The Kinematics Chapters

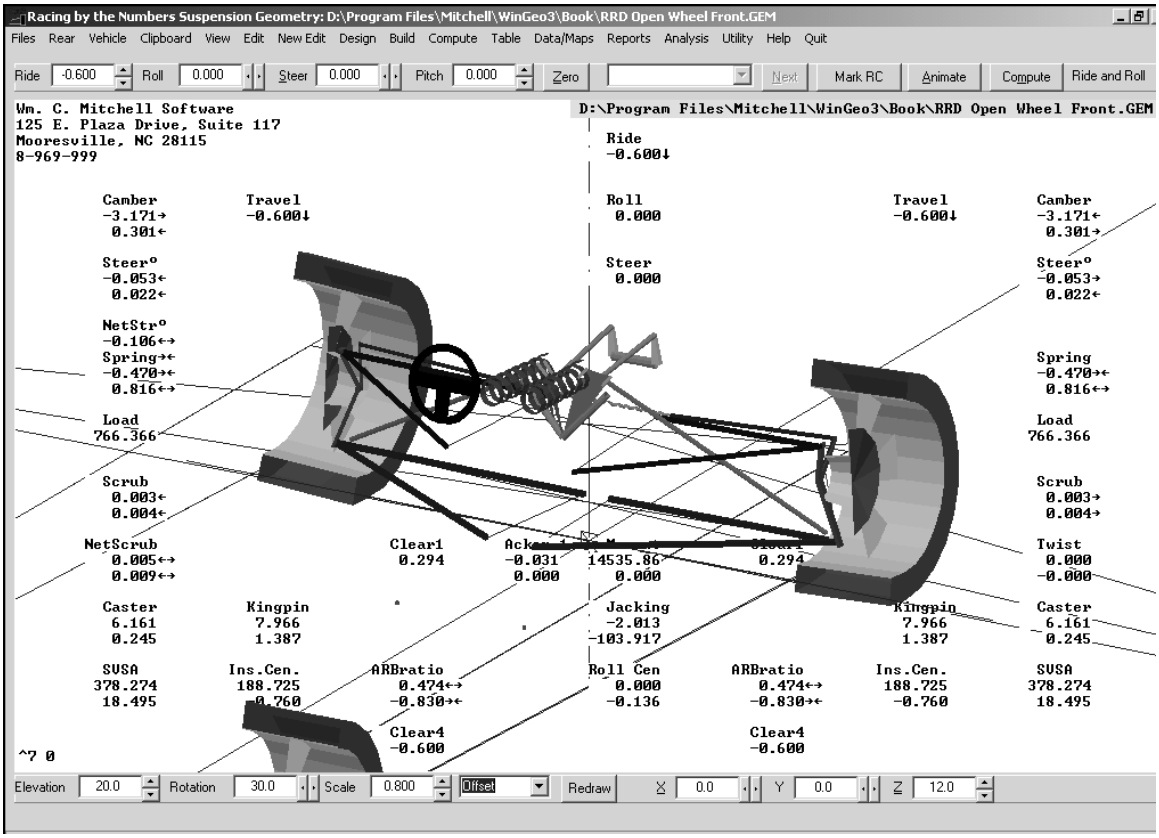
Understanding Kinematics

This portion of the book is concerned with the understanding of the hows and whys of kinematic motion (motion without the effect of forces and loads).

The WinGeo3 Software

The various **WinGeo3 Kinematic Models** which have been incorporated into the kinematic chapters can be found on the accompanying CD ROM. The WinGeo3 software is developed by **William (Bill) C. Mitchell.** The second addition of "An Introduction To Race Car Engineering" includes a later version of WinGeo3 (3.05). This later WinGeo3 version contains a number of additions not included in Book One. For information on further WinGeo3 upgrades, please contact Wm. C. Mitchell at Bill@Mitchellsoftware.com .

Author's Personal Note: If you are a user of WinGeo3 and have not recently updated your WinGeo3 software, I would strongly urge you do so. Throughout 2003/2004, the WinGeo3 software has seen many substantive changes, often, on a monthly basis.



5

WinGeo3 – Wm. C. Mitchell Software

A Basic Introduction

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

The **RACING BY THE NUMBERS™** programs are intended for engineers, experienced crew members, and newcomers to the sport. Over approximately the last twenty years, the programs have been successfully used by Formula One, Indy Car, Formula Atlantic, Winston Cup, SCCA club racers, short track oval, autocross and Formula SAE teams. Users have included professional engineers and design teams as well as racers new to computers. Major auto manufacturers in the United States, Europe, Asia and Africa also use the programs.

About the Programmer - Wm. C. Mitchell is a brilliant mathematician and software engineer. He has an undergraduate degree from CalTech, where he majored in mathematics and specialized in numerical analysis, or how to perform difficult calculations on a computer, followed by a Masters from Stanford University.

Some of his best known software programs are:

- WinGeo3
- Debrief 3
- Race Car Simulator
- Brake Calculator
- Gears and Acceleration
- Driving Simulator
- WinGeo3 Vehicle Dynamics Model – Currently in development

There are a number of different WinGeo3 versions the race engineer can use. The three primary programs are the **Regular** version, **Advanced** version and the **Premier** version. The Advanced version is the one used in this first book. The cost of the *Advanced* version is $495.00 and the cost of the Premier version is $1,895.00.

One of many enhancements found in the Premier version of WinGeo3 is that it allows the race engineer to download data from virtually any data system directly into WinGeo3. The race engineer can then watch the on track chassis kinematics in real, slowed or stepped time. The premier version can also be used to drive dynamic simulation programs.

WinGeo3 is, first and foremost, a **fully** three dimensional kinematics program which allows the user to study the motion of each suspension and chassis component in the minutest of details. The WinGeo3 program includes virtually all currently used racecar suspension systems. It begins with the geometry of the upright, wheel and tire and includes camber, toe steer, caster, etc. Then the calculations extend to the instant center, kinematic roll center, Ackerman and anti squat/anti dive. The final calculations involve the spring and shock mechanisms and describe the displacement as well as the motion ratios. If the user enters the spring and anti roll bar rates, the program will then calculate the load **change** at the contact patch as a result of the various kinematic changes seen by the springs and bars. The Premier version also

calculates changes in the suspension kinematics and loading due to tire deflection. The tire spring rate is entered by the user.

The suspension calculations are very accurate. The program uses 14 digit numbers in all calculations and seeks 0.00000005 inch accuracy. This is necessary to provide three-digit accuracy for motion ratios, which are derivatives of displacements.

Having access to an **accurate** and fully three dimensional kinematics program is **absolutely** essential for the design and set up of a winning racecar. There are quite a number of software packages (ranging from junk to ultra expensive) aimed at this market. I have used or at least played with most of these kinematics programs, and, in the end, always come back to WinGeo3. WinGeo3 has the depth of accuracy and available software components that the professional race engineer needs. Comparing what WinGeo3 can provide for the race engineer with many of the ultra expensive software packages, I believe WinGeo3 should sell in the $5000.00 to $10000.00 range but Bill, for his own personal reasons, wants his software available to every level of racer. The breadth and complexity of the mathematics used in WinGeo3 is really quite extraordinary. One other reason I use it is that you can phone up the software developer and bug him about something you want added to the program. If what you want is **reasonable**, timely and, you bug him enough, he will add it to the program. Try that with your $30,000.00 program.

WinGeo3 is not intended to be a substitute for modeling programs such as AutoCAD™, SolidWorks®, Pro/Engineer™, etc. which the race engineer will also need when designing a race car and/or race car components but when it comes to looking at kinematic motion of the race car, I have not found anything better than WinGeo3. Even when using the ADAMS™ software packages, a **great** but expensive software package, I still use WinGeo3 to look at possible on track kinematic changes because it is so fast and user friendly, it's accurate and is designed around what we need to know.

The WinGeo3 Demo – The WinGeo3 Advanced demo version works exactly the same as the non demo version except the user can only load the demo files and any changes the user makes cannot be saved. If you have purchased this book "**An Introduction to Race Car Engineering"** you will be able to contact Wm. C. Mitchell personally (not the author) to update the WinGeo3 demo to a fully functional program at a 10% discount.

Important Note
Before beginning the Kinematic chapters, the user needs to carefully read through all the WinGeo3 help files while thoroughly acquainting him/her self with the WinGeo3 program.

WinGeo3 is an extremely in depth and multifaceted software package, and, as a result, the help files make up a good sized book in themselves. Plan on spending many hours to acquire the basic operations of this software package. Like all major software packages, the ins and outs of WinGeo3 cannot be learned in an afternoon. The Windows version of WinGeo3 is as intuitive as any major software package but that doesn't make it simple.

The Kinematic chapters are many times less useful without the user being able to easily navigate through the WinGeo3 software.

I have worked with WinGeo3 between 150 and 200 days a year for the past eight or nine years and I am still learning new ways of using it. This is one major piece of software.

