceleration will result in a higher dynamic load at the LF and RR while decreasing the RF and LR load.

- Increasing the LR spring rate under pure acceleration will result in a higher dynamic load at the RF and LR while decreasing the LF and RR load.

**Note**: Changing a chassis track and/or wheelbase under static conditions will change the corner loads seen at the scales. Wan31A takes this change into consideration when the wheel loads are entered in the **A2** initial loads. What the Wan31A model looks at under dynamic conditions is the resultant changes in load transfer due to acceleration.

- Load the Wan31A symmetrical Chassis. Enter 1g of left turn lateral acceleration.

- The two kinetic co-ordinate cells (**Kin. x** and **Kin. y**) in the **A6** Box show the kinetic change from the initial A2 CG co-ordinates. In this case, the kinetic x co-ordinate remains at zero while the kinetic y co-ordinate moves from 0.0 to –18.00. The y co-ordinate of the sprung mass is still 0.0 while the dynamic kinetic y co-ordinate has moved from a static setting of 0.0 to an offset of 18.0" inches towards the right side of the chassis.

**Note**: Remember that the **pink** cells in A2 need to be changed in accordance with the blue cells directly above them **each** time an asymmetric track, wheelbase and/or initial load change is made.

- Change all of the tracks in Box **A1** from 33" to 40". Notice that as the track is widened, the lateral load transfer is reduced, in this case from 201.8 lb. to 166.5 lb. per corner.

- *Return the tracks to 33".*

  - Narrow the LF track from 33" to 30" and rebalance the A2 y pink cell by entering –0.750. Lateral load transfer at the front is 201.6 and 211.2 at the rear. A track change at any corner will result in a change in the overall amount of load transfer. Notice that for a **totally** symmetrical chassis, the change in load transfer is equal at each corner while any asymmetric kinematic condition will produce some form of asymmetric load transfer. The total lateral load transfer with all tracks at 33" is 403.6 (Cell X12 – Box **A6**). When the LF track is changed to 30", the total load transfer is now 412.8, an increase of 9.2 lb.

  - *Return the LF tracks to 33" and adjust the **A2** pink cell data.*

- Change all wheelbases from 52" to 40". Notice that making equal wheelbase changes at each corner does not affect the lateral load transfer. Changing the wheelbase equally only affected longitudinal load transfer.

  - *Return all wheelbases to 52*". *Return the left turn g force to zero*.

4) **A5 Inertial Forces – Longitudinal Acceleration**: Enter 1 g of inline forward acceleration force in Cell (*W9*). Notice that as before, the front loads are reduced by

128.1 lb. while the rear loads increased by 128.1 lb. The total longitudinal load transfer, as seen in the **A6** y total load transfer cell, is 256.2 lb.

- Experiment with different wheelbase lengths. Shortening the wheelbase will increase the amount of load transfer while lengthening the wheelbase will reduce the amount of load transfer. This is true whether all corners are changed or only one corner's wheelbase is changed.

  - *Return all wheelbases to 52*".

**Note**: Remember the **pink** cells in **A2** must be changed in accordance with the changes in the **blue** cell directly above them. Anytime an asymmetric track or wheelbase is created, these numbers will need to be changed.

- Experiment with the same type of iterations as previously covered but for right turn and braking scenarios.

Analysis of Banking in World and Vehicle co-ordinates by Wm. C. Mitchell:

When we measure forces we need a co-ordinate or reference system. Three values are required to measure a force. These values are usually described as vertical, lateral and fore-aft.

But what exactly does "vertical" mean? It usually refers to gravity and the forces pulling us toward the center of the earth. Lateral could be defined as east-west with fore-aft being north-south, but it is more useful to define fore-aft as the direction of travel OR the centerline of the vehicle. Lateral is perpendicular to the fore-aft or longitudinal axis.

But banked tracks confuse things. Do we define "vertical" relative to the earth or relative to the vehicle, which may be sitting on 30-degrees or more of banking?

When we define "vertical" relative to the vehicle then we usually call it a "normal" force, meaning it is perpendicular to the track surface. Then "lateral" is called "parallel" because it runs along the track surface. The "parallel" force relates to chassis roll and the values measured by an on-board data system.

For a car sitting on a banked track, we have 1g of vertical force. But the normal force is the cosine of the banking angle. For 30-degrees, the normal force is 0.866 g and the total corner loads would only be 86.6% of the total vehicle mass. To avoid the car sliding down the banking, a parallel force is required equivalent to -0.5 g or the sine of the banking angle.

Consider a track with 30-degree banking:
When the car is just sitting at rest, it is subject to 1.0 vertical G relative to the world.
In the Vehicle coordinates this is 0.866 g Normal and 0.500 g Parallel (0.886 is the cosine of 30 degrees and 0.500 is the sine).

If we take the Symmetrical chassis example (370 lbs on each corner), the static loads at 30 degrees banking are 421.3 and 219.5. With 1g of lateral acceleration, the normal load is 1281.718 lb. while the parallel load is 740.000 lb. The total load with 30 degrees of banking is 2021.718 lb. which results in an increase of 541.718 lb. compared to zero degrees of banking at 1g left turn lateral acceleration.

The corner loads at 1g left turn lateral acceleration are Inside = 168.2 lb. and Outside = 571.8 lb. compared to Inside = 431.6 lb. and Outside = 579.3 lb. with 30 degrees of banking.

**Note:** A **Banking Calculator** is included on a separate worksheet with each Wan31 model.

## Don't Forget the Pink Cells

5) **A5 Inertial Forces – Banking**: Increasing the banking angle increases the static inside loads and decreases the outside corner loads. The outside weight reduction has a higher factor than the inside weight gain factor. Placing a positive number in cell (*W8*) produces a bank where the left side of the chassis is angled down. Placing a negative number in cell (*W8*) results in the right side of the chassis angled down.

Reload Wan31 Symmetrical Chassis

- With zero banking, static corner loads are all 370 lb. With the chassis statically sitting on a 10 degree bank, the inside corner loads are increased by 29.4 lb. while the outside corner loads are decreased by 40.7 lb. Because of the difference between vertical load and normal load, the scales only see a total normal load of 1457.5 compared to a zero banking total normal load of 1480 lb. When asked how to explain why this happens, Bill Mitchell expounded as follows: "Going back to basic physics, if the chassis was sitting at a banking angle of 90 degrees, there would be zero normal load. Of course, without sufficient lateral acceleration, the chassis would also fall off the scales". In the 10 degree example, the left side bias increases to 54.8% but the rear bias and wedge remain unchanged, providing the chassis in not also yawed in relation to the angle of banking.

- Increasing the banking angle to 20 degrees results in a load increase of 46.7 lb. at the inside corners and a decrease of 91.3 lb. at the outside corners. Running on a banked track also results in considerable aerodynamic changes due to the changes in ride height. In this case the static ride heights went from 0.875" at all corners to 0.826" at the inside corners and 1.035 at the outside corners. The left side bias increased to 59.9%.

- An asymmetrical chassis sees asymmetrical changes as the result of banking.

**6) A5 Inertial Forces - Spring Pairs and Roll Rates**: As we learned in Chapter 10 various combinations of springs can produce the same roll rates. This concept is an extremely important one when the race engineer needs to keep the same mechanical balance but wants to change the dynamic ride heights for clearance and/or aerodynamic reasons. This concept is also one of the most misunderstood set up tools.

- Load Wan31A Symmetrical Chassis.

- With the Wan31A symmetric base set up, 400 lb. springs at each corner, and 1 g of left lateral acceleration, the corner loads are LF = 168.2, RF = 571.8, LR = 168.2 and RR = 571.8. The load changes are LF = -201.8, RF = 201.8, LR = -201.8 and RR = 201.8. The wedge = 50% and the amount of roll in degrees is -0.876, as seen in cell Y28.

  - Using the **Spring Pairs Rate** calculator, enter the current front spring rates of 400 lb./in into the #1 Box. The calculator indicates the roll rate is 200. In Box #2 enter a spring rate of 300 in the Left spring rate cell (Kw1) and a roll rate of 200 in the roll rate cell ($Kw_T$). The calculator indicates the right spring rate needs to be 600.

  - Returning to the Wan31A worksheet, remove the 1g of left turn acceleration, change the LF spring rate to 300 lb./in and the RF spring rate to 600 lb./in. Reset the loads, ride heights and wedge by adjusting the preload at the two front corners – LF = 0.2085 and RF = -0.2085. This brings the car back to the original setting. Notice that the left and right

preloads are the same except for the fact that the LF preload is increased while the RF preload is decreased.

