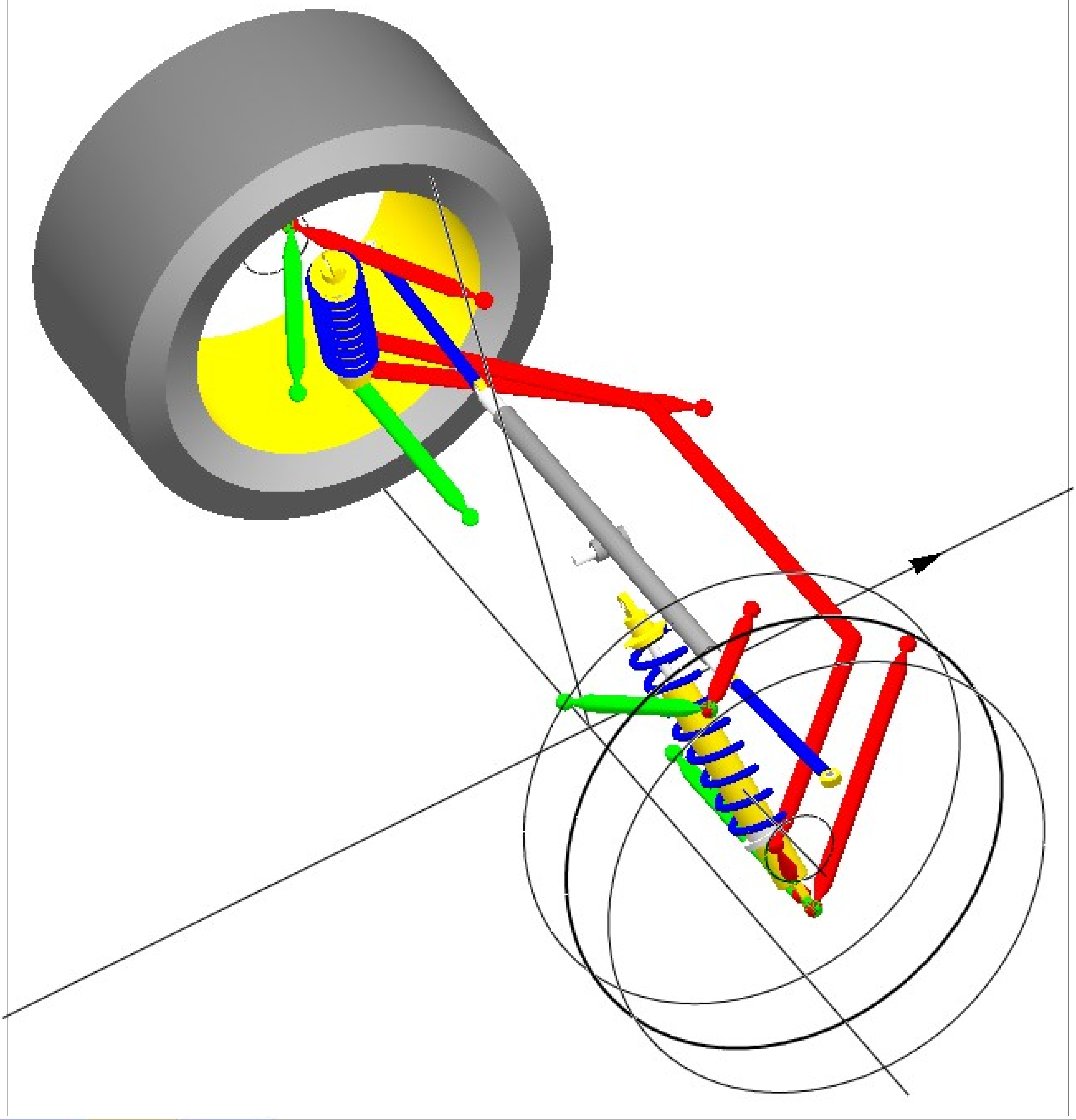

SusProg3D

Suspension by Design

Version 4.664C November 2019

SusProg3D - Suspension by Design

Robert D Small

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1 Overview

SusProg3D – Suspension by Design is a complete software package enabling the design, evaluation and visualization of race and road car suspension characteristics.

1.1 SusProg3D - Suspension by Design

SusProg3D provides for the design, evaluation and visualization of:

- Double A-arm
- Multi link suspension
  - lower A-arm, 2 upper links (virtual A-arm), toe link
  - lower A-arm, 2 upper lateral links, trailing link
  - upper A-arm, 2 lower links (virtual A-arm), toe link
  - upper A-arm, 2 lower links, trailing link
  - upper and lower lateral link, upper and lower trailing link, toe control link
  - upper and lower “virtual A-arms”, toe control link
  - upper transverse leaf spring, reversed lower A-arm and trailing link
  - single top link, reversed lower A-arm, upper and lower trailing links
  - single top link, parallel lower links, upper and lower trailing links
- Compound link suspensions (Porsche 928, Jaguar, Ford Thunderbird and Ford Integral Link (2015 Mustang))
- Trailing arm suspension
  - semi-trailing arm
  - trailing arm with upper and lower lateral links
  - trailing arm with upper and lower lateral links and toe control link
  - Volkswagen Beetle twin trailing links and toe control link.
- Macpherson strut
  - with A-arm and single pivot
  - with two lateral links and dual pivots
  - TriLink strut suspension
- Live rear axle (conventional)
  - Torque arm, twin trailing links with Panhard rod or Watts links
  - Torque tube with Panhard rod or Watts links
  - 3 or 4 trailing links with Panhard rod or Mumford, Watts or Woblink links
  - twin trailing arms with Panhard rod (NASCAR style), or Mumford or Watts links
  - 4 trailing links
- Live rear axle (speedway)
  - Torque tube with 4 trailing links and Jacobs ladder on 2 birdcages

- de Dion rear axle
    - 3 or 4 trailing links with Panhard rod or Mumford, Watts or Woblink links
    - twin trailing arms with Panhard rod or Mumford or Watts links (Alfetta style)
    - 4 trailing links
- Dead (non driving) axle
    - 3 or 4 trailing links with Panhard rod or Mumford, Watts or Woblink links
    - twin trailing arms with Panhard rod or Mumford or Watts links
    - 4 trailing links
- Automatic generation of roll centre and swing axle lengths.
- Automatic generation of chassis pivot points.
- Camber adjustment location on top, bottom or both links.
- Store and recall suspension design data.
- Display of camber, roll centre, castor and wheel scrub in roll and bump.
- A choice of shock absorber actuation styles for wishbone suspensions:
    - conventional outboard mounting
    - inboard mounting with rocking top arm
    - pushrod
    - pullrod
    - pushrod and floating shockabsorber
- Display of wheel rates at various stages in suspension travel
- Generation of spring design parameters
- Anti-roll bar rate calculations
- Dynamic chassis roll angle and weight transfer calculations
- Automatic generation of steering rack position to minimise bump steer
- Display of bump steer and toe-out in turn characteristics
- Driveshaft plunge
- Propshaft universal joint angles
- Weight distribution
- Automatic checking of a range of design parameters to find the "best" solution.

SusProg3D supports full 3D specification of all points.

Wishbone pivot axes may be tapered in both plan view and for anti-dive/anti-squat in side view, and for any chassis location point for suspension spring units.

User specified chassis datums.

User specified axis naming and orientation.

Camber and castor adjustment on specified wishbone links.

1.2 PC hardware and software requirements

- PC with Microsoft Windows 7, Windows 8 or Windows 10 (both 32-bit and 64-bit).
  Prior versions are no longer supported.
- A monitor with minimum 1024 x 768 resolution, preferred 1280 x 1024 resolution.
  SusProg3D displays best at 96dpi.
- OpenGL libraries.
  To run SusProg3D Viewer you will need GLU32.DLL and OPENGL32.DLL.
  These DLLs come with all current versions of Windows.
  For additional information about OpenGL, see www.opengl.org
  You will need an OpenGL video driver that supports version 1.2 (currently) and preferably version 2.1
- To use the Excel interface, you will need ExcelXP (version 10) or later. This is the version of Excel included with OfficeXP.
  Excel2000 (version 9) and earlier are not supported.
- A Windows compatible printer

1.3 To run the program

The installation program will create three entries in the Start menu.

Select 'Start' -> 'Programs' -> 'SusProg3D' -> 'SusProg3D'

If you create a desktop shortcut for SusProg3D, you can also add the name of the data file as a parameter to the target file name. Also change the Start directory to the location of the data file.

If you do not specify a data file, or the data file specified cannot be read, SusProg3D will generate a default file name for you. The name will be SP followed by six hex numbers (ie 0-9,A-F) plus a suffix of .s3d. This name will be shown on the title bar. This file can be renamed by using the File | Save As command.

1.4 Evaluation version

Until the program is registered, SusProg3D will operate in Evaluation mode. This is indicated by the "Evaluation" comment in the lower right corner of the screen.

In Evaluation mode, following restrictions apply:

- the wheel and tyre dimensions are fixed. There is a choice of 13", 15" and 17" wheel sizes.
- the upright, strut and axle dimensions are fixed.

The sample data files will all calculate correctly in Evaluation mode. The sample data sets are provided to enable a review of the capabilities of SusProg3D, using a number of typical configurations. They are not dimensionally accurate, but provide a reasonable set of dimensions.

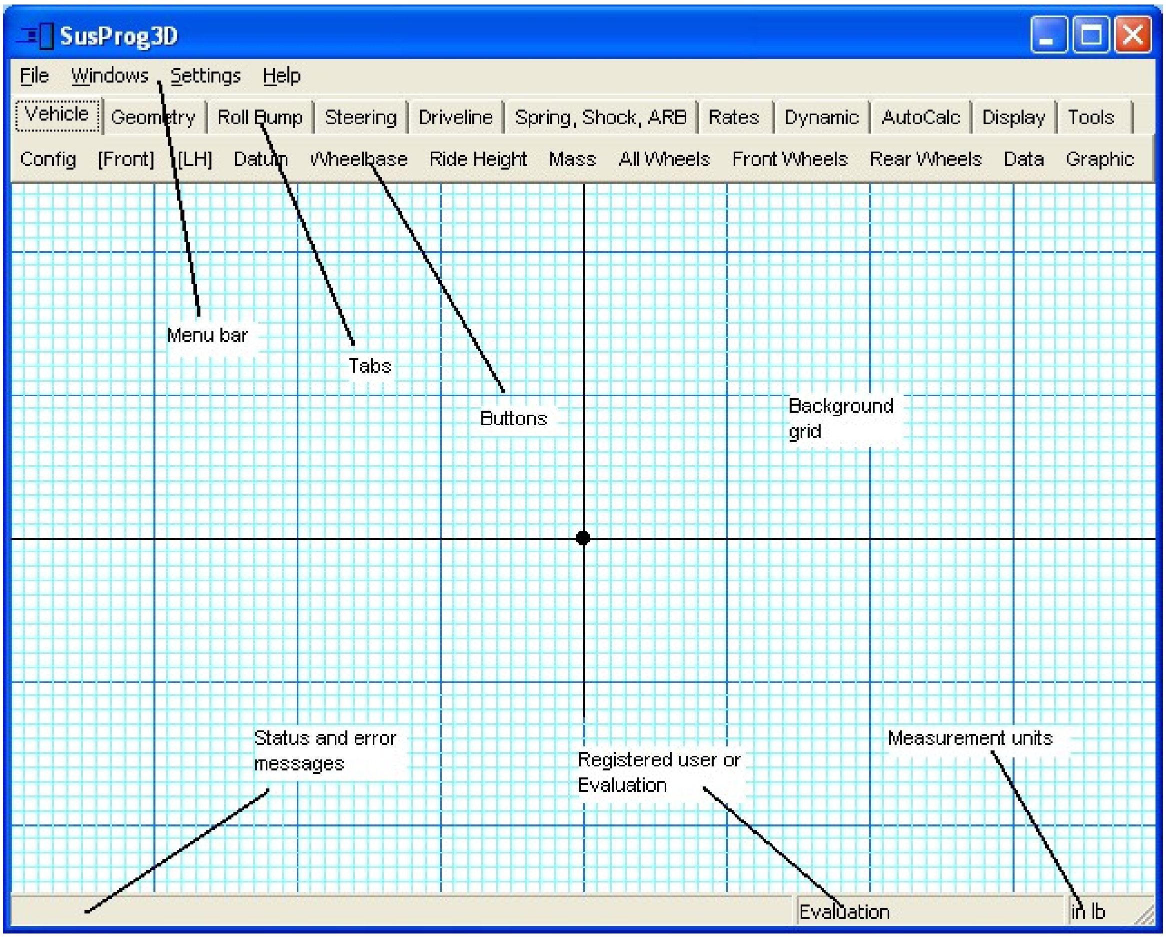
Srd912.s3d	Front	Wishbone, pullrod springs. 13" wheels.
	Rear	Wishbone, pushrod springs. 13" wheels.
Sedan.s3d	Front	Strut, 13" wheels
	Rear	Semi-trailing arm, 13" wheels
Subaru.s3d	Front	Strut, 13" wheels. Front wheel drive.

	Rear	Tri-strut, 13” wheels
Porsche928.s3d	Front	Wishbone, 15” wheels
	Rear	Porsche axle, 15” wheels.
Jaguar.s3d	Front	Wishbone, 15” wheels.
	Rear	Jaguar IRS, twin coilover shockabsorbers, 15” wheels.
LotusCortina.s3d	Front	Strut, 13” wheels
	Rear	Live axle, top trailing links, bottom A-frame, 13” wheels
GM4Link	Front	Wishbone, 15” wheels
	Rear	Live axle, top trailing links (converging on the axle), bottom trailing links
FalconAU.s3d	Front	Wishbone, 17” wheels
	Rear	Live axle, top and bottom trailing links, Watts linkage
HoldenVT.s3d	Front	Strut, 17” wheels
	Rear	Live axle, top and bottom trailing links, Watts linkage
Nascar.s3d	Front	Wisbone, 15” wheels, twin shocks, separate spring
	Rear	Live axle, twin trailing arms, panhard rod, separate springs.

2 User Interface

2.1 Screen layout

The initial SusProg3D screen consists of several regions, including a title bar, a menu bar, a set of tabs and tool bar buttons, the central display area, and a status line at the bottom.



The title bar includes the name of the data file in use, and minimize and close icons.

The menu bar has four menus - File, Windows, Settings, Display and Help, each with a number of items.

When a menu is selected, a list of the items will appear.

The set of tabs define the different areas of interest, such as Geometry and Spring. Each tab has a corresponding set of tool bar buttons. The tool bar buttons will activate a series of dialog boxes and display windows.

Dialog boxes are used to enter data. All dialog boxes contain buttons, delimited input fields (for both text and numeric values) and choice boxes.

Result windows contain the results of calculations. Result window interiors are scrollable. Scrolling the window across the data is done by moving a scroll bar along the bottom of the window, the right side of the window, or both. The scroll bar shows the window's position compared with the entirety of the data being displayed.

2.2 Exit

To exit SusProg3D, you can either select the Exit item in the File menu, or select the Exit icon in the title bar. Exit does not automatically save the data. If you need to save, then use File | Save or File | Save As before selecting Exit.

2.3 Status line

The status line displays error messages.

2.4 Toggle items

Some tool bar buttons act as toggles. They are identified by having their text enclosed in [] brackets. Selecting them switches the tool bar button description rather than opening a dialog box. An example is "[Chassis]" in the Steering section that, when selected, switches between "[Fixed]", "[Upright]" and "[Chassis]" in turn.

2.5 Keys

The F1 key will display the help file.

The F5 key will refresh the graphic display.

The F6 key or Ctrl-C will copy the display (as a bitmap image) to the clipboard. This image can be pasted (using Ctrl-V or the Paste command) into various applications such as Paint or Wordpad. The ‘+’ (plus) and ‘-‘ (minus) keys will zoom the display out and in.

The Print button will print the graphic direct to the printer. See Print the graphic for details.

2.6 Dialog box

However you select it, most tool bar buttons (the exceptions are toggle buttons, Result and Calculate buttons) will display a Dialog box. The Dialog box initially appears below the tab bar. You can move it around by moving the mouse pointer to the top line of the Dialog box, pressing the left mouse button, and moving the mouse while you hold the button down. When you let the button up, the Dialog box will stop where it is and remains there.

The Dialog box is a fixed size and cannot be resized or zoomed.

The Dialog box has a title on the top border line and a close icon (the ☒ button) at its upper right corner. The close icon, when clicked by the mouse, closes the Dialog box. The [Esc] key also closes the Dialog box.

Dialog boxes contain buttons, choices, input boxes and informational data.

When the dialog box has focus, the F6 key will copy the dialog (as a bitmap image) to the clipboard. This image can be pasted (using Ctrl-V or the Paste command) into various applications such as Paint or Wordpad.

2.6.1 Buttons

Each Dialog box typically has four buttons along the bottom. Usually labelled “Apply” (meaning “ Accept these input values, but leave the dialog open”),"OK" (meaning "I'm done. Close the Dialog box and accept the input values"), “Help” and "Cancel" (meaning "I want to close the Dialog box and ignore any changes made in it"). Note that if you do not change any values in a Dialog box, and press OK to close it rather than Cancel, then SusProg3D will assume that values have changed. The close icon and the Cancel button are identical in operation.

You push a button by clicking on it with the mouse, or by pressing [Enter] to select the default button. When you release the mouse button, the action specified takes place.

Notice that the OK button has a dotted rectangle around the text. This shows that the OK button is currently the default control within the Dialog box. If you press [Enter] while OK is the default, you are in effect pressing the OK button.

The default control within a Dialog box can be changed by pressing [Tab]. The distinctive default colours move from one button to the next with each press of [Tab]. This allows the user to press a button without using a mouse, by moving the default to the chosen button with [Tab], and then pressing [Enter] or [space] to perform the actual "press of the button".

When a Dialog box is open, one control is always highlighted. That is the active, or focused, control. For example, if a button has focus, the user can "press" the button by pressing [space]. Characters can be typed into an input line, or the input line edited, only if the input line has the focus.

The user can use [Tab] to move the focus from control to control within the Dialog box. Focus is usually shown by the change in colour of the prompt text. By default, the OK button has focus when the Dialog box is opened.

2.6.2 Radio buttons

Some Dialog boxes (for example AutoCalc | Chassis Limits) contain several items, only one of which can be selected at a time. These are indicated by unfilled circles ○. The currently selected item will be shown with a dot within the circle ⊙. To choose an item, move the focus with the cursor key and press [space], or click on it with the mouse. Radio buttons are so named because they function the same as the pushbuttons in a car radio, only one in the set is active at a time.

2.6.3 Check boxes

Some Dialog boxes (for example AutoCalc | Test Limits) contain several items, of which you can select as many (or as few) as you want. These items are shown by unfilled squares ☐. If an item is selected or ticked, it will be shown as ☑ or ☒. Selection method is identical to the radio buttons.

2.6.4 Labels

All input items (be they radio buttons, check boxes or numerical data) have associated descriptive labels.

2.6.5 Numeric input

The input box will display the existing value as a two or three decimal place number, 123.45 right justified. To change a single digit, either

- place the cursor on the wrong digit, press [Delete] and then press the correct digit, or
- place the cursor on the digit immediately to the right of the wrong digit, press [<-] (backspace), and then press the correct digit.

If it is required to enter more digits than are currently displayed, then place the cursor on a blank position and delete it. The number will move left one space. This enables additional digits to be inserted. If the cursor is in the left most position (the second space from the left) and the input line has focus, then the delete key will delete the entire value.

If the [Tab] key is used to move the focus to the desired input box, then pressing any key will delete the entire existing value and replace it with the new keystroke(s).

The only valid characters allowed as part of numeric values are "-" (prefix for negative values), "+" (prefix for positive values), "." (for the decimal point) and the digits zero to nine inclusive. Any other characters will be filtered out and not shown on the input line. It is not necessary to include the "+"

as all values not prefixed with minus "-" are positive. There is no need to keep the decimal points aligned, to enter a decimal point for whole numbers, or to enter any leading or trailing zeroes. If a number is incorrectly formatted (for example, has two decimal points or contains a space), then an error message will display. After clearing the error box, the cursor will remain on the input line for correction.

Similarly, there are values that are required to be positive, and if entered as negative, will cause a warning message. On clearing the warning box, the required sign conversion will be done and the correct value displayed.

Angular measurements can be entered as either "D° MM' Degree Minute" or "DD.dd Decimal degrees".
When using "D° MM' Degree Minute" there is no need to enter the degree or minute symbols. Just leave a space between the number of degrees and the number of minutes. To enter 5°15' just enter 5 space 15. If you enter a single number it will be taken as whole degrees, so if you enter 6, it will be the same as 6°00'. If you want to enter minutes only, you will need to prefix with 0 space, so to enter 30 minutes you will need to enter 0 space 30.
If the edit already contains a value showing the degree and minute characters then you need only overwrite the appropriate digit, leaving the degree and minute characters in place.

If using Imperial units,	enter 11 inches as 11 or 11.0 or 11.000.
	enter 3-1/4" as 3.25
	enter 1200 pounds as 1200 or 1200.000.
	generally, dimensions and weights will be displayed and printed to three decimal places.
	Dimensions within the range –99999.999 to +99999.999 (for linear dimensions, this is approx 1-1/2 miles) will be displayed as shown. Dimensions outside this range will be shown in scientific notation. For example, 123456.789 will be shown as 1.234E+05
If using Metric units,	enter 56mm as 56 or 56.0 or 56.00
	enter 34 and half mm as 34.5 or 34.50
	enter half mm as 0.5 or 0.50 or .5 or .50
	enter minus (or negative) 34 and half mm as -34.5 or -34.50
	generally, dimensions will be displayed and printed to two decimal places and weights to three decimal places.
	Dimensions within the range –999999.99 to +999999.99 (for linear dimensions, this is approx 1 kilometer) will be displayed as shown. Dimensions outside this range will be shown in scientific notation. For example, 1234567.89 will be shown as 1.234E+06

See unit settings for determining the units, and regional settings for determining the decimal separator character.

2.6.6 Regional settings

Numeric values that include a decimal separator will use the decimal symbol as specified in the regional settings.

This is specified in the "Number" tab of the Regional Settings Properties under Regional Settings in the operating system Control Panel.

2.7 Error and warning boxes

If there is an error that prevents the calculation being completed, a message will display in the status bar.

Some errors may have a warning box. Clear this box by selecting OK.

Usually any errors will be caused by forgetting to enter one or more required values, or entering a value with a negative sign when only a positive sign is expected.

2.8 Result window

A Result window has a title and a close icon (the same as a Dialog box).

The Results window can be closed and moved in the same manner as the Dialog box, additionally the contents can be scrolled both vertically and horizontally.

To print a portion of the data, select it using the mouse. Then “Print”. Only the selected text will be printed.

To print all of the data, clear any selection, then “Print”.

Use Printer Setup, Printer Font and Page Margins to set the printer and font sizes used, and the page margins.

2.9 File operations

There are several sub menu choices.

- New
- Open (vehicle)
- Open (front)
- Open (rear)
- Save
- Save As
- Printer Setup
- Printer Font
- Page Margins
- Print Options
- Print
- List of most recently used files
- Exit

2.9.1 Data file selection

The File menu includes a list of the Most Recently Opened files. Each time you open a file, it will be added to the top of this list. A maximum of 9 file names will be shown. "Double click" on a file name to open it.

Select File | Open. This will display the list of data files in the current directory. Select the file name, then select the Open button, or "double click" on the file name.

The default file suffix is .s3d. If your data file has a different suffix, either edit the default *.s3d

"Name" line by changing to the desired value, or include the file name as the parameter to the SusProg3D command as shown above.

"New" will open a new data file, and reset all the data values to zero or the standard default values.

There are three alternative "Open" menu choices.

Open (Vehicle) will open a data file, overwrite all the current data, and set all the data values to those in the file. This includes data which is specific to the vehicle, plus the data which is specific to the front and rear suspensions.

This is the normal file Open behaviour from previous versions.

To facilitate the creation of new vehicle data sets by combining the front suspension from one vehicle and the rear suspension from another, two additional file options are available.

Open (Front) and Open (Rear) function differently. They will also open a data file, but will only overwrite the data for the specified front or rear suspension, leaving the data for the other end unchanged. Any vehicle specific data will also remain unchanged.

Because each data file could have different chassis datum positions, it is suggested that the chassis datum (of the secondary data file) be relocated to the same position as the primary data file before the file copy. The following steps are suggested. Step 1. Open the secondary data file using Open(Vehicle) and relocate the datum to the required position. Save the data file. Step 2. Open the primary data file using Open(Vehicle). Step 3. Open the secondary data file, using Open (Front) or Open (Rear).

Vehicle mass and mass distribution will be recalculated.

Open (Front) and Open (Rear) will not update the following items:

Vehicle comments may need to be corrected.

Centre of Gravity height (used in anti-dive, anti-squat and dynamic calculations).

Lateral Acceleration (used in dynamic calculations).

The axle to datum distance and the wheelbase may not be correct. Adjust the datum location dimensions and recalculate. The wheelbase will then be correct.

The brake force and torque splits may need to be adjusted.

Some of the Dynamic values (wheelbase, mass distribution, centre of gravity and acceleration) may need to be adjusted or reloaded from vehicle values.

2.9.2 Save the data

Select File | Save or File | Save As.

Save will use the file name as displayed on the status line, appended with .s3d and overwriting the old file.

Save As will open a Dialog box, and expect a file name to be entered. This can also be used as a Copy/Rename operation.

2.9.3 Print vehicle data

Before printing, specify the printer, font and margins.

- Select Printer Setup (from the main menu, File then Printer Setup) and specify the printer, paper size, source and orientation.
- Select Printer Font (from the main menu, File then Printer Font) and specify the font, font style, and size. Because of the length of the print lines and the necessity to keep all the print data correctly aligned, the font choices will be limited to those with fixed font spacings. A good starting point is to use Courier New, Regular, 8 point. This will ensure that all lines will fit onto an A4 portrait page. The current font selection will become the new

default configuration.

- Select Page Margins (from the main menu, File then Page Margins) and specify the margins.
  ”Get Margins from Printer” will set the margins according to the actual page printable area.
  If “Wrap lines?” is ticked, then any line which would have been cut-off at the right margin will be wrapped around onto a second line. This can make the output difficult to read as the output columns will not line up.

Select Print Vehicle Data (from the main menu, File then Print Vehicle Data; or Vehicle > Data) and select which section(s) of vehicle data you wish to include. Then Print, and OK.

Geometry	will include all the basic suspension data.
Spring	will include all the spring actuation data.
Steering	will include all the steering data.
Driveline	will include all the Driveline data.
Misc	will include all the miscellaneous data for the complete vehicle.
Dynamic	will include all the dynamic data for the complete vehicle.
Pitch centre	will include all the pitch centre data for the complete vehicle. Because of the amount a data, it is suggested that this data be printed separately from the other data, with the printer set to landscape orientation.

Print the desired output (from the main menu, File then Print) and specify the printer (if necessary) and the number of copies. All output (as specified in the Settings) will print. If you specify ‘Print to file’ then Print will produce a text file. The file name will be the specified data file name with the suffix .TXT. Note that if a file already exists with the same name it will be overwritten without warning.

Besides the various values discussed in the Dialog boxes (both above and below), there are certain additional values included in the printout that are not otherwise available.

The SusProg3D program version, date and time, and the complete file name used will be printed as part of the page header.

The distance of the Ackermann point relative to the rear axle both as a dimension and a percentage of the wheelbase are also shown.

The section noted "Chassis reference dimensions" relates to an end view of the chassis, with the various points and dimensions relative to a stationary chassis, and the suspension moving up (in bump) and down (in droop).

The length of all the wishbones and links in end view is shown.

The wishbone angles are measured from the virtual pivot in end view, and may be different from the "real" wishbone angle relative to the actual wishbone pivot axis but are useful as a guide to balljoint articulation requirements.

The vehicle coordinates of all the upright pivot points and the moveable spring actuation points in full bump and full droop, relative to a stationary chassis and ground line, are shown. Note that these upright heights are different from the static upright height plus/minus the amount of wheel bump/droop. This is because the wheel travel is measured to the tyre cl, not the bottom of the upright. Due to camber change and distance from the upright pivot point to the tyre cl, usually less upright movement is required to move the tyre the required distance. The tyre contact point vertical value will be the actual maximum bump/droop dimension, and the lateral value will be the static track position adjusted by the amount of scrub.

2.9.4 Print the graphic

Before printing, specify the printer, margins and graphic print quality.

- Select Printer Setup (from the main menu, File then Printer Setup) and specify the printer, paper size, source and orientation.

- Select Page Margins (from the main menu, File then Page Margins) and specify the margins.
  ”Get Margins from Printer” will set the margins according to the actual page printable area.
- Select Graphic print quality (from the main menu, File then Graphic Print Quality) and specify the graphic print quality.
  - High
    This will print the graphic using the native printer resolution. Typically 300 to 720dpi. This will take the longest time to generate, and create the largest print spool file.
  - Low
    This will print the graphic at a quarter of the native printer resolution. Typically 75 to 180dpi. This will take the shortest time to generate, and create the smallest print spool file.
  - Medium
    This will print the graphic at a half of the native printer resolution. Typically 150 to 360dpi. Both generation time and the print file size will be in between those of High and Low.

Print the graphic (from the main menu, File then Print the graphic; or Vehicle > Graphic; or Display > Print) and specify the printer (if necessary) and the number of copies.

The graphic (as displayed on screen) will be scaled to fit the width of the page.

2.9.5 Exit SusProg

Select Exit (from the main menu, File then Exit).

Will exit SusProg3D.

Note that data changes are not saved (unless File | Save or File | Save As is used).

Configuration changes (such as units (ie millimetre kilogram or inch pound) and printer font name, style and size) are automatically saved on exit.

2.10 About

From the menu bar, select Help | About to open a message box displaying details about SusProg3D and the operating system.

The details include the SusProg3D version and build number

From the menu bar, select Help | OpenGL to open a message box displaying details about the OpenGL environment.

OpenGL hardware acceleration is dependant on correctly installed drivers, screen resolution and colour depth. Consult the documentation provided by the manufacturer of your video card. If your video card does not support OpenGL with either an ICD or MCD, then the default software emulation provided by the Microsoft OpenGL drivers will be used.

To enable OpenGL hardware acceleration with 3dfx video cards, consult the vendor’s documentation. SusProg3D has not been tested and may not run correctly with any 3dfx implementation of OpenGL libraries.

For additional information about OpenGL, see www.opengl.org

2.11 Settings

From the menu bar, select Settings.

Select Units to specify the units used for length and mass.

- Metric; for dimensions in millimetres and mass in kilograms
- Imperial; for dimensions in inches and weights in pounds.

Metric is the installation default.

Note that changing the unit setting does not change the data.
For example, if you are currently working in metric and have an open data file, and then decide to switch to working in imperial, you need to 1) save the data file, 2) change settings to imperial, then 3) reopen the the data file. You will get a message regarding the difference in units, so click "Cancel" (to keep SusProg3D as imperial, and to convert the data file from metric to imperial).

It is easiest if you change the unit setting before doing any work or opening a data file.

Select Motion Ratio to specify the method of displaying the shockabsorber and spring motion ratio.

- Wheel:Shock; the ratio will be the wheel travel divided by the shockabsorber travel. For example, if the wheel moves 25.0mm (1.0”) and the shockabsorber moves 20.0mm (0.787”) then the motion ratio will be 1.25
- Shock:Wheel; the ratio will be the shockabsorber travel divided by the wheel travel. For example, if the wheel moves 25.0mm (1.0”) and the shockabsorber moves 20.0mm (0.787”) then the motion ratio will be 0.8

Wheel:Shock is the installation default.

Select Axis System to specify the axis nomenclature and orientation.

For each axis, lateral, vertical and longitudinal, select the identifier (X, Y or Z) and the positive direction.

Imagine sitting in the vehicle, looking directly at the front of the vehicle. Lateral values are horizontal values measured from the vehicle centreline, and are either positive to the left (and negative to the right), or positive to the right (negative to the left). Vertical values are measured vertically from the ground or vertical datum plane, and are either positive upwards (and negative downwards), or positive downwards (and negative upwards). Longitudinal values are forward and backward values measured from the longitudinal datum, and are either positive values rearward (and negative forward), or positive forward (and negative rearward).

If the longitudinal axis is positive rearward, a negative value means the item is forward from the longitudinal datum reference point, and a positive value means the item is rearward from the longitudinal datum reference point; if the longitudinal axis is positive forward, a positive value means the item is forward from the longitudinal datum reference point, and a negative value means the item is rearward from the longitudinal datum reference point.

The SAE Recommended Practice, SAE J670e, uses a right-hand orthogonal axis system such that the X axis is horizontal and points forward, the Y axis points to the driver’s right and the Z axis points downward. The setting parameters for this axis system are lateral is Y with +ve RH, vertical is Z with +ve downward, and longitudinal is X, with +ve forward.

ISO 4130 and DIN 70000 as well as some CAD/CAM packages use a right-hand orthogonal axis system such that the X axis is horizontal and points forward, the Y axis points to the driver’s left and the Z axis points upward. The setting parameters for this axis system are lateral is Y with +ve LH, vertical is Z with +ve upward, and longitudinal is X, with +ve forward.

The SusProg3D default is a left-hand orthogonal axis system such that the Z axis is horizontal and points rearward, the X axis points to the driver’s left and the Y axis points upward. The setting parameters are lateral is X with +ve LH, vertical is Y with +ve upward, and longitudinal is Z, with +ve rearward.

All examples in this help file refer to the various axis as La (lateral axis), V (vertical axis) and Lo (longitudinal axis). For example, where the geometry configuration is described as “Wheel location and alignment” this means that a dimension in relation to the longitudinal, axis is required.

Select Wheel Mounting Flange to specify the wheel mounting flange datum and direction. Refer Wheel coordinates for additional details.

Select WheelToeMeasurement and then either "Degree" or "Offset and Length".
If you are using a laser wheel alignment tool (or similar) then these usually show the toe setting in degrees; if you are measuring the offset difference across the wheel then use "Offset and Length".

Select Angular units and then either "DD.dd Decimal degrees" or "D° MM' Degree Minute".
When using "D° MM' Degree Minute" there is no need to enter the degree or minute symbols. Just leave a space between the number of degrees and the number of minutes. To enter 5°15' just enter 5 space 15. If you enter a single number it will be taken as whole degrees, so if you enter 6, it will be the same as 6°00'. If you want to enter minutes only, you will need to prefix with 0 space, so to enter 30 minutes you will need to enter 0 space 30.
If the edit already contains a value showing the degree and minute characters then you need only overwrite the appropriate digit, leaving the degree and minute characters in place.
When using "DD.dd Decimal degrees" all calculated values are rounded to 0.01 of a degree; when using "D° MM' Degree Minute" all calculated values are rounded to 1 minute.
Note that 1 minute is approximately the same as 0.017 degree, so using "DD.dd Decimal degrees" is a slightly finer resolution.

Select Edit Font to choose the font used for all numeric inputs. The font size is fixed.

Select Result Font to choose the font used for all ‘on screen’ results outputs. In order to correctly align the data, the fonts are limited to those with fixed character spacing.

Select Printer Font to choose the font used for all print outs. In order to correctly align the data, the fonts are limited to those with fixed character spacing.

Display settings, see Display settings for details.

Start with last working file. Tick this if you want Susprog3D to automatically load the last used data file, otherwise Susprog3D will open with a new data set.

3 Coordinate system

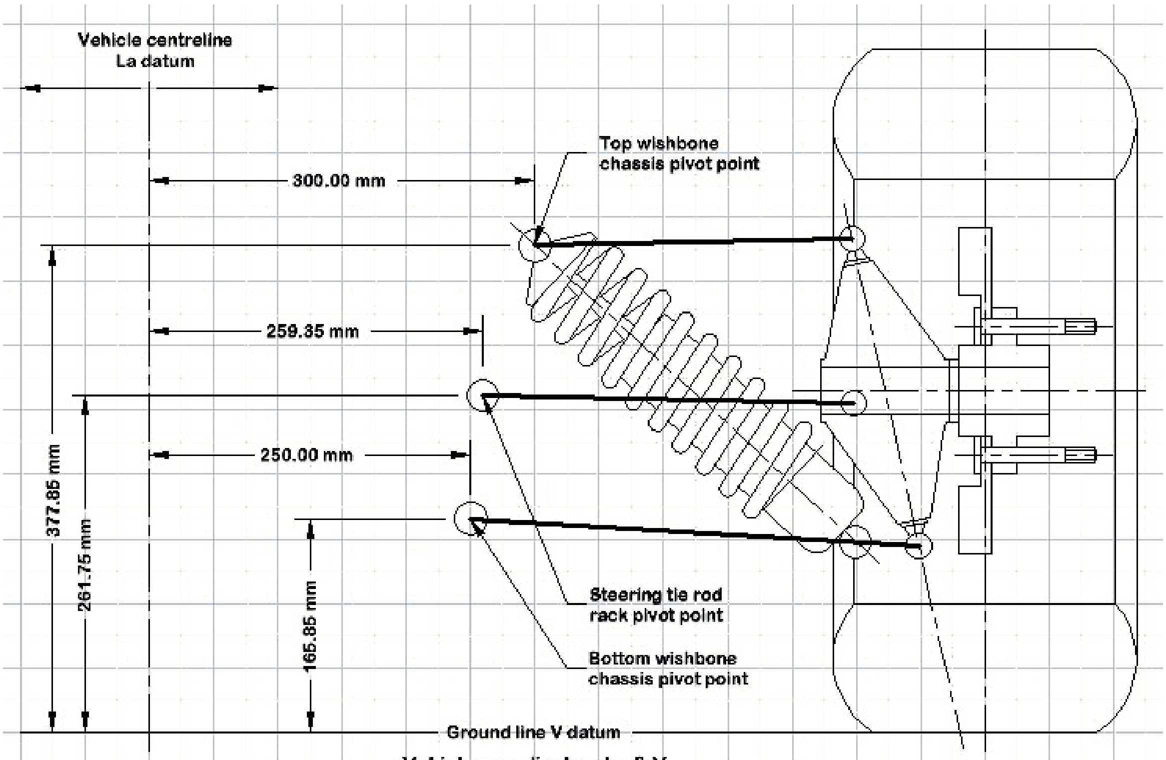
All coordinates are represented with three dimensional lateral, vertical and longitudinal values.

There are vehicle, chassis, upright and wheel coordinates.

Refer to Settings for additional details.

If you have 3D Coordinate Measuring Machine (CMM) or world coordinates for the upright/axle/strut points, and need to convert those coordinates to upright/axle/strut datum points, go to CMM.

3.1 Vehicle coordinates.

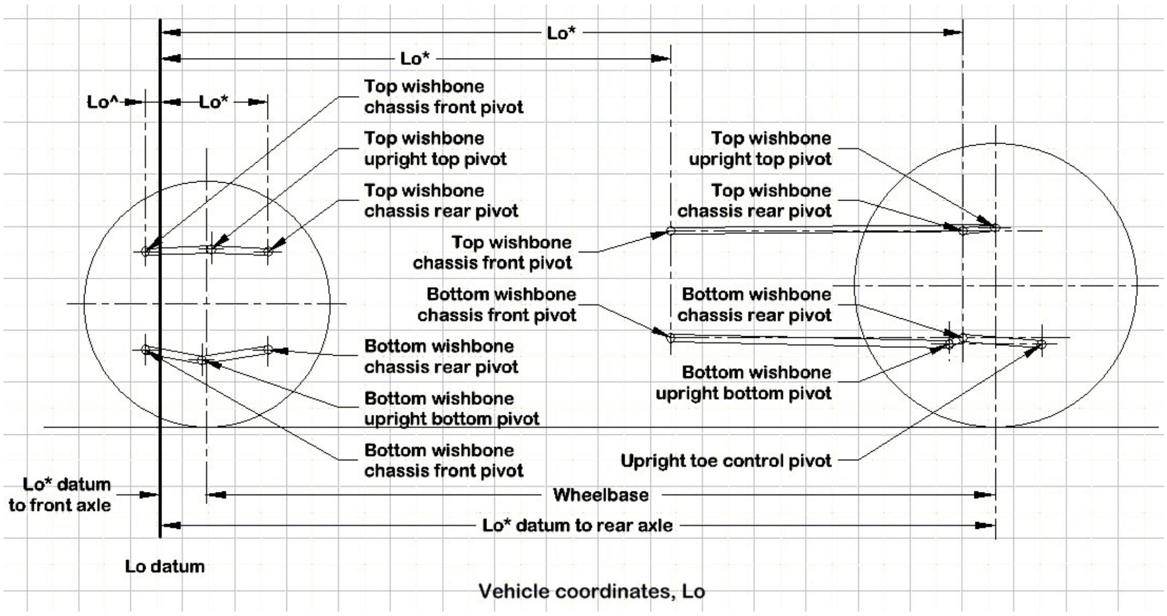


Vehicle coordinates, La & V

Lateral values are horizontal values measured from the vehicle centreline, vertical values are measured vertically from the ground line, and longitudinal values are measured from the longitudinal datum.

For example, consider the ball joint on the end of the steering rack, where the steering rack is mounted behind the front axle (in plan view) and the chosen longitudinal datum corresponds to the nominal axle centreline. Then the lateral dimension is 259.4 (ie the distance the rack ball joint is from the vehicle centreline in plan view), the vertical dimension is 261.7 (ie the height of the rack ball joint from the ground line datum) and the longitudinal dimension is 100.1 (ie the distance the rack ball joint is from the datum).

Depending on the chosen datum system, the lateral values will be shown as positive values for one side of the vehicle, and negative for the other.



Chassis mounting / pivot points are defined for each suspension linkage location, with each point having lateral, vertical and longitudinal dimensions

If the chosen longitudinal axis is +ve rearward, then Lo* values will be +ve; Lo^ values will be -ve. If the chosen longitudinal axis is +ve forwards, then Lo* values will be negative; Lo^ values will be positive.

Each wishbone pivots about an axis that passes through the front and rear pivot points.

The chassis virtual pivot point is the intersection of the wishbone pivot axis and a front view plane on the axle centreline. This is the point about which it can be considered that the wishbone is pivoting in front view and defines the effective front view wishbone length (also known as the virtual length) of the wishbone.

The upright virtual pivot point is that point where a vertical from the centre of the tyre contact point intersects the plane of the front & rear chassis pivot points and the upright pivot point.

In front view, the intersection of the lines through the top wishbone front view chassis virtual pivot point & upright virtual pivot point and the bottom wishbone front view chassis virtual pivot point & upright virtual pivot point together define the front view instant centre. The distance of the front view instant centre from the wheel contact centre is the front view swing axle length, and its height is the front view instant centre height. The roll centre is the point where the line from the front view instant centre to the wheel contact centre intersects a vertical on the vehicle centreline.

Similarly, there are the equivalent points in the side view plane which define the side view instant centre length, height and angle.

The wishbone normal point is that point where a line from the upright pivot point intersects the wishbone axis at 90 degrees and is used to define the shock absorber and antiroll bar link pickup points.

If the wishbone pivots are not in line, the chassis virtual points will move slightly in bump and droop due to backward and forward movement of the upright pivot point. If the wishbone pivot points are in line, the lateral and vertical values of both pivot points will be identical.

3.2 Chassis coordinates.

As an aid for chassis design and construction, most chassis are dimensioned from a convenient datum plane and this datum plane is then used for the chassis build, in either a jig or on a surface plate.

Chassis coordinates are vehicle independent and are represented with lateral, vertical and longitudinal values. The datums for the chassis are the chassis centreline (the lateral datum), a convenient horizontal surface, such as the plane of the undertray or the side sills (the vertical datum) and a single convenient point, such as a jig hole or other fixed point (which locates the longitudinal datum).

All chassis points (such as the wishbone mounting points) are then referenced to these datums.

For convenience, both LH and RH lateral values are entered as positive values (measured outwards from the chassis centreline).

To “position” the chassis at the required static ride heights, a front and rear ride height reference point must be specified. These can be any convenient “hard” point, such as a wishbone mounting bolt, and are dimensioned from the chassis datums. For each of the reference points, the actual ground based ride height must also be specified.

This provides for the common practice of designing and building the chassis in a horizontal position, but having the completed vehicle adopt a static ride position with the chassis is raked, usually nose down.

SusProg3D will then show, for all the chassis points, both the ground based vehicle coordinates and the chassis coordinates.

The default vertical datum is the ground plane, and the default longitudinal datum is the front axle centreline.

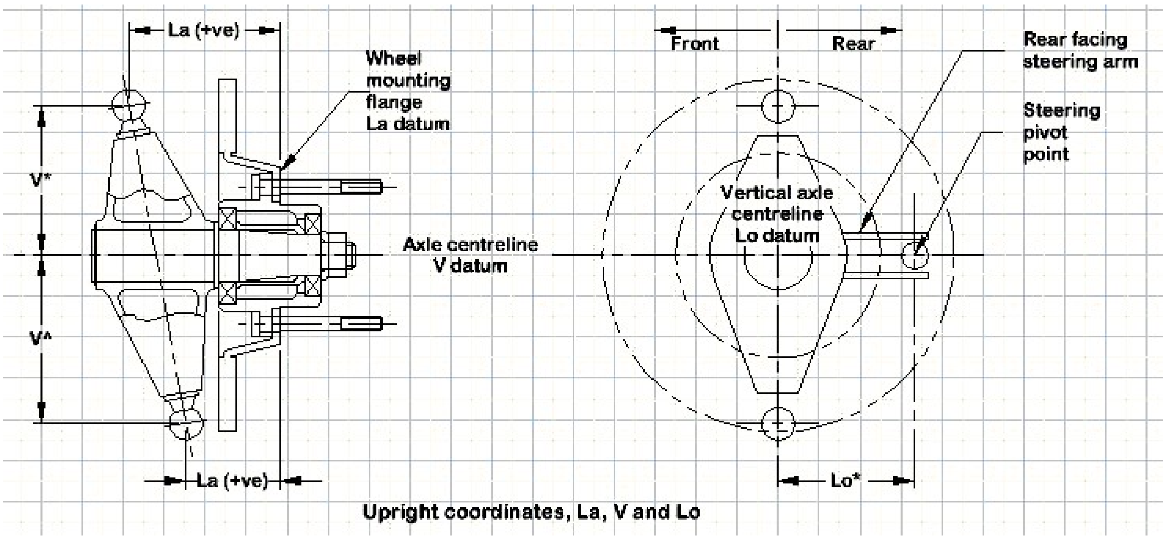
If you prefer to use the ground datum as the chassis vertical datum, particularly if you are measuring an existing completed vehicle, then note the vertical datum as “ground” and measure all chassis points from the ground. You may find it convenient to specify the ride height reference points and their ride heights, as this will provide an easy means of adjusting the ground clearance and rake, while maintaining all the chassis points relative to each other.

For further details on using a ground based vertical datum.

For further details on converting from a ground based to a chassis based vertical datum.

For further details on using a chassis based vertical datum.

3.3 Upright coordinates.



Upright coordinates are vehicle independent and are represented with lateral, vertical and longitudinal values. The datums for the upright are the wheel mounting flange and the axle (or hub) centreline.

All upright measurements are with the upright at zero camber, castor and toe position.

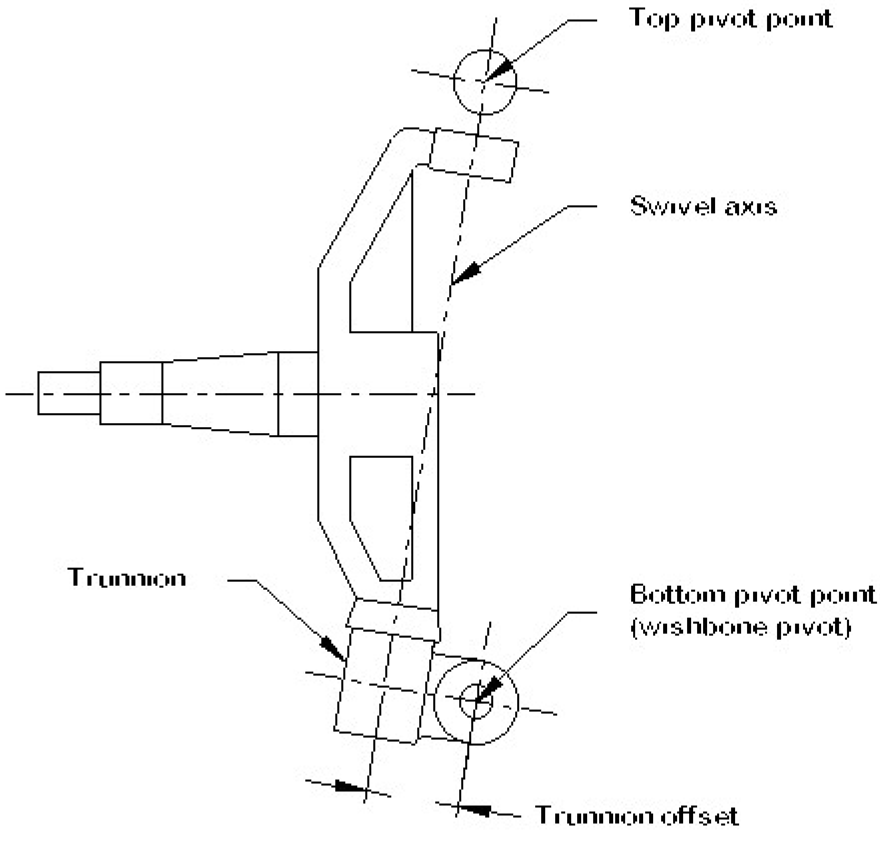
Again, imagine the upright viewed from the front of the vehicle. Lateral values are positive inboard of the wheel mounting flange, vertical and longitudinal values are measured from the axle centreline.

For the usual design of upright, the top pivot point(s) is above the axle centreline, and the bottom pivot point(s) is below the axle centreline. If the vertical axis is positive upward, then the top pivot vertical dimension V* will be positive and the bottom pivot vertical dimension V^ will be negative; if the vertical axis is positive downward, then the top pivot vertical dimension V* will be negative and the bottom pivot vertical dimension V^ will be positive.

Longitudinal values are measured from the axle centreline in side view, and will be positive to the rear, negative to the front (if the longitudinal axis is specified as +ve rear); or will be positive to the front, negative to the rear (if the longitudinal axis is specified as +ve front).

Usually, both upright pivot points will have +ve lateral dimensions, La.

Depending on the particular geometry type, there will be 3, 4 or 5 pivot mounting points.



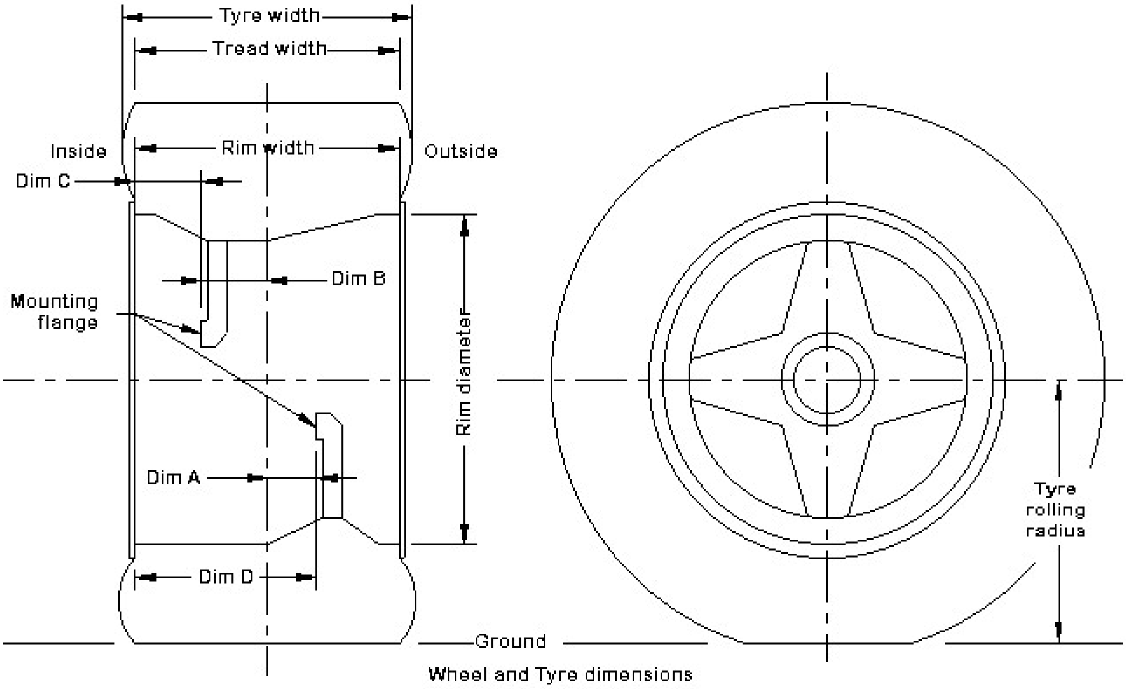
Typical Triumph Spitfire type front upright

For the older style trunnion joints where the wishbone pivot and king pin swivel axis are not coincident, the pickup point dimensions are to the horizontal wishbone pivot. An additional dimension, the “kingpin swivel offset”, is the distance from the horizontal wishbone pivot normal to the king pin swivel axis. If the king pin swivel axis is outboard from the wishbone pivot (as the Triumph Spitfire bottom trunnion) this dimension is positive. If the king pin swivel axis is inboard from the wishbone pivot (as the MGB top trunnion) this dimension is negative.
Typical examples are the Triumph Spitfire type front upright, with a top ball joint and a bottom trunnion, and the MGB with both top and bottom trunnions.

For ball joints, the “kingpin swivel offset” dimension must be left at zero.

3.4 Wheel coordinates.

Wheels have an offset value which determines the location of the wheel mounting flange relative to the wheel rim.



Wheel and Tyre dimensions

There are alternative methods for specifying the wheel mounting flange location. See Settings.

Offset The datum is the rim centreline. The offset is positive when the mounting flange (or face) is closer to the inside of the wheel, and negative when the mounting flange is closer to the outside of the wheel.

For the wheel in the upper half of the above diagram, Dim B is positive.

For the wheel in the lower half of the above diagram, Dim A is negative.

This is the default SusProg3D datum and direction.

Inset The datum is the rim centreline. The inset is positive when the mounting flange (or face) is closer to the outside of the wheel, and negative when the mounting flange is closer to the inside of the wheel.

For the wheel in the upper half of the above diagram, Dim B is negative.

For the wheel in the lower half of the above diagram, Dim A is positive.

German standard DIN 7829 refers to this dimension as “depth of impression” and uses the prefix “ET”

Backset The datum is the inside face of the inboard rim flange. Backsets are positive when the mounting flange (or face) is towards the outside of the wheel.

For the wheel in the upper half of the above diagram, Dim C is positive.

For the wheel in the lower half of the above diagram, Dim D is positive.

Note that this dimension requires that the rim width be specified, in order to locate the rim centreline.

3.5 LH and RH coordinates.

All chassis and vehicle reference points can be specified different LH and RH.

The [LH] or [RH] tab choice will indicate the currently selected vehicle side.

This tab acts as a toggle, and selecting this tab will switch LH to RH, and RH to LH.

When a dialog box is opened, the title will include the currently selected car side. If the car side is not shown, then the dialog box applies to both sides.

Where points can be specified differently for each side of the vehicle, there will be a “RH identical?” (if inputting the LH side) or “LH identical?” (if inputting the RH side) check box.
If both sides are currently the same, this box will be “ticked”. If there is a difference between the LH and RH side, then this box will be "clear" or "not ticked".
If the dimensions you enter are to be applied to both sides, “tick” this box.
If you do not wish to apply the dimensions to the other side, “untick” or “clear” this box.

It is suggested that the side of the vehicle with the positive lateral axis be used.

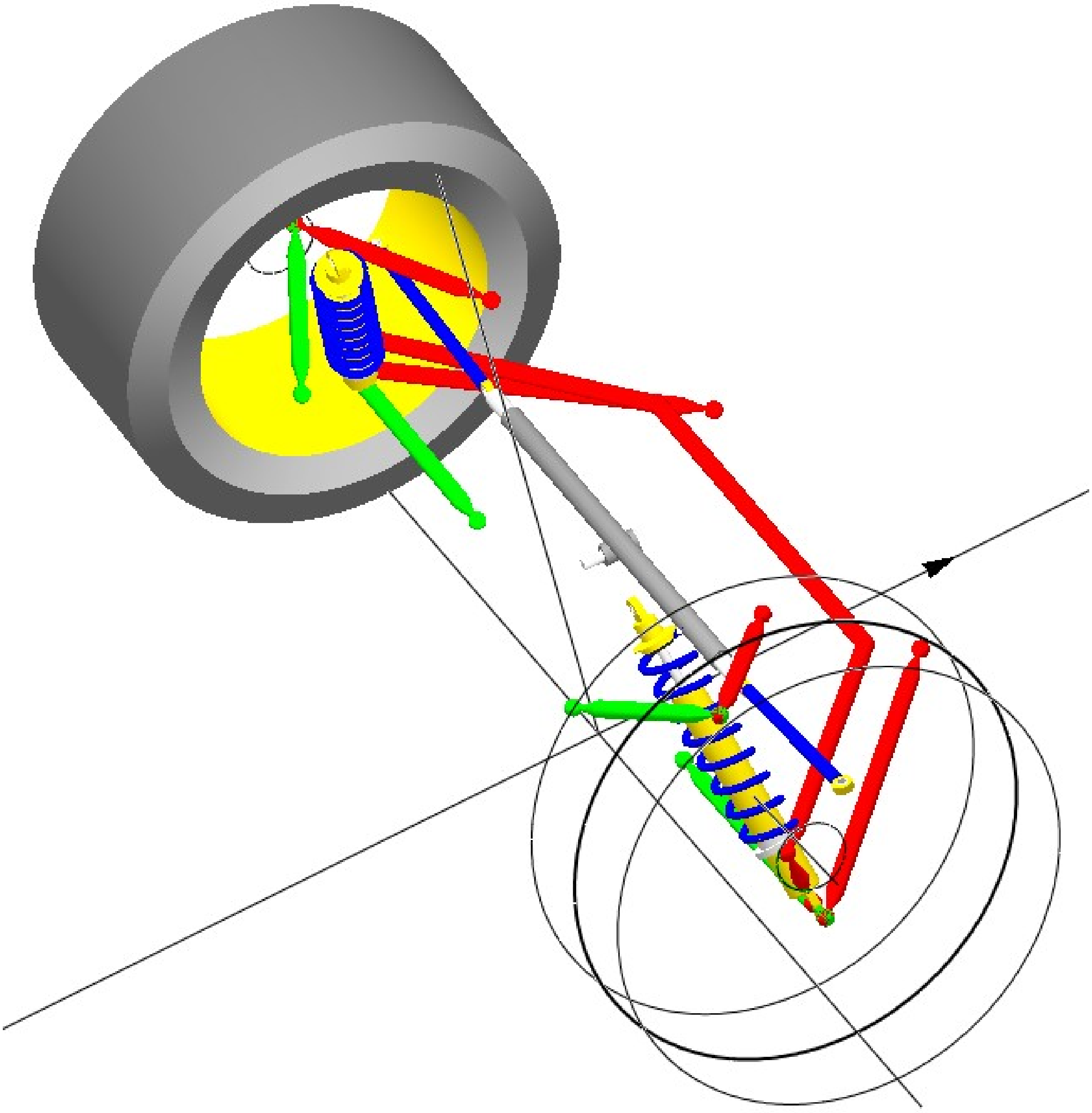
4 Suspension geometry types

SusProg3D supports the following suspension geometry types.

Description	Front	Rear
Double A-arm, toe link	Yes	Yes
The classis unequal length, non parallel wishbone format		
Lower A-arm, upper virtual A-arm, toe link.	Yes	Yes
A typical example is the PorscheGT3 rear suspension.		
Lower A-arm, upper parallel links, trailing link.	No	Yes
A typical example is the Plymouth Prowler rear suspension.		
Upper A-arm, lower virtual A-arm, toe link.	Yes	Yes
A typical example is the Mitsubishi Galant front suspension.		
Upper A-arm, lower trailing and lateral links, toe link.	No	Yes
A typical example is the Mitsubishi Galant rear suspension.		
Upper and lower lateral links, twin trailing links, toe link.	No	Yes
A typical example is the Chevrolet Corvette C4 rear suspension.		
Upper and lower virtual A-arms, toe link.	Yes	Yes
A typical example the Mercedes multilink rear suspension.		
Upper transverse leaf spring, lower reversed A-arm and trailing link	No	Yes
As used on the Triumph GT6		
Upper lateral link, lower reversed A-arm, twin trailing links.	No	Yes
The classic ‘60s sports and racing cars rear suspension.		
Lower lateral link, upper reversed A-arm, twin trailing links	No	Yes
An alternative version of the classic ‘60s sports and racing cars rear suspension.		
Upper lateral link, lower parallel links, twin trailing links.	No	Yes
A variation of the reversed lower A-arm.		
Ford Integral Link	No	Yes
As used on the 2015 Mustang and other Ford platforms		
Ford Twin I-Beam	Yes	No
As used on various Ford trucks and SUVs		
Volkswagen twin trailing links	Yes	No
As used on the on the original Beetle		
Jaguar IRS	No	Yes
with the driveshaft as the camber control link.		
H-arm and camber control link	No	Yes
as used on the Ford Thunderbird		
Porsche 928	No	Yes
Semi-trailing arm	No	Yes
Semi-trailing arm, camber control and toe control links.	No	Yes
As used on the Mazda RX7		

Trailing arm, upper and lower lateral links.	No	Yes
Typical examples are the pre '84 Chevrolet Corvette, the BMW E36 and the Lotus Europa.		
Trailing arm, upper and lower lateral links, toe control link	No	Yes
Typical examples are the Honda Civic and Integra.		
Macpherson strut	Yes	Yes
with lower A-arm or the typical lateral link and anti-roll bar		
Strut, lower "virtual A-arm", toe link	Yes	Yes
Used on some BMW models		
Tri-link strut	No	Yes
with single trailing link and two lateral links		
Live axle (torque arm), 4 trailing links (birdcage) + Panhard rod	No	Yes
Live axle (torque arm), 4 trailing links (birdcage) + Watts linkage	No	Yes
Live axle (torque arm), 2 trailing links (torque arm slider) + Panhard rod	No	Yes
Live axle (torque arm), 2 trailing links (torque arm slider) + Watts linkage	No	Yes
Live axle (torque tube) + Panhard rod	No	Yes
Live axle (torque tube) + Watts linkage	No	Yes
Winters: 4 trailing links, 2 birdcages + Jacobs ladder	No	Yes
the typical speedway rear suspension		
Live /de Dion / rigid axle, 2 trailing arms + Mumford linkage	Yes	Yes
Live / de Dion / rigid axle, 2 trailing arms + Panhard rod Nascar style	Yes	Yes
Live / de Dion / rigid axle, 2 trailing arms + Watts linkage	Yes	Yes
Live / de Dion / rigid axle, 3 or 4 trailing links + Panhard rod	Yes	Yes
Live / de Dion / rigid axle, 3 or 4 trailing links + Mumford linkage	Yes	Yes
Live / de Dion / rigid axle, 3 or 4 trailing links + Watts linkage	Yes	Yes
Live / de Dion / rigid axle, 4 trailing links	Yes	Yes

4.1 Double A-arm, toe link



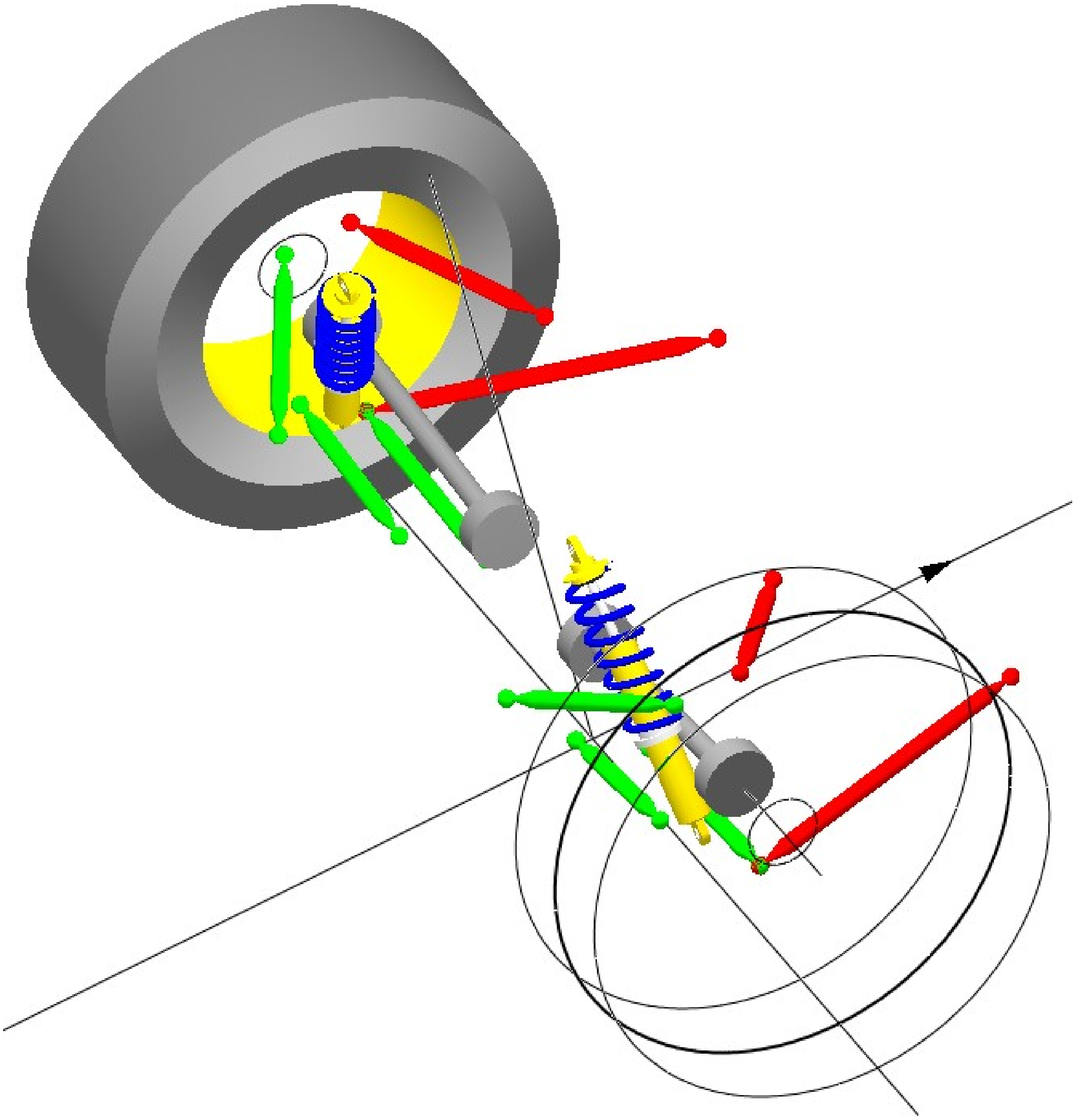
The classic double A-arm with a separate toe control link. Usually configured with unequal length non parallel A-arms, but can also be parallel A-arms, either equal or unequal length.

Five chassis mounting points.

> When used as a front suspension there are two chassis mounting points for each A-arm and one for the steering tie rod (which can be either the end of the steering rack or the tie rod mounting on the steering linkage).
>
> When used as a rear suspension there either four or five chassis mounting points. Two chassis mounting points for each A-arm plus the toe control link can be a fifth chassis mounting point, or the toe link mounting can be common with one of the A-arm link mountings, or it can be on one of the A-arm links.

Three upright mounting points, one top A-arm, one bottom A-arm and either a steering arm or a toe control link mounting.

4.2 Lower A-arm, upper "virtual A-arm", toe link



Five chassis mounting points.

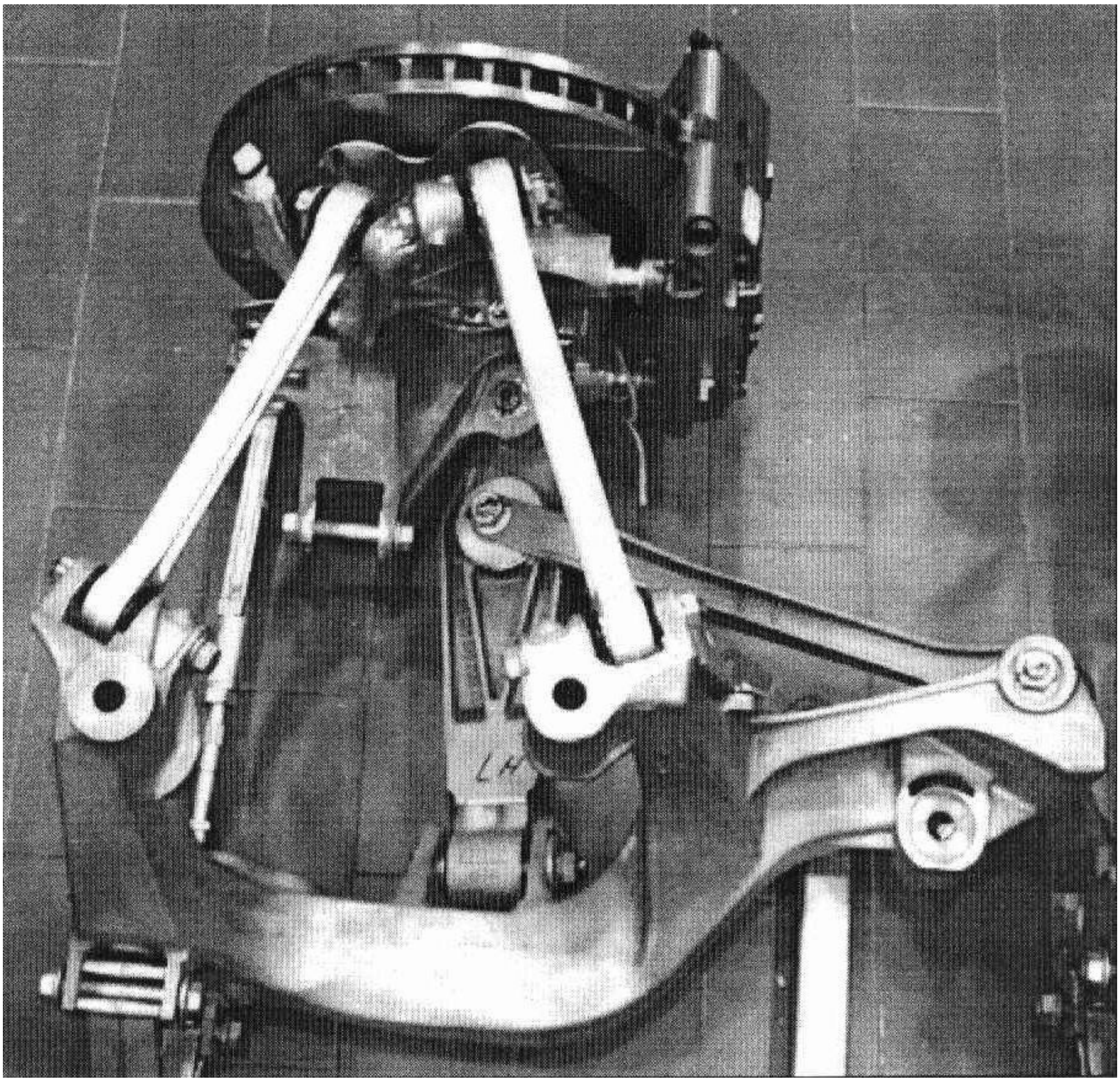
When used as a front suspension there are five chassis mounting points, two for each A-arm and one for the steering tie rod (which can be either the end of the steering rack or the tie rod mounting on the steering linkage).

When used as a rear suspension there either four or five chassis mounting points. Two chassis mounting points for each A-arm plus the toe control link can be a fifth chassis mounting point, or the toe link mounting can be common with one of the A-arm link mountings, or it can be on one of the A-arm links.

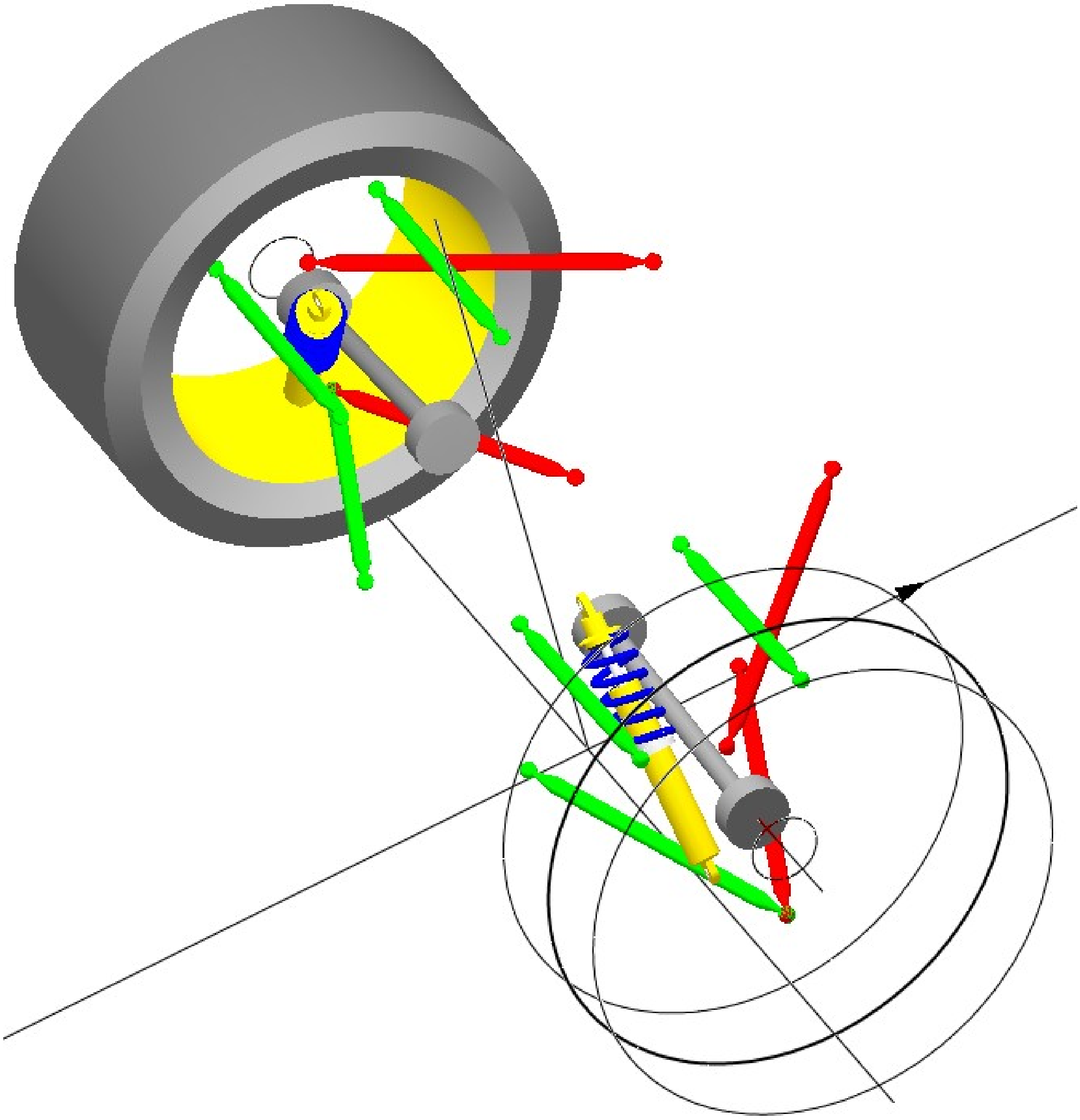
Four upright mounting points, one for the lower A-arm, one for each link of the upper "virtual A-arm", and one for the toe link.

In the PorscheGT3 rear suspension the lower lateral link and the lower trailing link act as a lower A-arm, with two chassis mounting points and a single upright mounting point. The pair of angled (in plan view) upper links converge to form a “virtual” A-arm, and the toe control link controls the toe.

In the case of the PorscheGT3, the lower A-arm is implemented as a trailing link connecting part way along the lateral link. However, for calculation purposes, the lower link lengths need to be specified as the distance from chassis pivot to the upright pivot.