WinGeo3 Examples used in Book One – Because WinGeo3 is such an in depth program we will only be able to look at approximately 10% of the program's potential throughout the kinematic chapters.

To cover each aspect of every kinematic example would require looking at literally tens of thousands of WinGeo3 examples. Obviously, that many examples cannot be included in this book but the reader is strongly encouraged to spend considerable time going beyond the base kinematic examples.

Simply working through the base kinematic examples are not enough to develop a complete background in suspension and chassis kinematics.

Loading WinGeo3 – To load WinGeo3:

- Place the CD in the CD drive
- Open *My Computer*
- Click on the CD drive
- Click on the Geo-Demo
- Click on the Set Up
  - Set Up Launcher (Setup EXE)

or

- Place the CD in the CD drive
- Click on *Start*
  - Click on *Control Panel*
  - Click on *Add/Remove Programs*
  - Follow the computer prompts

Working with the Advanced Demo – The demo files are **not** loaded by going to (*Files* – *Open*) but rather by clicking on the demo files found at the bottom of the page.

- Open the program
- The *Initial Options* box will appear
  - Click on *Done*
  - If you don't want to see the *Initial Options* box each time the program is opened, click on *Don't show this message again*
- Click **ONCE** on the *Load Intro to Race Car Engineering* box
  - If you accidentally click twice, the computer operating system will think you have given it a second command. You will need to close the program and begin again. Unlike the regular version of WinGeo3, you cannot simply go to the *File/Open* menu.
  - Click on one of the IRCE files
- The user can also click on the *Load Demo Files* box to look at some of the Mitchell Demos

Left Mouse Click – Right Mouse Click

- A **right** mouse click on the main graphics screen will open the *Geometry Control Dialog* box as described shortly.
- A **Left** mouse click on the main graphics' screen will open the 3-*D rendering* screen. This option allows the user to quickly measure any point on the chassis and/or the co-ordinates between points.

Single Point Co-ordinate

- Load the *IRCE Open Wheel front* file

- Using the left mouse button, click on the bottom left side pushrod mounting point
- Releasing the left mouse button will take the user to the 3-D rendering screen as shown in Figure 5-1

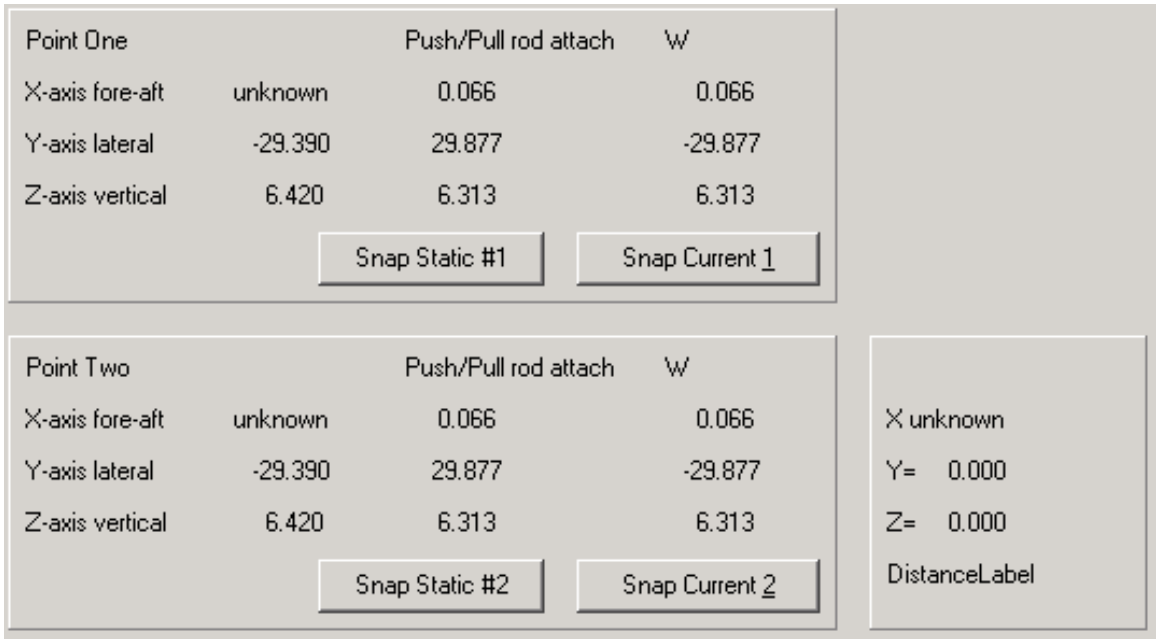


Figure 5-1

- Looking at the upper left hand box (Point One), there are various x, y, and z co-ordinates shown. The first column shows x = unknown, y = -29.390 and z = 6.420. The x is shown as unknown because the screen was set at standard (**rear view**) which only shows the y and z components of the three dimensional image. The y component shows a negative number indicating it is on the left side of the chassis i.e. all standard views in WinGeo3 are seen from the rear of the chassis.

- The second column first indicates that the user has clicked on the push rod. It then shows the three static co-ordinates of the lower push rod mount. Notice the numbers in the first column are not quite the same as the numbers in the second column. The reason for this is because the left mouse cursor was not directly over the lower push rod co-ordinates when it was clicked. Clicking on the *Snap Static #1* box automatically snaps the cursor directly over the lower pushrod co-ordinates resulting in the first and second columns matching as shown in Figure 5-2.

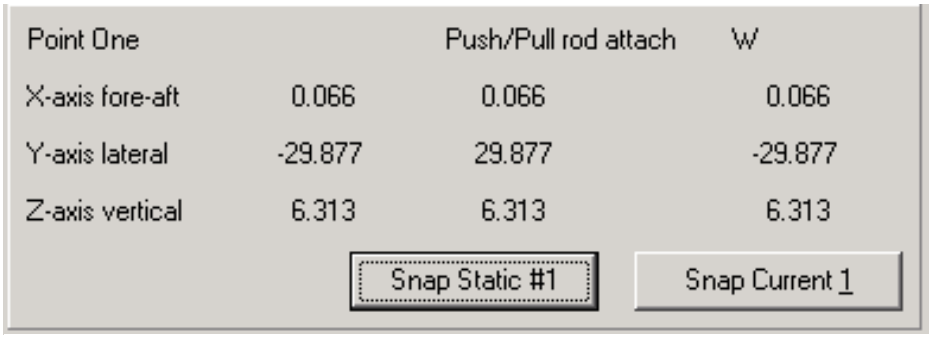


Figure 5-2

- Currently, both the *Point One* and *Point Two* boxes show the same co-ordinate because at this juncture, only one chassis point has been identified by the cursor.

- Click on the *Done* box to return the program to the main graphics' screen

- Add –0.200" *Ride* and 0.300^{O} *Roll* and then click on Compute as shown in Figure 5-3

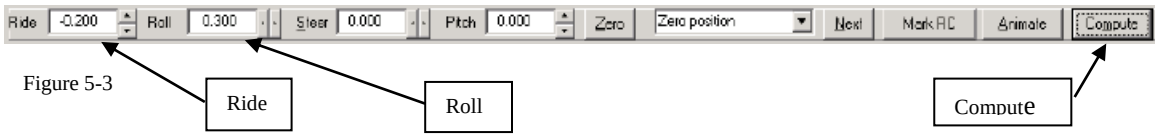


Figure 5-3

Ride

Roll

Compute

- Reclick on the lower left push rod mounting point. When the 3-D rendering screen appears, click on the *Snap Current 1* box. The far right column now shows the lower left side push rod mounting **dynamic** co-ordinates as seen in Figure 5-4

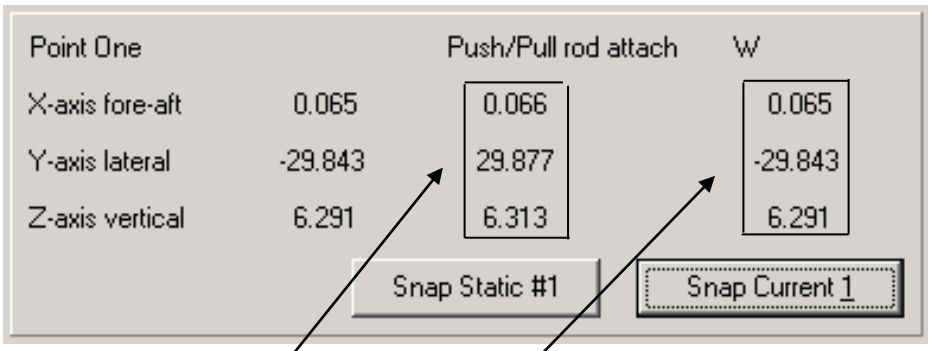


Figure 5-4

Static Co-ordinates

Dynamic Co-ordinates

Two Point Co-ordinates

- Return to the main graphics' screen and return the chassis to its static position by clicking on the *Zero* box as shown in Figure 5-5.