- Applying 1 g of left turn lateral acceleration, we see the corner loads, load transfer, wedge and amount of chassis roll is the same as the first example when all four springs were 400 lb.

- What has changed is the dynamic ride heights which are now asymmetric - LF = 1.346, RF = 0.734, LR = 1.184 and RR = 0.572. The original ride heights (400 lb. springs) were LF = 1.181, RF = 0.569, LR = 1.181 and RR = 0.569. Notice that the rear ride heights are virtually the same but the front ride heights have changed considerably.

- Using the **Spring Pairs Rate** calculator, enter a 500 lb./in spring rate in Box #2 while keeping the 200 lb. roll rate. The calculator now shows the right front spring needs to be a 333.3 lb./in.

  - Returning to the Wan31A worksheet, change the LF spring rate to 500 lb./in and the RF spring rate to 333.3 lb./in. Rebalance the car by changing the LF preload to –0.125 and the RF preload to 0.125.

  - With 1 g of left turn lateral acceleration, the corner loads, load transfer, wedge and amount of roll remain the same as in the first two examples.

  - The dynamic ride heights are now LF = 1.081, RF = 0.470, LR = 1.179 and RR = 0.567.

  - Remove 1g of left turn acceleration.

- To take the spring pairs and roll rate example to the extreme, use the **Spring Pairs Rate** calculator to enter a spring rate of 225 in Box #2 while retaining the 200 roll rate. The calculator shows a right side spring rate of 1800. Enter the springs as follows - LF = 225 and RF = 1800, LR = 225 and RR = 1800. Adjust the preload as follows – LF = 0.486, RF = -0.486, LR = 0.486 and RR = -0.486 to rebalance the chassis.

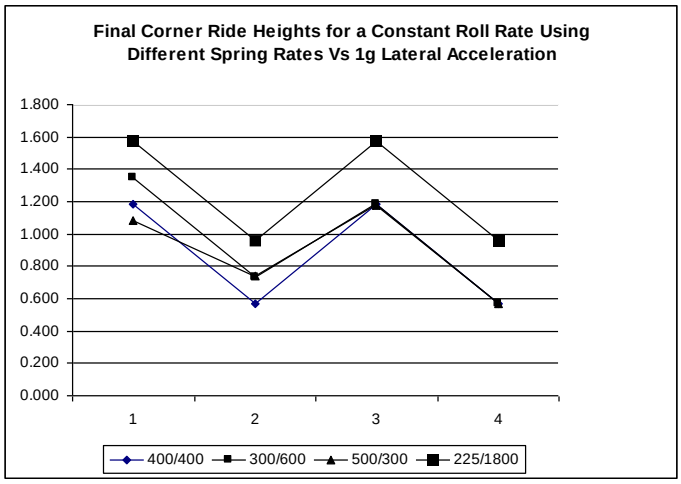
  - Enter 1 g of left turn lateral acceleration. Notice that the corner loads, load transfer, wedge and amount of roll still match the first 400 lb./in spring rate example. The ride heights are - LF = 1.573", RF = 0.962", LR = 1.573" and RR = 0.962".

- The following table and accompanying graph show the final ride heights and how they change from the previous four examples with 1g of left turn acceleration.

Table 14-1

| Springs | Ride | Ride | Ride | Ride |
|---|---|---|---|---|
| LF/RF | LF | RF | LR | RR |
| 400/400 | 1.181 | 0.569 | 1.181 | 0.569 |
| 300/600 | 1.346 | 0.734 | 1.184 | 0.572 |
| 500/333 | 1.081 | 0.47 | 1.179 | 0.567 |
| 225/1800 | 1.573 | 0.962 | 1.573 | 0.962 |

## Don’t Forget the Pink Cells




- If the front and/or rear combination of springs do not match the original roll rates, the chassis will exhibit asymmetric load transfer. For example, LF = 300, RF = 500, LR = 400 and RR = 400. The chassis is rebalanced by changing the preloads as follows – LF = 0.2083, RF = -0.125, LR = 0 and RR = 0. In this case, the corner loads, under lateral acceleration, are asymmetric because the load transfer is asymmetric. The load transfer is LF = -195.3, RF =195.3, LR = -208.3 and RR = 208.3. The wedge has changed from 50% to 49.1% and the roll has changed from 0.876 to 0.904 degrees. The new corner loads are LF = 174.7, RF =565.3, LR = 161.7 and RR = 578.3.

**7) A4 Anti/Jacking**: Up to this point, all of our inertial forces have been passing through the springy bits (springs, roll bars and shocks). Box **A4** now allows us to include the suspension kinematics in the load transfer calculations, and, as ever, the words, “*It’s just not that simple”* are rather prophetic. How action and reaction forces pass through and are affected by the suspension bits is **extremely** complex. Having said that, the Wan31A model goes a long way in allowing the user to understand the basics of anti and jacking force effects resulting from the suspension kinematics.

- One problem we faced in using Excel was that the anti and jacking forces are closed loop or iterative in nature. The amount of corner load affects the extent of the anti/jacking forces but the anti/jacking forces, in turn, affect the amount of corner load. Our original program included closed loop calculations but since we also needed to make the program quasi user crash proof, the current version of Wan31A uses only one set of built-in iterations. In actual fact, for most practical dynamic conditions, the difference between running up to a thousand iterations and only one iteration, is, at the most, 0.52 pounds. This is due primarily to the genius of the primary programmer Dr. Juan Salinas (*Thanks Juan, You had no idea what you were getting into*).

8) **A4 Anti/Jacking – Independent Suspension (A4.1)**: This set of cells allows the user to include the suspension kinematics in the **Lateral** load transfer calculations. **A4.1** is for **both** front and rear independent suspension. In order to turn on the anti/jacking component, the user needs to change the zeros in the green boxes to ones.

- The IC front view co-ordinates are entered in the yellow boxes where $\underline{e}$ = the IC height and $\underline{a_y}$ = the IC length. These co-ordinates are calculated for the user from the WinGeo3 software. Though the Wan31A model used in Book One is not set up to read real time on track data, the user can look at any dynamic condition using WanGeo3 and then enter the appropriate IC co-ordinates in Wan31A. As we will see, in a subsequent chapter, track data from virtually any data acquisition system can be played through WinGeo3. WinGeo3, in turn, allows the user to look at the suspension motion and kinematics at any moment on the track (depending on the rate the data was collected).

    - Load the Wan31A Symmetric Chassis. Check to see that all the green cells in **A4** are **zeros**.

    - Enter 1 g of left turn lateral acceleration in Box **A5**. The corner loads are LF = 168.2 lb., RF = 571.8 lb., LR = 168.2 lb. and RR = 571.8 lb. The load transfer in LF = -201.8 lb., RF = 201.8 lb., LR = -201.8 lb. and RR = 201.8 lb. Looking at the **Splits & Changes worksheet** we see that the front side to side split is –403.6 lb. and the rear side to side split is –403.6 lb.

    - Place a 1 in the two front green cells in **A4.1**. The front kinematic forces are now included in the inertial forces calculations. The $\underline{e/a}$ cells calculate the slope of the IC or height divided by length. The resultant kinematic inertial forces are seen in the blue Force cells. As expected, the inside corner sees a negative kinematic force while the outside corner sees a positive kinematic force. These forces are combined with the spring, bar and shock forces and are displayed in Box **A6**. The wheel loads are now LF = 157.8 lb., RF = 582.2 lb., LR = 178.6 lb. and RR = 561.4 lb. The load transfer is LF = -212.2 lb., RF = 212.2 lb., LR = -191.4 lb. and RR = 191.4 lb. Looking at the **Splits and Changes** worksheet, we see that the front side to side split is – 424.5 lb. and the rear side to side split is –382.8 lb.

    - Place a 1 in all four of the green A4.1 cells. Both the front and rear suspension kinematic inertial forces are now included in the left turn lateral acceleration forces. The corner loads are back to LF = 168.2 lb., RF = 571.8 lb., LR = 168.2 lb. and RR = 571.8 lb. Because all the corners in this example have the same IC co-ordinates, the resultant inertial corner loads are the same as if the suspension kinematics were not included but the **amount** of inertial forces passing through the **springs** has changed. The A4 lateral forces are now LF = -9.4616 lb., RF = 32.1700 lb., LR = -9.4616 lb. and = 32.1700 lb. As a result, the new spring forces are LF = 57.6 lb., RF = 419.6 lb., LR = 57.6 lb. and RR = 419.6 lb. as opposed to LF = 48.2 lb., RF = 451.8 lb., LR = 48.2 lb. and RR = 451.8 lb. before the jacking forces were included in the calculations. The ride heights have also changed.