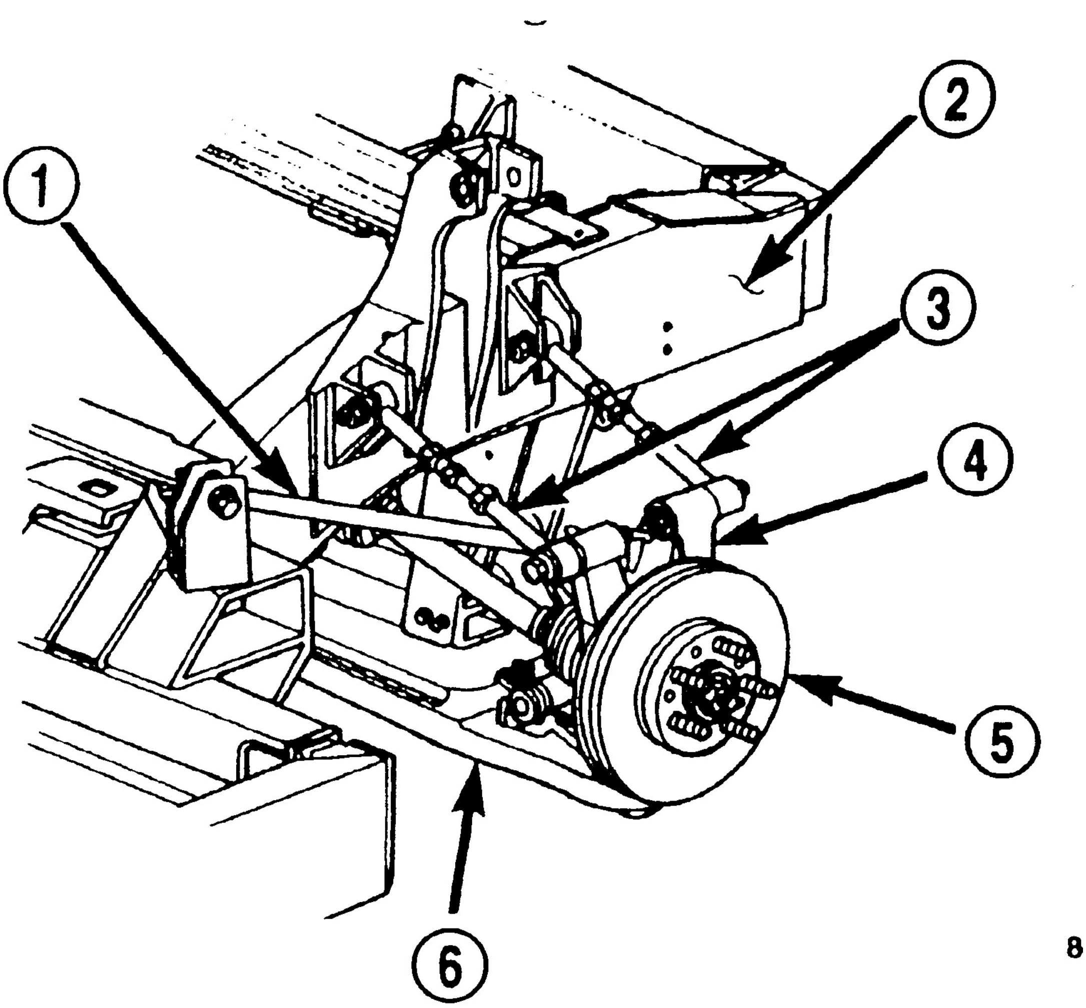
4.3 Lower A-arm, upper parallel links, trailing link



Five chassis mounting points, two for the lower A-arm, one for each of the upper lateral links, and one for the trailing link. The upper lateral links are generally parallel (in plan view) and symmetrically disposed about the axle centreline.

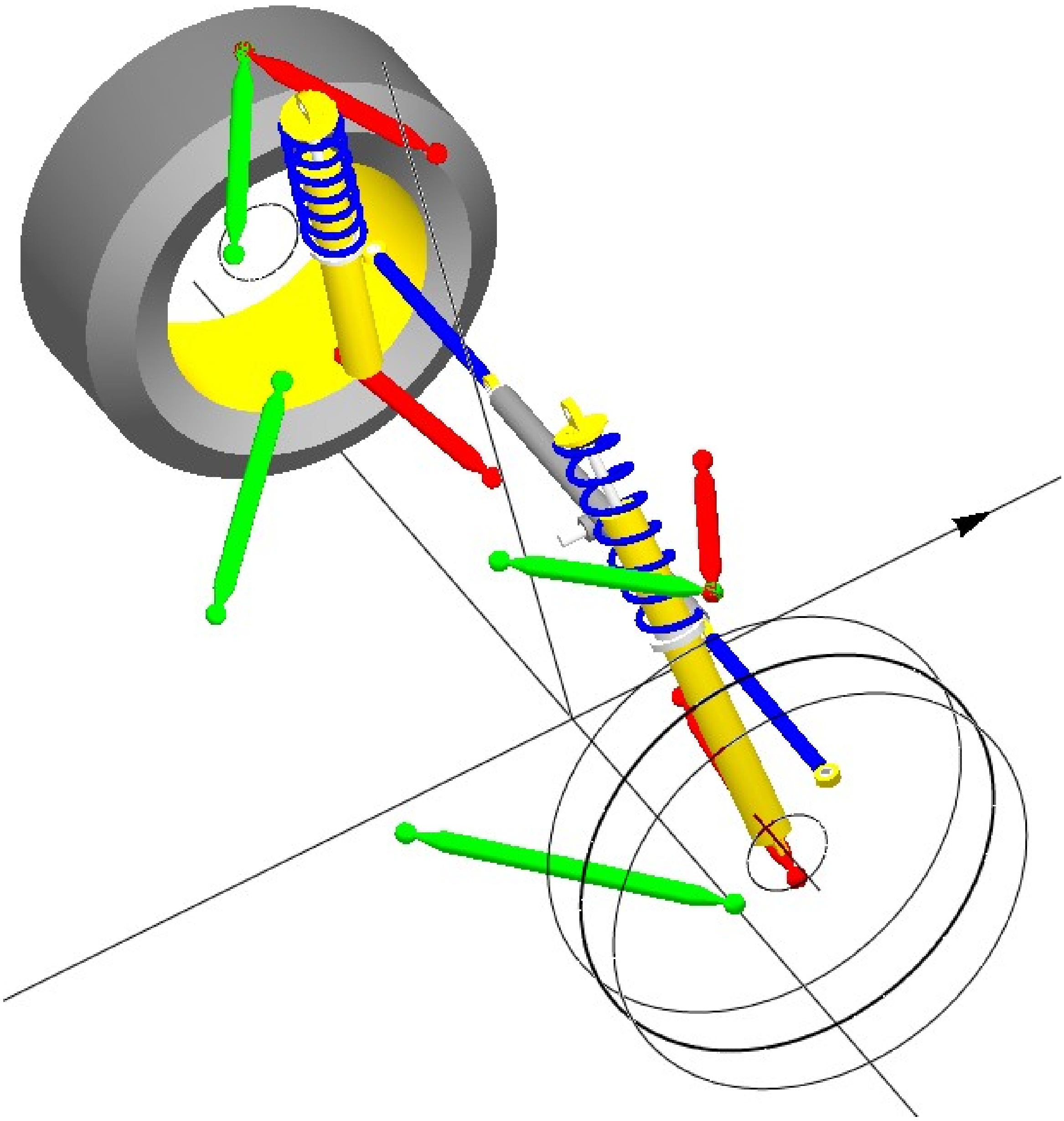
Four upright mounting points, one for the lower A-arm, one for each upper lateral link, and one for the trailing link.

The Plymouth Prowler rear suspension is typical of this configuration.



1 Trailing link
2 Chassis
3 Upper lateral links
4 Upright
5 Disk rotor and wheel hub
6 Lower A-arm

4.4 Upper A-arm, lower "virtual A-arm", toe link

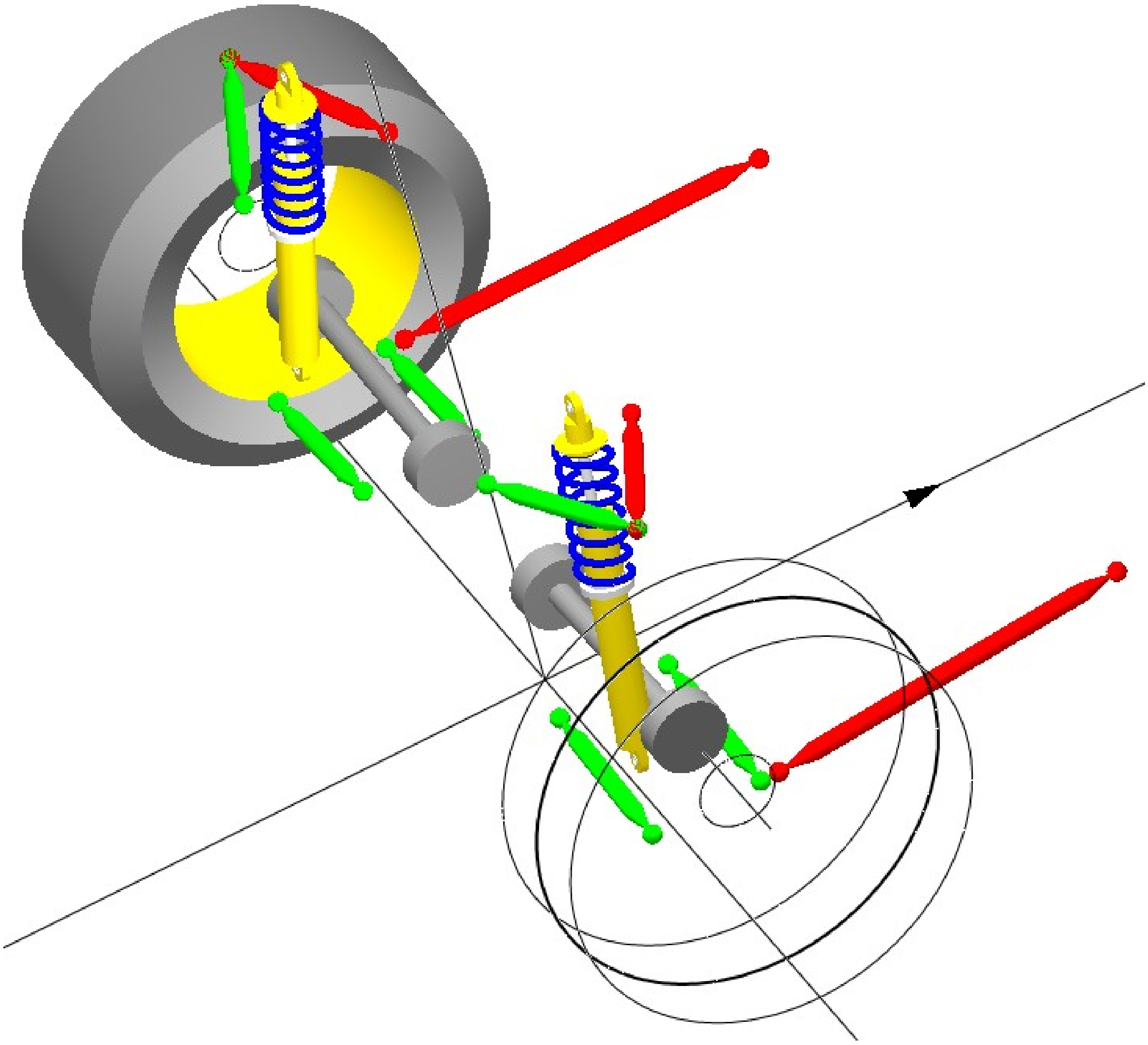


Five chassis mounting points.

> When used as a front suspension there are five chassis mounting points, two for each A-arm and one for the steering tie rod (which can be either the end of the steering rack or the tie rod mounting on the steering linkage).
>
> When used as a rear suspension there either four or five chassis mounting points. Two chassis mounting points for each A-arm plus the toe control link can be a fifth chassis mounting point, or the toe link mounting can be common with one of the A-arm link mountings, or it can be on one of the A-arm links.

Four upright mounting points, one for the upper A-arm, one for each link of the lower "virtual A-arm", and one for the tie rod pivot (on the steering arm).

4.5 Upper A-arm, lower trailing and lateral links, toe link

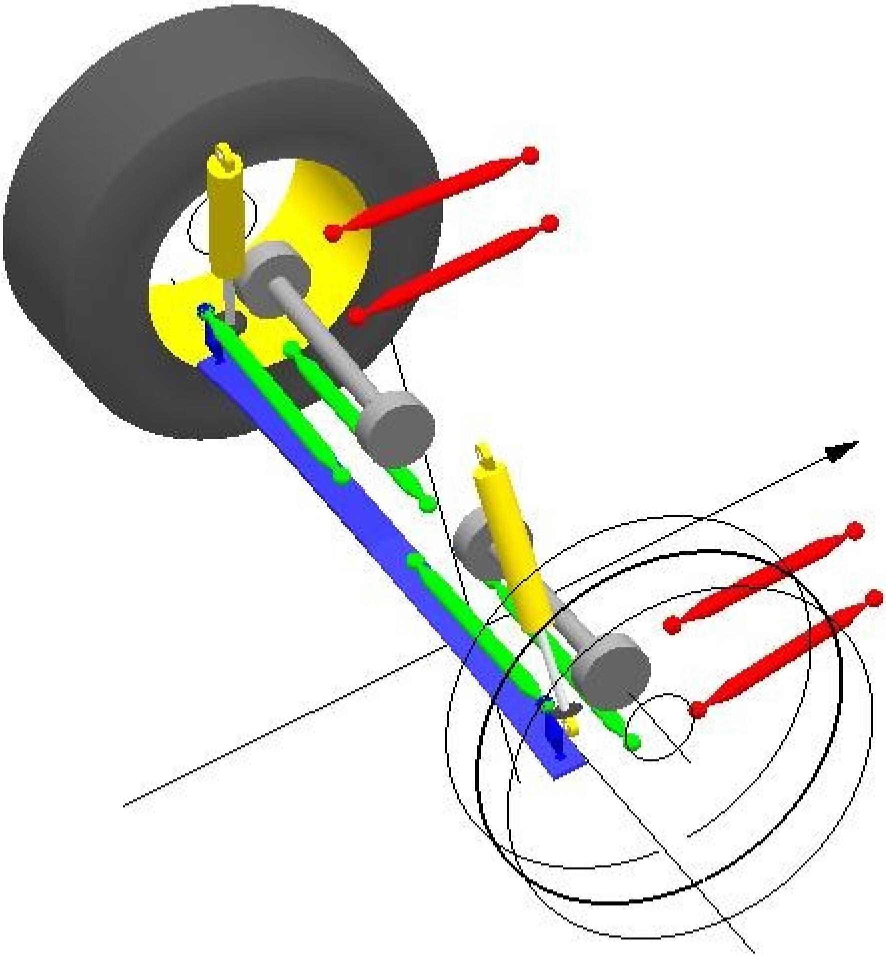


Five chassis mounting points, two for the upper A-arm, one for each of the lower trailing and lateral links, and one for the toe control link.

Five upright mounting points, two for the upper A-arm, one for each of the lower trailing and lateral links, and one for the toe control link.

The Mitsubishi Galant has the lower trailing and lateral links arranged as a "virtual A-arm".

4.6 Upper and lower lateral links, twin trailing links, toe link



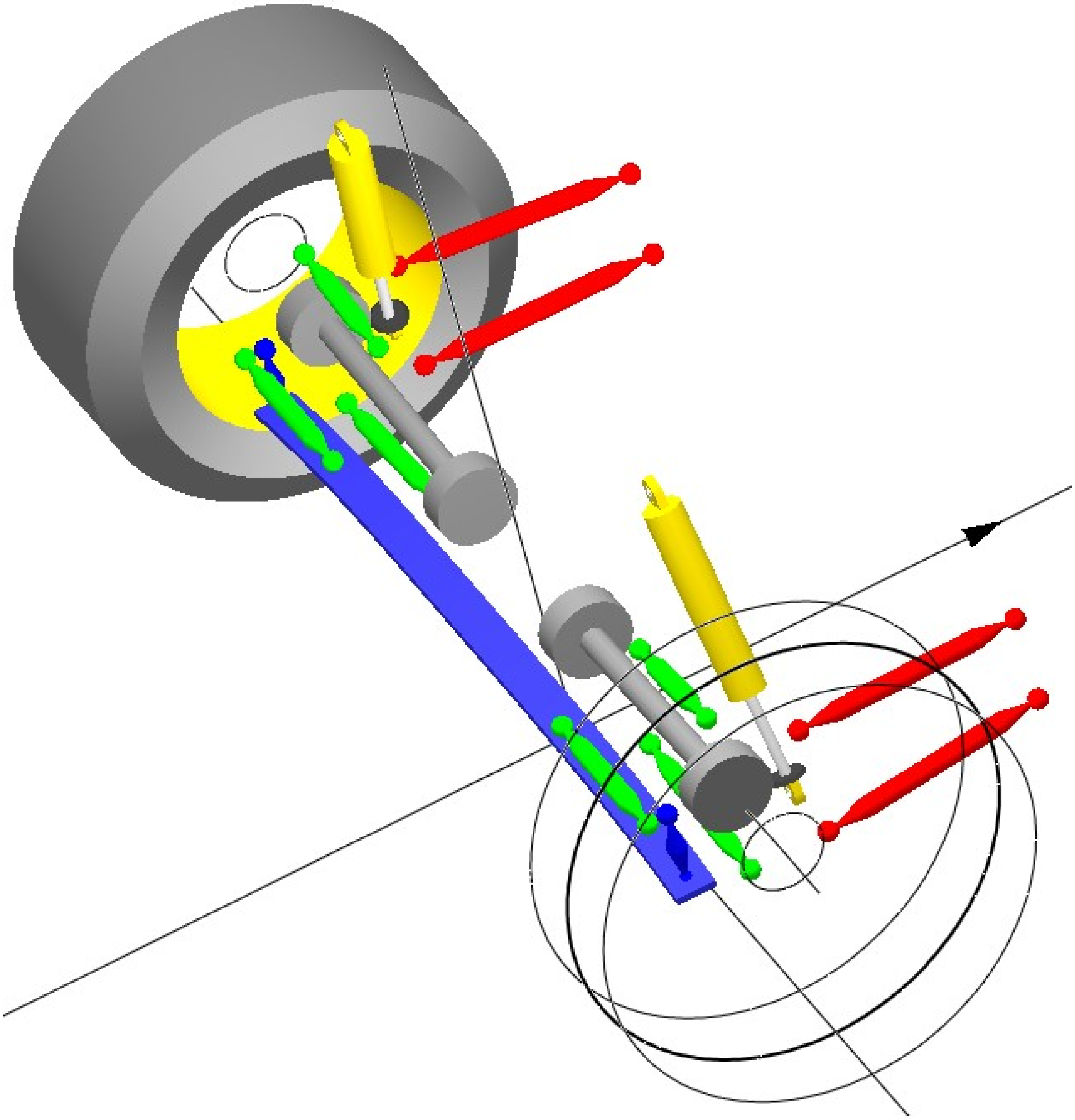
Five chassis mounting points, one for each lateral link, one for each trailing link, and one for the toe control link.

Five upright mounting points, one for each lateral link, one for each trailing link, and one for the toe control link.

The top lateral link can be either a bespoke link, or the driveshaft can act as the suspension link.

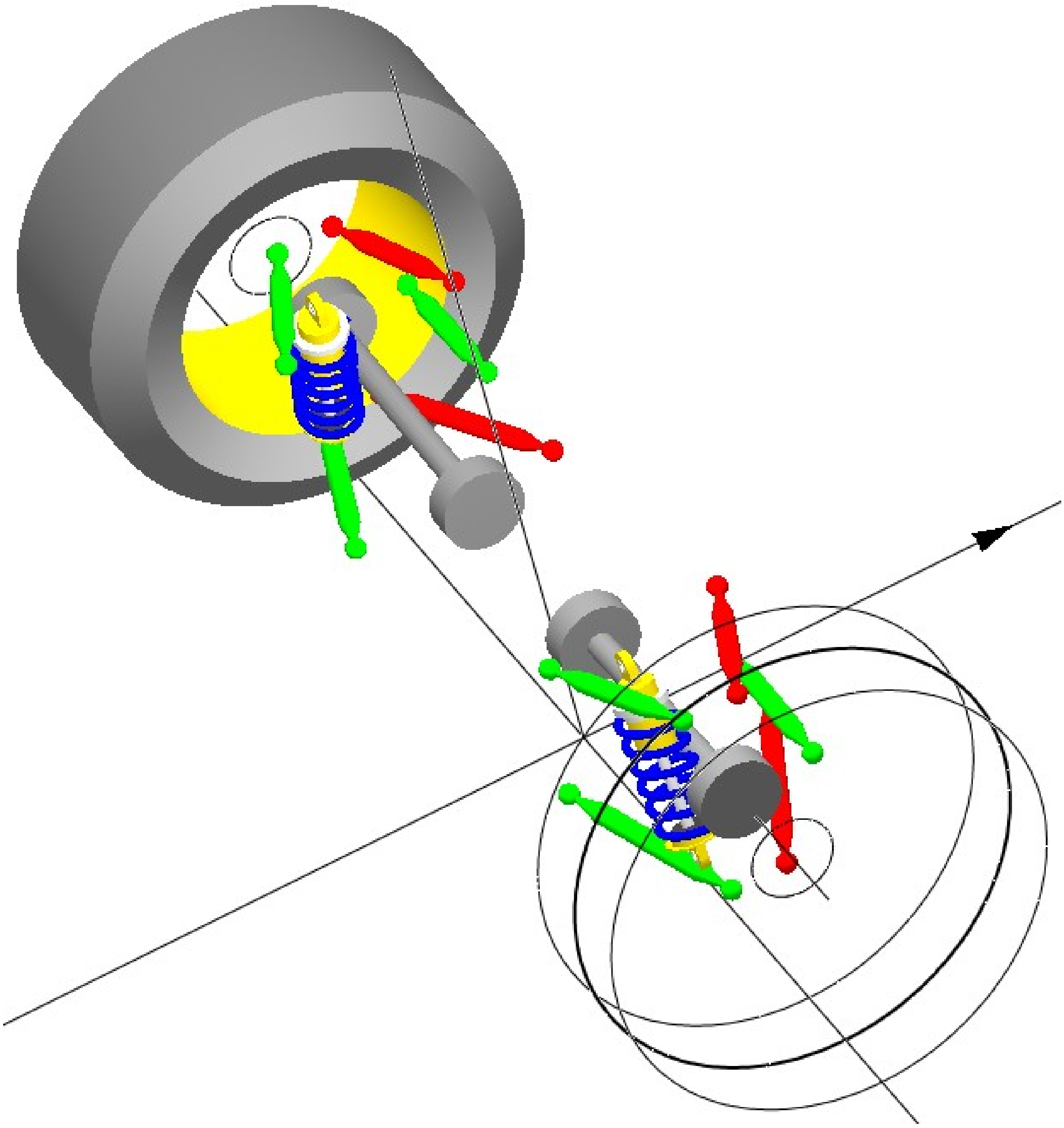
Specify the driveshaft as "Fixed length driveshaft (top lateral link) to have the driveshaft as a suspension link, or specify the driveshaft as either "Variable (splined)" or "Variable (plunging joint)" to use a bespoke top lateral link.

The Corvette C4 uses the driveshaft as the upper lateral link. Specify the driveshaft as "Fixed length driveshaft (top lateral link)".



The modified design uses a separate lateral link as the suspension lateral link. This relieves the drive shaft of the suspension loads and enables the use of CV joints. Specify the driveshaft as either "Variable (splined)" or "Variable (plunging joint)".

4.7 Upper and lower "virtual A-arms", toe link



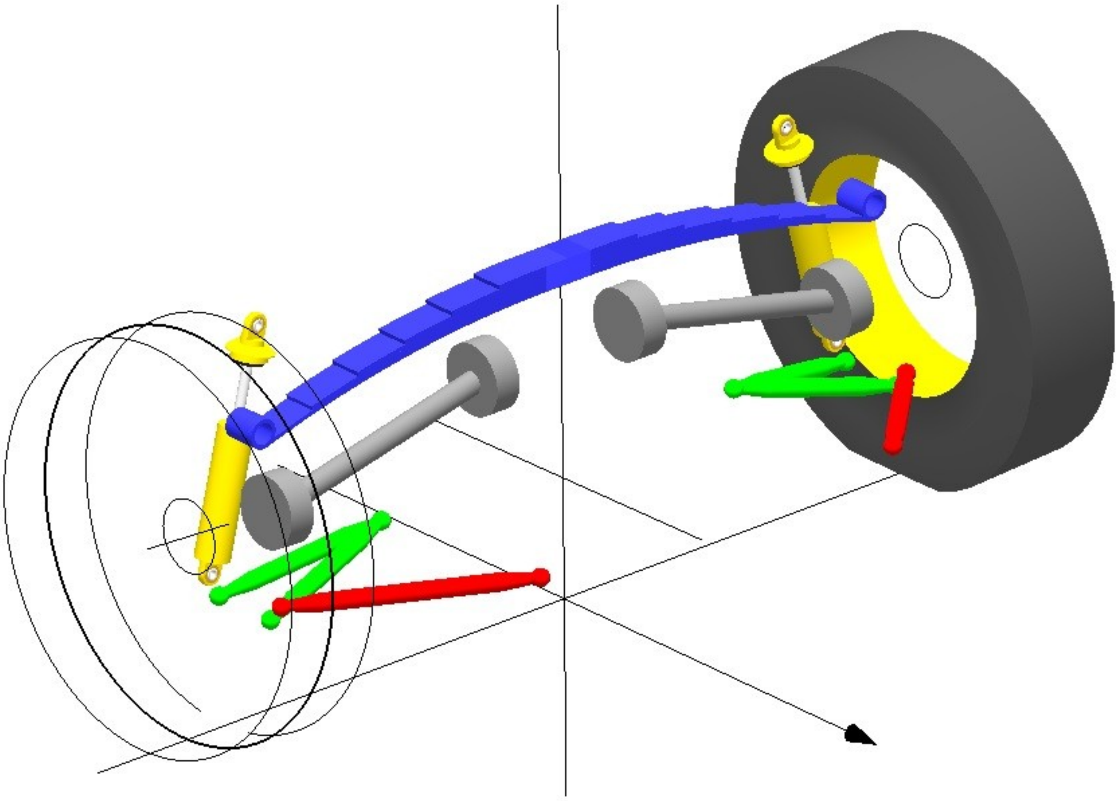
Five chassis mounting points

When used as a front suspension there are five chassis mounting points, two for each A-arm and one for the steering tie rod (which can be either the end of the steering rack or the tie rod mounting on the steering linkage).

When used as a rear suspension there either four or five chassis mounting points. Two chassis mounting points for each A-arm plus the toe control link can be a fifth chassis mounting point, or the toe link mounting can be common with one of the A-arm link mountings, or it can be on one of the A-arm links.

Five upright mounting points, one for each link of the upper "virtual A-arm", one for each link of the lower "virtual A-arm", and one for the toe control link.

4.8 Upper transverse leaf spring, lower reversed A-arm and trailing link

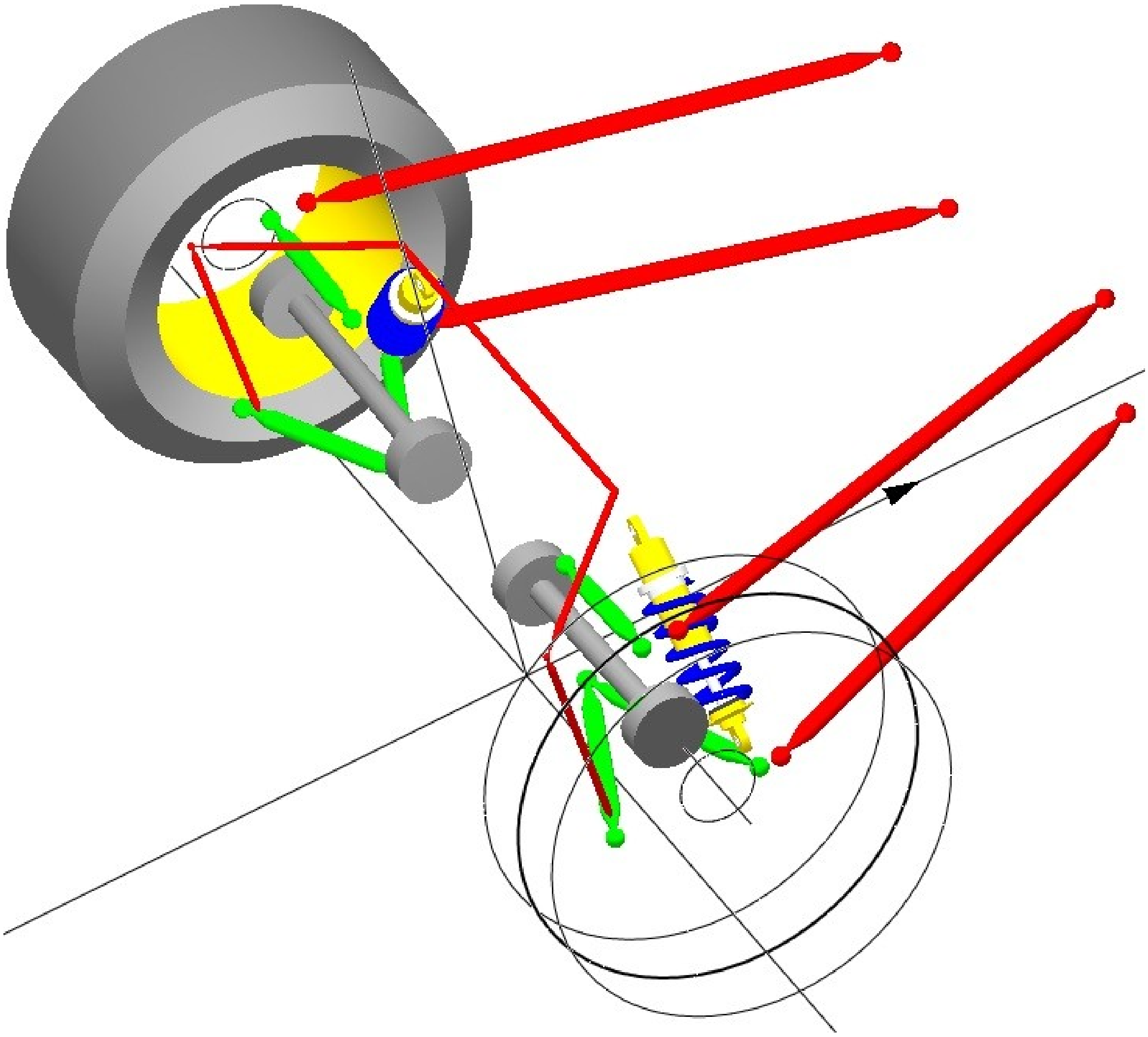


As used on the TriumphGT6.

Three chassis mounting points, one for the transverse leaf spring, one for the lower reversed A-arm, and one for the trailing link.

Four upright mounting points, one for the transverse leaf spring, one for each link of the lower reversed A-arm, and one for the trailing link.

4.9 Upper lateral link, lower reversed A-arm, twin trailing links

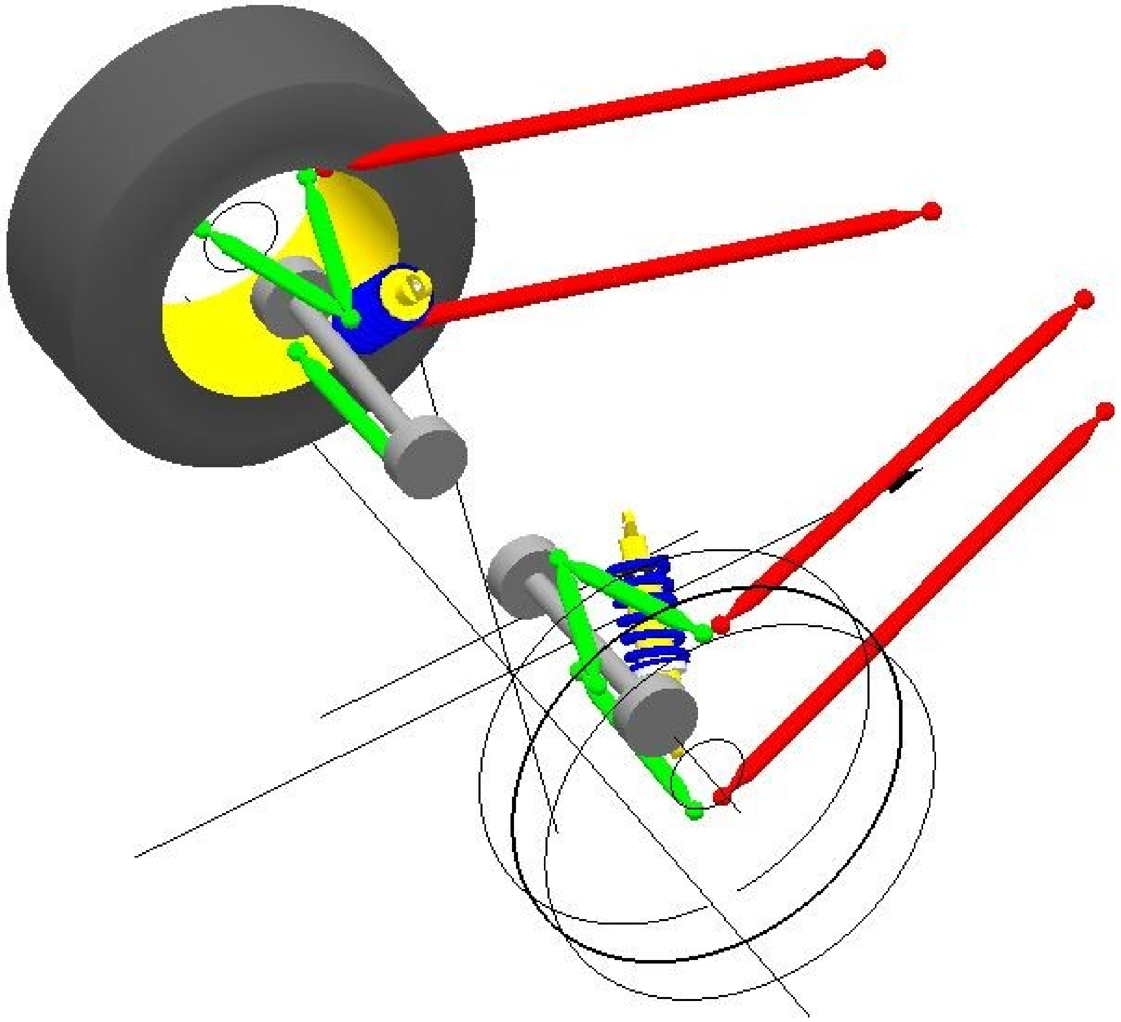


The classic ‘60s sports and racing cars rear suspension.

Four chassis mounting points, one for the upper lateral link, one for the lower reversed A-arm, and one for each of the trailing links.

Five upright mounting points, one for the upper lateral link, one for each link of the lower reversed A-arm, and one for each of the trailing links.

4.10 Lower lateral link, upper reversed A-arm, twin trailing links

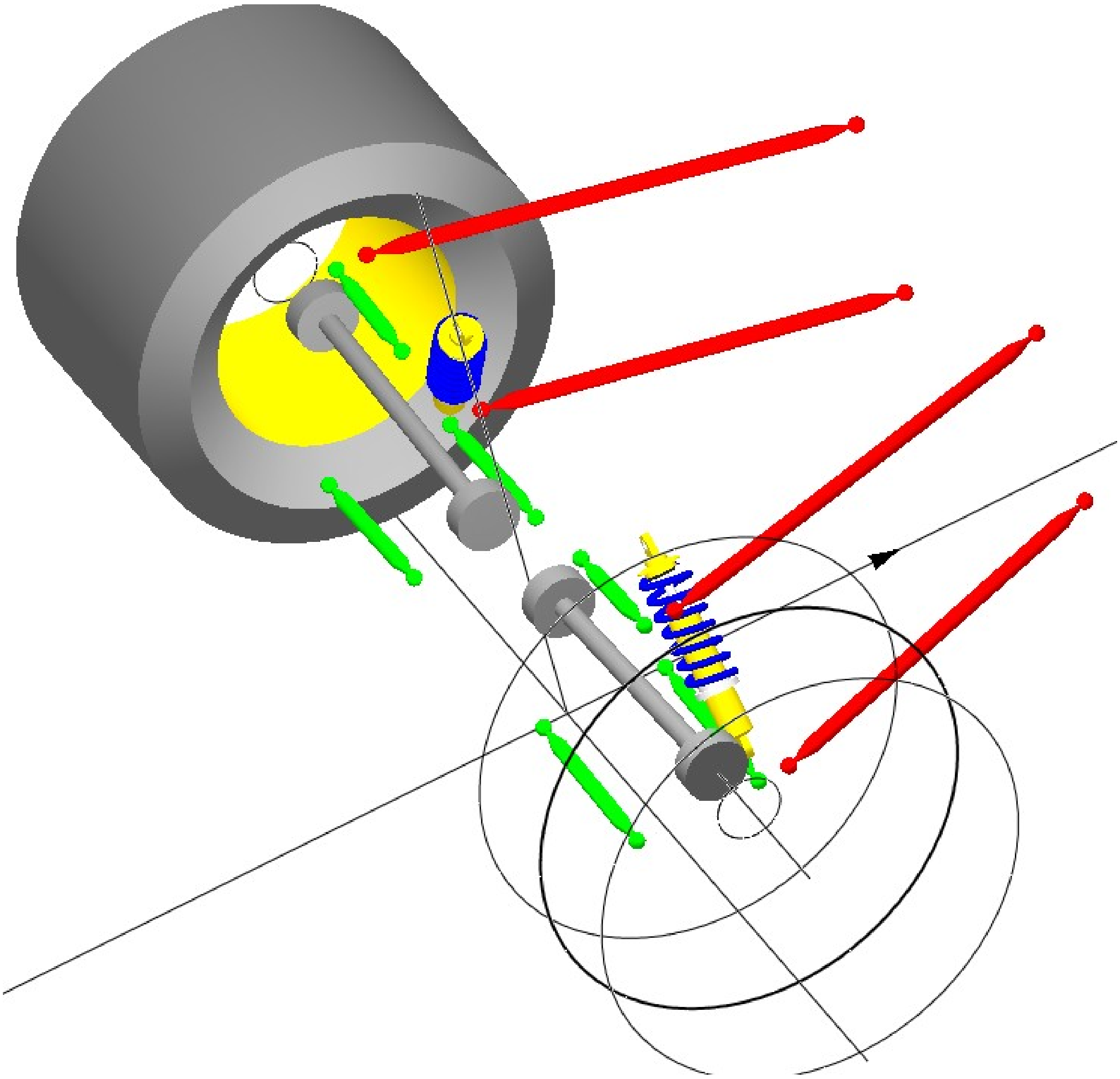


An alternative version of the classic ‘60s sports and racing cars rear suspension.

Four chassis mounting points, one for the upper reversed A-arm, one for the lower lateral link, and one for each of the trailing links.

Five upright mounting points, one for each link of the upper reversed A-arm, one for the lower lateral link, and one for each of the trailing links.

4.11 Upper lateral link, lower parallel links, twin trailing links

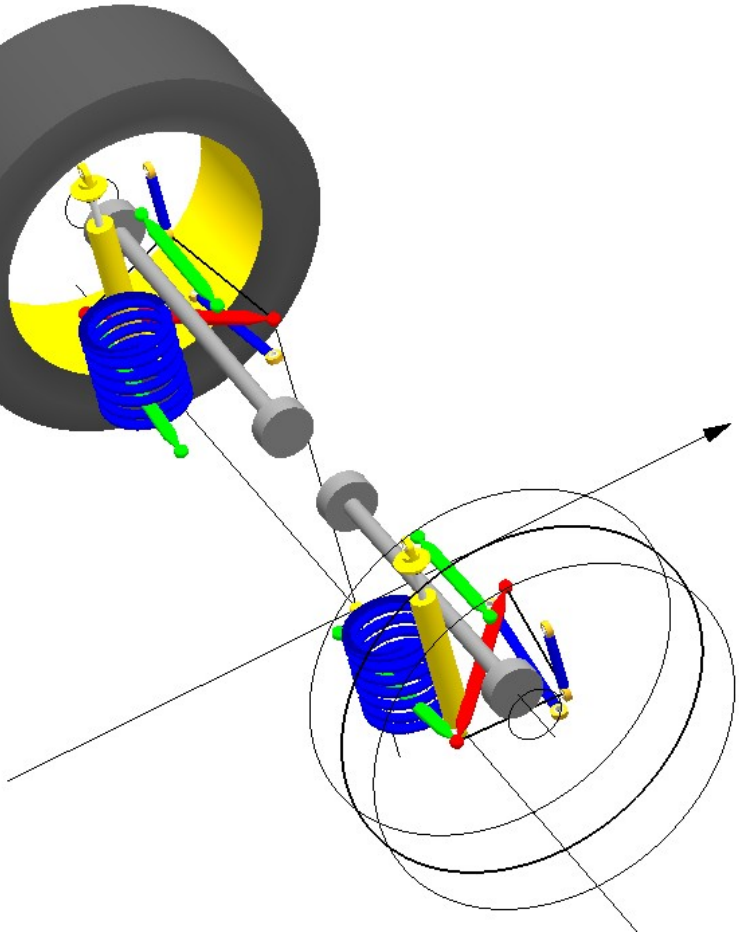


A variation of the reversed lower A-arm.

Five chassis mounting points, one for the upper lateral link, one for each lower lateral links, and one for each of the trailing links. The lower lateral links are generally parallel (in plan view) and symmetrically disposed about the axle centreline.

Five upright mounting points, one for the upper lateral link, one for each lower lateral link, and one for each of the trailing links.

4.12 Ford Integral Link

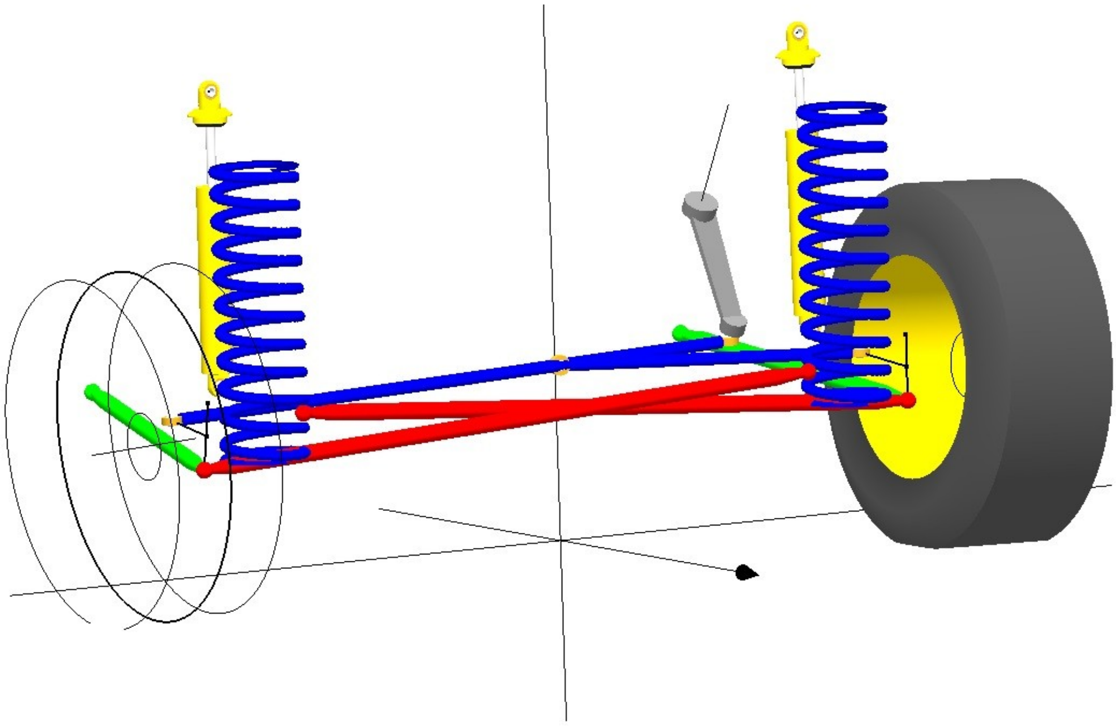


The Ford Integral Link consists of the following components:

- The single top link controls the wheel camber.
- The bottom control arm controls wheelbase and, in conjunction with the integral link, caster.
- The toe link controls wheel toe.
- The knuckle supports the wheel hub and bearing. There is mounting point for the camber control link, the caster control link, the toe control link, and the lower control arm.

The static camber, caster and toe can be set via the Geometry | Alignment menu.

4.13 Ford Twin I-Beam



The Ford Integral Link consists of the following components:

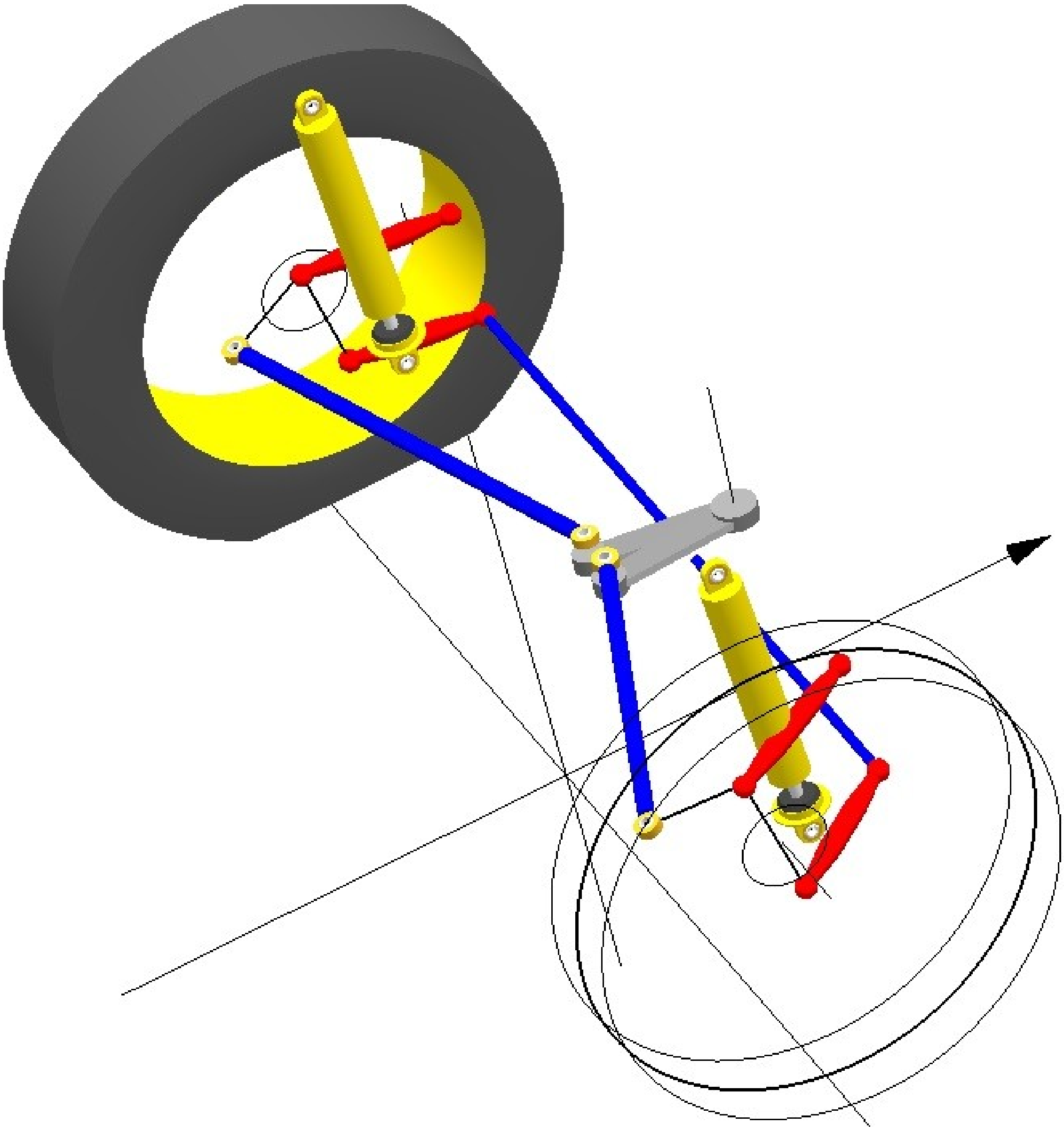
- The I-Beam controls wheelbase and the camber and caster. On some models, the camber and caster can be adjusted by offset bushes. This functionality is not modelled by SusProg3D.
- The radius rod controls the wheelbase, and, in the actual vehicle, controls the I-Beam radially.
- The toe link controls wheel toe.
- The stub axle supports the wheel hub and bearing and the steering arm. Early model stub axles used a kingpin, later models upper and lower ball joints.

The static camber, caster and toe can be set via the Geometry | Alignment menu.

Geometrically the combination of I-Beam and radius rod is equivalent to a pair of A-arms with common chassis mounting points, one A-arm connecting to the top of the kingpin (or top balljoint) and the other A-arm connecting to the bottom of the kingpin (or bottom balljoint).
For simplicity, SusProg3D shows the suspension as a single A-arm, and dimensions the links accordingly.

The steering is also simplified with both tie rods considered to be straight, and the connection from the primary tie rod to the secondary tie rod on the centreline of the primary tie rod.

4.14 Volkswagen twin trailing links



The Volkswagen twin trailing link consists of the following components:

- Twin upper and lower trailing links.
- The toe link controls wheel toe.
- The upright supports the wheel hub and bearings and the steering arm. Early model stub axles used trunnions, later models upper and lower ball joints.

The static camber, caster and toe can be set via the Geometry | Alignment menu.

Geometrically each trailing link is equivalent to an A-arm with lateral axis. One end of the A-arm axis is the trailing link chassis mounting point.

With a conventional suspension, the other end of the A-arm axis is any convenient point along the line between the trailing link chassis mounting point and the trailing link chassis mounting point on the opposite side.
For the Porsche 718 K suspension, the other end of the A-arm axis is usually on the vehicle centreline, and lower down, resulting in an inclined pivot axis in front view.

4.15 Compound link

Compound link designs are those where the suspension linkages are asked to perform additional functions instead of tension or compression loadings.

The currently supported configurations are

- Jaguar IRS
- H-arm + camber link, similar to the Ford Thunderbird
- Porsche 928

The top link (or driveshaft) controls the wheel camber.

The bottom wishbone controls wheelbase and both caster and toe.

The static camber, caster and toe can be set via the Geometry | Alignment menu.

For the bottom link lengths, the front link length is the length from the front chassis pivot to the front upright pivot, the diagonal link length is from the rear chassis pivot to the front upright pivot, and the rear (toe) link length is the length from the rear chassis pivot to the rear upright pivot.

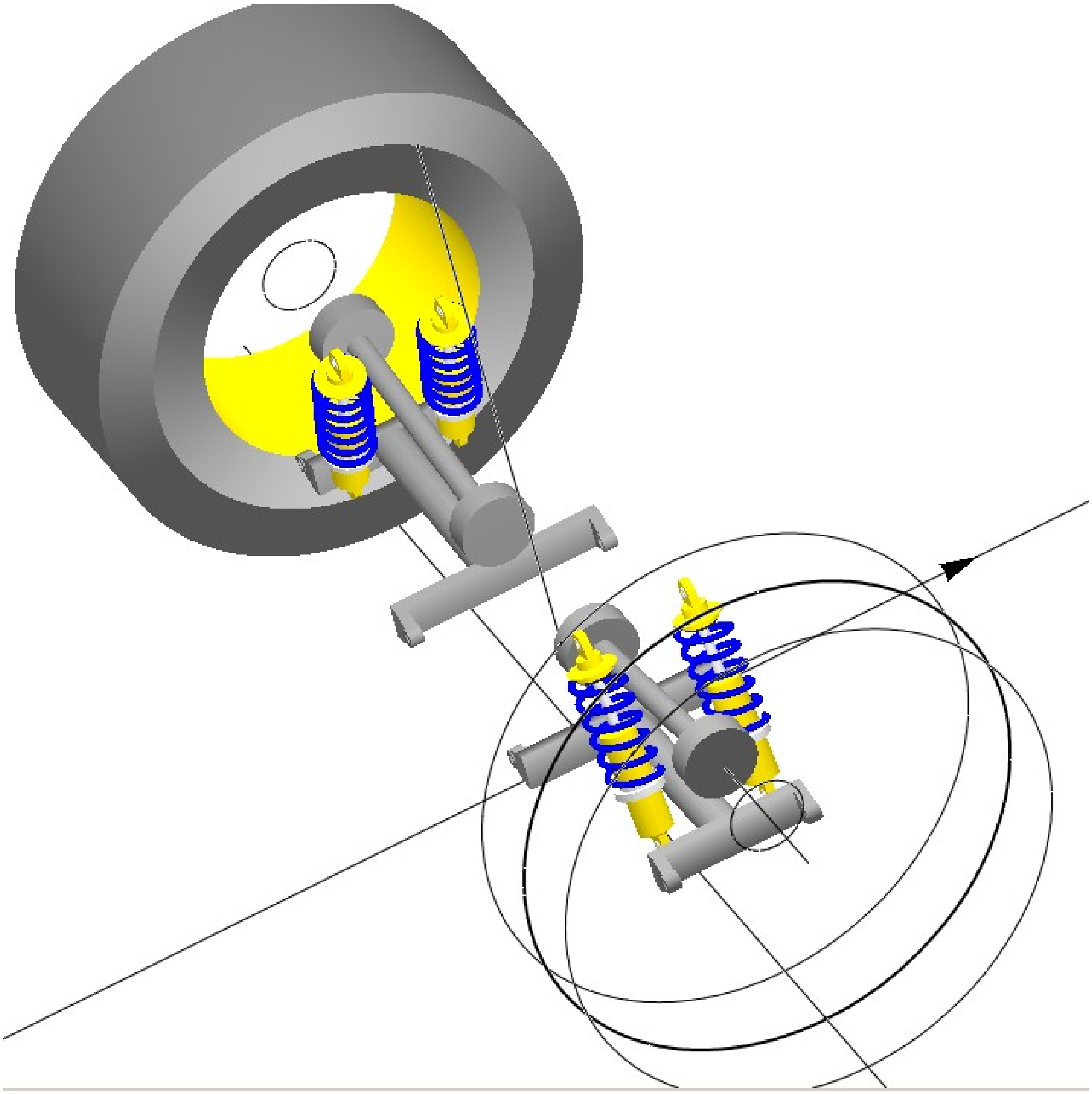
The twist offset and upright base length are used to specify the location of the bottom wishbone rear upright pivot point, relative to the plane of the other three wishbone points (ie front and rear chassis mountings and the front upright mounting point) in side view. If the rear upright mounting point is in the same plane (as the other three points) then the twist offset is zero; if the rear upright mounting point is above the plane (of the other three points) then the twist offset is positive; and if the rear upright mounting point is below the plane (of the other three points) then the twist offset is negative.

If the bottom wishbone rear (toe) link length is specified, then this will determine the static wheel toe alignment.

If the bottom wishbone twist offset is specified, then this will determine the static wheel caster alignment.

The toe reference length will default to the tyre diameter if it is not specified.

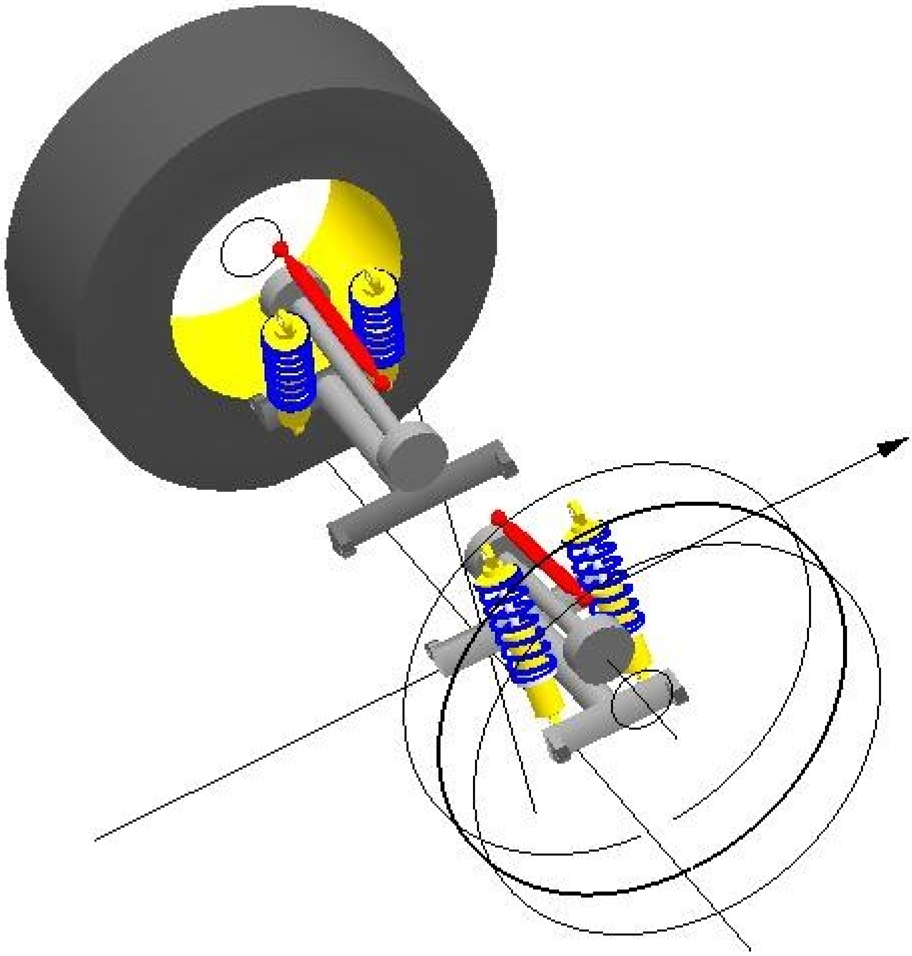
4.15.1 Jaguar IRS



The original OEM design uses the drive shaft as the suspension lateral link.

Three chassis mounting points, one for the driveshaft, two for the I-arm.

Three upright mounting points, one for the driveshaft, two for the I-arm.



The modified design uses a separate lateral link as the suspension lateral link. This relieves the drive shaft of the suspension loads and enables the use of CV joints.

Three chassis mounting points, one for the lateral link, two for the I-arm.

Three upright mounting points, one for the lateral link, two for the I-arm.

For the OEM design, specify the driveshaft as "Fixed length driveshaft (top lateral link).

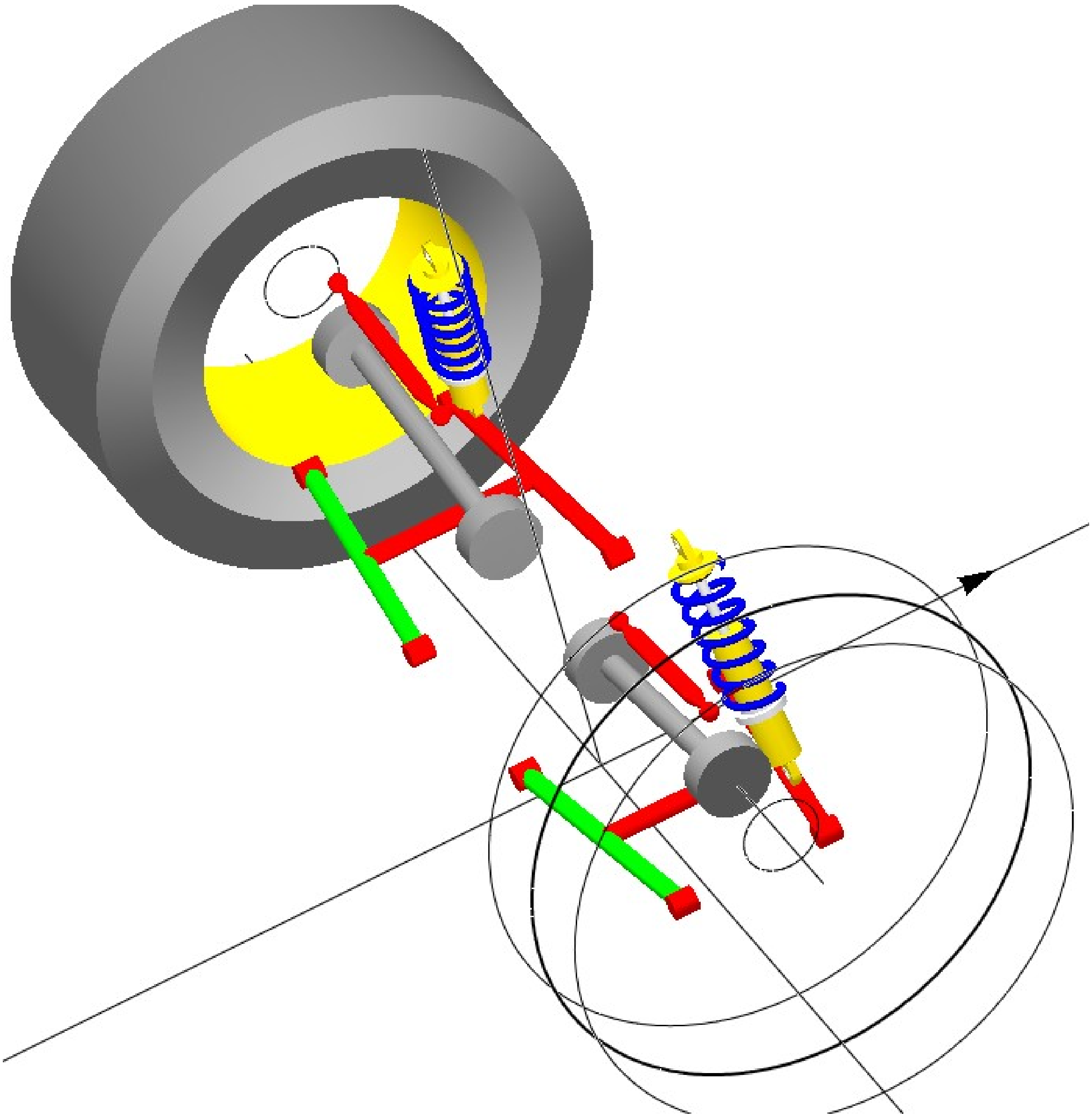
For the modified design, specify the driveshaft as either "Variable (splined)" or "Variable (plunging joint)".

In the Jaguar IRS all driving and braking loads are reacted by the lower lateral I-arm in torsion and bending. Reactions to all wheel centre inputs in the longitudinal direction result in torsional loading of the lower member. In the OEM design the fixed length (and fixed universal joints) driveshaft acts as the upper camber control link and controls the front view instant centre. The side view instant centre is controlled solely by the lower member.

In the OEM design the chassis top pivot point corresponds to the inboard driveshaft universal joint centre, and the upright top pivot point corresponds to the outboard driveshaft universal joint centre, and only the lateral value is entered.

The toe control pivot points are already established as part of the basic suspension geometry. There is only the capability to display the toe changes.

4.15.2 H-arm + camber link

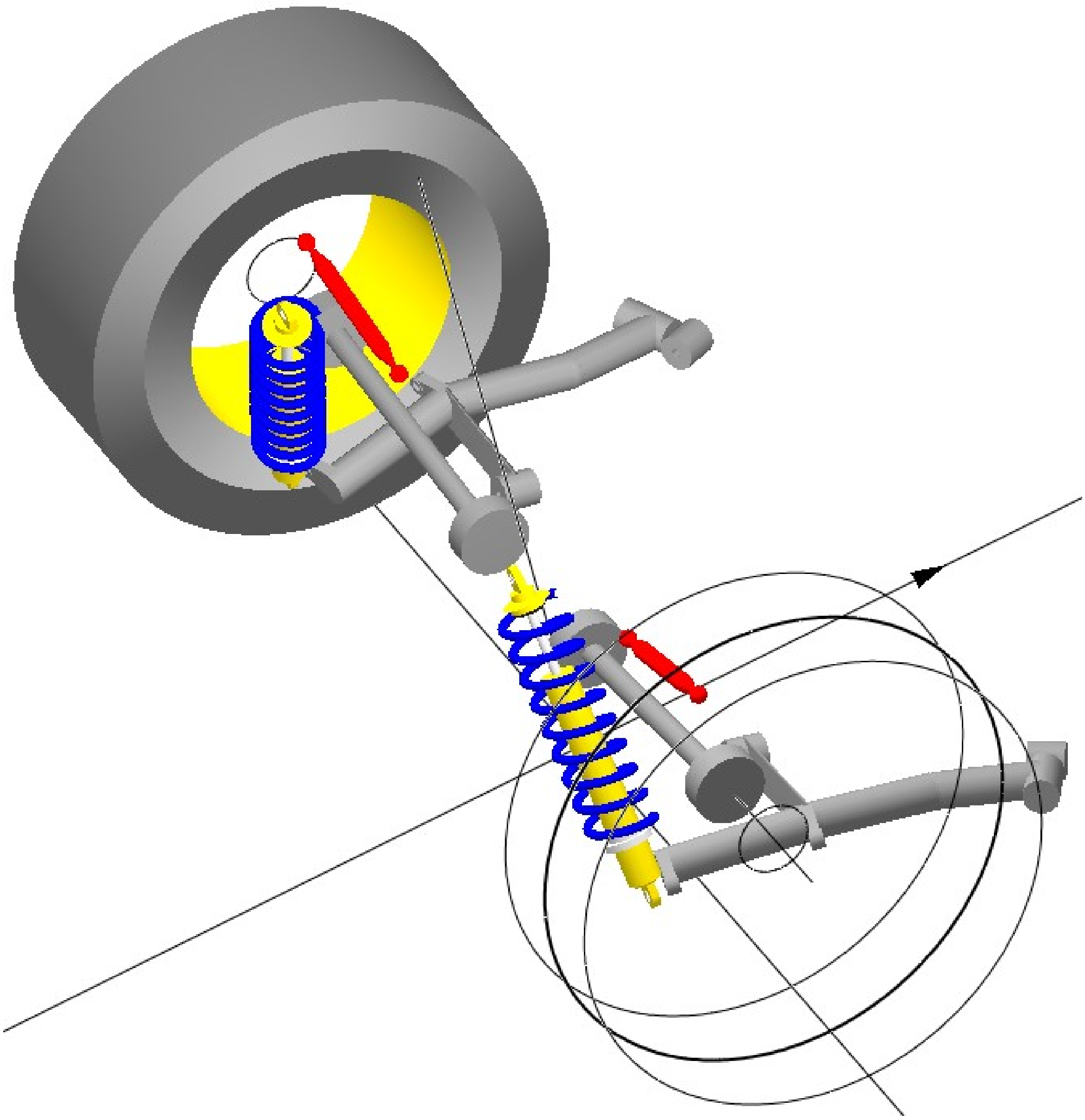


Three chassis mounting points, one for the top camber control link, two for the H-arm.

Three upright mounting points, one for the top camber control link, two for the H-arm.

In the H-arm IRS all driving and braking loads are reacted by the lower lateral H-arm in torsion and bending. Reactions to all wheel centre inputs in the longitudinal direction result in torsional loading of the H-arm. The upper camber control link controls the front view instant centre. The side view instant centre is controlled solely by the H-arm.

4.15.3 Porsche 928



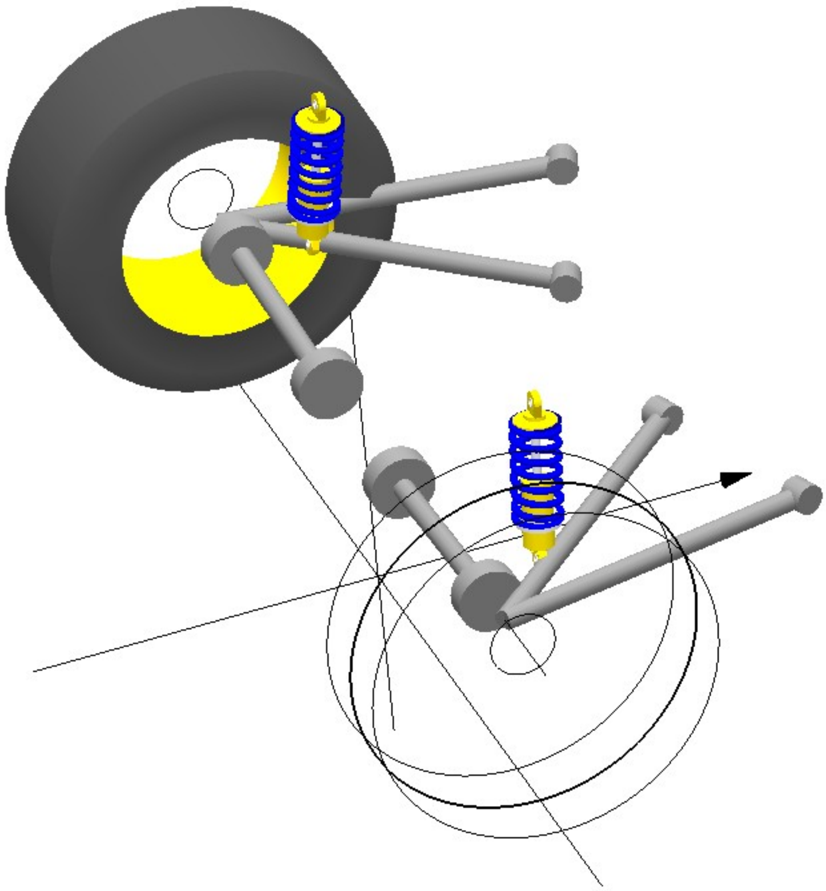
Three chassis mounting points, one for the top camber control link, two for the trailing arm.

Three upright mounting points, one for the top camber control link, two for the trailing arm.

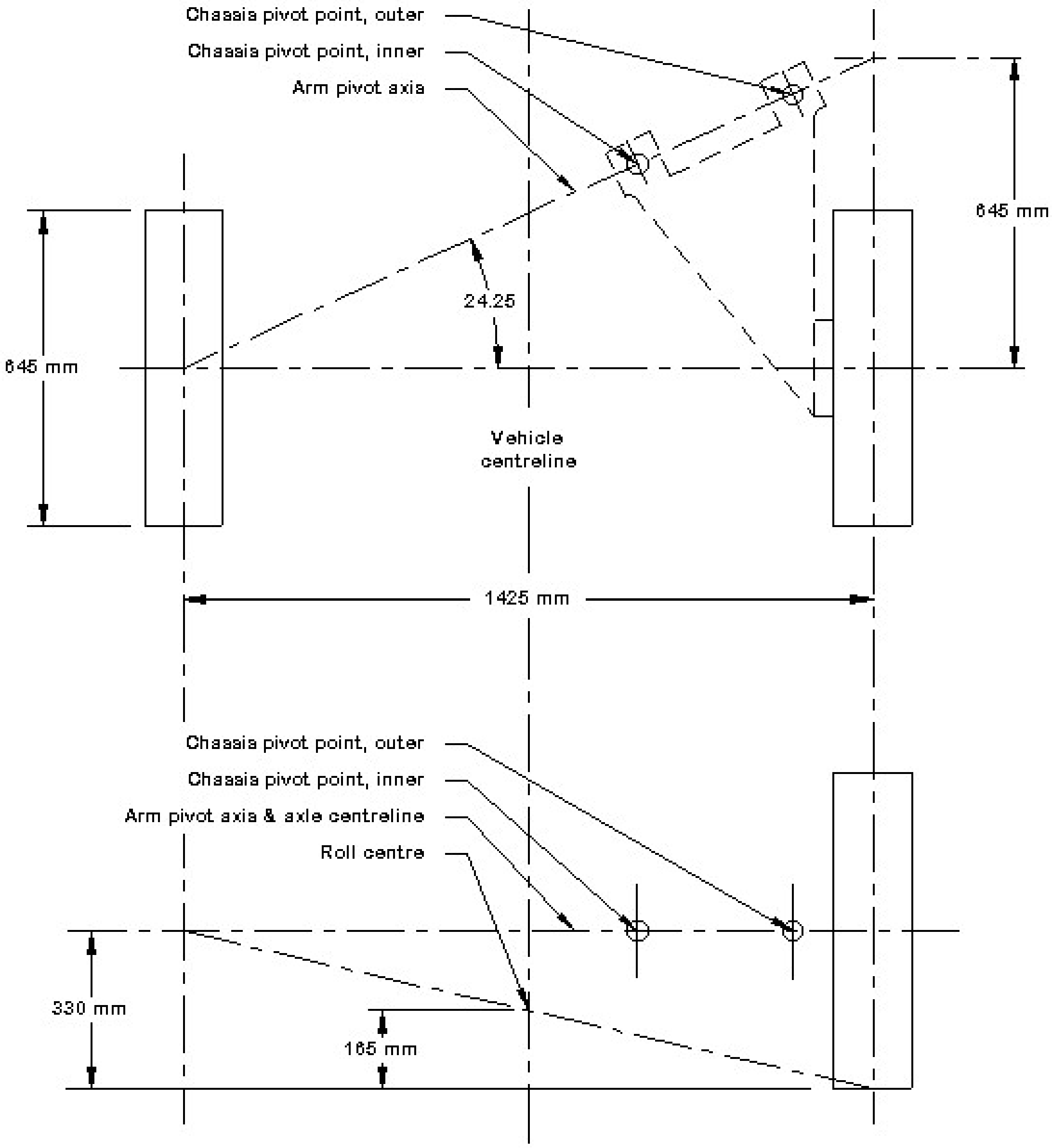
With the Porsche 928 IRS, the lower trailing arm reacts longitudinal and lateral loads largely in bending. The lower lateral link reacts only camber control loads, and contributes virtually nothing to the longitudinal and toe loads. The upper camber control link controls the front view instant centre. The side view instant centre is controlled solely by the lower member.

There is no allowance for the articulation of the Porsche 928 trailing arm chassis pivot.

4.16 Semi-trailing arm (also includes trailing arm and swing axle)



Two chassis mounting points for the trailing arm.



Typical semi-trailing arm layout

In this configuration, the axle hub, spindle and trailing arm are combined into a single assembly with the trailing arm attached to the chassis at two mounting points, and these define both the front view instant centre (roll centre) and side view instant centre.