Figure 5-5

Clicking on the *Zero* box returns the chassis to its static position

- Add –0.300" of *Ride* and 0.500^{O} of *Roll* and then click on compute.

- Place the mouse cursor over the left lower push rod mounting position and depress the left mouse button. While holding the mouse button down, drag the cursor directly over the right lower push rod mounting position. Releasing the mouse button will bring up the 3-D rendering screen. Click on *Snap Current 1* in both the *Point1* and *Point 2* boxes.

- Both the static and dynamic lower push rod co-ordinates are now shown in the *Point 1* and *Point 2* boxes as shown in Figure 5-6.

- The right lower box shows the x, y and z horizontal and vertical differences between the two points. The Dist = 59.729 number is the distance between the two points (as if measured by a

ruler). If both points are close to being at the same vertical height, as they are in this case, the y number and the distance number may be the same if only three decimal points are shown – Figure 5-6.

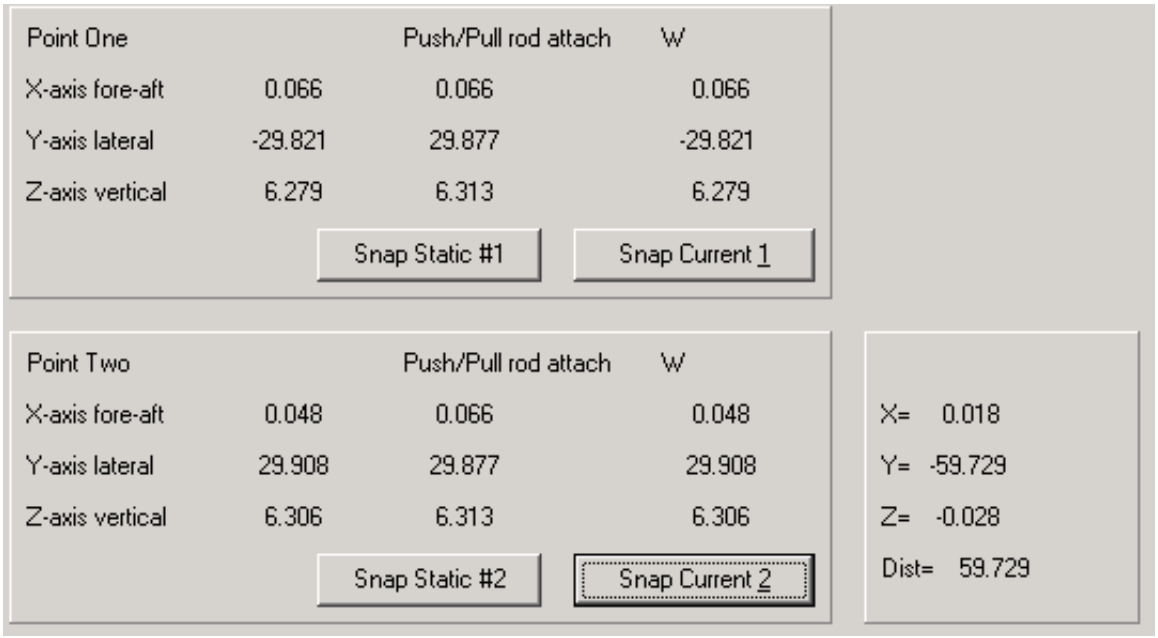


Figure 5-6

- If the vertical distance of the two points are considerably different, as between the top and bottom mounting points of a push rod, then the distance measured along the push rod will be quite different than the vertical and/or horizontal distance.

An Overview of the Relative WinGeo3 Demo Menus

Files: Read geometry (*.gem) files and save for future use. Also Print files and exit the program. See Files menu in the help files. (Regular WinGeo3 versions only)

Files – The *New, Open, Edit, Save and Save As* components are not used in the demo version.

- *Fancy Print* – is used to either print and/or look at the suspension data. The user has the option of static data, dynamic data or a blank sheet.
    - When simply looking at the data using *Fancy Print*, click anywhere on the printed area and then use the up/down arrows to scroll the page up or down.
    - To leave *Fancy Print* without printing click on *Cancel*
    - To leave *Fancy Print* after printing click on *redraw*

Clipboard: Copy the contents of the screen into the Windows clipboard or into a graphic file. This allows you to paste the graphics into other programs, such as Microsoft Word. This is a convenient way to create reports and use the complete capabilities of other Windows programs. You can also add notes or comments to the graphic. See *Clipboard menu* in the help files.

View: Select the viewing angle of the graphic. The standard view is from the rear of the vehicle looking towards the front. You can change the viewing angle and scale to examine the vehicle from any position. See *View menu* in the help files.

Edit: Enter the suspension points, notes and description. You can specify the X-axis (fore-aft), Y-axis (lateral) and Z-axis (height) values of each suspension point. You can also define the origin of your co-ordinate measuring system. The Edit commands also define the structure of the suspension - whether there is a Data Potentiometer and whether it is connected to the Lower A arm, the Upper A arm, or the Bell Crank Pivot. You can also enter Notes and a Description. See *Edit menu* in the help files.

- The Edit menu is used to enter suspension data points and to define the structure of the suspension. Each suspension point must have X, Y and Z co-ordinates to define fore-aft, lateral and height positions. The structure specifies that the coil-spring is attached to the Lower A arm, the Upper A arm or Hub.

- The suspension points are broken into groups for editing. To edit a group you must know to what group it belongs. The Upper and Lower A arm points are in the Suspension group. Springs, shocks and data pots are in the Auxiliary group.

- The first, and often most crucial decision is to edit the *Left side*, the *Right side*, or *Both Sides* of the suspension. If you choose to edit both sides of the suspension, then *Left* and *Right* values will be changed whenever you change a suspension point.

- The lateral (Y-axis) values are measured from the centerline of the car out. Both Left and Right suspension points have positive Y-axis (lateral) values. The only time you should have a negative Lateral value is in the rare case when a Bell Crank for the right side suspension is on the left side of the car, or vice versa.

    - Edit: Suspension
      Edit the primary suspension points including upper and lower A arms. X-axis values represent the fore-aft dimension measured from the centerline of the tire contact patch (right side if different). If you have specified a different Origin, then that origin will be used, but the direction is still the same. Negative values are forward of the centerline. Positive values are aft. See Edit: Measure: Origin

        - Y-axis values are measured OUT from the centerline of the car, or whatever origin you have chosen. Both Left and Right sides are measured OUT from the centerline. Negative values are rare. The program translates Left side points to negative values for computing. When you look at output reports you will see negative lateral values for the left side of the car. This definition of a co-ordinate system violates the right hand rule, but it works. See Edit: Origin and Edit:

        - Measure: Origin
          Z-axis values are measured from the ground up, or from whatever Origin you choose. See Edit: Measure: Origin

    - Edit: Steering
      Edit the steering points including the steering tie-rod. The example shown in the help file is a rear-steer car because the X-axis is positive or behind the axle centerline. The tie rod points S outboard and T inboard are shown below. The steering box ratio is 2.0 inches per 360 degrees. The steering rack moves 2.0 inches laterally for each 360 degrees of rotation of the steering wheel. 90 degrees of rotation move the rack 0.500 inches. See Utility: Steering Box Ratio

- Edit: Auxiliary
  Edit the spring, shock absorber and data pot points. Also specify the attachment points for each link. In the example shown in the *Help File*, the spring and shock are attached to the Lower A arm while the Data Pot is attached to the Upper A arm. Be very careful with the attachment points because it is possible to attach the link to one component even though the point is in the vicinity of another component. See Edit: Measure: Origin

- Edit: Swaybar
  Edit the anti roll bar or swaybar points. This can be either a U-bar type (usually found on sedans, stock cars and production cars) or a T-bar (usually found on formula cars with push-rods or pull-rods). T-bar types often have a third spring, though a U-bar may have a third spring.
  The U-bar type swaybar bar is located on the chassis at points X and Y. There is an extension of the bar (or a blade) running from point X to point R. Then there is a link from point R down to the upper A arm. Be careful that the Swaybar is attached to the proper point. The Want_Swaybar box must be checked so that Want_Swaybar is true.

- Edit: Third Spring / U-Bar
  A U-bar is the traditional form of anti roll bar with the bar running across the car. Each end of the bar is attached to the suspension. When the left and right sides of the suspension move together (ride height change), the bar rotates at both ends and applies no force to the suspension. When the left and right sides of the suspension move in opposite directions (chassis roll), the bar twists and applies forces to each side of the suspension. The energy required to twist the bar reduces the amount of chassis roll. Thus, we have an "anti roll bar" "also referred to as a "swaybar."

- Edit: Pivot
  This is the bell-crank pivot used for Push-rod and Pull-rod suspensions.