    - The above example presented the kinematics as if the chassis had zero roll angle and zero squat, when, in fact, the chassis was shown to have rolled neg. 0.876 degrees. In order to find the IC co-ordinates with the new ride heights, we need to go to WinGeo3. After loading the Symmetrical Chassis, go to compute, solve for clearance and enter the new Wan31A ride heights. We need to enter ride heights rather than roll angle in WinGeo3 because WinGeo3 looks at **changes** in ride, roll and squat while the Wan31A model moves from what points the rides, roll angle, pitch and squat were at the static setting.

- When we enter the new Wan31A ride/clearance heights into WinGeo3 we find the IC heights are LF = 7.998, RF = 5.945, LR = 7.998 and RR = 5.945. The IC lengths are LF = 129.380, RF = 112.668, LR = 129.380 and RR = 112.668. Enter these numbers into the appropriate **A4.1** $\underline{e}$ and $\underline{a_y}$ cells.

    - The A4 forces are now LF = -10.397 lb., RF = 30.172 lb., LR = -10.397 lb. and = 30.172 lb. As a result, the new spring forces in **A6** are LF = 58.6 lb., RF = 421.6 lb., LR = 58.6 lb. and RR = 421.6 lb.. The ride heights have also changed.

    - Compared to the spring load calculations without the suspension kinematic forces, the left side springs are each seeing a **larger** load of 10.4 lb. while the right side springs are seeing a **smaller** load of -30.2 lb.

**Note**: Most simulation programs determine the IC co-ordinates by running the track data corner motions through software such as WinGeo3. Of course, even running on track data through WinGeo3 and into a simulation model such as Wan31A requires a series of closed loop iterations to more closely determine what the loads, ride heights, etc. would be after Wan31A changes. *It's just not that simple*. Wm. C. Mitchell's new WinGeo3 Vehicle Dynamics Version software automatically changes the IC co-ordinates within the dynamic's section of the program.

    - *Return all cell numbers to their base settings*. The best method is to close Wan31A without saving and then reopen the model for the next series of operations.

- Load Wan31A Symmetrical Chassis. Change the rear spring rates from 400 lb./in to 600 lb./in. Rebalance the ride heights by deloading the rear springs by –0.2083 each. Using the **Spring Pairs Rate** calculator, we see that the front has a roll rate of 200 while the rear roll rate is 300.

    - Enter 1 g of left turn lateral acceleration. The loads are LF = 208.5 lb., RF = 531.5 lb., LR = 127.8 lb., and RR = 612.2 lb. As expected with a higher rear roll rate the rear tires are less balanced side to side than the front tires. The **Splits** worksheet shows the front split at –322.9 lb. and the rear split at –484.4 lb.

    - With the green cells in **A4** still set at zero, take note of the final ride heights in **A6** – LF = 1.120", RF = 0.630", LR = 1.120" and RR = 0.630". Using WinGeo3, enter the left and right side ride/clearance heights.

    - Enter the new IC co-ordinates from WinGeo3 into the appropriate Wan31A **A4.1** cells – left side = 7.998/129.380 and right side = 5.945/112.668. Replace the zeros in the **A4** green cells with ones.

    - Loads are LF = 204.3, RF = 535.7, LR = 132.0 and RR = 608.0. It is **important** to note that when the suspension kinematics are included in this left turn example, the left side loads are decreased and the right side loads are increased. The chassis kinematics can be designed to **increase** or **decrease** corner dynamic loads. More on this will follow in subsequent chapters.

    - Spring Loads are LF = 97.0 lb., RF = 387.4 lb., LR = 20.2 lb. and RR = 455.9 lb.

- Ride heights are LF = 1.115", RF = 0.675", LR 1.115" and RR = 0.675". Notice that the left side ride heights are equal and the right side ride heights are equal.

9) **A4.2 Anti/Jacking – Track Bar**: The live axle and track bar rear suspension are discussed in Chapter 16.

10) **A4.3 Anti/Jacking – Inline Acceleration**: Just as in the case of the front view suspension kinematics, the positioning of the side view IC can not only increase or decrease the amount of load the springs see but can also add or subtract the percentage of load transfer each rear wheel see.

    - Load the Wan31A Symmetric Chassis. Place 1g of inline acceleration in Box **A5**. Place a 1 in both **A4.3** green rearward acceleration cells.

        - The front corner loads are reduced to 241.9 lb. while the rear corner loads increase to 498.1 lb. The rear to front load splits are 256.2 lb. as seen on the **Splits** worksheet. The side to side splits are equal.

            - The **A4.3** left and right rear anti forces are 99.0775 lb. each.

            - The loads on the springs are 121.9 lb. front and 279.0 lb. rear.

            - The ride heights are LF = 1.188", RF = 1.188", LR = 0.810" and RR = 0.810".

        - Arbitrarily change the LR IC co-ordinates in A4.3 to 19.876/123.514. Notice that the **A4.3** anti forces are now asymmetrical at LR = 119.082 lb. and RR = 99.078lb. As a result, everything from corner loads to ride heights are now asymmetrical. The total rearward load transfer is still the same amount but the LR and RF corners are now seeing ten pounds more than the RR and LF corners. This type of change is very important for **all** types of oval track racing. Asymmetric kinematic changes are also used when running on road course tracks which have a preponderance of left or right turns.

            - The corner loads are LF = 236.9 lb., RF = 246.9 lb., LR = 503.1 lb. and RR = 493.1 lb. The wedge has changed from 50% to 50.7%.

            - The ride heights are now LF = 1.196", RF = 1.181", LR = 0.842" and RR = 0.827". Even though the LR corner sees a larger load than the RR, its ride height is higher than at the RR. In fact, both the left side ride heights are higher than the corresponding right side ride heights.

            - It is also interesting to look at the amount of spring deflection/motion. In this case, the left side spring deflection is less than the corresponding right sides.

- The following table shows the various relationships between Corner Load, Spring Load, Spring Deflection and Ride Height when looking at the previous side view IC kinematic examples.

**Left to Right Comparisons** 19.876/123.514 17.876/133.514

| Forward Acceleration | LF | RF | | LR | RF |
|---|---|---|---|---|---|
| Corner Load | Less | Greater | | Greater | Less |
| Spring Load | Less | Greater | | Less | Greater |
| Spring Deflection | Less | Greater | | Less | Greater |
| Ride Height | Greater | Less | | Greater | Less |

11) **A4 Anti/Jacking – Brake**: Just as in the inline acceleration case, positioning of the side view IC can not only increase or decrease the amount of load the springs see but can also add or subtract the percentage of load transfer seen at all four corners:

- Load the Wan31A Symmetric Chassis.

- Enter 1 g of braking acceleration in the appropriate A5 Box. The pF cell allows the user to enter the percentage of front to rear brake force. Start with pF = 50% and all green cells in A4.4 set to zero. The percentage of front to rear brake force does not change the amount of load transfer, but, as we will soon discover, it does affect the kinematic forces, which, in turn, can affect the amount of asymmetric load seen at each corner.

  - With the suspension kinematics not included in the calculations, the corner loads are LF = 489.1 lb., RF = 498.1 lb., LR = 241.9 lb. and RR = 241.9 lb. Each front corner gains 128.1 lb. while each rear corner loses 128.1 lb.

  - The spring loads are 378.1 lb. at the front corners and 121.9 lb. at the rear corners. Spring deflection/motion is 0.945” at the front corners and 0.305” at the rear corners.

  - The ride heights are LF = 0.567”, RF = 0.567”, LR = 1.183” and RR = 1.183”.

- Change all four **A4.4** braking related green cells from zeros to ones.
  - The corner loads and amount of load transfer remains the same and are still symmetrical but the front spring loads change from 378.1 lb. to 328.5 lb. and the rear spring loads change from 121.9 lb. to 171.5 lb. Front spring deflection changes from 0.945” to 0.821” at the front and from 0.305” to 0.429” at the rear.
  - Ride height changes from 0.567” to 0.686” at the front and from 1.183” to 1.064” at the rear.

  - The side to side front and rear splits are both equal at –256.2 lb.

  - The total anti forces as seen in **A4.4** are 49.5388 at the front corners and –49.5388 at the rear corners.

- Change the front brake bias from 50% to 70%. The corner loads and amount of load transfer still remains the same but the spring loads, spring deflection and ride heights do change. The front spring loads and spring deflection decrease, while the front ride heights are raised. Just the opposite takes place at the rear.

- Keep the front brake bias at 70% while increasing the **LF** IC height from 17.876" to 19.876" and lowering the **RF** IC height from 17.876" to 15.876".