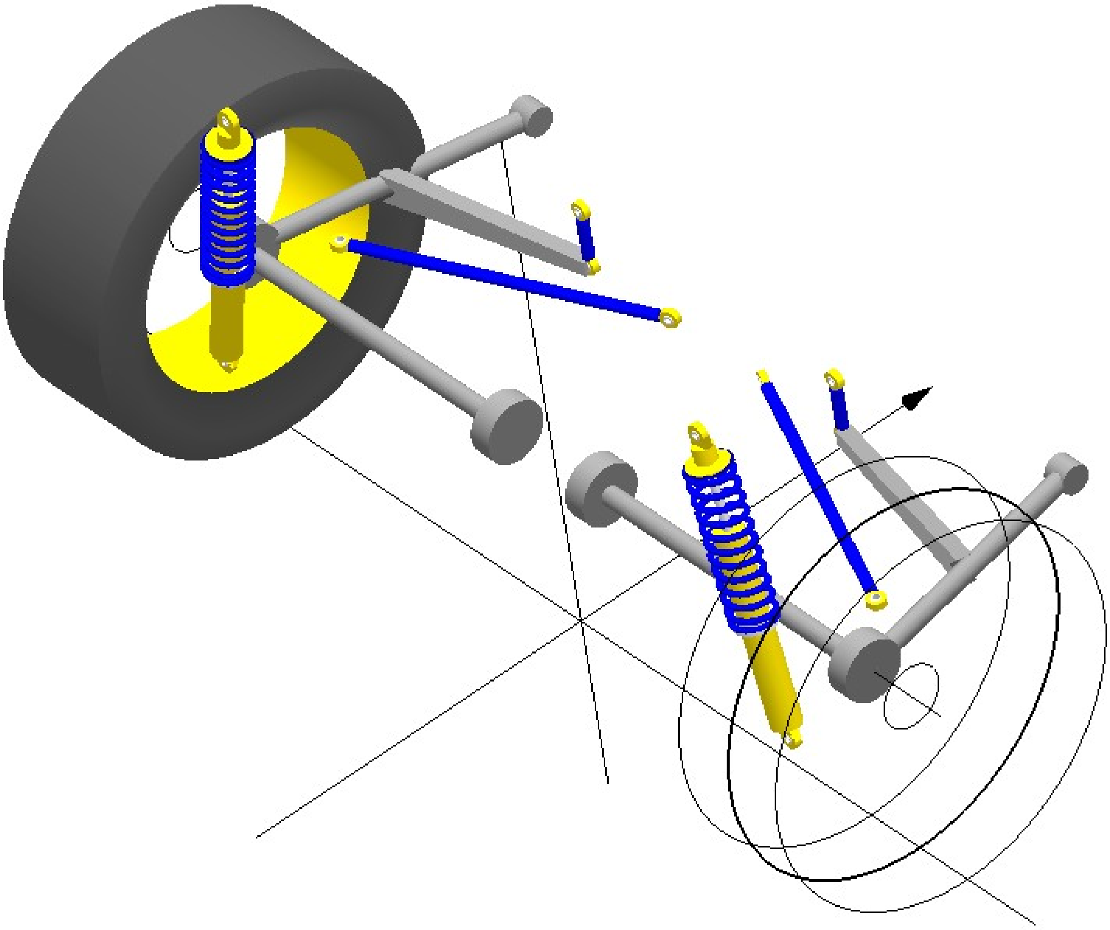
Generally, the semi-trailing arm has a pivot axis angle around 20 to 30 degrees.

If both pivots are on, or very close to, a line at right angles to the vehicle centreline, then this is referred to as a “Trailing arm”. The rear suspension on the original Austin/Morris Mini is a typical example.

If both pivots are on, or very close to, a line parallel to the vehicle centreline, then this is referred to as a “Swing axle”.

Note that the original Volkswagen rear suspension, which is usually called a “Swing axle” is actually more of a “Semi-swing axle” as the pivot axis angle is around 60 degrees. The trailing arm which connects to the torsion bar acts as the outboard pivot, with the driveshaft universal joint acting as the inner pivot.

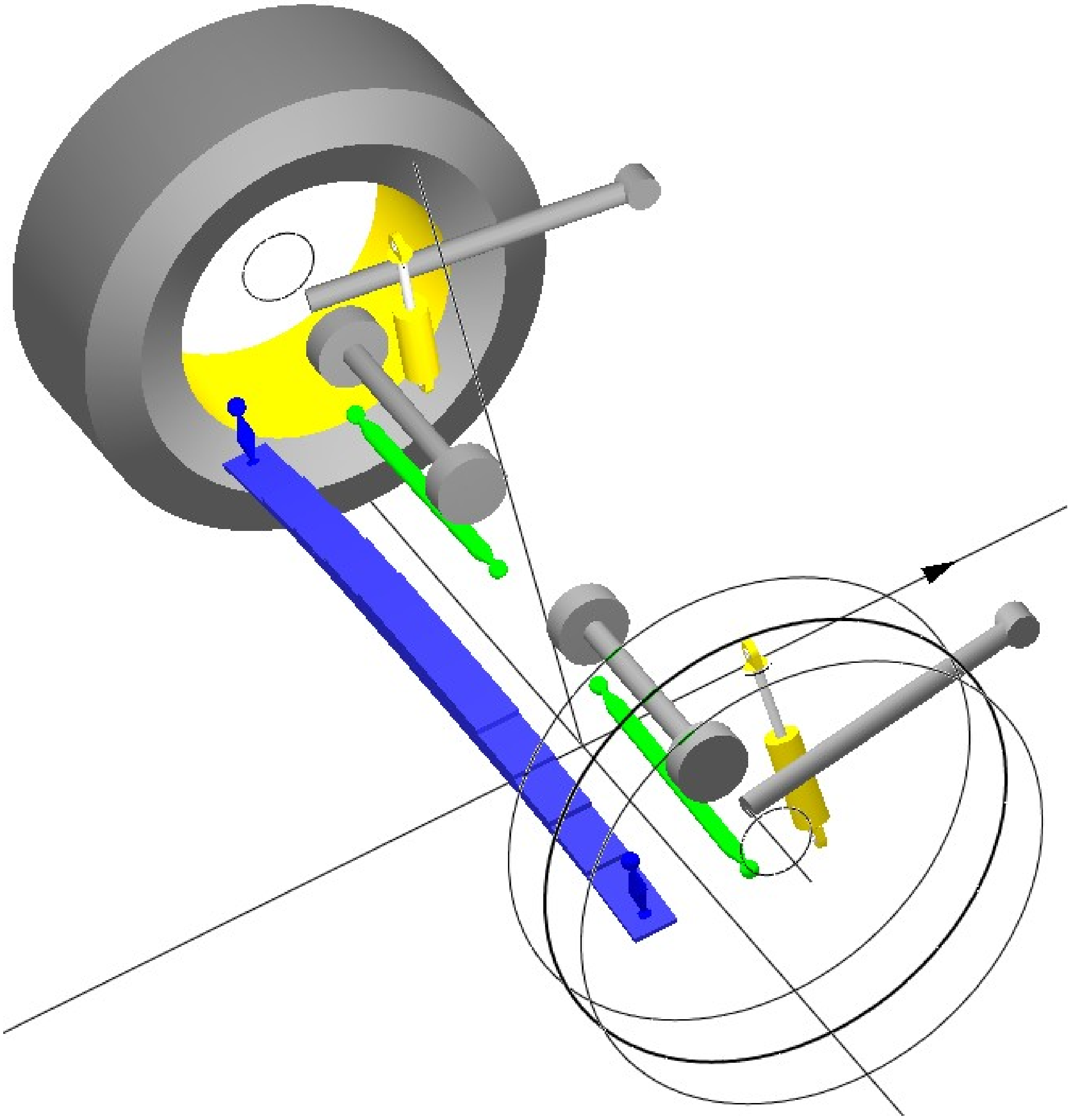
4.17 Semi-trailing arm, camber control and toe control links.



Three chassis mounting points. One for the trailing arm, one for the camber control link, one for the toe control link.

In this configuration, the axle hub and spindle assembly (Mazda refer to this as the “triaxial floating hub outer assembly”) and trailing arm are combined into a single assembly with the trailing arm attached to the chassis at one mounting point, which defines the side view instant centre.

4.18 Trailing arm, upper and lower lateral links

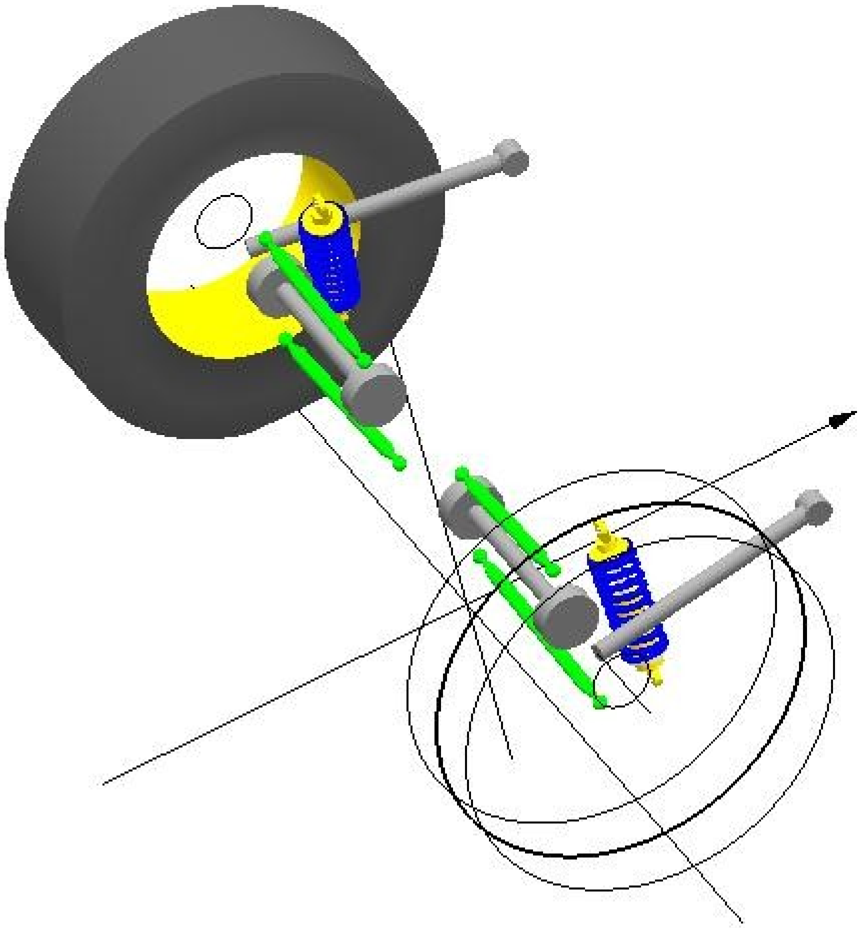


Three chassis mounting points, one for each lateral link, one for the trailing arm.

Three trailing arm mounting points, one for each lateral link and one for the trailing arm.

The top lateral link can be either a bespoke link, or the driveshaft can act as the suspension link.

Specify the driveshaft as "Fixed length driveshaft (top lateral link) to have the driveshaft as a suspension link, or specify the driveshaft as either "Variable (splined)" or "Variable (plunging joint)" to use a bespoke top lateral link.

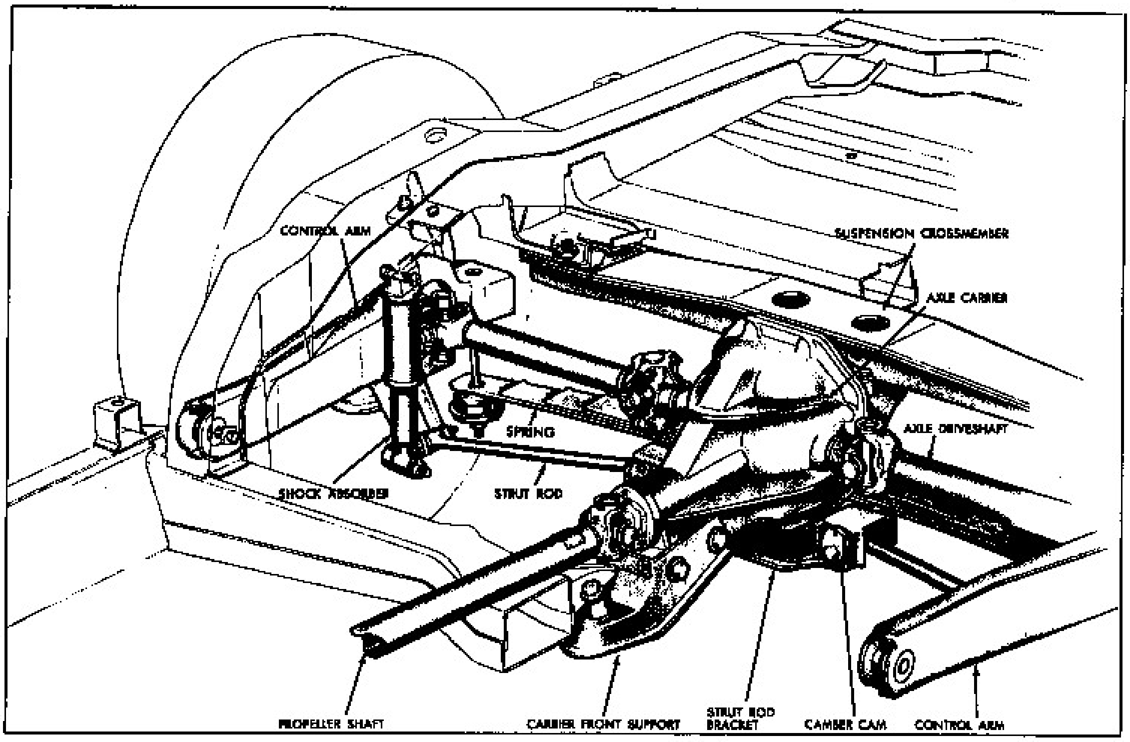


In this configuration, the axle hub and spindle and trailing arm are combined into a single assembly with the trailing arm attached to the chassis. There are two lateral control links which attach to the chassis and to the trailing arm assembly. The lateral control links are generally positioned on the axle centreline (in plan view).

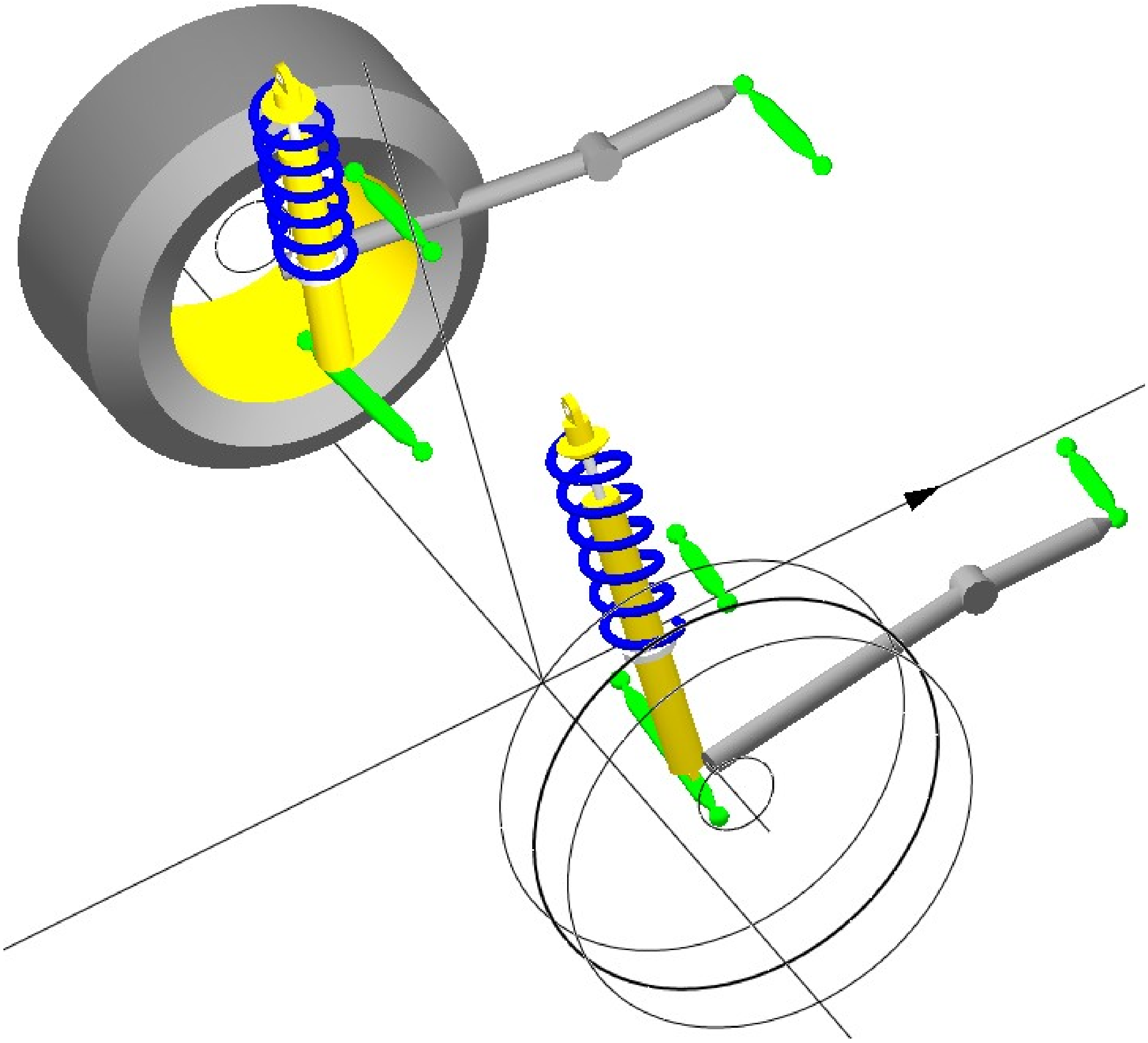
Vehicles with this type of rear suspension include the Lotus Europa and BMW E36 (both with coil springs) and pre ’84 Chevrolet Corvette (with transverse leaf spring).

Both the Corvette and the Lotus Europa use the driveshaft as the top lateral link. Make sure that the driveshaft is set to "Fixed length driveshaft (top lateral link)".

Camber (and roll centre location) is primarily controlled by the pair of lateral links. Caster (and side view instant centre location) is primarily controlled by the trailing arm chassis mounting. Toe is primarily controlled by the chassis trailing arm mounting.


CONTROL ARM
SUSPENSION CROSSMEMBER
AXLE CARRIER
SPRING
AXLE DRIVESHAFT
SHOCK ABSORBER
STRUT ROD
PROPELLER SHAFT
CARRIER FRONT SUPPORT
STRUT ROD BRACKET
CAMBER CAM
CONTROL ARM

4.19 Trailing arm, upper and lower lateral links, toe control link



Four chassis mounting points, one for each lateral link, one for the trailing arm and one for the toe control link.

Four trailing arm mounting points, one for each lateral link, one for the trailing arm, and one for the toe control link.

In this configuration, the axle hub and spindle and trailing arm are combined into a single assembly with the trailing arm attached to the chassis. There are two lateral control links which attach to the chassis and to the trailing arm assembly. The lateral control links are generally positioned on the axle centreline (in plan view).

The toe is controlled by the toe control link which connects to the trailing arm forward of the chassis mounting point, and consequently there is some lateral compliance and sideways movement of the trailing arm mounting on the chassis.

Vehicles with this type of rear suspension include Honda Civic and Integra.

Camber (and roll centre location) is primarily controlled by the pair of lateral links. Caster (and side view instant centre location) is primarily controlled by the trailing arm chassis mounting. Toe is primarily controlled by the toe control link.

4.20 Strut types

There are variations of the strut suspension:

- Macpherson strut
- Strut, lower "virtual A-arm", toe link
- Tri-link strut.

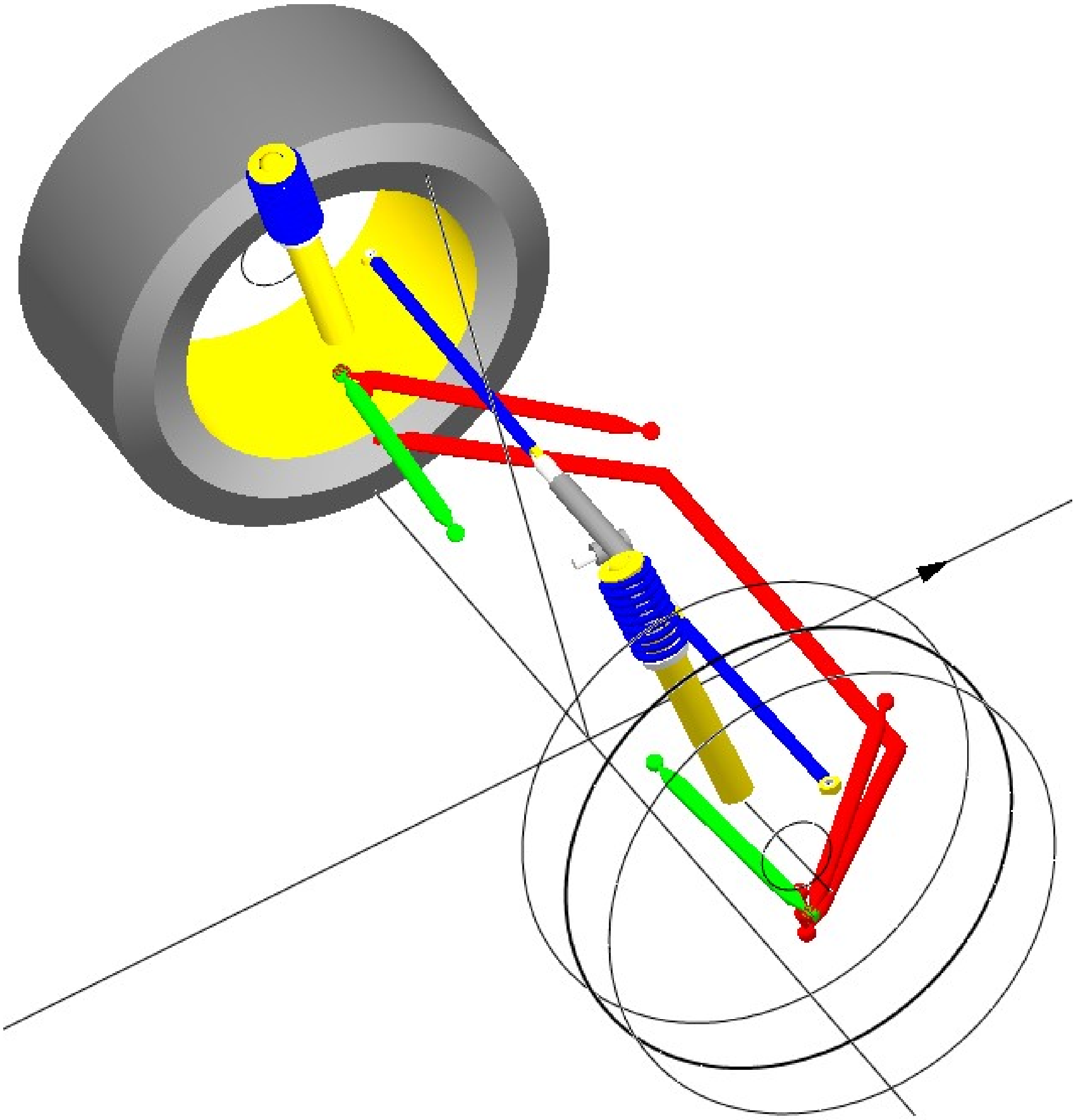
The strut and knuckle can be one of two basic styles,

- Integral strut tube and knuckle, where the strut tube is pressed into and often welded onto, the knuckle. This is typical of older vehicles.
- Separate strut tube and knuckle, where the knuckle is bolted to the strut tube, usually with one hole elongated to allow for a small amount of camber adjustment. This is typical of current vehicles.

The steering arm can be attached to either the knuckle or the strut tube.

When the spring is specified as "Coilover", the only applicable input values for the are for Mass and Spring Parameters.

4.20.1 Macpherson strut, toe link



The classic production car Macpherson strut.

When used as a front suspension there are four chassis mounting points, one for the strut rod top mounting, two for the lower A-arm and one for the steering tie rod (which can be either the end of the steering rack or the tie rod mounting on the steering linkage).

When used as a rear suspension there are either three or four mounting points, one for the strut rod top mounting, two for the lower A-arm, and either a separate toe link mounting, or the toe link mounting can be common with one of the A-arm link mountings.

Three strut mounting points, one for the strut rod top mounting, one bottom A-arm and either a steering arm or a toe control link mounting.

The coil spring is most commonly mounted on the strut, but it can also be specified as a separate spring.

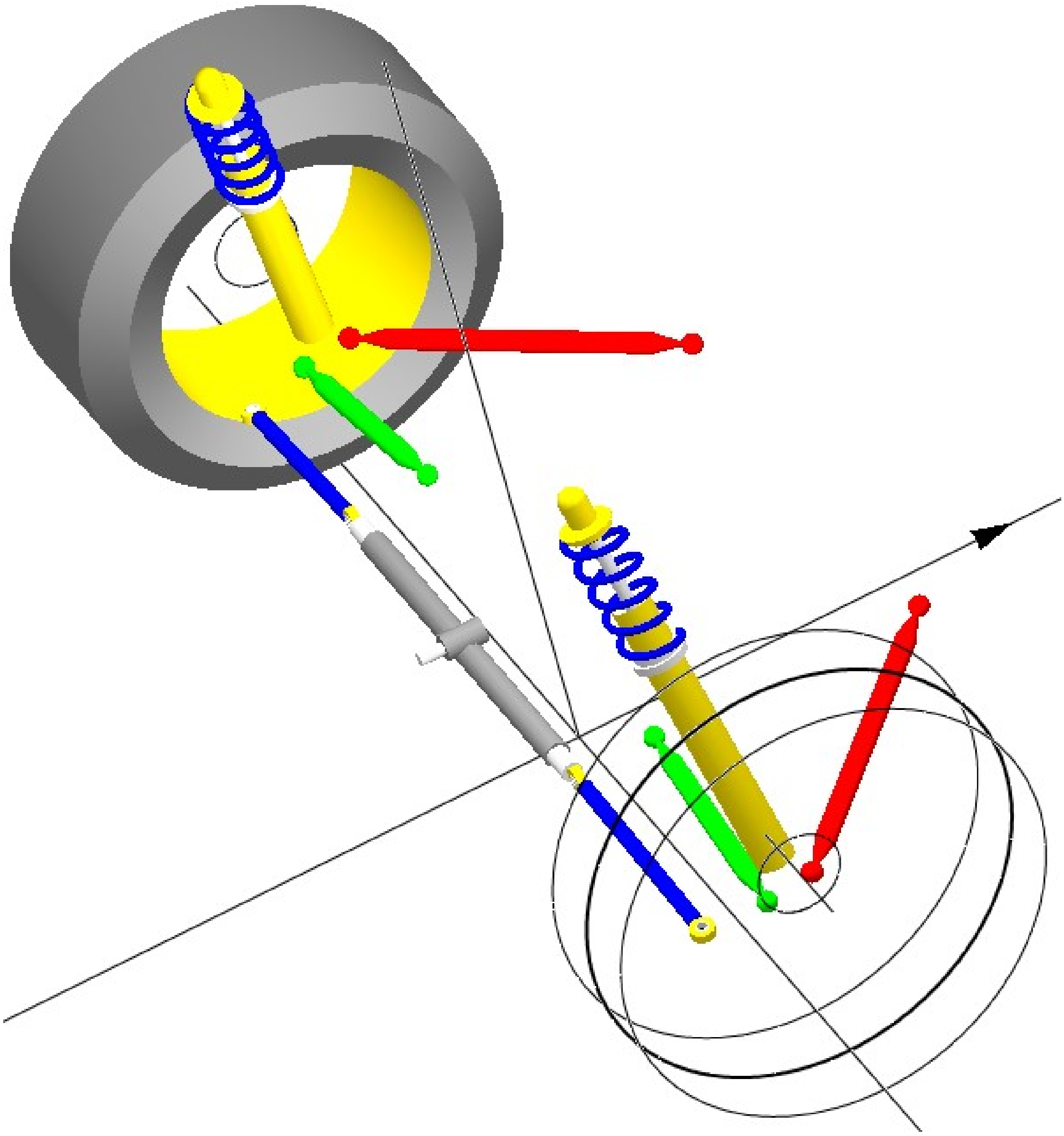
The design of the wishbone can take several forms.

Two of the most common styles are

- a single lateral control arm with a trailing link (where the anti-roll bar is used as the trailing link in which case this is the classis "Macpherson strut")
- a one-piece 'sickle' or 'L' shaped arm

The king-pin inclination and caster are measured from the strut rod mounting point on the chassis and the bottom wishbone strut ball joint.

4.20.2 Strut, lower "virtual A-arm", toe link



When used as a front suspension there are four chassis mounting points, one for the strut rod top mounting, one for each lower link and one for the steering tie rod (which can be either the end of the steering rack, or the tie rod mounting on the steering linkage).

When used as a rear suspension there are either three or four mounting points, one for the strut rod top mounting, one for each lower link, and either a separate toe link mounting, or the toe link mounting can be common with one of the lower link mountings.

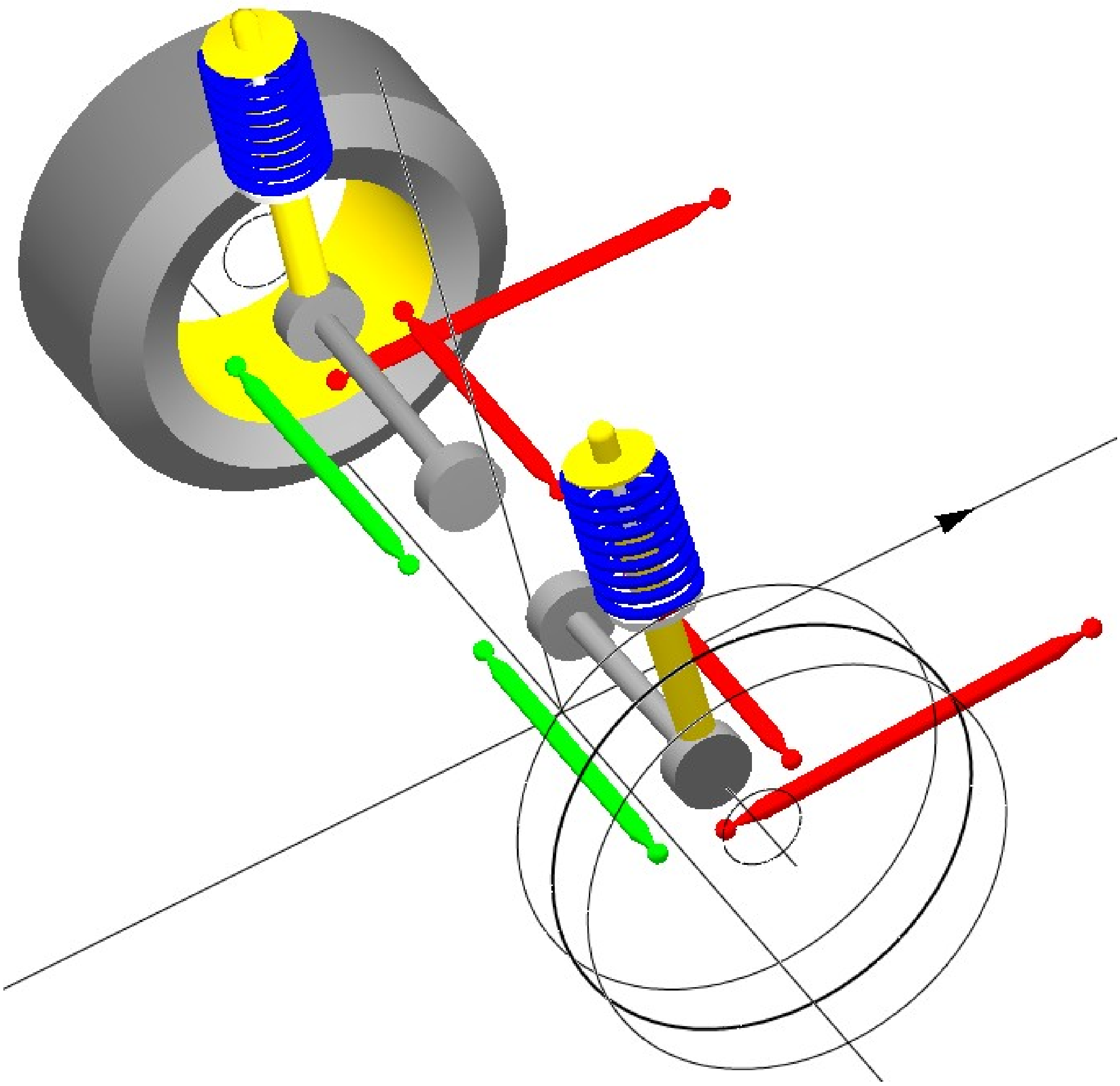
Four strut mounting points, one for the strut rod top mounting, one for each lower link and either a steering arm or a toe control link mounting.

In this configuration, commonly used on some BMW models, the bottom of the strut is located by two links, each with their own ball joint pivot, with the links angled (in plan view) to meet at a "virtual pivot" point. This makes it easier to package the components such that the steering axis (which passes through the virtual pivot point) can be moved further outboard than would otherwise be possible.

The two links are usually arranged as a lateral link (which controls camber) and a diagonal link (which controls caster). Where these two links meet (in plan view) is the "virtual pivot point".

The king-pin inclination and caster are measured from the strut rod mounting point on the chassis and the "virtual pivot point".

4.20.3 Tri-link strut



Four chassis mounting points, one for the strut rod top mounting, one for each lateral link, one for the trailing link. The arrangement of the links consists of two lateral links (usually parallel in plan view and of equal lengths) and a single trailing link. The strut top mounting needs only to provide minimal (or no) rotational capability. This is only suitable for rear suspension systems.

Four strut mounting points, one for the strut rod top mounting, one for each lower lateral link and one for the trailing link.

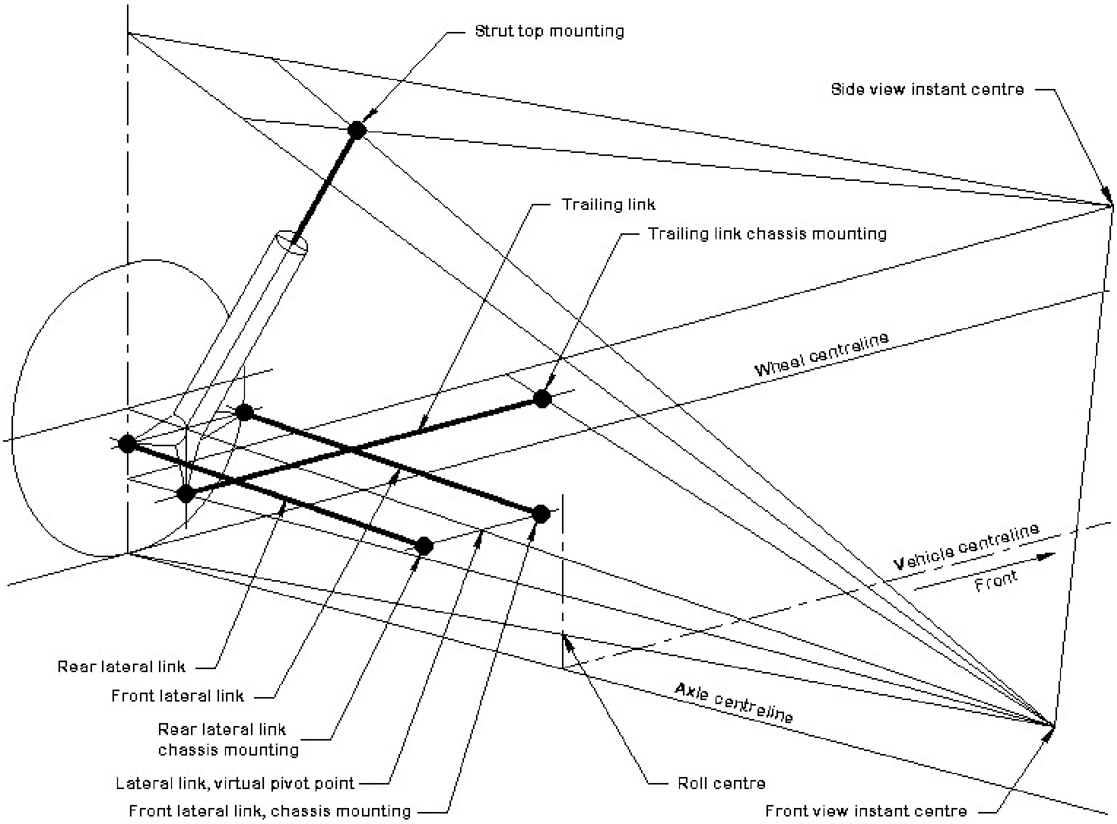
The tri-link strut is dimensioned the same as a normal strut, except that the trailing link and lateral link mountings are all part of, and dimensioned relative to, the knuckle.

The strut and knuckle can be integral or separate.

The king-pin inclination is not applicable. Caster is defined as the amount the strut assembly is 'tilted' (in side view) from the strut datum position.

The front view instant centre (roll centre) is defined by the strut rod axis and the lateral links.

The side view instant centre is defined by the strut rod axis and the trailing link.



Tri-link strut

4.21 Live / de Dion / rigid axle

There are four basic configurations, with each configuration as either "live axle", "de Dion" or "Rigid" or "Winters"

A live axle includes a crown wheel and pinion and provides drive to the wheels.

A de Dion axle has a separate (generally chassis mounted) differential with universal jointed driveshafts to the wheels.

A rigid axle (also known as a dead axle) has no provision for driving the wheels.

The Winters, or speedway, axle combines a torque tube and centre section with a single open axle shaft. The locating links are all attached to birdcages.

For front suspensions, the longitudinal links lead from the chassis forwards to the axle and are known as “leading links”; for rear suspensions, the longitudinal links trail from the chassis rearwards to the axle and are known as “trailing links”.

The following configurations are supported for front suspension

- 2 leading arms with Mumford linkage, Panhard rod, or Watts linkage.
- 3 or 4 leading links with Mumford linkage, Panhard rod, or Watts linkage.

The following configurations are supported for rear suspension

- 2 trailing arms with Mumford linkage, Panhard rod (NASCAR style) or Watts linkage (Alfetta style).
- 3 or 4 trailing links with Mumford linkage, Panhard rod, or Watts linkage.
- 4 trailing links, with at least one pair converging (in plan view) to provide the lateral location.
- Torque arm, four trailing links and birdcage with Panhard rod or Watts linkage (live axle only)
- Torque arm, two trailing links and torque arm slider with Panhard rod or Watts linkage (live axle only)
- Torque tube with Panhard rod or Watts linkage (live axle only)
- Winters axle, four trailing links, 2 birdcages and Jacobs ladder

When a torque arm axle is specified (in conjunction with a Panhard rod or Watts linkage) the lateral location of the axle is determined by the Panhard rod or Watts linkage and the torque arm slider; the primary fore and aft location of the axle is by the two trailing links; and the “tilt” of the axle is controlled by the torque arm slider in its chassis mounting.
The axle housing and the torque arm are considered to be a single rigid entity.
The torque arm is generally on the vehicle centreline in plan view.

When a torque tube axle is specified (in conjunction with a Panhard rod or Watts linkage) the lateral location of the axle is determined by the Panhard rod or Watts linkage and the torque tube ball joint; the primary fore and aft location of the axle is by torque tube ball joint; and the “tilt” of the axle is controlled by the torque tube.
The axle housing and the torque tube are considered to be a single rigid entity.
The torque tube is generally on the vehicle centreline in plan view.

With the Winters style torque tube axle the lateral location is determined by the Jacobs ladder, the fore and aft location by the four trailing links (which are often arranged in a Z with the top link trailing and the bottom link leading) and the “tilt” of the axle is controlled by the torque tube. There is a small amount of variation in the torque tube length and in deflection of the torque tube to the centre section. The internal driveshaft is usually splined at the torque tube ball end and connected to a "spherical" spline at the centre section end to allow for this.

When 2 trailing / leading arms are specified (in conjunction with a Mumford linkage, Panhard rod or Watts linkage) the lateral location of the axle is determined by the Mumford linkage, Panhard rod or Watts linkage; the primary fore and aft location of the axle is by the pair of trailing / leading arms; and the “tilt” of the axle is controlled by the trailing / leading arms.
The trailing / leading arms generally converge (in plan view) and can mount to a common or individual chassis mounting(s).

When 3 or 4 trailing / leading links are specified (in conjunction with a Panhard rod, Mumford or Watts linkage) the lateral location of the axle is determined by the Panhard rod, Mumford or Watts linkage; the primary fore and aft location of the axle is by the lower pair of trailing / leading links; and the “tilt” of the axle is controlled by the upper trailing / leading link(s).
Any compliance will be in the upper pair of links.
The trailing / leading links are generally parallel to the vehicle centreline in plan view.

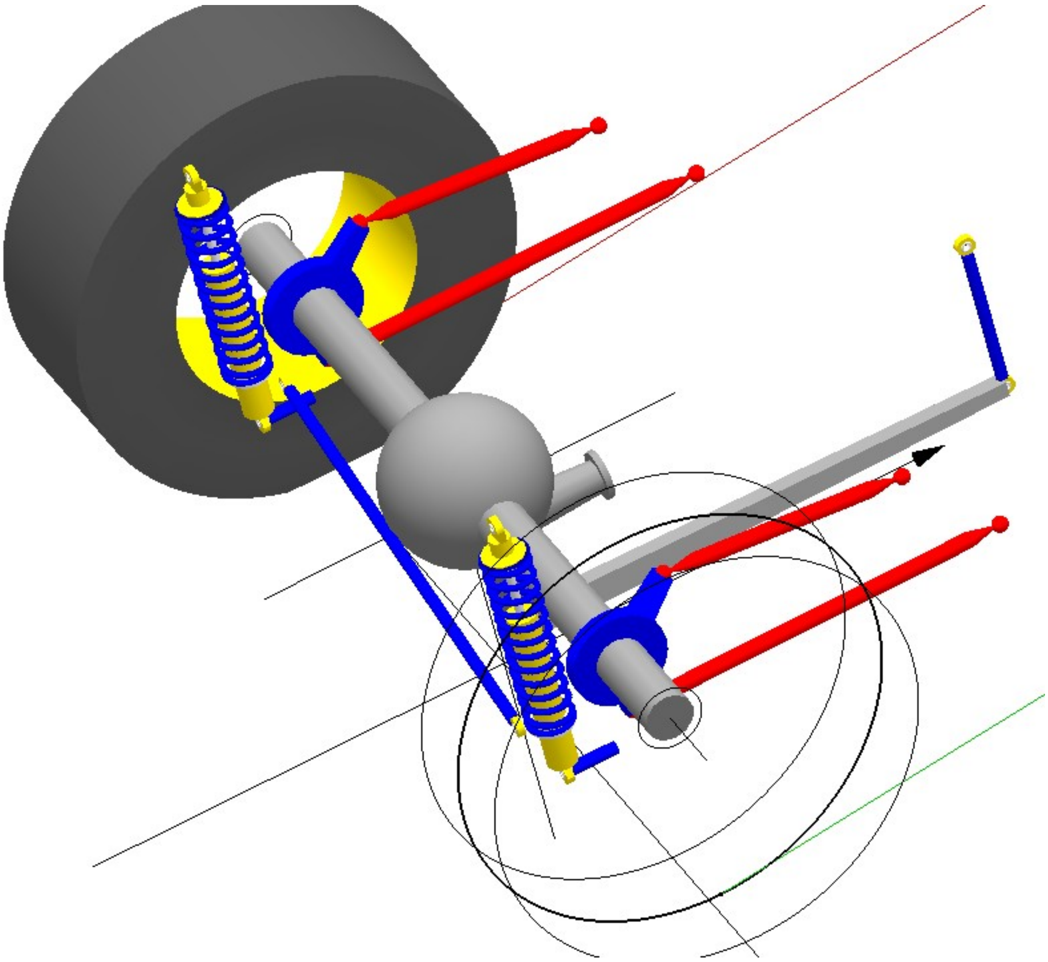
When 4 trailing links are specified (without a Panhard rod, Mumford or Watts linkage) it will be assumed that the lateral location of the axle is determined by the pair of trailing links with the smaller axle separation distance – the lateral link pair; the primary fore and aft location of the axle is by the pair of trailing links with the greater axle separation distance – the fore and aft link pair; and the “tilt” of the axle is controlled by the lateral link pair.
Any compliance will be in the lateral link pair.

Where it is not possible to locate the axle such that all links would connect without error, then the

axle will adopt a "mid way" position, so that the amount that one link is "compressed" is equal to the amount the other link is "extended". This presumes that the axle is torsionally stiff and that this deflection (compliance) is accommodated in the links themselves or in the link bushes.
The total of this "compression" and "extension" is called "compliance" and will be shown in the roll and bump output.

This also applies to the "bottom A arm" configuration as used by the early Lotus Cortina, where the bottom pair of links provides lateral location, with the upper pair of links providing both fore and aft and the "rotation" location. In this configuration, there will not be any link error in the upper links.

4.21.1 Torque arm + 4 trailing links and birdcage + Panhard rod



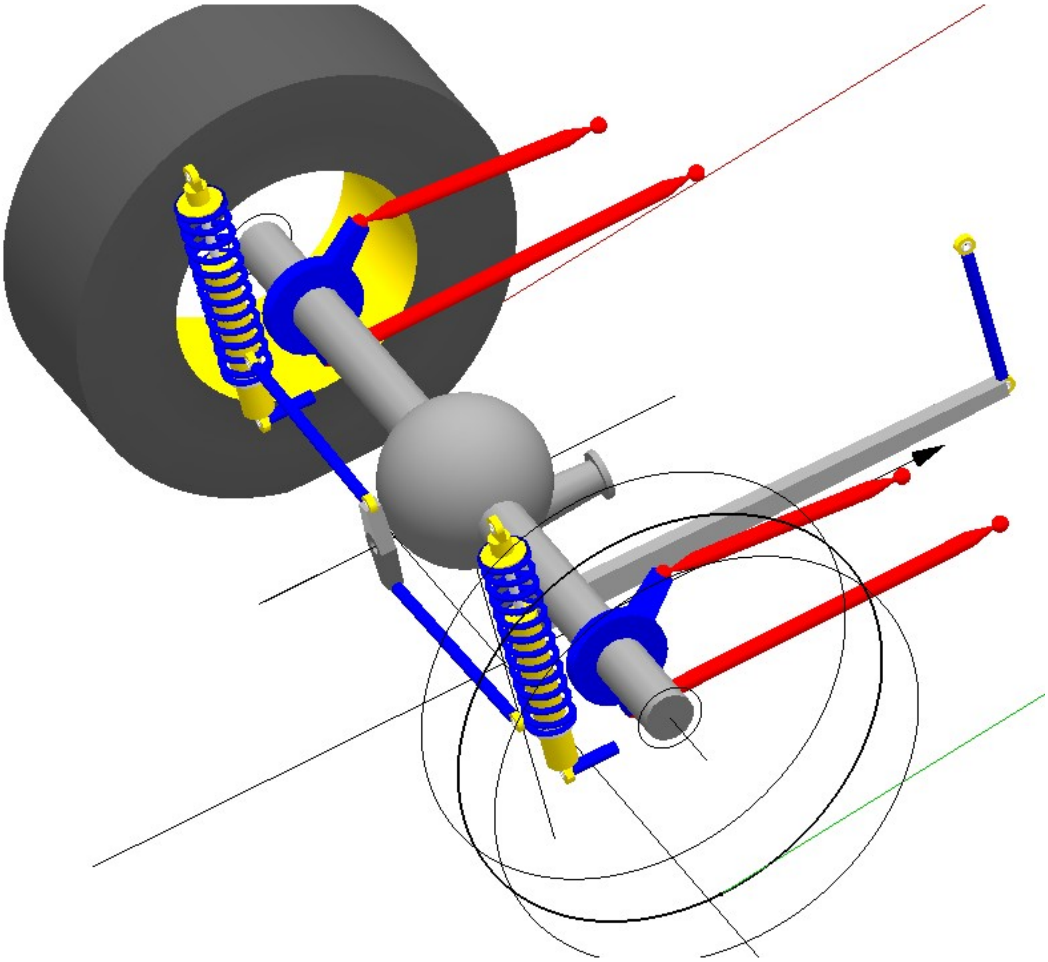
The four trailing links are connected to the axle with a birdcage. The birdcage is axially located and free to rotate on the axle tube.

The axle is located sideways with a Panhard rod and vertically with a link from the torque arm to the chassis.

Six chassis mounting points: four for the trailing links, one for the torque arm link, and one for the Panhard rod.

Six axle mounting points: four for the trailing links (on the birdcage), one for the the torque arm link, and one for the Panhard rod (on the axle).

4.21.2 Torque arm + 4 trailing links and birdcage + Watts linkage



The four trailing links are connected to the axle with a birdcage. The birdcage is axially located and free to rotate on the axle tube.

The axle is located sideways with a Watts linkage and vertically with a link from the torque arm to the chassis.

The Watts linkage can be either “axle mounted” or “chassis mounted”. This refers to the location of the Watts lever pivot axis.

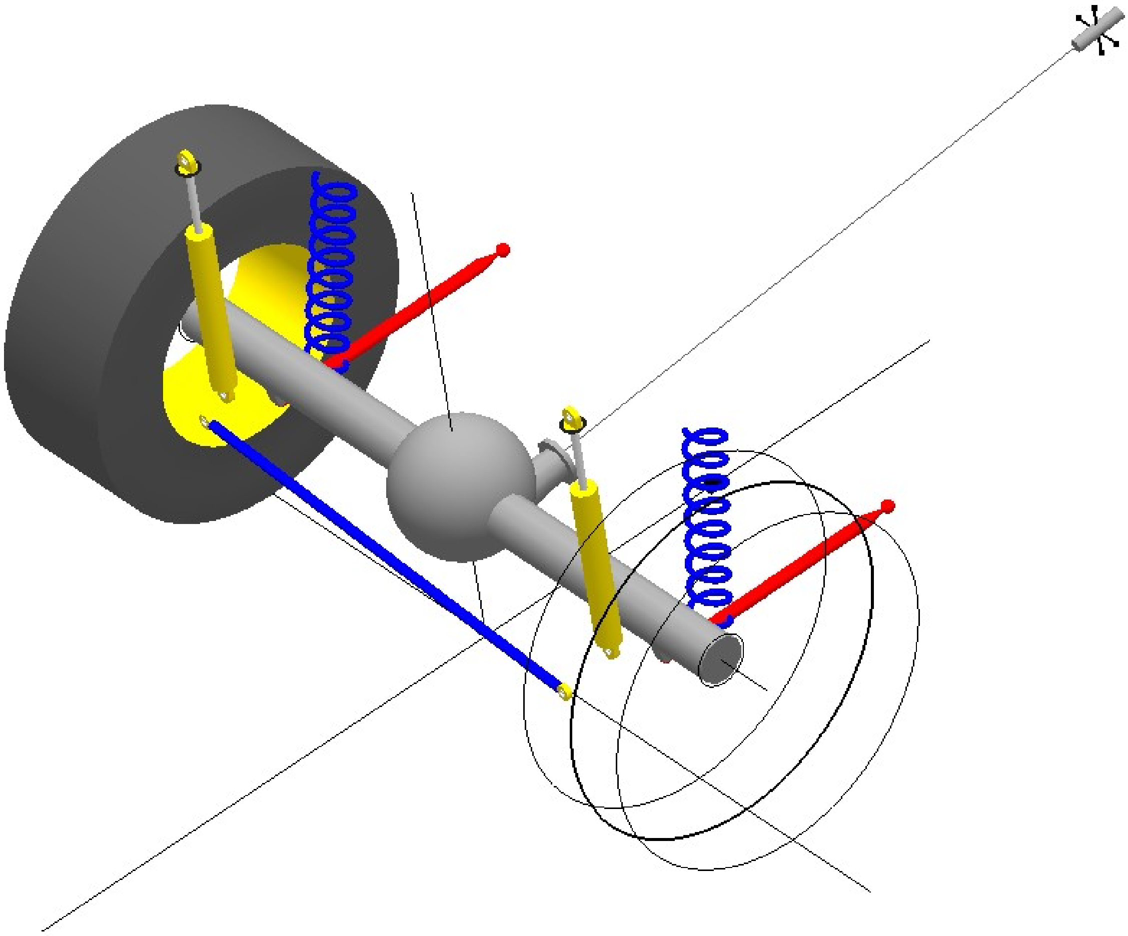
Axle mounted Watts link pivot.

> Seven chassis mounting points: four for the trailing links, one for the torque arm link, and two for the Watts links.
>
> Seven axle mounting points: four for the trailing links (on the birdcage), one for the the torque arm link, and two for the Watts pivot of which one is a reference point to determine the Watts pivot axis.

Chassis mounted Watts link pivot.

> Seven chassis mounting points: four for the trailing links, one for the torque arm link, and two for the Watts pivot of which one is a reference point to determine the Watts pivot axis.
>
> Seven axle mounting points: four for the trailing links (on the birdcage), one for the the torque arm link, and two for the Watts links (on the axle).

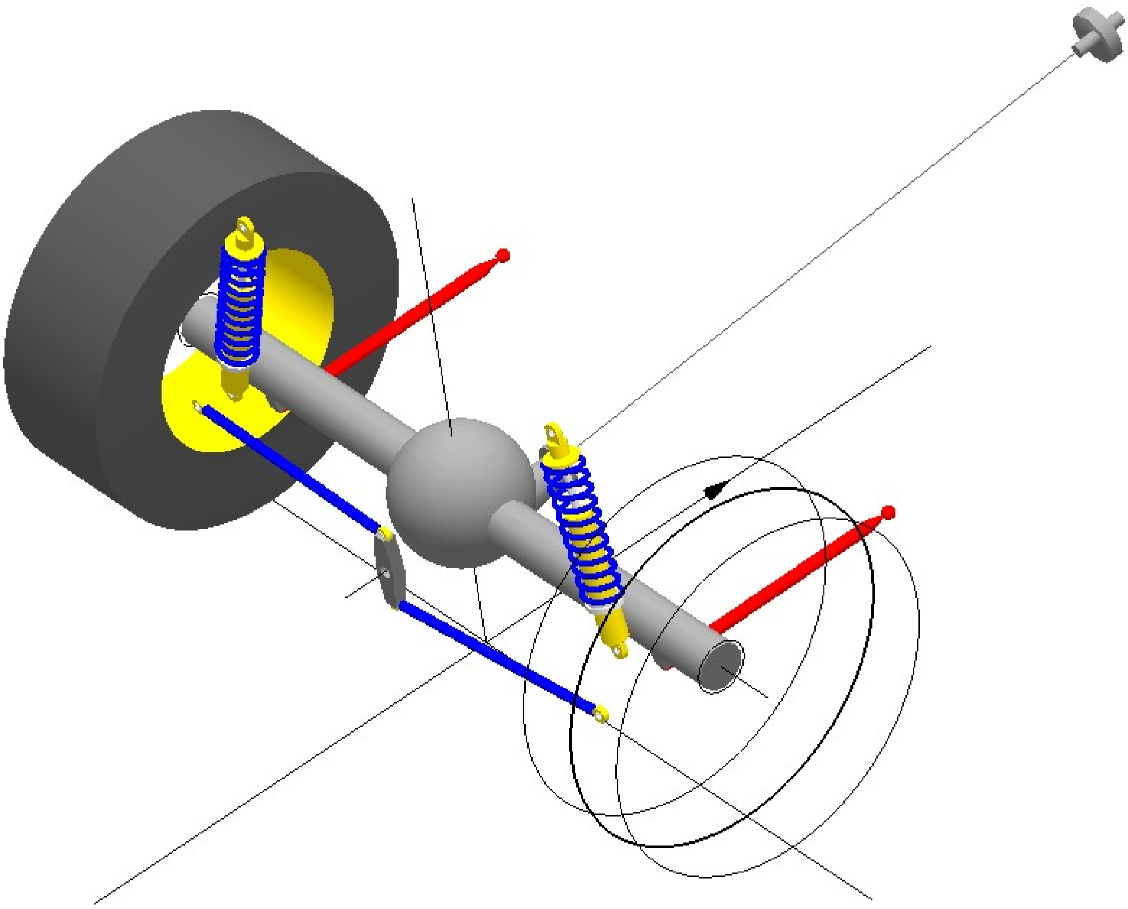
4.21.3 Torque arm + Panhard rod



Four chassis mounting points: one for the torque arm slider bearing, one for each trailing link, one for the Panhard rod.

Five axle mounting points: two for the torque arm slider of which one is reference point to determine the slider axis, one for each trailing link, one for the Panhard rod.

4.21.4 Torque arm + Watts linkage



The Watts linkage can be either “axle mounted” or “chassis mounted”. This refers to the location of the Watts lever pivot axis.

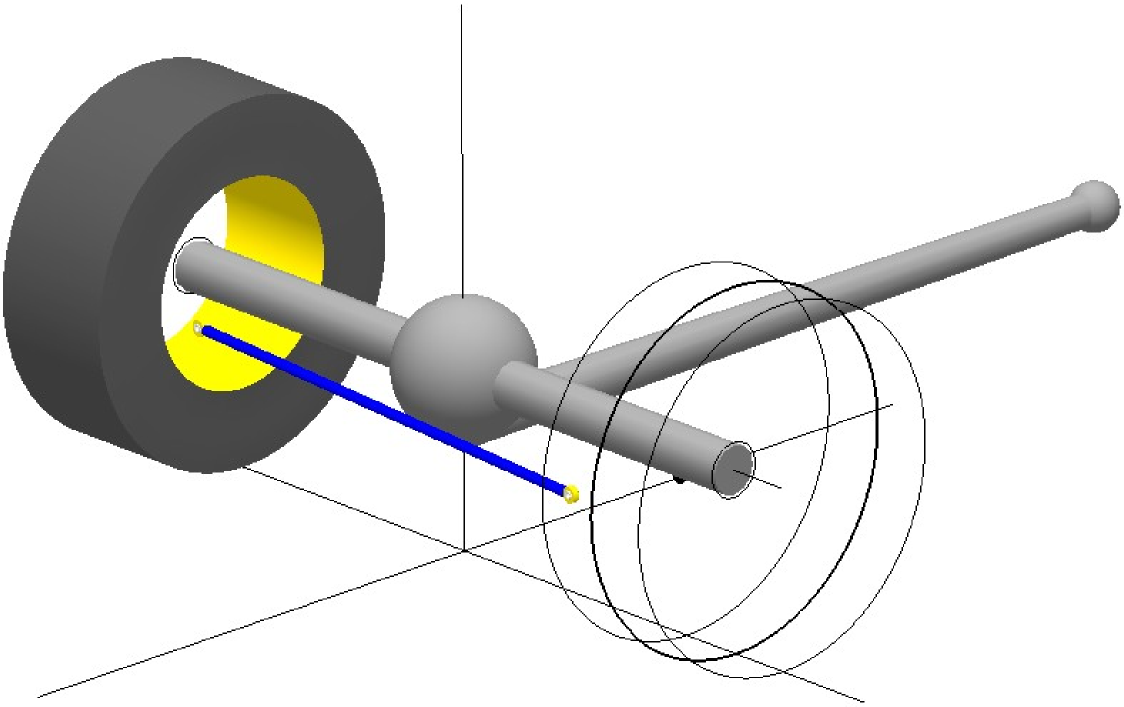
Axle mounted Watts link pivot.

> Five chassis mounting points: one for the torque arm slider bearing, one for each trailing link, one for each Watts lateral link.
>
> Six axle mounting points: two for the torque arm slider of which one is a reference point to determine the slider axis, one for each trailing link, and two for the Watts pivot of which one is a reference point to determine the pivot axis.

Chassis mounted Watts link pivot.

> Five chassis mounting points: one for the torque arm slider bearing, one for each trailing link, and two for the Watts pivot of which one is a reference point to determine the pivot axis.
>
> Six axle mounting points: two for the torque arm slider of which one is a reference point to determine the slider axis, one for each trailing link, one for each Watts lateral link.

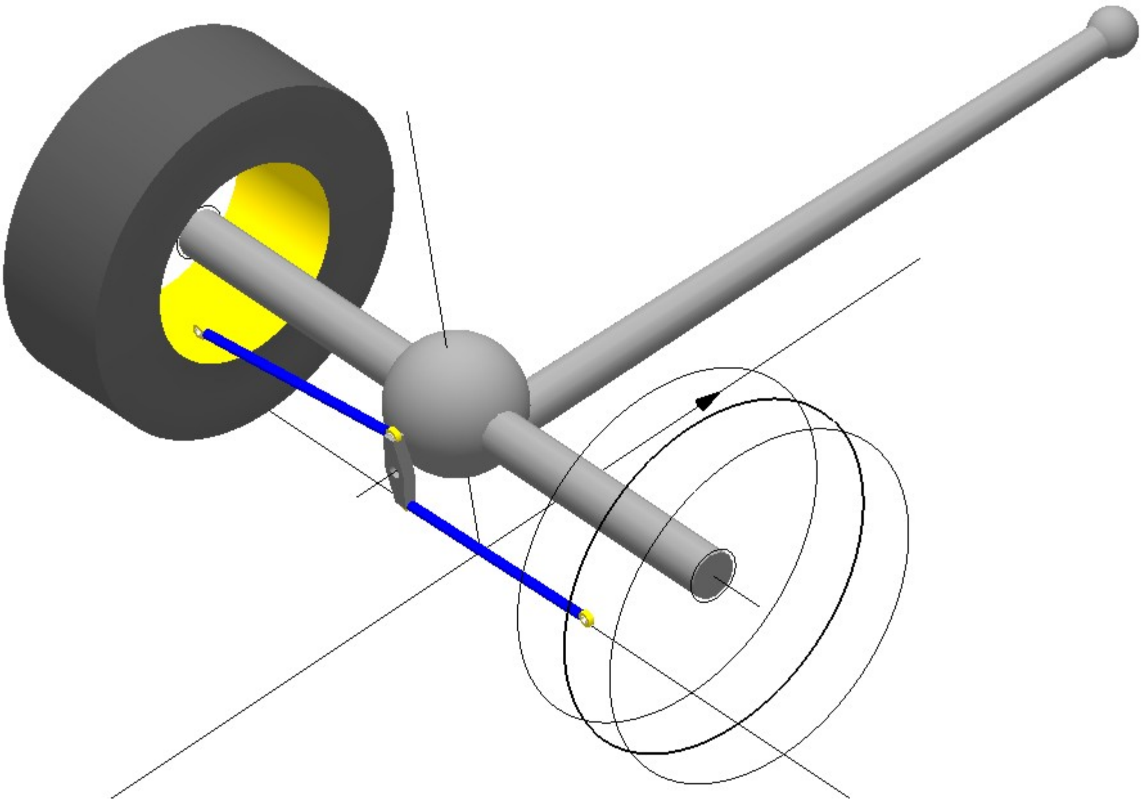
4.21.5 Torque tube + Panhard rod



Two chassis mounting points, one for the torque tube ball joint, and one for the Panhard rod. The torque tube mounting can be the same point as the rear gearbox universal.

Two axle mounting points, one for torque tube ball joint, one for the Panhard rod.

4.21.6 Torque tube + Watts linkage



The Watts linkage can be either “axle mounted” or “chassis mounted”. This refers to the location of the Watts lever pivot axis.

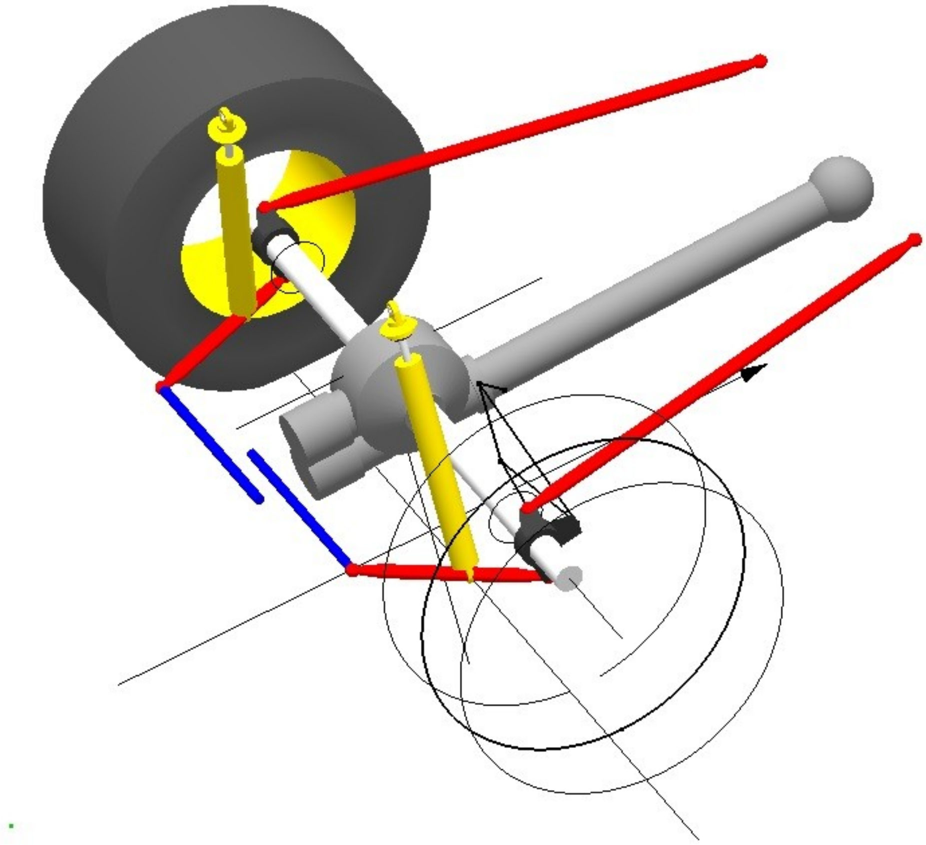
Axle mounted Watts link pivot.

> Three chassis mounting points: one for the torque tube ball joint, one for each Watts lateral link.
>
> Three axle mounting points: one for torque tube ball joint, and two for the Watts pivot of which one is a reference point to determine the pivot axis.

Chassis mounted Watts link pivot.

> Three chassis mounting points: one for the torque tube ball joint, and two for the Watts pivot of which one is a reference point to determine the pivot axis.
>
> Three axle mounting points, one for torque tube ball joint, one for each Watts lateral link.

4.21.7 Winters: 4 trailing links, 2 birdcages + Jacobs ladder



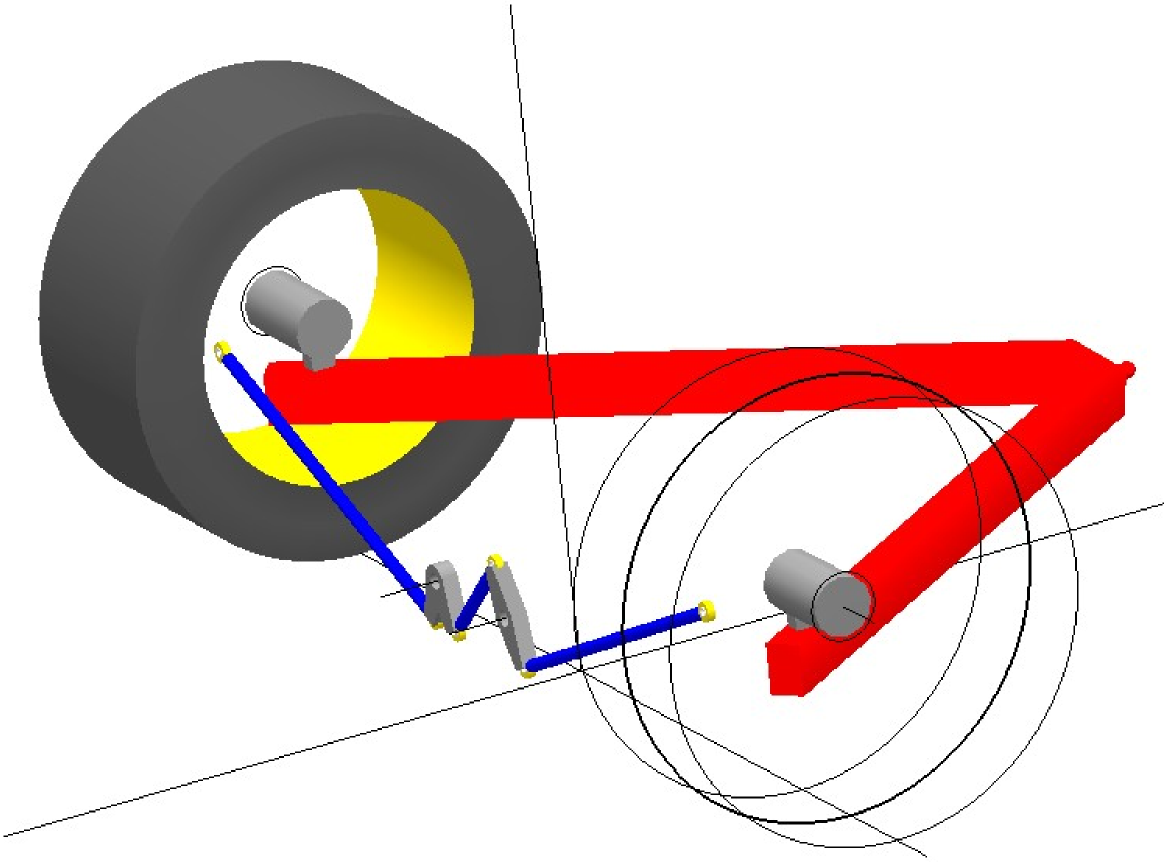
This is the typical speedway midget rear suspension. The axle is open style with the suspension links attached to a birdcage on each side. A Jacobs ladder is used for lateral location. The longitudinal links are usually arranged in a "Z" with the top link trailing and the bottom link leading.

The Winters rear axle is typical with the torque tube ball joint located just behind the crankshaft and offset to the left.

There are seven chassis mounting points: one for each trailing / leading link, two for the Jacobs ladder, and one for the torque tube ball joint.

There are six axle mounting points: one for each trailing / leading link, one for the Jacobs ladder, all on a birdcage, plus the torque tube ball joint.

4.21.8 2 trailing arms + Mumford linkage



Rear suspension is configured with two trailing arms.

The two trailing / leading arm mountings can be a single point.

The Mumford linkage can be either “axle mounted” or “chassis mounted”. This refers to the location of the Mumford bellcrank and lever pivots.

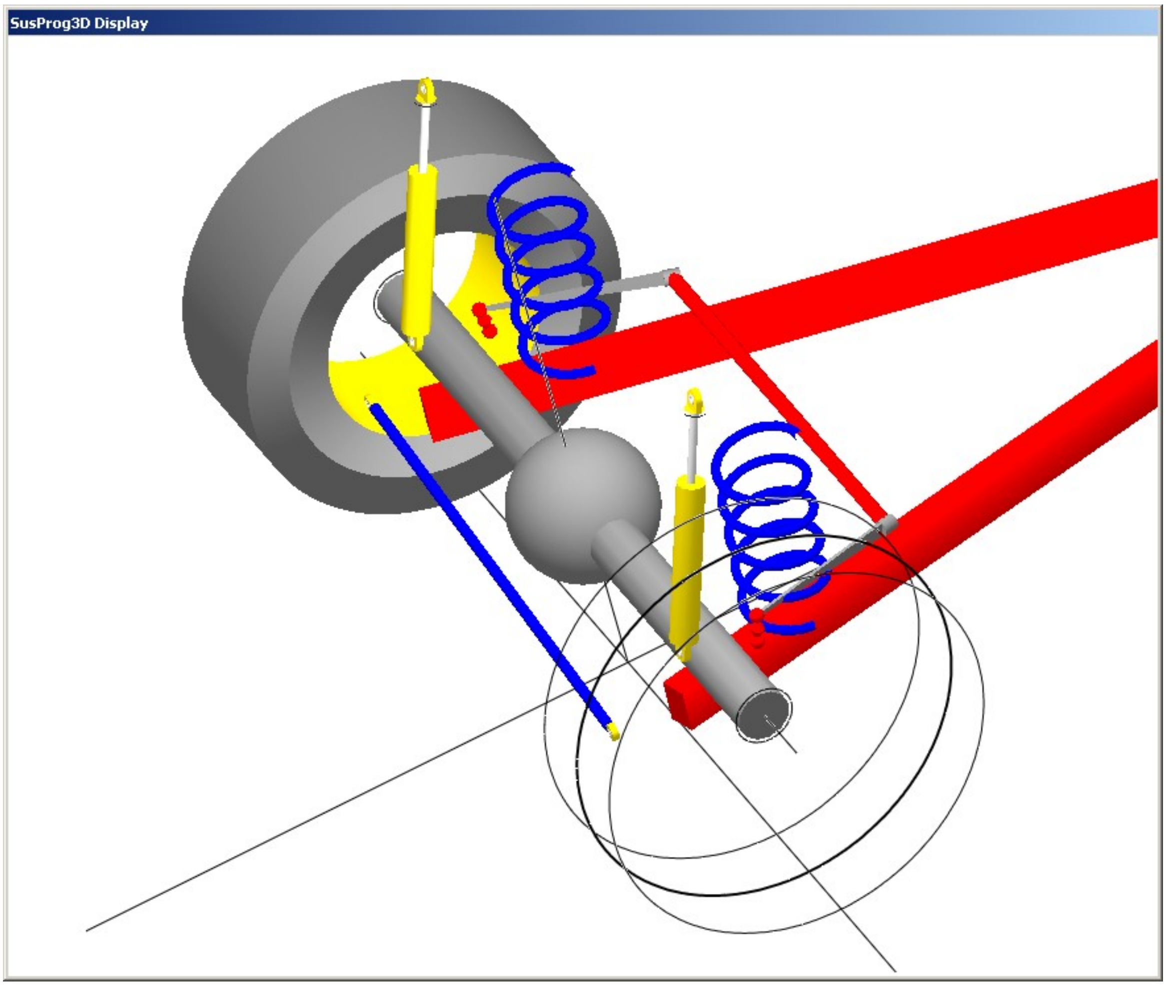
Chassis mounted Mumford linkage.

> Four or five chassis mounting points: one for each trailing arm(s), three for the Mumford pivots of which one is a reference point to determine the bellcrank pivot axis.
>
> Four axle mounting points: one for each trailing arm, one for each Mumford lateral link.

Axle mounted Mumford linkage.

> Three or four chassis mounting points: one for each trailing arm(s), one for each Mumford lateral link.
>
> Five axle mounting points: one for each trailing arm(s), three for the Mumford pivots of which one is a reference point to determine the bellcrank pivot axis.

4.21.9 2 trailing arms + Panhard rod

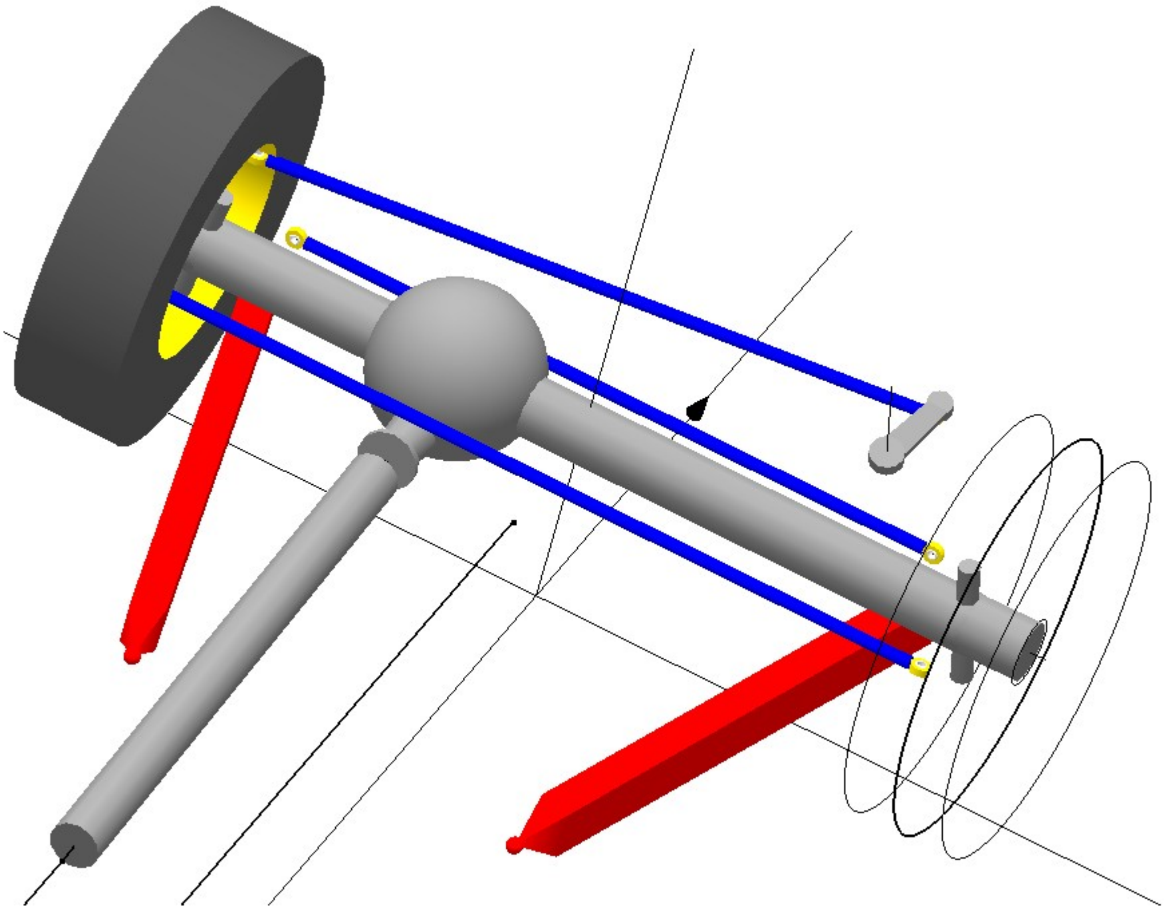


Typical twin trailing arm and Panhard rod rear suspension configured with two trailing arms.

