

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.

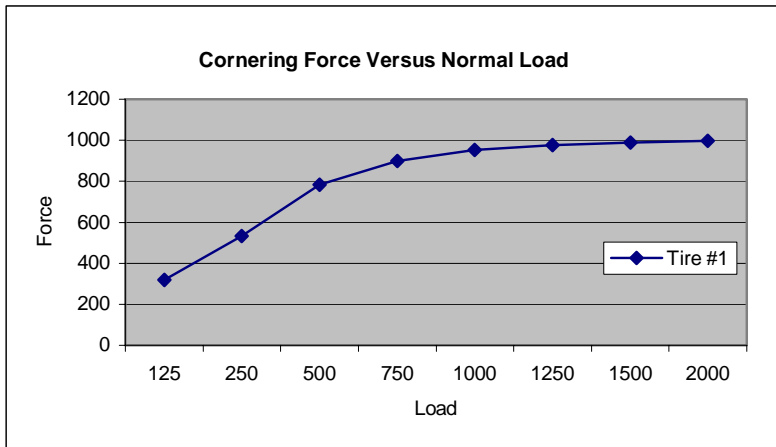
Kinetic Center Co-ordinates: The kinetic center is the **theoretical** mass center when dynamic acceleration forces are applied to the chassis. The center of mass co-ordinates of an object do not move when affected by inertial acceleration forces but the **kinetic center** co-ordinates do change as indicated 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)

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:

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

Where:

L_T = load transfer

W = total chassis weight

g = lateral acceleration force

CG_Z = center of gravity height of the total chassis

t = track

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.

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.

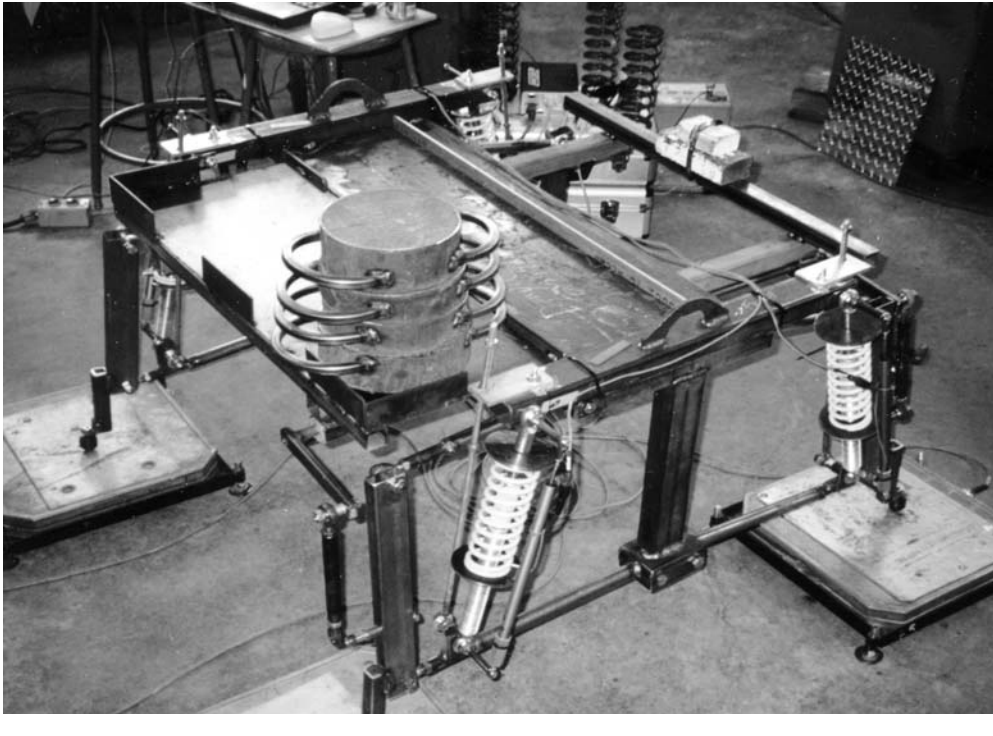


Figure 14-1

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.

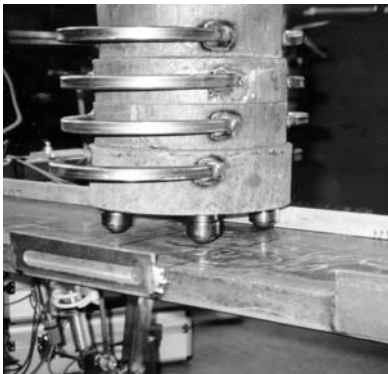


Figure 14-2

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
 - 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 (W_u) – The model shows the total unsprung weight of the car plus the total unsprung weight x, y & z co-ordinates.
- Sprung (W_s) – 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 (F_s) – 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 (z₀) – 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	2.5	16	1		deg	
A4.3	Bar Geom	h3	10.58	11.72	53.503	53.75		
		h4						
		AA						
		BB						
		IC	10.58	11.72	53.503	53.75		
		rt	0.501	Fce =	0	0		
		0/1	0	0	1	1		
		e	11.05	11.9	9.25	9.25		
A4.4	Accel	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		
		0/1	1	1	1	1		
A4.4	Brake	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		
A4.5	Total Antis		0	0	0	0	Total	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%	

A6 Solution		(1) LF	(2) RF	(3) LR	(4) RR	Total	
A6.1	Loads						
	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	FR	0.0		0.0		
	Damper	Fs	0.0	0.0	0.0	0.0	0.0
A6.2	Motion						
	Wheel	dP	3.232	3.327	3.265	2.412	
	Spring	d	1.596	1.531	3.265	2.412	
	RollBar	dR	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	
			<i>NoseDn</i>	<i>Left</i>			
A6.3	Ride		(1) LF	(2) RF	(3) LR	(4) RR	
	Initial	zo	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.