- Edit: Halfshaft or Driveshaft

- Edit: Clearance and C.G.
  Edit the chassis clearance points. These can be any points, but should be common reference points. With stock cars, common clearance points are the bottom of the rocker panels. The center of gravity is also on this form. The center of gravity refers to the sprung chassis only and moves with the chassis. The effects of the sprung mass (uprights, wheels and tires) and the moving links are ignored. The CG location is only used for the Anti dive/anti squat calculations and the Roll Center moment arm calculation.

- Edit: Trailing Link

- Edit: Rearaxle - Truck Arm
  Truck arms are rectangular steel beams running from points near the centerline of the chassis back to solid mounts to the rear axle. Mathematically, this is modeled as twin links on each side running from a single forward mounting point to a pair of distinct mounts on the rear axle. The spring and shock can be attached to the truck arms. In common stock car practice, the springs are attached to the truck arm while the shocks are attached to the rearaxle.

- Edit: Lateral control
  The lateral link is commonly a panhard rod or track rod with one end (point I) on the chassis and the other (point J) on the axle.

- Edit: Forces (springs and bars)
  This form allows the user to enter spring and swaybar rates. These can be used to calculate loads on the tires.

  - In some versions of the program you can also enter a spring rate for the tires and then compute suspension travel taking into account tire squish. This can have a significant effect on the results.

- Edit: Origin

- Edit: Rotation Point – Discussed in Chapter 6

- Edit: Axis Calculator

  - **This** is a fairly complex component but if you are doing any type of design or redesign work, you will want to go through this section carefully.

- Edit: Track Calculator

Design: These commands allow you to design a suspension by specifying suspension characteristics and determining the suspension points which will create the desired suspension characteristics. For instance, you can specify an Instant Center location and the suspension points will be moved to create a suspension with the desired Instant Center location. This process creates entirely new parts. See *Design menu* in the *Help Files*.

- The Design menu is used to create a suspension which meets specific design objectives. For instance, you can define a suspension which has a specific kingpin with Kingpin Axis, scrub, caster and trail. Or you can modify a suspension to have a specific Instant Center or Roll Center. The necessary suspension points are changed while preserving other points.

- The Design capability permits you to create a suspension with specific characteristics and saves a lot of trial-and-error attempts to create the desired suspension. Of course, it may not be physically possible to create the desired suspension. The desired points may be within the engine block.

  - Design: Extend Upper A arm
    Extend (or contract) the length of the Upper A arm from the existing ball joint through the inner pickup points A and C. This preserves the instant centers while changing the length of the A arm. This can affect roll center movement.

    After extending (or contracting) the length of the A arm, the points that change are shown with a yellow background. In this case, the inner pickup points A and C change while the ball joint remains unchanged.

    Extending the Lower A arm moves points A and C. Extending the Upper A arm moves points D and F. All three co-ordinates of each point are changed as the A arm is extended along a line through the ball joint.

  - Design: Extend Lower A arm
    Extend (or contract) the length of the Lower A arm from the existing ball joint through the inner pickup points D and F. This preserves the instant centers while changing the length of the A arm. This can affect roll center movement.

    - After extending (or contracting) the length of the A arm the points that change are shown with a yellow background. In this case, the inner pickup points D and F change while the ball joint remains unchanged.

- Extending the Lower A arm moves points A and C. Extending the Upper A arm moves points D and F. All three co-ordinates of each point are changed as the A arm is extended along a line through the ball joint.

- Design: Kingpin, scrub and caster
  Specify the kingpin axis through the ball joints B and E.

- Design: Steering Tie-rod
  This assures that the steering tie-rod is aimed at the same Instant Center as defined by the Upper and Lower A arms. This minimizes bump steer.

- Design: Instant Center
  Specify the front view instant center and change the vertical heights of the inner pickup points A, C, D and F. The plan view co-ordinates are not changed.

- Design: Instant Center / Roll Center
  The desired Instant Center and Roll Center are created by moving the height of the inner pick-up points A, C, D and F. Only the height of the inner points is changed.

- Design: Side-View Swing Arm
  The SVSA Instant Center defines the anti dive, anti squat properties.

- The desired Side-View Swing Arm (Side-view Instant Center) is created by moving the height of the inner pick-up points A, C, D and F. Only the heights are changed.

Build: These commands permit you to build a suspension from existing parts. You can specify an upright and then mount it in various positions by specifying camber, toe steer and caster angle. This reflects the way suspensions are created in the real world. The popular Fixture commands are here. The Fixture, developed in association with Bob Leonard of The Leonard Company, permits the user to measure the upright/hub points very accurately and then mount it in the desired location. The A arms are then adjusted to fit between the chassis location and the desired location of the upright. See *Build menu* in the *Help Files*.

- The Build menu permits you to create a suspension from existing parts. You can specify an upright and then mount it in various positions by specifying camber, toe steer and caster angle. This reflects the way suspensions are created in the real world. Note: Many Build commands only work for Double A arm and MacPherson Strut suspensions.

  - Build: Tire Diameter
    Changing the tire size raises or lowers all of the suspension points. This can also be used to quickly change all of the height values. If you have a reason to change all the height values, use this procedure. To raise the chassis use this to raise the points. Then use the normal editing procedure to reset the tire diameter value. In the example shown in the *Help File,* the tire diameter was changed to 26.5 from 24.5. This raises the chassis points one inch.

  - Build: Track Width
    Changing the track width moves the ball joints and changes the track. The track is changed by altering the A arms and preserving the hub/upright and the kingpin parameters. Only the Y-axis (lateral) value is changed.

  - Build: Camber Angle
    Change the camber angle but retain the upright/wheel/tire structure. This moves the ball joints to obtain the desired camber angle. Here the initial camber is changed from 0 to -1

degree. Only the Y-axis (lateral) and Z-axis (height) of the ball joints and the static camber are changed.

- Build: Kingpin Angle and Scrub
  The A arms are altered to move the kingpin axis while preserving the hub/upright. Only the Y-axis (lateral) and Z-axis (height) of the ball joints and the static camber are changed.

- Build: Caster angle and Trail
  The A arms are altered to move the kingpin axis while preserving the hub/upright. The ball joints are moved and the static camber is changed.

- Build: Kingpin and Caster
  Specify kingpin and caster by changing the ball joint points B and E.

- Build: Create Symmetry
  This command forces the suspension to be symmetric by making the left side match the right side suspension. The program will list each point that differs and ask if you want to change that point.

- Build: Move Points
  This command is designed to fix data entry errors. Occasionally data is entered with the wrong origin or reference points. For instance, the rear suspension co-ordinates may be entered using the front suspension as a reference point. This can not be corrected by changing the origin because that simply alters the displayed values, not the internal values.

  - The Move Points command simply adjusts all the points (other than the origin) by the same amount. It only changes points; it does not change additional parameters such as tire diameter or track. After moving points, you should very carefully review the points in the Edit menu.

- **Build: Setup** (Permanent Changes)
  Teams often make setup changes to adjust their suspension. They may shim an inner pickup point to change camber, toe steer or caster. Teams have a ready supply of shims to make suspension changes quickly and repeatedly. Well-prepared teams have reports showing the effect of various shim adjustments. These commands assist in preparing such reports.

  - Many suspension pieces have adjustments, such as a toe adjustment, that change the perpendicular length of the A arm. Almost all steering tie rods have an adjustment that changes static toe steer.

  - The WinGeo3 program has two sets of setup commands with a subtle distinction. The Build > Setup commands make permanent changes and generate a new suspension. Both suspension and suspension parts are changed. Moving one inner pickup point may produce a different A arm because the dimensions of the A arm are changed. If only one inner pickup point is changed, the distance between the inner pickup points may change. This change may be small enough to be within the tolerance of the physical part (bolt holes have a certain amount of flexibility) but may require a new part.

  - When you make a setup change from the Build menu, the points are changed. If you implement the change by leaving the form and then reenter the form, the previous

change will not be visible. Trying to undo the first change may not return you to the original points.

- The Compute > Setup commands make temporary changes to the existing suspension. These changes require the user to maintain the same physical A arms. This means that a lateral change to an inner pickup point will require a slight fore-aft change to maintain the base of the A arm at the same length. For instance, moving the upper forward point of CoilDemo.gem 0.500 inches laterally requires a 0.021 inch adjustment in the fore-aft direction to maintain the 6.000 inch distance between upper inner pickup points.

- When you make a setup change from the Compute Menu, the points are not changed. If you implement the change by leaving the form and then reenter the form, the previous change will be visible. The original points are never changed.

- Build: Compare Files
  This command compares all the points of two files and lists the differences.

Build: Fixture

The *Build Fixture* Help Files have not yet been implemented, and, as this is a important component of the WinGeo3 program, it will be briefly outlined here as well as discussed through various kinematic examples in Chapters 6 through 9.