The two trailing / leading arm mountings can be a single point.

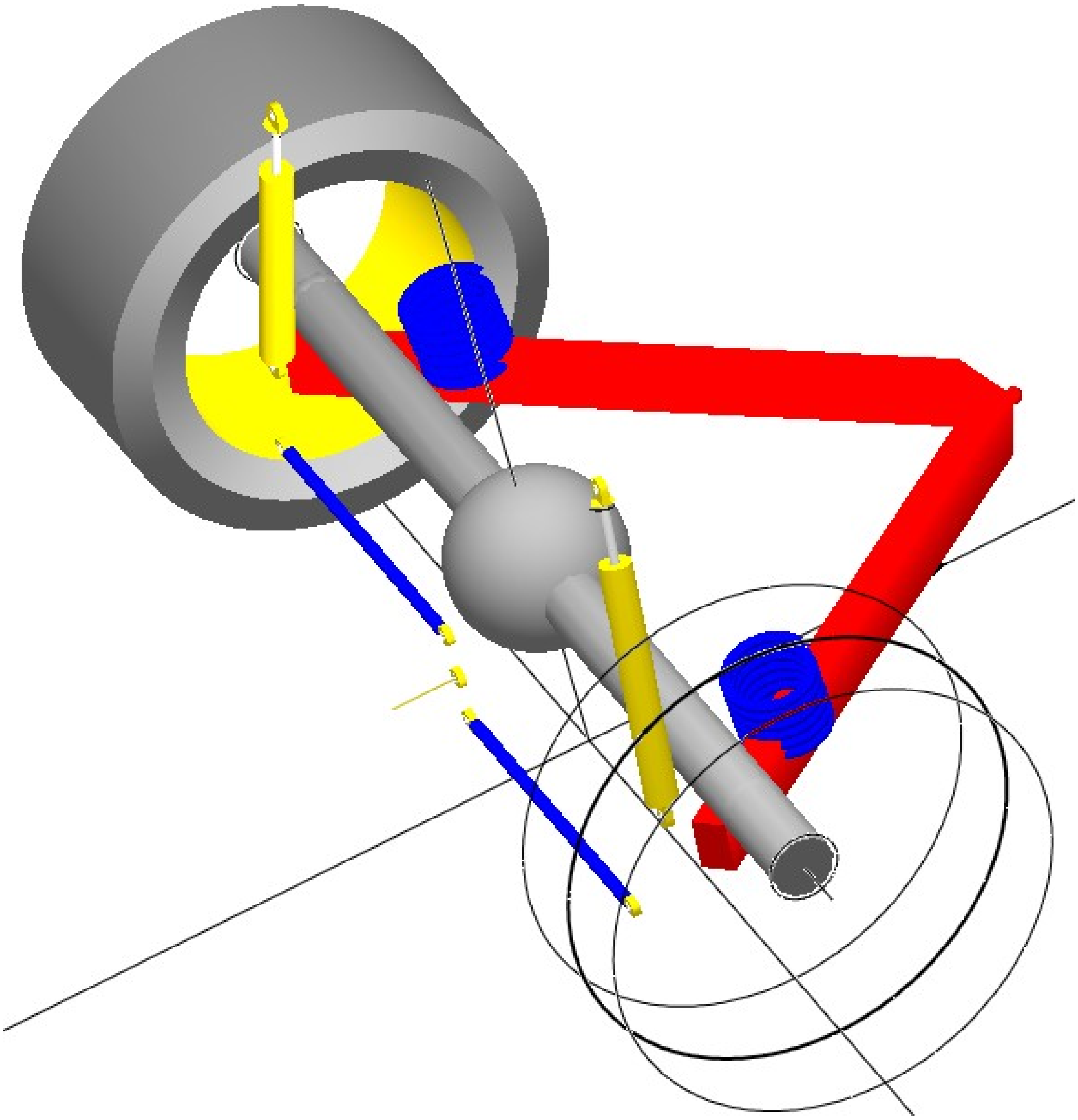
Two or three chassis mounting points: one for each trailing / leading arm(s), one for the Panhard rod.

Three axle mounting points: one for each trailing / leading arm, one for the Panhard rod.



Typical twin trailing arm and Panhard rod front suspension configured with two leading arms.

4.21.10 2 trailing arms + Watts linkage



The two trailing arm mountings can be a single point.

The Watts linkage can be either “axle mounted” or “chassis mounted”. This refers to the location of the Watts lever pivot axis.

Axle mounted Watts link pivot.

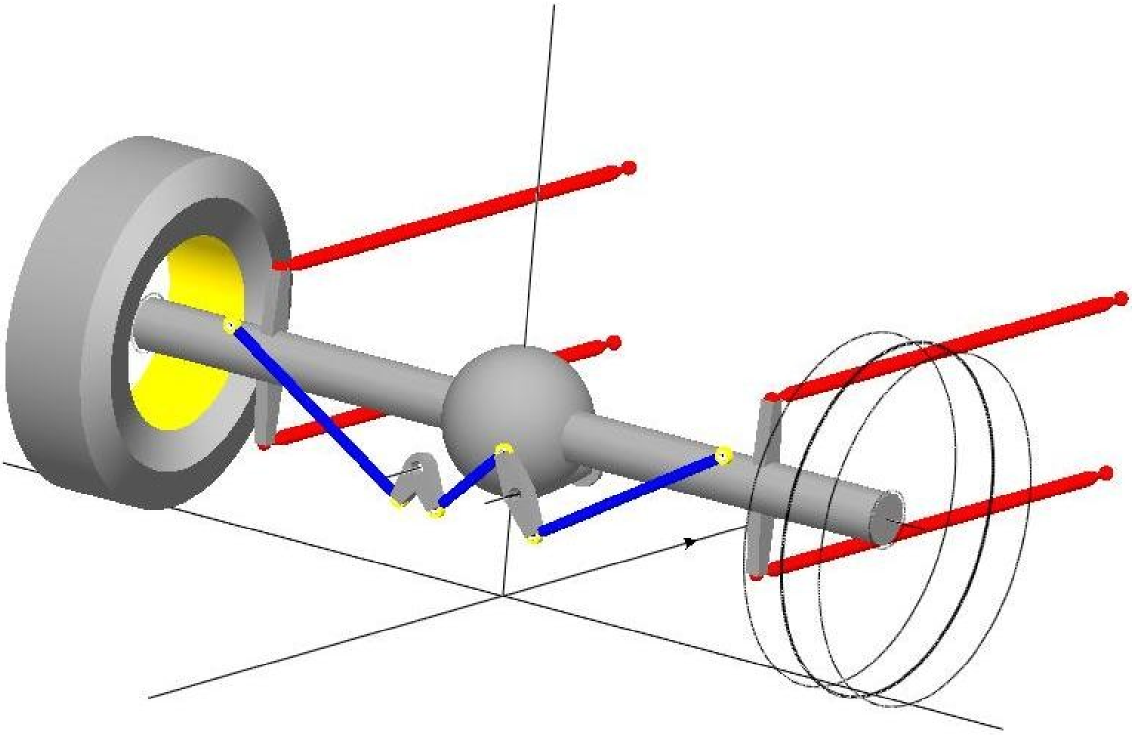
> Three or four chassis mounting points: one for each trailing arm(s), one for each Watts lateral link.
>
> Four axle mounting points, one for each trailing arm, and two for the Watts pivot of which one is a reference point to determine the pivot axis.

Chassis mounted Watts link pivot.

> Four chassis mounting points: one for each trailing arm, and two for the Watts pivot of which one is a reference point to determine the pivot axis.
>
> Three or four chassis mounting points: one for each trailing arm, one for each Watts

lateral link.

4.21.11 3 or 4 trailing links + Mumford linkage



The 3 trailing link configuration has only one top link which can be located on the left or right side, or centrally.

The Mumford linkage can be either “axle mounted” or “chassis mounted”. This refers to the location of the Mumford bellcrank and lever pivots.

Chassis mounted Mumford linkage.

Six or seven chassis mounting points: three or four for the trailing links, three for the Mumford pivots of which one which is a reference point to determine the bellcrank pivot axis.

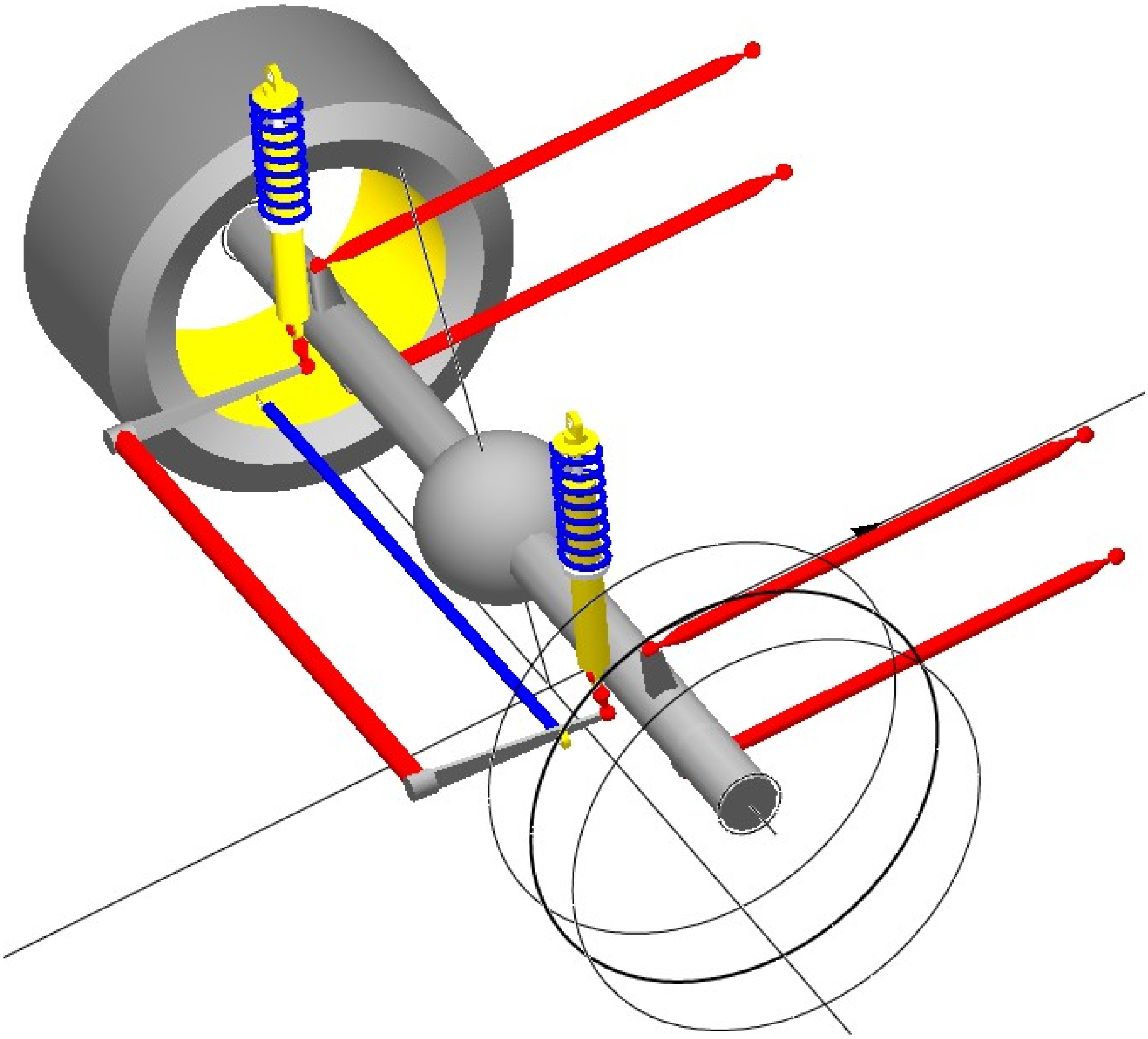
Five or six axle mounting points: three or four for the trailing links, one for each Mumford lateral link.

Axle mounted Mumford linkage.

Five or six chassis mounting points: three or four for the trailing links, one for each Mumford lateral link.

Six or seven axle mounting points: three or four for the trailing links, three for the Mumford pivots of which one is a reference point to determine the bellcrank pivot axis.

4.21.12 3 or 4 trailing links + Panhard rod

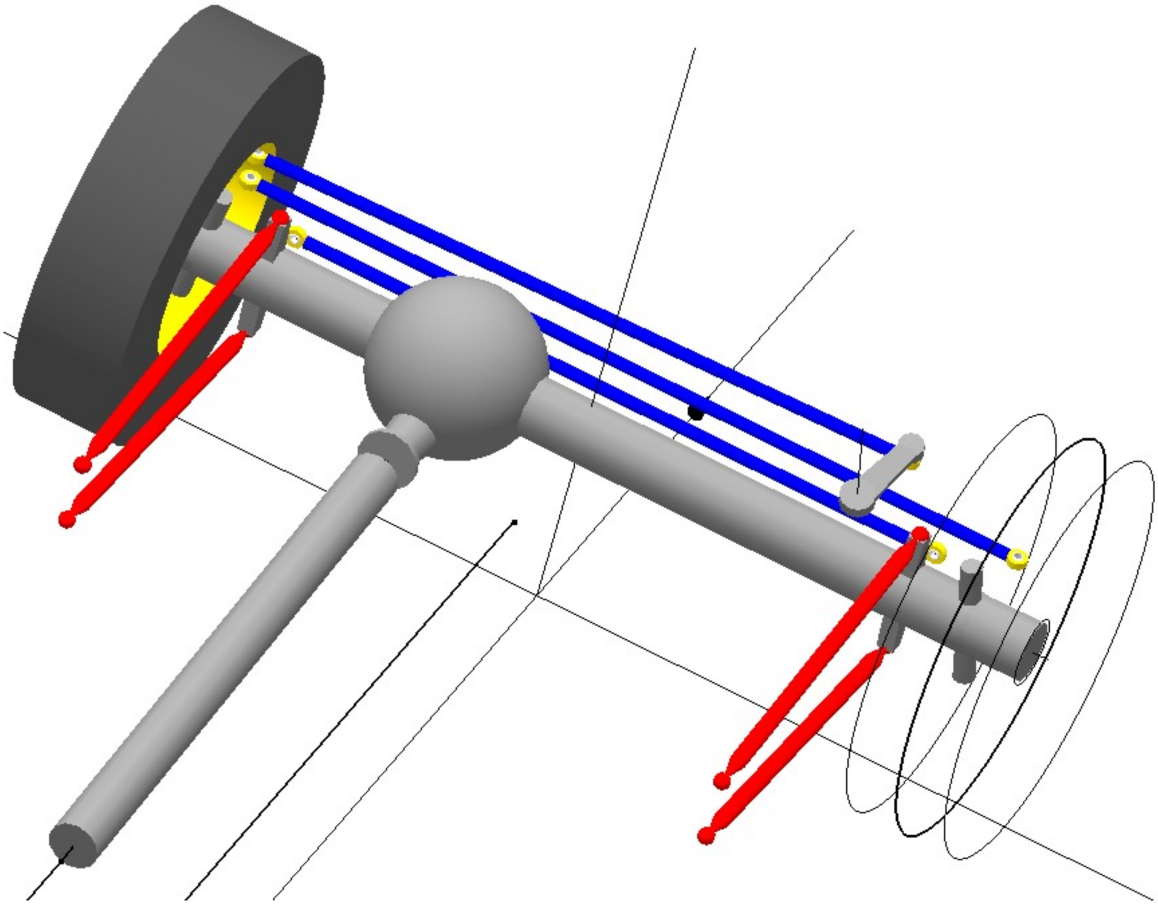


Typical rear suspension with 4 trailing links and Panhard rod.

The 3 trailing / leading link configuration has only one top link which can be located on the left or right side, or centrally.

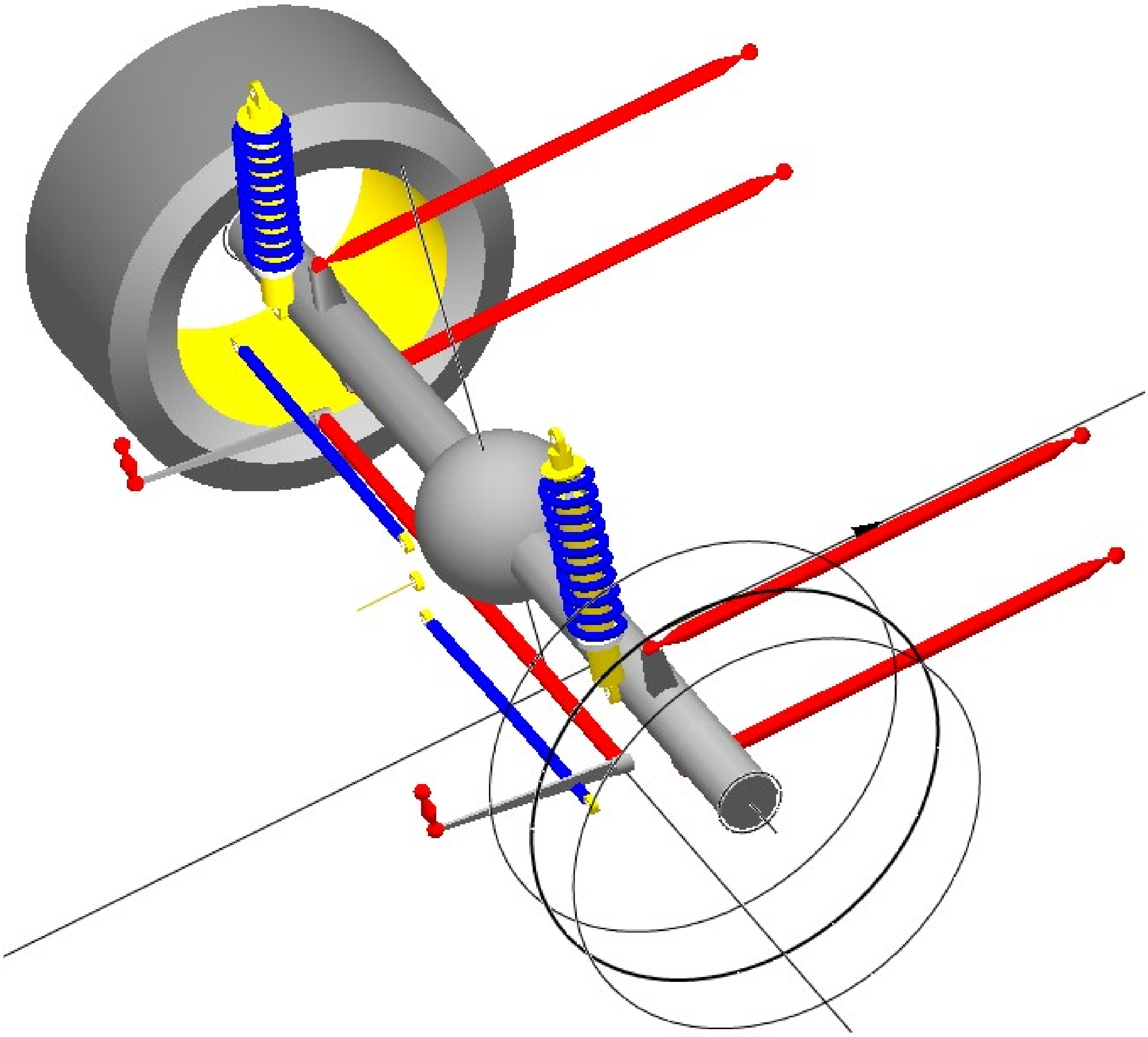
Four or five chassis mounting points: one for each trailing / leading link, one for the Panhard rod.

Four or five axle mounting points: one for each trailing / leading link, one for the Panhard rod.



Typical front suspension with 4 leading links and Panhard rod.

4.21.13 3 or 4 trailing links + Watts linkage



The 3 trailing link configuration has only one top link which can be located on the left or right side, or centrally.

The Watts linkage can be either “axle mounted” or “chassis mounted”. This refers to the location of the Watts lever pivot axis.

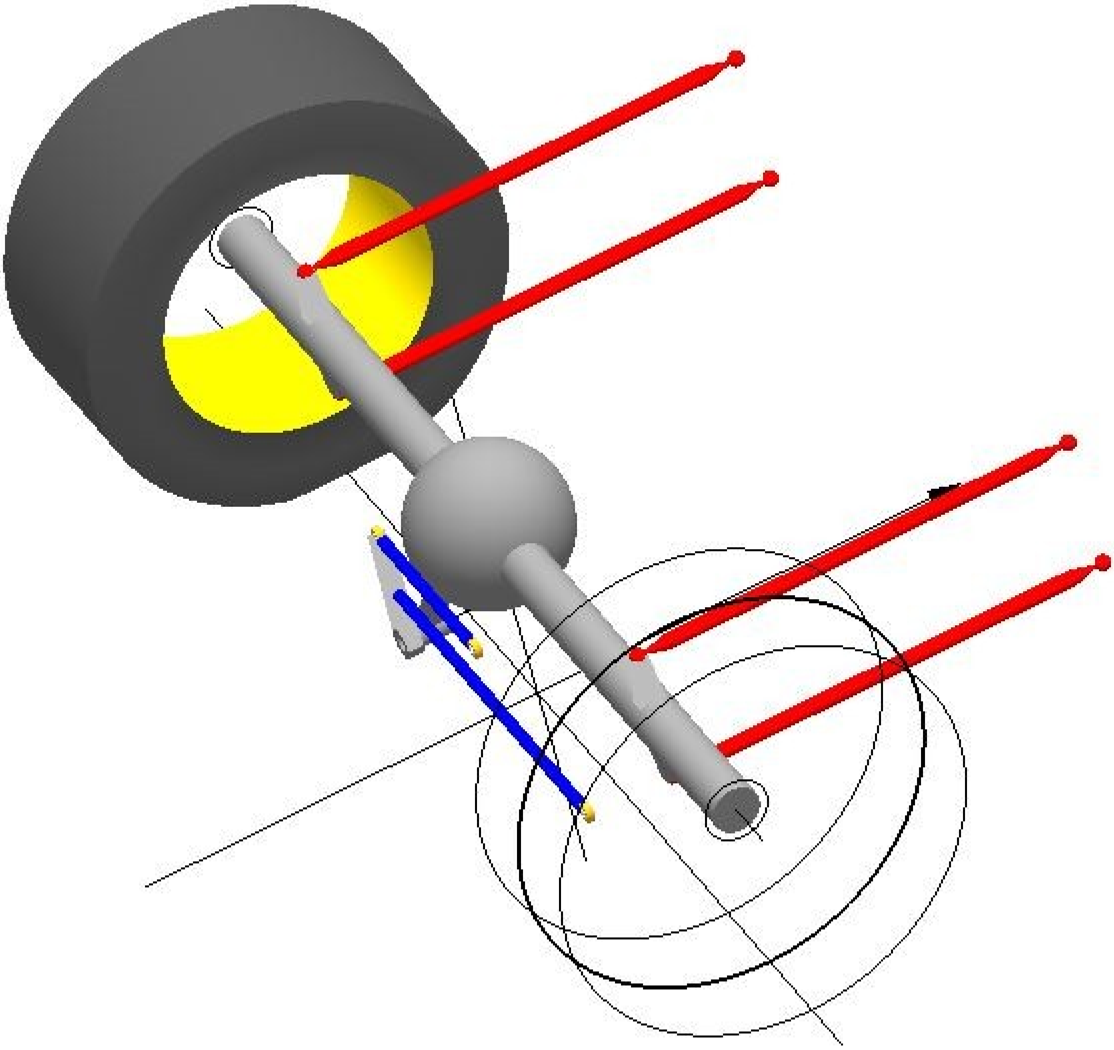
Axle mounted Watts link pivot.

> Five or six chassis mounting points: one for each trailing link, one for each Watts lateral link.
>
> Five or six axle mounting points: one for each trailing link, and two for the Watts pivot of which one is a reference point to determine the pivot axis.

Chassis mounted Watts link pivot.

> Five or six chassis mounting points: one for each trailing link, and two for the Watts pivot of which one is a reference point to determine the pivot axis.
>
> Five or six chassis mounting points: one for each trailing link, one for each Watts lateral link.

4.21.14 3 or 4 trailing links + Woblink



The 3 trailing link configuration has only one top link which can be located on the left or right side, or centrally.

The Woblink can be either “axle mounted” or “chassis mounted”. This refers to the location of the Woblink lever pivot axis.

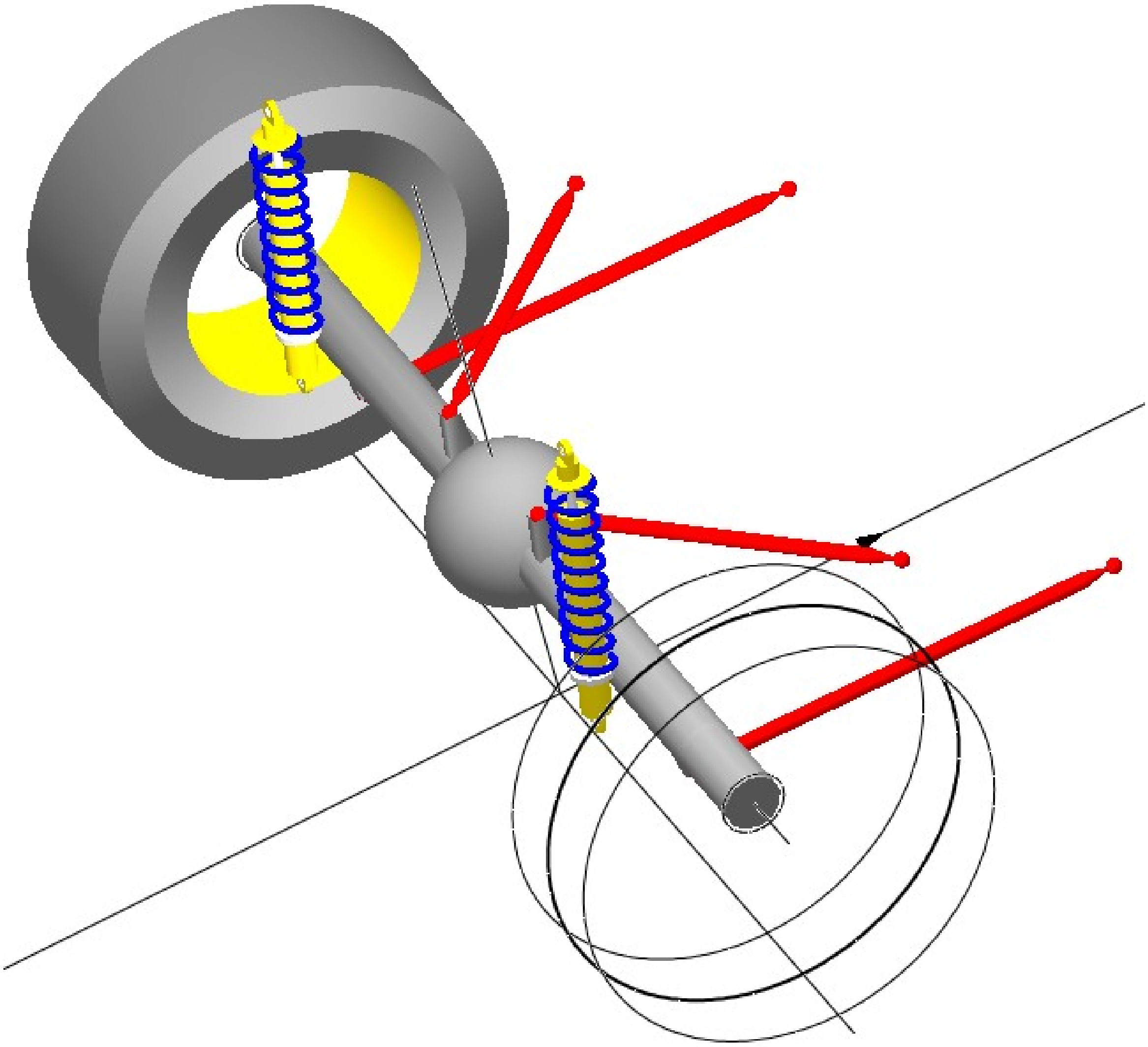
Axle mounted Woblink pivot.

> Five or six chassis mounting points: one for each trailing link, one for each Woblink lateral link.
>
> Five or six axle mounting points: one for each trailing link, and two for the Woblink pivot of which one is a reference point to determine the pivot axis.

Chassis mounted Woblink pivot.

> Five or six chassis mounting points: one for each trailing link, and two for the Woblink pivot of which one is a reference point to determine the pivot axis.
>
> Five or six axle mounting points: one for each trailing link, one for each Woblink lateral link.

4.21.15 4 trailing links

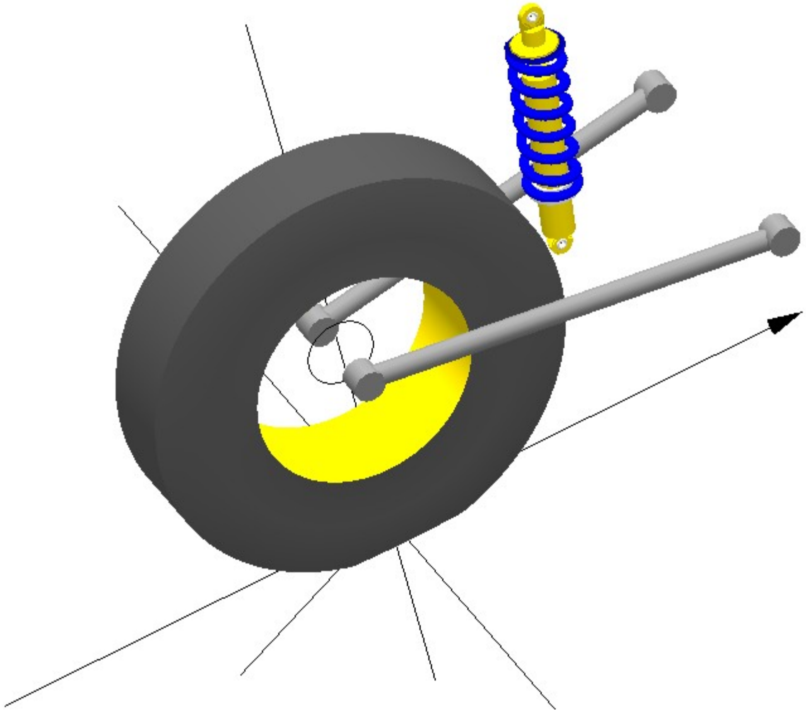


In some configurations, either the upper pair or the lower pair of links is arranged as an A-arm with a single mounting.

There are four chassis mounting points, one for each trailing link.

There are four axle mounting points, one for each trailing link.

4.22 Mono wheel - trailing arm



Two chassis mounting points for the trailing arm.

In this configuration, the axle hub, spindle and trailing arm are combined into a single assembly with the trailing arm attached to the chassis at two mounting points. The front view instant centre (roll centre) is on the ground on the wheel centreline, and the side view instant centre is on the trailing arm chassis pivot.

Generally, the trailing arm has a pivot axis at right angles to the vehicle centreline. The rear suspension on most motorcycles and quad bikes is a typical example.

5 Vehicle

Sets the basic vehicle parameters

Config	Specify the basic vehicle suspension
Datum	Specify the chassis measurement datum
Wheelbase	Specify the wheelbase
Ride height	Specify the ride height location points, and the ride height
Mass	Specify and calculate the mass distributions
Wheel and tyre	Specify the wheel and tyre sizes
Data	Print the vehicle data
Graphic	Print the vehicle graphic
ECalc	Specify the modules and calculate

5.1 Configure

From the Vehicle tab, select Config.

For each of the front and rear of the vehicle,

- select the suspension type
- specify where the brakes are located, either inboard or outboard.
  Live and rigid rear axles will default to outboard brake location.
- enter the front wheel brake force percentage.
  This can be done by either entering a value (in the range 0 to 100) in the "front %" edit box, or by picking the slider and moving it left (to decrease the front brake %) or right (to increase the front brake %).
- specify if the vehicle is front wheel drive or rear wheel drive.

Select both for four wheel drive.
Both Jaguar, de Dion and live axle rear suspensions will default to rear wheel drive.
Rigid axles will disable drive at that end of the vehicle.

- if the vehicle is 4WD, enter the front axle drive torque percentage.
  This can be done by either entering a value (in the range 0 to 100) in the "front %" edit box, or by picking the slider and moving it left (to decrease the front torque %) or right (to increase the front torque %).

Optionally, descriptive comments can be added for each of

- general, for the vehicle or project itself
- front suspension,
- rear suspension
- front wheel and tyre
- rear wheel and tyre

Vehicle configuration must be specified before any data is entered or calculated.

Depending on the particular components selected, some tab items may not be available.

For designers of scale models, the vehicle scale can be specified. This is currently only used by Viewer to display some graphic elements. For example, designers of 1/5th scale radio control vehicles may prefer to work in Designer in model dimensions, then setting the scale value to 0.2 will result in Viewer displaying suspension links, Driveline components etc in a more appropriate size.

The default is 1.0 (ie full size).

5.2 Datum

From the Vehicle tab, select Datum.

The vehicle reference datums are fixed. The vertical datum is the ground, the lateral datum is the vehicle centreline, and the longitudinal datum is a plane through the chassis longitudinal datum reference point. There is only one set of vehicle datum axes and it is used for both front and rear suspensions.

The chassis vertical and longitudinal datums can be specified; the chassis lateral datum is the chassis centreline.

- The chassis vertical datum is a horizontal plane, usually the ground plane, chassis undertray, or some other convenient flat reference plane.
- The chassis longitudinal datum is controlled by specifying a single point, the longitudinal datum reference point.
  This is a convenient point from which all longitudinal dimensions are taken. This point need not be on the chosen vertical datum plane, and can be at any convenient height. It can be on the right or the left side of the vehicle.

The chassis points are dimensioned from the chassis datum.

Both the front and rear longitudinal datum to axle centreline dimensions must be entered. These can initially be an approximation, and are used to calculate the wheelbase. Depending on the chosen Geometry configuration, a more accurate figure may be required as part of the Alignment settings.

Chassis datum:

Vertical datum	Identify the vertical datum plane by name.
Longitudinal datum	Identify the longitudinal datum reference point by name. This could be a suspension mounting point or any convenient hard point on the

	chassis structure.
Longitudinal datum reference point	Specify the distance the point is from the vehicle centreline (the lateral dimension) and the height the point is above or below the vertical datum reference plane (the vertical dimension). A positive lateral dimension is on the side of the vehicle with the positive lateral axis; a negative lateral dimension is on the side of the vehicle with the negative lateral axis. If the vertical axis is +ve upward, then a positive vertical dimension is above the vertical datum plane, negative vertical dimension is below the vertical datum plane. If the vertical axis is +ve downward, then a negative vertical dimension is above the vertical datum plane, positive vertical dimension is below the vertical datum plane.
Longitudinal datum to front axle centreline	Specify the nominal distance from the longitudinal datum reference point, horizontally, to the front axle centreline. If the longitudinal axis is +ve rearward, then a negative dimension indicates the axle centreline is forward from the longitudinal datum reference point, and a positive dimension indicates the axle centreline is rearward from the longitudinal datum reference point. If the longitudinal axis is +ve foreward, then a positive dimension indicates the axle centreline is forward from the longitudinal datum reference point, and a negative dimension indicates the axle centreline is rearward from the longitudinal datum reference point.
Longitudinal datum to rear axle centreline	Specify the nominal distance from the longitudinal datum reference point, horizontally, to the rear axle centreline. If the longitudinal axis is +ve rearward, then a negative dimension indicates the axle centreline is forward from the longitudinal datum reference point, and a positive dimension indicates the axle centreline is rearward from the longitudinal datum reference point. If the longitudinal axis is +ve foreward, then a positive dimension indicates the axle centreline is forward from the longitudinal datum reference point, and a negative dimension indicates the axle centreline is rearward from the longitudinal datum reference point.

Chassis datum surface:

This defines the size of the chassis datum surface. If using a ground based datum, then leave all these dimensions zero. If using a actual chassis datum, like a surface plate or a build table or jig, then this will define a rectangular surface representative of the actual chassis datum surface.

Front edge of datum surface	The distance the front edge of the chassis build surface is from the longitudinal datum.
Rear edge of datum surface	The distance the rear edge of the chassis build surface is from the longitudinal datum.
Datum surface width	The chassis build surface width.

For further details on using a ground based vertical datum.

For further details on converting from a ground based to a chassis based vertical datum.

For further details on using a chassis based vertical datum.

The specified datum location can be realigned.

5.3 Wheelbase

From the Vehicle tab, select Wheelbase.

The vehicle wheelbase is calculated from the calculated front and rear wheel positions.

If the wheel location point is specified as “Wheel centre / axle” then the wheelbase will be shown with two sets of dimensions, one will be the “on ground” dimension and the other will be the “ Wheel centre / axle” dimension.

If the wheel location point is specified as “On ground” then the wheelbase is measured on the ground between the tyre contact patch centrelines with the specified camber, castor and toe.

If the wheel location point is specified as “Wheel centre / axle” then the wheelbase is measured between then wheel centres at hub height, with the specified camber, castor and toe.

If the wheelbase is not identical on both sides, or the front wheels are not inline, or the rear wheels are not inline, then the wheelbase will be shown for both sides of the vehicle, the difference between them, and the relative positions of the front and rear wheels.

Initially, the front and rear wheels are specified relative to the chosen longitudinal datum, and these dimensions will determine the wheelbase.

The Geometry calculations can also change the longitudinal position of the wheels, and this will recalculate the wheelbase.

5.4 Ride Height

From the Vehicle tab, select Ride Height.

Specify the number and location of the ride height reference points.
If only two points are specified, the chassis will be located relative to the ground with no side rake.

Even if you are only designing one end of the vehicle, both front and rear ride height reference points must be entered, together with their static ride heights, as these dimensions control the vehicle attitude and the height of all chassis location points from the ground.

Enter the coordinates and the description of the front and rear ride height reference points relative to the chassis lateral, vertical and longitudinal datums. These can be any convenient chassis or body point.

Ideally, the front ride height reference point(s) should be in the region of the front axle, and the rear ride height reference point(s) should be in the region of the rear axle.

Specify the height of each ride height reference point from the ground, with the vehicle in the static ride position. This will determine the all the chassis dimensions relative to the ground plane.

When the static geometry is calculated, the chassis will be “moved” and all the chassis mounting points recalculated relative to the ground, with the wheel alignment set to that specified in the "Settings" dialog.

For further details on using a ground based vertical datum.

For further details on using a chassis based vertical datum.

Resetting vehicle static ride height.

Following the initial calculations, you may decide that the vehicle static ride height as originally specified is no longer appropriate, and you wish to determine the effect on the wheel alignment and other suspension settings of changing the ride height.

This may be particularly appropriate when you have measured a vehicle in its road "ride height" condition, and wish to see the effect of lowering it for track use, or raising it for off-road use.

Enter the new ride heights.

In Geometry | Configuration, choose the appropriate wheel location and alignment option.

When the “Top and bottom wishbones + steering” option is specified, this means that the resultant wheel alignment will be the new values calculated. This corresponds to raising or lowing the vehicle without making any adjustments to the wishbone dimensions or toe. Track, wheelbase and axle cl to datum dimensions will be calculated. Static wheel alignment camber, caster and toe settings will be set to the new values calculated.

When the “Top and bottom wishbones + wheel toe” option is specified, this means that the resultant wheel camber and caster will be the new values calculated. This corresponds to raising or lowing the vehicle without making any adjustments to the wishbone dimensions, but resetting the toe. Track, wheelbase and axle cl to datum dimensions will be calculated. Static wheel alignment camber and caster settings will be set to the new values calculated.

When any other option is specified, this means that the resultant wheel alignment will be maintained at that specified in Geometry | Alignment. Depending on which links are specified, the various wheel alignment settings, datum dimensions, track and wheelbase will be calculated as noted above.

For the complete vehicle, repeat the calculation for both front and rear suspensions.

5.5 Vehicle mass and centre of gravity

From the Vehicle, Rates or Dynamic tab, select Mass.

Mass

The unsprung corner mass are for the upright, tyre and wheel assembly. For a live axle, each rear corner will include half the mass of the axle.

The vehicle corner mass are the mass of each corner as measured by each individual corner scale. This includes both the sprung and unsprung mass.

The sprung corner mass and all the percentage distributions will be calculated.

For the Spring and Anti-roll bar rates calculations, only the sprung mass (total, for the appropriate end of the vehicle under design) is used.

For the Dynamic calculations, the sprung and unsprung masses for both ends must be entered.

Centre of Gravity

Although there are three sets of CofG locations shown, only the Vehicle CofG height can be entered. All other dimensions will be calculated.

Enter the height of the centre of gravity. This is the height from the ground of the complete vehicle. See Centre of Gravity calculation.

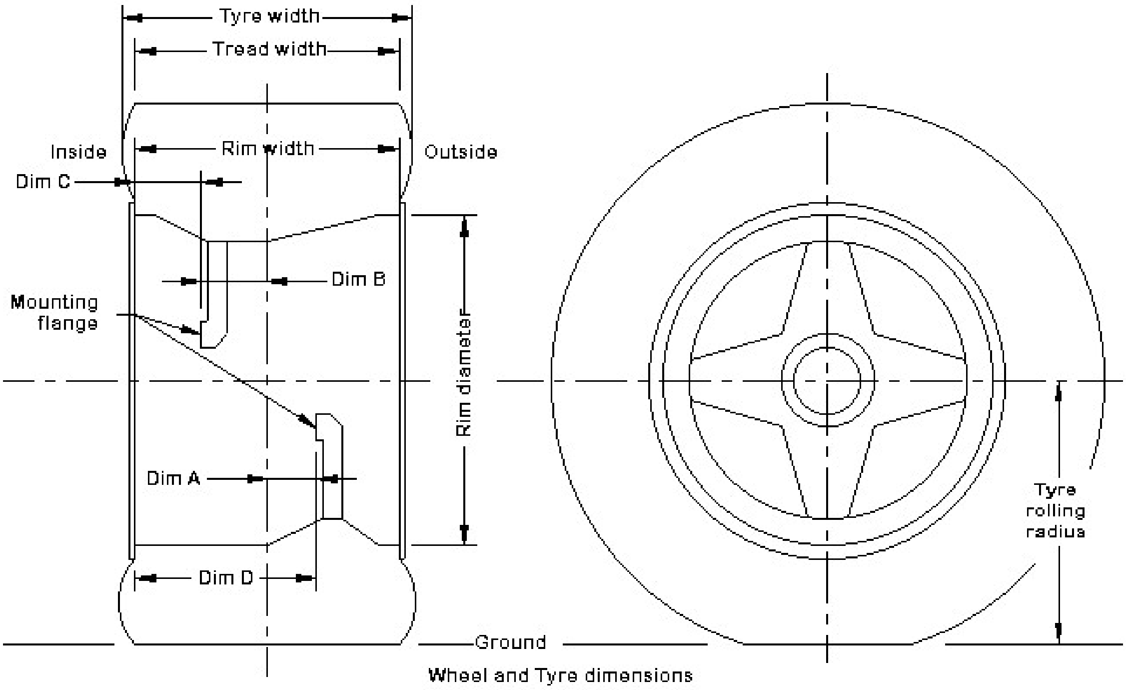
After calculating, the location of the centre of gravity of the sprung mass (ie the chassis) will be shown.

Both the vehicle and chassis centre of gravity are referenced in the same way. The lateral dimension is from the vehicle centreline, the vertical dimension is from the ground upwards (and is always positive), and the longitudinal dimension is from the front axle centreline (and is always positive).

Also shown is the CofG location of the chassis referenced to the chassis datums.

Once all the values have been entered the mass totals and distributions, and the centre of gravity locations can be calculated with the Apply button.

5.6 Wheel and tyre



Wheel and Tyre dimensions

From the Vehicle tab, select All Wheels, Front Wheels or Rear Wheels.

If you select “All Wheels”, the initial data shown will be for the wheel referenced in the dialog title. This is the car end and car side currently specified in Geometry. When you “Apply” or “OK”, then all four wheel and tyres will be set to the values specified.

If you select “Front Wheels”, the initial data shown will be for the wheel referenced in the dialog title. This is the car side currently specified in Geometry. When you “Apply” or “OK”, and the “ Symmetric” box is ticked, then both front wheel and tyres will be set to the values specified. When you “Apply” or “OK”, and the “Symmetric” box is not ticked, then only the wheel referenced in the dialog title will be set to the values specified.

If you select “Rear Wheels”, the initial data shown will be for the wheel referenced in the dialog title. This is the car side currently specified in Geometry. When you “Apply” or “OK”, and the “ Symmetric” box is ticked, then both rear wheel and tyres will be set to the values specified. When you “Apply” or “OK”, and the “Symmetric” box is not ticked, then only the wheel referenced in the dialog title will be set to the values specified.

Generally production vehicles will have all four wheels the same. Even if there are variations, it may still be more convenient to initially specify all wheels identically, then update the individual wheel(s) that differs.

The following dimensions relate to the wheel

- the rim diameter.
- the rim width.
- the mounting offset, inset or backset. Note that this dimension is measured in accordance with the specified mounting flange setting. See wheel coordinates.

The following dimensions relate to the tyre

- tyre tread width
- tyre section width (ie the overall width of the tyre across the sidewalls)
- the rolling radius. This is usually somewhat less than half the diameter due to the loaded

deflection of the tyre.

- the diameter. This is the overall diameter of the inflated tyre. It will always be greater than twice the rolling radius.
- The tyre spring rate. Enter the rate in either N/mm or lb/in using the related input box.

The following dimensions relate to the wheel and / or tyre

- the toe reference length. This is the distance over which the toe in or toe out is measured. If the toe reference length is left at zero, it will default to the wheel diameter.

The following dimension relates to the fitting of the wheel onto the hub

- spacer thickness.

If working in metric mode, then the edit boxes will display the metric dimensions, and additional inch dimensions will be shown. Dimensions can be entered in either mm or inches. Specify which by selecting the appropriate button. Wheel and tyre sizes are traditionally measured in inches, and this saves converting to mm.

If working in imperial mode, then only inch dimensions will be shown and can be entered.

For the Geometry calculations only the tyre deflected radius (ie the rolling radius), toe reference length, rim width and mounting offset are needed. All other dimensions can remain at zero.

For the Spring calculations the tyre rate is needed.

For the Dynamic calculations both the tyre deflected radius and the tyre rate are needed.

Note that if the tyre rate is zero, then this is assumed to be an "infinitely stiff" tyre with no deflection under load.

All other values are for information only, are not used by SusProg3D calculations and can remain at zero. There is space for a 70-character comment (for example, the tyre make and size).

For the wheel and tyre to display correctly, all dimensions should be input.

5.7 Undertray

To assist with the visual confirmation of the vehicle attitude, a basic undertray can be specified.

The undertray is broken down into three sections; front, centre and rear. Each section has four reference points which define a flat plane.

It is suggested that the front section corresponds to the section in front of the front axle or front wheels. This could be the front splitter or the front wing.

For a single seat racing car, the centre section could be the flat bottom or chassis undertray. For a sedan or touring car, the plane of the sidesills might be appropriate.

The sections can overlap.

5.8 Data

See Print the data for details.

5.9 Graphic

See Print the graphic for details.

5.10 VCalc

Recalculates the complete vehicle; front and rear, for the selected modules.

The dialog is similar to, and operates in the same way, as the ECalc dialog.
The difference is that ECalc does one end of the vehicle, VCalc does both ends.

6 Geometry

Defines the basic suspension characteristics in the static (normal ride height) position.

Config	Specify the suspension calculation options
Chassis	Specify the chassis mounting points (where the suspension linkages attach to the chassis, usually ball joints or rubber bushes)
Upright[1]	Specify the upright dimensions
Trailing arm[1]	Specify the trailing arm dimensions
Strut[1]	Specify the strut dimensions
Axle[1]	Specify the axle (axle housing plus pinion), brackets (suspension linkage attachment points), plus any "built-in" camber and toe settings.
Watts[2]	Specify the Watts linkage dimensions
Mumford[2]	Specify the Mumford linkage dimensions
Instant centres	Specify the linkage instant centres
Track	Show the track
Wheel and tyre	Specify the wheel and tyre dimensions
Alignment	Specify the wheel alignment (camber, caster and toe) and location
Turn[3]	Specify the angle to turn the front wheels
Travel Limits	Specify the maximum bump and droop travel
Calc	Calculate the basic suspension
Results	Display the complete basic suspension data
ECalc	Specify the modules and calculate

1. Depending on the specified suspension type, only one of these will be shown.

2. Depending on the specified suspension type, only one of these will be shown.

3. Only for front suspension and specific config types

6.1 Config

The suspension geometry type is specified in Vehicle Configure.

The suspension geometry calculation options are specified here.

From the Geometry tab, select Config.

Instant centre location.

There are two alternative ways to specify the swing axle lengths and instant centres. These alternatives will vary according to the suspension type.

Wheel location and alignment.

There are several alternative ways to specify the wheel location and alignment. These alternatives will vary according to the suspension type.

If working on an existing vehicle, and it is difficult to accurately measure the wishbone link lengths, then use the vehicle track and distance of the axle centreline to the datum, as these can usually be measured very accurately. Specify the Geometry configuration as " Wheel location and alignment", and enter the camber, caster, toe, wheel centreline to the lateral and longitudinal datums as measured on the vehicle.

This option is generally more useful in the initial design stages, where the establishment of chassis pickup pivot point axes, roll centre location and camber change characteristics are more important than actual wishbone lengths, and the wheel location is determined by the required track.

Ensure that the distance of the axle centreline from the longitudinal datum (refer Geometry | Alignment or Vehicle | Datum) and the lateral datum (refer Geometry | Alignment) are both specified. Note that the "half track" is required, as this allows for asymmetric track vehicles.

Geometry | Calculation will then establish the correct link lengths.

The other options are generally more useful once the required suspension characteristics have been established, and it is required to see the effect on changing wheel settings while maintaining certain fixed suspension linkages. This may also be used where there are design constraints which require specific suspension elements to be used.

Subsequent calculations can be done with the required links fixed to vary the other links, track and axle centreline datum distance as appropriate.

If you choose a configuration option that does not allow any link lengths to be specified, then the upright/strut/axle will be positioned on the vehicle centreline at the distance from the longitudinal datum as specified in the Datum or Alignment settings.

If you choose a configuration option that does require one or more link lengths, then the upright/strut/axle will be located in the appropriate position.

Track/Wheelbase reference point

Specify if the wheel location point is "On ground" (ie the centreline of the wheel and tyre on the ground) or "Wheel centre / axle" (ie the centreline of the wheel and tyre on the axle). See Track and Wheelbase for details.

6.1.1 Double A-arm, toe link

Instant centre location.

There are two alternative ways to specify the swing axle lengths and instant centres,

- "Suspension link chassis mounting points".
  All chassis pivot points must be entered in the Chassis Design.
  Geometry | Calculate will use the specified chassis pivot values to calculate the front view swing axle length and roll centre height and the side view swing axle length, side view instant centre height and the anti-dive/squat angle.
  The Instant Centre dialog will show the calculated swing axle lengths and instant centre locations.
- "Swing axle lengths and roll/pitch centre heights".
  The swing axle lengths and roll centre heights must be entered in Geometry | ICs.
  All chassis pivot point lateral dimensions must be entered in the Chassis Design.
  Geometry | Calculate will use the specified swing axle lengths, roll centre heights and chassis pivot lateral values to calculate the chassis pivot vertical values.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting

dimensions), choose one of the following geometry configuration options.
In all cases, if the instant centre location is determined by “Suspension link chassis mounting points” then all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified, and if the instant centre location is determined by “Swing axle lengths and roll/pitch centre heights” then the wishbone chassis mounting lateral and longitudinal dimensions must be specified, and the appropriate instant centre and swing arm length dimensions must be specified.

- Wheel location and alignment.
  The top and bottom wishbone chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.
- Top wishbone + wheel alignment.
  The top and bottom wishbone chassis mountings, top wishbone link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and bottom wishbone link lengths will be calculated.
- Bottom wishbone + wheel alignment.
  The top and bottom wishbone chassis mountings, bottom wishbone link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top wishbone link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose one of the following geometry configuration options. If the wheel camber is adjusted by means of an “upright camber shim” then use one of these options to see the effect of changing the camber shim thickness.

- Top and bottom wishbones + wheel toe.
  The top and bottom wishbone chassis mountings and link lengths, and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.
- Top and bottom wishbones + steering linkage + turn.
  This option allows for specifying a steering input to be specified, and for all the calculations to done with the front wheels steered.
  The top and bottom wishbone chassis mountings and link lengths, and chassis rack and upright steering arm balljoints must be specified.
  It is recommended that the Steering is dimensioned and calculated before this option is used.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.2 Lower A-arm, upper "virtual A-arm", toe link

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.

- Wheel location and alignment.
  The bottom A-arm and top link chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.
- Top links + wheel alignment.

The top links chassis mountings and lengths, bottom A-arm chassis mountings, and wheel alignment must be specified.
The track, distance of the axle centreline from the Z datum, and bottom A-arm link lengths will be calculated.

- Bottom wishbone + wheel alignment.
  The bottom A-arm and top link chassis mountings, bottom wishbone link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose one of the following geometry configuration options

- Top links + bottom wishbone + wheel toe.
  The top link chassis mountings and link lengths, and bottom wishbone chassis mountings and link lengths, and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.
- Top links + bottom wishbone + toe linkage.
  The top link chassis mountings and link lengths, bottom wishbone chassis mountings and link lengths, and toe control chassis mounting and link length must be specified.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.3 Lower A-arm, upper parallel links, trailing link

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.

- Wheel location and alignment.
  The bottom A-arm and top link chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.
- Bottom A-arm + wheel alignment.
  The bottom A-arm and top link chassis mountings, bottom A-arm link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose one of the following geometry configuration options

- Top lateral links + trailing link + bottom A-arm.
  The top link chassis mountings and link lengths, bottom A-arm chassis mountings and link lengths must be specified.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.4 Upper A-arm, lower "virtual A-arm", toe link

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.

- Wheel location and alignment.
  The top A-arm and bottom link chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.
- Top A-arm + wheel alignment.
  The top A-arm chassis mountings and link lengths, bottom link chassis mountings, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and bottom link lengths will be calculated.
- Bottom links + wheel alignment.
  The bottom links chassis mountings and lengths, top A-arm chassis mountings, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top A-arm link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose the following geometry configuration option

- Top A-arm + bottom links + wheel toe.
  The top A-arm and bottom links chassis mountings and link lengths, and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.
- All links + turn.
  This option allows for specifying a steering input to be specified, and for all the calculations to done with the front wheels steered.
  The top A-arm and bottom links chassis mountings and link lengths, and chassis rack and upright steering arm balljoints must be specified.
  It is recommended that the Steering is dimensioned and calculated before this option is used.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.5 Upper A-arm, lower trailing and lateral links, toe link

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.

- Wheel location and alignment.
  The top A-arm and bottom link chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.
- Top A-arm + wheel alignment.

The top A-arm chassis mountings and link lengths, bottom link chassis mountings, and wheel alignment must be specified.
The track, distance of the axle centreline from the Z datum, and bottom link lengths will be calculated.

- Bottom front link + trailing link + wheel alignment.
  The bottom front link and trailing link chassis mountings and lengths, top A-arm chassis mountings, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top A-arm link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose the following geometry configuration option

- Top A-arm + bottom front link + trailing link + wheel toe.
  The top A-arm and bottom front link and trailing link chassis mountings and link lengths, and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.
- All links
  The top A-arm, trailing and lateral links chassis mountings and link lengths, and upright toe control balljoints must be specified.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.6 Upper and lower lateral links, twin trailing links, toe link

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.

- Wheel location and alignment.
  All link chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.
- Top trailing and lateral links + wheel alignment.
  The top trailing and lateral link chassis mountings and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and bottom lateral and trailing link lengths will be calculated.
- Bottom trailing and lateral links + wheel alignment.
  The bottom trailing and lateral link chassis mountings and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top lateral and trailing link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose the following geometry configuration option

- All top and bottom links + wheel toe.
  All link chassis mountings and top and bottom trailing and lateral link lengths, and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.
- All links

All link chassis mountings and link lengths, and upright toe control balljoints must be specified.
The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.7 Upper and lower "virtual A-arms", toe link

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.

- Wheel location and alignment.
  All link chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.

- Top links + wheel alignment.
  The top link chassis mountings and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and bottom link lengths will be calculated.

- Bottom links + wheel alignment.
  The bottom link chassis mountings and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose the following geometry configuration option

- All top and bottom links + wheel toe.
  All link chassis mountings and top and bottom trailing and lateral link lengths, and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.

- All links
  All link chassis mountings and link lengths, and upright toe control balljoints must be specified.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.8 Upper transverse leaf spring, lower reversed A-arm and trailing link

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.
Note that the leaf spring mounting point on the chassis is input in the spring section.

All upright mounting points lateral, vertical and longitudinal dimensions must be specified.
Note that the leaf spring mounting point on the upright is input in the spring section.

To maintain the static wheel alignment settings (and calculate the link dimensions), choose the following geometry configuration option.

- Leaf spring + wheel alignment.
  The transverse leaf spring chassis mounting and main leaf length length, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and bottom link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose the following geometry configuration option.
All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.

- Leaf spring + all links
  The transverse leaf spring chassis mounting and main leaf length length, and A-arm and trailing link lengths must be specified.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.9 Upper lateral link, lower reversed A-arm, twin trailing links

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.

- Wheel location and alignment.
  All link chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.

- Top links + wheel alignment.
  The top trailing and lateral link chassis mountings and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and bottom link lengths will be calculated.

- Bottom trailing link + front A-arm link + wheel alignment.
  The bottom trailing link and reverse A-arm chassis mountings and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose the following geometry configuration option

- Trailing links + top lateral link + front A-arm link + wheel toe.
  All link chassis mountings and trailing, top lateral and front reverse A-arm link lengths, and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.

- All links
  All link chassis mountings and link lengths, and upright toe control balljoints must be specified.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.10 Lower lateral link, upper reversed A-arm, twin trailing links

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.

- Wheel location and alignment.
  All link chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.
- Top trailing link + front A-arm link + wheel alignment.
  The top trailing and front A-arm link chassis mountings and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and bottom link lengths will be calculated.
- Bottom links + wheel alignment.
  The bottom trailing link and reverse A-arm chassis mountings and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose the following geometry configuration option

- Trailing links + bottom lateral link + front A-arm link + wheel toe.
  All link chassis mountings and trailing, bottom lateral and front reverse A-arm link lengths, and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.
- All links
  All link chassis mountings and link lengths, and upright toe control balljoints must be specified.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.11 Upper lateral link, parallel lower links, twin trailing links

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.

- Wheel location and alignment.
  All link chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.
- Top links + wheel alignment.
  The top trailing and lateral link chassis mountings and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and bottom link lengths will be calculated.

- Bottom trailing link + bottom front lateral link + wheel alignment.
  The bottom trailing and front lateral link chassis mountings and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose the following geometry configuration option

- Trailing links + top lateral link + bottom front lateral link + wheel toe.
  All link chassis mountings and trailing, top lateral and bottom front lateral link lengths, and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.
- All links
  All link chassis mountings and link lengths, and upright toe control balljoints must be specified.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.12 Ford Integral Link

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment

- To calculate the control arm and link dimensions given the static wheel alignment settings and the chassis mounting points, specify ‘Wheel location and alignment.’

  The chassis mounting points, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The trailing arm dimensions will be calculated.
- To calculate the static wheel alignment settings given the chassis mounting points, control arm and link dimensions, specify 'Top link + bottom A-arm + integral link + toe link.’

  The chassis mounting points and the control arm dimensions must be specified.
  The track, wheelbase, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.13 Ford Twin I-Beam

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment

- To calculate the control arm and link dimensions given the static wheel alignment settings and the chassis mounting points, specify ‘Wheel location and alignment.’

  The chassis mounting points, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The I-beam and radius rod dimensions will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose one of the following geometry configuration options.

- I-Beam and radius rod + wheel toe.
  The I-Beam and radius rod chassis mountings and link lengths, and wheel alignment toe setting must be specified.

The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.

- I-Beam and radius rod + steering linkage + turn.
  This option allows for specifying a steering input to be specified, and for all the calculations to done with the front wheels steered.
  The I-Beam and radius rod chassis mountings and link lengths, and steering gear and linkage and upright steering arm balljoints must be specified.
  It is recommended that the Steering is dimensioned and calculated before this option is used.
  The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

Note that the I-Beam and radius rod lengths are not the actual lengths of those items. They are the lengths as measured from the centre of the stub axle ball joints (or from the ends of the kingpin) to the centre of the appropriate chassis mounting bush.
See link lengths.

6.1.14 Volkswagen twin trailing links

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment

To maintain the static wheel alignment settings (and calculate the link dimensions), choose one of the following geometry configuration options.
In all cases all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.

- Wheel location and alignment.
  The top and bottom trailing link chassis mountings, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The link lengths will be calculated.

- Top trailing link + wheel alignment.
  The top and bottom trailing link chassis mountings, top trailing link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and bottom trailing link lengths will be calculated.

- Bottom trailing link + wheel alignment.
  The top and bottom trailing link chassis mountings, bottom trailing link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, and top trailing link lengths will be calculated.

To maintain the chassis mountings and link lengths (and calculate the static wheel alignment), choose one of the following geometry configuration options. If the wheel camber is adjusted by means of an "upright camber shim" then use one of these options to see the effect of changing the camber shim thickness.

- Top and bottom trailing links + wheel toe.
  The top and bottom trailing link chassis mountings and lengths, and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.

- Top and bottom trailing links + steering linkage + turn.
  This option allows for specifying a steering input to be specified, and for all the calculations to done with the front wheels steered.
  The top and bottom trailing link chassis mountings and lengths, and chassis rack and

upright steering arm balljoints must be specified.
It is recommended that the Steering is dimensioned and calculated before this option is used.
The track, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

When using any of the above options that require the trailing link length(s) to be specified, then in order to correctly calculate the lateral offset of the trailing link upright mounting, the reference length is that length from the trailing link upright mounting to the trailing link chassis mounting on the opposite side of the vehicle. This is because, geometrically, the trailing links are equivalent to an A-arm pivoting on the two chassis mounting points.

6.1.15 Jaguar IRS

Instant centre location.

There are two alternative ways to specify the swing axle lengths and instant centres,

- "Suspension link chassis mounting points".
  All chassis pivot points must be entered in the Chassis Design.
  Geometry | Calculate will use the specified chassis pivot values to calculate the front view swing axle length and roll centre height and the side view swing axle length, side view instant centre height and the anti-dive/squat angle.
  The Instant Centre dialog will show the calculated swing axle lengths and instant centre locations.
- "Swing axle lengths and roll/pitch centre heights".
  The swing axle lengths and roll centre heights must be entered in Geometry | ICs.
  All chassis pivot point X dimensions must be entered in the Chassis Design.
  Geometry | Calculate will use the specified swing axle lengths, roll centre heights and chassis pivot lateral values to calculate the chassis pivot vertical values.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
In all cases, if the instant centre location is determined by "Suspension link chassis mounting points" then all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified, and if the instant centre location is determined by "Swing axle lengths and roll/pitch centre heights" then the wishbone chassis mounting lateral and longitudinal dimensions must be specified, and the appropriate instant centre and swing arm length dimensions must be specified.

- Wheel location and alignment.
  The wheel lateral and longitudinal position, and the wheel alignment must be specified.
  The link lengths will be calculated.
- I-link + wheel alignment.
  The I-link front and diagonal lengths (chassis pivot to upright pivot), upright offset, and the wheel alignment must be specified.
  The distance of the axle centreline from the Z datum, and driveshaft lengths will be calculated.

To maintain the driveshaft UJ location and bottom wishbone chassis mountings and I-link lengths (and calculate the static wheel alignment), choose the following geometry configuration option.

- I-link + driveshaft (fixed wheel alignment).
  The I-link front and diagonal lengths (chassis pivot to upright pivot), upright offset, and driveshaft length must be specified.
  The distance of the axle centreline from the Z datum, and wheel alignment will be calculated.

6.1.16 H-arm + camber link

Instant centre location.

There are two alternative ways to specify the swing axle lengths and instant centres,

- “Suspension link chassis mounting points”.
  All chassis pivot points must be entered in the Chassis Design.
  Geometry | Calculate will use the specified chassis pivot values to calculate the front view swing axle length and roll centre height and the side view swing axle length, side view instant centre height and the anti-dive/squat angle.
  The Instant Centre dialog will show the calculated swing axle lengths and instant centre locations.
- “Swing axle lengths and roll/pitch centre heights”.
  The swing axle lengths and roll centre heights must be entered in Geometry | ICs.
  All chassis pivot point X dimensions must be entered in the Chassis Design.
  Geometry | Calculate will use the specified swing axle lengths, roll centre heights and chassis pivot lateral values to calculate the chassis pivot vertical values.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
In all cases, if the instant centre location is determined by “Suspension link chassis mounting points” then all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified, and if the instant centre location is determined by “Swing axle lengths and roll/pitch centre heights” then the wishbone chassis mounting lateral and longitudinal dimensions must be specified, and the appropriate instant centre and swing arm length dimensions must be specified.

- Wheel location and alignment.
  The wheel lateral and longitudinal position, and the wheel alignment must be specified.
  The link lengths will be calculated.
- H-arm + wheel alignment.
  The H-arm front and diagonal lengths (chassis pivot to upright pivot), upright offset, and the wheel alignment must be specified.
  The distance of the axle centreline from the Z datum, and camber link length will be calculated.

To maintain the top and bottom wishbone chassis mountings and link lengths (and calculate the static wheel alignment), choose the following geometry configuration option.

- H-arm + camber link (fixed wheel alignment) .
  The H-arm front and diagonal lengths (chassis pivot to upright pivot), upright offset, and camber link length must be specified.
  The distance of the axle centreline from the Z datum, and wheel alignment will be calculated.

6.1.17 Porsche 928

Instant centre location.

There are two alternative ways to specify the swing axle lengths and instant centres,

- “Suspension link chassis mounting points”.
  All chassis pivot points must be entered in the Chassis Design.
  Geometry | Calculate will use the specified chassis pivot values to calculate the front view swing axle length and roll centre height and the side view swing axle length, side view instant centre height and the anti-dive/squat angle.
  The Instant Centre dialog will show the calculated swing axle lengths and instant centre locations.
- “Swing axle lengths and roll/pitch centre heights”.

The swing axle lengths and roll centre heights must be entered in Geometry | ICs.
All chassis pivot point X dimensions must be entered in the Chassis Design.
Geometry | Calculate will use the specified swing axle lengths, roll centre heights and chassis pivot lateral values to calculate the chassis pivot vertical values.

Wheel location and alignment.

To maintain the static wheel alignment settings (and calculate the link and/or chassis mounting dimensions), choose one of the following geometry configuration options.
In all cases, if the instant centre location is determined by “Suspension link chassis mounting points” then all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified, and if the instant centre location is determined by “Swing axle lengths and roll/pitch centre heights” then the wishbone chassis mounting lateral and longitudinal dimensions must be specified, and the appropriate instant centre and swing arm length dimensions must be specified.

- Wheel location and alignment.
  The wheel lateral and longitudinal position, and the wheel alignment must be specified.
  The link lengths will be calculated.
- Trailing link + wheel alignment.
  The trailing link front and diagonal lengths (chassis pivot to upright pivot), upright offset, and the wheel alignment must be specified.
  The distance of the axle centreline from the Z datum, and camber link length will be calculated.

To maintain the top and bottom wishbone chassis mountings and link lengths (and calculate the static wheel alignment), choose the following geometry configuration option.

- Trailing link + camber link (fixed wheel alignment) .
  The trailing link front and diagonal lengths (chassis pivot to upright pivot), upright offset, and camber link length must be specified.
  The distance of the axle centreline from the Z datum, and wheel alignment will be calculated.

6.1.18 Semi-trailing arm (also includes trailing arm and swing axle)

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment

- To calculate the semi-trailing arm dimensions given the static wheel alignment settings and the chassis mounting points, specify ‘Chassis mounts + wheel location and alignment.’

  The chassis mounting points, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The semi-trailing arm dimensions will be calculated.
- To calculate the chassis mounting points given the static wheel alignment settings and the semi-trailing arm dimensions, specify ‘Semi-trailing arm + wheel alignment.’

  The semi-trailing arm dimensions, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The chassis mounting points will be calculated.
- To calculate the static wheel alignment settings given the chassis mounting points and the semi-trailing arm dimensions, specify ‘Chassis mounts + semi-trailing arm,’

  The chassis mounting points and the semi-trailing arm dimensions must be specified.
  The track, wheelbase, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.1.19 Semi-trailing arm (fixed outer pivot, suspended inner pivot), toe link.

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

- To calculate the chassis trailing arm mounting dimensions, the camber link length and the toe link length given the static wheel alignment settings and the chassis mounting points, specify ‘Chassis mounts + wheel location and alignment.’

  The wheel lateral and longitudinal position, and wheel alignment must be specified.
  All trailing arm dimensions must be specified.
  The chassis trailing arm mounting, camber link orientation, and camber and toe control link lengths will be calculated.

- To calculate the static wheel alignment settings given the chassis mounting points, trailing arm dimensions, and camber and toe control link lengths, specify ‘Chassis mounts + trailing arm + camber and toe links.’

  The trailing arm chassis mounting, the camber control link orientation, mounting and length, and the toe control link mounting and length must be specified.
  All trailing arm dimensions must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber, caster and toe will be calculated.

Camber link orientation.

Specify if the camber control link hangs down from the chassis (ie the camber control arm is below the chassis mounting point. This is the production car orientation.) or the camber control link stands up from the chassis (ie the camber control arm is above the chassis mounting point).

6.1.20 Trailing arm, upper and lower lateral links

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

- To calculate the trailing arm dimensions and the lateral link lengths given the static wheel alignment settings and the chassis mounting points, specify ‘Chassis mounts + wheel location and alignment.’

  The wheel lateral and longitudinal position, and wheel alignment (camber, caster and toe) must be specified.
  The trailing arm lateral link mountings must be specified.
  All three chassis mounting points lateral, vertical and longitudinal dimensions must be specified.
  The trailing arm mounting and lateral link lengths will be calculated.

- To calculate the chassis mounting points given the static wheel alignment settings and the trailing arm dimensions, specify ‘Trailing arm + wheel location and alignment.’

  The chassis trailing arm mounting, lateral link chassis mountings, trailing arm dimensions and static wheel alignment must be specified.
  The lateral link lengths, track, distance of the axle centreline from the Z datum, wheel alignment camber, caster and toe will be calculated.

- To calculate the lateral location of the chassis mounting point for the trailing arm given the chassis mounting points, lateral link lengths, trailing arm dimensions and static wheel alignment toe-in, specify ‘Chassis mounts + trailing arm + lateral links + wheel toe.’

Specifying an adjustable chassis trailing arm mounting lateral value is equivalent to the usual practice of shimming the trailing arm mounting to provide wheel toe change.

The chassis trailing arm mounting (vertical and longitudinal), lateral link chassis mountings, lateral link lengths, trailing arm dimensions and static wheel alignment toe-in must be specified.
The track, distance of the axle centreline from the Z datum, wheel alignment camber, caster and toe will be calculated.

- To calculate the static wheel alignment settings given the chassis mounting points and the trailing arm dimensions, specify ‘Chassis mounts + trailing arm + lateral links.’

  The chassis trailing arm mounting and the lateral link chassis mountings and lengths must be specified.
  All trailing arm dimensions must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber, caster and toe will be calculated.

6.1.21 Trailing arm, upper and lower lateral links, toe control link

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment.

- To calculate the trailing arm dimensions and the lateral and toe link lengths given the static wheel alignment settings and the chassis mounting points, specify ‘Chassis mounts + wheel location and alignment.’

  The wheel lateral and longitudinal position, and wheel alignment (camber, caster and toe) must be specified.
  All chassis mounting points lateral, vertical and longitudinal dimensions must be specified.
  All trailing arm dimensions must be specified.
  The chassis trailing arm mounting and lateral and toe control link lengths will be calculated.

- To calculate the static wheel alignment settings given the chassis mounting points and the trailing arm dimensions, specify ‘Chassis mounts + trailing arm + lateral and toe links.’

  The chassis trailing arm mounting and the lateral link chassis mountings and lengths must be specified.
  All trailing arm dimensions must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber, caster and toe will be calculated.

6.1.22 Macpherson strut / Strut, lower "virtual A-arm", toe link

Instant centre location.

There are two alternative ways to specify the swing axle lengths and instant centres,

- “Suspension link chassis mounting points”.
  All chassis pivot points must be entered in the Chassis Design.
  Geometry | Calculate will use the specified chassis pivot values to calculate the front view swing axle length and roll centre height and the side view swing axle length, side view instant centre height and the anti-dive/squat angle.
  The Instant Centre dialog will show the calculated swing axle lengths and instant centre locations.
- “Swing axle lengths and roll/pitch centre heights”.
  The swing axle lengths and roll centre heights must be entered in Geometry | ICs.

All chassis pivot point lateral dimensions must be entered in the Chassis Design. Geometry | Calculate will use the specified swing axle lengths, roll centre heights and chassis pivot lateral values to calculate the chassis pivot vertical values.

Wheel location and alignment.

Specifying an adjustable top mounting lateral value is equivalent to the usual practice of slotting the top ball joint housing holes to provide lateral adjustment and corresponding wheel camber change, and similarly specifying an adjustable top mounting longitudinal value is equivalent to moving the top ball joint housing fore and aft to provide castor change.

To maintain the static wheel alignment settings (and calculate the link and/or strut top mounting dimensions), choose one of the following geometry configuration options.
In all cases, if the instant centre location is determined by “Suspension link chassis mounting points” then all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified, and if the instant centre location is determined by “Swing axle lengths and roll/pitch centre heights” then the bottom wishbone chassis mounting lateral and longitudinal dimensions must be specified, and the appropriate instant centre and swing arm length dimensions must be specified.

- Wheel location and alignment.
  The wheel lateral and longitudinal position, and wheel alignment must be specified.
  The strut top mounting and link lengths will be calculated.

- Strut mounting + wheel alignment.
  The strut top mounting and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum and link lengths will be calculated.

- Bottom wishbone + wheel alignment.
  The strut top mounting is adjustable in both the lateral direction to provide camber adjustment and longitudinal direction to provide castor adjustment.
  The bottom wishbone mounting points and link lengths, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum and strut top mounting will be calculated.

- Strut mounting Z + bottom fr + wheel alignment.
  The strut top mounting is adjustable in the lateral direction to provide camber adjustment and the bottom wishbone rear link is length adjustable to provide castor adjustment.
  The top strut mounting longitudinal dimension, both bottom wishbone chassis mountings, bottom front link length and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, strut top mounting lateral dimension, and bottom rear link length will be calculated.

- Strut mounting Z + bottom rr + wheel alignment.
  The strut top mounting is adjustable in the lateral direction to provide camber adjustment and the bottom wishbone front link is length adjustable to provide castor adjustment.
  The top strut mounting longitudinal dimension, both bottom wishbone chassis mountings, bottom rear link length and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, strut top mounting lateral dimension, and bottom front link length will be calculated.

To maintain the top mounting point and the static wheel alignment, choose one of the following geometry configuration options. The strut dimensions will be adjusted to achieve the specified camber. For strut type A, the strut rod top lateral dimension will be calculated, for strut type B, the strut axis angle will be calculated, for strut type C, the strut adjustment angle will be calculated, and for strut type D, the strut axis angle will be calculated. For fixed struts, the adjustment point is effectively the strut tube bottom point, and for adjustable struts it is the knuckle mounting point A.

- [Strut mounting + track + wheel alignment].
  The strut top mounting, track and wheel alignment settings are fixed.
  The bottom wishbone chassis mountings, strut top mounting, track and wheel alignment settings must be specified.