    - Notice that the total amount of frontward load transfer is still the same but it is now asymmetric, and, as a result, the corner loads are also asymmetrical with the LF = 502 lb., RF = 494.2 lb., LR = 238.0 lb. and RR = 245.8 lb. This is an interesting study in how diagonal corner loads affect each other when attached to an infinitely rigid body. Take time to compare the resultant corner loads with the anti forces seen in the **A4.4** total anti cells. The current anti forces are LF = 77.1138, LR = 61.5948, LR and RR = -29.723.

    - The greater the front brake bias is, the larger the various asymmetries will be (providing the chassis has front anti dive geometry).

- The race engineer needs to run **literally** hundreds of different iterations of this type in order to begin understanding the role anti and jacking forces play in a chassis dynamic balance.

**Combined Inertial Forces**: Race cars, whether they race on road courses or oval tracks, spend much of their time in a state of combined acceleration i.e. some combination of lateral and longitudinal acceleration. Therefore it is very important for the race engineer to know how these combinations affect corner load distribution and overall chassis balance. Though this first symmetric chassis is intended only as an introduction to load transfer and to introduce the basics of Wan31A, it is still highly recommended that the reader thoroughly understand these basics before proceeding to the next chapters. During this section, constantly refer to the **Splits and Changes** worksheet.

**Note:** When using the Wan31A Models, we are primarily concerned with manipulating corner loads, balancing combined front loads with combined rear loads and balancing the side to side and rear to front loads to as high a degree as possible – the smaller the split, the better the balance. For pure lateral acceleration, we want to have the front combined loads and rear combined loads as balanced as possible. For pure inline longitudinal acceleration with a rear drive car, we want as much load on the rear tires as possible. For ultimate pure braking acceleration, we want to keep the front to rear loads in relation to the brake bias.

When we begin combining the Wan31A models with the tire maps (Wan31B), we will soon realize that simply balancing the splits is far from the complete answer in regards to ultimate performance levels. Performance also depends upon load level ranges. It's easy to understand that if both the front and rear side to side splits are the same and the combined front and combined rear loads are the same, the chassis will be lateral acceleration neutral. It is not so easy, without the tire maps, to determine if a less balanced front split with a higher combined front load will produce a higher lateral force than a rear with a closer split with a lower combined rear load. That will depend on the tire map and every type of tire will have a different map – Chapter 19, 20 & 21.

12) **A5 Combined Inertial Forces – Anti Roll Bars**:

- Load the Wan31A Symmetric Chassis. Add 1 g of left turn acceleration. The corner load percentages as seen on the **Splits and Changes** worksheet are LF = 11.4%, RF = 38.6%, LR = 11.4% and RR = 38.6%.

- Add 0.7 g of forward longitudinal acceleration. The corner load percentages are now LF = 5.3%, RF = 32.6%, LR = 17.4% and RR = 44.7%.

    - The ride heights are LF = 1.396", RF = 0.785", LR = 0.965" and RR = 0.354".

- Add a 200 lb. front anti roll bar. The corner load percentages are now LF = 0.8% RF = 37.1%, LR = 22.0% and RR = 40.1%. Adding a front bar increased the load on the RF and LR while decreasing the load on the LF and RR.

    - The ride heights are LF = 1.294", RF = 0.887", LR = 0.863" and RR = 0.456". The ride height changes will become much more important when we begin to look at aerodynamics in Chapter 17 and shock velocity in Chapter 16.

**Important Note**: As in all cases where anti roll bars are added, make sure you follow the W22 and Z22 cell protocol as outlined on page 14-28.

    - Adding a front bar not only reduces total chassis roll but also degrades the front balance and helps the rear balance. How much the front and rear balance is changed can be controlled by the bar rate. The roll angle changes from 0.876 deg. to 0.584 deg.

- Remove the front roll bar and add a 200 lb. rear anti roll bar. The corner load percentages are now LF = 9.9% RF = 28.0%, LR = 12.9% and RR = 49.2%. Notice that when using a rear anti roll bar, the RR and LF corners gain load while the LR and RF corners lose load.

    - The ride heights are LF = 1.294", RF = 0.887", LR = 0.863" and RR = 0.456". Notice that the ride heights are the same whether the bar is mounted at the front or the rear (provided the wheel rates remains unchanged).

    - Adding a rear bar not only reduces total chassis roll but also degrades the rear balance and aids the front balance. Again how much the front and rear balance is changed can be controlled by the bar rate.

- Add a 200 lb. anti roll bar at the front and rear of the chassis. Notice that the load percentages are the same as when the chassis ran with no roll bar but the ride heights are different at LF = 1.243", RF = 0.938", LR = 0.812" and RR = 0.507". The LF and LR rides are lower while RF and RR rides are higher. Roll angle has changed to 0.438 deg.

    - Adding front and rear roll bars of equal rates and preloads **doesn't** change the amount and type of load transfer but it **does** reduce the amount of roll, providing everything else is symmetrical.

    - *Reload the Wan31 Symmetrical Chassis*.

- Mount a 200 lb. bar at the front with no bar at the rear. Preload the LF roll bar by turning the LF link/adjuster (Preload cell) 1" (Using the **Left/Right Link/Pushrod Thread Calculator** for ½ NF rod ends, we find that the link/adjuster would need to be turned in 10 turns). By preloading the bar on the left side we add static load to the LF and RR and subtract static load from the RF and LR. The LF and RR static corner loads are increased by 66.7 lb. while the RF and LR static corner loads are decreased by 66.7 lb.

    - When 1 g of left turn lateral acceleration is added, we see that the front loads are more evenly balanced than without the preloads but the rear loads are less evenly balanced. However, even with the addition of 1" of LF bar preload, the front is still less balanced than the rear. Adjusting only one anti roll bar link changes the diagonal cross weight (wedge). Adjusting both the left and right side roll bar link/adjusters the same amount does not affect the

static corner loads and ride height settings, providing they all have the same motion ratios.

- *Reload the Wan31 Symmetrical Chassis*.

13) **A5 Combined Inertial Forces – Spring Pairs and Preload:** Changing springs in pairs and/or spring preload in pairs does not **measurably** change the left side bias, rear bias or wedge (diagonal cross weight) but it can create dynamic asymmetries.

- Reload the Wan31A Symmetric Chassis. Add 1 g of left turn lateral acceleration and 0.7 g of forward longitudinal acceleration. The corner load percentages are LF = 5.3%, RF =32.6%, LR = 17.4% and RR = 44.7%.
  - The dynamic biases are Left =22.7%, Rear = 62.1% and Wedge = **50.0%**
  - Splits are LF-RF = -403.6, LR –RR = -403.6, LR-LF = 179.3 and RR –RF = 179.3. Notice even though the corner loads are asymmetric, the front and rear side to side splits are equal. The left and right side rear to front splits are also equal.
  - Change the longitudinal acceleration from 0.7 inline to 0.7 braking. The splits are the same as in the inline acceleration example except that the rears are now minus 179.3 lb.
- Return to 1 g left turn and 0.7 g inline acceleration. Change both rear springs from 400 lb./in to 600 lb./in – **do not** adjust the preload. Notice that the left side and rear bias remain the same at left = 22.7% and rear = 62.1% but the wedge is now asymmetric at 44.5%.
  - The corner load percentages have changed to LF = 8.0%, RF = 29.9%, LR = 14.7% and RR = 47.4%. The stiffer rear springs, as expected, have helped the front balance and further degraded the rear balance. This would be true for both left and right turns. For the left turn the RF/LR diagonal percentage has decreased while the LF/RR diagonal percentage has increased. Oval track racers refer to this as the chassis dewedging.
    - Splits are LF-RF = -322.9, LR –RR = -484.4, LR-LF = 98.6 and RR –RF = 260.0.
  - Change the longitudinal acceleration from 0.7 inline to 0.7 braking. The front and rear side to side splits remain the same as the previous example but the left and right side rear to front splits are now reversed at left –260.0 lb. and right –98.6 lb.
    - Corner load percentages are LF = 20.1%, RF = 42.0%, LR = 2.6% and RR = 35.3%.
- Maintain the current acceleration forces but replace the rear springs with 400 lb./in ones. Add 1" of preload to both rear springs. Notice that the ride heights, pitch and squat changed but the corner loads and wedge remained the same.
  - Change the rear springs back to 600 lb./in. Take a look at the current loads and then add 1" of preload to the rear springs. Even though changing the rear springs to 600 lb./in resulted in asymmetric dynamic load transfer, changing the rear preloads by the same amount still had no further effect on the wedge.