Build Fixture is both a design and set up tool. For symmetrical chassis, the *Fixture Both* mode is used while for an asymmetric chassis, the *Fixture Left* and *Fixture Right* modes are used.

When you activate the fixture routine from the **Build** menu, you get the following form - Figure 5-7. The user can select among several options. These choices are designed to simplify the user's task by allowing the choice of specific operations rather than offering a single form with too many options.

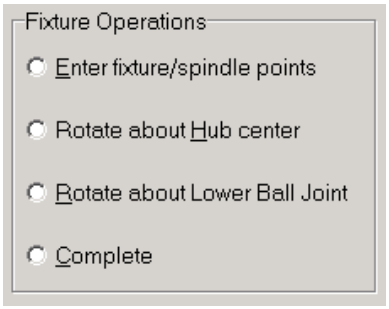


Figure 5-7

Enter fixture/spindle points

Rotate about Hub center – like the original Fixture

Rotate about Lower Ball Joint

Complete – all of the above on one form – requires a large screen to be effective

Enter fixture/spindle points – This mode is primarily used to look at **upright/spindle design**. The upper left corner in Figure 5-8 has editing fields for the upright/spindle points. These reference the upper and lower ball joints and the steering tie rod relative to the center of the hub. This is where the hub meets the face of the spacer/brake hat. It is not quite the same as the center of the wheel where most sanctioning bodies measure track. The form also includes the Rim Width, Offset and Spacer.

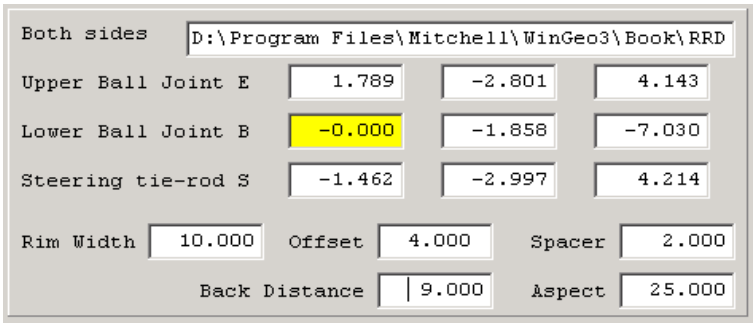


Figure 5-8

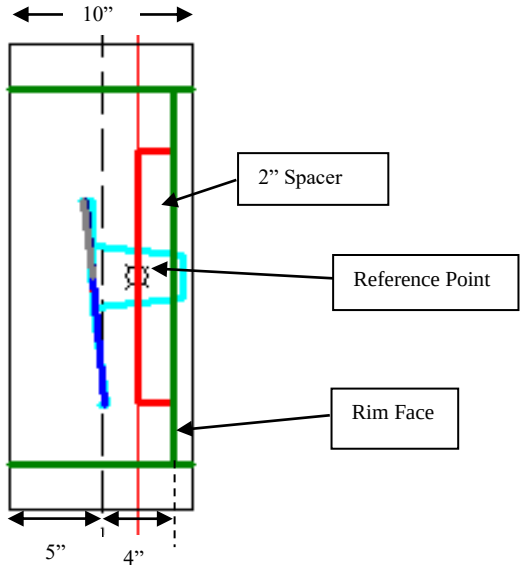


Figure 5-9

Figure 5-9 shows the fixture points and the detail of the wheel and tire. The example has an extreme Offset of 4.0” with a Rim Width of 10.0” and a Spacer of 2.0”. The green lines, while viewing the software screen, represent the wheel. The 4.0” offset with a 10.0” rim width represents a 9.0” distance from the wheel center to the backside and 1.0” from the wheel center to the outside rim.

- When using a non demo version, the **Files** menu allows you to **Open, Save** and **Save As** a *.fix file containing the fixture dimensions. The user can measure his existing uprights and save them in files. Then it becomes easy to mate any upright with the chassis points.

- The fixture points are measured with Camber = Toe steer = LBJangle = 0.0. Usually the upright/spindle is placed in a jig with the spindle or hub parallel with the bottom of the measuring jig as shown in Chapter 6.

- When you enter the fixture form, the upright/spindle points will be calculated from the existing suspension points. This involves taking the existing suspension and rotating the upright/spindle to a standard position with Camber=0, Toe steer=0 and LBJangle=0. These points can be changed with the editing fields or by opening a FIX file.

The *Enter fixture/spindle points* mode is used to analyze various spindle/upright configurations for:

- Kingpin Angle – Figure 5-10

- Caster Angle – Figure 5-10

- Ball Joint Spread (aligned dimension between the two ball joints) – Figure 5-10

- Hub offset (Front view ball joint axis to hub mounting surface) – Figure 5-10

- Hub Trail (Side view ball joint axis to center line of spindle) – Figure 5-10

Making changes in Fixture / Enter fixture/spindle points does **not** automaticlly change the Edit / Suspension co-ordinates.

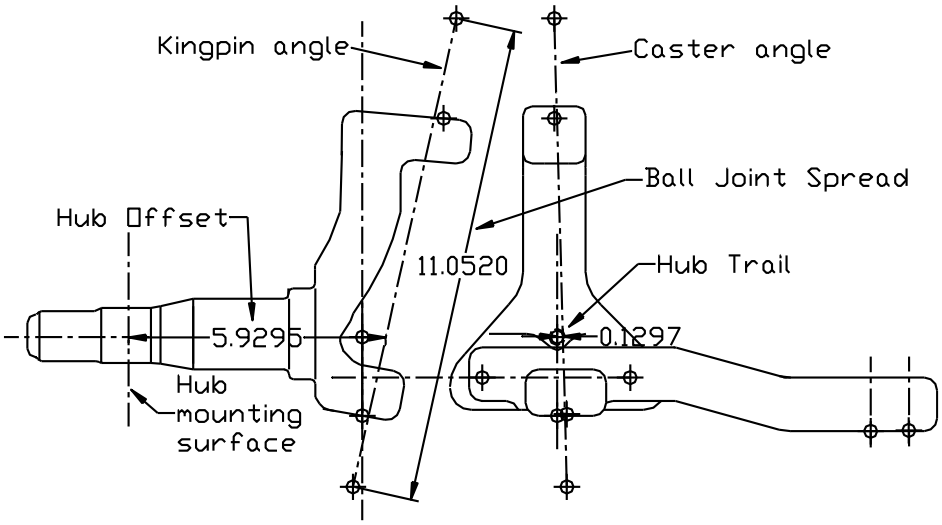


Figure 5-10

Rotate about Hub center – This mode rotates the suspension assembly about the hub center. This mode is primarily used to redesign both the upper and lower control arms to fit a particular spindle/upright design and setting. When the suspension assembly is rotated about the hub center, both the upper and lower control arm lengths change.

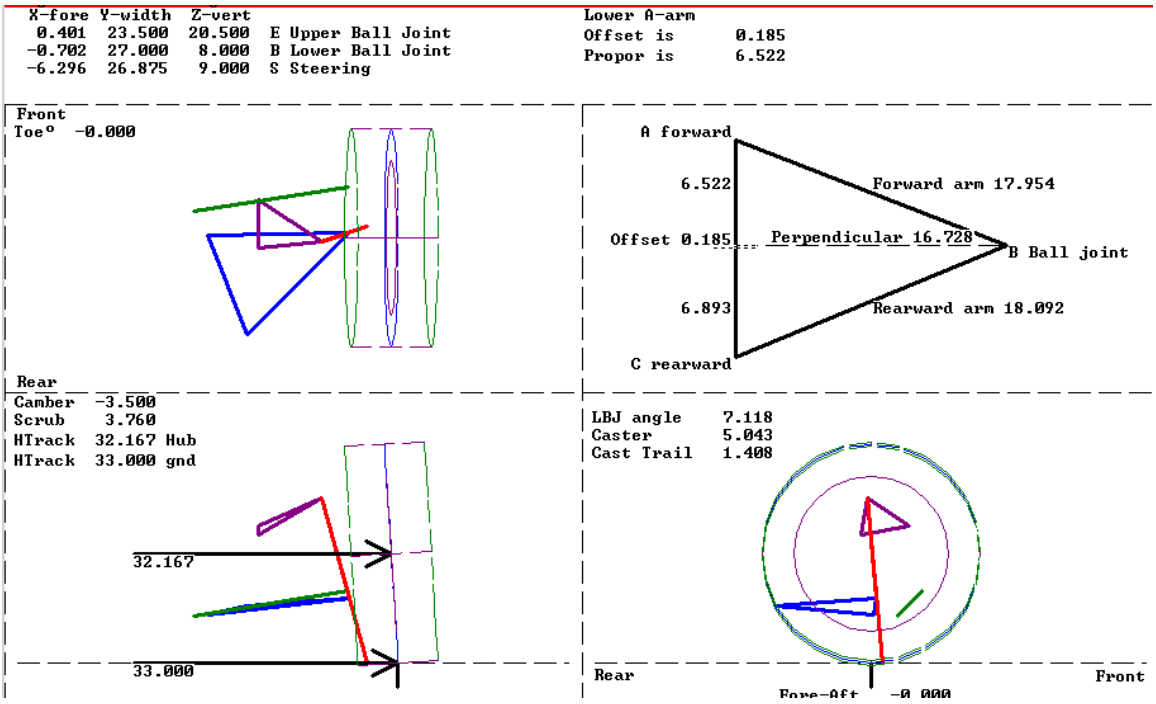


Figure 5-11

This form shows three views of the upright/spindle as well as a detail of the fixture points. The upright/spindle, A arms and tire are shown from the top (upper-left), rear (lower-left) and side (lower right). The upper right panel shows the lower control arm dimensions.