The bottom wishbone link lengths, strut-knuckle adjustment angle, and distance of the axle centreline from the Z datum will be calculated.

- [Strut mounting + bottom wishbone + wheel alignment].
  The strut top mounting, bottom wishbone and wheel camber and toe settings are fixed.
  The bottom wishbone chassis mountings and link lengths, strut top mounting, and wheel alignment settings must be specified.
  The track, caster and distance of the axle centreline from the Z datum will be calculated.
- [Strut mounting + bottom wishbone + steering + wheel alignment].
  This option allows for specifying a steering input to be specified, and for all the calculations to done with the front wheels steered.
  The strut top mounting and the bottom wishbone chassis mounting and link lengths, including steering tierod, are fixed.
  The bottom wishbone chassis mountings and link lengths, strut top mounting, chassis rack and strut steering arm balljoints and wheel camber must be specified.
  It is recommended that the Steering is dimensioned and calculated before this option is used.
  The track, distance of the axle centreline from the Z datum, wheel alignment caster and toe will be calculated.

To maintain the link lengths and top mounting point (and calculate the static wheel alignment), choose one of the following geometry configuration options

- Strut mounting + bottom wishbone + wheel toe.
  The strut top mounting and the bottom wishbone chassis mounting and link lengths are fixed.
  The bottom wishbone chassis mountings and link lengths, strut top mounting and wheel alignment toe setting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber and caster will be calculated.
- Strut mounting + bottom wishbone + steering linkage + turn.
  This option allows for specifying a steering input to be specified, and for all the calculations to done with the front wheels steered.
  The strut top mounting and the bottom wishbone chassis mounting and link lengths, including steering tierod, are fixed.
  The bottom wishbone chassis mountings and link lengths, strut top mounting, chassis rack and strut steering arm balljoints must be specified.
  It is recommended that the Steering is dimensioned and calculated before this option is used.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber, caster and toe will be calculated.

6.1.23 Tri-link strut

Instant centre location.

There are two alternative ways to specify the swing axle lengths and instant centres,

- “Suspension link chassis mounting points”.
  All chassis pivot points must be entered in the Chassis Design.
  Geometry | Calculate will use the specified chassis pivot values to calculate the front view swing axle length and roll centre height and the side view swing axle length, side view instant centre height and the anti-dive/squat angle.
  The Instant Centre dialog will show the calculated swing axle lengths and instant centre locations.
- “Swing axle lengths and roll/pitch centre heights”.
  The swing axle lengths and roll centre heights must be entered in Geometry | ICs.
  All chassis pivot point lateral dimensions must be entered in the Chassis Design.
  Geometry | Calculate will use the specified swing axle lengths, roll centre heights and chassis pivot lateral values to calculate the chassis pivot vertical values.

Wheel location and alignment.

Specifying an adjustable top mounting lateral value is equivalent to the usual practice of slotting the top ball joint housing holes to provide lateral adjustment and corresponding wheel camber change, and similarly specifying an adjustable top mounting longitudinal value is equivalent to moving the top ball joint housing fore and aft to provide castor change.

To maintain the static wheel alignment settings (and calculate the link and/or strut top mounting dimensions), choose one of the following geometry configuration options.
In all cases, if the instant centre location is determined by “Suspension link chassis mounting points” then all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified, and if the instant centre location is determined by “Swing axle lengths and roll/pitch centre heights” then the bottom wishbone chassis mounting lateral and longitudinal dimensions must be specified, and the appropriate instant centre and swing arm length dimensions must be specified.

- Wheel location and alignment.
  The wheel lateral and longitudinal position, and wheel alignment must be specified.
  The strut top mounting and link lengths will be calculated.
- Strut mounting + wheel alignment.
  The strut top mounting and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum and link lengths will be calculated.
- Strut mounting Z + fr lateral link + wheel alignment.
  The strut top mounting is adjustable in the lateral direction to provide camber adjustment and the trailing link is length adjustable to provide castor adjustment. The rear lateral link provides the toe adjustment.
  The top strut mounting longitudinal dimension, front lateral link chassis mountings and length, trailing link chassis mounting and length and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, strut top mounting lateral dimension, trailing link length and rear lateral link length will be calculated.
- Strut mounting X + trailing link + wheel alignment.
  The strut top mounting is adjustable in the longitudinal direction to provide caster adjustment and the lateral links are length adjustable to provide camber adjustment.
  The top strut mounting lateral dimension, trailing link chassis mounting and length and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, strut top mounting longitudinal dimension, and both lateral link lengths will be calculated.
- Trailing link + fr lateral link + wheel alignment.
  The strut top mounting is adjustable in both the lateral direction to provide camber adjustment and longitudinal direction to provide castor adjustment.
  The trailing link mounting points and length, front lateral link mounting points and length, and wheel alignment must be specified.
  The track, distance of the axle centreline from the Z datum, strut top mounting, and rear lateral link length will be calculated.

To maintain the top mounting point and the static wheel alignment, choose one of the following geometry configuration options. The strut dimensions will be adjusted to achieve the specified camber. For strut type A, the strut rod top lateral dimension will be calculated, for strut type B, the strut axis angle will be calculated, for strut type C, the strut adjustment angle will be calculated, and for strut type D, the strut axis angle will be calculated. For fixed struts, the adjustment point is effectively the strut tube bottom point, and for adjustable struts it is the knuckle mounting point A.

- [Strut mounting + track + wheel alignment].
  The strut top mounting, track and wheel alignment settings are fixed.
  The trailing and lateral link mounting points, strut top mounting, track and wheel alignment settings must be specified.
  The trailing and lateral link lengths, strut-knuckle adjustment angle, and distance of the axle centreline from the Z datum will be calculated.

- [Strut mounting + all links + wheel alignment].
  The strut top mounting, trailing and lateral link mounting points and lengths and wheel camber settings are fixed.
  The trailing and lateral link mounting points and lengths, strut top mounting, and wheel camber settings must be specified.
  The track, strut-knuckle adjustment angle, caster and toe, and distance of the axle centreline from the Z datum will be calculated.

To maintain the link lengths and top mounting point (and calculate the static wheel alignment), choose the following geometry configuration options

- Strut mounting + all links (fixed wheel alignment).
  The strut top mounting and the link chassis mounting and lengths are fixed.
  The bottom lateral and trailing link chassis mountings and lengths, and strut top mounting must be specified.
  The track, distance of the axle centreline from the Z datum, wheel alignment camber, caster and toe will be calculated.

6.1.24 Live axle (torque arm) - 4 trailing links and birdcage + Panhard rod

Longitudinal link orientation.

Conventionally, rear suspension is configured with trailing links; front suspension is configured with leading links.

Panhard rod chassis mounting

Specify which end of the Panhard rod is the mounted to the chassis.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle (including torque arm) dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.

- Axle alignment.
  Specify the nominal centreline of the axle from the longitudinal datum.
  The axle offset and wheel lead will be zero.
  The pinion angle can be specified.
  All torque arm and Panhard rod chassis and axle mounting points must be specified.
  The axle will be positioned appropriately and the trailing link lengths, torque arm link length and Panhard link length will be calculated.

To maintain the torque arm chassis mounting and axle dimensions, trailing link mountings and lengths, torque arm link and Panhard rod chassis mounting and length, choose the following geometry configuration option

- Torque arm + all links.
  All torque arm, trailing link and Panhard rod chassis and axle mounting points must be specified.
  Trailing link, torque arm link and Panhard rod lengths must be specified.
  The birdcage will be rotated to connect with the upper and lower trailing links, and will then locate the axle longitudinally.

6.1.25 Live axle (torque arm) - 4 trailing links and birdcage + Watts linkage

Longitudinal link orientation.

Conventionally, rear suspension is configured with trailing links; front suspension is configured with leading links.

Watts linkage location.

Specify where the Watts lever pivot is located, either on the chassis or on the axle.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle (including torque arm) dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.

- Axle alignment.
  The axle offset and wheel lead will be zero.
  Specify the nominal centreline of the axle from the longitudinal datum.
  The pinion angle can be specified.
  All torque arm and Watts link chassis and axle mounting points must be specified.
  The axle will be positioned appropriately and the trailing link lengths, torque arm link length and Watts link lengths will be calculated.

To maintain the torque arm chassis mounting and axle dimensions, trailing link mountings and lengths, torque arm link and Watts link chassis mounting and length, choose the following geometry configuration option

- Torque arm + all links.
  All torque arm, trailing link and Watts link chassis and axle mounting points must be specified.
  Trailing link, torque arm link and Watts link lengths must be specified.
  The birdcage will be rotated to connect with the upper and lower trailing links, and will then locate the axle longitudinally.

6.1.26 Live axle (torque arm slider) - 2 trailing links + Panhard rod

Longitudinal link orientation.

Conventionally, rear suspension is configured with trailing links; front suspension is configured with leading links.

Panhard rod chassis mounting

Specify which end of the Panhard rod is the mounted to the chassis.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle (including torque arm) dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.

- Torque arm + axle alignment.
  Specify the nominal centreline of the axle from the longitudinal datum.
  All torque arm and Panhard rod chassis and axle mounting points must be specified.
  The axle will be positioned appropriately (the torque arm slider will be located on the chassis mounting point) and the wheel location, trailing link lengths and Panhard link length will be calculated.
  If the torque arm is compliant, then the axle alignment will be as specified, and there will be an initial torque arm compliance.
  If the trailing links are compliant, then the axle toe will be determined by the torque arm mounting.

To maintain the torque arm chassis mounting and axle dimensions, trailing link mountings and lengths and Panhard rod chassis mounting and length, choose the following geometry configuration option

- Torque arm + trailing links + Panhard link.
  All torque tube, trailing link and Panhard rod chassis and axle mounting points must be

specified.
Trailing link and Panhard rod lengths must be specified.
The axle will be positioned appropriately.

Compliance location.

The torque arm slider is always positioned through the centre of the chassis mounting. The torque arm slider is free to move longitudinally, and also can also pivot, but is restrained in the vertical direction. Similarly, the Panhard rod is considered “rigid” and the length between mounting points is constant. Because of these constraints, the axle assembly will generally move sideways in bump and droop (primarily as a consequence of the Panhard rod arc).
The torque arm is considered to be “rigid” in the vertical plane.

Choose one of the following compliance options.

- Trailing link compliance
In this mode, the torque arm slider is constrained in both horizontal and vertical directions. The torque arm is also “rigid” in the horizontal plane. The primary constraints are the torque arm slider mounting (both horizontally and vertically), and the Panhard rod. Because of these constraints, as the axle assembly moves sideways in bump and droop (primarily as a consequence of the Panhard rod arc), it will also bump steer (controlled by the torque arm slider mounting). In turn, this requires slight compliance in the trailing link mountings.
This mode should be used when the trailing links have rubber bushes.

- Torque arm compliance
In this mode, the torque arm slider is free to move laterally within the chassis mounting bearing, and/or the torque arm itself can deflect horizontally. The trailing links are considered “rigid” and the length between mounting points is constant. The primary constraints are the torque arm slider mounting (vertically), the trailing links, and the Panhard rod. Because of these constraints, as the axle assembly moves sideways in bump and droop (primarily as a consequence of the Panhard rod arc) and the axle bump steer is controlled by the trailing links, this requires horizontal compliance in the torque arm and/or the torque arm slider mounting.
This mode should be used when the trailing links have Heim joints.

6.1.27 Live axle (torque arm slider) - 2 trailing links + Watts linkage

Longitudinal link orientation.

Conventionally, rear suspension is configured with trailing links; front suspension is configured with leading links.

Watts linkage location.

Specify where the Watts lever pivot is located, either on the chassis or on the axle.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle (including torque arm) dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.

- Torque arm + axle alignment.
Specify the nominal centreline of the axle from the longitudinal datum.
All torque arm and Watts linkage chassis and axle mounting points must be specified.
The axle will be positioned appropriately (the torque arm slider will be located on the chassis mounting point) and the trailing link lengths and Watts link length will be calculated.
If the torque arm is compliant, then the axle alignment will be as specified, and there will be an initial torque arm compliance.
If the trailing links are compliant, then the axle toe will be determined by the torque arm mounting.

To maintain the torque arm chassis mounting and axle dimensions, trailing link mountings and lengths and Watts linkage mounting and length, choose the following geometry configuration option

- Torque arm + trailing links + Watts linkage.
  All torque tube, trailing link and Watts linkage chassis and axle mounting points must be specified.
  Trailing link and Watts link lengths must be specified.
  The axle will be positioned appropriately.

Compliance location.

The torque arm slider is always positioned through the centre of the chassis mounting. The torque arm slider is free to move longitudinally, and also can also pivot, but is restrained in the vertical direction. Similarly, the Watts linkage is considered “infinitely stiff” and the length between mounting points is constant. Because of these constraints, the axle assembly will generally have no movement sideways in bump and droop.
The torque arm is considered to be “rigid” in the vertical plane.

Choose one of the following compliance options.

- Trailing link compliance
  In this mode, the torque arm slider is constrained in both horizontal and vertical directions. The torque arm is also “rigid” in the horizontal plane. The primary constraints are the torque arm slider mounting (both horizontally and vertically), and the Watts linkage.
  This mode should be used when the trailing links have rubber bushes.

- Torque arm compliance
  In this mode, the torque arm slider is free to move laterally within the chassis mounting bearing, and/or the torque arm itself can deflect horizontally. The trailing links are considered “rigid” and the length between mounting points is constant. The primary constraints are the torque arm slider mounting (vertically), the trailing links, and the Watts linkage.
  This mode should be used when the trailing links have Heim joints.

6.1.28 Live axle (torque tube) + Panhard rod

Panhard rod chassis mounting

Specify which end of the Panhard rod is the mounted to the chassis.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle (including torque tube) dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.

- Torque tube + axle alignment.
  All torque tube and Panhard rod chassis and axle mounting points must be specified.
  The axle will be positioned appropriately (the torque tube ball joint will be located on the chassis mounting point) and the Panhard link length will be calculated.

To maintain the torque tube chassis mounting and axle dimensions, and Panhard rod chassis mounting and length, choose the following geometry configuration option

- Torque tube + Panhard link.
  All torque tube and panhard rod chassis and axle mounting points must be specified.
  Panhard rod length must be specified.
  The axle will be positioned appropriately.

6.1.29 Live axle (torque tube) + Watts linkage

Watts linkage location.

Specify where the Watts lever pivot is located, either on the chassis or on the axle.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle (including torque tube) dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment be specified.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.

- Torque tube + axle alignment.
  All torque tube and Watts linkage chassis and axle mounting points must be specified.
  The axle will be positioned appropriately (the torque tube ball joint will be located on the chassis mounting point) and the Watts link length will be calculated.

To maintain the torque tube chassis mounting and axle dimensions, and Watts linkage mounting and length, choose the following geometry configuration option

- Torque tube + Watts linkage.
  All torque tube and Watts linkage chassis and axle mounting points must be specified.
  Watts link length must be specified.
  The axle will be positioned appropriately.

6.1.30 Winters: 4 trailing links, 2 birdcages + Jacobs ladder

Longitudinal link orientation.

Conventionally, rear suspension is configured with trailing links; front suspension is configured with leading links.

Jacobs ladder

Specify on which side of the vehicle is the Jacobs ladder. Currently this must be on the right hand side.

Instant centre location

Will be calculated.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle (including torque tube) dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.

- Torque tube axle.
  All axle torque tube and birdcage dimensions must be specified.
  All suspension links and torque tube ball chassis mounting points must be specified.
  The axle will be positioned with the torque tube ball joint located on the chassis mounting point (with no torque tube alignment error), with the axle "straight across" the frame.
  The birdcages will be positioned vertically.
  All longitudinal link lengths and Jacobs ladder dimensions will be calculated.

To maintain the torque tube chassis mounting and axle dimensions, the longitudinal link lengths and Jacobs ladder dimensions, choose the following geometry configuration option

- All top and bottom links + Jacobs ladder.
  All torque tube axle mounting points must be specified.
  All chassis mounting points must be specified.
  All longitudinal link and Jacobs ladder lengths must be specified.
  The axle will be positioned appropriately. Note that this may result in a torque tube alignment error.

6.1.31 Live axle or deDion - twin trailing arms + Mumford linkage

The choice between "live axle" and "de Dion" is specified in Vehicle Config.

Rear suspension is configured with two trailing arms; front suspension is configured with two leading arms.

Mumford linkage location.

Specify where the Mumford bellcrank is positioned, either on the left or right side.

Instant centre location.

There are two alternative ways to specify the swing axle lengths and instant centres,

- “Suspension link chassis mounting points”.
  All chassis pivot points, and the Mumford bellcrank angle and lever length, must be entered in the Chassis Design.
  Geometry | Calculate will use the specified chassis pivot values to calculate the roll centre height and the side view swing axle length, side view instant centre height and the anti-dive/squat angle. The lateral links will be calculated.
  The Instant Centre dialog will show the calculated swing axle lengths and instant centre locations.

- “Roll centre height”.
  The roll centre height must be entered in Geometry | ICs.
  All chassis pivot points must be entered in the Chassis Design.
  Geometry | Calculate will use the specified roll centre height to (re)calculate the Mumford bellcrank angle and lever arm lengths and the lateral link lengths.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
The wheel toe can be specified for the front suspension only.
In all cases the wheel alignment - camber, caster and toe – and location will be calculated.
In all cases the the Mumford intermediate link length will be calculated.

- Axle alignment.
  All trailing arm and Mumford linkage chassis and axle mounting points must be specified.
  The longitudinal wheel location must be specified.
  The axle will be positioned appropriately and all link lengths will be calculated.

To maintain the trailing arm chassis mountings and lengths, and Mumford linkage chassis mountings, bellcrank dimensions and link lengths, choose the following geometry configuration options

- Both bottom links + Mumford linkage.
  All trailing arm and Mumford linkage chassis and axle mounting points must be specified.
  All link lengths must be specified.
  The axle will be positioned appropriately.

6.1.32 Live axle or deDion - twin trailing arms + Panhard rod

The choice between "live axle" and "de Dion" is specified in Vehicle Config.

Rear suspension is configured with two trailing arms; front suspension is configured with two leading arms.

Panhard rod chassis mounting

Specify which end of the Panhard rod is the mounted to the chassis.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
The wheel toe can be specified for the front suspension only.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.
The wheel toe can be specified for the front suspension only.

- Axle alignment.
  All trailing / leading arm and Panhard rod chassis and axle mounting points must be specified.
  The longitudinal wheel location must be specified.
  The axle offset and wheel lead will usually be zero.
  The axle will be positioned appropriately and all link lengths will be calculated.

To maintain the trailing / leading arm chassis mountings and arm lengths, and Panhard rod chassis mounting and length, choose the following geometry configuration option

- Both bottom links + Panhard link.
  All trailing / leading arm and Panhard rod chassis and axle mounting points must be specified.
  Both trailing / leading arm and Panhard rod lengths must be specified.
  The axle will be positioned appropriately.

6.1.33 Live axle or deDion - twin trailing arms + Watts linkage

The choice between "live axle" and "de Dion" is specified in Vehicle Config.

Rear suspension is configured with two trailing arms; front suspension is configured with two leading arms.

Watts linkage location.

Specify where the Watts lever pivot is located, either on the chassis or on the axle.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
The wheel toe can be specified for the front suspension only.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.

- Wheel location + axle alignment.
  All trailing link and Watts linkage chassis and axle mounting points must be specified.
  The longitudinal wheel location must be specified (either in Wheel Alignment or Axle Static Alignment)
  The wheel lead will be zero.
  The axle will be positioned appropriately and all link lengths will be calculated.

To maintain the trailing link chassis mountings and link lengths, and Watts linkage chassis mounting and link lengths, choose the following geometry configuration option

- Both bottom links + Watts linkage.
  All trailing link and Watts linkage chassis and axle mounting points must be specified.
  Both bottom trailing link and Watts linkage lengths must be specified.
  The axle will be positioned appropriately.

6.1.34 Live axle or deDion - 3 or 4 link + Mumford linkage

The choice between "live axle" and "de Dion" is specified in Vehicle Config.

Longitudinal links.

Specify the number of longitudinal links; 4 link, 4 link (LH birdcage), 4 link (RH birdcage), 3 link (no top LH link), 3 link (no top RH link).

Longitudinal link orientation.

Conventionally, rear suspension is configured with trailing links; front suspension is configured with leading links.

Mumford linkage location.

Specify where the Mumford bellcrank is positioned, either on the left or right side.

Instant centre location.

There are two alternative ways to specify the swing axle lengths and instant centres,

- “Suspension link chassis mounting points”.
  All chassis pivot points, and the Mumford bellcrank angle and lever length, must be entered in the Chassis Design.
  Geometry | Calculate will use the specified chassis pivot values to calculate the roll centre height and the side view swing axle length, side view instant centre height and the anti-dive/squat angle. The lateral links will be calculated.
  The Instant Centre dialog will show the calculated swing axle lengths and instant centre locations.

- “Roll centre height”.
  The roll centre height must be entered in Geometry | ICs.
  All chassis pivot points must be entered in the Chassis Design.
  Geometry | Calculate will use the specified roll centre height to (re)calculate the Mumford bellcrank angle and lever arm lengths and the lateral link lengths.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
The wheel toe can be specified for the front suspension only.
In all cases the wheel alignment - camber, caster and toe – and location will be calculated.
In all cases the Mumford intermediate link length will be calculated.
Some options are not applicable if a Birdcage is specified.

- Wheel location + axle alignment.
  All trailing link and Mumford linkage chassis and axle mounting points must be specified.
  The longitudinal wheel location must be specified (either in Wheel Alignment or Axle Static Alignment)
  The axle will be positioned centrally and all link lengths will be calculated.

To maintain the top and bottom trailing link chassis mountings and link lengths, and Mumford linkage chassis mountings, bellcrank dimensions and link lengths, choose the following geometry configuration options

- All top and bottom links + Mumford linkage.
  All trailing link and Mumford linkage chassis and axle mounting points must be specified.
  All link lengths must be specified.
  The axle will be positioned appropriately.

6.1.35 Live axle or deDion - 3 or 4 link + Panhard rod

The choice between "live axle" and "de Dion" is specified in Vehicle Config.

Longitudinal links.

Specify the number of longitudinal links; 4 link, 4 link (LH birdcage), 4 link (RH birdcage), 3 link (no top LH link), 3 link (no top RH link).

Longitudinal link orientation.

Conventionally, rear suspension is configured with trailing links; front suspension is configured with leading links.

Panhard rod chassis mounting

Specify which end of the Panhard rod is the mounted to the chassis.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
The wheel toe can be specified for the front suspension only.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.
The wheel toe can be specified for the front suspension only.
Some options are not applicable if a Birdcage is specified.

- Wheel location + axle alignment [+ wheel toe].
  All trailing / leading link and panhard rod chassis and axle mounting points must be specified.
  The longitudinal wheel location must be specified (in Axle Static Alignment)
  The axle offset and wheel lead will be zero.
  The axle will be positioned centrally and all link lengths will be calculated.

To maintain the top and bottom trailing / leading link chassis mountings and link lengths, and lateral location chassis mountings and link lengths, choose the following geometry configuration options

- All top and bottom links + Panhard link [+ wheel toe].
  All trailing / leading link and Panhard rod chassis and axle mounting points must be specified.
  All link lengths must be specified.
  The axle will be positioned appropriately.

6.1.36 Live axle or deDion - 3 or 4 link + Watts linkage

The choice between "live axle" and "de Dion" is specified in Vehicle Config.

Longitudinal links.

Specify the number of longitudinal links; 4 link, 4 link (LH birdcage), 4 link (RH birdcage), 3 link (no top LH link), 3 link (no top RH link).

Longitudinal link orientation.

Conventionally, rear suspension is configured with trailing links; front suspension is configured with leading links.

Watts linkage location.

Specify where the Watts lever pivot is located, either on the chassis or on the axle.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle dimensions and all required chassis mounting point lateral, vertical and

longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
The wheel toe can be specified for the front suspension only.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.
Some options are not applicable if a Birdcage is specified.

- Wheel location + axle alignment.
  All trailing link and Watts linkage chassis and axle mounting points must be specified.
  The longitudinal wheel location must be specified (in Axle Static Alignment)
  The wheel lead will be zero.
  The axle will be positioned centrally and all link lengths will be calculated.

To maintain the top and bottom trailing link chassis mountings and link lengths, and lateral location chassis mountings and link lengths, choose the following geometry configuration options

- All top and bottom links + Watts linkage.
  All trailing link and Watts linkage chassis and axle mounting points must be specified.
  All link lengths must be specified.
  The axle will be positioned appropriately.

6.1.37 Live axle or deDion - 3 or 4 link + Woblink

The choice between "live axle" and "de Dion" is specified in Vehicle Config.

Longitudinal links.

Specify the number of longitudinal links; 4 link, 4 link (LH birdcage), 4 link (RH birdcage), 3 link (no top LH link), 3 link (no top RH link).

Longitudinal link orientation.

Conventionally, rear suspension is configured with trailing links; front suspension is configured with leading links.

Woblink location.

Specify the location of the Woblink lever pivot, either on the chassis or on the axle, and the side of the vehicle the links are attached.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
The wheel toe can be specified for the front suspension only.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.
Some options are not applicable if a Birdcage is specified.

- Wheel location + axle alignment.
  All trailing link and Woblink chassis and axle mounting points must be specified.
  The longitudinal wheel location must be specified (in Axle Static Alignment)
  The wheel lead will be zero.
  The axle will be positioned centrally and all link lengths will be calculated.

To maintain the top and bottom trailing link chassis mountings and link lengths, and lateral location chassis mountings and link lengths, choose the following geometry configuration options

- All top and bottom links + Woblink.
  All trailing link and Woblink chassis and axle mounting points must be specified.
  All link lengths must be specified.
  The axle will be positioned appropriately.

6.1.38 Live axle or deDion - 4 links

The choice between "live axle" and "de Dion" is specified in Vehicle Config.

Usually one pair of links are arranged to converge on the axle to provide the lateral control.

Longitudinal link orientation.

Conventionally, rear suspension is configured with trailing links; front suspension is configured with leading links.

Wheel location and alignment.

Choose one of the following geometry configuration options.
In all cases the axle dimensions and all required chassis mounting point lateral, vertical and longitudinal dimensions must be specified.
In some cases, the axle static alignment can be specified.
The wheel toe can be specified for the front suspension only.
In all cases the wheel alignment - camber, caster and toe - and location will be calculated.

- Wheel location + axle alignment.
  All trailing link chassis and axle mounting points must be specified.
  The longitudinal wheel location must be specified (in Axle Static Alignment)
  The axle offset and wheel lead will be zero.
  The axle will be positioned centrally and all link lengths will be calculated.

To maintain the top and bottom trailing link chassis mountings and link lengths, and lateral location chassis mountings and link lengths, choose the following geometry configuration options

- All top and bottom links.
  All trailing link chassis and axle mounting points must be specified.
  All link lengths must be specified.
  The axle will be positioned appropriately.

6.1.39 Mono wheel - trailing arm

Instant centre location.

The instant centre location is determined by the chassis pivot points.

Wheel location and alignment

- To calculate the trailing arm dimensions given the static wheel alignment settings and the chassis mounting points, specify ‘Chassis mounts + wheel location and alignment.’

  The chassis mounting points, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The trailing arm dimensions will be calculated.

- To calculate the chassis mounting points given the static wheel alignment settings and the trailing arm dimensions, specify ‘Trailing arm + wheel alignment.’

  The trailing arm dimensions, wheel lateral and longitudinal position, and wheel alignment must be specified.
  The chassis mounting points will be calculated.

- To calculate the static wheel alignment settings given the chassis mounting points and the trailing arm dimensions, specify ‘Chassis mounts + trailing arm,’

  The chassis mounting points and the trailing arm dimensions must be specified.
  The track, wheelbase, distance of the axle centreline from the Z datum, and wheel alignment camber, caster and toe will be calculated.

6.2 Car end and car side

The [Front] or [Rear] tab choice will indicate the currently selected vehicle end.

The [LH] or [RH] tab choice will indicate the currently selected vehicle side.

These tabs acts as a toggle, and selecting this tab will switch between each of two.

Depending on the suspension geometry configuration, some menu bar items may not be available.

When a dialog box is opened, the title will include the currently selected car end and car side. If the car side is not shown, then the dialog box applies to both sides. If the car end is not shown, then the dialog box applies to both ends.

6.3 Chassis

From the Geometry tab, select Chassis.

Chassis mounting points:
Note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

6.3.1 Double A-arm

If the configuration option “Swing axle lengths and roll/pitch centre heights” is specified, the chassis mounting vertical dimensions cannot be input, and will be calculated. The swing axle lengths and roll centre height must be specified.

Enter the values for the top wishbone front & rear pivot points.

Enter the values for the bottom wishbone front & rear pivot points.

The longitudinal values need not be entered, and if left at 0.00, they will be set to default values such that the wishbone base length is approximately equal to the tyre rolling radius.

If the configuration does not include the steering linkage, the toe control mounting values are not required, and the Roll & Bump calculations will assume that there is no toe change in bump and droop.

6.3.2 Lower A-arm, upper "virtual A-arm", toe link

Enter the values for the top front & rear links pivot points.

Enter the values for the bottom A-arm front & rear pivot points.

The longitudinal values for the A-arm and the top links need not be entered, and if left at 0.00, they will be set to default values such that the A-arm base length and distance between the top link chassis mountings is approximately equal to the tyre rolling radius.

If the configuration does not include the toe linkage, the toe control mounting values are not required, and the Roll & Bump calculations will assume that there is no toe change in bump and droop.

6.3.3 Lower A-arm, upper parallel links, trailing link

Enter the values for the top lateral links pivot points.

Enter the values for the bottom A-arm front & rear pivot points.

Enter the lateral and vertical values for the trailing link pivot points.

The longitudinal values for the A-arm and the lateral links need not be entered, and if left at 0.00, they will be set to default values such that the A-arm base length and distance between the lateral link chassis mountings is approximately equal to the tyre rolling radius.

6.3.4 Upper A-arm, lower "virtual A-arm", toe link

Enter the values for the top A-arm front & rear pivot points.

Enter the values for the bottom links pivot points.

The longitudinal values for the A-arm and the lateral links need not be entered, and if left at 0.00, they will be set to default values such that the A-arm base length and distance between the lateral link chassis mountings is approximately equal to the tyre rolling radius.

If the configuration does not include the toe linkage, the toe control mounting values are not required, and the Roll & Bump calculations will assume that there is no toe change in bump and droop.

6.3.5 Upper A-arm, lower trailing and lateral links, toe link

Enter the values for the top A-arm front & rear pivot points.

Enter the values for the bottom lateral and trailing links pivot points.

The longitudinal values for the A-arm and the lateral links need not be entered, and if left at 0.00, they will be set to default values such that the A-arm base length and distance between the lateral link chassis mountings is approximately equal to the tyre rolling radius.

6.3.6 Upper and lower lateral links, twin trailing links, toe link

Enter the values for the top trailing and lateral links pivot points.

Enter the values for the bottom trailing and lateral links pivot points.

Enter the values for the toe control pivot points.

If the configuration does not include the toe linkage, the toe control mounting values are not required, and the Roll & Bump calculations will assume that there is no toe change in bump and droop.

6.3.7 Upper and lower "virtual A-arms", toe link

Enter the values for the top links pivot points.

Enter the values for the bottom links pivot points.

Enter the values for the toe control pivot points.

If the configuration does not include the toe linkage, the toe control mounting values are not required, and the Roll & Bump calculations will assume that there is no toe change in bump and droop.

6.3.8 Upper transverse leaf spring, lower reversed A-arm and trailing link

Enter the values for the bottom trailing link and reverse A-arm apex pivot points.

The transverse leaf spring is also a suspension member.

The spring mounting point on the chassis, together with the basic spring dimensions, must also be specified.

There are some additional implementation notes.

6.3.9 Upper lateral link, lower reversed A-arm, twin trailing links

Enter the values for the top trailing and lateral links pivot points.

Enter the values for the bottom trailing link and reverse A-arm apex pivot points.

6.3.10 Lower lateral link, upper reversed A-arm, twin trailing links

Enter the values for the top trailing link and reverse A-arm apex pivot points.

Enter the values for the bottom trailing link and lateral link pivot points.

6.3.11 Upper lateral link, lower parallel links, twin trailing links

Enter the values for the top trailing and lateral links pivot points.

Enter the values for the bottom lateral links and trailing link pivot points.

6.3.12 Ford Integral Link

Enter the values for the top control link pivot point.

Enter the values for the bottom control arm and toe control link pivot points.

6.3.13 Ford Twin I-Beam

Enter the values for the I-Beam and radius rod chassis pivot points.

6.3.14 Volkswagen twin trailing links

Enter the values for the top trailing link pivot point and the top torsion bar pivot mounting.

Enter the values for the bottom trailing link pivot point and the bottom torsion bar pivot mounting.

With a conventional suspension, the torsion bar pivot mounting is any convenient point along the line between the trailing link chassis mounting point and the trailing link chassis mounting point on the opposite side.
For the Porsche 718 K suspension, the torsion bar pivot mounting is usually on the vehicle centreline, and lower down, resulting in an inclined pivot axis in front view.

If the configuration does not include the steering linkage, the toe control mounting values are not required, and the Roll & Bump calculations will assume that there is no toe change in bump and droop.

6.3.15 Jaguar/H-arm + camber link/Porsche928

If the configuration option “Swing axle lengths and roll/pitch centre heights” is specified, the chassis mounting vertical dimensions cannot be input, and will be calculated. The swing axle lengths and roll centre height must be specified.

For the Jaguar, the top pivot points correspond to the driveshaft universal joint centres.

Enter the values for the top pivot point.

Enter the values for the bottom wishbone front & rear pivot points.

The longitudinal values need not be entered, and if left at 0.00, they will be set to default values such that the wishbone base length is approximately equal to the tyre rolling radius.

If the configuration does not include the steering linkage, the toe control mounting values are not required, and the Roll & Bump calculations will assume that there is no toe change in bump and droop.

6.3.16 Semi-trailing arm (also includes trailing arm and swing axle)

Depending on the Geometry configuration selected, not all values can be input. If the values are " read only", they will be calculated.

Enter the lateral, vertical and longitudinal values for the two chassis pivot points.

For a semi-trailing arm or trailing arm, the two pivot points are called ‘Outer’ and ‘Inner’.

For a swing axle, the two pivot points are called ‘Front’ and ‘Rear'.
It is common in this configuration to use a single jointed half shaft as one of the suspension links.

6.3.17 Semi-trailing arm (fixed outer pivot, suspended inner pivot), toe link.

Enter the chassis trailing arm mounting (if required), toe control link mounting, and toe link mounting.

6.3.18 Trailing arm, upper and lower lateral links

Depending on the Geometry configuration selected, not all values need be input. Conversely, some input values may be recalculated.

Enter the chassis top and bottom lateral link mountings, and, if required, the chassis trailing arm mounting.

6.3.19 Trailing arm, upper and lower lateral links, toe control link

Depending on the Geometry configuration selected, not all values need be input. Conversely, some input values may be recalculated.

Enter the chassis upper and lower lateral link mountings, toe control link mounting, and, if required, the chassis trailing arm mounting.

6.3.20 Strut

Depending on the Geometry configuration selected, not all values need be input. Conversely, some input values may be recalculated.

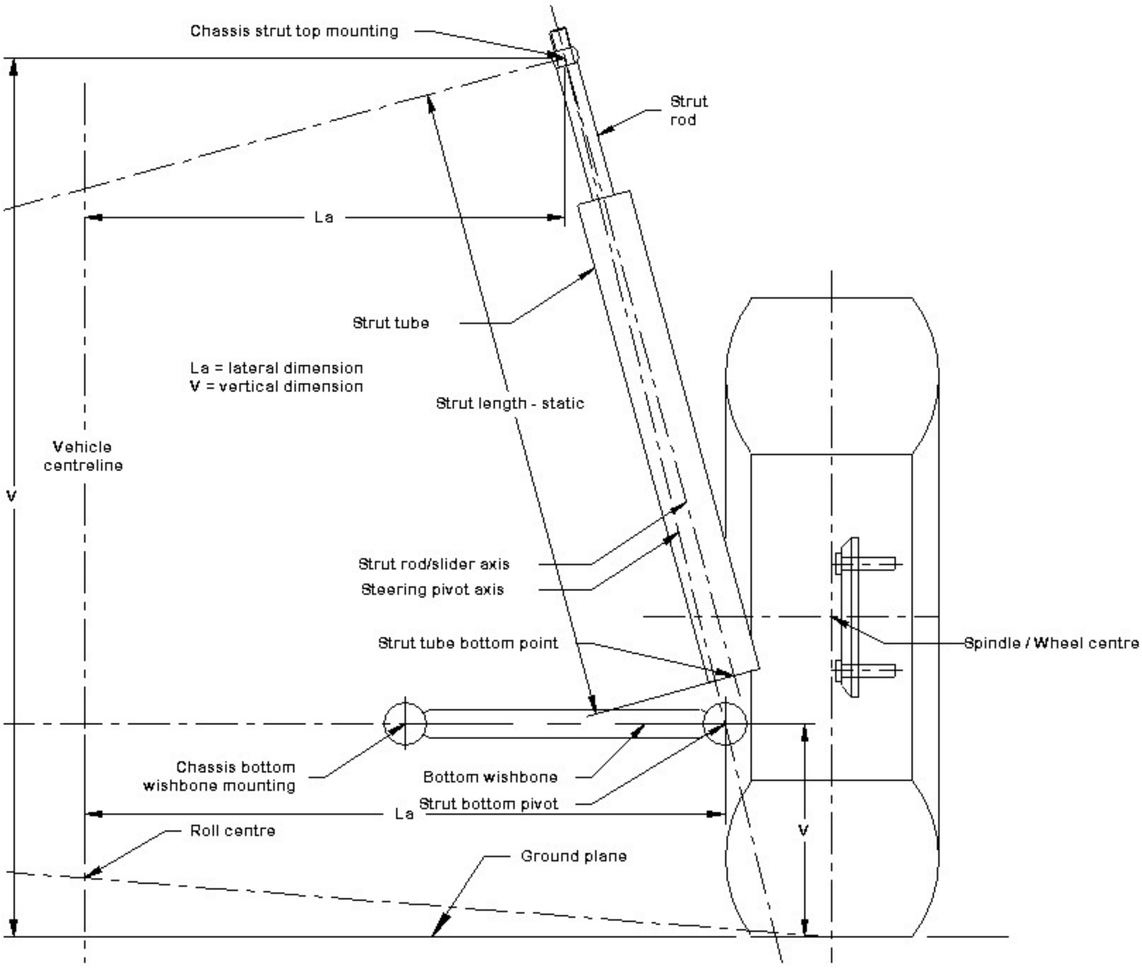
Enter the chassis top strut mounting pivot point values.

Value	Comment
Lateral	If the 'strut top mounting' option is selected, this will fix the strut top mounting lateral value, otherwise it will be calculated.
Vertical	If input, will be as specified. If the input value is zero, the vertical dimension will be calculated to put the chassis mounting point on the same point as the strut rod top pivot point.
Longitudinal	If the 'strut top mounting, Z' option is selected, this will fix the strut top mounting longitudinal value, otherwise it will be calculated.

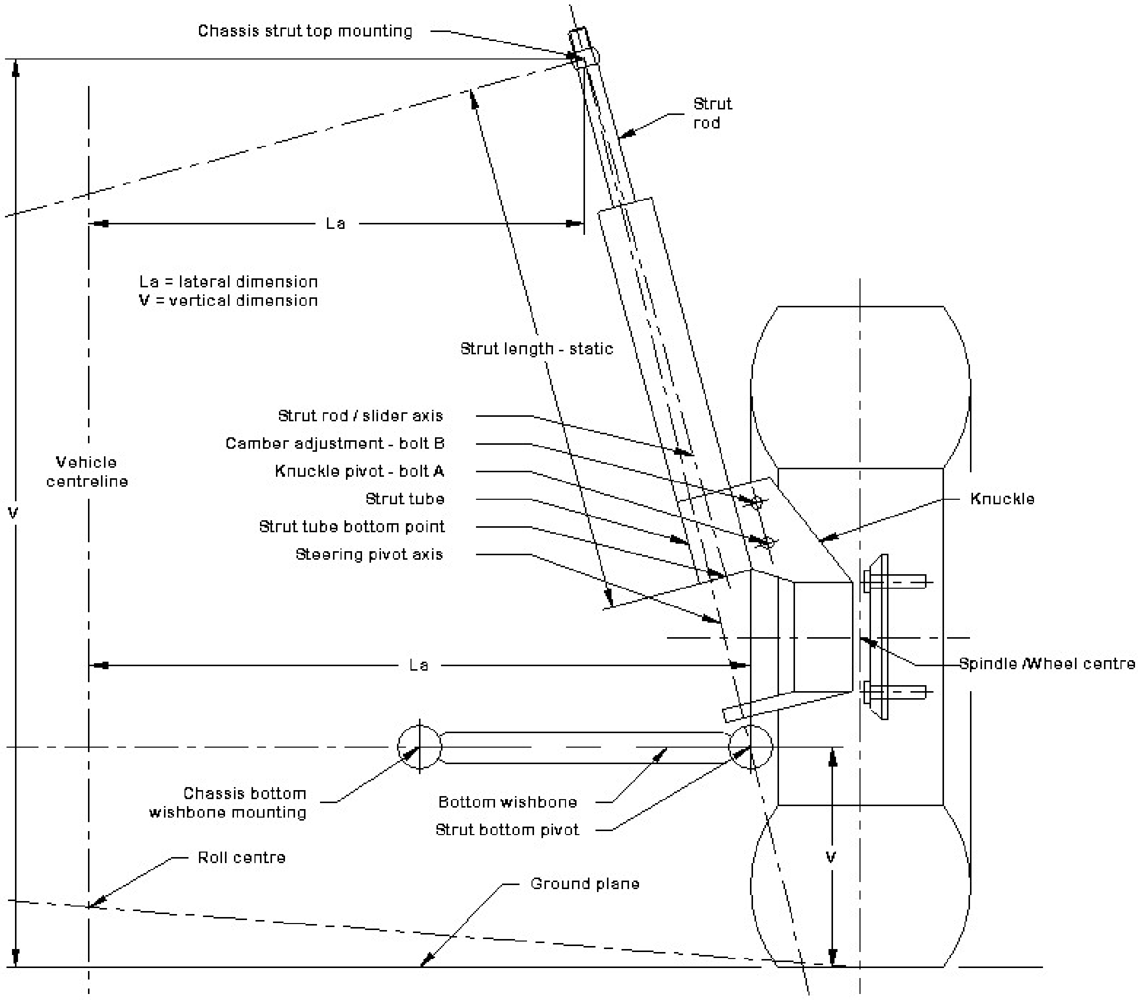
Enter the values for the bottom link front & rear pivot points.

The longitudinal values need not be entered, and if left at 0.00, they will be set to default values such that the wishbone base length is approximately equal to the tyre rolling radius.

If the configuration does not include the steering linkage, the toe control mounting values are not required, and the Roll & Bump calculations will assume that there is no toe change in bump and droop.



Typical MacPherson strut front suspension relative to vehicle reference planes (Integral knuckle and strut tube)



Typical MacPherson strut front suspension
relative to vehicle reference planes
(Seperate knuckle and stut tube)

6.3.21 Live axle (torque arm) - 4 trailing links with birdcage + Panhard rod

Enter the lateral, vertical and longitudinal values for the trailing link chassis mounting points.

Enter the lateral, vertical and longitudinal values for the Panhard rod chassis mounting point.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

Enter the lateral, vertical and longitudinal values for the torque arm link chassis pivot point.

Usually, the torque arm is offset to one side of the chassis centreline (in plan view) to clear the driveline. The lateral dimension will be either positive (if offset along the positive lateral axis) or negative (if offset along the negative lateral axis).

6.3.22 Live axle (torque arm) - 4 trailing links with birdcage + Watts linkage

Enter the lateral, vertical and longitudinal values for the trailing link chassis mounting points.

Depending on the chosen configuration, enter the lateral, vertical and longitudinal values for either the Watts axis pivot points, or the Watts links.

Except for the chassis mounted Watts linkage reference point P2, note that lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

If the Watts linkage is chassis mounted, then P1 is the actual chassis pivot point, and the lateral value will be zero. P2 is a point along the pivot axis and is referenced relative to P1. If the axis is parallel to both the the chassis lateral and vertical datum, then the lateral dimension will be 0, the vertical dimension will be 0.0 and the longitudinal dimension will be some convenient value, say 100mm.

Enter the lateral, vertical and longitudinal values for the torque arm link chassis pivot point.

Usually, the torque arm is offset to one side of the chassis centreline (in plan view) to clear the driveline. The lateral dimension will be either positive (if offset along the positive lateral axis) or negative (if offset along the negative lateral axis).

6.3.23 Live axle (torque arm) - 2 trailing links and torque arm slider + Panhard rod

Enter the lateral, vertical and longitudinal values for the torque arm slider chassis pivot point.

Enter the lateral, vertical and longitudinal values for the trailing link chassis mounting points.

Enter the lateral, vertical and longitudinal values for the Panhard rod chassis mounting point.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

Usually, the torque arm is offset to one side of the chassis centreline (in plan view) to clear the driveline. The lateral dimension will be either positive (if offset along the positive lateral axis) or negative (if offset along the negative lateral axis).

6.3.24 Live axle (torque arm) - 2 trailing links and torque arm slider + Watts linkage

Enter the lateral, vertical and longitudinal values for the torque arm slider chassis pivot point.

Enter the lateral, vertical and longitudinal values for the trailing link chassis mounting points.

Depending on the chosen configuration, enter the lateral, vertical and longitudinal values for either the Watts axis pivot points, or the Watts links.

Except for the chassis mounted Watts linkage reference point P2, note that lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

If the Watts linkage is chassis mounted, then P1 is the actual chassis pivot point, and the lateral value will be zero. P2 is a point along the pivot axis and is referenced relative to P1. If the axis is parallel to both the the chassis lateral and vertical datum, then the lateral dimension will be 0, the vertical dimension will be 0.0 and the longitudinal dimension will be some convenient value, say 100mm.

Usually, the torque arm is offset to one side of the chassis centreline (in plan view) to clear the driveline. The lateral dimension will be either positive (if offset along the positive lateral axis) or negative (if offset along the negative lateral axis).

6.3.25 Live axle (torque tube) + Panhard rod

Enter the lateral, vertical and longitudinal values for the torque tube ball joint chassis pivot point.

Enter the lateral, vertical and longitudinal values for the Panhard rod chassis mounting point.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

Usually, the torque tube ball joint is on the chassis centreline (in plan view) and the lateral value will be zero. If, however, it is offset, then the lateral dimension will be either positive (if offset along the positive lateral axis) or negative (if offset along the negative lateral axis).

6.3.26 Live axle (torque tube) + Watts linkage

Enter the lateral, vertical and longitudinal values for the torque tube ball joint chassis pivot point.

Depending on the chosen configuration, enter the lateral, vertical and longitudinal values for either the Watts axis pivot points, or the Watts links.

Except for the chassis mounted Watts linkage reference point P2, note that lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

If the Watts linkage is chassis mounted, then P1 is the actual chassis pivot point, and the lateral value will be zero. P2 is a point along the pivot axis and is referenced relative to P1. If the axis is parallel to both the the chassis lateral and vertical datum, then the lateral dimension will be 0, the vertical dimension will be 0.0 and the longitudinal dimension will be some convenient value, say 100mm.

Usually, the torque tube ball joint is on the chassis centreline (in plan view) and the lateral value will be zero. If, however, it is offset, then the lateral dimension will be either positive (if offset along the positive lateral axis) or negative (if offset along the negative lateral axis).

6.3.27 Winters: 4 trailing links, 2 birdcages + Jacobs ladder

Longitudinal links that attach to the chassis in front of the axle are trailing links; longitudinal links that attach to the chassis behind the axle are leading links. But all links are referred to as trailing links.

The longitudinal links can be arranged with all four links in the same direction (either trailing or leading) or with the links in a "Z" configuration, usually with the top link trailing and the bottom link leading, similar to a Watts linkage.

Enter the lateral, vertical and longitudinal values for the trailing link chassis mounting points.

Enter the lateral, vertical and longitudinal values for the torque tube ball joint chassis pivot point.

Enter the lateral, vertical and longitudinal values for the Jacobs ladder chassis mounting point.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

Usually, the torque tube ball joint is on the chassis centreline (in plan view) and the lateral value will be zero. If, however, it is offset, then the lateral dimension will be either positive (if offset along the positive lateral axis) or negative (if offset along the negative lateral axis).

6.3.28 Live axle/deDion - twin trailing arms + Mumford linkage

Enter the lateral, vertical and longitudinal values for the trailing link chassis pivot points, LH and RH.

Depending on the chosen configuration, enter the lateral, vertical and longitudinal values for the Mumford bellcrank axis pivot points, and the Mumford lever pivot point.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, vertical values are measured from the chassis vertical datum, and longitudinal values from the chassis longitudinal datum.

Except for the Mumford bellcrank reference point P2, note that lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

The Mumford bellcrank axis P2 is a point along the pivot axis and is referenced relative to P1. If the axis is parallel to both the the chassis lateral and vertical datum, then the lateral dimension will be 0, the vertical dimension will be 0.0 and the longitudinal dimension will be some convenient value, say 100mm.
The Mumford lever axis is always parallel to the bellcrank axis.

6.3.29 Live axle/deDion - twin trailing arms + Panhard rod

Rear suspension is configured with trailing arms; front suspension is configured with leading arms.

Enter the lateral, vertical and longitudinal values for the trailing / leading arm chassis pivot points, LH and RH.

Enter the lateral, vertical and longitudinal values for the Panhard rod chassis mounting point.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

6.3.30 Live axle/deDion - twin trailing arms + Watts linkage

Enter the lateral, vertical and longitudinal values for the trailing link chassis pivot points, LH and RH.

Depending on the chosen configuration, enter the lateral, vertical and longitudinal values for either the Watts axis pivot points, or the Watts links.

Except for the chassis mounted Watts linkage reference point P2, note that lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

If the Watts linkage is chassis mounted, then P1 is the actual chassis pivot point, and the lateral value will be zero. P2 is a point along the pivot axis and is referenced relative to P1. If the axis is parallel to both the the chassis lateral and vertical datum, then the lateral dimension will be 0, the vertical dimension will be 0.0 and the longitudinal dimension will be some convenient value, say 100mm.

6.3.31 Live axle/deDion - 3 or 4 link + Mumford linkage

Enter the lateral, vertical and longitudinal values for the trailing link chassis pivot points, LH top, LH bottom, RH top, RH bottom (as required).

Depending on the chosen configuration, enter the lateral, vertical and longitudinal values for the Mumford bellcrank axis pivot points, and the Mumford lever pivot point.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, vertical values are measured from the chassis vertical datum, and longitudinal values from the chassis longitudinal datum.

Except for the Mumford bellcrank reference point P2, note that lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

The Mumford bellcrank axis P2 is a point along the pivot axis and is referenced relative to P1. If the axis is parallel to both the the chassis lateral and vertical datum, then the lateral dimension will be 0, the vertical dimension will be 0.0 and the longitudinal dimension will be some convenient value, say 100mm.
The Mumford lever axis is always parallel to the bellcrank axis.

6.3.32 Live axle/deDion - 3 or 4 link + Panhard rod

Rear suspension is configured with trailing links; front suspension is configured with leading links.

Enter the lateral, vertical and longitudinal values for the trailing / leading link chassis pivot points, LH top, LH bottom, RH top, RH bottom (as required).

Enter the lateral, vertical and longitudinal values for the Panhard rod chassis mounting point.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

6.3.33 Live axle/deDion - 3 or 4 link + Watts linkage

Enter the lateral, vertical and longitudinal values for the trailing link chassis pivot points, LH top, LH bottom, RH top, RH bottom (as required).

Depending on the chosen configuration, enter the lateral, vertical and longitudinal values for either the Watts axis pivot points, or the Watts links.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, vertical values are measured from the chassis vertical datum, and longitudinal values from the chassis longitudinal datum.

Except for the chassis mounted Watts linkage reference point P2, note that lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

If the Watts linkage is chassis mounted, then P1 is the actual chassis pivot point, and the lateral value will be zero. P2 is a point along the pivot axis and is referenced relative to P1. If the axis is parallel to both the the chassis lateral and vertical datum, then the lateral dimension will be 0, the vertical dimension will be 0.0 and the longitudinal dimension will be some convenient value, say 100mm.

6.3.34 Live axle/deDion - 3 or 4 link + Woblink

Enter the lateral, vertical and longitudinal values for the trailing link chassis pivot points, LH top, LH bottom, RH top, RH bottom (as required).

Depending on the chosen configuration, enter the lateral, vertical and longitudinal values for either the Woblink axis pivot points, or the Woblink links.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, vertical values are measured from the chassis vertical datum, and longitudinal values from the chassis longitudinal datum.

Except for the chassis mounted Woblink reference point P2, note that lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

If the Woblink is chassis mounted, then P1 is the actual chassis pivot point, and the lateral value will be zero. P2 is a point along the pivot axis and is referenced relative to P1. If the axis is parallel to both the the chassis lateral and vertical datum, then the lateral dimension will be 0, the vertical dimension will be 0.0 and the longitudinal dimension will be some convenient value, say 100mm.

6.3.35 Live axle/deDion - 4 link

Enter the lateral, vertical and longitudinal values for the trailing link chassis pivot points, LH top, LH bottom, RH top, RH bottom.

The lateral values for both RH and LH points are positive and are measured from the vehicle centreline outwards, horizontally from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

6.3.36 Mono wheel - trailing arm

Depending on the Geometry configuration selected, not all values can be input. If the values are " read only", they will be calculated.

Enter the lateral, vertical and longitudinal values for the two chassis pivot points, LH and RH.

6.4 Upright/Trailing Arm/Strut/Axle

From the Geometry tab, select Upright, Strut, Trailing arm, or Axle.

6.4.1 Upright

Upright coordinates are vehicle independent and are represented with lateral, vertical and longitudinal values. The datums for the upright are the wheel mounting flange and the axle (or hub) centreline.

Again, imagine the upright viewed from the front of the vehicle. Lateral values are axial dimensions (along the axle or spindle) from the wheel mounting flange, vertical and longitudinal values are radial dimensions from the axle centreline.

All upright measurements are measured with the upright at zero camber, castor and toe position.

The lateral dimension of points inboard of the wheel mounting flange are always positive, regardless of the direction of the positive lateral axis.

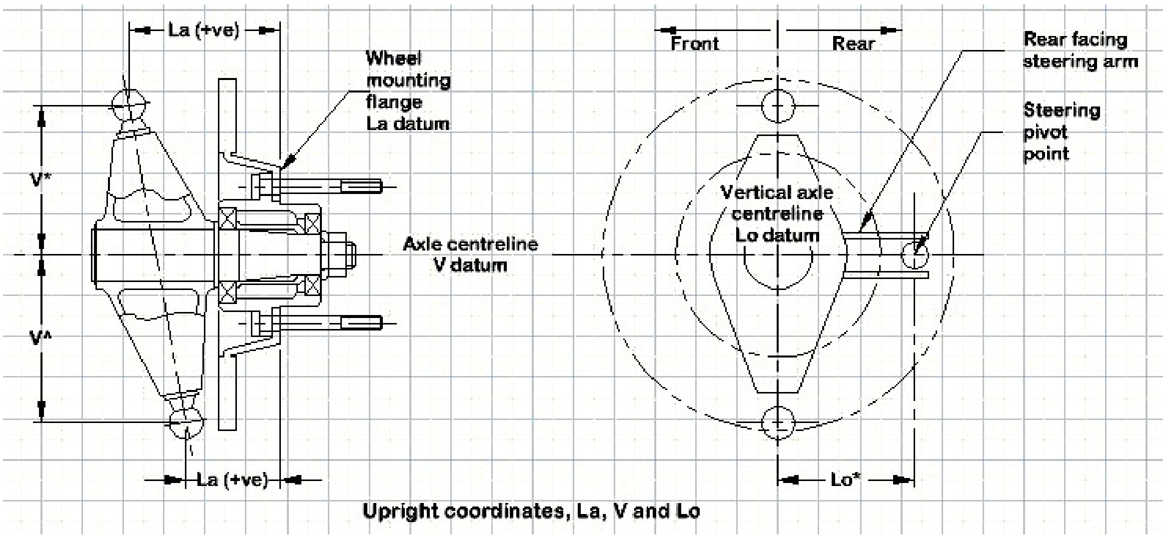
For the usual design of upright, the top pivot point(s) is above the axle centreline, and the bottom pivot point(s) is below the axle centreline. If the vertical axis is positive upward, then the top pivot vertical dimension will be positive and the bottom pivot vertical dimension will be negative; if the vertical axis is positive downward, then the top pivot vertical dimension will be negative and the bottom pivot vertical dimension will be positive.

Longitudinal values are measured radially from the axle centreline in side view, and will be positive to the rear, negative to the front (if the longitudinal axis is specified as +ve rear); or will be positive to the front, negative to the rear (if the longitudinal axis is specified as +ve front).

If you have been provided with upright mounting points in vehicle coordinates, use the CMMtoUpright tool to convert back to upright coordinates.

Depending on the particular geometry type, there will be 3, 4 or 5 pivot mounting points.

Enter the required values for the upright top and bottom pivot points.



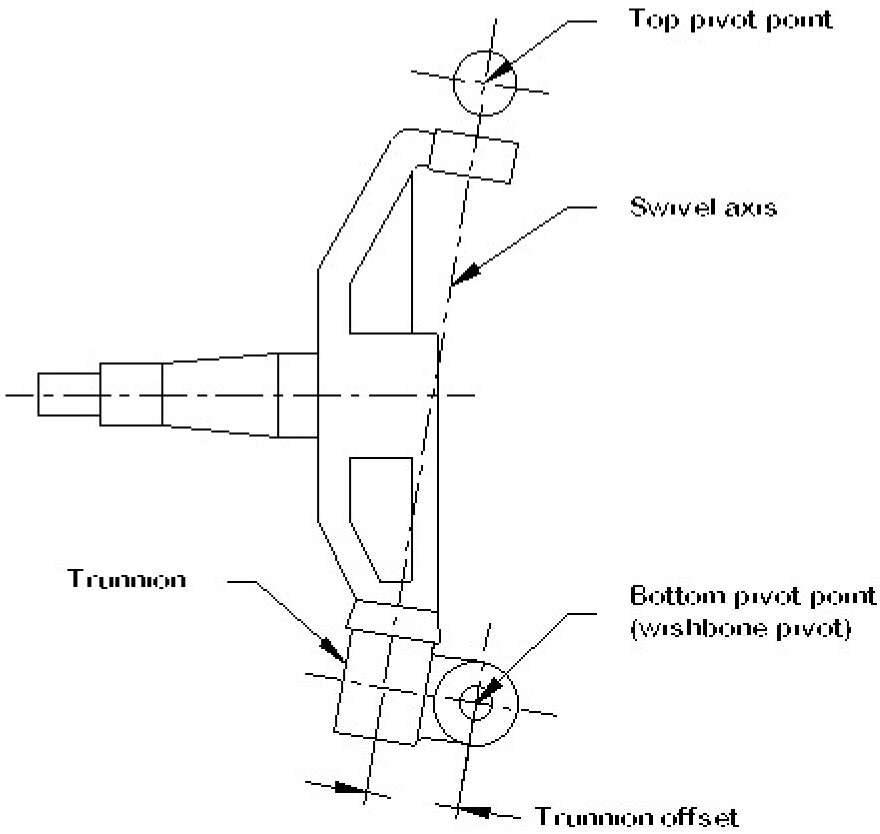
Some upright designs do not use a ball joint, but instead use a kingpin swivel (sometimes called a trunnion). The kingpin swivel is arranged such that it can only rotate about the king pin axis, usually on some kind of bush or bearing. Some uprights us a thread.

For these joints the upright kingpin point is used as the major reference point. The wishbone pivot is then dimensioned from the kingpin point. The swivel offset is the distance from the horizontal wishbone pivot normal to the king pin swivel axis. If the a-arm pivot is further out from the kingpin swivel axis (as the Triumph Spitfire bottom trunnion) this dimension is positive. If the a-arm pivot is back toward the the hub face datum from the kingpin swivel axis (as the MGB top trunnion) this dimension is negative.
Typical examples are the Triumph Spitfire type front upright, with a top ball joint and a bottom trunnion, and the MGB with both top and bottom trunnions. The later Skyline also use a top kingpin swivel.

The kingpin swivel can also have a vertical offset. This offset is measured along the kingpin axis. If the a-arm pivot is above the kingpin point, then this dimension will be positive.

For ball joints, the kingpin swivel offsets are zero.

When the suspension geometry is calculated, the kingpin swivel is rotated around the kingpin axis such that the a-arm pivot (in the swivel) is parallel to the a-arm chassis pivot axis (in plan view). The kingpin swivel will always be kept in alignment with the kingpin axis. If there is any misalignment in side view (usually because the a-arm chassis pivot axis isn't at right angles to the kingpin axis) then this will be reported. In the ideal world, the a-arm pivot (in the swivel) would always be parallel to the a-arm chassis pivot axis. If there is any misalignment then this will eventually lead to wear and unwanted movement in the a-arm swivel bearing or the kingpin swivel bearing.



Typical Triumph Spitfire type front upright

For most wishbone Geometry calculations the toe control mounting values are not required as the wheel alignment toe is specified, and in this case the Roll & Bump calculations will assume that there is no toe change in bump and droop. If all links and steering are fixed, then the Roll & Bump calculations will calculate the toe change in bump and droop.

For all other suspension types, the toe control mounting values are required. The Roll & Bump calculations will calculate the toe change in bump and droop.

The spindle reference point is a “user defined” point and can be at any location along the axle (or spindle). The position is measured axially from the wheel mounting flange. It is positive if inboard from the wheel mounting flange.

The spindle centre point is located on the axle centreline, in the plane of the wheel and tyre centre. There is no user input for this point.

After Geometry | Calculate, the vehicle coordinate values for these points will be shown in the Result window.

6.4.1.1 Upright camber shims

For double A-arm configurations, there is provision for specifying an “upright camber shim”. This shim is fitted between the upright body and the upright pivot bracket. The upright pivot bracket is often extended to include the toe control pivot, in which case adjusting camber has little or no effect on toe settings. It also is a way of decoupling camber and KPI, so that each may be adjusted independently of the other.

Currently, there are five upright camber shim styles available:

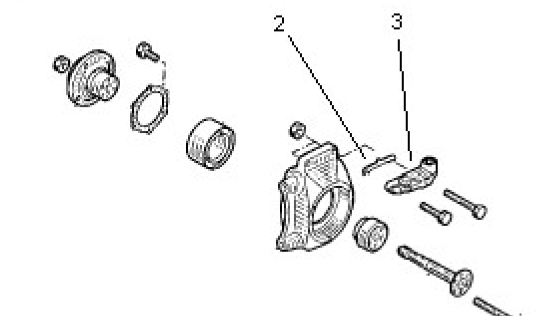
None	The design of the upright does not incorporate camber shims.

Top pivot only	The camber shim adjusts the top upright pivot only. Adding shims will increase positive camber; and for a front steer car, usually increase toe-in.
Top pivot and toe control	The camber shim adjusts both the top upright pivot and the toe control point by the same amount. Adding shims will increase positive camber; toe is unchanged.
Bottom pivot only	The camber shim adjusts the bottom upright pivot only. Adding shims will increase negative camber; and for a front steer car, usually increase toe-in.
Bottom pivot and toe control	The camber shim adjusts both the bottom upright pivot and the toe control point by the same amount. Adding shims will increase negative camber; toe is unchanged.

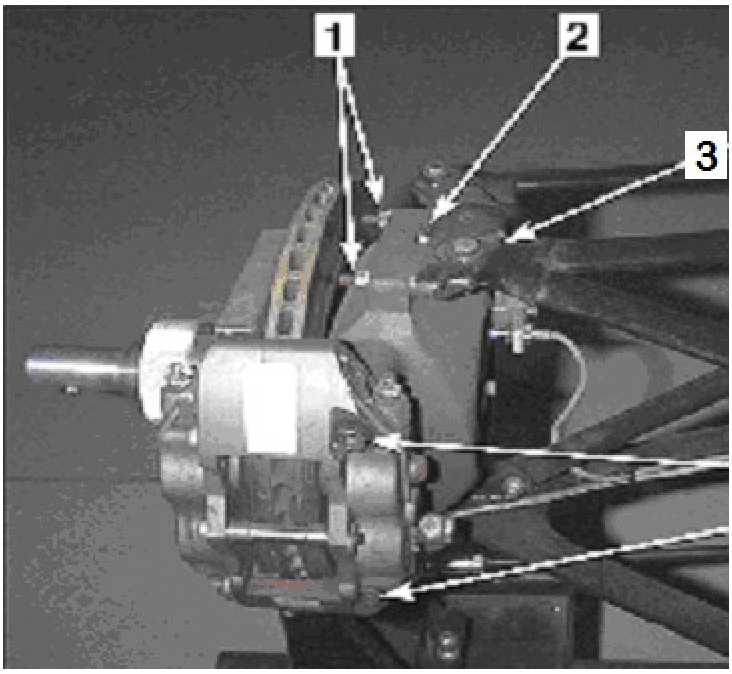
Specify the pivot point lateral dimensions **without** shims.

Specify the shim thickness - this is the thickness of one shim.

Specify the number of shims.
For maximum adjustability, specify a shim pack half the maximum number with the camber at the design setting. This will allow for maximum camber adjustment from the design setting.



Front upright assembly



Typical front suspension assembly showing upright camber shim [2]. In this example, the bracket [3] combines the top A-arm mounting and the steering arm. The camber shim adjusts both the top upright pivot and the steering arm by the same amount.

6.4.1.2 Graphic

After entering the required dimensional data, click on the “Graphic” tab. This will display an isometric representation of the upright.

It will show the wishbone mounting points, steering arm and king pin axis as appropriate.

It is intended that this graphic will provide a basic visual confirmation that all the elements are in the expected position and orientation.
The upright is drawn with a dotted line indicating the centre of the tyre, and, for the front suspension, a dashed line indicating the king pin axis.

The axis labelled “INSIDE” – “OUTSIDE” is the spindle or axle centreline (the vertical datum axis), the axis with the arrow points to the front of the vehicle (the longitudinal datum axis), the vertical axis is the lateral datum axis.
The upright is viewed as though you were standing forward of the axle centreline, in the centre of the vehicle, looking down at the upright.
The plane of the longitudinal and vertical axes is the hub mounting plane (reference surface).

All pivot points are drawn with a line starting at the datum intersection, along the lateral axis, then backwards or forwards parallel to the longitudinal axis, and finally up or down parallel to the vertical axis.

If you “click” on a pivot point, a hint will show with the identification of that point.

6.4.2 Trailing arm (independent suspension)

Trailing arms come in two basic configurations: double pivot and single pivot. The single pivot types will have additional lateral control links.

They are usually large castings or fabrications which comprise a hub carrier (which houses the hub shaft bearings and hub shaft) extended with one or two ‘legs’ terminating in bushes which then attach to the chassis.

Measuring hints.

When measuring a trailing arm it is probably easiest to set up the trailing arm on a flat surface, with the axle and bearings in place. The axle will usually have small machining location centres in each end which can be used as location points.
Draw two lines on the surface at right angles. These will be the lateral and longitudinal datum lines.

Since the axle and the pivot axis may not be co-planar, it may be easiest to use the axle ends and one mounting bush to define the vertical datum plane.

You will need packing blocks and shims to place under the hub section, and under each of the mounting points. Adjust the blocks so that the axle is horizontal and that the centre of one of the mounting bushes (probably the outer (or front) one) is at the same height as the axle centre. Call this mounting bush ‘A’. Make sure that the centreline of the axle is directly above the longitudinal datum line, and that the face of the wheel hub is on the lateral datum line. This will now have the axle and one mounting point in a plane parallel to the vertical datum plane, and some distance above it. Note this dimension ‘B’.

Now measure the lateral and longitudinal dimensions of the two mounting points (as close to the bush centre as possible) from the lateral and longitudinal datum lines.
The vertical dimension of mounting point ‘A’ will be zero. Measure the height of the other mounting point (as close to the centre as possible). The vertical dimension of this mounting point will be the measured dimension less the ‘B’ dimension.

This same technique can be used to locate the spring, shockabsorber and anti-roll bar linakge mounting points.

If you are unable to remove or disassemble the trailing arm, then reasonable dimensions can be made by placing a straight edge across the wheel mounting flange and measuring the mounting offsets. For the initial calculations you can assume that the axle and pivot axis are co-planar, and that both mounting points have zero vertical dimensions.

6.4.2.1 Semi-trailing arm (includes trailing arm and swing axle)

The chassis mounting points are all dimensioned relative to the wheel mounting flange, the axle centreline and a horizontal plane through the axle centreline (in side view).

Note that the semi-trailing arm datums are the same as when the semi-trailing arm is positioned with zero camber, zero inclination and zero toe. Zero inclination (in side view) means that the axle centre and the chassis mounting are horizontal. This is also the same as zero caster.

It is easiest to measure the semi-trailing arm removed from the vehicle. If this is not possible then take care to ensure that the correct reference datums are used to establish these dimensions.

If you have been provided with semi-trailing arm mounting points in vehicle coordinates, use the CMM tool to convert back to trailing arm coordinates.

In this type of semi-trailing arm, the arm and the hub and spindle assembly are rigidly fixed together.

The spindle reference point is a “user defined” point and can be at any location along the axle (or spindle). The position is measured axially from the wheel mounting flange. It is positive if inboard from the wheel mounting flange.

The spindle centre point is located on the axle centreline, in the plane of the wheel and tyre centre. There is no user input for this point.

For a semi-trailing arm or trailing arm, the two pivot points are called ‘Outer’ and ‘Inner’.

For a swing axle, the two pivot points are called ‘Front’ and ‘Rear'.
It is common in this configuration to use a drive shaft with a single universal joint as one of the suspension links. In this case, the vertical and longitudinal dimensions of the "drive shaft" link must be zero, because the drive shaft must be at right angles to the plane of the wheel. Also, if the "drive shaft" link is the rear link, then either the trailing arm dimensions, or the chassis mounting points, should be adjusted to minimise the "mounting error" because the calculations are using the front mount point as the reference point. As long as the "mounting error" is small the error will be insignificant.

See above for measuring hints.

Calculation note.

If the semi-trailing arm mounting points on the chassis and the dimensions of the semi-trailing arm are both specified, it is possible that there is a small difference in the calculated distance between the two chassis mounting points and the two semi-trailing arm mounting points. When the arm is fitted to the vehicle, there is often enough flexibility (especially if rubber bushes are used), free play in the bolt holes, or shim washers to allow for this.

For SusProg3D calculation purposes, the semi-trailing arm outer (or front) mounting will always be coincident with the corresponding chassis mounting point. The semi-trailing arm inner (or rear) mounting will be located along the pivot axis (as defined by the two mounting points), but may not be coincident with the chassis mounting point. This offset will be noted as ‘Mounting error’ and will be positive if the span of the semi-trailing arm mountings is greater than the span of the chassis mountings.

6.4.2.2 Trailing arm

The lateral link mounting points and the chassis mounting point are all dimensioned relative to the wheel mounting flange, the axle centreline and a horizontal plane through the axle centreline (in side view).

Note that the trailing arm datums are the same as when the trailing arm is positioned with zero camber, zero inclination and zero toe. Zero inclination (in side view) means that the axle centre and the chassis mounting are horizontal. This is also the same as zero caster.

It is easiest to measure the trailing arm removed from the vehicle. If this is not possible then take care to ensure that the correct reference datums are used to establish these dimensions.

If you have been provided with trailing arm mounting points in vehicle coordinates, use the CMM tool to convert back to trailing arm coordinates.

In this type of trailing arm, the arm and the hub and spindle assembly are rigidly fixed together.

The spindle reference point is a “user defined” point and can be at any location along the axle (or spindle). The position is measured axially from the wheel mounting flange. It is positive if inboard from the wheel mounting flange.

The spindle centre point is located on the axle centreline, in the plane of the wheel and tyre centre. There is no user input for this point.

See above for measuring hints.

6.4.2.3 Mono wheel - trailing arm

The chassis mounting points are all dimensioned relative to the wheel mounting flange, the axle centreline and a horizontal plane through the axle centreline (in side view).

Note that the trailing arm datums are the same as when the trailing arm is positioned with zero camber, zero inclination and zero toe. Zero inclination (in side view) means that the axle centre and the chassis mounting are horizontal. This is also the same as zero caster.

It is easiest to measure the trailing arm removed from the vehicle. If this is not possible then take care to ensure that the correct reference datums are used to establish these dimensions.

If you have been provided with trailing arm mounting points in vehicle coordinates, use the CMM tool to convert back to trailing arm coordinates.

In this type of trailing arm, the arm and the hub and spindle assembly are rigidly fixed together.

The spindle reference point is a “user defined” point and can be at any location along the axle (or spindle). The position is measured axially from the wheel mounting flange. It is positive if inboard from the wheel mounting flange.

The spindle centre point is located on the axle centreline, in the plane of the wheel and tyre centre. There is no user input for this point.

The two pivot points are called ‘LH’ and ‘RH’.

See above for measuring hints.

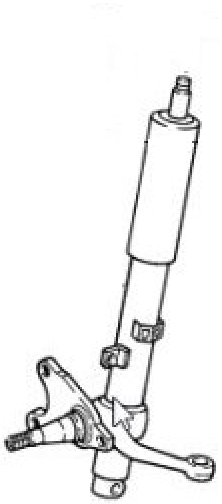
Calculation note.

If the trailing arm mounting points on the chassis and the dimensions of the trailing arm are both specified, it is possible that there is a small difference in the calculated distance between the two chassis mounting points and the two trailing arm mounting points. When the arm is fitted to the vehicle, there are often shim washers to allow for this.

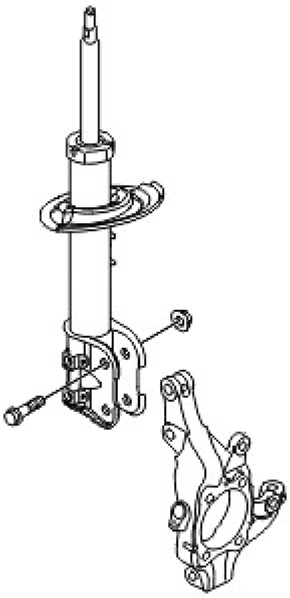
For SusProg3D calculation purposes, the trailing arm will be laterally located with any mounting error equal on each mounting. This offset will be noted as ‘Mounting error’ and will be positive if the span of the semi-trailing arm mountings is greater than the span of the chassis mountings.

6.4.3 Strut

Depending on the type of strut (integral knuckle or separate knuckle) there are various alternative dimension points which define the basic strut configuration.



- for integral strut tube and knuckle type - strut & knuckle (fixed). Data input A or B.



- for separate strut tube and knuckle type - strut & knuckle (adjustable). Data input C or D.

The bottom wishbone ball joint pivot(s) position and the CV joint position are both dimensioned relative to the wheel mounting flange, the axle centreline and a vertical line through the axle centreline parallel to the strut rod axis with the strut rod vertical (in side view).

Note that the knuckle datums are the same as the strut position with zero camber and zero toe. If the axle centreline is on the strut rod axis (in side view), then this is also the same as zero caster.