- Changing the front and/or rear spring preload by the same amount allows the race engineer to alter the static and dynamic ride heights without affecting load transfer.

14) **A5 Combined Inertial Forces – Dynamic Tire Radius Changes:** Changes in loaded tire radius **can** affect a chassis diagonal percentage (wedge).

- Load Wan31A Symmetrical Chassis. Enter 1 g lateral and 0.7 g forward (inline) acceleration. Corner loads are LF = 78.5 lb., RF = 482.2 lb., LR = 257.8 lb. and RR = 661.5 lb.

  - Load change from static set up LF = -291.5 lb., RF = 112.2 lb., LR = -112.2 lb. and RR = 291.5 lb.

  - Using the **Tire Spring Rate** worksheet, we can calculate the radius changes due to dynamic load **changes –** new loaded radius = 11.50. LF = 0.146, RF = -0.056, LR = 0.056 and RR = -0.146.

  - When the tire radius changes are entered in the A1 "Radius Change" cells, we see that there is no change in wedge or corner loads, but the ride heights change.

  - *Reload the Wan31 Symmetrical Chassis*.

- Open Wan31A Symmetrical Chassis. Enter 1 g lateral and 0.7 g forward longitudinal acceleration and change the rear springs from 400 lb./in to 600 lb./in. **Don't** rebalance the chassis by changing the rear preload. Corner loads are LF = 118.9 lb., RF = 441.8 lb., LR = 217.5 lb. and RR = 701.8 lb. The wedge is at 44.5%

  - Load change from static set up is LF = -251.1 lb., RF = 71.8 lb., LR = -152.5 lb. and RR = 331.8 lb.

  - Using the **Tire Spring Rate** worksheet, we can calculate the radius changes due to dynamic load changes. LF = 0.126", RF = -0.036", LR = 0.076" and RR = -0.166"

  - When the tire radius changes are entered in the A1 radius change cells, we see that the wedge has changed from 44.5% to 45.8%, a change of 1.3%. The new corner loads are LF = 109.3, RF = 451.4, LR = 227.1 and RR = 692.2.

  - Comparing these new loads to the corner loads before we recalculated the loaded tire radius, we find the differences are LF = -9.6, RF = 9.6, LR = 9.6 and RR = -9.6

  - Of course, as in so many cases within a load transfer model, the actual change in tire loaded radius is an iterative process. A change in load produces a change in tire radius but a change in tire radius, in turn, produces a change in corner load. If the user is familiar with Excel, he/she should feel free to build in their own circular calculations.

  - As we will see, when working with aero loads in Chapter 18, asymmetric aero loads can affect the loaded tire radius. On a stiffly sprung chassis these

changes can affect wedge and corner loads quite significantly **if** the chassis is running different wheel rates at the front than at the rear.

15) **A5 Combined Inertial Forces – Spring Splits With and Without Rebalancing the Preload:** This section is **not** just for the oval track racers since, although to a much smaller extent, road racers are also **constantly** dealing with asymmetries. The difference is that oval racers are always looking for new asymmetric combinations while the road racers, for the most part, are trying to prevent unwanted asymmetries.

- Load Wan31A Symmetrical Chassis. Make sure all the inertial loads are zero.
    - Enter 1 g of left turn lateral acceleration and 0.7 of inline forward acceleration.
    - Looking at the **Splits and Changes** worksheet, we see that the front side to side split is –403.6 and the rear side to side split is also –403.6. The combined front load is at 37.9% while the rear load is at 62.1%.
    - Corner load percentages are LF = 5.3%, RF = 32.6%, LR = 17.4% and RR = 44.7%. The wedge percentage is 50.0%.
    - Return all inertial acceleration forces to zero. Using the **Spring Pairs Rate** calculator, we find that if we want to run a 300 lb./in spring in the RF while keeping the roll rate factor at 200, we need to replace the LF spring with a 600 lb./in spring.
    - Change the front spring split to 600/300 and rebalance the chassis by removing –0.2083" of preload at the LF and adding 0.2083" of preload at the RF, confirming that all A6 wheel loads are 370 lbs.
    - Enter 1 g of left turn lateral acceleration and 0.7 of forward longitudinal acceleration.
    - Looking at the **Splits and Changes** worksheet we see that the front side to side split is now –433.6, the rear side to side to side split is –373.7. The combined front load is still at 37.9% and the rear load is still at 62.1%.
    - Corner load percentages are LF = 4.3%, RF = 33.6%, LR = 18.4% and RR = 43.7%. The wedge percentage is now 52.0%.
    - This spring change, for a left turn, further degraded the front cornering balance and improved the rear cornering balance.
    - Because the rear split has decreased, inline acceleration should improve.
    - With a stiffer LF spring, a higher percentage of braking load transfer will go to the LF.
- Reverse the front springs and preload – (LF = 300/0.2083 and RF = 600/-0.2083).
    - Looking at the **Splits and Changes** worksheet, we see that the front and rear split is now reversed with the front at –373.8 and the rear at –433.5. The combined front load is still at 37.9% and the rear load is still at 62.1%.

- Corner load percentages are LF = 6.3%, RF = 31.6%, LR = 16.4% and RR = 45.7%. The wedge percentage has now dropped to 48.0%.

- This spring change, for a left turn, helped the front corner balance and degraded the rear cornering balance.

- Because the rear split has increased, inline acceleration would most likely be degraded.

**Note**: Previously we had discovered that during pure lateral acceleration, changing the spring rates (splits), providing we kept the same roll factor, did not affect the corner loads. However, we now see that if lateral acceleration is combined with longitudinal acceleration, changing the spring splits does affect corner loads and load asymmetries. How these last two spring changes affect a chassis balance under combined left turn and inline acceleration is opposite to what **many** crew chiefs and race engineers think it is.

- Go back to the LF 600 and RF 300 spring split but change from 0.7 g forward acceleration to 0. 7 g of braking in combination with 1 g of left turn acceleration.

  - Looking at the **Splits and Changes** worksheet, we see that the front side to side split is now –373.7 and the rear side to side to side split is –433.7. The combined front load is 62.1% and the rear load is at 37.9%.

  - Corner load percentages are LF = 18.4%, RF = 43.7%, LR = 4.3% and RR = 33.6%. The wedge percentage is now 48.0%

  - The spring change, for left turn/braking, improved the front cornering balance and further degraded the rear cornering balance, just the opposite of left turn/Acceleration. Now doesn't that just complicate things! *This is a **key** tuning tool.*

- Reverse the front spring split and preloads. As in the previous example under left turn/braking the chassis balance is reversed from left turn/acc. Under left turn/braking while running a LF = 300 and RF 600 spring split, the front performance is degraded while the rear performance is increased.

- Running the spring splits in the rear for the 300/600 and 600/300 examples yields the same results – 300/600 under left turn/acceleration further balances the front and unbalances the rear. This same combination under left turn/braking further unbalances the front while helping the rear balance. The 600/300 split is just the opposite.

- Just changing the springs without rebalancing the static loads yields quite a different result.

  - A 300/600 front split without a preload change results in a static split of front = -83.3 and rear = +83.3. The static wedge is 55.6%. With 1 g of left turn and 0.7 forward acceleration the splits are front = -457.1 and rear = -350.2. The dynamic wedge is 53.6%. Under these conditions, the front balance is drastically reduced while the rear balance is considerably improved. Few racers would be dull enough not to at least try and reset the balance but it is pretty clear that even a small preload imbalance can change the chassis balance quite considerably. On a stiffly sprung formula chassis, missing the preload rebalance by 0.020" can be catastrophic.

Notice that in Tables 14-3 and 14-4 the total front and total rear loads do not change. What changes is the percentage of load seen by the LF versus RF and LR vs RR. Table 14.3 shows the 300/600 spring split has the best front balance while the 600/300 split has the best rear balance. Table 14-4 shows the 600/300 spring split has the best front balance while the 300/600 split has the best rear balance.

**% of Corner Loads**

| Springs | % Corner Loads @ 1g left & 0.7g Acc. | | | | |
|---|---|---|---|---|---|
| LF/RF | LF | RF | LR | RR | Wedge |
| 400/400 | 5.3 | 32.6 | 17.4 | 44.7 | 50% |
| 600/300 | 4.3 | 33.6 | 18.4 | 43.7 | 52% |
| 300/600 | 6.3 | 31.6 | 16.4 | 45.7 | 48% |

Table 14-3

**% of Corner Loads**

| Springs | % Corner Loads @ 1g left & 0.7g Braking | | | | |
|---|---|---|---|---|---|
| LF/RF | LF | RF | LR | RR | Wedge |
| 400/400 | 17.4 | 44.7 | 5.3 | 32.6 | 50% |
| 600/300 | 18.4 | 43.7 | 4.3 | 33.6 | 48% |
| 300/600 | 16.4 | 45.7 | 6.3 | 31.6 | 52% |

Table 14-4

16) **A5 Combined Inertial Forces - Spring changes that also change the roll rate factor**: Any spring change combinations that also change the roll rate factor will automatically introduce a new level of asymmetry.