The panel at the bottom of the screen allows the user to enter **Half-track** (measured at hub height), **Camber**, **Toe steer**, and **Caster** or **LBJ angle.** The LBJ angle is the angle from the center of the hub to the lower ball joint. This angle is zero when the fixture points are determined.

Toe steer is measured in **degrees**, not inches or millimeters with Toe-Span.

The half-track dimension is measured to the center of the wheel, not the fixture reference point. This is the point where most sanctioning bodies measure track.

The user can specify either **Caster** or **LBJangle**. The one selected will be shown in white. The other will be shown on a yellow background.

The **Zero** button will set Camber=0, Toe steer=0 and LBJangle=0. But any change to the setup involving a rotation about the Hub Center will move the lower ball joint and change the lower A arm.

The ***utility*** menu within the *Fixture* mode allows the user to look at the resulting changes to the **upper** and **lower** control arms.

Rotate about Lower Ball Joint – Of the various **Fixture** modes, this is the **mode** I use the most. It is primarily used when designing or redesigning upper and/or lower control arms to fit changes in the upright/spindle design or settings. The upper control arm is automatically changed when either/or the spindle set up or lower control arm dimensions are changed. The lower control arm dimensions can be changed by using the fixture's upper right form (forward arm, rearward arm, offset and perpendicular length. Making changes in *Fixture / Rotate about Lower Ball Joint* changes the suspension co-ordinates in *Edit / Suspension*.

The Figure 5-12 form has the same four views and values for **Camber, Toe steer, Caster** or **LBJ angle.** But Hub-track is no longer applicable. Instead of selecting track, the user must define the Lower A arm. This can be done by specifying the lengths of the forward and rearward arms or the user may specify the perpendicular distance and offset. These choices are made in the upper-left corner.

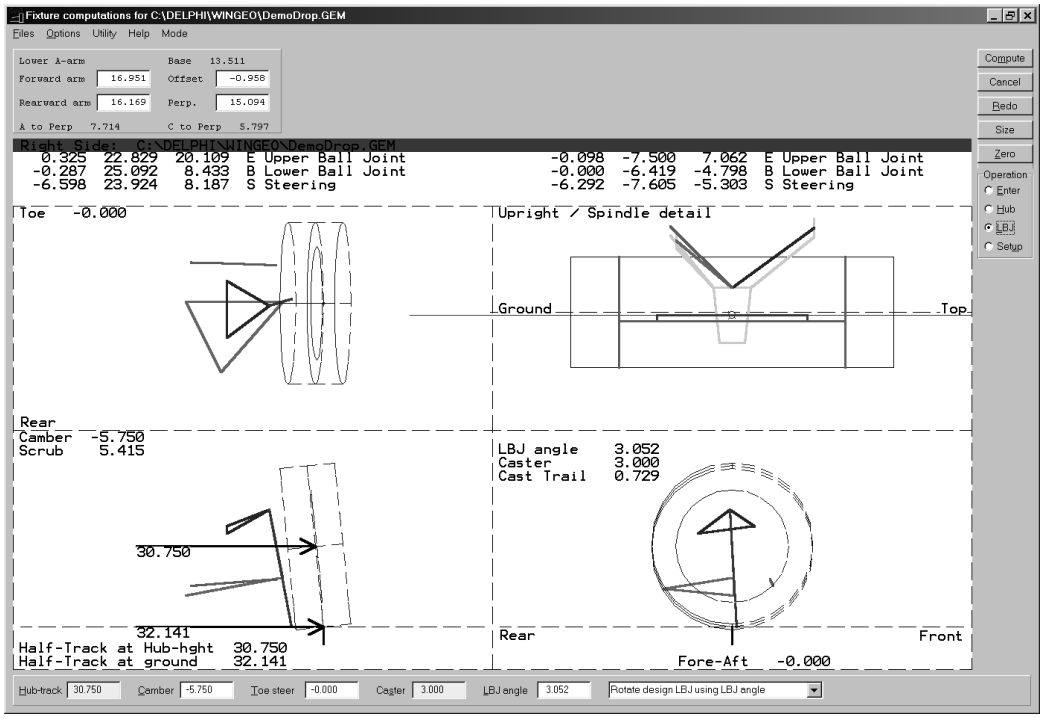


Figure 5-12

Control Arm Offset - An offset of 0 means the arms are equal length. The upper control arm in Figure 5-13 has a base/cross link length of 8.083". It is 4.428" from D (forward) to the perpendicular and 1.655" from F (rearward) to the perpendicular. The offset is 1.655"-3.0415" = -1.386". the forward A arm is 10.098" while the rearward A arm = 9.226".

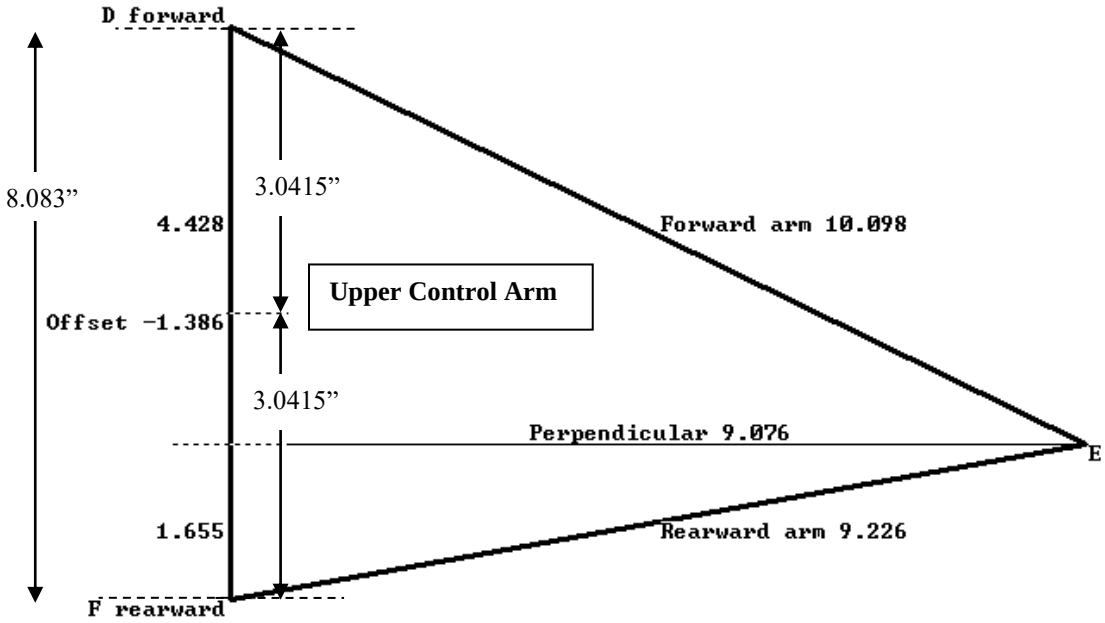


Figure 5-13

Figure 5-13 shows the A arm with the perpendicular horizontal and base vertical, not as the A arm fits on the car.

Compute: Solve for the suspension points in different chassis positions. You can specify ride height, roll angle and steering input and then calculate the suspension parameters (camber, toe, instant center, roll center, etc.) for that position. You can also perform iterative calculations such as running ride height through a range of values, such as -3.0 to +1.0 inches in increments of 0.1 inch. You can also solve for spring displacement or shock displacement, data pot readings, or wheel travel (to simulate a one-wheel bump). See *Compute Menu* in the *Help Files*.

- Compute: Keyboard Control
  Specify Ride Height, Roll angle and Steering input with keyboard input. Then compute the suspension parameters for that chassis position. The chassis position can be entered with the controls shown in the Help File or with the arrow keys used in the DOS Freebody program. The Up and Down arrows change ride height. The Left and Right arrows change roll angle. The hot key for this command is Ctrl+K. The editing screen has a Compute button which does the same thing. This permits the user to get back to this basic function easily.

- Compute: Rotation Point
  This report shows the effect of different rotation points. In the example below the alternate rotation point is at -10.0 inches lateral (left of center of the car) and 5.0 inches above the ground. The effect is to lower the chassis 0.346 inches and move it laterally -0.181 inches. This movement is shown on the right side of the form multiplied by a factor of ten.