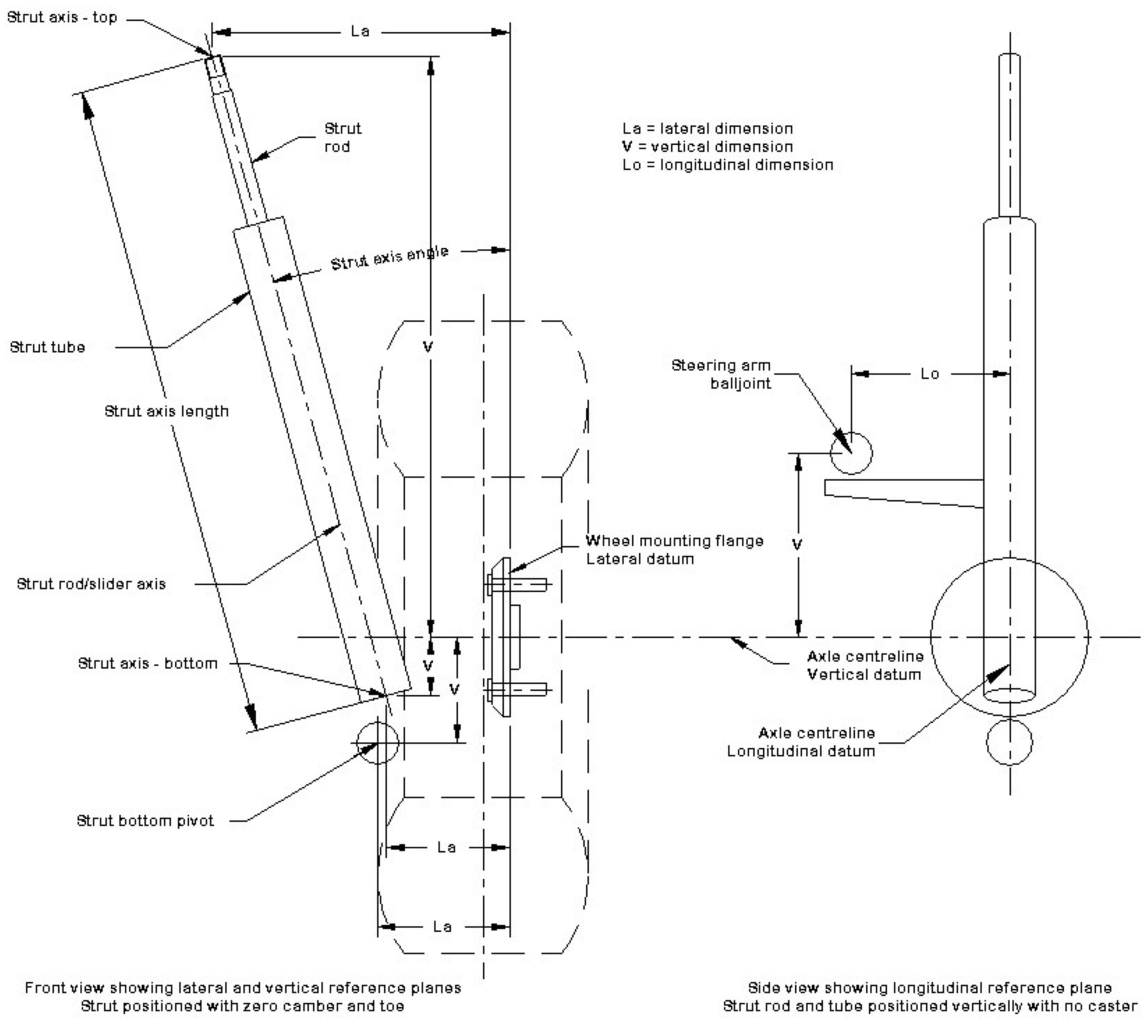
It is easiest to measure the strut removed from the vehicle. If this is not possible then take care to ensure that the correct reference datums are used to establish these dimensions.

If you have been provided with strut points in vehicle coordinates, use the CMMtoStrut tool to convert back to strut coordinates.

The spindle reference point is a “user defined” point and can be at any location along the axle (or spindle). The position is measured axially from the wheel mounting flange. It is positive if inboard from the wheel mounting flange.

The spindle centre point is located on the axle centreline, in the plane of the wheel and tyre centre. There is no user input for this point.

6.4.3.1 Integral strut tube and knuckle



Typical MacPherson strut front suspension
relative to strut datum refence planes
(Integral knuckle and strut tube)

In this type of strut, the strut tube & knuckle are rigidly fixed together.

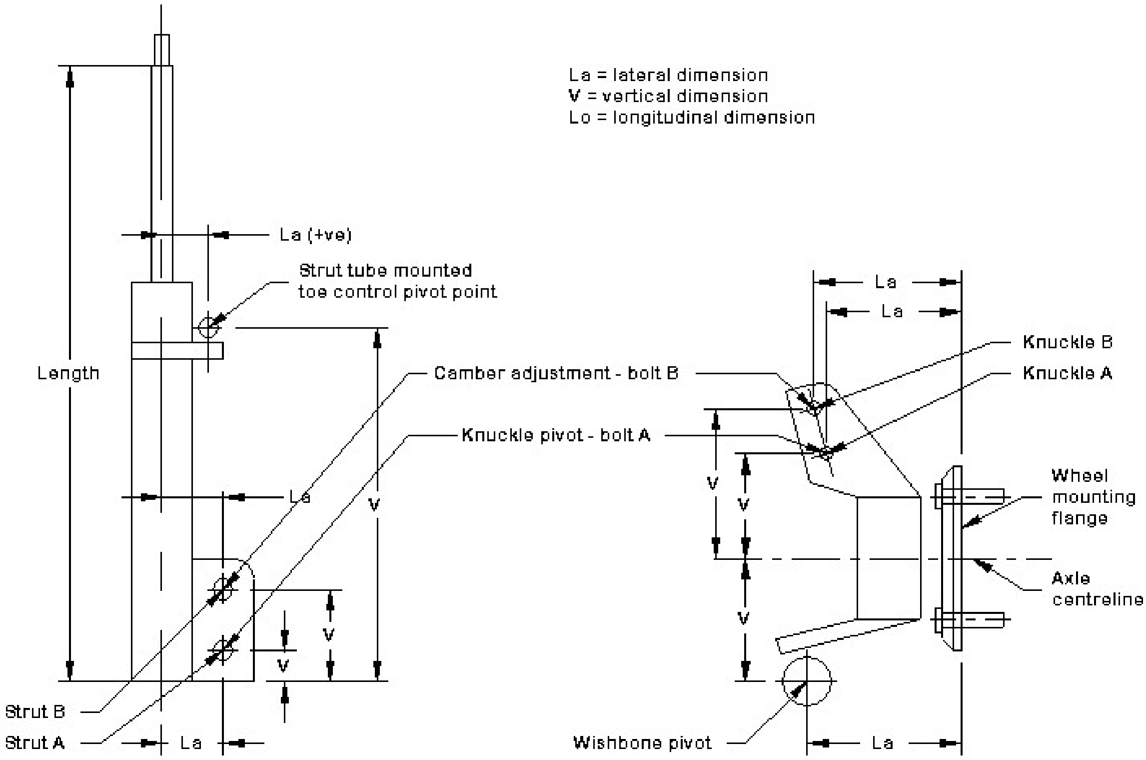
- The strut data input style is 'A'.
  This is specified with the strut rod top and strut tube bottom dimensions, referenced to the

wheel mounting flange, the axle centreline and a vertical line through the axle centreline parallel to the strut rod axis with the strut rod vertical (in side view). The “strut axis – top” dimension is to the top of the strut rod in the fully extended position, and the “strut axis – bottom” measurement is to the bottom of the strut tube. Both points are on the centreline of the strut rod and/or tube. If the vertical axis is positive upward, then if the strut tube bottom point is below the stub axle centreline then the vertical value must be negative; if the vertical axis is positive downward, then if the strut tube bottom point is below the stub axle centreline then the vertical value must be positive. You can measure to the end of the strut rod with the rod in any position (although fully extended is probably best). This allows both the stub axle centreline and the bottom ball joint to be offset from the strut rod axis.
The strut axis length and strut axis angle will be calculated. The “strut axis – bottom” point is also used to define the strut length.

- The strut data input style is 'B'.
  This is specified with the strut tube bottom dimensions, the strut axis angle, and the strut axis length (optional, will default to tyre diameter if left at zero), all referenced to the wheel mounting flange, the axle centreline and a vertical line through the axle centreline parallel to the strut rod axis with the strut rod vertical (in side view). The “strut axis – bottom” measurement is to the bottom of the strut tube. Both points are on the centreline of the strut rod and/or tube. If the vertical axis is positive upward, then if the strut tube bottom point is below the stub axle centreline then the vertical value must be negative; if the vertical axis is positive downward, then if the strut tube bottom point is below the stub axle centreline then the vertical value must be positive. You can measure to the length of the strut with the rod in any position (although fully extended is probably best).
  The “strut axis – top” point will be calculated. The “strut axis – bottom” point is also used to define the strut length.

Although the steering arm can be attached to the knuckle or strut tube, the steering ball joint is measured relative to the wheel mounting flange, the axle centreline and a vertical line through the axle centreline parallel to the strut rod axis with the strut rod vertical (in side view). The steering arm location is only used to display an appropriately positioned steering arm.

6.4.3.2 Separate strut tube and knuckle



Typical MacPherson strut tube assembly and bolt-on knuckle relative to stut datum reference planes

In this type of strut, the upright or knuckle is bolted to brackets welded to the strut tube, with a limited amount of adjustablity.

- The strut data input style is 'C'.
  This is specified with the knuckle mounting holes on the strut tube (Strut A & B, referenced to the strut tube bottom and strut axis), the strut axis length (optional, will default to tyre diameter if left at zero), the strut mounting holes on the knuckle (Knuckle A & B, referenced to the wheel mounting flange, the axle centreline and a vertical line through the axle centreline), and the knuckle/strut adjustment angle (which can be left as zero. Typically this angle is in the range of + or - 1 degree).
  The “strut axis – top” and “strut axis – bottom” points, strut axis length and strut axis angle will be calculated. The “strut axis – bottom” point is also used to define the strut length.
- The strut data input style is 'D'.
  This is specified with the bottom knuckle mounting holes on the strut tube (Strut A, referenced to the strut tube bottom and strut axis), the strut axis length (optional, will default to tyre diameter if left at zero), the bottom strut mounting holes on the knuckle (Knuckle A, referenced to the wheel mounting flange, the axle centreline and a vertical line through the axle centreline), and the strut axis angle.
  The “strut axis – top” and “strut axis – bottom” points, strut axis length and strut axis angle will be calculated. The “strut axis – bottom” point is also used to define the strut length.

In vehicle side view, the strut tube mountings are symmetrical about the strut tube axis. Both Strut A & B longitudinal dimensions will default to zero.

In vehicle side view, if the strut tube axis is offset from the axle centreline, then Knuckle A & B longitudinal dimensions should reflect this offset. Both Knuckle A & B longitudinal dimensions must be the same.
If necessary, rotate the knuckle (in side view) so that the knuckle mounting points A and B are in the same vertical line. Then measure all knuckle dimensions in this position.

As an alternative method of adjusting the strut axis angle, especially as a method of adjusting wheel camber settings, some strut and knuckle combinations (for example, the Holden Harrop front strut) allow the knuckle mounting B point lateral dimension to be adjusted (usually by a vernier adjustment). This can be simulated by changing the knuckle mounting B point lateral dimension.

The steering arm can be attached to the knuckle or strut tube.

- · If attached to the knuckle, the steering ball joint is measured relative to the wheel mounting flange, the axle centreline and a vertical line through the axle centreline parallel to the strut rod axis with the strut rod vertical (in side view). Specify the steering arm location as 'knuckle' and enter the dimensions in the ‘steering arm balljoint (knuckle)'.
- · If attached to the strut tube, the steering ball joint is measured relative to the strut tube bottom and strut axis. Note that if the ball joint is offset in the lateral direction towards the outside of the vehicle, then the lateral dimension is positive. Specify the steering arm location as 'strut tube' and enter the dimensions in the ‘steering arm balljoint (strut tube)'. The ball joint dimensions relative to the knuckle will be calculated.

6.4.4 Axle (conventional)

This is the conventional axle and diff centre section with enclosed axle shafts.
It can be non-floating, semi-floating or full floating.

There are three sets of axle dimensions

- Housing, diff and hubs
- Mounting brackets
- Static alignment.

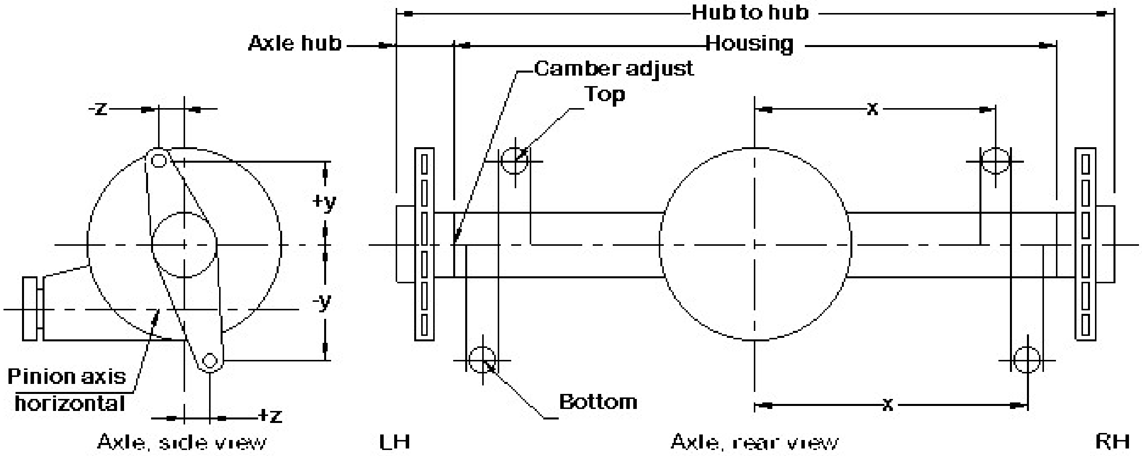
Plus

- Graphic

6.4.4.1 Housing, diff and hubs

If the axle housing is a typical production car item and has no adjustment for camber and toe, then the axle housing length will be specified as the distance over the axle wheel mounting flanges, and the axle hub length will be zero. The overall hub to hub length will be the same as the axle housing length. All dimensions for LH and RH hub alignment should be set to zero.

If the axle is a deDion, then the axle hub length is then the length from the outboard universal joint mounting flange to the wheel mounting flange, the axle housing length will be the distance between the mounting flanges of the left and right outboard universal joints, and the overall hub to hub length will be distance across the left and right wheel mounting flanges.



If the axle housing is a typical Australian V8 Supercar item and has adjustable "hub carriers", then the axle housing length is the fixed centre section. The axle hub length is then the length of the "hub carrier" from the axle centre section mounting face to the wheel mounting flange. The nominal hub to hub length will be the width of the centre section plus the length of both hub carriers. This will vary slightly with camber and toe.

The spindle reference point is a “user defined” point and can be at any location along the axle (or spindle). The position is measured axially from the wheel mounting flange. It is positive if inboard from the wheel mounting flange.

The spindle centre point is located on the axle centreline, in the plane of the wheel and tyre centre. There is no user input for this point.

For live axle, all points are specified relative to the axle centrelines, usually with the pinion horizontal.
If it is more convenient to measure the mounting points relative to a horizontal datum which is not parallel to the axle pinion (in side view) then the pinion angle must be specified.

The pinion lateral location is specified relative to the centre of the axle housing. If the pinion is offset in the direction of the positive lateral axis, then the lateral value will be positive, if offset in the direction of the negative lateral axis, then the lateral value will be negative.

The pinion vertical offset is specified as the distance from the pinion shaft centreline to the axle centre. Note that this dimension is always normal to the pinion shaft centreline, so be careful if the pinion angle is non-zero. If the vertical axis is positive upwards, then a negative dimension means the pinion is below the axle centreline.

The pinion length is the distance from the face of the pinion flange to the axle centreline.

For a torque tube axle, the torque tube length is measured to the centre of the torque tube ball joint.

The pinion angle is relative to the horizontal axle datum. If the vertical axis is positive upwards, then a positive angle is “pinion nose up” and a negative angle is “pinion nose down”; if the vertical axis is positive downwards, then a positive angle is “pinion nose down” and a negative angle is “ pinion nose up”.

The hub alignment is the “built-in” axle alignment. Again it is measured for each hub, with the both the axle centre section and pinion horizontal.

Note that there are no “wheel alignment” settings for rear live axle. The wheel camber and toe settings are controlled by the axle hub alignment onto the housing, and the subsequent alignment of the entire axle assembly by the locating links.

For a front live axle, there are additional inputs.

The hub alignment includes caster and king pin inclination angles.
Caster is the inclination of the steering axis (the king pin) in side view. It is measured from the vertical, and is positive if the top of the king pin is rearward, and the bottom of the king pin is

forward. Note that this is relative to the horizontal axle datum. If the axle is tilted when installed in the vehicle, then the wheel alignment caster will be different to this axle caster. Caster is typically between 0 and 10 degrees.
KPI is the angle of the steering axis (the king pin) in front view. It is measured from the vertical, and is positive if the top of the king pin is inclined towards the centre of the vehicle, and the bottom of the king pin is inclined outwards. KPI is typically between 5 and 10 degrees.
In the usual driven front axle, the steering axis intersects the drive axle universal.

The steering arms are also specified. There are two steering arms (one LH and one RH) that connect to the tie rod, which connect the two wheels. There is a third steering arm that connects to the drag link, which connects to the steering box (the pitman arm).
Note that the steering arm balljoint is dimensioned from the hub mounting face (not the axle centre). See upright.

6.4.4.2 Mounting brackets

Rear suspension is configured with trailing links; front suspension is configured with leading links.

Enter the lateral, vertical and longitudinal values for the trailing / leading link axle pivot points, LH top, LH bottom, RH top, RH bottom (as required).

The torque tube axle mounting point is the torque tube ball joint..

The torque arm slider axle has two points which define the torque arm slider, P1 and P2. P1 is one end of the slider, and is dimensioned from the axle datums. Typically the lateral value will be zero (if the slider mounting is on the vehicle centreline), the vertical value will be below the axle (when the torque arm is below the propshaft) and the longitudinal value will be the length of the toque arm. P2 is defined relative to P1. If the slider axis is parallel to the vehicle centreline (in plan view) then the lateral dimension will be zero; if the slider axis is horizontal then the vertical dimension will be 0.0; and the longitudinal dimension will be the slider length. Generally the slider will be positioned longitudinally in the centre of the chassis mounting bearing.

Depending on the chosen configuration, enter the lateral, vertical and longitudinal values for the Panhard rod axle mounting point, or the Mumford lever pivot axis points, or the Watts lever pivot axis points, or the two Watts links.

For live axle, all mounting points are specified relative to the axle centrelines, usually with the pinion horizontal.
If it is more convenient to measure the mounting points relative to a horizontal datum which is not parallel to the axle pinion (in side view) then the pinion angle must be specified (in the housing, diff and hubs section).

For deDion, all mounting points are specified relative to the axle hub centrelines, and not the deDion tube.

For a rigid (non driving) axle, all mounting points are specified relative to the central axle tube.

The lateral values for RH and LH points are both positive and are measured from the centre of the axle housing outwards.
Lateral values for single points (that are usually on or close to the vehicle centreline in plan view) are either positive (if along the positive lateral axis) or negative (if along the negative lateral axis).

For all points, vertical values are measured vertically from the axle housing centreline, and longitudinal values horizontally from the axle housing centreline. If the vertical axis is positive upwards, a positive value for the pivot point means it is above the axle centreline, a negative value for the pivot point means it is below the axle centreline; if the vertical axis is positive downwards, a negative value for the pivot point means it is above the axle centreline, a positive value for the pivot point means it is below the axle centreline. If the longitudinal axis is positive rearward, a positive value means the pivot point is to the rear, a negative value means the pivot point is to the front; if the longitudinal axis is positive forward, a negative value means the pivot point is to the rear, a positive value means the pivot point is to the front.

For the twin trailing arm style, the vertical dimension (in side view) is the distance from the centreline of the axle to the centreline of the trailing arm (ie normal to the centreline of the trailing arm). The “sign” of the dimension will determine whether the trailing arm is mounted above or below the axle.

If the Watts linkage is axle mounted, then P1 is the actual axle pivot point, and the lateral value will be zero. P2 is a point along the pivot axis and is referenced relative to P1. If the axis is horizontal, then the lateral dimension will be 0.0, the vertical dimension will be 0.0 and the longitudinal dimension will be some convenient value, say 100mm (4.0").

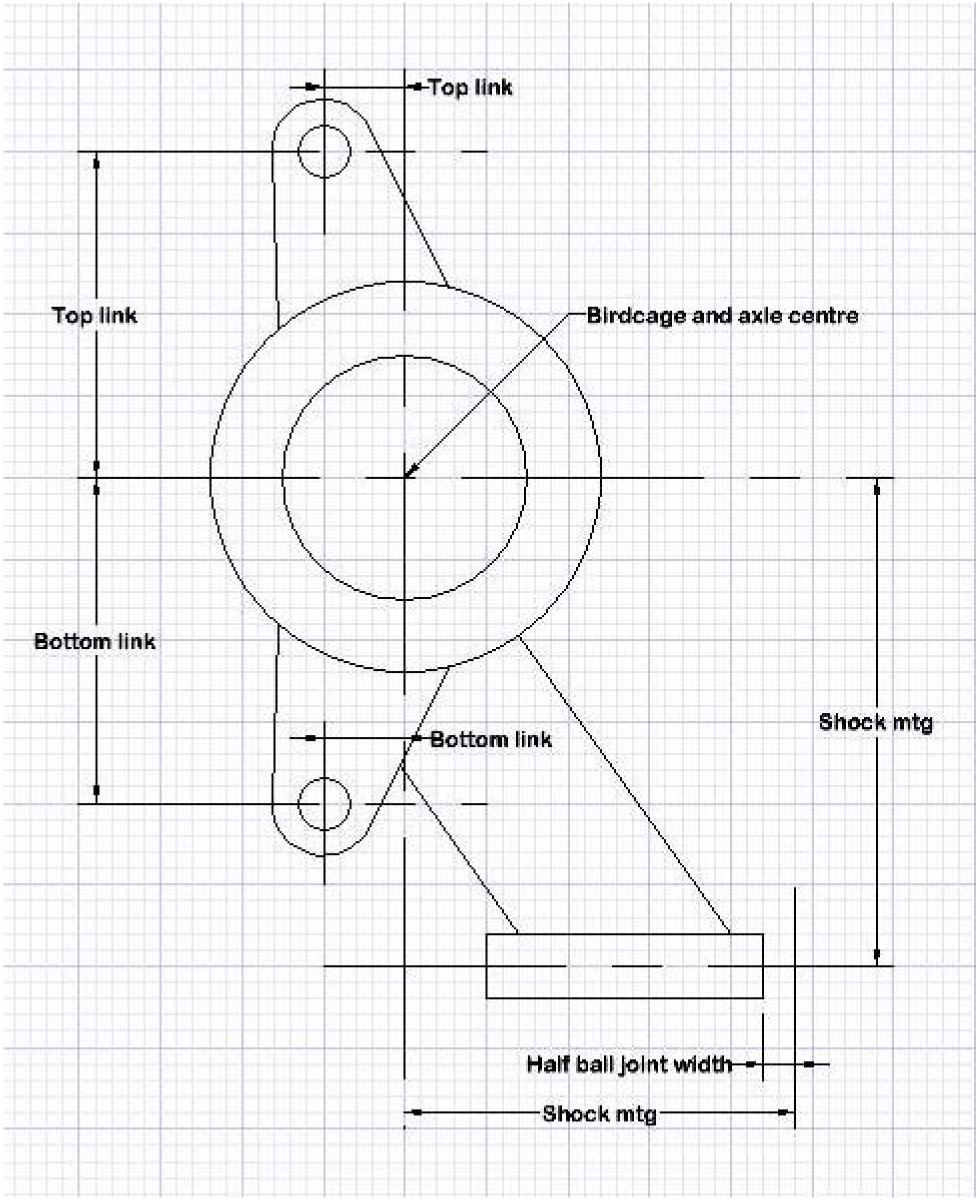
6.4.4.3 Birdcage

The typical birdcage is located on the axle, is axially restrained, but has radial freedom. It is used with a pair (the upper and lower links) of trailing links.

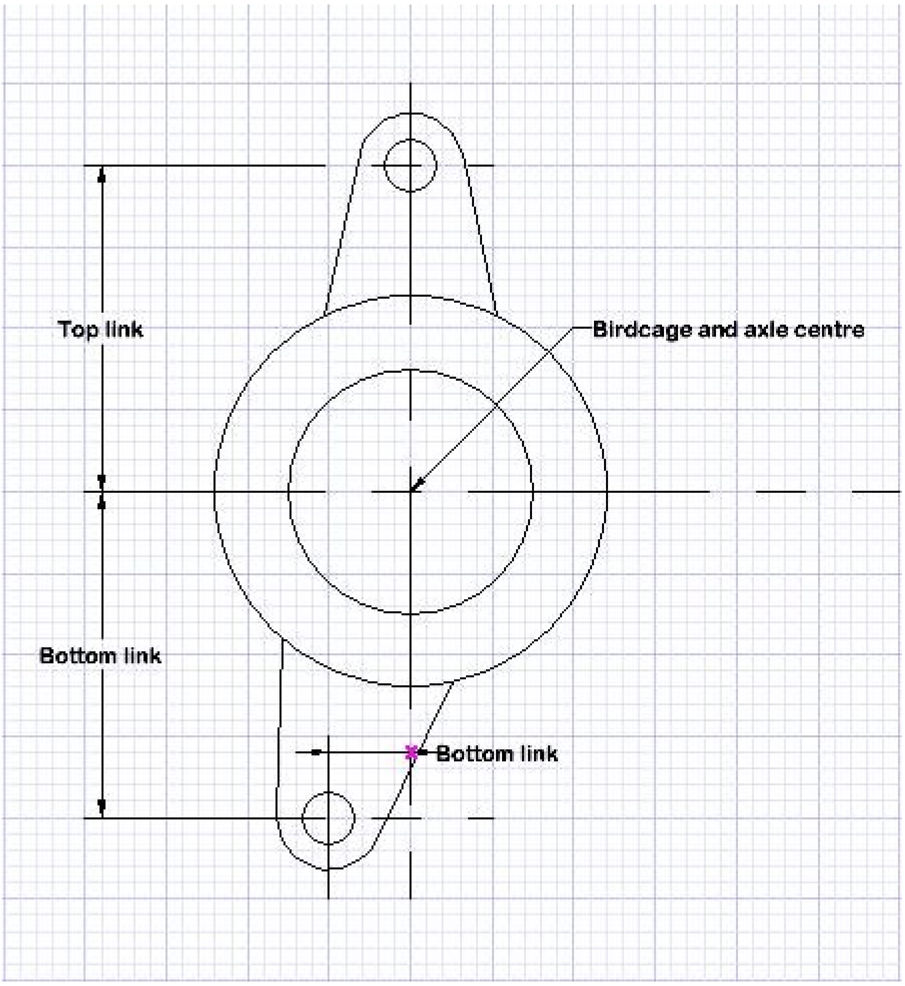
With a torque arm axle the usual configuration is with 4 trailing links (with each upper and lower pair connected to the birdcage) with a Panhard or Watts linkage (connected to the axle) providing lateral location. The torque arm locates the axle and take the torque reaction.

With a four link live axle, one pair of links is attached to brackets on the axle and the other pair of links is attached to the birdcage. This allows the axle to rotate in bump and droop and removes any twisting of the axle. Lateral location is provided by a Panhard or Watts linkage (connected to the axle).

If the birdcage includes the shock mount, then measure it with the shock mount horizontal.



If the birdcage has only the upper and lower trailing link mounts, then measure it with the upper link mount on the vertical axis through the bearing centre.



The lateral dimensions (width) for all points are measured from the axle centre.

6.4.4.4 Static alignment

Enter the longitudinal datum to axle centreline. This is the distance that the centre of the axle (as defined above) is from the longitudinal datum.
This value can be entered in Vehicle Datum, and Geometry Alignment

The pinion angle is specified relative to the ground plane. If the vertical axis is positive upwards, then a positive angle is “pinion nose up” and a negative angle is “pinion nose down”; if the vertical axis is positive downwards, then a positive angle is “pinion nose down” and a negative angle is “ pinion nose up”.
Most production cars run 3 or 4 degrees of pinion nose down, as this helps to dampen the prop shaft oscillations.

The axle offset is the sideways offset of the axle in the static position. The centre of the axle is the mid point between the LH and RH wheel reference points (either the wheel centres on ground, or the wheel centres at hub height). The offset is the distance this “axle mid point” is from the lateral datum. For most vehicles it will be zero.

The wheel lead is the distance that one wheel is “ahead” (in a longitudinal sense) of the other. For most vehicles it will be zero.
The individual wheel longitudinal positions can also be entered in Geometry Alignment.

6.4.4.5 Graphic

After entering the required dimensional data, click on the “Graphic” tab. This will display an isometric front view representation of the axle.

It will show the axle housing centreline and the two hubs, the axle pinion, the link brackets, and the steering arms and king pin axis as appropriate.

It is intended that this graphic will provide a basic visual confirmation that all the elements are in the expected position and orientation.

If you “click” on a pivot point, a hint will show with the identification of that point.

6.4.5 Axle (speedway)

This is the speedway style axle assembly.
The wheels or hubs are splined to the axle and both the centre section and the locating links rotate on the axle.
Winters and Halibrand are examples.

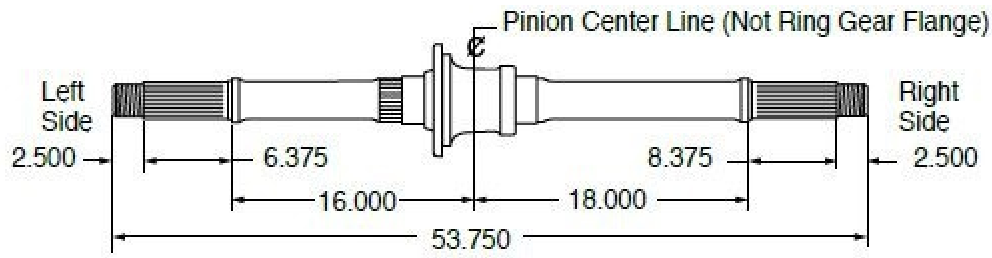
There are three sets of axle dimensions

- Axle and centre
- Mounting brackets
- Static alignment.

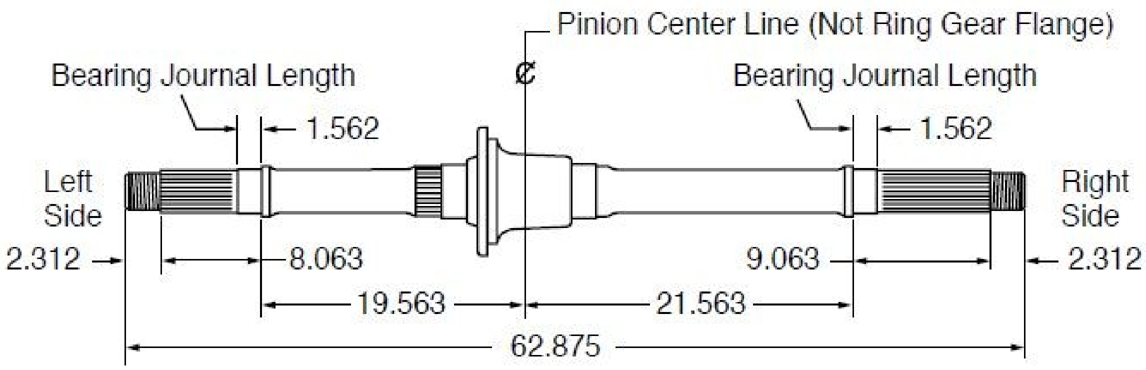
Plus

- Graphic

6.4.5.1 Axle and centre section



Winters 44-1 Midget axle



Winters 52-1 Sprint axle

Axle shaft length is the distance from the pinion centreline to the axle flange.

Axle hub length is the distance from the axle flange to the end of the axle splines.

Axle thread length is the length of the wheel nut thread.

The overall length is the sum of the above, and should match the overall length of the axle.

Gear centre is the distance between the pinion and coupler shaft. Typically 3" (76.20mm).

Coupler is the length, in side view, from the axle centreline to the centre of the spline in the coupler. It is not the length of the coupler shaft.

Torque tube length is the length, in side view, from the axle centreline, to the centre of the torque tube ball joint. Usually there is some provision for torque tube slip so this measurement should be the nominal length.

Note that for this release the axle centreline is the midpoint between the axle splined ends. For the 44-1 axle the axle centreline is 2" to the right from the pinion centreline.

This will be changed in the next release and the pinion centre will be used as the axle centre.

Also, for the wheels, for this release the wheel spacer thickness equals the width of the spacers between the axle flange and the birdcage plus the width of the birdcage bearing plus the total width any spacers outboard from the birdcage.

This will be changed in the next release and the wheel spacer thickness will only be the width of any spacers outboard from the birdcage.

6.4.5.2 Mounting brackets

Longitudinal links that attach to the chassis in front of the axle are trailing links; longitudinal links that attach to the chassis behind the axle are leading links. But all links are referred to as trailing links.

All links, including the Jacobs ladder, are "fixed" to the axle via birdcages. Measure the birdcage link points with the birdcage in the vertical position.

Enter the lateral, vertical and longitudinal values for the longitudinal link axle pivot points, LH top, LH bottom, RH top, RH bottom.

Enter the lateral, vertical and longitudinal values for the Jacobs ladder birdcage mounting point.

The lateral values for RH and LH points are both positive and are measured from the axle centreline outwards.

Note that this release uses the axle centreline (not the pinion centreline) as the datum for the lateral values. For the typical speedway axle this means that the axle centre is offset from the pinion centre.

This will be changed in the next release and all lateral dimensions will be referenced from the pinion centre.

For all points, vertical values are measured vertically from the axle housing centreline, and longitudinal values horizontally from the axle housing centreline. If the vertical axis is positive upwards, a positive value for the pivot point means it is above the axle centreline, a negative value for the pivot point means it is below the axle centreline; if the vertical axis is positive downwards, a negative value for the pivot point means it is above the axle centreline, a positive value for the pivot point means it is below the axle centreline. If the longitudinal axis is positive rearward, a positive value means the pivot point is to the rear, a negative value means the pivot point is to the front; if the longitudinal axis is positive forward, a negative value means the pivot point is to the rear, a positive value means the pivot point is to the front.

6.4.5.3 Static alignment

The static alignment will be calculated.

The axle offset is the sideways offset of the axle in the static position. The centre of the axle is the mid point between the LH and RH wheel reference points (either the wheel centres on ground, or the wheel centres at hub height). The offset is the distance this “axle mid point” is from the lateral datum. For most vehicles it will be zero.

Note that this release uses the axle centreline (not the pinion centreline) to determine axle offset.

This will be changed in the next release and the axle offset will be referenced to the pinion centre.

The longitudinal datum to axle centreline is the distance that the centre of the axle (as defined above) is from the longitudinal datum.

If the Wheel location and alignment option is "Torque tube axle" then this value is derived from the position of the torque tube ball joint housing on the chassis, and the length of the torque tube. Together these determine the position of the axle. Note that this option will always position the torque tube ball exactly at the chassis torque tube ball joint housing with zero alignment error.

If the Wheel location and alignment option is "All top and bottom links + Jacobs ladder" then this value is derived from the lengths of the longitudinal links. Together with the Jacobs ladder dimensions, these will determine the position of the axle. Note that this may result in a torque tube alignment error.

The wheel lead is the distance that one wheel is “ahead” (in a longitudinal sense) of the other. For most vehicles it will be zero.
The individual wheel longitudinal positions can also be entered in Geometry Alignment.

6.4.6 Stub axle

Stub axle coordinates are vehicle independent and are represented with lateral, vertical and longitudinal values. The datums for the upright are the wheel mounting flange and the stub axle centreline.

Again, imagine the stub axle viewed from the front of the vehicle. Lateral values are axial dimensions (along the axle or spindle) from the wheel mounting flange, vertical and longitudinal values are radial dimensions from the stub axle centreline.

All stub axle measurements are measured with the stub axle at zero camber, castor and toe position.

The lateral dimension of points inboard of the wheel mounting flange are always positive, regardless of the direction of the positive lateral axis.

For the usual design of the stub axle, the top pivot point(s) is above the axle centreline, and the bottom pivot point(s) is below the axle centreline. If the vertical axis is positive upward, then the top pivot vertical dimension will be positive and the bottom pivot vertical dimension will be negative; if the vertical axis is positive downward, then the top pivot vertical dimension will be negative and the bottom pivot vertical dimension will be positive.

Longitudinal values are measured radially from the stub axle centreline in side view, and will be positive to the rear, negative to the front (if the longitudinal axis is specified as +ve rear); or will be positive to the front, negative to the rear (if the longitudinal axis is specified as +ve front).

If you have been provided with stub axle mounting points in vehicle coordinates, use the CMMtoUpright tool to convert back to stub axle coordinates.

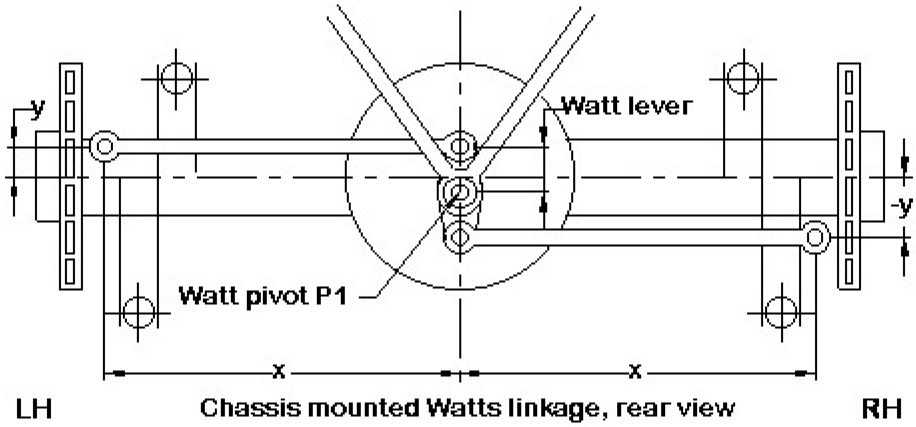
Enter the required values for the stub axle top and bottom pivot points.

For the early models, the reference points are the centre of the top and bottom ends of the kingpin. For the later models, the reference points are the centre of the top and bottom ball joints.

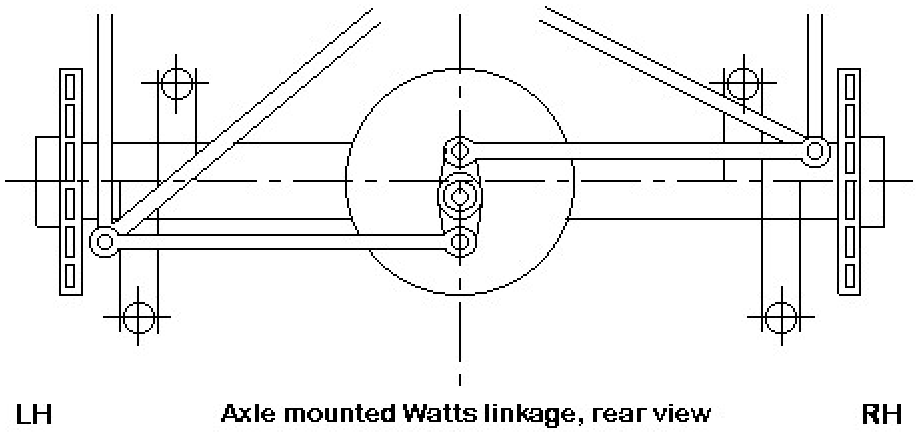
6.5 Watts

From the Geometry tab, select Watts

Specify the length of the Watts lever from the pivot point to the rod mounting point.



Chassis mounted Watts linkage, rear view



Axle mounted Watts linkage, rear view

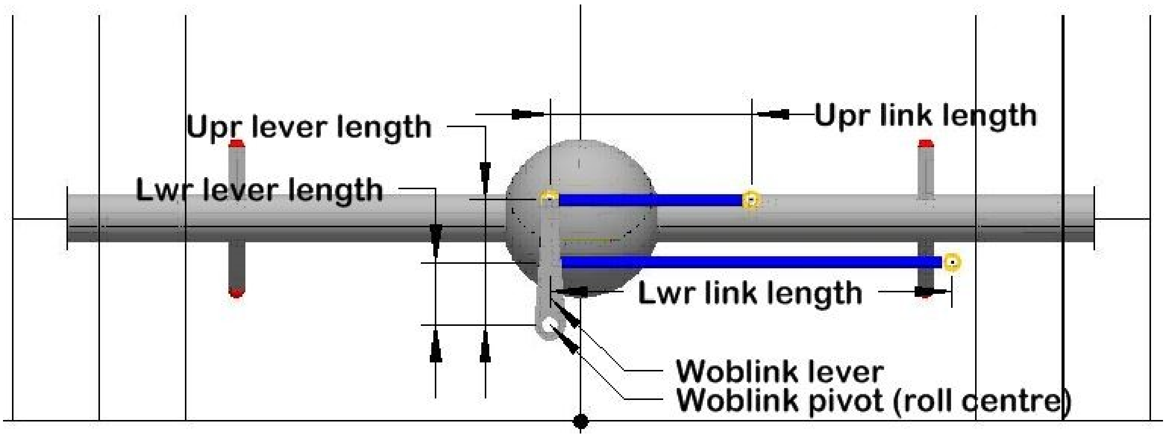
SusProg3D currently only supports a symmetrical Watts linkage. The pivot point must be on the axle or vehicle centreline, the lengths of the upper and lower Watts lever must be the same, and the lengths of the horizontal links must be the same.

6.6 Woblink

From the Geometry tab, select Woblink

Specify the length of the Woblink lever from the pivot point to the upper and the lower link mounting points.

If the Geometry Config is specified as "All top and bottom links + Woblink" then the upper and lower link lengths must be specified in Geometry -> Links. For all other Geometry Config options the link lengths will be calculated.



6.7 Mumford

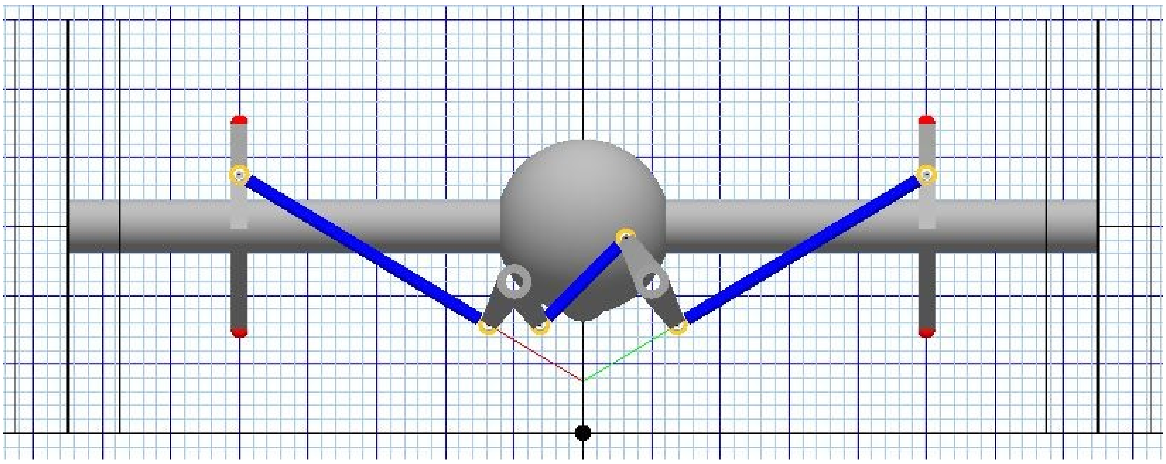
From the geometry tab, select Mumford

SusProg3D currently only supports a symmetrical chassis mounted Mumford linkage.

The roll centre is determined by the two lateral links, and the position of the link points is a combination of the link and lever lengths; and this requires that the lateral link lengths, Mumford chassis pivot points, and bellcrank and lever dimensions must be specified or calculated. The Mumford intermediate link length is always calculated.

If the instant centre location is specified as “Suspension link chassis mounting points” then the Mumford lever length and bellcrank angle must be specified.
The same dimension will be used for all bellcrank and lever arms.
The bellcrank angle must be between 0 and 180, and is typically between 60 and 120 degrees.

If the instant centre location is specified as “Roll centre height”, then all three link lengths, the bellcrank angle, and the bellcrank and lever lengths will be calculated to achieve the specified roll centre.
The lateral link lengths and the bellcrank and lever lengths will be calculated such that the levers are 90 degrees to the links; and the bellcrank angle will be calculated such that the bellcrank intermediate link arm is parallel to the lever.



6.8 Jacobs ladder

The Jacobs ladder consists of a triangular body section, and a pair of straps.

The apex of the body connects to the axle, and the straps connect the ladder to the chassis.

The instant centre is the intersection of the line of the straps, the roll centre is where the line connecting the apex of the ladder and the instant centre crosses the vehicle centreline.

The equivalent length Panhard rod is not the distance from the instant centre to the ladder apex, but the locus of the path described by the ladder apex.
In fact, a well designed Jacobs ladder will closely approximate a Roberts linkage, an early form of straight line motion linkage.
With a well designed Jacobs ladder the equivalent Panhard rod length would be at least twice the track.

For an ideal linkage the ladder sides and straps should be the same length as the distance between the the two link chassis mounts, and the ladder base length half the distance between the the two link chassis mounts.

If the Geometry calculation option is "Torque tube axle", the Jacobs ladder dimensions will be calculated using the distance between the strap chassis mounts, making the strap lengths and ladder base length half that distance, and the ladder sides calculated so that the ladder will connect to the axle birdcage.

Roberts linkage is named after Richard Roberts (1789–1864)
https://en.wikipedia.org/wiki/Roberts_Mechanism

6.9 Instant Centres

From the Geometry tab, select ICs to specify or check the roll centre, swing axle length, side view instant centre and swing axle dimensions.

Depending on the geometry, there may be two alternative ways to specify the swing axle lengths and instant centres,

From the Geometry tab, select Configure and choose either ”Suspension link chassis mounting points” or “Swing axle lengths and roll/pitch centre heights”.

If the instant centre location is “Suspension link chassis mounting points”, then all the instant centre dimensions will be calculated.

Swing axle and roll centre (front view)

> The front view swing axle and roll centre is referenced in the front view plane of the axle.
>
> The swing axle length will usually be a positive value, generally in the range of 1 to 3 times the track.
> Note that a negative swing axle length means that the linkage instant centre is outboard on the same side of the vehicle, rather than the opposite side of the vehicle.
>
> The roll centre height is the intersection of the lines from each tyre contact centreline to the instant centre of the suspension linkages.
>
> The roll centre height can be positive (above ground), zero (on ground) or negative (below ground).
>
> If the roll centre offset is non-zero, then it is offset in the same direction as the positive lateral axis (ie if positive, it is offset in the same direction as the positive lateral axis; if negative it is offset in the same direction as the negative lateral axis).

Anti-dive / anti-squat (side view)

The Anti-dive / anti-squat instant centre and effective angle are referenced in the side view plane of the tyre.

Front axle: For a positive anti-dive effect, the intersection point will be behind the front axle and will be a positive dimension; for a negative (or pro-dive) effect, the intersection point will be ahead of the front axle and will be a negative dimension.

Rear axle: For a positive anti-squat effect, the intersection point will be ahead of the rear axle and will be a positive dimension; for a negative (or pro-squat) effect, the intersection point will be behind the rear axle and will be a negative dimension.

The instant centre height is the intersection of the lines from each tyre contact centreline to the instant centre of the suspension linkages.

The instant centre height can be positive (above ground), zero (on ground) or negative (below ground).

If the suspension linkages are parallel (in side view) there is no intersection point, but they can be angled to achieve the same result.

The swing axle and the side view instant centre apply to both sides of the vehicle, so there are LH and RH values.

If the vehicle is symmetrical, then only one side need be input, and the other side will be set to the same values. If the vehicle is not symmetrical, or the symmetrical checkbox is cleared, then values for both sides will need to be input.

6.9.1 Suspension link chassis mounting points

If the instant centre location is “Suspension link chassis mounting points”, then the instant centre dimensions will be calculated.

Swing axle and roll centre (front view)

The front view swing axle length is the distance (measured horizontally) from the tyre contact cl to the instant centre of the suspension linkages.

The roll centre height is the intersection of the lines from each tyre contact centreline to the instant centre of the suspension linkages.

The roll centre offset is the distance that the roll centre is offset from the vehicle centreline.

Anti-dive / anti-squat (side view)

Front axle: For a positive anti-dive effect, the intersection point will be behind the front axle and will be a positive dimension; for a negative (or pro-dive) effect, the intersection point will be ahead of the front axle and will be a negative dimension. If the linkages are parallel, and there is no intersection point, a positive angle is equivalent to a positive anti-dive effect.

Rear axle: For a positive anti-squat effect, the intersection point will be ahead of the rear axle and will be a positive dimension; for a negative (or pro-squat) effect, the intersection point will be behind the rear axle and will be a negative dimension. If the linkages are parallel, and there is no intersection point, a positive angle is equivalent to a positive anti-squat effect.

Geometry | Calculate will use the specified chassis dimensions to calculate the swing axle lengths and instant centres.

The swing axle and the side view instant centre apply to both sides of the vehicle, so there are LH and RH values.

6.9.2 Swing axle lengths and roll/pitch centre heights

If the instant centre location is “Swing axle lengths and roll/pitch centre heights”, then the instant centre dimensions must be entered.

The swing axle and the side view instant centre apply to both sides of the vehicle, so there are LH and RH values.

If the vehicle is symmetrical, then only one side need be input, and the other side will be set to the same values. If the vehicle is not symmetrical, or the symmetrical checkbox is cleared, then values for both sides will need to be input.

Swing axle and roll centre (front view)

- The front view swing axle length is the distance (measured horizontally) from the tyre contact cl to the instant centre of the suspension linkages.
  This dimension will be positive if the instant centre is inboard from the wheel centreline.
- The roll centre height is the intersection of the lines from each tyre contact centreline to the instant centre of the suspension linkages.
  This dimension will be positive if the roll centre is above ground.
- The roll centre offset is the distance that the roll centre is offset from the vehicle centreline.
  This dimension will be positive in the direction of the positive lateral axis.

The swing axle length will usually be a positive value, generally in the range of 1 to 3 times the track.
The roll centre height can be positive, zero or negative.

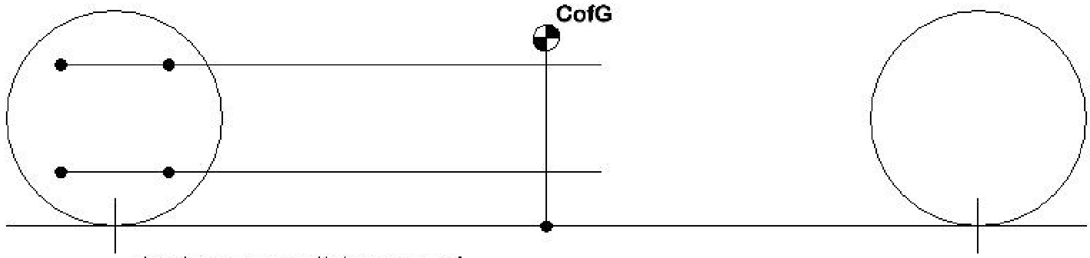
Anti-dive / anti-squat (side view)

Either

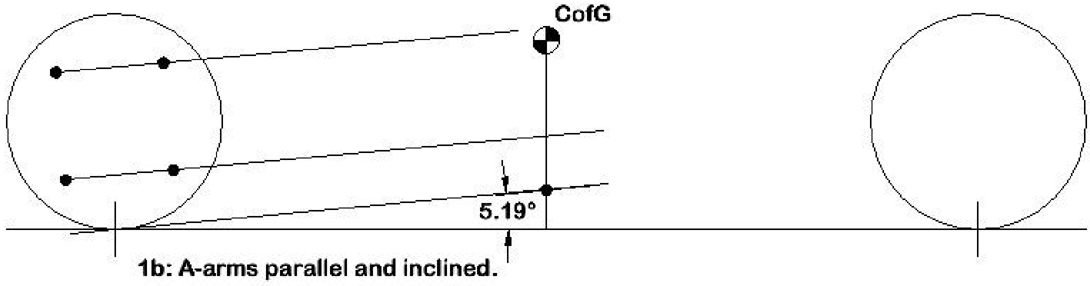
- Enter the side view swing axle length and instant centre height (which can be positive, zero or negative) and select the Height radio button,

or

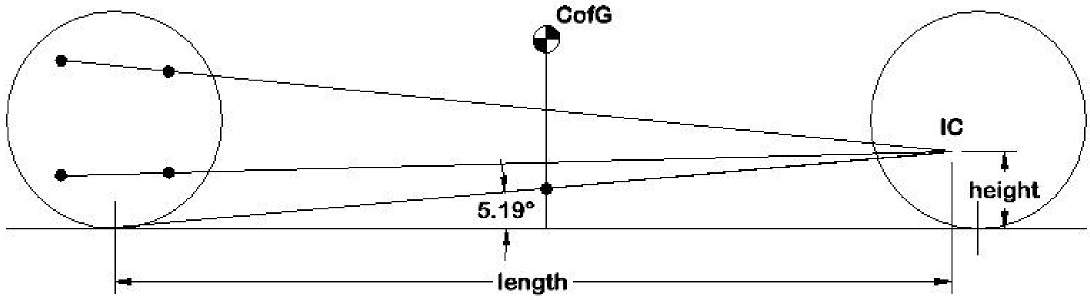
- Enter the side view swing axle length and anti-dive/squat angle and select the Angle radio button. If the angle is zero, then both wishbone pivot axis will be parallel to the ground (in side view).



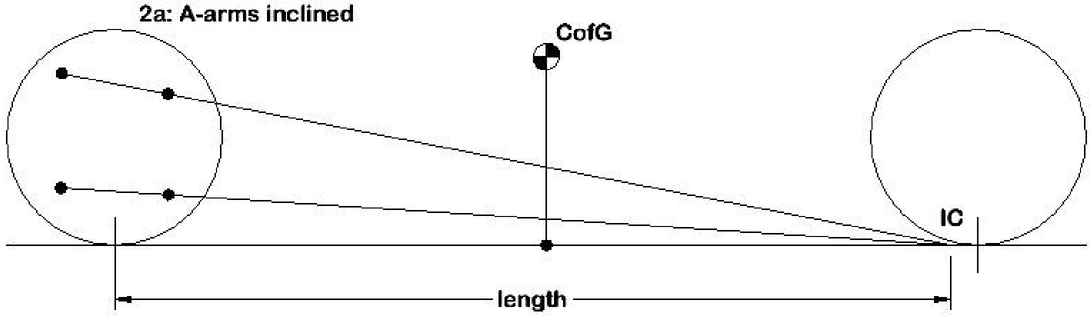
1a: A-arms parallel to ground.



1b: A-arms parallel and inclined.



2a: A-arms inclined



2b: A-arms inclined

Option 1a	A-arms parallel to the ground with the side view instant centre on the ground. No anti-dive. Specify the length, height and angle all zero. "Calculate using" not used.
Option 1b	Upper and lower A-arms parallel, and inclined with respect to the ground. Specify the angle, with both length and height zero. :Calculate using" angle.
Option 2a	A-arms inclined with respect to each other. Specify either - the length, angle and "Calculate using" angle, or - the length, height and "Calculate using" height.
Option 2b	A-arms inclined with respect to each other with the side view instant centre on the ground. No anti-dive. Specify the length, and both height and angle zero. "Calculate using" not used.

The diagrams illustrate typical front suspension layouts where the side view swing arm instant centre is around the rear axle. As drawn, length, height and angle are all positive. If the IC is below ground then the height and angle will be negative.

For the rear suspension, where the side view swing arm intersection point is typically around the front axle. In this case length is considered positive if the IC is forward of the rear axle, height and angle are both positive if the IC is above ground.

Geometry | Calculate will use the specified dimensions to calculate the front & rear wishbone chassis pivot vertical values, maintaining the specified lateral and longitudinal values (as entered in Geometry | Chassis).

Note that the calculated chassis pivot point coordinates will be rounded to the appropriate number of decimal places. Because of this, when the calculation is done using the chassis pivot points, the calculated swing axle dimensions may differ slightly from those originally specified.

6.9.3 Swing axle lengths and roll/pitch centre heights - Strut

The geometry instant centres and swing arm lengths are defined by the intersection of two planes. The strut rod slider axis and the chassis top mounting point together define one of the planes, and the three pivot points of the bottom links define the other. The two instant centres are the roll centre (in front view) and the pitch centre (in side view).

The front view instant centre, roll centre and swing arm length are calculated from the strut slider axis and the linkage pivot points, in the plane of the axle.

The side view instant centre and swing arm length are calculated from the strut slider axis and the linkage pivot points, in the plane of the wheel.

From the Geometry tab, select Configure and choose either ”Suspension link chassis mounting points” or “Swing axle lengths and roll/pitch centre heights”.

The strut rod slider axis and the chassis top mounting point together define one of the projection planes which determine the instant centre locations. If the anti-squat is specified as “Strut” then the anti-squat will be calculated from the strut rod inclination and a horizontal bottom wishbone.

If the instant centre location is determined by “Suspension link chassis mounting points” then the instant centres will be calculated. All required chassis mounting point lateral, vertical and longitudinal dimensions must be specified. The instant centre values shown in Geometry | ICs will all be “read only”.

If the instant centre location is determined by “Swing axle lengths and roll/pitch centre heights” then the bottom wishbone chassis mounting lateral and longitudinal dimensions must be specified, and the appropriate instant centre and swing arm length dimensions must be specified in Geometry | ICs

- either the front view swing axle length or roll centre height can be specified (but not both), and
- either the side view swing axle length or the side view instant centre height or the anti angle can be specified (but not more than one of them).

This option will calculate the bottom wishbone chassis mounting vertical dimensions.

6.10 Link lengths

From the Geometry tab, select Link Lengths.

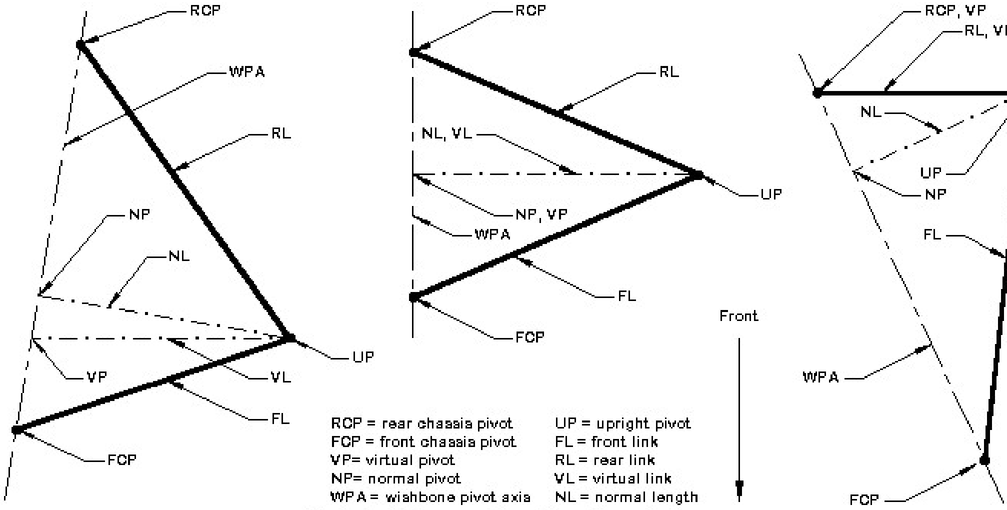
All link lengths are measured between the two pivot points. There is no allowance made for any offsets in the link, or for A-arms where the links do not joint at the apex.

6.10.1 Link lengths

A-arms have five dimensions.

The front and rear link lengths are the actual link pivot to pivot lengths, as is the base length. The normal length is a calculated length.

The normal length is the distance from the normal point to the apex. The normal point is the point on the A-arm pivot axis where a line drawn from the apex to the pivot axis intersects at 90 degrees.



Typical wishbone configurations (plan view)

The normal lengths will always be calculated. Depending on the geometry configuration, the front and rear links lengths will also be calculated.

Semi-trailing arm link lengths are measured the same as an A-arm, except that the apex is on the axle at the wheel mounting face, and length dimensions are taken from that point. There is no option to specify link lengths, they will be calculated.

The chosen geometry configuration option will determine if any of the link lengths can be altered.

For the rear suspension, it is important that the links and pivot points that control the basic upright location and the upright toe control are correctly identified, especially as in some designs a single chassis pivot point has several functions.

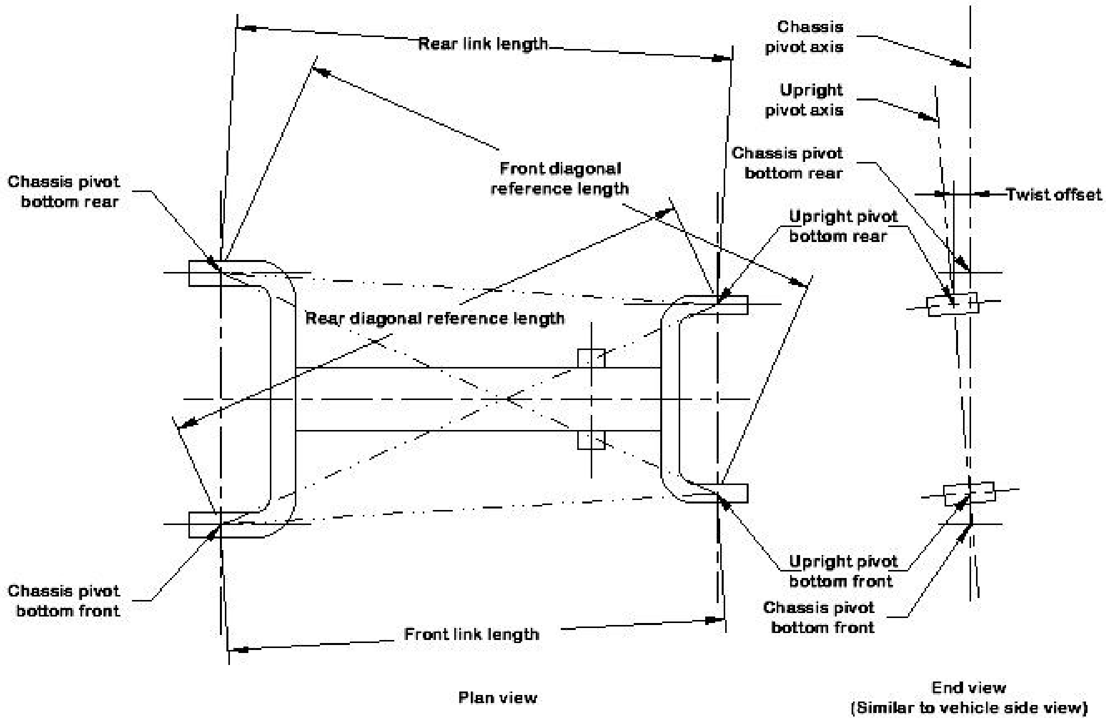
6.10.2 Ford Twin I-Beam

Note that the I-Beam and radius rod lengths are not the actual lengths of those items. They are the lengths as measured from the centre of the stub axle ball joints (or from the ends of the kingpin) to the centre of the appropriate chassis mounting bush.

6.10.3 Volkswagen twin trailing links

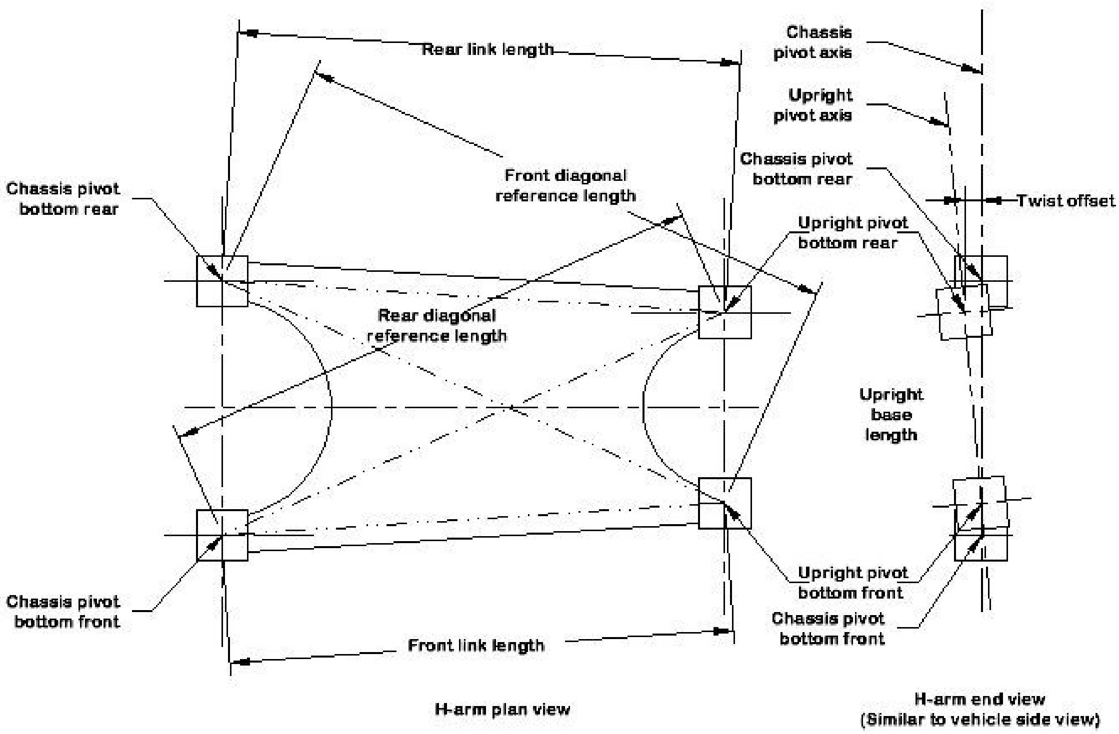
Enter topic text here.

6.10.4 Control arm (Jaguar)



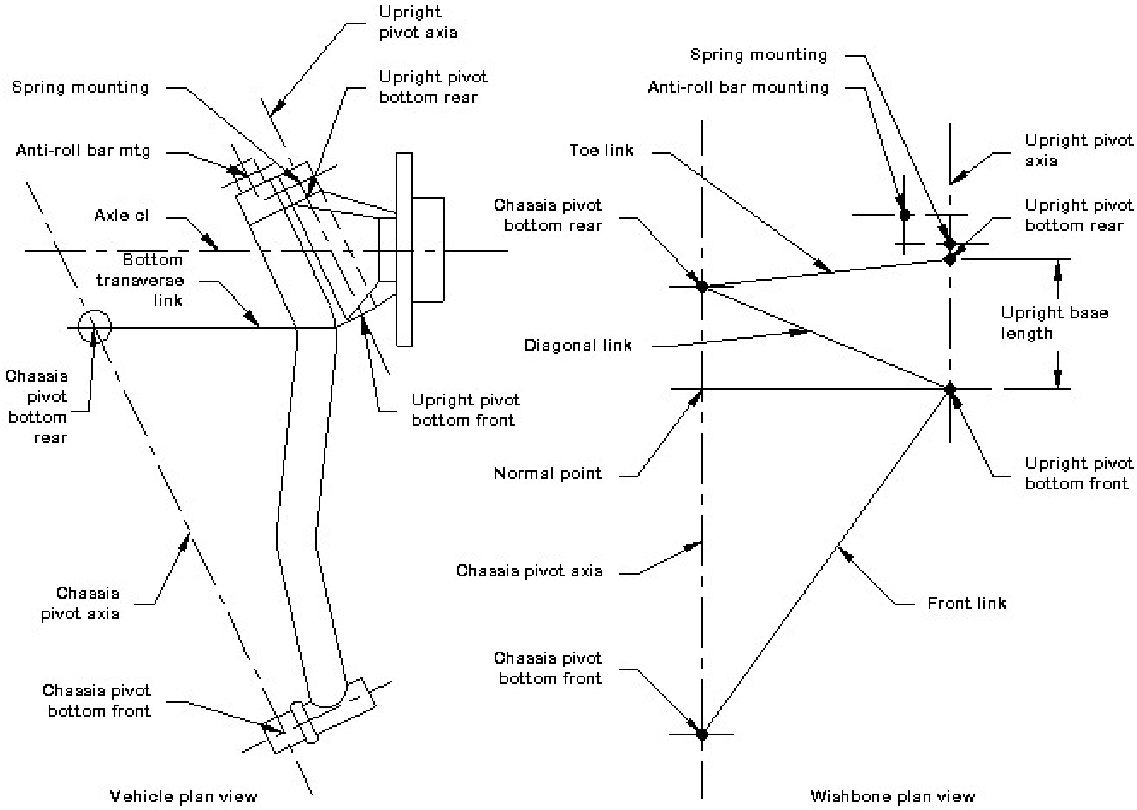
Jaguar rear control arm

6.10.5 Control arm (H arm)



Typical H-Arm control arm

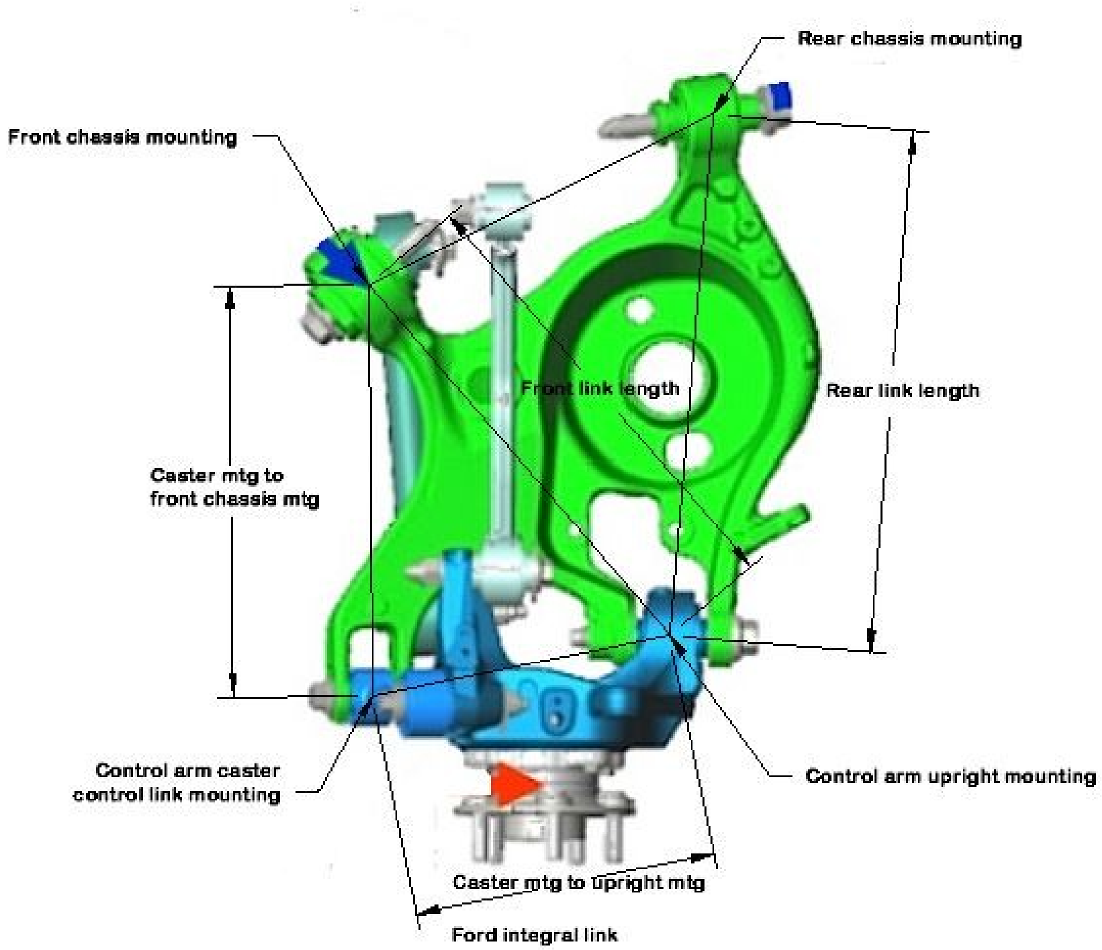
6.10.6 Control arm (Porsche 928)



Porsche 928 rear bottom wishbone

6.10.7 Control arm (Ford Integral Link)

For the bottom control arm, the front link length is the length from the front chassis pivot to the upright pivot, and the rear link length is the length from the rear chassis pivot to the upright pivot. The caster control mounting is dimensioned from the front chassis mounting, and from the upright mounting.The control arm plane is defined by the two chassis pivot points and the single upright pivot point. If the control arm caster control link pivot is not in the plane of the control arm, then there will be a twist offset.



6.11 Track

6.11.1 Independent suspensions

From the Geometry tab, select Track.

If the wheel location point is specified as “Wheel centre / axle” then the track will be shown with two sets of dimensions, one will be the “on ground” dimension and the other will be the “Wheel centre / axle” dimension.

If the wheel location point is specified as “On ground” then the track is measured on the ground between the tyre contact patch centrelines with the specified camber, castor and toe.

If the wheel location point is specified as “Wheel centre / axle” then the track is measured between then wheel centres at hub height, with the specified camber, castor and toe.

The axle offset is the lateral distance from the vehicle centreline to the centre of the track.

NASCAR specify that track is measured at hub height at the tyre centre (width) with the wheels in the straight ahead position.
For example, if both wheels have negative camber, then the NASCAR track will be narrower than the “on ground” track measurement.
In practice, it is the average of two measurements, one at the front of the tyre and the other at the rear of the tyre, across the outside of the tyre tread minus the tread width, taken at hub height.

This is "display only" and will be calculated from the specified wishbone link lengths, or the specified half track.

6.11.2 Live axle/deDion

From the Geometry tab, select Track.

If the wheel location point is specified as “Wheel centre / axle” then the track will be shown with two sets of dimensions, one will be the “on ground” dimension and the other will be the “Wheel centre / axle” dimension.

If the wheel location point is specified as “On ground” then the track is measured on the ground between the tyre contact patch centrelines with the specified camber, castor and toe.

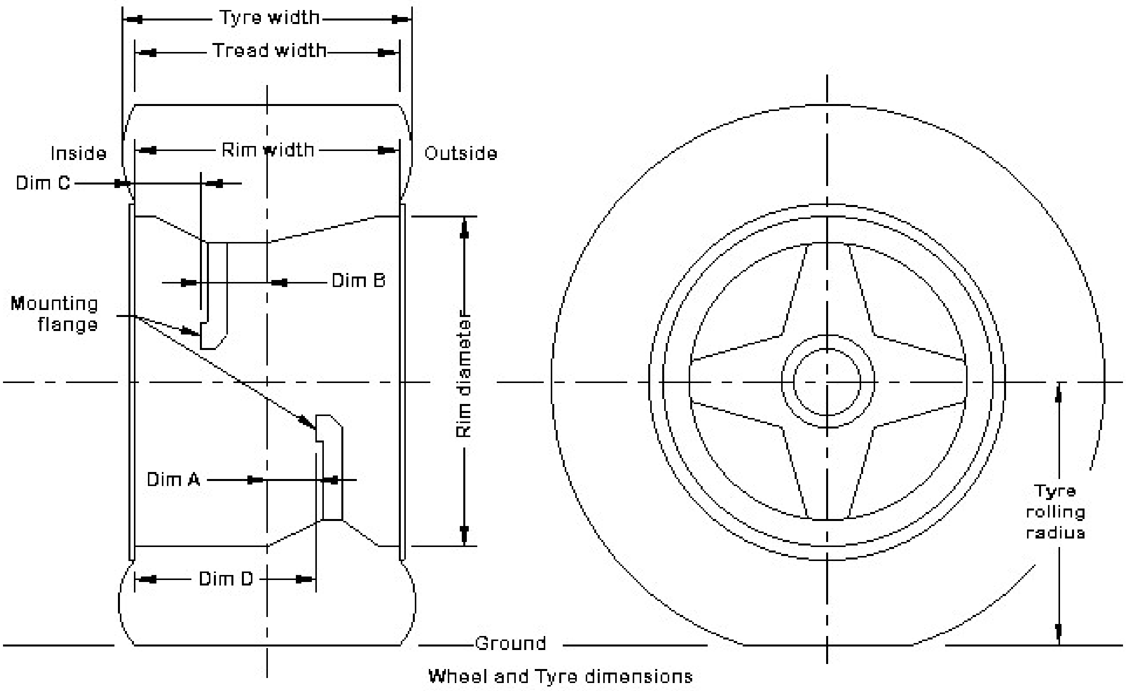
If the wheel location point is specified as “Wheel centre / axle” then the track is measured between then wheel centres at hub height, with the specified camber, castor and toe.