- Load the Wan31A Symmetrical Chassis. Check to see that all the inertial loads are set to zero. Replace the front springs with LF = 300 and RF = 500. Rebalance the static chassis by increasing the LF preload by 0.2085 and decreasing RF = -0.125. As seen in the **Springs Pairs Calculator,** the front roll factor is now 188.

- Enter 1g of left turn and 0.7g of forward acceleration. As a result of the lower front spring roll rate factor, the front left turn balance has improved while the rear left turn balance has further degraded.

17) **A5 Combined Inertial Forces – Single Spring Changes:** Once again this is **not** entirely the domain of the oval racer. As previously discussed in the spring chapter, a small change in spring free height, a small indiscretion with preload, using a spring with an incorrect rating and/or using a non linear spring can lead to some rather nasty asymmetries.

**Note**: Changing a spring and then resetting the static balance does **not** affect static loads but it **does** affect dynamic loads.

- Load the Wan31A Symmetrical Chassis. Check to see that all the inertial loads are set to zero. Change the RF spring to a 600 lb./in spring. Rebalance the static loads and ride heights by decreasing the RF preload by –0.2083".

- Enter 1g of left turn and 0.7g of forward acceleration. The wheel load percentages are LF = 4.6%, RF = 33.3%, LR = 18.1% and RR = 44.0%. The front split is –424.0, the rear split is –383.2 and the wedge is 51.4%. Increasing the RF spring rate helps the rear balance and degrades the front balance as ΔR% is 25.9% and ΔF% is 28.8%.

- Load the Wan31A Symmetrical Chassis. Check to see that all the inertial loads are set to zero. Change the LF spring to a 600 lb./in spring. Rebalance the static loads and ride heights by decreasing the LF preload by –0.2083.

    - Enter 1 g of left turn and 0.7 g of inline acceleration. The wheel load percentages are LF = 3.5%, RF = 34.4%, LR = 19.2% and RR = 42.9%. The front split is –456.7 while the rear split is –350.6. The wedge is 53.6%. Increasing the LF spring rate helps the rear balance and degrades the front balance but at a different rate than the RF change - ΔR% is 23.7% and ΔF% is 30.9%.

- Load the Wan31A Symmetrical Chassis. Check to see that all the inertial loads are set to zero. Change the RR spring to a 600 lb./in spring. Rebalance the static loads and ride heights by decreasing the RR preload by –0.2083".

    - Enter 1 g of left turn and 0.7 g of inline acceleration. The wheel load percentages are LF = 7.1%, RF = 30.8%, LR = 15.6% and RR = 46.5%. The front split is –350.6, the rear split is –456.6 and the wedge is 46.4%. Increasing the RR spring rate helps the front balance and degrades the rear balance - ΔF% is 23.7% and ΔR% is 30.9%.

- Load the Wan31A Symmetrical Chassis. Check to see that all the inertial loads are set to zero. Change the LR spring to a 600 lb./in spring. Rebalance the static loads and ride heights by decreasing the LR preload by –0.2083".

    - Enter 1 g of left turn and 0.7 g of inline acceleration. The wheel load percentages are LF = 6.0%, RF = 31.9%, LR = 16.7% and RR = 45.4%. The front split is –383.3 the rear split is –424.0 and the wedge is 48.6%. Increasing the LR spring rate helps the front balance and degrades the rear balance but at a different rate than the RR change - ΔF% is 25.9% and ΔR% is 28.7%

- Notice that **RF** = 600 or **LR** = 600 combinations have the opposite front and rear side to side load splits.

**Note**: We obviously need to understand what effect each set up change has on chassis balance for all acceleration phases from braking, turn in, apex and full acceleration, be it intentional or accidental.

18) **A5 Combined Inertial Forces – Single Spring Preload Changes**:

**Note**: Changing spring preload **does** affect the static loads and ride heights but it does **not** affect how the springs react to inertial loads. However, changing the static rides by adjusting the springs preload does change the front and side view IC co-ordinates, which, in turn, can change the types and amounts of load transfer.

**Note**: Changing preloads **will** change the static wedge percentage but it will **not** change either the side to side weight bias or the rear to front weight bias. The static corner load adjustments, due to a static wedge change, will be retained during inertial acceleration.

- Load the Wan31A Symmetrical Chassis. Check to see that the four **A4.1** green cells are switched off and that no inertial loads are present. Enter 1 g left turn and 0.7 g forward acceleration.

    - Increasing the LF spring preload by 1" will change the wedge from 50% to 36.5%. Dewedging the RF/LR by putting in 1" of preload in the LF adds 100 lb. **static** load to the LF and RR while decreasing the RF and LR by 100

lb. The **dynamic** ride heights change from LF = 1.396", RF = 0.785", LR = 0.965" and RR = 0.354" to LF = 2.038", RF = 1.124", LR = 1.126" and RR = 0.212". Now the Δ in F% is 13.8% while the Δ in R% is 40.8%. This results in further degradation of the chassis balance.

- *Reset all preloads to zero.*

- Increasing the RR preload by 1" will change the wedge from 50% to 36.5%. The resultant corner loads are the same as in the LF example but the ride heights are now LF = 1.254", RF = 0.946", LR = 1.304" and RR = 0.996". Notice the diagonal ride height relationships. See box #4 in the "Splits & Changes" worksheet.

  - *Reset all preloads to zero*.

- Increasing both the LF and RR preload by 0.5" will change the wedge from 50% to 36.5% as before. The resultant corner loads are the same as in the two previous examples but the ride heights are now LF = 1.646", RF = 1.035", LR = 1.215" and RR = 0.604", and the diagonal ride height differences are the same as without any preload.

  - *Reset all preloads to zero*.

- Changing the LF preload by 0.5" and the RF by –0.5" changes the wedge from 50% to 36.5%. As before, the LF and RR each see a **static** 100 lb. increase while the RF and LR each see a decrease of 100 lb.

  - The resultant corner loads are the same as in the three previous examples but the ride heights are now LF = 1.548", RF = 0.633", LR = 1.117" and RR = 0.202". The diagonal differences are changed substantially.
  - *Reset all preloads to zero*.

- Changing the LF and RF preload by 0.5" does not change the wedge or corner loads

  - The ride heights have changed to LF = 1.887", RF = 1.275", LR = 0.975" and RR = 0.363".

  - *Reset all preloads and accelerations to zero*.

- Changing the LF by 0.5" and the LR by 0.5" does not change the wedge from 50% and the corner loads are the same as if no preload was added.

  - Add 1g left & 0.7g forward acceleration.

  - The ride heights have changed to LF = 1.798", RF = 0.883", LR = 1.367" and RR = 0.452".

  - *Reset all preloads to zero*

- Changing the LF by 0.5" and the LR by -0.5" changes the wedge from 50% to 36.5%, the LF and RR each see a **static** 100 lb. increase while the RF and LR each see a decrease of 100 lb.

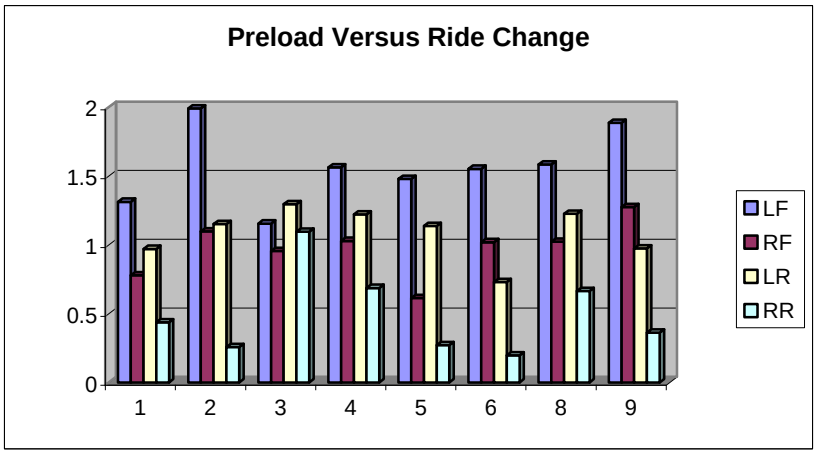
- The ride heights have changed to LF = 1.637”, RF = 1.025”, LR = 0.725” and RR = 0.113”. Notice the front and rear ride height relationships.