- Compute: Wheel travel
  Set the right and left wheel travel and compute the ride and roll. The user can enter the Left and Right wheel travels rather than Ride and Roll. This is very convenient for one wheel bumps.

- Compute: Iterations
  Perform an iteration as selected with the Geometry Control Dialog.

- Compute: Ride iteration
  Perform an iteration of ride height values. The range of ride height values is specified with the form shown below. You specify the minimum (-2.0 below), the maximum (+2.0 below) and the increment (0.1 below). You also specify the values for roll angle and steering input.

- Compute: Roll Iteration
  Perform an iteration of roll angle values. The range of roll angle values is specified with the form shown below. You specify the minimum (0.0 below), the maximum (+4.0 below) and the increment (0.1 below). You also specify the values for ride height and steering input.

- Compute: Steer Iteration
  Perform an iteration of steering input values. The range of steering input values is specified with the form shown below. You specify the minimum (0.0 below), the maximum (+4.0 below) and the increment (0.1 below). You also specify the values for ride height and roll angle.

- Compute: Ride and Roll Iteration
  Perform an iteration of both Ride height and Roll angle. The range of iteration values is specified in the form below. Here Ride goes from -2.0 to +2.0 by 0.1 inch while the Roll angle goes from 0.0 to 4.0 by 0.1 degree. You also specify the value for steering input.

- Compute: Ride and Steer Iteration
  Perform an iteration of both Ride height and Steering input. The range of iteration values is specified in the form below. Here Ride goes from -2.0 to +2.0 by 0.1 inch while the Steering input goes from 0.0 to 4.0 by 0.1 degree. You also specify the value for Roll angle.

- Compute: Solve for Spring
  This allows you to specify the displacement of the spring and calculate the Ride and Roll corresponding to that displacement. In the example below, the left spring has an extension of 0.25 inches while the Right spring has compressed 0.5 inches.

- Compute: Solve for shock
  This allows you to specify the displacement of the shock and calculate the Ride and Roll corresponding to that displacement. In the example below, the left shock has an extension of 0.25 inches while the Right shock has compressed 0.5 inches.

- Compute: Solve for Data pot
  This allows you to specify the displacement of the Data Potentiometers and calculate the Ride and Roll corresponding to that displacement. With the same displacements of +0.25 left and -0.50 Right, this gives a Ride of -0.367 and a Roll angle of 2.091 degrees.

- Compute: Solve for Clearance
  This permits you to solve for specific chassis clearance values. In this case, the chassis clearance points were established at 26.0 inches wide and 6.0 inches off the ground, the

approximate position of rocker panels on a stock car. We want to calculate the suspension parameters when the Left side is 6.5 inches high and the Right is 5.0 inches high.

- Compute: Solve for Load
  This command allows the user to specify the load on each tire. The load must come from the movement of the springs and swaybar. You must specify spring rates in order to solve for load. Having done this, you might specify a load on the left tire of -50 pounds and on the right tire of +200 pounds.

- Compute: Solve for Steering Angle
  This command allows the user to specify a steering angle for the right tire. In the example below, the desired angle is 3 degrees. You can also specify Left and Right side shock values.
- **Compute: Solve for Setup** - The user needs to be aware of the differences between *Build Set Up* (permanent change) and *Compute Solve for Set Up* (temporary change).
  Teams often make setup changes to adjust their suspension. They may shim an inner pickup point to change camber, toe steer or caster. Teams have a ready supply of shims to make suspension changes quickly and repeatedly. Well-prepared teams have reports showing the effect of various shim adjustments. These commands assist is preparing such reports.

  Many suspension pieces have adjustments, such as a toe adjustment that changes the perpendicular length of the A arm. Almost all steering tie rods have an adjustment that changes static toe steer.

  The WinGeo3 program has two sets of setup commands with a subtle distinction. The Build > Setup commands make permanent changes and generate a new suspension. Both suspension and suspension parts are changed. Moving one inner pickup point may produce a different A arm because the dimensions of the A arm are changed. If only one inner pickup point is changed, the distance between the inner pickup points may change. This change may be small enough to be within the tolerance of the physical part (bolt holes have a certain amount of flexibility) but may require a new part.

  When you make a setup change from the Build menu, the points are changed. If you implement the change by leaving the form and then reenter the form, the previous change will not be visible. Trying to undo the first change may not return you the original points.

  The Compute > Setup commands make temporary changes to the existing suspension. These changes require the user to maintain the same physical A arms. This means that a lateral change to an inner pickup point will require a slight fore-aft change to maintain the base of the A arm at the same length. For instance, moving the upper forward point of CoilDemo.gem 0.500 inches laterally requires a 0.021 inch adjustment in the fore-aft direction to maintain the 6.000 inch distance between upper inner pickup points.

  When you make a setup change from the Compute Menu, the points are not changed. If you implement the change by leaving the form and then reenter the form, the previous change will be visible. The original points are never changed.

- Compute: Pitch Angle …
  Change the pitch angle of the suspension. The dialogue shown in the Help File will change the pitch angle to 1.2 degrees. This rotates the chassis and changes Caster and Caster Trail as well as other variables.

Table: View - Table of Values

- Tables of Values have columns of suspensions values (Camber, Toe steer, Roll center location) for a variety of suspension positions, each represented in a row. There are nine built-in tables with definitions and names of the columns of suspension values. The program can also accommodate nine user-defined tables. These can be created by the user for his specific applications. The user may have as many sets of nine tables as he desires.

- As previously discussed, the Table controls can also be accessed through the *View* menu.

- The WinGeo3 program generates tables of values for a succession of suspension positions. The table shown in the *Help File* shows suspension positions for the standard demo path, ranging from full braking to cornering and finally full power. The table includes the suspension positions (ride, roll and steer) and calculated camber, steer, netsteer, Ackerman, scrub, netscrub, instant center location, roll center location, spring displacement, motion ratio and clearance.
- The suspension graphic is reduced in size to allow room for the table.

- Each time you compute a new suspension position, that value appears at the top of the table. Previous values are moved down in the table. The table can be cleared when desired.

Reports: Examine reports containing the X-Y-Z values for all of the suspension points after a calculation. You can also see problems encountered in the calculations. There are also several reports that compare points or results. See *Reports menu* in the help files.

- Reports: Load Path file
  The Path is a series of chassis positions which can be very useful. It is easy to select a chassis position from the Path by either pulling down the list of positions or with the Next button. There is a complete New / Open / Edit / Save / Save As / C lose / Print / Used … menu for handling Path data.

- Edit Path files

- Reports: GAP Analysis (see Chapter 6, page 33 for outline of **G**raphical **A**nalysis **P**rogram). Perform GAP analysis on the existing GAP data array. Every computation is added to the GAP data until the array is cleared with the following command. Some commands, such as the Iteration commands, clear the GAP data array before beginning computations. There is a limit of about 3500 suspension computations in the GAP data array.

- Reports: Clear GAP array

- Reports: Points
  This report shows the original data points BEFORE any computations. A portion of a report is shown below:

- Reports: Solved
  This report shows the location of the suspension points after a computation. The example below shows the points for -0.5 ride and 1.0 degree of roll.

Analysis: Many specific reports that augment the values displayed on the primary graphic. These reports include theoretical analysis and additional detail on matters such as Instant Centers, Side-View Swing-Arm, Ackerman, Rising Rate and the Pitch Center. See *Analysis menu* in the help files.

- Analysis: Origin
  The Origin form allows the user to see the effect of different co-ordinate systems on measuring chassis points. The user can try different co-ordinate systems and see the effect on chassis points.
  The Origin form also has the ability to identify points with the mouse and determine their measurements in both the user's co-ordinate system and the RbyN co-ordinate system.

- Analysis: Fundamental Analysis
  This form analyses the relationship between the front view Virtual Swing-Arm and Ride Camber, Roll Camber and Ride Scrub. The front-view Virtual Swing-Arm is represented by a line from the Instant Center to the tire contact point. Analysis of this relationship can explain how camber reacts to ride changes (ride camber) or roll changes (roll camber). It also explains how scrub (track change) reacts to ride height changes (ride scrub). Understanding this relationship is crucial to knowledge of suspension geometry.

- Analysis: Derivative Analysis
  This report approaches the fundamental relationship from the other direction. It uses a small change in ride height to compute Ride Camber and thus infer the length of the virtual swing-arm and the instant center. But it expands the analysis from the front view used in Fundamental Analysis to the side view swing-arm (SVSA) and an analysis of Ride Caster.

- Analysis: Instant Center
  This form provides detailed analysis of the Instant Center determination for double A arm suspensions. There are both analytical values and graphical displays.

- Analysis: A arm Analysis
  This report analyzes A arms and produces a perpendicular length and an offset describing where the perpendicular intersects the rotation axis. This can help categorize the A arms.