The axle offset is the lateral distance from the vehicle centreline to the centre of the track.

NASCAR specify that track is measured at hub height at the tyre centre (width) with the wheels in the straight ahead position.
For example, if both wheels have negative camber, then the NASCAR track will be narrower than the “on ground” track measurement.
In practice, it is the average of two measurements, one at the front of the tyre and the other at the rear of the tyre, across the outside of the tyre tread minus the tread width, taken at hub height.

This is "display only" and will be calculated from the specified axle dimensions and alignment, wheel sizes and alignment settings.

6.12 Wheel and tyre



Wheel and Tyre dimensions

From the Geometry tab, select Wheel.

The data shown will be for the wheel referenced in the dialog title. This is the car end and car side currently specified. When you “Apply” or “OK”, and the “Symmetric” box is ticked, then both wheel and tyres (for that car end) will be set to the values specified. When you “Apply” or “OK”, and the “ Symmetric” box is not ticked, then only the wheel referenced in the dialog title will be set to the values specified.

Generally production vehicles will have all four wheels the same. Even if there are variations, it may still be more convenient to initially specify all wheels identically, then update the individual

wheel(s) that differs.
See Vehicle | All Wheels.

The following dimensions relate to the wheel

- the wheel diameter.
- the rim width.
- the mounting offset. Note that this dimension is measured relative to the wheel centreline, and is negative if the hub mounting surface is offset towards the outside of the vehicle, typical of front wheel drive vehicles.

The following dimensions relate to the tyre

- tyre tread width
- tyre section width (ie the overall width of the tyre across the sidewalls)
- the rolling radius. This is usually somewhat less than half the diameter due to the loaded deflection of the tyre.
- the diameter. This is the overall diameter of the inflated tyre. It will always be greater than twice the rolling radius.
- The tyre spring rate. Enter the rate in either N/mm or lb/in using the related input box.

The following dimensions relate to the wheel and / or tyre

- the toe reference length. This is the distance over which the toe in or toe out is measured. If the toe reference length is left at zero, it will default to the wheel diameter.

The following dimension relates to the fitting of the wheel onto the hub

- spacer thickness.

If Designer is in metric mode, then the edit boxes will display the metric dimensions, and additional inch dimensions will be shown. Dimensions can be entered in either mm or inches. Specify which by selecting the appropriate button. Wheel and tyre sizes are traditionally measured in inches, and this saves converting to mm.

If Designer is in imperial mode, then only inch dimensions will be shown and can be entered.

For the Geometry calculations only the tyre deflected radius (ie the rolling radius), toe reference length and wheel offset are needed. All other dimensions can remain at zero.

For the Spring calculations the tyre rate is needed.

For the Dynamic calculations both the tyre deflected radius and the tyre rate are needed.

Note that if the tyre rate is zero, then this is assumed to be an "infinitely stiff" tyre with no deflection under load.

All other values are for information only, are not used by SusProg3D calculations and can remain at zero. There is space for a 79-character comment (for example, the tyre make and size).

For the wheel and tyre to display correctly, all dimensions should be input.

6.13 Wheel alignment

From the Geometry tab, select Alignment.

6.13.1 Wheel alignment

Depending on the chosen Geometry calculation configuration, some wheel alignment settings will be determined by the geometry and will be calculated.

Enter the required static wheel camber and castor, both in degrees.

Enter the required static wheel toe, in degrees, mm or inches (as appropriate).
Toe-in is always positive; toe-out is always negative.
If the toe is non-zero and is either mm or inches, the toe reference length must also be specified. This is usually the rim diameter. Some laser wheel alignment equipment defaults to 1000mm for the reference length.

If required, enter distance from the vehicle centreline (ie the lateral datum), horizontally, to the wheel location point.
If the wheel location point is “On ground”, then this is measured horizontally on the ground datum from the tyre contact patch centreline to the vertical plane of the lateral datum with the wheel at the specified camber, castor and toe.
If the wheel location point is “Wheel centre /axle”, then this is measured horizontally from the wheel centre on the axle (or spindle) to the vertical plane of the lateral datum with the wheel at the specified camber, castor and toe.
For symmetrical vehicles, with the lateral datum on the vehicle centreline, this will be half the actual track dimension.
For asymmetric vehicles (where the axle is “offset” to one side) then the LH and RH dimensions will be different.
This dimension is always positive.

If required, enter distance from the longitudinal datum reference point, horizontally, to the wheel location point.
If the wheel location point is “On ground”, then this is measured horizontally on the ground datum from the tyre contact patch centreline to the vertical plane of the longitudinal datum reference point with the wheel at the specified camber, castor and toe. If there is zero toe, then this is the same as the actual axle centreline to longitudinal datum.
If the wheel location point is “Wheel centre /axle”, then this is measured horizontally from the wheel centre on the axle (or spindle) to the vertical plane of the longitudinal datum reference point with the wheel at the specified camber, castor and toe. If there is zero toe, then this is the same as the actual axle centreline to longitudinal datum.
For asymmetric vehicles (where the axle is “offset” to one side) then the LH and RH dimensions will be different.

If incorporated in the upright design, the wheel camber can also be adjusted by means of an “ upright camber shim”.

After the Geometry | Calculation, the upright pivot inclination (kingpin axis inclination or steering axis inclination), scrub radius and trail will be shown.

The scrub radius is the distance in front view between the king pin axis and the center of the contact patch of the wheel, where both would theoretically touch the road.

The kingpin axis is the line between the upper and lower ball joints of the hub. On a MacPherson strut, the top pivot point is the strut bearing, and the bottom point is the lower ball joint. The inclination of the steering axis is measured as the angle between the steering axis and a vertical line from center contact area of the tire.

6.13.2 Jaguar IRS/H-arm + camber link/Porsche 928

For the typical Jaguar and H-arm IRS where the chassis pivot points are parallel to both the ground (in side view) and the vehicle centreline (in plan view), and there is no “twist” in the bottom wishbone itself (that is, the chassis pivot axis and upright pivot axis are coincident in side view, and the vertical offset is 0.0) then set both caster and toe to zero and specify a configuration option that does not require that the bottom link offset be specified.

6.13.3 Semi-trailing arm

Enter the camber and toe values.

Any value entered for castor will be ignored, and changed to zero.

In the bump and droop display the value of castor is indicative of the angular movement of the semi-trailing arm in side view.

6.13.4 Mono wheel - trailing arm

Enter the camber and toe values.

Any value entered for castor will be ignored, and changed to zero.

In the bump and droop display the value of castor is indicative of the angular movement of the semi-trailing arm in side view.

Camber and toe are typically zero.

Track is always zero, but it is possible to have a small centreline offset.

6.13.5 Trailing arm, upper and lower lateral links

Enter the camber, inclination and toe values.

In the bump and droop display the value of inclination is indicative of the angular movement of the trailing arm in side view.

6.13.6 Live axle/deDion

For the front axle

- The wheel alignment camber, caster and KPI settings are calculated from the axle configuration (by adjusting the hub camber, caster and KPI settings) and the axle location (as determined by the locating links).
- The wheel alignment toe setting can be specified.
- In the bump and droop results the value of “pinion” is indicative of the angular movement of the axle in side view, and “caster” is the actual wheel alignment caster.

For the rear axle

- The wheel alignment settings are calculated from the axle configuration (by adjusting the hub camber and toe settings) and the axle location (as determined by the locating links).
- In the bump and droop results the value of “pinion” is indicative of the angular movement of the axle in side view.

6.14 Turn

For the front suspension only, and if the Geometry | Configuration option includes “+ Turn”.

From the Geometry tab, select Turn.

Enter the vehicle turn direction, the initial wheel alignment toe setting, and the enter the required turn angle, in degrees. This is the angle through which the outer wheel is turned, from the initial toe setting position. The turn angle of the inner wheel will be determined by the steering geometry. The initial wheel alignment toe setting is that for the “straight ahead” position, on the outside wheel.

After doing calculations with a turn angle specified, all the static alignment settings will be those with the wheels now turned to the specified angle. This will mean that, for example, the static toe setting will now include the turn angle.

This is the main reason that the initial wheel alignment is now required, as this will enable subsequent calculations to always start from the “straight ahead” wheel alignment.

The turn direction and the roll direction are now decoupled. This makes it possible to see the effect of steering in the opposite direction. For example, an understeering car in a left hand turn will be rolling onto the right side, and will also have the wheels steered left. But an oversteering car in the same left hand turn, while rolling onto the right hand side, will have the wheels steered to the right.

6.15 Travel limits

From the Geometry tab, select Travel.

Enter the appropriate values. Note that both values are positive.

If the specified bump and droop is greater than is geometrically possible, an error message will display and require the appropriate action. Generally a reduction in wheel travel increment will be required.

If the maximum and minimum wheel travel is set by specifying the open and closed shock absorber lengths (See Rates | Travel), then this will be noted here, and the maximum and minimum wheel travel values cannot be changed here. If you do need to set the maximum and minimum wheel travel values then go to Rates | Travel and set them there, ensuring that “Limit by wheel travel” is checked.

6.16 Calculate

From the Geometry tab, select Calculate.

After all required dimensions have been input, SusProg3D will calculate all other dimensions.

The status bar will display a message ‘Calculating...’ followed by either ‘OK’ or an error message.

On fast processors, the ‘Calculating...’ message may not remain long enough to be visible.

6.17 Display the results

If some of the results are needed, then the appropriate Dialog box can be opened. For example, if it is required to check the roll centre height because of using fixed chassis pivot points, then Geometry | ICs will open the Dialog box and display the calculated values. (Use Cancel to close the Dialog box if no input values are changed).

From the Geometry tab, select Result.

This will display a window with all the calculated suspension values. If it is needed to change a value, it is necessary to close the result window first.

If this menu choice is made without first doing the calculation the result will be blank. Note that if you change a value and then select result without redoing the calculation, the displayed results may be inconsistent. It's always safest to do a calculate before a result.

```
SusProg3D Designer 3.50.0.205 Wishbone:
Chassis Z Datum on Front axle centreline (tyre contact point)
Chassis pivot points - top    - from car cl       x    300.00    300.00
(actual front/rear)           - from ground       y    383.20    373.28
                              - from datum        z   -132.50    132.50
                     - bottom - from car cl       x    250.00    250.00
                              - from ground       y    165.84    165.85
                              - from datum        z   -132.50    132.50
Chassis pivot points - top    - from car cl       x    300.00    300.00
(virtual/normal)              - from ground       y    378.24    377.85
                              - from datum        z      0.00     10.62
                     - bottom - from car cl       x    250.00    250.00
                              - from ground       y    165.85    165.85
                              - from datum        z      0.00    -10.06
Upright pivot points - top    - from wheel flange x    150.00
```

```
(on upright)                    - from hub cl       y    120.00
                                - from axle cl      z      0.00
                       - bottom - from wheel flange x    100.00
                                - from hub cl       y   -120.00
                                - from axle cl      z      0.00
Upright pivot points - top      - from car cl       x    546.68
(from car datum)                - from ground       y    383.23
                                - from datum        z     10.82
                     - bottom   - from car cl       x    598.70
                                - from ground       y    144.57
                                - from datum        z    -10.06
Front view IC length (swing axle)                       3000.00
Front view IC height (swing axle)                        321.43
Roll centre height                                        75.00
Side view IC length                                     6634.78
Side view IC height                                      138.64
Anti-dive angle                                            1.20
Track (actual, with specified settings)                 1400.00
Top link length (virtual/normal)                         246.97    246.74
                (front/rear)                             285.29    275.24
Bottom link length (virtual/normal)                      349.50    349.35
                   (front/rear)                          370.19    377.32
Tyre contact cl from Z datum                               0.00
Tyre rolling radius                                      265.00
Wheel offset                                               0.00
Camber                                                    -0.50
Upright pivot inclination and offset             12.30    69.78
Castor angle and trail                            5.00    22.71
Wheel toe reference length                               330.00
Static toe in                                              1.00
```

6.18 ECalc

Allows several modules to be calculated from one point.

For example, if a chassis mounting point is changed, you can recalculate all modules with one click.

See ECalc

7 Roll and bump the chassis

Note that Geometry | Calculate must complete without error before this operation can be done.

7.1 Configure

Specify the bump and roll increments and the roll axis.

From the Roll Bump tab, select Configure, and then choose "Bump and droop increments", "Roll increments" and "Roll centre and axis".

Note that any changes to the bump and droop increments or limits; the roll increments or limits, will clear all calculated data and all calculations will need to be redone.

7.1.1 Bump and droop increments

Enter the wheel bump and droop maximum travel. Note that both values are positive.

If the maximum and minimum wheel travel is set by specifying the open and closed shock absorber lengths (See Rates | Travel), then this will be noted here, and the maximum and minimum wheel travel values cannot be changed here. If you do need to set the maximum and minimum wheel travel values then go to Rates | Travel and set them there, ensuring that “Limit by wheel travel” is checked.

The default values for maximum travel increment are 100mm (4.0") for both bump and droop.

Enter the wheel bump and droop increments. Note that both values are positive.

The default values for wheel travel increment are 20mm (0.75") for both bump and droop.

If the specified bump and droop is greater than is geometrically possible, an error message will display and require the appropriate action. Generally a reduction in maximum wheel travel will be required.

It is permissible to set the wheel droop to zero, but the wheel bump must be greater than zero.

Bump calculations are done for as many positions as required.
For example, if wheel travel increment is 10mm, maximum bump is 85mm, and maximum droop is 75mm, the bump and droop calculations will be done at the 85, 80, 70, 60, 50, 40, 30, 20, 10, static, -10, -20, -30, -40, -50, -60, -70 and -75mm positions for a total of 18 calculations, 9 bump + static + 8 droop.

7.1.2 Roll increments

Enter the maximum roll (in degrees). Note that this value is positive.

Enter the required values for the chassis roll calculation & display increments, and the starting position for the roll calculations.

The roll calculation interval specifies the steps taken in internal calculations as the chassis is rolled. Starting from the initial roll centre, the chassis is rolled by the calculation interval and the resultant roll centre found. The chassis is then rolled by the calculation interval about this new roll centre and the resultant roll centre found. This process continues until the chassis has been rolled by the required amount (as specified by the display increment). This enables a degree of "dynamism" to the roll centre. Be aware that the smaller the calculation interval, the longer the calculation time.

The default values for chassis roll increments are 0.5 degree for display and 0.25 degree for calculate, and the starting position defaults to the static position.

The chassis roll increment can be set to zero.

Roll calculations are done for as many positions as required.
LH roll means that the chassis is rolling onto the left hand side; the left hand suspension is moving

into bump, and the right hand side into droop. It is the equivalent of a right hand turn.
Similarly, RH roll means that the chassis is rolling onto the right hand side; the right hand suspension is moving into bump, and the left hand side into droop. It is the equivalent of a left hand turn.
For example, if the maximum roll is 5 degrees and the display interval is 1 degree, the roll calculations will be done at the 5° LH, 4° LH, 3° LH, 2° LH, 1° LH, 0°, 1° RH, 2° RH, 3° RH, 4°RH, 5° RH positions for a total of 11 calculations.

If a roll starting position other than Static is specified, then this position will be the 0° position for the chassis roll calculations.

For example, if wheel travel increment is 20mm, the maximum roll is 4 degrees and the chassis roll increment is 0.5°, and the initial bump position is 40mm, the chassis will be bumped 40mm, and then the chassis will be rolled through 0.5°, 1.0°, 1.5°, 2.0°, 2.5°, 3.0°, 3.5° and 4.0° both LH and RH

7.1.3 Roll centre and axis

Specify the chassis roll centre location and the roll axis.

If the chassis roll location is set to 'Fixed roll centre' then the chassis will be rolled about the initial roll centre regardless of the calculated roll centre position.

If the chassis roll location is set to 'SemiDynamic roll centre' then the chassis roll centre will be at the resultant roll centre height, but positioned on the vehicle centreline. Both [CRA94a] and [REIM96] suggest that the chassis always rolls about a point on (or very close to) the vehicle centreline.

If the chassis roll location is set to 'Dynamic roll centre' then the chassis roll centre will be the resultant roll centre (both in height and offset).

If the chassis roll axis is set to ‘Horizontal’ (the traditional and default method) then the vehicle end is rolled about the roll centre, with no account taken of the roll centre at the opposite end of the vehicle. [MILL95] suggests that inclined axis calculations are infrequently used.

If the chassis roll axis is set to ‘Inclined’ then the vehicle end is rolled about the inclined roll axis, where the roll axis is the line joining the roll centre (of the vehicle end being rolled) and the static roll centre at the opposite end of the vehicle. In order to use this option, make sure that both the roll centre (at the opposite end of the vehicle) and the wheelbase have been specified. These values are shown in the dialog panel for reference. Note that using this option when there are large amounts of sideways roll centre movement may lead to an undesirable ‘diagonal pitching’ condition.

7.2 Car end

The [Front] or [Rear] tab choice will indicate the currently selected vehicle end.

These tabs acts as a toggle, and selecting this tab will switch between each of two.

Depending on the vehicle configuration, some menu bar items may not be available.

When a dialog box is opened, the title will include the currently selected car. If the car end is not shown, then the dialog box applies to both ends.

7.3 Calculate

After all required dimensions have been entered, SusProg3D will calculate the suspension characteristics in chassis roll and wheel bump & droop.

Before the full range of bump and droop calculations can be calculated, Geometry **|** Calculate must complete without error.

From the Roll Bump tab, select Calculate.

This will do all Geometry and Roll Bump calculations.

The status bar will display a message ‘Calculating...’ followed by either ‘OK’ or an error message.

On fast processors, the ‘Calculating...’ message may not remain long enough to be visible.

For suspension designs where the roll centre migrates far from the original static position, small amounts of roll can produce large amounts of chassis movement. Setting either the roll centre location to ‘Fixed roll centre’ or the chassis roll increment to zero (or very small value) will allow Roll and Bump to execute.

7.4 Display the results

From the Roll Bump tab, select Result.

This will display a window with all the calculated suspension values. See Geometry | Result above.

```
Chassis roll values calculated every 1.00 degrees. Right hand turn.

Semi dynamic roll centre


outer wheel (lh)                                                   roll centre
                camber    castor     scrub     tramp     toein    offset    height
fvsax
      static     -0.50      5.00      0.00      0.00      1.00      0.00     75.00
3017.17
  1.00 roll       0.25      5.09     -0.05      0.22      1.00    -57.47     74.61
2637.51
  2.00 roll       0.97      5.18     -0.20      0.43      1.00   -114.24     73.45
2344.46
  3.00 roll       1.65      5.27     -0.42      0.64      1.00   -169.59     71.56
2109.60
  2.00 roll+      0.43      5.36      1.54      0.78      1.00   -176.13     42.86
1982.25
 20.00 bump


inner wheel (rh)                                                   roll centre
                camber    castor     scrub     tramp     toein    offset    height
fvsax
      static     -0.50      5.00      0.00      0.00      1.00      0.00     75.00
3017.17
  1.00 roll      -1.28      4.91     -0.06     -0.22      1.00     57.47     74.61
3534.24
  2.00 roll      -2.10      4.82     -0.24     -0.44      1.00    114.24     73.45
4289.57
  3.00 roll      -2.95      4.73     -0.55     -0.65      1.00    169.59     71.56
5514.82
  2.00 roll+     -2.42      5.00      1.50     -0.08      1.00    176.13     42.86
3186.05
 20.00 bump


lh wheel                                                       roll centre height
                camber    castor     scrub     tramp     toein   chassis    ground
fvsax
 80.00 bump      -2.74      5.72      1.91      1.38      1.00     40.37    -39.63
1540.32
 60.00 bump      -2.04      5.53      2.65      1.04      1.00     47.90    -12.10
```

1766.70								
40.00 bump	-1.44	5.36	2.60	0.70	1.00	56.21	16.21	2053.56
20.00 bump	-0.93	5.18	1.72	0.35	1.00	65.25	45.25	2438.41
static	-0.50	5.00	0.00	0.00	1.00	75.00	75.00	3000.00
20.00 droop	-0.16	4.82	-2.59	-0.36	1.00	85.46	105.46	3935.50
40.00 droop	0.08	4.64	-6.08	-0.72	1.00	96.64	136.64	5914.61
60.00 droop	0.23	4.47	-10.50	-1.08	1.00	108.59	168.59	13601.12
80.00 droop	0.25	4.29	-15.91	-1.46	1.00	121.36	201.36	-25052.03

	side view swing axle (lh)		
	length	height	angle
80.00 bump	7381.47	157.88	1.23
60.00 bump	7161.47	153.06	1.22
40.00 bump	6968.83	148.29	1.22
20.00 bump	6795.57	143.51	1.21
static	6634.78	138.64	1.20
20.00 droop	6480.01	133.60	1.18
40.00 droop	6324.55	128.28	1.16
60.00 droop	6160.52	122.57	1.14
80.0 80.0 droop	5977.51	116.29	1.11

Scrub is the distance the wheel cl moves laterally from the static position.
Positive scrub is the distance the wheel cl moves outwards, and negative scrub is the distance the wheel cl moves inwards.

Tramp is the distance the wheel contact cl moves backward and forward from the static position. Positive tramp is movement in the direction of the positive longitudinal axis, and negative tramp is movement in the direction of the negative longitudinal axis.

Sax is the swing axle length, measured from the wheel contact cl to the instantaneous centre of the suspension links. A negative swing axle length means that the swing axle instant centre is outboard of the wheel.

Roll centre offset is the horizontal distance of the roll centre from the vehicle cl.
Positive roll centre offset is in the direction of the positive lateral axis, and negative roll centre offset is in the direction of the negative lateral axis.

Roll centre height is the vertical distance of the roll centre above the ground line.
Negative roll centre height is the distance of the roll centre below the ground line. "Chassis" roll centre heights are the distances from the static ground line with the chassis stationary and the wheel moving up (bump) and down (droop). This is analogous to a vehicle wheel moving up and down with a (nominally) stationary chassis. "Ground" roll centre heights are the distances from the ground line with the chassis moving down (wheel bump) and up (wheel droop). This is analogous to a vehicle chassis moving up and down on a stationary ground plane, for example under braking. Roll centre heights for the roll positions are also "ground" heights.

Toe-in is the amount of toe-in (in either mm or inches) at each bump and roll position.
A positive value is toe-in, a negative amount is toe-out.
For wishbone and strut suspensions, the toe control pivots are not used and the wheel toe is held at the static setting. As part of the Steering calculations, the Roll&Bump data is recalculated. If, after doing the Steering calculation, the Roll&Bump is displayed (note! Do not recalculate) the toe variation will be incorporated into the roll and bump data.

For all other suspension types, the toe control pivot points are specified and the wheel toe will vary accordingly.

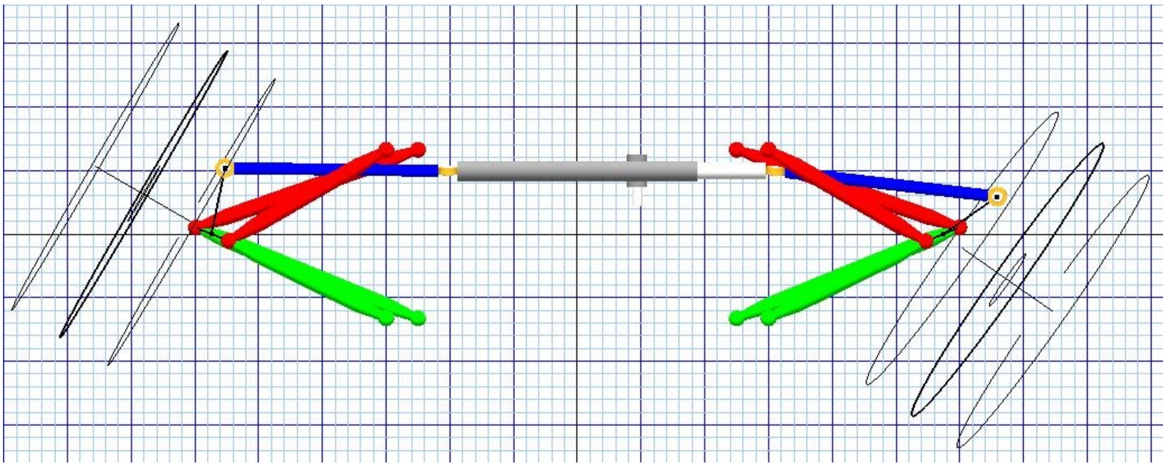
7.5 ECalc

Allows several modules to be calculated from one point.

For example, if the roll and bump increments are changed, you can recalculate all modules with one click.

See ECalc

8 Steering



Note that this module is equally applicable to the rear suspension for bump steer analysis, although the terminology is more appropriate for the front suspension.
No Ackermann or toe-out-in-turn calculations are done for the rear suspension.

Also Roll&Bump | Calculate must successfully execute before this can be calculated.

8.1 Configure

From the Steering tab, select Configure.

For the front of the vehicle, there are a number of steering configuration options.

Steering type.	For IFS, specify either 'Rack and pinion', 'Pitman arm, centre link, idler arm' or 'Pitman arm, intermediate rod, idler arm'. For Volkswagen trailing arm suspension, specify either 'Rack and pinion' or 'Pitman arm'. For live axle, specify either 'Lateral drag link' or 'Longitudinal drag link' or 'Rack and pinion (axle mounted)'
C-factor	For rack and pinion steering. This is the distance the rack moves for one complete turn (360 degrees) of the steering wheel, typically in the range 1-1/2" - 2" (38mm - 50mm). Together with the steering arms, this determines the steering ratio. For race cars this will range from 20:1 (slow) to less than 10:1 (very fast).
Steering box ratio	For recirculating ball and drag link steering. This is the number of turns of the input shaft (the steering wheel) for one turn of the output shaft (the pitman arm). It is usually easier to measure the amount the pitman arm rotates (in degrees) for one turn of the input shaft. The the steering ratio is 360 / the pitman arm rotation degrees. Ratios around 16:1 are typical. Note that this is not the overall steering ratio.
Steering gearbox location.	Specify either left hand drive or right hand drive. Note that this is the location of the steering gearbox.
Steering arm and tie rod location.	Front steer has the steering arms projecting forward from the upright (or strut) and the steering tie rods are ahead of the front axle.

	Rear steer has the steering arms projecting rearward from the upright (or strut) and the steering tie rods are behind the front axle. This is specified by entering the appropriate longitudinal dimension for the steering arm balljoint. For a front live axle, this is the location of the steering tie rod(s).
Pitman arm rotation.	For both recirculating ball and lateral drag link configurations. Specify either opposed or synchronous. This is determined by the rotation of the pitman arm relative to the steering arm in plan view. For front live axle, the steering arm is the one to which the drag link connects. In an opposed configuration, the pitman arm rotates in the opposite direction to the steering arm. In a synchronous configuration, the pitman arm rotates in the same direction as the steering arm. For example, when turning left, the steering arm is rotated anti-clockwise (counter clockwise). If the pitman arm rotates clockwise, this is opposed. If the pitman arm rotates anti-clockwise (counter clockwise), then this is synchronous.
Tie rod connection	For the 'Pitman arm, intermediate rod, idler arm' configuration. In the 'Conventional' configuration, the tie rod connects the steering arm to the Pitman or idler arm on the same side of the vehicle. In the 'Crossed' configuration, the tie rod connects the steering arm to the Pitman or idler arm on the opposite side of the vehicle.
Pitman arm orientation	For longitudinal drag link configuration. In the straight ahead position, is the pitman arm 'upwards' or 'downwards'.
Rack and pinion configuration type.	Rack and pinion only. Specify the configuration type.

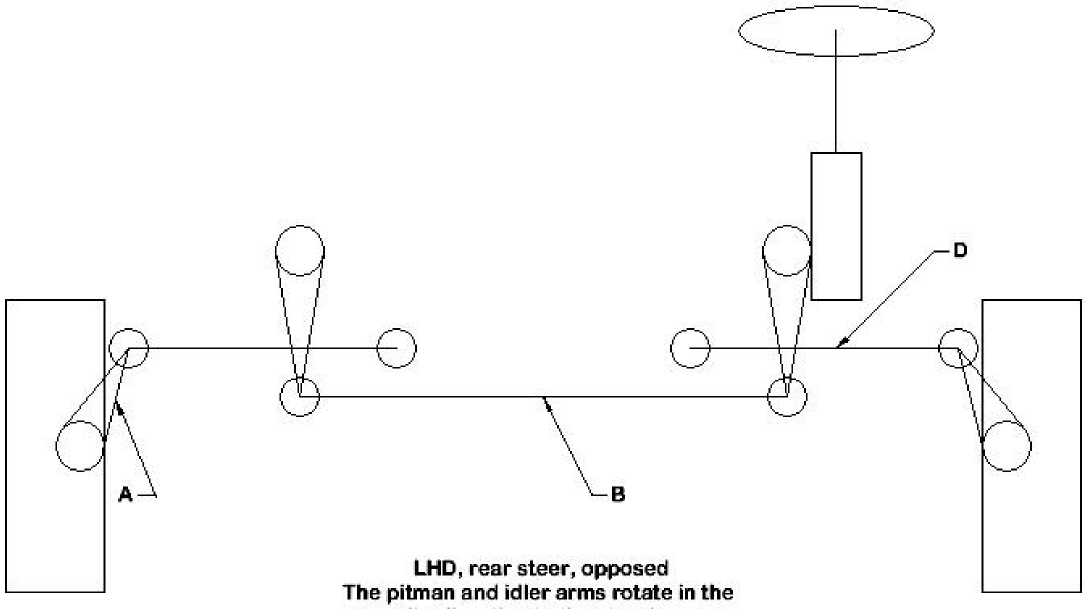
Type 1	Tie rod joints connect to each end of the rack. The rack housing is central on the rack, and the pinion is at the left hand end of the housing (for left hand drive) or the right hand end of the housing (for right hand drive). The usual passenger and sports car configuration.
Type 2	Tie rod joints connect to each end of the rack. The rack housing is central on the rack, and the pinion is in the centre of the housing. The typical “single-seater” configuration and some Porsches.
Type 3	The tie rod joints are close together in the centre of the rack, with the housing extending outwards in both directions. The pinion is at the left hand end of the housing (for left hand drive) or the right hand end of the housing (for right hand drive). Often used in conjunction with struts and high mounted steering arms.
Type 4	The tie rod joints are close together, connecting to one end of the rack. The housing and pinion extend to either the left (for left hand drive) or the right (for right hand drive). Preferred by Audi and VW.

This is only used to draw a representative steering rack. It has no effect on the steering calculations.

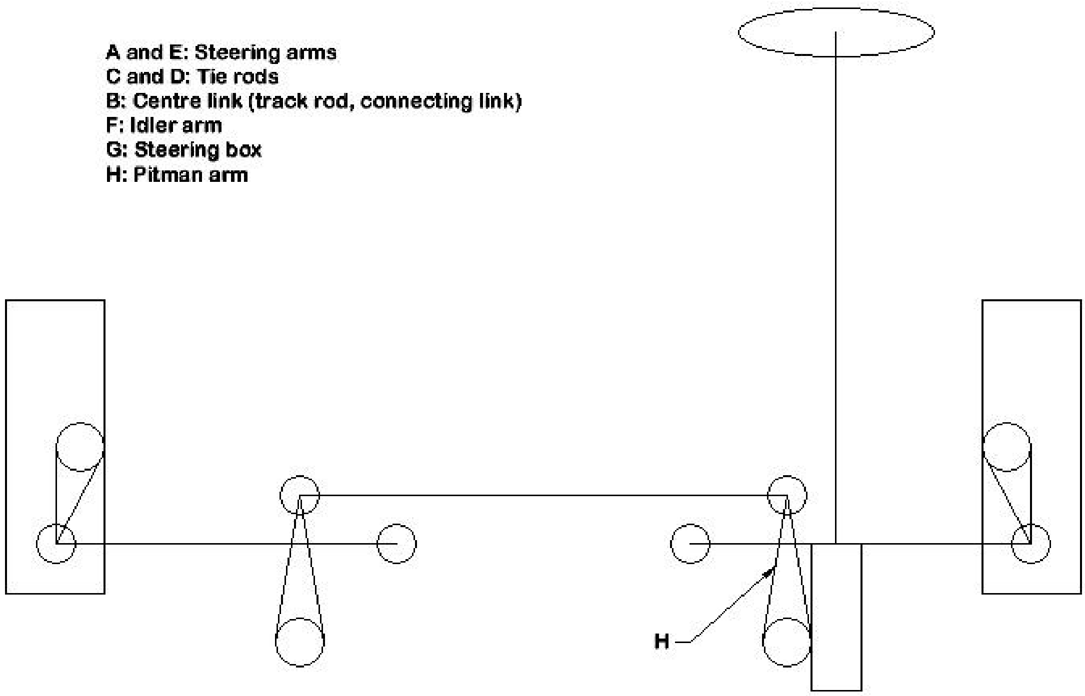
In all cases, the required dimensions are those for the centre of the tie rod ball joint where it attaches to the steering rack.

For the rear of the vehicle, the options are determined by the basic geometry configuration.

Geometry type	Toe link configuration
Double A-arm	Specify either a chassis mounted toe link, or an A-arm mounted toe link.
Strut (with a single lower A-arm)	In both cases the other end of the toe link attaches to the upright or strut. The upright or strut mounting point will be specified as part of the upright or strut. For the chassis mounted toe link, the chassis point will be specified as part of the chassis, and for the A-arm mounted toe link, the A-arm mounting point will be specified as part of the A-arm
All other geometry	The toe link will be either; a toe link, one end attached to the chassis, the other to the upright or strut, or combined with one of the suspension members. In either case, the chassis point will be specified as part of the chassis.



LHD, rear steer, opposed
The pitman and idler arms rotate in the opposite direction to the steering arms



LHD, front steer, opposed
The pitman and idler arms rotate in the opposite direction to the steering arms

8.2 Car end and car side

The [Front] or [Rear] tab choice will indicate the currently selected vehicle end.

The [LH] or [RH] tab choice will indicate the currently selected vehicle side.

These tabs acts as a toggle, and selecting this tab will switch between each of two.

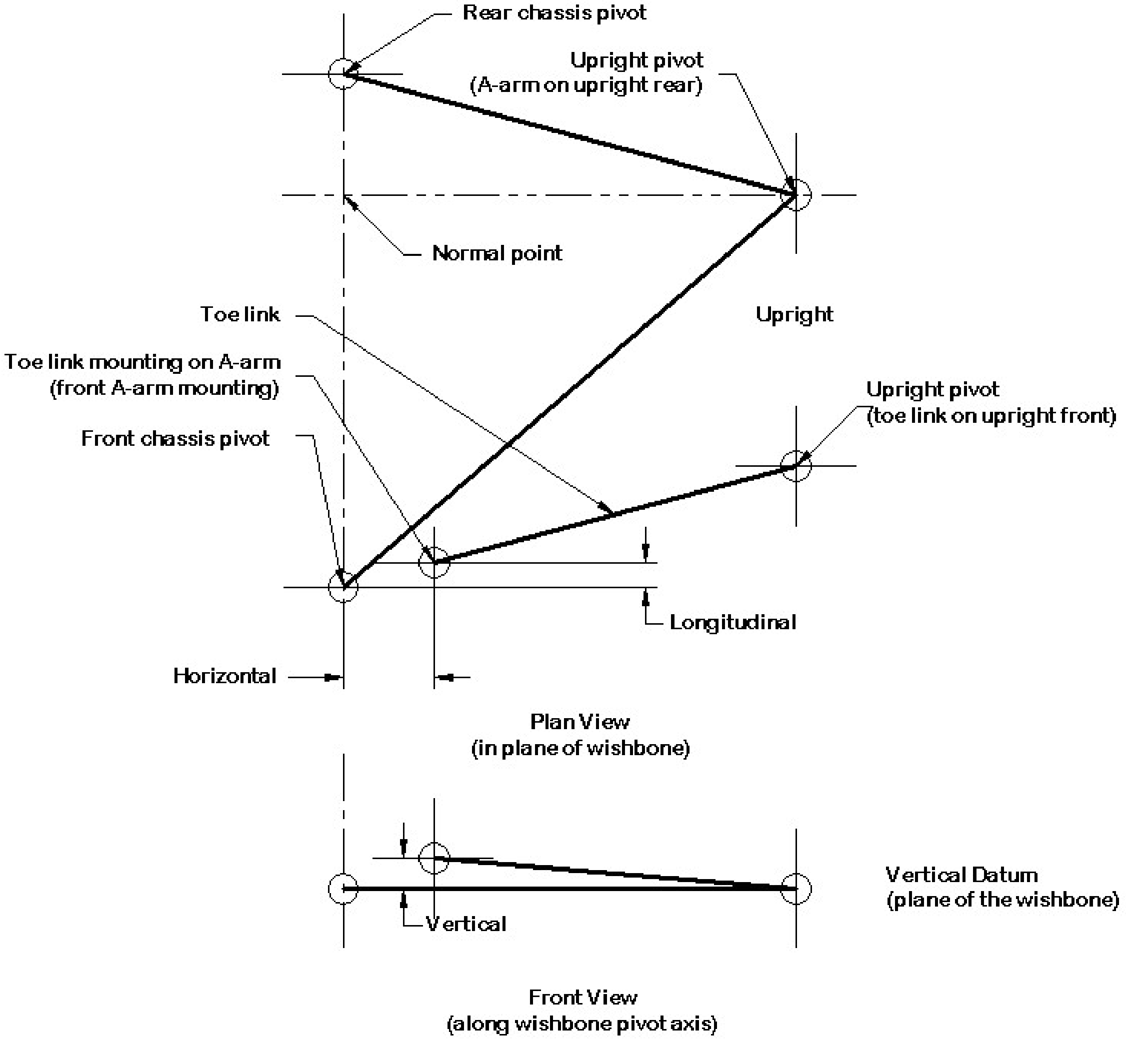
Depending on the vehicle configuration, some menu bar items may not be available.

When a dialog box is opened, the title will include the currently selected car end and car side. If the car side is not shown, then the dialog box applies to both sides. If the car end is not shown, then the dialog box applies to both ends.

8.3 A-arm (toe control link pickup point).

From the Steering tab, select A-arm.

Enter the values for the toe link ball joint pickup point.



In the above diagram, the toe link is referenced the front A-arm chassis pivot.
The lateral dimension is positive, because the attaching point is outboard from the A-arm chassis pivot axis.
The vertical dimension will be positive (if the vertical axis is positive upwards), because the attaching point is above the plane of the A-arm.
The longitudinal dimension will be positive (if the longitudinal axis is positive in the rearward direction), because the attaching point is rearward from the A-arm front chassis mounting point.

A-arm mounting points:
Note that lateral values are horizontal measurements from the A-arm chassis pivot axis, vertical values are vertical measurements from the A-arm plane, and longitudinal values are horizontal measurements from the chosen A-arm chassis pivot.

Specify the A-arm (either upper or lower) and the A-arm chassis pivot point that the toe link mounting point is referenced from (either front or rear).

The plane of the A-arm is defined by the three A-arm points: the two chassis mounting points and the upright mounting point.

The A-arm is considered to be rigid and the appropriate A-arm link is restrained from any radial movement. To minimise any rotational tendencies, the A-arm mounting should be positioned so that the centre line of the toe link pivot is coincident with the appropriate A-arm chassis mounting pivot.

8.4 Rack location (toe control link chassis pickup point)

From the Steering tab, select Rack Location or Chassis.

Enter the values for the rack ball joint pickup point.

This is the same dialog box as the initial chassis design.

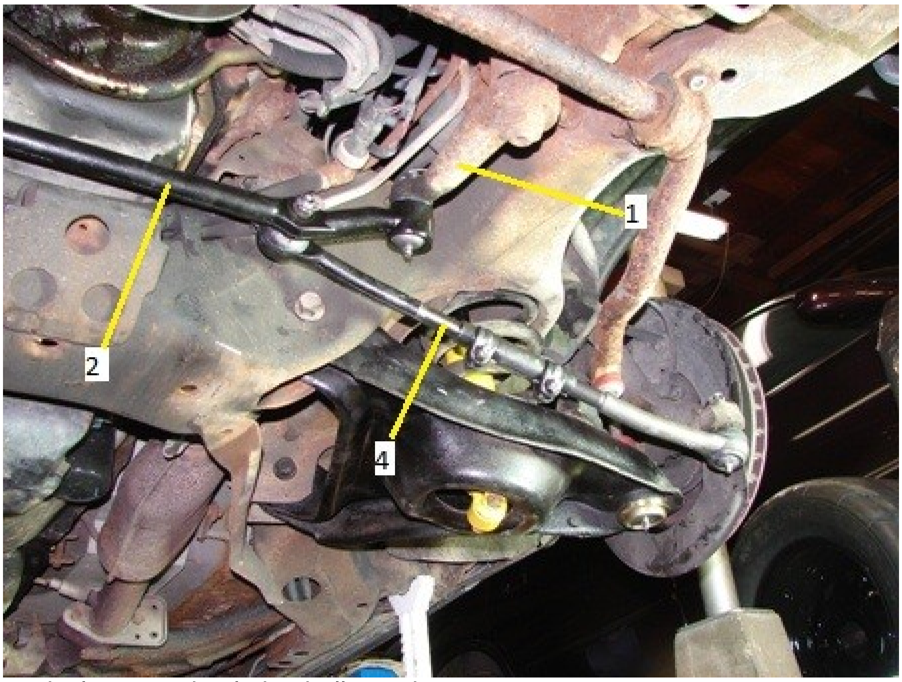
Chassis mounting points:
Note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

If you specify the upright steering arm ball joint and want to calculate the rack location to minimise the amount of bump steer, skip this menu choice and see Calculate the optimum rack position.

8.5 Steering gear (centre link)

From the Steering tab, select Steering Gear.

The various components of a recirculating ball steering mechanism with centre link are specified here.



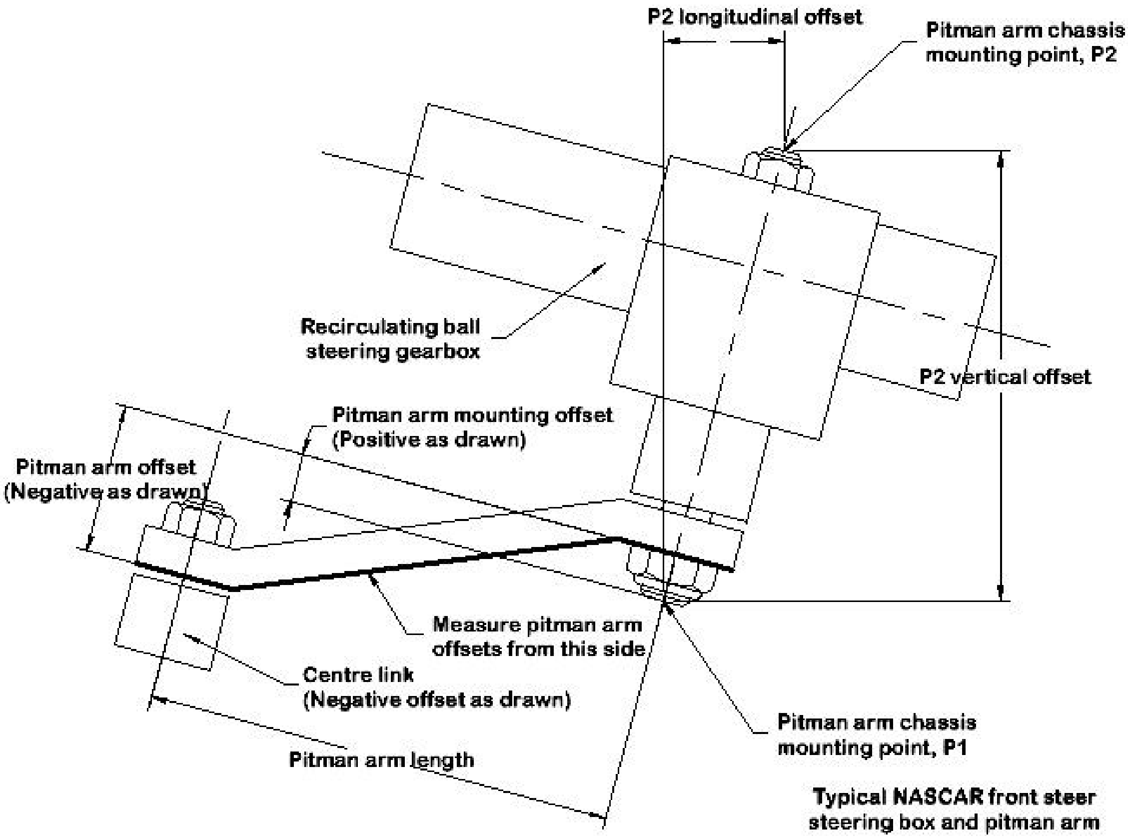
Typical LHD recirculating ball steering gear.
This is the LH side with Pitman arm [1] and centre link [2].
The tie rod [4] connects the the centre link to the steering arm.
The steering configuration is LHD, front steer, opposed rotation.

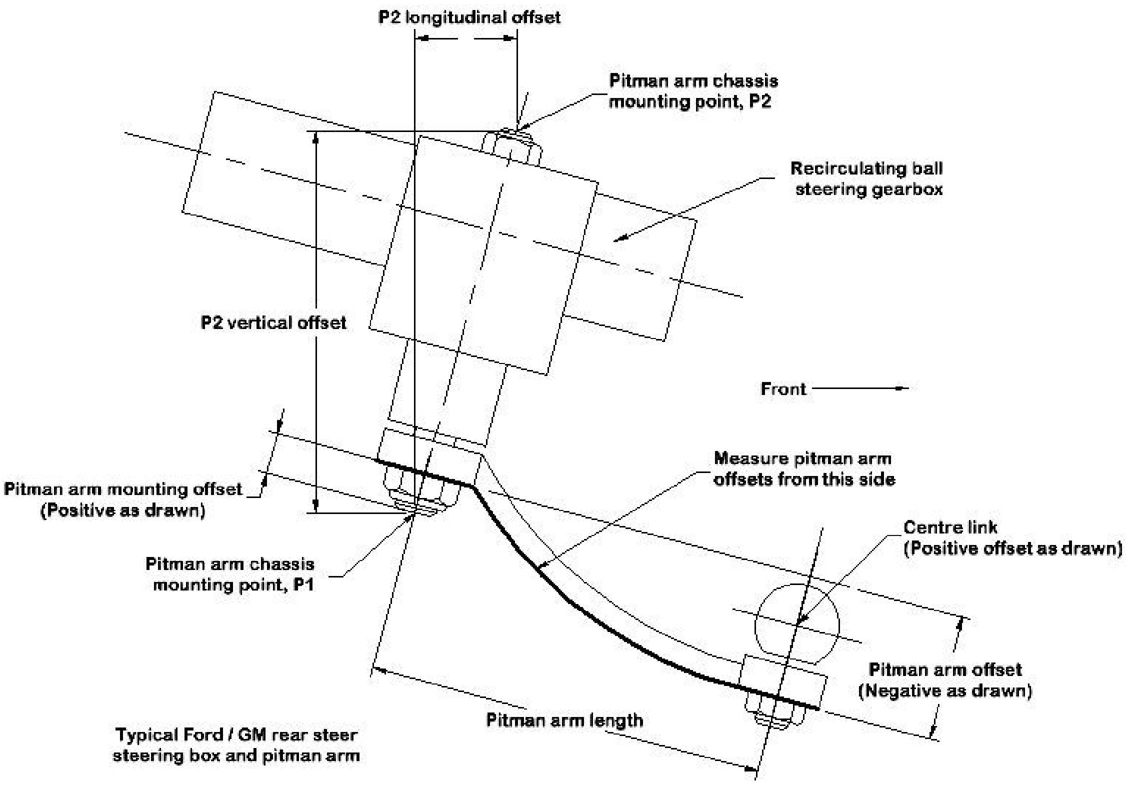
Typical LHD recirculating ball steering gear.
This is the RH side with centre link [2] and idler arm [3].
The tie rod [4] connects the the centre link to the steering arm.
The steering configuration is LHD, front steer, opposed rotation.

8.5.1 Pitman arm (centre link)

Enter the values for the pitman arm chassis mounting points, P1 and P2. These are two points on the steering gearbox sector shaft and define the pitman arm rotation axis. P1 is the primary location point (close to the pitman arm) and P2 is the secondary location point (on the top of the steering box).

Enter the length and offsets of the pitman arm.





Chassis mounting point P1:
Note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical

datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

Chassis mounting point P2:
Note that these dimensions are relative to P1, and will be positive or negative in accordance with the specified axis system. They are measured in the chassis datum position, and P2 is always above P1.
Usually the P2 lateral dimension will be zero, unless the steering gear is not mounted vertically (in front view). If P2 is outboard of P1 then the P2 lateral dimension will be positive; if P2 is inboard of P1 then the P2 lateral dimension will be negative.
If the vertical axis is positive upwards, then the P2 vertical dimension will be positive, otherwise the P2 vertical dimension will be negative. Note that this is a vertical dimension (relative to the vertical datum) and not the axial distance between P1 and P2.
Usually P2 will be “ahead” of P1, as this angles the steering box so that the worm shaft is aligned with the steering wheel shaft. If P2 is ahead of P1, and the longitudinal axis is “positive forward” then the P2 longitudinal dimension will be positive; if the longitudinal axis is “positive rearward” then the P2 longitudinal dimension will be negative.

Pitman arm length:
This is always positive.

Pitman arm datum surface:
This is the retaining nut contact surface of the pitman arm mounting boss on the steering gear shaft.

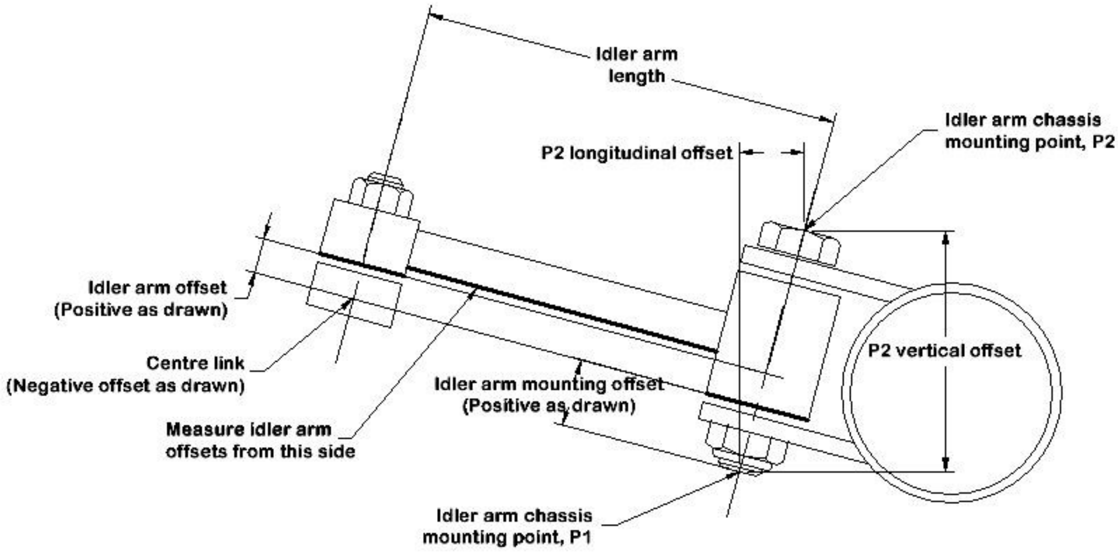
Pitman arm mounting offset:
This is measured axially from P1 to the pitman arm datum surface. If the pitman arm datum surface is offset towards P2 (the usual case) then this dimension will be positive.

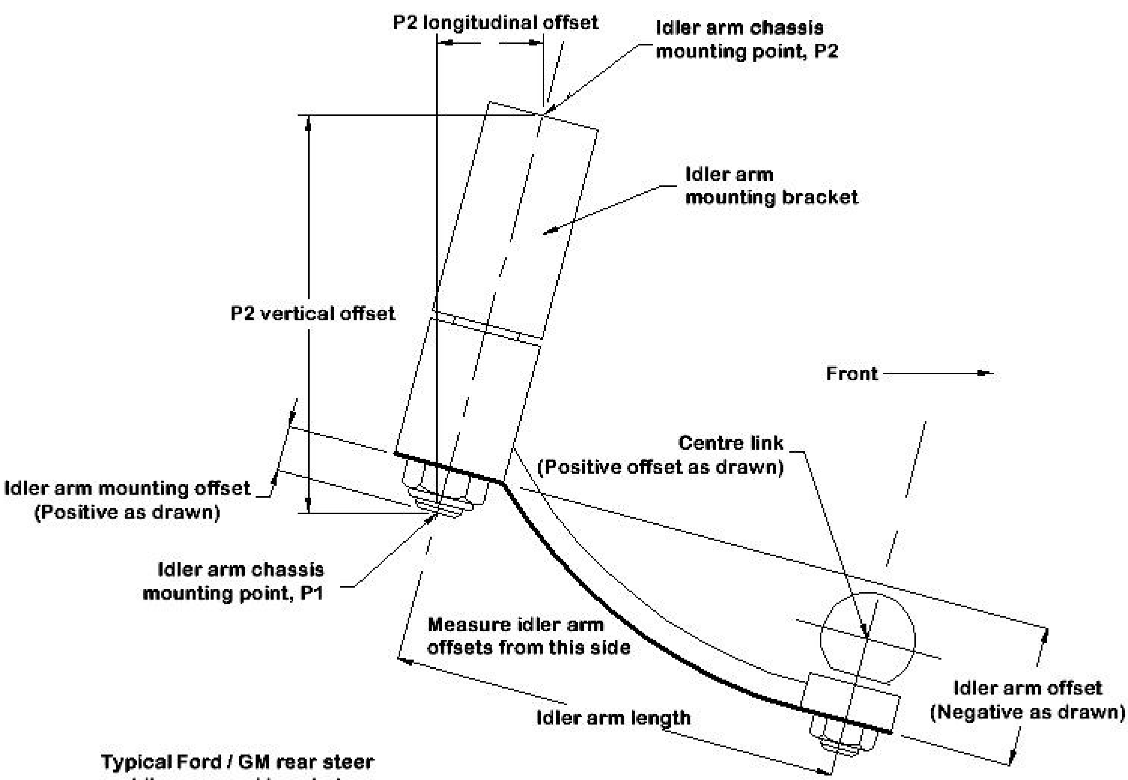
Pitman arm offset:
This is measured axially on the pitman arm datum surface, from the sector shaft mounting surface to the centre link mounting. If the pitman arm is cranked downwards (away from P2, the usual case) then this dimension will be negative.

8.5.2 Idler arm (centre link)

Enter the values for the idler arm chassis mounting points, P1 and P2. These are two points on the idler arm pivot shaft and define the idler arm rotation axis. P1 is the primary location point (usually on the underside of the idler arm) and P2 is the secondary location point (usually on the topside of the idler arm).

Enter the length and offsets of the idler arm.





Chassis mounting point P1:
Note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

Chassis mounting point P2:
Note that these dimensions are relative to P1, and will be positive or negative in accordance with the specified axis system. They are measured in the chassis datum position, and P2 is always above P1.
Usually the P2 lateral dimension will be zero, unless the steering gear is not mounted vertically (in front view). If P2 is outboard of P1 then the P2 lateral dimension will be positive; if P2 is inboard of

P1 then the P2 lateral dimension will be negative.
If the vertical axis is positive upwards, then the P2 vertical dimension will be positive, otherwise the P2 vertical dimension will be negative. Note that this is a vertical dimension (relative to the vertical datum) and not the axial distance between P1 and P2.
Usually P2 will be “ahead” of P1, so that the idler arm pivot axis is parallel to the steering gear sector shaft in side view. If P2 is ahead of P1, and the longitudinal axis is “positive forward” then the P2 longitudinal dimension will be positive; if the longitudinal axis is “positive rearward” then the P2 longitudinal dimension will be negative.

Idler arm length:
This is always positive.

Idler arm datum surface:
This is the face of the idler arm closest to the mounting point P1.

Idler arm mounting offset:
This is measured axially from P1 to the idler arm datum surface. If the idler arm datum surface is offset towards P2 (the usual case) then this dimension will be positive.

Idler arm offset:
This is measured axially on the idler arm datum surface, from the chassis pivot shaft mounting surface to the centre link mounting surface. If the idler arm is cranked downwards (away from P2, the usual case) then this dimension will be negative.

Idler arm mounting error:
After calculating, the idler arm mounting error will be shown in results data.
This is the amount that the idler mounting point is out of parallel in side and front view. In most cases, it is desired that both idler and pitman arms rotation axis are parallel. Add the offset error to the idler arm chassis pivot P2 point if required.

8.5.3 Centre link

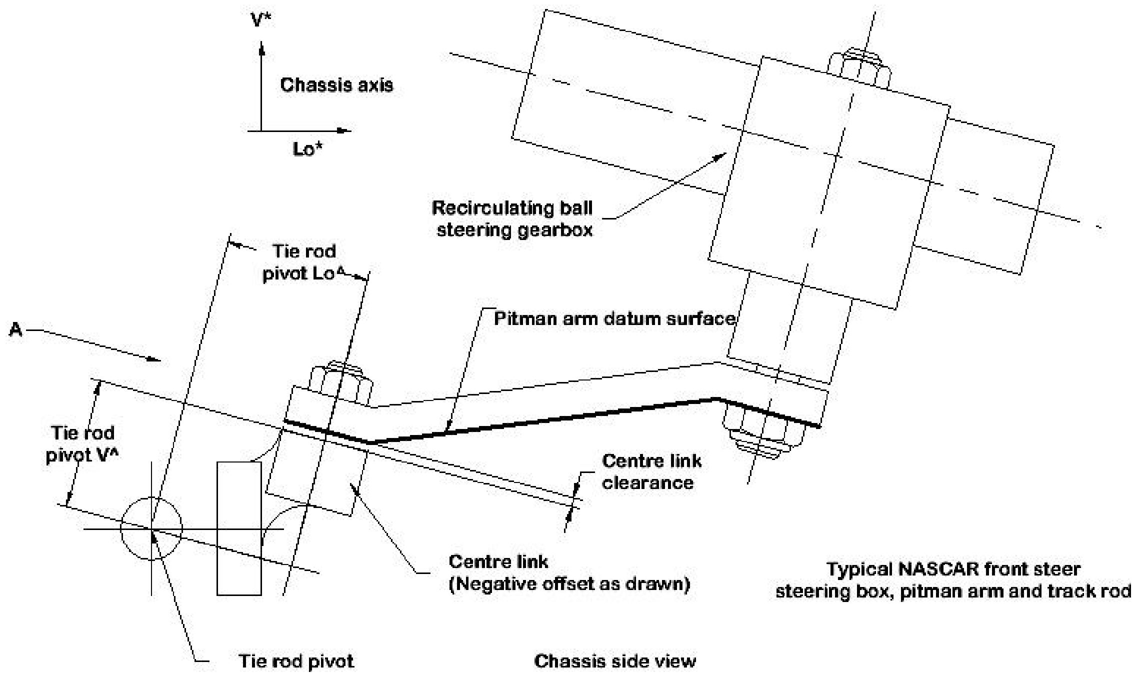
Enter the values for the tie rod pivot points on the centre link. The centre link is also known as "track rod" or "connecting link".

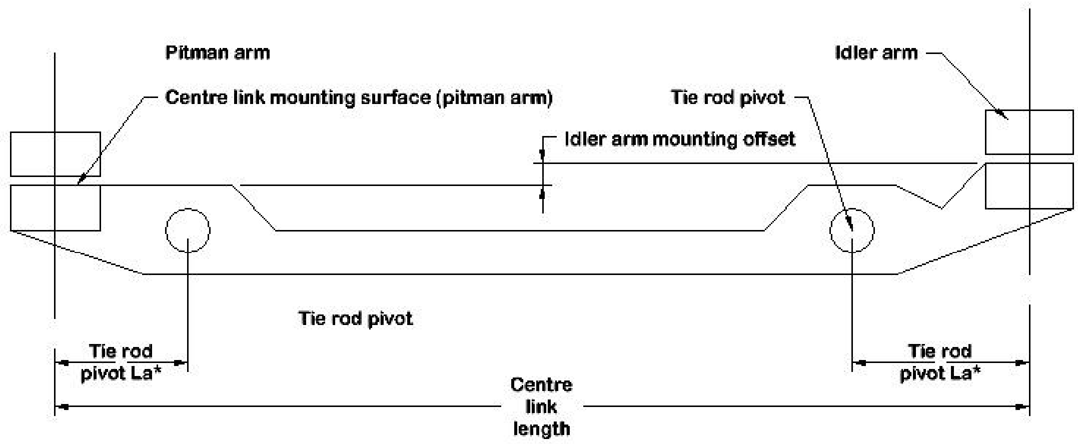
Enter the values for the centre link to pitman and idler arm clearances.

Specify if the centre link is mounted outside or inside the pitman / idler arm.

Enter the value for the centre link length (Pitman arm pivot to idler arm pivot)

Specify where the tie rods are relative to the centre link in plan view. The tie rods will be either in front of the centre link, or behind the centre link.





View in direction of arrow A
Typical for LHD

Centre link mounting surfaces:

These are the faces of the centre link adjacent to the pitman and idler arm. The pitman arm end is the primary centre link mounting surface. The idler arm end is the secondary centre link mounting surface.

Tie rod pivots:

These can be specified as offsets from the centre link pitman and idler arm pivots, or as chassis datum coordinates.

Centre link offsets.

Note that these dimensions are offsets relative to the centre link mounting faces and the pitman / idler arm pivots, and will be positive or negative in accordance with the specified axis system

Usually the tie rod pivots are inboard of the pitman / idler arm pivots. If the tie rod pivot is inboard of the pitman / idler arm pivot then lateral dimension will be negative.

If the tie rod pivot is “above” the plane of the centre link mounting surface, and if the vertical axis is positive upwards, then the vertical dimension will be positive, otherwise the vertical

dimension will be negative.
If the tie rod pivot is “behind” the pitman / idler arm pivot, and if the longitudinal axis is positive rearwards, then the longitudinal dimension will be positive, otherwise the longitudinal dimension will be negative.

Chassis datum coordinates.
Note that these dimensions are relative to the chassis datums, and will be positive or negative in accordance with the specified axis system.

Specify the input dimensions as either "Centre link offsets" or "Chassis datum". When the calculation is done, the other dimensions will be calculated.

If you specify the steering calculation as [Fixed] or [Upright] then the tie rod pivot dimensions must be input. If you specify the steering calculation as [Chassis] then the tie rod pivot dimensions cannot be input, and will be calculated to minimise the amount of bump steer. See Calculate the optimum rack position.

Centre link length:
This is always positive. It is the distance between the pitman and idler arm pivot points.

Centre link mounting clearance:
These clearances are always positive. They are the distance between the centre link mounting surface and the pitman / idler arm datum surfaces. In some production cars, this clearance is virtually zero and restrains the centre link radially.

Centre link idler arm mounting offset:
After calculating, the centre link idler arm mounting offset will be shown in results data. This is the amount that the idler mounting datum surface is out of the plane of the pitman mounting datum surface. In most cases, it is desired that both idler and pitman arms rotation axis are in the same plane. Adjust the idler arm offsets if required.

8.5.4 Alignment (centre link)

The direction of the Pitman and idler arms (either forward or rearward facing) will be determined by the direction the of the steering arms, and whether the Pitman arm rotation is opposed or synchronous.

Pitman arm alignment.
This is defined as the lateral offset of the centre link end of the Pitman arm from a position parallel to the vehicle centreline (in plan view).

If the Pitman arm is parallel to the vehicle centreline (in plan view) then this offset will be zero.

If the Pitman arm is angled outwards from the vehicle centreline (in plan view) then this offset will be positive.

If the Pitman arm is angled inwards from the vehicle centreline (in plan view) then this offset will be negative.

Generally, if the centre link length is the same as the Pitman arm pivot to idler arm pivot length, then both Pitman arm and idler arm will be parallel to the vehicle centreline (the offset will be zero); if the centre link length is less than the Pitman arm pivot to idler arm pivot length, then both Pitman arm and idler arm will incline inwards (the offset will be negative); and if the centre link length is greater than the Pitman arm pivot to idler arm pivot length, then both Pitman arm and idler arm will incline outwards (the offset will be positive).

The idler arm will be positioned according to the length of the centre link, and the idler arm offset will be calculated.

The idler arm offset is defined as the lateral offset of the centre link end from a position parallel to the vehicle centreline (in plan view).

If the idler arm is parallel to the vehicle centreline (in plan view) then this offset will be zero.

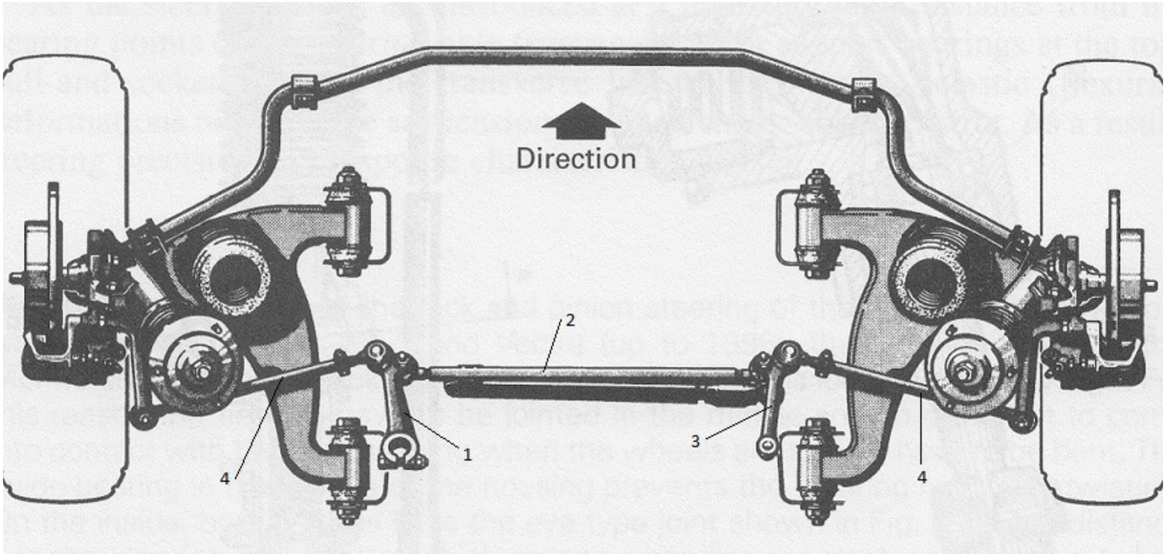
If the idler arm is angled outwards from the vehicle centreline (in plan view) then this offset will be positive.

If the idler arm is angled inwards from the vehicle centreline (in plan view) then this offset will be negative.

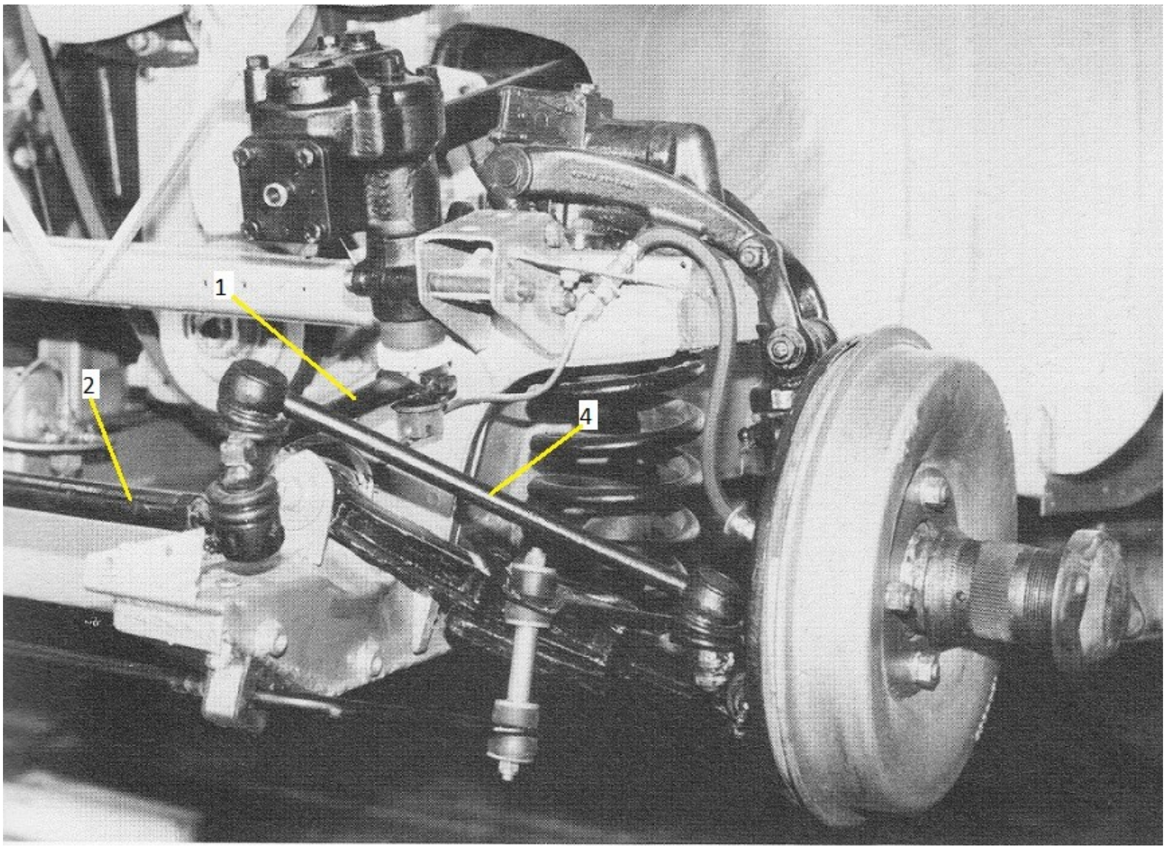
8.6 Steering gear (intermediate rod)

From the Steering tab, select Steering Gear.

The various components of a recirculating ball steering mechanism with intermediate rod are specified here.



Typical LHD recirculating ball steering gear with Pitman arm [1], intermediate rod [2], and idler arm [3].
The tie rods [4] connect the the Pitman and idler arms to the steering arms.
The tie rod ball joints are on the top of the Pitman and idler arms; the intermediate rod ball joints are below the Pitman and idler arms.
The steering configuration is LHD, rear steer, opposed rotation.

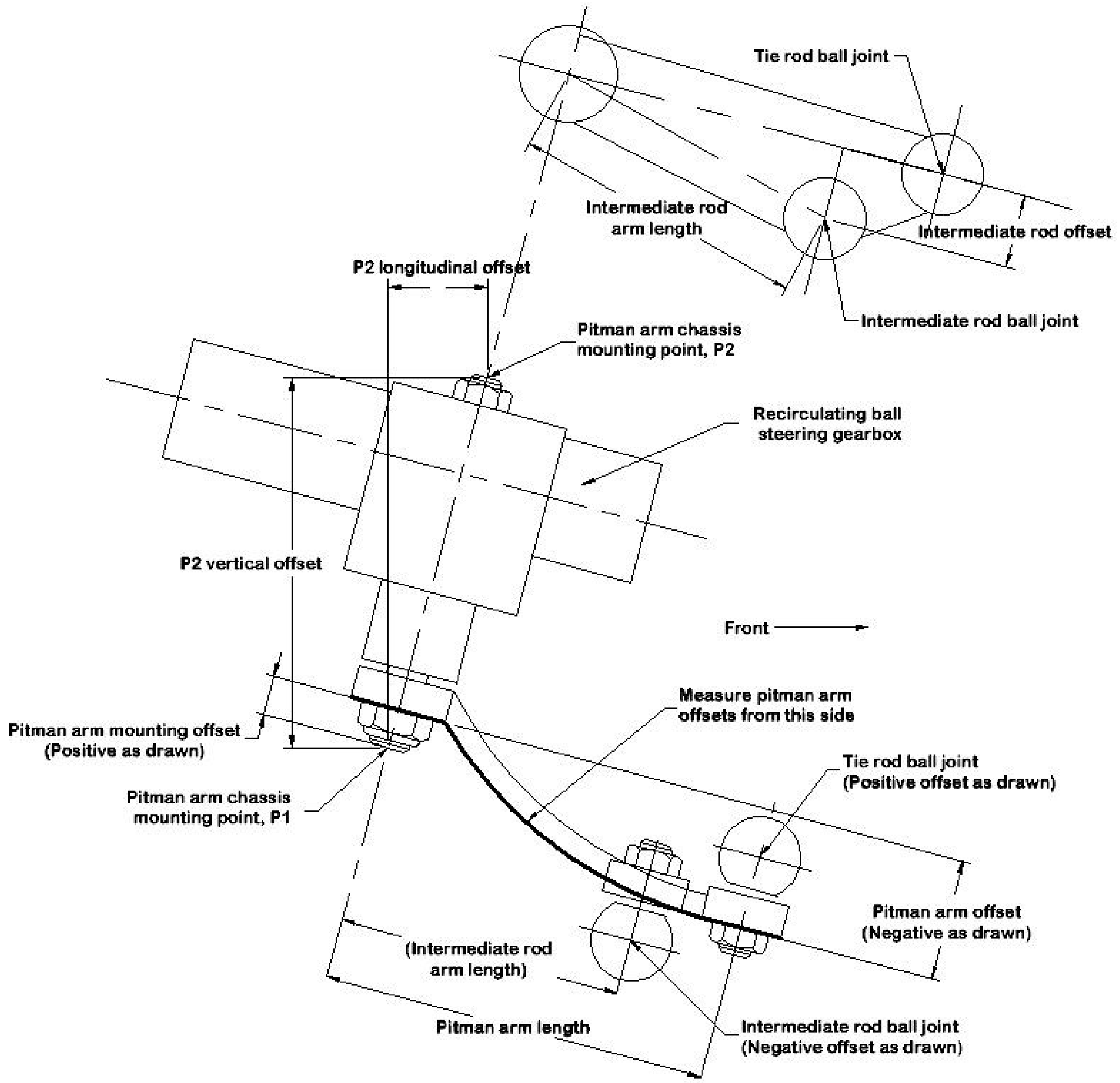


Austin-Healy BN1/BN2 front suspension.
LHD recirculating ball steering gear with Pitman arm [1] and intermediate rod [2].
The tie rod [4] connects the the Pitman arm to the steering arm.
The tie rod ball joints are on the top of the Pitman arm; the intermediate rod ball joints are below the Pitman arm.
The steering configuration is LHD, front steer, synchronous rotation.

8.6.1 Pitman arm (intermediate rod)

Enter the values for the pitman arm chassis mounting points, P1 and P2. These are two points on the steering gearbox sector shaft and define the pitman arm rotation axis. P1 is the primary location point (close to the pitman arm) and P2 is the secondary location point (on the top of the steering box).

Enter the length and offsets of the pitman arm.



Steering box and pitman arm

Chassis mounting point P1:
Note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

Chassis mounting point P2:
Note that these dimensions are relative to P1, and will be positive or negative in accordance with the specified axis system. They are measured in the chassis datum position, and P2 is always above P1.
Usually the P2 lateral dimension will be zero, unless the steering gear is not mounted vertically (in front view). If P2 is outboard of P1 then the P2 lateral dimension will be positive; if P2 is inboard of P1 then the P2 lateral dimension will be negative.
If the vertical axis is positive upwards, then the P2 vertical dimension will be positive, otherwise the P2 vertical dimension will be negative. Note that this is a vertical dimension (relative to the vertical datum) and not the axial distance between P1 and P2.
Usually P2 will be “ahead” of P1, as this angles the steering box so that the worm shaft is aligned with the steering wheel shaft. If P2 is ahead of P1, and the longitudinal axis is “positive forward” then the P2 longitudinal dimension will be positive; if the longitudinal axis is “positive rearward” then the P2 longitudinal dimension will be negative.

There are two ball joints on the Pitman arm, the tie rod ball joint and the intermediate rod ball joint.