- *Reset all preloads to zero*

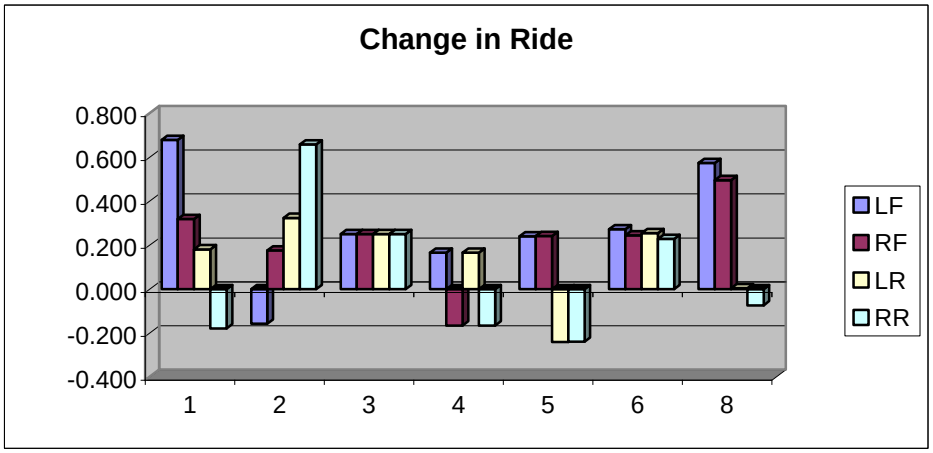
The previous preload versus ride height examples, as seen in Table 14-5 and its accompanying graphs, is simply a small sample of the possible preload iterations.

Table & Graph 14-5

| Base @ 0.7 acc & 1g lateral | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Preload Vs Ride | # | Wedge | LF | LF | RF | RF | LR | LR | RR | RR |
| Base | 1 | 50% | 1.313 | Change | 0.779 | Change | 0.971 | Change | 0.437 | Change |
| LF = 1" | 2 | 36.5% | 1.992 | 0.679 | 1.098 | 0.319 | 1.152 | 0.181 | 0.258 | -0.179 |
| RR = 1" | 3 | 36.5% | 1.155 | -0.158 | 0.955 | 0.176 | 1.295 | 0.324 | 1.095 | 0.658 |
| LF & RR = 0.5" | 4 | 36.5% | 1.563 | 0.250 | 1.029 | 0.250 | 1.221 | 0.250 | 0.687 | 0.250 |
| LF = 0.5" & RF = -0.5" | 5 | 36.5% | 1.479 | 0.166 | 0.613 | -0.166 | 1.137 | 0.166 | 0.271 | -0.166 |
| LF = =0.5" LR = -0.5" | 6 | 36.5% | 1.553 | 0.240 | 1.020 | 0.241 | 0.730 | -0.241 | 0.197 | -0.240 |
| LF & RR 0.5" | 8 | 50.0% | 1.585 | 0.272 | 1.024 | 0.245 | 1.226 | 0.255 | 0.665 | 0.228 |
| LF & RF 0.5" | 9 | 50.0% | 1.887 | 0.574 | 1.275 | 0.496 | 0.975 | 0.004 | 0.363 | -0.074 |




Graph 14-5 shows the **change** in ride height from the previous examples.




**Don’t Forget the Pink Cells**

# Additional General Truths

**Static Basic Truths**

1. **Static (Preload) -**Increasing the preload at one corner increases the static load at that corner and its diagonal corner by the same amount while decreasing the static load at the opposite diagonal corners by the same amount. This takes place whether the chassis is symmetrical or asymmetrical.

    - If the RF preload is increased, the LF, RF and RR static ride heights will increase with the RF increasing the most. The LR ride height will decrease.

2. **Static (Preload) -**Increasing the preload at one corner **will** result in static diagonal load transfer and change the amount of static diagonal percentage (wedge) but will **not** change the static side to side or front to rear bias.
3. **Static (Bias) -**Increasing the static left side bias while keeping the same total chassis weight equally increases the left side static corner loads while equally decreasing the right side static corner loads. Changing the left side static bias will not change the static chassis diagonal percentage (wedge) or the static front to rear bias.

    - If preload is not used to readjust the ride height, the left side ride heights will decrease while the right side ride heights will increase. The ride height changes will only be symmetrical if the chassis is completely symmetrical. If one end of the chassis has stiffer springs and/or higher motion ratios, that end will see proportionally larger ride increases.

        - **Static -**Increasing the static rear bias equally increases both static rear corner loads while equally decreases both static front corners. Changing the static rear bias will not change the static side bias or the static diagonal percentage (wedge).

        - If preload is not used to readjust the ride height the rear ride heights will decrease while the front ride heights will increase. The ride height changes will only be symmetrical if the chassis is completely symmetrical.

5. **Static (Bias) -**Changing both the static left side bias and static rear bias will not change the static diagonal percentage (wedge). When both the left side and rear bias are at a percentage other than 50%, all of the corner loads will be dissimilar i.e. the corner loads will be completely asymmetric.

6. **Static (Spring Rate)** – Changing a single spring rate without resetting the static chassis balance will result in static load transfer and a change in static diagonal percentage (wedge). This change will not change the static left side or static rear bias.

    - If the RF spring rate is increased, the LF, RF and RR static ride heights will increase with the RF increasing the most. The LR ride height will decrease.

7. **Static (Spring Rate)** – Decreasing a single spring rate without resetting the static chassis balance will result in a lower static ride height at that corner while seeing an increased ride height at its diagonal corner. The two opposite diagonal corners will see a decrease in ride height.

8. **Static (Spring Rate)** – Increasing a single spring rate without resetting the static chassis balance will result in a higher static ride height at that corner while seeing a decreased ride height at its diagonal corner. The two opposite diagonal corners will see an increase in ride height.

9. **Static (Spring Rate)** – Decreasing a single spring rate without resetting the static chassis balance will result in a larger static load transfer change at each corner than if the single static spring rate was increased.

10. **Static (Motion Ratio)** – Changing a single motion ratio without resetting the static chassis balance will result in static load transfer and a change in static diagonal percentage (wedge). This change will not change the static left side or static rear bias.

    - If the RF motion ratio is increased, the LF, RF and RR static ride heights will increase with the RF increasing the most. The LR ride height will decrease

11. **Static (Spring Rate)** – Changing each of the front and/or rear spring rates on a left to right **symmetrical** chassis, by the same amount without resetting the static chassis will result in a ride height change but will not change the static corner loads, bias or diagonal percentage (wedge).

    - If the stiffness of the rear springs are increased by an equal amount both the front and rear ride heights will increase with the rears increasing proportionally more than the fronts.

12. **Static (Spring Rate)** – Changing the front and/or rear spring rates, on a **asymmetrical** chassis by the same amount without resetting the static chassis balance will not change the static left side and rear bias but will result in a asymmetric change in ride height, corner loads, and diagonal percentage (wedge).

    - If the stiffness of the rear springs is increased by an equal amount on an asymmetric chassis, the ride heights will increase and/or decrease in proportion to the chassis asymmetries.

13. **Static (Motion Ratios)** – Changing the front and/or rear motion ratios by the same amount without resetting the static chassis balance and adjusting the spring preload will result in a ride height change but will not change the static corner loads, bias or diagonal percentage (wedge).

    - If the rear spring motion ratios are each increased by an equal amount both the front and rear ride heights will increase with the rears increasing proportionally more than the fronts.

14. **Static (Preload)** – Changing the front and/or rear preloads by the same amount will result in a ride height change but will not change the static corner loads, bias or diagonal percentage (wedge).

    - If the rear spring preload is increased by an equal amount, both the front and rear ride heights will increase with the rears increasing proportionally more than the fronts.

15. **Static (Tire Radius)** – Changing all four tire radii by the same amount on a **symmetrical** chassis does not change the static corner loads but results in an equal change in ride height.

16. **Static (Tire Radius)** – Changing all four tire radii by the same amount on an **asymmetrical** chassis will result in a change in the static corner loads.

17. **Static (Tire Radius)** – Increasing a single static tire radius will result in an equal increase in load at that corner and its diagonal corner and an equal decrease in static corner load at the opposite diagonal corners.

    - If the RF tire radius is increased the LF, RF and RR static ride heights will increase with the RF increasing the most. The LR ride height will decrease

18. **Static (Anti Roll Bar)** – Adding a front and/or rear anti roll bar, if adjusted to natural preload, will not change the static corner loads, biases or ride heights.