- Analysis: Side-View Swing-Arm

- Analysis: Anti dive, Anti squat
  This form calculates the anti dive and anti squat calculations for both inboard and outboard suspensions.

- Analysis: Anti roll Bar and 3rd Spring

Utility: Set options such as Units (Standard or Metric) and Toe steer options (degrees or inches/mm). These commands are the odds and ends which do not fit anywhere else. See *Utility menu* in the *Help File*.

- Utility: Units
  Suspension positions can be measured in units of either Standard (inches) or Metric (millimeters). If the data is Standard, it can be converted to Metric by changing units. If the data is Metric, it can be converted to Standard by changing units. When processing multiple files, they should all have the same units.

- Utility: Motion Ratio
  The spring and shock motion ration can be displayed as either Motion Ratio or Velocity Ratio. The Motion Ratio is spring displacement / wheel travel and is usually less than 1.0. Velocity Ratio is wheel travel / spring displacement and is usually greater than 1.0.

- Utility: Toe steer Measurement
  Toe can be measured in degrees or in a linear distance (inches or mm), as many teams do in the field. If you choose the linear measurement, you must also specify a reference

distance called Toe Span. This value is entered on the Steering editing screen. Toe Span is 28.0 inches in the example shown below. The Utility menu also includes an example of Toe Span as shown below. The example shows how -1.719 degrees of toe on the left side translates to -0.840 inches. On the right side 1.720 degrees of toe equates to 0.841 inches of toe on the right.

- Utility: Error Warning Level
  There are multiple levels of error warnings. Some "errors" are inherent to certain suspensions, such as parallel lines when constructing an instant center. These can be very annoying, particularly when running many computations. The Error Warning Levels allow the user to control the number of messages displayed. There are currently three levels of error warnings:

  - Show All Warnings
  - Ignore Intersecting lines (parallel)
  - No error warnings (Some messages can not be ignored and will be shown)
  - From time to time, the computer operating system will go into a series of closed loop iterations when the program is asked to solve a mathematical problem that has no solution. In this case, a series of error messages will be displayed. If the user wants to cycle through these messages quickly, he/she can simply hold down the Esc key until the error messages end. It is not recommended that the user turn off the error messages because 99 times out of a 100 the error messages are telling the user they have introduced some form of incompatibility, either in the suspension co-ordinates or in dynamic motion.

- Utility: Ackerman option
  There are two different ways to calculate Ackerman. The classic way constructs lines perpendicular to the wheels and determines a turn center. This has problems when there is static toe steer. The other uses the kingpin and steering tie rod. The user can select one or both.

  - Toe steer perpendicular
  - Kingpin center
  - Both computations

- Utility: Edit Option
  There are two options for editing display. The standard is Check sums. The distance from A to B is 17.757 inches. The other option is Incline angle. The inclination of the A-to-B link is -0.807 degrees.

- Utility: Half-track Option
  Track can be entered as Full track (66.0 inches in most demos) or Half track (33.0 inches). Full track is natural for symmetric cars because track is a common reference value. Half track is more natural for asymmetric cars where few measurements are the same from left to right. Stock cars are a natural for Half track. The Half track measurement is from the centerline of the car (however that is determined) to the center of the tire contact patch. If you do not choose the Half track option, then the car will still have different tracks left and right.

- Utility: Steering Box Ratio
  Specify whether the steering input is in degrees or rack travel or horizontal motion of the pitman arm. With the degrees option, you enter the degrees of rotation of the steering wheel and the program calculates rack travel.
  Steering is a confusing subject because there are three ways to specify the steering input and two ways to measure the resulting toe steer angle. You must be very careful defining the steering options.

  Steering Input: Rack and Pinion
  Steering input can be specified as rack travel (the original method) or steering wheel degrees. Rack travel is entered as inches (standard units) or millimeters (metric units). If you specify the use of the steering box ratio, then you enter the steering wheel degrees and the rack travel is calculated as Input Degrees * Box Ratio / 360.0. The units of the Box Ratio value are inches per 360 degrees (or millimeters per 360 degtrees). See Edit: Steering

  Steering Input: Draglink
  For draglink steering system's the box ratio is degrees per degree. A 12:1 box will reduce 180 degrees of steering wheel movement to 15.0 degrees of rotation of the steering box. This value is then translated to the lateral movement of the end of the draglink arm. In the example below, 45 degrees of steering wheel movement represents 3.75 degrees of rotation of the steering arm. Since the arm is 5.219 inches long, the effective rack travel is 0.324 inches.

  Steering Input: Angle
  The steering input can also be specified as degrees of the right front tire. This works if you calibrate your steering value in degrees. For instance, you can specify a steering angle of -1.2 degrees and the program will determine the steering input that produces that value. This option can be done with Compute: Solve for Steering Angle or with data, Steering Input: Data

  - When you take the steering input from a data file, there is one additional option. You can rescale the steering value with a multiple and additive factor. See Data: Compute map / animate

  Steer Angle:
  Toe steer can be measured in degrees or in inches or millimeters. Degrees are logical and rational but most teams measure toe steer as a distance: the difference between the distance between the front of the tires and the rear of the tires. There is even a SAE definition for this measurement of toe steer. The Utility: Toe steer Measurement command switches from one to the other and also provides an example of the relationship between the two measurements.

- Utility: Initial Options
  This form appears when you first start the program. It prompts the user to make several initial choices that most will rarely change. These include the choice of units (metric or standard), toe steer units (degrees or inches/mm), motion ratio vs. velocity ratio and names (road racing or stock car).

- Utility: Ball Joint Calculator
  This form allows the user to determine the center of a ball joint from the available end. In the example shown in the *Help File* the center of the ball joint is 1.157 inches from the tip. The ball joint is at 30 degrees fore-aft and 15 degrees lateral inclination.

Geometry Control Dialog: Files

Files - This page allows you to select the files which are included in the computations. In the example shown in the *Help File* both files are checked and will be displayed. The colors associated with each file are shown on the right side of the page. Each part may be displayed in a selected color or hidden.

Geometry Control Dialog: Values tab

Values - This page permits you to select the values which are displayed on the graphic. You check the values you wish to display, such as Camber and Instant Center. Check the Derivatives box to show motion ratios and other derivatives, such as dSteer / dRide. If you are not seeing something you need to look at on the main graphics screen this is where you will need to go to add it. From time to time the screen may also become to crowded with the various value outputs in which case the user will need to go to the *Values* page and removed some of the overlapping values.

Derivatives can be informative. The value dSteer / dRide specifies how much Toe steer changes as a function of ride height. This is a measure of bump steer. The same principle applies to other derivatives, including dCamber / dRide and dScrub / dRide. I find the derivatives extremely informative and pretty well keep them on screen at all times.

The motion ratios for spring, shock and data pot are defined as dDisplacement / dRide. A measure of Rising Rate would be the second derivative of displacement with respect to ride height.

Geometry Control Dialog: Parts (Solid-Model)

Parts (Solid-Model) This page contains the parts of a suspension and the Solid-Model graphic controls.

Geometry Control Dialog: Sketch tab

Sketch Some parts of the car can be sketched in various levels of detail. Sketch parts include the roof or roll-over bar of the vehicle and the driver's helmet. The tire and rim are also sketched parts. This page allows you to select the colors and the amount of detail for each part. The level of detail also contains a "No sketch" choice which eliminates the sketch. You can also turn off all sketch features.

Geometry Control Dialog: Screen Layout Tab

Screen layout: Choose whether to show the graphic with the Ground frame of reference where the ground remains stationary and the car moves. This was used in the DOS Freebody program. An alternative is the Vehicle frame of reference where everything is relative to the chassis. The car remains stationary and the ground moves. The Font is the graphical font.
The Trace Point allows you to select one point and see the point co-ordinates on the screen.

Geometry Control Dialog: Iterations Tab

Iterations This page sets iteration ranges for various possible iterations. When you select an iteration from the Compute Menu, or use the Ctrl+I hot key, it will use the ranges and increment from this page.

Help: Access documentation and explanations and an About screen. See *Help Menu* in the *Help File*.

Quit: Quit the program.

Very Important Note: Changing the **Ride Heights** and saving the resultant suspension co-ordinate changes.

A chassis, particularly a new chassis, is often measured while sitting directly on the build plate (0, 0, 0 Origin). The designer can then go to **Compute**, **Solve for Clearance** and put in the set up ride heights (clearances). Once the new clearances (ride heights) are entered, the **Compute** button is clicked. The new suspension co-ordinates can then be **saved** by going to **File**, **Save Current Car.** The new co-ordinates will not be shown in the **Edit** mode until the program is closed and then reopened under the name used in **Save Current Car**.

If the team requires, for example, that the inner/forward right side lower control arm co-ordinates for set up purposes need to be moved back to their as measured x and/or y co-ordinates, this can be accomplished under **Edit, Origin**.