19. **Static (Anti Roll Bar)** – Adding preload to a roll bar adjuster link will equally increase the static corner loads at that corner and its diagonal corner while equally decreasing loads at the opposite diagonals.

    - If the RF roll bar static preload is increased, the RF and LR loads will increase, the RF and RR ride heights will increase and the LF and LR ride heights will decrease.

20. **Static (Damper)** – If the **gas preload** is increased on all **dampers** by the same amount, the corner ride heights will increase by a proportional amount. *Only in the virtual world*.

    - A symmetrical chassis will see symmetrical ride height changes while asymmetrical chassis will see asymmetrical ride height changes.

21. **Static (Damper)** – If one **damper** has a gas preload different than the other three dampers, and, if the chassis has not been rebalanced by readjusting the spring or roll bar preload, it will result in static load transfer and a change in diagonal percentage (wedge).

    - If the RF damper nose/preload is increased the LF, RF and RR static ride heights will increase with the RF increasing the most. The LR ride height will decrease.

22. **Static (Fuel)** – With the **fuel cell** laterally centered and rearward of the center of the chassis, added fuel will add weight to both the front and rear corners in proportion to the rearward offset (fuel rearward bias).

23. **Static (Banking)** – Increasing the banking angle increases the static inside corner loads and decreases the outside corner loads. The outside weight reduction has a higher factor than the inside weight gain factor. Running at some banking angle reduces the chassis total normal load.

**Dynamic Basic Truths (Assuming Left Turn)**

**Don't Forget the Pink Cells** – When changing the Track, Wheelbase, Unsprung Weight etc. always remember to match the pink F35 and G 25 cells to match the F34 and G 34 cells?

24. **Dynamic (Inertial Load Transfer) –** The amount of lateral load transfer is dependent on the (chassis mass * g force * CG height) divided by the track width. The amount of longitudinal load transfer is dependent on the (chassis mass * g force * CG height) divided by the wheelbase.

25. **Dynamic (Track) –** Changing the width of any track will change the amount of lateral load transfer.

    - Narrowing the track will increase the amount of load transfer for any given amount of lateral acceleration (inertial force).
    - Widening the track will decrease the amount of load transfer for any given amount of lateral acceleration (inertial force).
    - Narrowing the LF track by 1" does **not** result in **exactly** the same change in load transfer than if the LF and RF were both narrowed by 0.5" but it is very close. The ride heights are changed.

**Note**: A change is ride height will also result in a change in IC co-ordinates, which, in turn, alter the proportions of force passing though the suspension bits as opposed to the springy bits.

26. **Dynamic (Track) –** Changing the width of a left side track by a prescribed amount results in virtually the same amount of lateral load transfer than if a right side track was changed by that same amount; however, the ride heights are changed.

- Narrowing the left front will see higher left side ride heights and lower right side ride heights than if the right front was narrowed by the same amount.

27. **Dynamic (Track)** – A change in a **single** track width will result in a change in how the longitudinal acceleration and braking load transfer is distributed. The amount of longitudinal load transfer or diagonal percentage (wedge) is unchanged.

    - A narrower LF track during rearward or forward acceleration will see a higher percentage of the load transfer change at the LF/RR diagonal. If the chassis sees rearward acceleration, the LF will see a proportional greater load loss than the RF while the RR will see a proportionally greater increase in load than the LR i.e. the LF will see less corner load than the RF and the LR will see less corner load than the RR.

28. **Dynamic (Wheelbase)** – Changing any or all of the four wheelbases will result in a change in the amount of longitudinal load transfer.

    - Shortening the LF wheelbase will result in more longitudinal load transfer.

29. **Dynamic (Wheelbase)** – A change in a **single** wheelbase length will result in a change in how lateral load transfer is transferred. The amount of lateral load transfer and diagonal percentage (wedge) is unchanged.
    - A shorter LF wheelbase during left turn lateral acceleration will see a higher percentage of the load transfer at the RF/LR. The LF corner load will be higher than the LR and the RF corner load will be higher than the RR.
        - Shortening the LF wheel base will proportionally increase the front loads to the rear loads, shortening the RF wheelbase will increase the rear corner loads proportionally to the front corner loads, shortening the LR wheelbase will increase the rear corner loads proportionally to the front corner loads and shortening the RR wheelbase will increase the front corner loads proportionally to the rear corner loads.

30. **Dynamic (Wheelbase)** – Changing the front and/or rear wheelbase by equal amounts will not affect lateral load distribution.

31. **Dynamic (Spring Pairs)** – Different combinations of spring rates can produce the same roll rates while changing the dynamic ride heights. After the spring change the chassis needs to be rebalanced by adjusting the spring preload.

    - Using the spring rate formula, the mechanical balance can be kept the same while changing the dynamic ride heights in order to change chassis clearance and/or aerodynamic loads.

32. **Dynamic (Spring Pairs)** – If a front and/or rear spring change combination doesn't match the original roll rate(s), the chassis will exhibit asymmetric load transfer and ride heights.

33. **Dynamic (Single Spring Change)** – It is an **important** General Truth that the stiffer spring will receive the highest percentage of load transfer in bump. In contrast, the stiffer spring will also lose a higher percentage of the load transfer in rebound.

34. **Dynamic (Anti/Jacking)** – The amount of inertial forces that pass through the suspension bits as opposed to the springy bits is a factor of the IC slope i.e. IC height divided by IC length.

    - The front view ICs control the amount of lateral jacking forces while the side view ICs control the amount of longitudinal anti dive, anti lift and anti squat forces seen at the front and rear suspension.

35. **Dynamic (Anti/Jacking)** – The positioning of the suspension ICs co-ordinates does not control the amount of lateral and longitudinal load transfer but can control the proportioning of the load transfer.

    - Running a higher percentage of anti squat at the left rear as opposed to the right rear will result in a higher percentage of the longitudinal inertial load transfer moving to the left rear contact patch. The corner with the highest anti squat factor will squat less.

    - Running a higher percentage of anti dive at the right front as opposed to the left front will result in a higher percentage of the longitudinal inertial load transfer moving to the right front contact patch. The corner with the highest anti dive factor will dive less.

36. The greater the front brake percentage, the greater the front anti dive reaction. Increasing the percentage of front brake bias will not change the total percentage of load transfer, but, all other things being equal, it will decrease the total front dive. If the RF has a higher anti dive factor, increasing the front brake bias will increase the RF to LF load split.

37. **Dynamic (Anti Roll Bars)** – Adding a front roll bar will decrease the overall chassis roll, change the ride heights, and, will add load to the front outside corner and its diagonal while removing load from the front inside corner and its diagonal.

    - A front roll bar during lateral acceleration will degrade the front balance while helping the rear balance.

38. **Dynamic (Anti Roll Bars)** – Adding a rear anti roll bar will decrease the overall chassis roll, change the ride heights and add load to the rear outside corner and its diagonal while removing load from the rear inside corner and its diagonal.

    - A rear roll bar during lateral acceleration will degrade the rear balance while helping the front balance.

    - A roll bar changes the chassis diagonal percentage during roll.

39. **Dynamic (Anti Roll Bars)** – During longitudinal acceleration the anti roll bar will have no effect on load transfer or the dynamic ride heights providing the chassis is **completely** symmetrical. A roll bar may well twist during longitudinal acceleration if the chassis has an asymmetric set up.

40. **Dynamic (Anti Roll Bars)** – While running a higher spring roll rate at the **rear,** the chassis can be rebalanced by running a front anti roll bar.

41. **Dynamic (Aero)** – Changes to Aerodynamic load is proportioned to the four corners in relation to the aero pressure center co-ordinates and the chassis mechanical asymmetries.

42. **Dynamic (Aero)** – Changes in ride heights affect the aerodynamic loads and the aero pressure center co-ordinates.



Michael Rowley – My right and left hand man in all things digital.
(Congratulations on that artificial intelligence project)

## Additional Pink Cell Calculations

**Dynamic Squat** – In order for the user to view the **dynamic** changes in squat (cell W28), he/she needs to copy the **static** value of cell W27 into cell V27.

**Change in Ride** – In order for the user to view the **dynamic** changes in ride high (cell W39 through Z39), he/she needs to copy the **static** values of cells W35 through Z35 into cells W38 through Z38.

**Cell H37** (Total $CG_Z$) is not used in Book One.

**Copying Cell Information (Values)** – Highlight the cell to be copied, click on **copy**, highlight the cell you want to copy the values into, go to **Edit** – **Paste Special** and click on **Value**.