Pitman arm tie rod ball joint dimensions:

Arm datum surface:	This is the retaining nut contact surface of the pitman arm mounting boss on the steering gear shaft.
Arm length:	This is always positive.
Arm mounting offset:	This is measured axially from P1 to the pitman arm datum surface. If the pitman arm datum surface is offset towards P2 (the usual case) then this dimension will be positive.
Arm offset:	This is measured axially on the pitman arm datum surface, from the sector shaft mounting surface to the tie rod mounting surface. If the pitman arm is cranked downwards (away from P2, the usual case) then this dimension will be negative.
Ball joint offset:	This is measured axially from the pitman arm datum surface to the centre of the tie rod ball joint. If the ball joint is offset towards P2 then this dimension will be positive.

Pitman arm intermediate rod ball joint dimensions:

Arm datum surface:	This is the retaining nut contact surface of the pitman arm mounting boss on the steering gear shaft.
Arm length:	This is always positive.
Arm mounting offset:	This is measured axially from P1 to the pitman arm datum surface. If the pitman arm datum surface is offset towards P2 (the usual case) then this dimension will be positive.
Arm offset:	This is measured axially on the pitman arm datum surface, from the sector shaft mounting surface to the intermediate rod mounting surface. If the pitman arm is cranked downwards (away from P2, the usual case) then this dimension will be negative.
Ball joint offset:	This is measured axially from the pitman arm datum surface to the centre of the tie rod ball joint. If the ball joint is offset towards P2 then this dimension will be positive.
Intermediate rod offset:	This is the offset of the intermediate rod ball joint from the line of the Pitman arm axis and the tie rod ball joint in plan view. If the intermediate rod ball joint is closer to the vehicle centreline than the tie rod ball joint, this dimension is negative; if the intermediate rod ball joint is further from to the vehicle centreline than the tie rod ball joint, this dimension is positive.

8.6.2 Idler arm (intermediate rod)

The idler arm is dimensioned in the same way as the Pitman arm.

Because most vehicles with this type of steering are symmetrical, tick the "Idler arm symmetric with Pitman arm" box and the Pitman arm mounting points and dimensions will be copied when the "Apply" or "OK" button is clicked.

Even if the layout is not symmetrical, it may still be easier to tick the "Idler arm symmetric with Pitman arm" then "Apply" to copy the dimensions across. Then untick the "Idler arm symmetric with Pitman arm" and change the dimensions.

8.6.3 Intermediate rod

Enter the length of the intermediate rod.

If the steering is [Chassis] then the tie rod end positions will be calculated, the steering arms positioned accordingly, and the length of the intermediate rod calculated.

8.6.4 Alignment (intermediate rod)

The direction of the Pitman and idler arms (either forward or rearward facing) will be determined by the direction the of the steering arms, and whether the Pitman arm rotation is opposed or synchronous.

Pitman arm alignment.
This is defined as the lateral offset of the tie rod end of the Pitman arm from a position parallel to the vehicle centreline (in plan view).

If the Pitman arm is parallel to the vehicle centreline (in plan view) then this offset will be zero.

If the Pitman arm is angled outwards from the vehicle centreline (in plan view) then this offset will be positive.

If the Pitman arm is angled inwards from the vehicle centreline (in plan view) then this offset will be negative.

Idler arm alignment.
The idler arm offset is defined as the lateral offset of the tie rod end from a position parallel to the vehicle centreline (in plan view).

If the idler arm is parallel to the vehicle centreline (in plan view) then this offset will be zero.

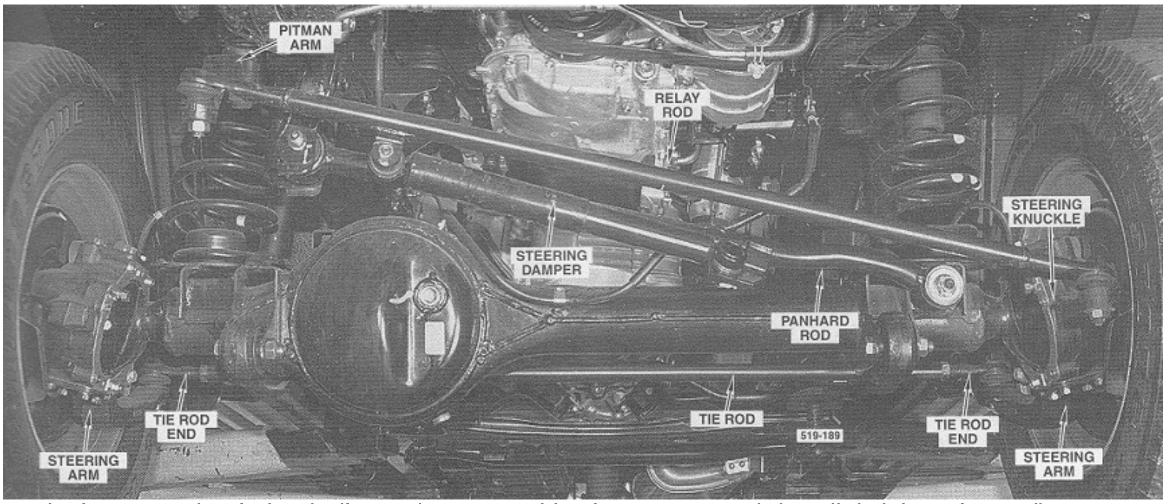
If the idler arm is angled outwards from the vehicle centreline (in plan view) then this offset will be positive.

If the idler arm is angled inwards from the vehicle centreline (in plan view) then this offset will be negative.

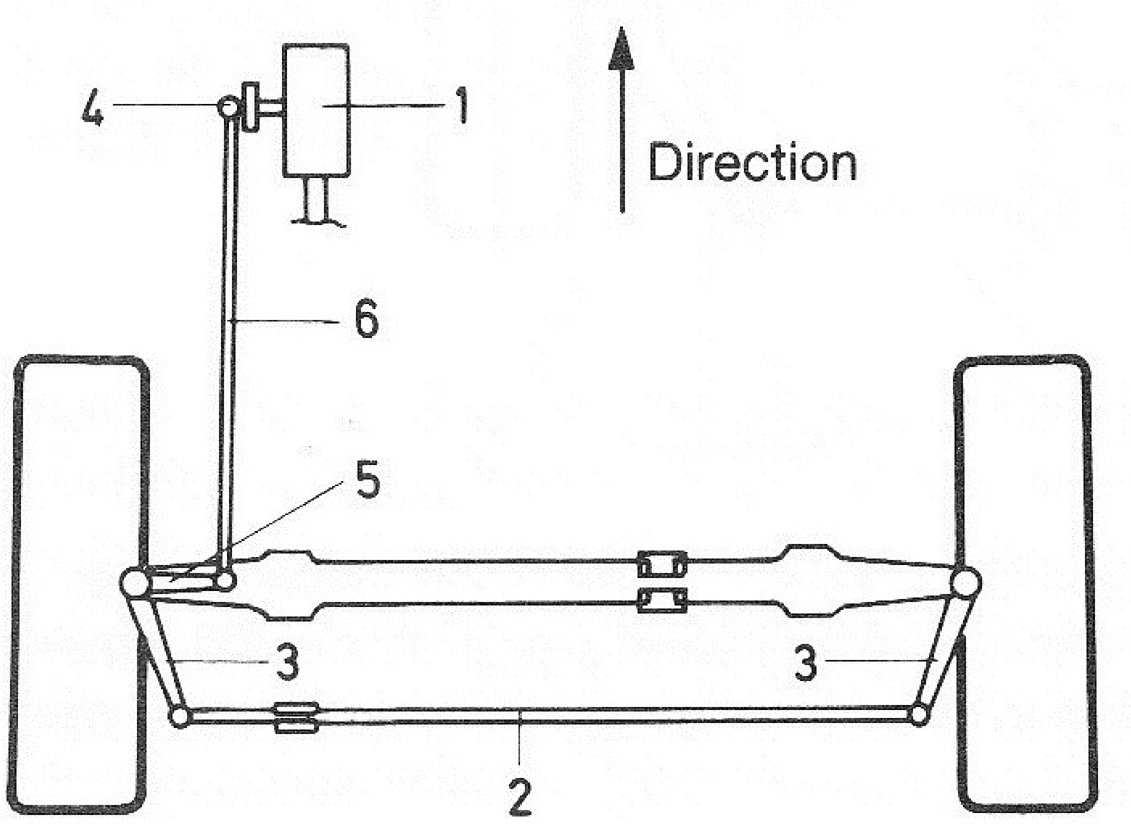
8.7 Steering gear (drag link)

From the Steering tab, select Steering Gear.

The various components of a recirculating ball and drag link steering mechanism are specified here.



Typical RHD recirculating ball steering gear with Pitman arm and drag link (aka relay rod)
The tie rod connects the steering arms.
The steering configuration is lateral drag link, RHD, rear steer, synchronous rotation.

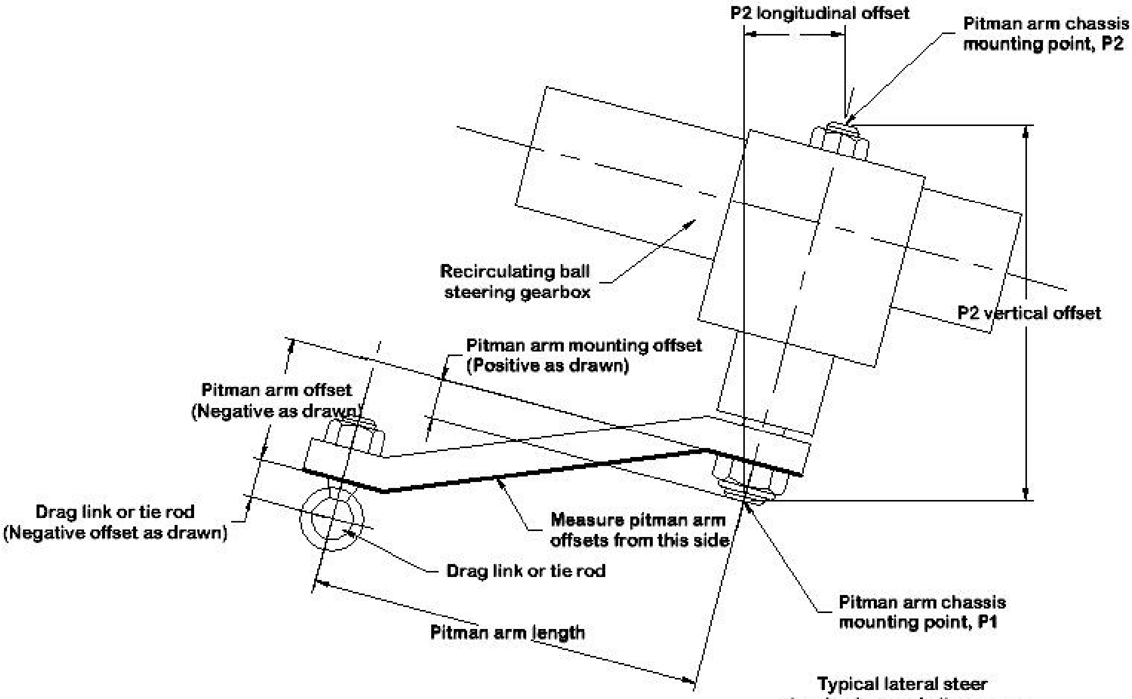


Typical LHD recirculating ball steering gear with Pitman arm [4] and longitudinal drag link [6]
The tie rod [2] connects the steering arms [3].
The steering configuration is longitudinal drag link, LHD, rear steer.

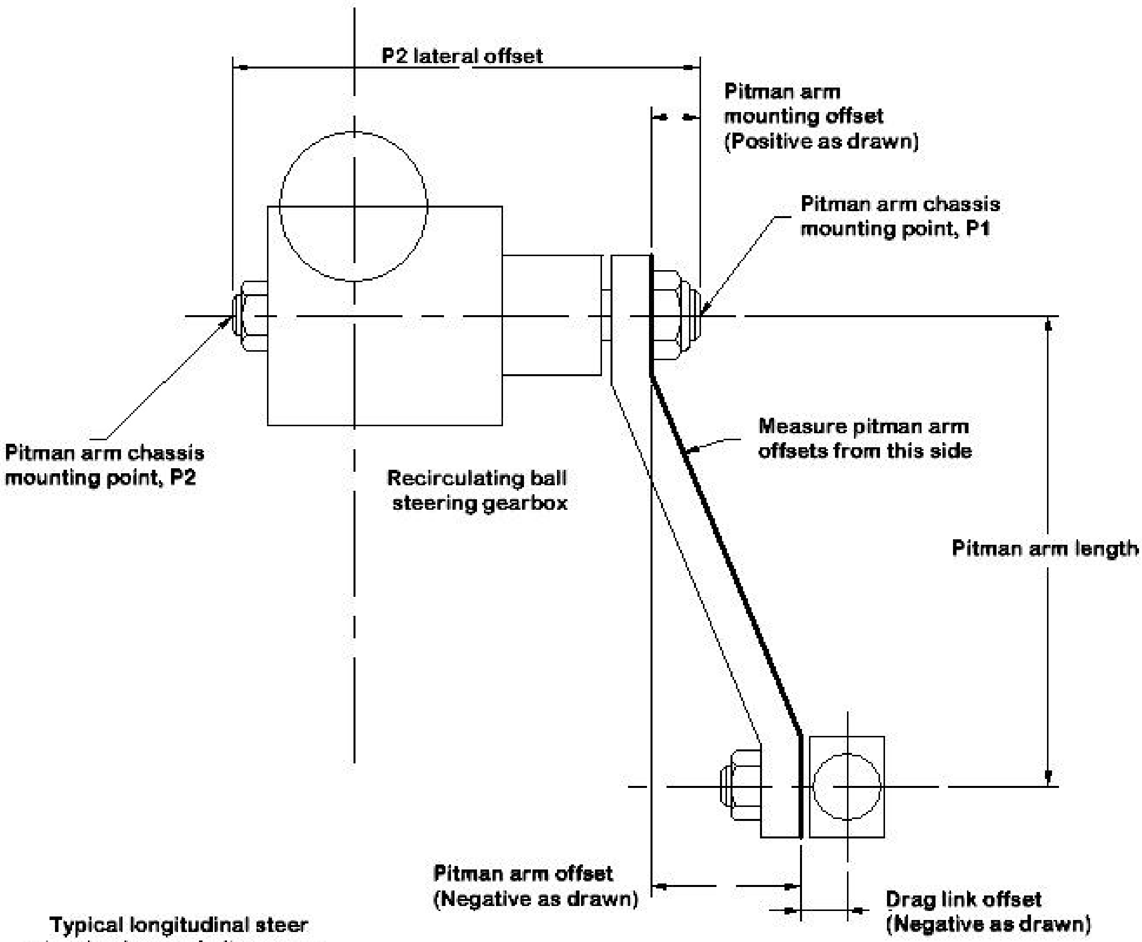
8.7.1 Pitman arm (drag link)

Enter the values for the pitman arm chassis mounting points, P1 and P2. These are two points on the steering gearbox sector shaft and define the pitman arm rotation axis. P1 is the primary location point (close to the pitman arm) and P2 is the secondary location point (on the top of the steering box).

Enter the length and offsets of the pitman arm.



Typical lateral steer steering box and pitman arm



Typical longitudinal steer steering box and pitman arm

Chassis mounting point P1:

Note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

Chassis mounting point P2:
Note that these dimensions are relative to P1, and will be positive or negative in accordance with the specified axis system. They are measured in the chassis datum position.
If P2 is outboard of P1 then the P2 lateral dimension will be positive; if P2 is inboard of P1 then the P2 lateral dimension will be negative.
If the vertical axis is positive upwards, then the P2 vertical dimension will be positive, otherwise the P2 vertical dimension will be negative. Note that this is a vertical dimension (relative to the vertical datum) and not the axial distance between P1 and P2.
Usually the P2 vertical and longitudinal dimension will be zero, with the steering gear mounted so that the sector shaft axis is "across" the vehicle and the Pitman arm rotates in a vertical plane parallel to the vehicle centreline.

Pitman arm length:
This is always positive.

Pitman arm datum surface:
This is the retaining nut contact surface of the pitman arm mounting boss on the steering gear shaft.

Pitman arm mounting offset:
This is measured axially from P1 to the pitman arm datum surface. If the pitman arm datum surface is offset towards P2 (the usual case) then this dimension will be positive.

Pitman arm offset:
This is measured axially on the pitman arm datum surface, from the sector shaft mounting surface to the drag link mounting surface. If the pitman arm is cranked towards P2 then this dimension will be positive.

8.7.2 Idler arm (drag link)

From the Steering tab, select Steering Arm.

Enter the values for the idler arm / drag link balljoint.

This is the same dialog box as the initial axle design.

8.7.3 Tie rod (drag link)

The length of the tie rod will be calculated using the specified wheel alignment, in the straight ahead position.

8.7.4 Drag link

Specify if the drag link is mounted outside or inside the pitman arm, and the distance from the pitman arm datum surface to the ball joint centre.

The length of the drag link will be calculated using the specified wheel alignment and pitman arm alignment, in the straight ahead position.

8.7.5 Alignment (drag link)

Pitman arm alignment in the straight ahead position.

Lateral drag link This is defined as the lateral offset of the drag link end of the Pitman arm from a position parallel to the vehicle centreline (in plan view).

If the Pitman arm is parallel to the vehicle centreline (in plan view) then this offset will be zero.

If the Pitman arm is angled outwards from the vehicle centreline (in plan view) then this offset will be positive.

If the Pitman arm is angled inwards from the vehicle centreline (in plan view) then this offset will be negative.

Longitudinal drag link

This is defined as the longitudinal offset of the drag link end of the Pitman arm from a vertical position (in vehicle side view).

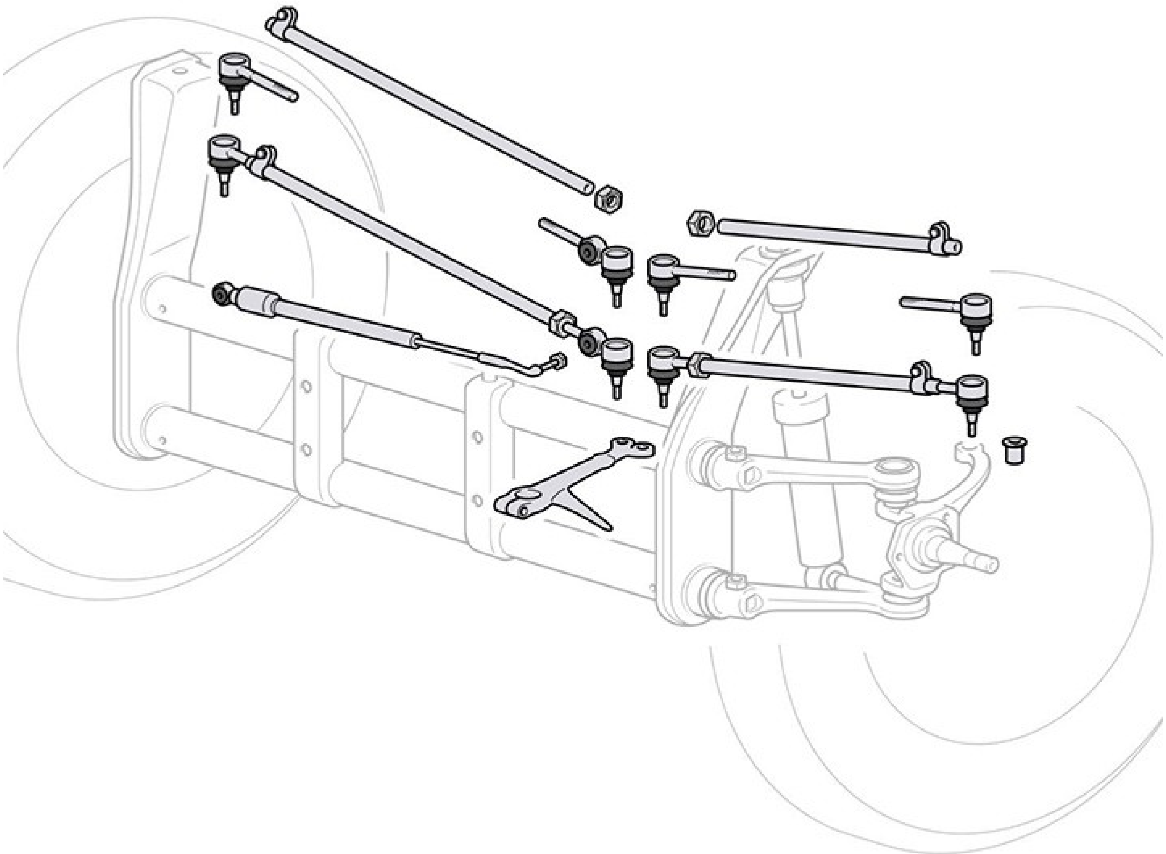
If the Pitman arm is vertical (in vehicle side view) then this offset will be zero.

If the Pitman arm is angled forwards from the vertical position (in vehicle side view) then this offset will be positive (if the longitudinal axis is positive in the forward direction) or negative (if the longitudinal axis is negative in the forward direction).

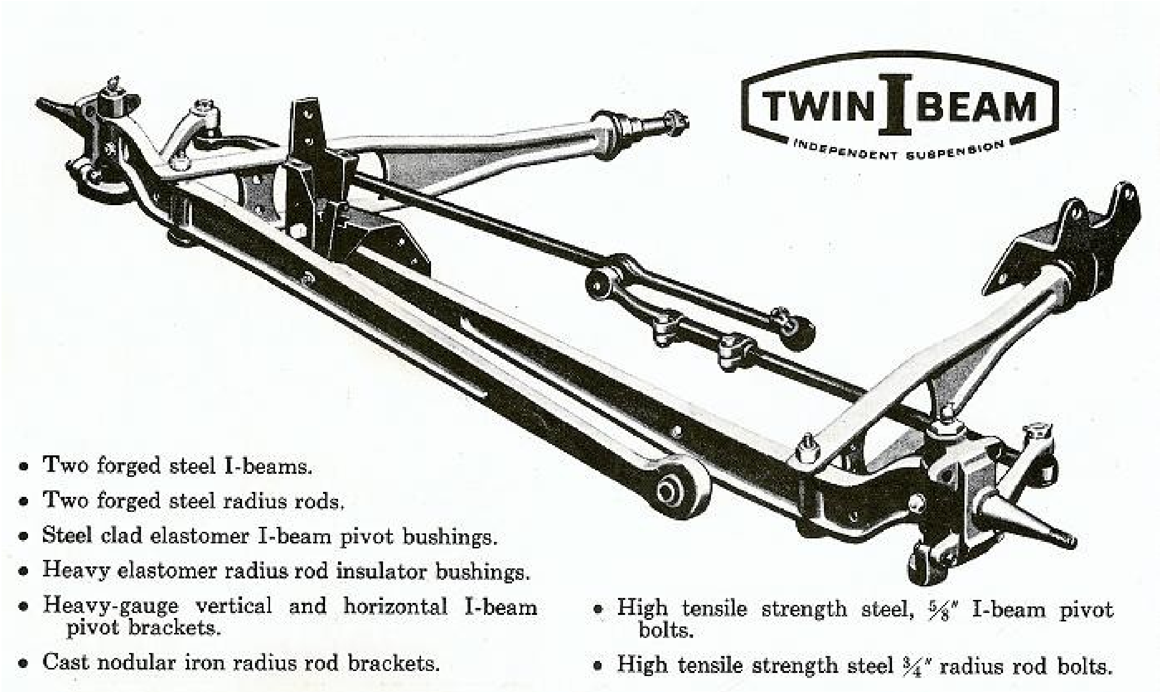
If the Pitman arm is angled backwards from the vertical position (in vehicle side view) then this offset will be negative (if the longitudinal axis is positive in the forward direction) or positive (if the longitudinal axis is negative in the forward direction).

8.8 Steering gear (direct)

These steering configurations use a steering box with a single Pitman arm.

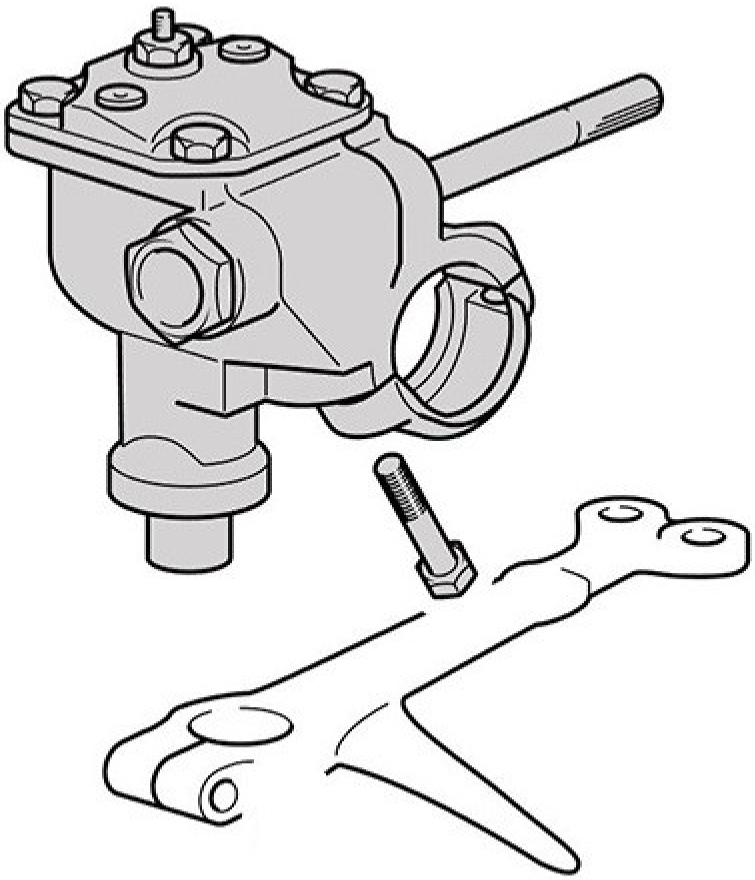


Typical Volkswagen Beetle steering, showing the two tie rods connected to a single Pitman arm.



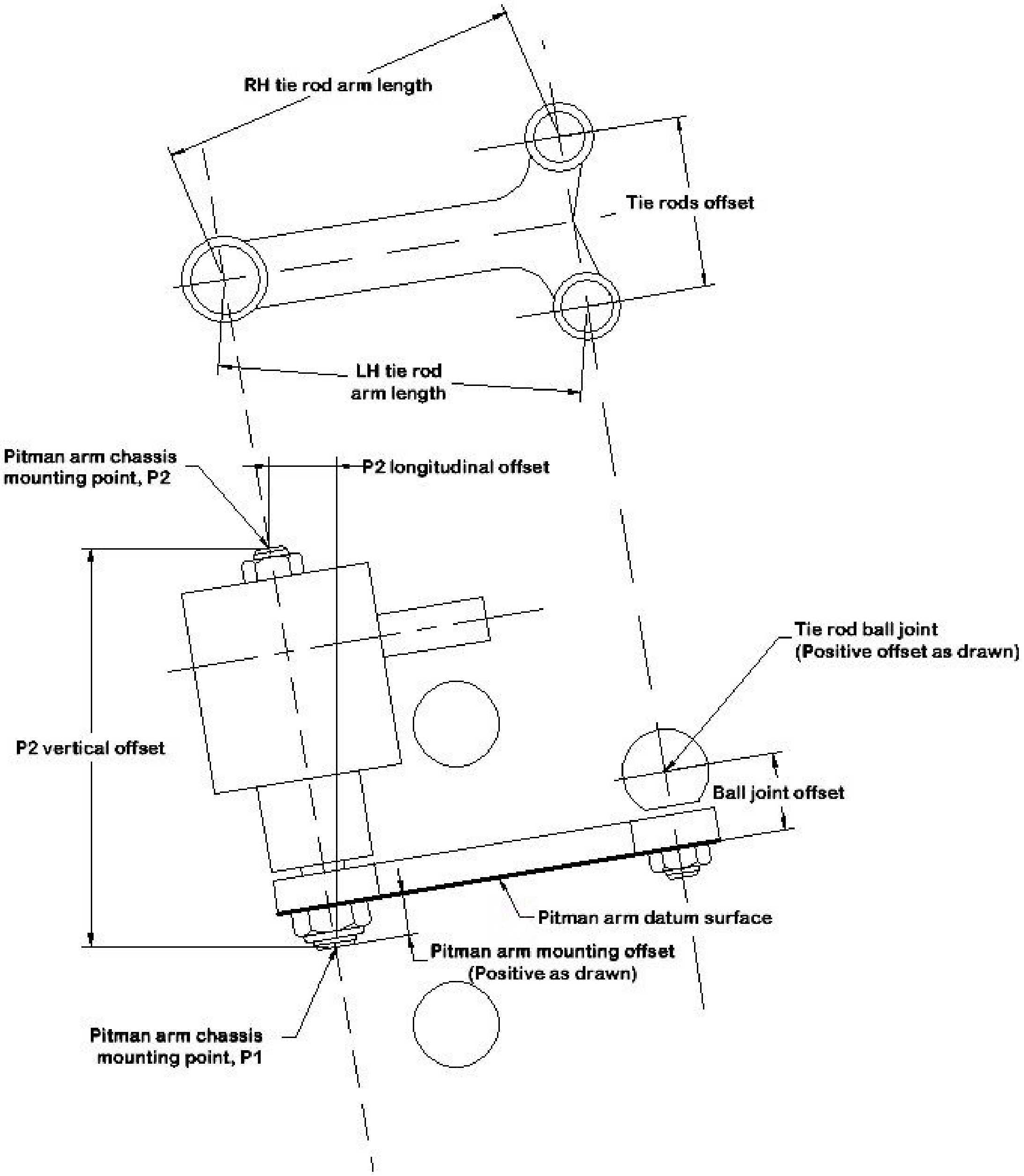
Typical Ford Twin I-Beam steering, showing the RH tie rod connecting to the Pitman arm (not shown) and RH front wheel, and the LH tie rod connecting to the RH tie rod and the LH front wheel.

8.8.1 Pitman arm (direct)



Enter the values for the pitman arm chassis mounting points, P1 and P2. These are two points on the steering gearbox sector shaft and define the pitman arm rotation axis. P1 is the primary location point (close to the pitman arm) and P2 is the secondary location point (on the top of the steering box).

Enter the length and offsets of the pitman arm.



Chassis mounting point P1:
Note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either [ground based vertical datum](), or [chassis based vertical datum](), and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

Chassis mounting point P2:
Note that these dimensions are relative to P1, and will be positive or negative in accordance with the specified axis system. They are measured in the chassis datum position, and P2 is always above P1.
Usually the P2 lateral dimension will be zero, unless the steering gear is not mounted vertically (in front view). If P2 is outboard of P1 then the P2 lateral dimension will be positive; if P2 is inboard of P1 then the P2 lateral dimension will be negative.
If the vertical axis is positive upwards, then the P2 vertical dimension will be positive, otherwise the P2 vertical dimension will be negative. Note that this is a vertical dimension (relative to the vertical datum) and not the axial distance between P1 and P2.
Usually P2 will be “ahead” of P1, as this angles the steering box so that the worm shaft is aligned with the steering wheel shaft. If P2 is ahead of P1, and the longitudinal axis is “positive forward”

then the P2 longitudinal dimension will be positive; if the longitudinal axis is “positive rearward” then the P2 longitudinal dimension will be negative.

There are two ball joints on the Pitman arm for the LH and RH tie rods.

Pitman arm LH and RH tie rod ball joint dimensions:

Arm datum surface:	This is the retaining nut contact surface of the pitman arm mounting boss on the steering gear shaft.
Arm length:	This is always positive.
Arm mounting offset:	This is measured axially from P1 to the pitman arm datum surface. If the pitman arm datum surface is offset towards P2 (the usual case) then this dimension will be positive.
Arm offset:	This is measured axially on the pitman arm datum surface, from the sector shaft mounting surface to the tie rod mounting surface. If the pitman arm is cranked downwards then this dimension will be negative.
Ball joint offset:	This is measured axially from the pitman arm datum surface to the centre of the tie rod ball joint. If the ball joint is offset towards P2 then this dimension will be positive.

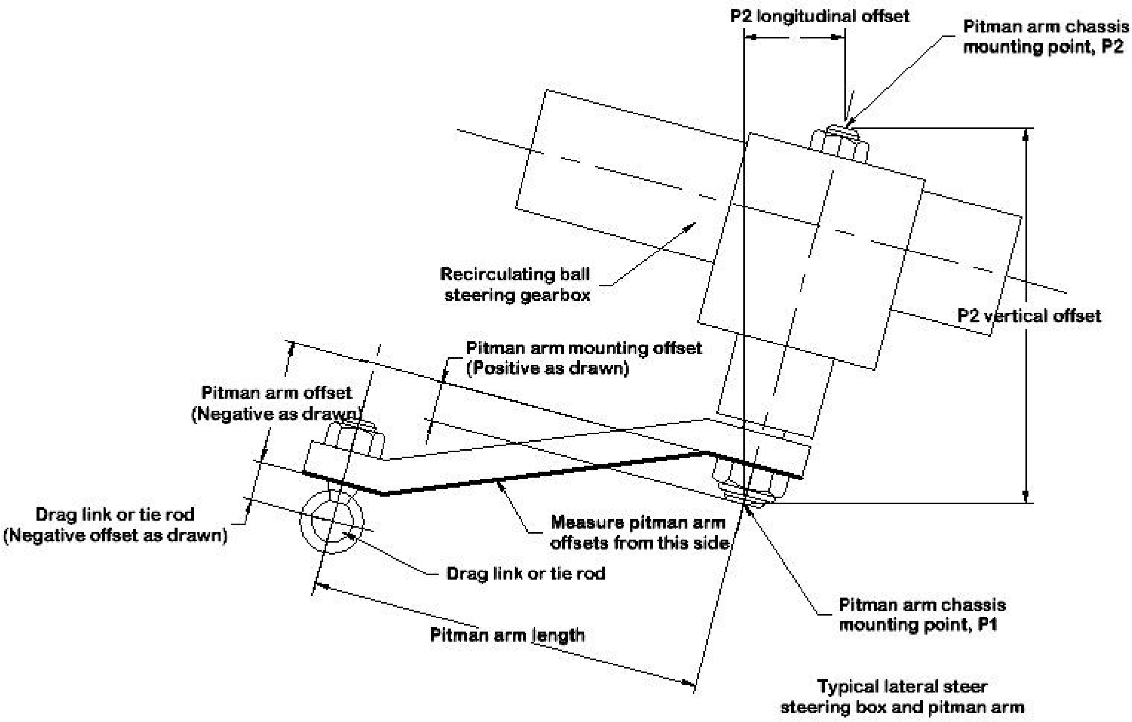
Tie rod offset:

This is the offset between the LH and RH rod ball joints in plan view.
This dimension is always positive.

8.8.2 Ford Twin I-Beam

Enter the values for the pitman arm chassis mounting points, P1 and P2. These are two points on the steering gearbox sector shaft and define the pitman arm rotation axis. P1 is the primary location point (close to the pitman arm) and P2 is the secondary location point (on the top of the steering box).

Enter the length and offsets of the pitman arm.



There are two tie rods.

One tie rod (the primary tie rod) connects from the pitman arm to the steering arm on the opposite side of the vehicle. For a LHD car, the steering gear is on the LH side, and the primary tie rod connects directly to the RH wheel.

The other tie rod (the secondary tie rod) connects to a point on the primary tie rod some distance from the point where the primary tie rod connects to the Pitman arm, and then to the wheel. For a LHD car, the secondary tie rod connects to the primary tie rod and to the LH wheel.

Note that the tie rod linkage isn't a dimensionally exact representation of the Ford linkage, but it is a reasonable approximation.

8.9 Steering arm (or toe control pickup point)

From the Steering tab, select Steering Arm.

Enter the values for the steering arm balljoint, or toe control pickup point.

This is the same dialog box as the initial upright / strut / axle design.

If you specify the rack location and want to calculate the upright steering arm ball joint to minimise the amount of bump steer, skip this menu choice and see calculate optimum steering arm position.

The steering arm length may need to be entered.

If the longitudinal dimension for the steering arm ball joint is ahead of the king pin axis, then this is front steer. If the longitudinal dimension for the steering arm ball joint is behind the king pin axis, then this is rear steer.

8.10 Wheelbase

From the Steering tab, select Wheelbase.

The wheelbase is calculated in accordance with the specified wishbone link lengths, the wheel alignment settings and/or the datum to front axle and datum to rear axle dimensions.

If you are only designing the front suspension, you will need to enter the rear axle to datum distance so that the wheelbase can be calculated.

8.11 Calculate the optimum rack or steering arm position

From the Steering tab, select the button between Wheelbase Datum and Travel.

This is a toggle button, and will be Fixed, Chassis, one of Chassis X or Chassis Y or Chassis Z and Upright. Clicking the button will advance to the next available option. The available options will depend on the specific steering / toe control configuration.

The chassis pivot points depend on the specific steering / toe control configuration.

- Rack and pinion. The chassis points are the tie rod pivots on the end of the rack.
- Recirculating ball with centre link. The chassis points are the tie rod pivots on the centre link. The pitman and idler arms must be fully dimensioned, together with the centre link clearances and length.
- Recirculating ball with intermediate link. The chassis points are the tie rod pivots on the Pitman and idler arms.
  The pitman and idler arms must be fully dimensioned.
- Recirculating ball. The chassis points are the tie rod pivot(s) on the Pitman arm.
  The pitman arm must be fully dimensioned.
- Rear suspension with a separate toe control link, the chassis points are the toe control link pivots on the chassis.

Fixed	Both the chassis location coordinates and the steering arm ball joint upright dimensions must be input. Calculate the toe variation with specified chassis and steering arm ball joint positions.
Chassis	The upright steering arm ball joint dimensions must be input. Using the specified upright steering arm ball joint position, the ideal chassis pivot positions will be calculated to minimise the toe variation, and positioned in line with the upright points in plan view. For recirculating ball with centre link steering this option will maintain the Pitman and idler arm mounting points and dimensions. It will change the tie rod mounting points on the centre link. For other recirculating ball type steering this option will only calculate the optimum tie rod mounting positions. Both the ideal and the actual position will be noted in the results.
Chassis X Chassis Y Chassis Z	Only one of these will be available, and will be the same as the character used for the longitudinal axis. The calculation is similar to the Chassis calculation above, but allows for specifying the longitudinal position of the chassis pivot. For the Volkswagen trailing link suspension, this option will be the same character as used for the lateral axis. The calculation is similar to the Chassis calculation above, but will hold the specified lateral position, ie it will not move the tie rod position laterally.

Upright — The chassis pivot point coordinates must be input.

Calculate the upright steering arm ball joint position to minimise the toe variation using the specified chassis pivot point location.

The upright steering arm ball joint points will be calculated to minimise the amount of bump steer. If the length of the steering arm is zero, the steering arm length will be calculated to position the steering arm ball joint in line with the chassis pivot point in plan view.

8.12 Toe-out in turn increment

From the Steering tab, select Toe turn.

Enter the required values.

The maximum turn angle is the angle through which the outside wheel is turned (from the straight ahead position). The default value is 30.00 degrees.

The increment can be any value (not exceeding the maximum turn angle). The default value is 5 degrees

The increment will determine the number of calculation points.
For example, if the maximum is 30 degrees, and the increment is 5 degrees, then there will be 6 calculations in each direction plus the straight ahead calculation; a total of 13 calculation points.

Toe-out in turn will be calculated for both wheels, with each wheel turned through the specified angle(s).

The outside wheel is turned through the specified increment (starting from the static alignment position) and the steering linkage is used to determine the resulting position of the inside wheel.

Depending on the steering configuration, when the outer wheel is turned the inner wheel may turn through a greater angle (typically when Ackermann geometry is employed) or a lesser angle (typically when anti-Ackermann geometry is employed). In either case, the calculation limit is reached when one wheel reaches a maximum turn angle of 57 degrees (1 radian). You will need to adjust the maximum turn angle if the calculation limit is reached.

If the rack travel or steering linkage determines the steering angle.

Often the steering turn angle is limited by the actual rack travel or the individual components of the steering linkage. To establish the maximum turn angle start with a reasonable value (say 20 degrees), and then do the steering calculation. Use the display and turn the wheels. Adjust the maximum turn angle and repeat until the required rack travel and/or turn angle is achieved. The maximum turn angle can be specified in decimal degrees.

Note for Excel exports.

Previous versions (V4.77 and earlier) always generated 13 calculation points. To avoid changing the Excel data, ensure that the maximum turn angle is exactly 6 times the increment angle.

8.13 Calculate

Before the steering calculations can be calculated, Roll Bump | Calculate must complete without error.

From the Steering tab, select Calculate.

This will do all Geometry, Roll Bump and Steering calculations.

The status bar will display a message ‘Calculating...’ followed by either ‘OK’ or an error message.

On fast processors, the ‘Calculating...’ message may not remain long enough to be visible.

8.14 Display the results

From the Steering tab, select Result.

This will open a result window with all the calculated steering values.

```
Auto-calculated rack pivot
Rack pivot point   -from car cl     x      259.36
                   -from ground     y      261.75
                   -from datum      z      100.08
Steering arm pivot -from wheel mtg  x      150.00
(on upright)       -from hub cl     y        0.00
                   -upright cl      z      100.00
Steering arm pivot -from car cl     x      548.07
(from car datum)   -from ground     y      255.05
                   -from datum      z      100.08
Toe link length (actual)                    288.79
Wheel toe reference length                  330.00

Bump steer           absolute                      relative
              degree          mm             degree          mm
100.00 bump     0.28        1.63    toe in     0.11        0.63    toe in
 80.00 bump     0.23        1.31    toe in     0.05        0.31    toe in
 60.00 bump     0.20        1.12    toe in     0.02        0.12    toe in
 40.00 bump     0.18        1.03    toe in     0.01        0.03    toe in
 20.00 bump     0.17        1.00    toe in     0.00        0.00
     static     0.17        1.00    toe in     0.00        0.00
 20.00 droop    0.17        1.00    toe in     0.00        0.00
 40.00 droop    0.17        0.97    toe in     0.01        0.03   toe out
 60.00 droop    0.15        0.86    toe in     0.02        0.14   toe out
 80.00 droop    0.11        0.64    toe in     0.06        0.36   toe out
100.00 droop    0.04        0.22    toe in     0.14        0.78   toe out

    Toe out in turns                  Camber gain/loss
     Outer     Inner    Rack travel    Outer     Inner
      0.00     -0.35          -0.29    -0.50     -0.47
      5.00      4.74           8.28    -0.89     -0.04
     10.00     10.11          16.99    -1.18      0.57
     15.00     15.86          25.76    -1.37      1.34
     20.00     22.08          34.51    -1.46      2.29
     25.00     29.05          43.18    -1.44      3.49
     30.00     37.35          51.73    -1.33      5.08
```

8.15 ECalc

Allows several modules to be calculated from one point.

For example, if the rack location is changed, you can recalculate all modules with one click.

See ECalc

8.16 Notes

Bump steer values are calculated for all positions of bump and droop, and are shown with both absolute and relative values. Absolute values are the actual toe-in or toe-out dimensions incorporating the specified static wheel setting. Both an angular value (in degrees) and a measurement (in mm) are shown. The measurement is based on the wheel toe reference length, which would usually be the wheel rim diameter. Relative values are calculated from the static wheel position and show the actual bump steer deviation from the static position.

For wishbone and strut suspensions, the Roll&Bump data is also updated with the toe changes. Select Roll&Bump then Result. Do not recalculate, as the Roll&Bump calculation always uses a fixed toe-in, only the Steering calculation uses the calculated toe-in.

Toe out in turn shows the effect of steering on the front wheel alignment.

The front wheels are steered through a range of angles, starting with a maximum LH turn back to the straight ahead position, then to a maximum RH turn. The The maximum turn angle and turn angle increment are set in Toe Turn.

The “toe out in turn” value is the included angle between the two front wheels.
A positive value means that the pair of wheels are “toed in”; a negative value means that the pair of wheels are “toed out”.
Increasing negative values means that the wheels are increasingly toeing out as the steering is turned.

Ackermann geometry will increasingly toe out; anti-Ackermann will increasingly toe in.

The individual wheel toe angles are also shown.
In a LH turn, the RH wheel will be turning in a "toe-in" direction and the LH wheel will be turning in a "toe-out" direction.
In a RH turn, the RH wheel will be turning in a "toe-out" direction and the LH wheel will be turning in a "toe-in" direction.

Also shown is the amount of steering rack or steering linkage movement required.

For both camber and caster, the actual values and the gain / loss are also shown.

The jacking effect figure is the amount that the bottom ball joint rises and falls as the wheel is turned.

The steering ratio is calculated for each position. It is calculated using the rack C-factor, the distance the rack moves from one position to the next, and the corresponding change in wheel toe angle. Strictly, it is the average steering ratio between each position rather than the actual steering ratio at that position.

For vehicles equipped with recirculating ball steering box (instead of rack and pinion) and the steering tie rods connected to a drag or cross link, then the inner tie rod ball joint is equivalent to the rack ball joint.

The steering arm actual and effective lengths are calculated.
The actual length is the distance from the upright ball joint to the king pin axis (normal to the king pin axis), and the effective length is the distance between the king pin axis and the steering tie rod (normal to both lines).

The rack C-factor is the distance the rack moves for one turn of the pinion.
For recirculating ball steering, the steering box ratio is the number of turns of the input shaft (the steering wheel) for one turn of the output shaft (the pitman arm).

The steering ratio - nominal (straight ahead) is the kinematic ratio between the steering wheel and the steered wheels

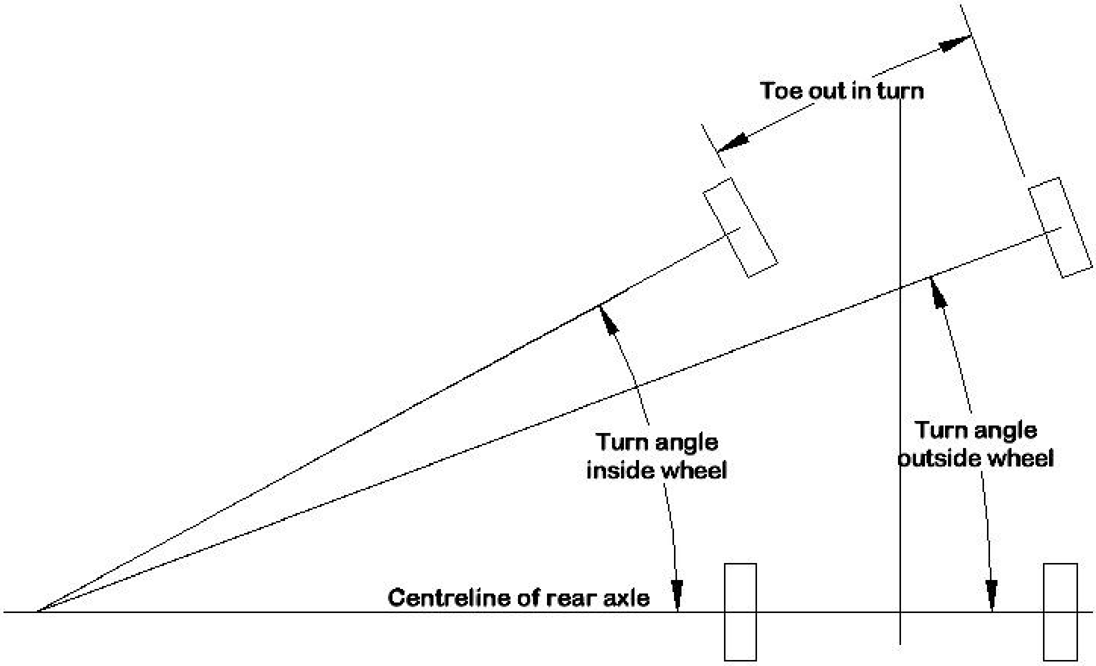
The turning radius is the theoretical turning radius at the centre of the tyre contact.
A line normal to the outside wheel is projected back to the line of the rear axle and this intersection point is used as the turning point. No allowance is made for tyre slip angle.

The turning circle (curb-to-curb) is twice the turning radius plus the tyre width.

The steering wheel turns, lock to lock is the number of turns of the steering wheel for the full rack travel or maximum steer angle. It assumes a constant rack C-factor (rack and pinion) or steering box ratio (recirculating ball).

Ackermann calculation.

For 100% Ackermann, the inner wheel must be turned such that the lines drawn from the centre of the tyre contact point (normal to the tyre centreline) both meet on the line drawn from the rear axle. The pair of wheels are "toed out".
Note that "toe out" is negative and "toe in" is positive.



Wheel angles for 100% Ackermann steering

If the inner wheel is turned further than required, then the Ackermann percentage will be greater than 100%.
If the inner wheel is turned less than required, but is still turned greater than the outside wheel, then the Ackermann percentage will be less than 100%.
If the inner wheel is turned the same as the outer wheel, then the Ackermann percent will be 0%. In this instance, the wheels are parallel.
If the inner wheel is turned less than the outer wheel, then the Ackermann percentage will be negative. In this instance the pair of wheels are "toed in".

For small turn angles, the initial wheel alignment setting has a far greater influence than the Ackermann effect.

For example, if the initial wheel alignment is toe-out, then the initial toe-out will be greater than that required for 100% Ackermann, hence the Ackermann percent may be much greater than 100%. At some further turn angle, the steering geometry starts to exert more influence.

Similarly, if the initial wheel alignment is toe-in, then the initial toe-out will be much less than that required for 100% Ackermann (and may even be negative).

All of the above assumes a zero slip angle on all tyres.

This version calculates the actual camber and caster settings. SusProg3D V4.25 and earlier, used the following formula to estimate the camber change in turn.

> Camber gain/loss is the actual camber as the wheel is turned through the wheel steer angles. For realistic steer angles, a positive kingpin inclination angle causes a positive camber on the outer wheel and positive castor causes a negative camber on the outer wheel. See [DIXO96] for a complete description.
>
> The actual camber angle is $\gamma = \gamma_o + \arccos(\sin\theta_k \cos\delta) + \theta_k + \arccos(\sin\theta_c \sin\delta) - 180$

where γ_o is the initial camber, θ_k is the kingpin inclination angle, θ_c is the castor angle, and δ is the wheel steer angle.

9 Driveline

There are several driveline configurations.

- Independent suspensions and deDion rear suspension have driveshafts, typically incorporating a chassis mounted differential or transmission with a pair of driveshafts to each wheel.
- Live front axle suspensions have propshafts, typically incorporating a longitudinally mounted transfer box with either a single or two-piece propshaft connecting to the front axle.
- Live rear axle suspensions have propshafts, typically incorporating a longitudinally mounted transmission with either a single or two-piece propshaft connecting to the rear axle.
- 4WD vehicles typically have a transmission (gearbox) and a transfer box. The transfer box is driven from the transmission, and the transfer box output shaft(s) are parallel to the transmission shaft. The front propshaft is driven from the transfer box. The rear propshaft can be driven from either the gearbox or the transfer box.

Note that this is equally applicable to the front suspension for inboard front brakes or FWD/4WD, although the terminology is more appropriate for the rear suspension.

Also Roll&Bump | Calculate must successfully execute before this can be calculated.

9.1 Configure

The basic vehicle Driveline configuration is specified in Vehicle | Config, by specifying the brake location, FWD, RWD and suspension geometry.

This section further specifies the Driveline type.

From the Driveline tab, select Configure.

For front IFS, there will be a driveshaft if either inboard brakes or front wheel drive is specified.
For front live axle, there will be a propshaft.

For the rear there will be a driveshaft if the suspension type is Jaguar, or the suspension type is IRS and either inboard brakes or rear wheel drive is specified, or de Dion.
There will be a propshaft for live axle (except de Dion).

For a driveshaft:

Specify either "Variable" or "Fixed" length driveshaft.

Variable length is for the type of driveshaft with sliding splines and (usually) fixed hookes-type universal joints.
Fixed length driveshafts are constant length and (usually) have Constant Velocity joints which provide the necessary axial length variations. For fixed length driveshaft, enter the length if required.

In the case of a swing axle suspension there is only one universal joint. The universal joint will be located on the trailing arm “link” that has zero vertical and longitudinal offsets.
If the universal joint is on the rear link, then try and minimise the ‘mounting error’ reported in the static geometry results. Do this by adjusting the longitudinal offset of the front link, or the longitudinal location of the chassis mounting point.

For the suspension types where the driveshaft is used as a suspension member, for example, Corvettes and Jaguars, there is an additional driveshaft option "Fixed length driveshaft (top lateral link). This uses the driveshaft as the top lateral link.

For a propshaft:

Specify either one-piece or centre bearing (two piece).

Specify the spline location.

- “Input shaft spline” is where the propshaft length (universal joint to universal joint) is fixed, and the input universal joint is part of a sliding yoke that is splined to the transmission output shaft. This is the typical front engine- RWD configuration.
- “Output shaft spline” is the opposite arrangement to the “input shaft spline”, in that the splined end slides on the output shaft. An uncommon arrangement.
- “Fixed flanges, spline” is where the propshaft has a flange at each end (which may be a circular flange, or a yoke that attaches to the universal cross) and the propshaft itself has a sliding spline.

For a 4WD vehicle with a transfer box, the rear propshaft can be driven from either the transmission or the rear of the transfer box. Specify which. In this case, the front propshaft is always driven from the front of the transfer box.

Specify the engine / transmission axis. This requires two points, one is the front of the engine. Often the nose of the crankshaft, or the centre of the crankshaft pulley is a convenient point. The other is the centre of the transmission universal joint (in the static vehicle position). If the rear propshaft doesn’t connect to the transmission (it connects to the transfer box) then this point can be any convenient point that defines the rear end of the engine / transmission axis.
For the “long style” torque tube axle, the gearbox universal joint will be the same point as the torque tube mounting.
It is assumed that the transmission output is coaxial with the engine crankshaft.

Specify the transfer box axis. This requires two points, one is the centreline of the front universal. The other is the centre of the transmission universal joint (in the static vehicle position). If the rear propshaft doesn’t connect to the transfer box (it connects to the transmission) then this point can be any convenient point that defines the rear end of the transfer box axis.
It is assumed that the transfer box is parallel with the engine / transmission axis.

If there is a centre bearing, specify the centre bearing uj centre, in the static or nominal position.

All axial movement of the propshaft(s) will be either 1) along the line of the engine / transmission, or 2) along the line of the axle pinion shaft, or 3) within the propshaft. If a two piece propshaft is specified as “Fixed flanges, spline” then is it assumed that the length variation is in the second propshaft (ie the propshaft between the centre bearing and the axle).

When specifying propshaft lengths and universal joint centres, remember that it is always to the universal joint centre. This may require that you allow for the distance from the universal joint centre to the face of the attaching flange, and add or subtract this dimension as appropriate.

Torque tube rear axles generally come in two configurations: the “long style” where the torque tube extends all the way from the rear axle to the gearbox and the torque tube ball joint is concentric with the gearbox universal; and the “short style” where the torque tube extends about halfway between the axle and the gearbox with the torque tube ball joint supported on an intermediate cross member, with a short propshaft connecting to the gearbox.
For the “long style”, specify the propshaft as “none”. This will also set the gearbox universal joint to be the same point as the torque tube mounting.

Chassis mounting points:

Note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

If there are no driveline components, none of the following commands will be available.

9.2 Car end and car side

The [Front] or [Rear] tab choice will indicate the currently selected vehicle end.

The [LH] or [RH] tab choice will indicate the currently selected vehicle side.

These tabs acts as a toggle, and selecting this tab will switch between each of two.

Depending on the vehicle configuration, some menu bar items may not be available.

When a dialog box is opened, the title will include the currently selected car end and car side. If the car side is not shown, then the dialog box applies to both sides. If the car end is not shown, then the dialog box applies to both ends.

9.3 Driveline components - driveshaft

9.3.1 Gearbox

This is the inboard end of the driveshaft.

From the Driveline tab, select Gearbox.

Enter the values for the gearbox, transmission or differential UJ point.

If it is needed to calculate the UJ location to minimise the amount of driveshaft plunge, do not enter these dimensions.

Chassis mounting points:
Note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

9.3.2 Hub

This is the outboard (or wheel) end of the driveshaft.

From the Driveline tab, select Hub.

Enter the lateral value of the UJ point.

Note that only a lateral value is entered as it is assumed that the UJ is on the stub axle centreline.

9.3.3 Length

From the Driveline tab, select Length.

Specify either "Variable" or "Fixed" length driveshaft. Variable length is for the type of driveshaft with sliding splines and (usually) fixed hookes-type universal joints. Fixed length Drivelines are constant length and (usually) have Constant Velocity joints which provide the necessary axial length variations. For fixed length driveshaft, enter the length if required.

After calculation, the distance between the centrelines of the CV joints will also be shown for reference. If it is required that the driveshaft length be equal to the distance between the centrelines of the CV joints then enter a value of 0.00 and the correct value will be calculated.

9.4 Driveline components - propshaft

The engine / transmission centreline, transfer box centreline, and centre bearing (if applicable) are all specified in the driveline configuration.

9.4.1 Length

From the Driveline tab, select Length.

After calculation, the propshaft length(s) will also be shown.

9.5 Calculate the optimum UJ position

From the Driveline tab, select the toggle button, which will be Auto or Fixed. Each selection will change to the next in turn.

Fixed The gearbox universal joint location must be input.

Auto Calculate the gearbox universal joint position to minimise the amount of driveshaft plunge, and be positioned in line with the upright universal joint in plan view.

The upright universal joint location must be input.

Auto will always recalculate the driveshaft length (whether variable or fixed length) to be equal to the distance between the universal joint centrelines in the static position.

AutoCalc is not available for deDion, live axle or Jaguar rear suspensions, and will always be [Fixed].

9.6 Calculate

Before the driveline calculations can be calculated, Roll Bump | Calculate must complete without error.

From the Driveline tab, select Calculate.

This will do all Geometry, Roll Bump and Driveline calculations.

The status bar will display a message ‘Calculating...’ followed by either ‘OK’ or an error message.

On fast processors, the ‘Calculating...’ message may not remain long enough to be visible.

9.7 Display the results

From the Driveline tab, select Result.

This will open a result window with all the calculated Driveline values.

```
Fixed inner uj pivot, fixed length driveshaft
Inner uj pivot point -from car cl      x      150.00
                     -from ground      y      250.00
                     -from datum       z        0.00
Outer uj pivot point -from wheel mtg   x      150.00
Outer uj pivot point -from car cl      x      522.61
(from car datum)     -from ground      y      273.68
                     -from datum       z        0.00
Driveshaft length (static)                     365.00
Length between uj pivot cls (static)           373.36
                Drive shaft   Universal joint         UJ Angle
                   length         plunge          inner     outer
```

100.00	bump		-7.31	18.17	14.14
80.00	bump		-9.05	15.36	12.34
60.00	bump		-9.99	12.51	10.32
40.00	bump		-10.17	9.62	8.12
20.00	bump		-9.64	6.69	5.75
	static	365.00	-8.37	3.72	3.22
20.00	droop		-6.36	0.71	0.54
40.00	droop		-3.51	2.34	2.31
60.00	droop		0.30	5.46	5.35
80.00	droop		5.29	8.66	8.64
100.00	droop		11.87	11.98	12.26

9.8 ECalc

Allows several modules to be calculated from one point.

For example, if the gearbox universal location is changed, you can recalculate all modules with one click.

See ECalc

9.9 Notes

For a variable length driveshaft the nominal or static driveshaft length will be calculated from the centres of the universal joints at the static position.

For a variable length driveshaft, negative plunge is the amount of extension required from the static length and positive plunge is the amount of compression required from the static length.

For a fixed length driveshaft, negative plunge is the amount of outwards movement that must be provided by the CV joint, and positive plunge is the amount of inwards movement that must be provided. Plunge is measured from the nominal centreline of the CV joint outer housing. All plunge is assumed to be in the inboard joint. In practice, the driveshaft length would be adjusted such that the required plunge is approximately equal in both directions.

The length of a fixed length driveshaft is the distance between the CV joint inner spider centrelines. The CV joint outer housing centreline is used to define the chassis and upright dimensions that locate the inner and outer joints, and to calculate the distance between the CV joint centrelines.

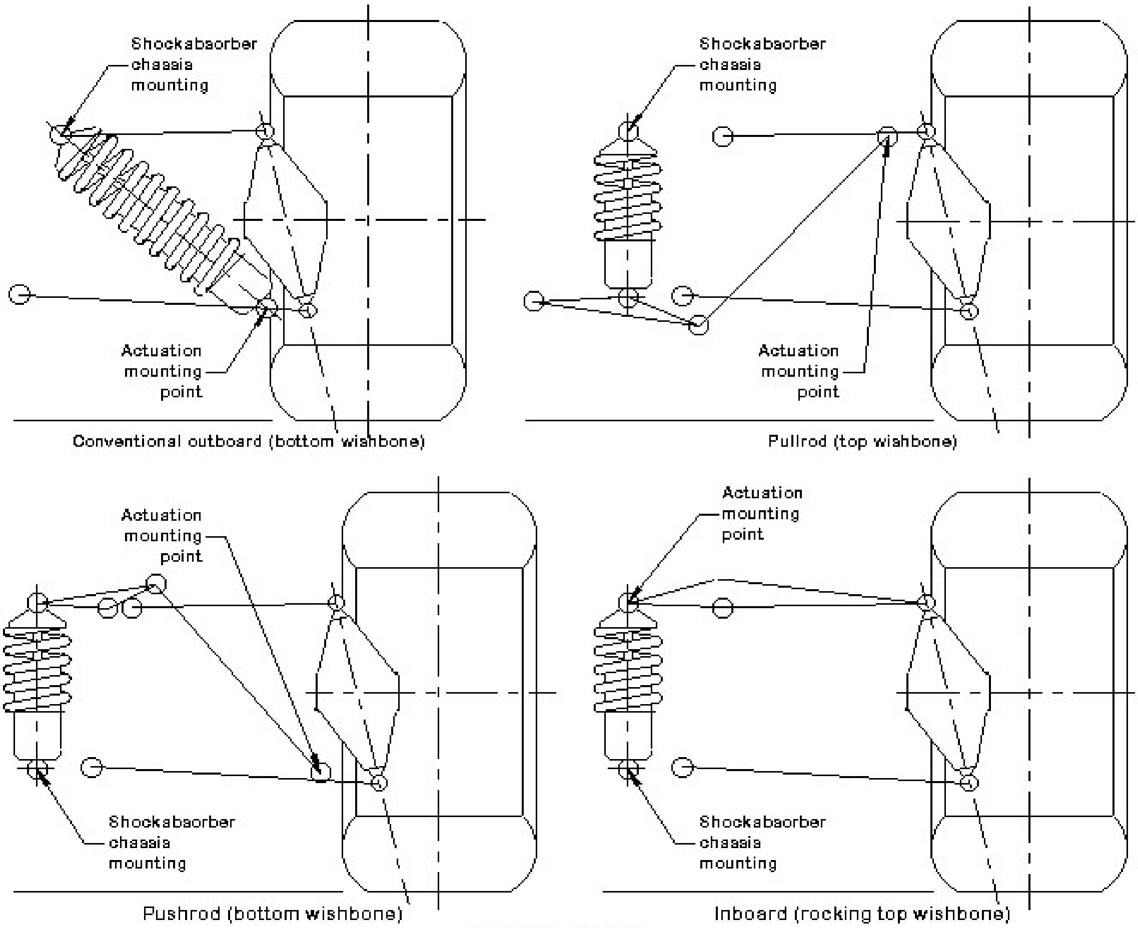
Designers of older vehicles fitted with rubber doughnuts that provide the required axial movement should specify fixed length driveshaft where the length is equal to the uj centreline length. This ensures the minimum deflection of the doughnut in the static position.

Also shown is the amount of angular movement that the driveshafts adopt during suspension travel for both inner and outer universals.

For both one and two-piece propshafts, it is assumed that all length variation is provided at the transmission universal joint, by way of a splined connection. A positive value for plunge means that the spline move inwards, and a negative value means that it moves outwards.

The propshaft angles are the true angles between the two shaft centrelines. They are always shown as positive angles.

10 Spring, shockabsorber & antirollbar



Suspension types

Note that before any of the spring, shockabsorber and/or anti-roll bar can be calculated, Roll Bump | Calculate must complete without error.

Note:

If you change the suspension travel limits when doing Geometry calculations you must redo the Spring Rate calculations to use the new values for the maximum wheel bump and droop travel.

Some of the values require that the full bump and full droop positions have been calculated. If these results are displayed after calculating the Static values, but before doing the Rates calculation, then some of these values may be incorrect. If these results are displayed after doing the Rates calculation, they will be correct.
The values are those that rely on the bump and droop data include the shockabsorber compressed and extended lengths, and the spring compressed length and preload.
Additionally, the spring parameters require that the mass and spring dimensions have been specified.

10.1 Configure

In addition to specifying the basic linkage geometry in Vehicle Configure, the location style of bellcrank, shockabsorber(s), spring(s) and antiroll bar is specified here.

From the Spring, Shock, ARB tab, select Config.

SusProg3D allows for various combinations of bellcrank, one or two shockabsorbers, one or two springs and an antiroll bar. The spring can be located independently from the shockabsorber, or as a coilover mounted on the shockabsorber.

Most racing vehicles have a single shockabsorber with a coilover spring per side.

Other common variations include

- NASCAR front, with two shockabsorbers and a single spring
- Jaguar rear, with two coilover shockabsorbers
- Most production car trailing arm rear, with a single shockabsorber and spring
- Some older production cars have lever arm shockabsorbers. MGB and Austin-Healy are typical. In this case specify the shock as 'Lever arm'. There are no motion ratio calculations for the lever arm shockabsorber.

Shock 1	Specify the location style of the (primary or only) shockabsorber.
Shock 2	Specify the location style of the second shockabsorber. If there is not a second shockabsorber, then choose ‘none’.
Spring 1	Specify the location style of the (primary or only) spring.
Spring 2	Specify the location style of the second spring. If there is not a second spring, then choose ‘none’.
Bellcrank	Specify the location style of the pushrod or pullrod. If there is not a bellcrank, then choose ‘none’.
Antirollbar	Specify the location style of the antirollbar. If there is not an antirollbar, then choose ‘none’. Even if there is an antirollbar, it is usually easier to exclude it from the initial calculations until the other suspension components have been dimensioned and calculated.

Specify if the shock body attaches to the chassis or to the wishbone, upright or bellcrank. This is used to correctly display the shock absorber orientation.

The specified configuration will be the same for both sides of the vehicle. For example, if you have currently selected [Front] and [RH], and specify that there is a second shockabsorber, this will apply to both [Front] [RH] and [Front] [LH].

There is complete freedom to specify different LH and RH mounting points for the same component.

The following limitations currently apply:

- The minimum selection is a single shockabsorber, “Shock 1” with a coilover spring, “ Spring 1”.
- If a spring is specified as ‘Coilover’ then there must be a corresponding shockabsorber. For example, if Spring 2 is ‘Coilover’ then Shock 2 cannot be ‘none’.
- Bellcrank monoshock and third spring configurations are not supported.
- There is only provision for a single shockabsorber with coilover spring in conjunction with bellcrank actuation. This version does not support the Riley and Scott configuration where the shockabsorber and spring are attached to separate arms on the bellcrank.

If the combination of suspension elements specified is not supported, an error message will display indicating the invalid combination.

10.2 Car end and car side

The [Front] or [Rear] tab choice will indicate the currently selected vehicle end.

The [LH] or [RH] tab choice will indicate the currently selected vehicle side.

These tabs acts as a toggle, and selecting this tab will switch between each of two.

Depending on the vehicle configuration, some menu bar items may not be available.

When a dialog box is opened, the title will include the currently selected car end and car side. If the car side is not shown, then the dialog box applies to both sides. If the car end is not shown, then the dialog box applies to both ends.

10.3 Chassis mounting

From the Spring, Shock, ARB tab, select Chassis Mtg.

Each shockabsorber and 'non-coilover' spring will require a chassis mounting point.

Enter the values for the shock absorber(s) chassis mounting point.

If the spring is not a ‘coilover’, then enter the values for the spring(s) chassis mounting point.

If the spring is a ‘coilover’, there is not a spring chassis mounting input, as the spring shares the shockabsorber mounting point.

For struts with 'coilover', there is no chassis mounting input required, as the chassis mounting point is the strut mounting point.

Note that for the bellcrank floating shockabsorber type where the shockabsorber connects between the bellcrank and wishbone, there is no chassis mounting input required. This input is for the shockabsorber mounting to the wishbone. See suspension actuation point.

Torsion bar location

Longitudinal torsion bar connecting to the bottom wishbone.

Actuation point.
Specify if the torsion bar attaches to the rear wishbone chassis mounting or the front wishbone chassis mounting.

Anchor point.
Specify if the torsion bar extends forward along the wishbone pivot axis; extends rearwards along the wishbone pivot axis; or has a specified anchor point (the torsion bar is not co-axial with the wishbone pivot axis).

Chassis anchor point.
If a specified anchor point, enter the point coordinates relative to the chassis datum. After calculation this will show the actual anchor point.

Transverse torsion bar.

Actuation point.
For the transverse torsion bar that uses the bottom trailing link as the arm, this point is the bottom trailing link chassis mounting.
For the transverse torsion bar where the arm "slides" on top of the axle tube, this point should be in the centre of the arm.

Anchor point.
The anchor point is the "fixed" end of the torsion bar, with some type of adjustment for ride height. It is usually on the opposite side of the vehicle, so in this case the sign of the lateral dimension will be negative.

For a T-bar antiroll bar the chassis mounting points are the points where the horizontal chassis mounting tube attaches to the chassis.

Chassis mounting points:
Note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

10.4 Leaf spring chassis mounting

From the Shock, Spring and Arb tab, select Chassis.

The primary chassis location point is the spring centre bolt. The vertical dimension is taken to the underside of the main leaf, the lateral dimension is taken to the spring centre bolt (which would usually be zero for a lateral leaf spring, but is positive in the direction of the positive lateral axis if the mounting is offset), and the longitudinal dimension is taken to the spring centre bolt.

There are three other dimensions, which specify the “tilt” of the spring mounting in plan, front and side view. These are specified in degrees, and are relative to the positive axis directions.

In most cases, if the vehicle is sitting level in the static position (relative to the chassis datums) then all of these dimensions can be left at zero. Small differences will have little effect on the calculations.

“Front view tilt” controls the “tilt” of the spring mounting in front (or rear) view. If the spring mounting pad is not horizontal in front view, then this will the “tilt” (in degrees) of the mounting pad.

If the positive lateral axis is	and the positive vertical axis is	and the positive longitudinal axis is	and the design side is	and the design side is higher than the other side, then the angle is
LH	upwards	rearwards	RH	negative
			LH	positive
		forwards	RH	positive
			LH	negative
	downwards	rearwards	RH	positive
			LH	negative
		forwards	RH	negative
			LH	positive
RH	upwards	rearwards	RH	positive
			LH	negative
		forwards	RH	negative
			LH	positive
	downwards	rearwards	RH	negative
			LH	positive
		forwards	RH	positive
			LH	negative

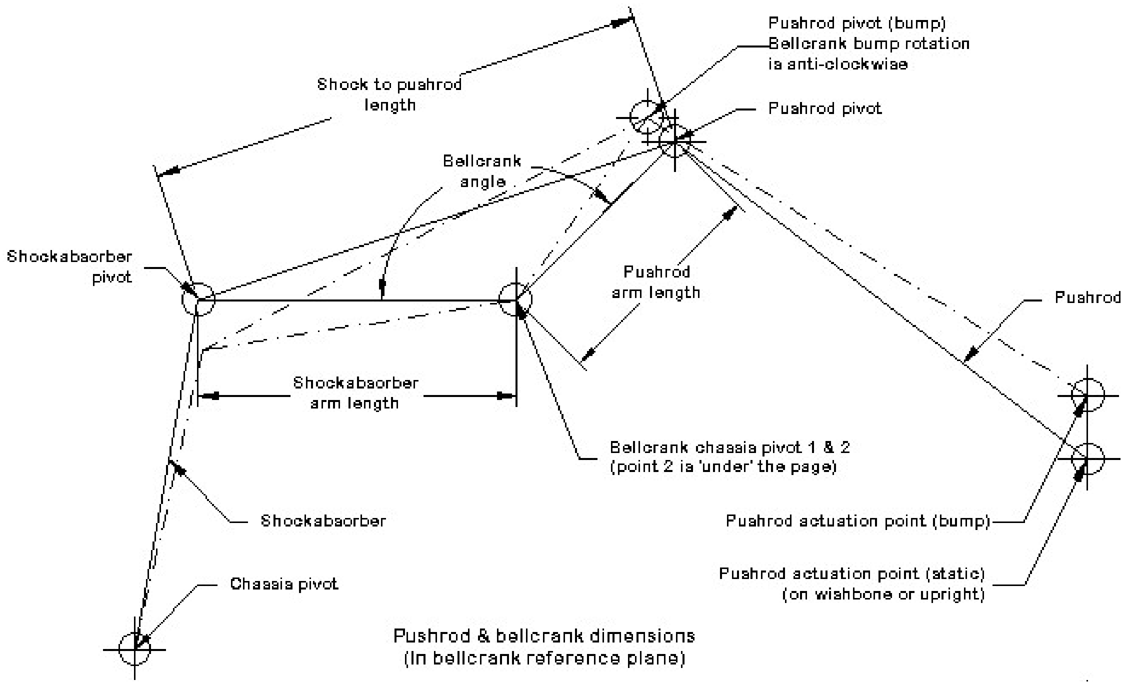
Similarly, “Side view tilt” controls the “tilt” of the spring mounting in side view. If the spring mounting pad is not horizontal in side view, then this will the “tilt” (in degrees) of the mounting pad.

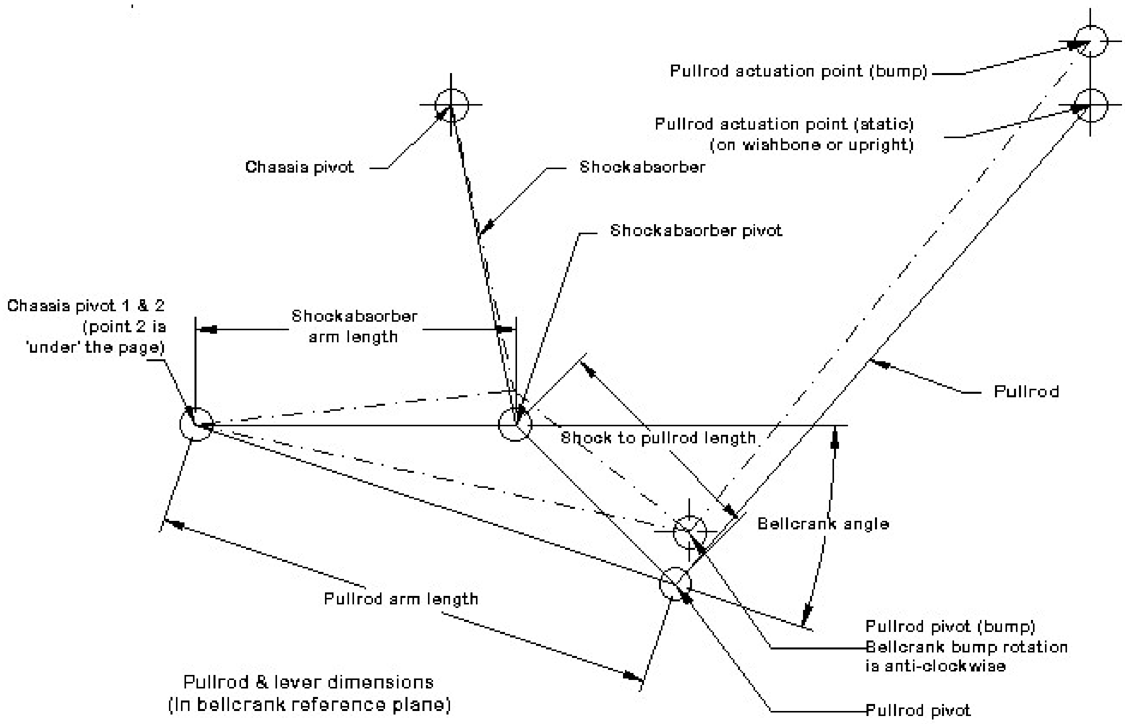
If the positive vertical axis is	and the positive longitudinal axis is	and the rear side is higher than the front side, then the angle is
upwards	rearwards	negative
	forwards	positive
downwards	rearwards	positive
	forwards	negative

Similarly, “Plan view twist” controls the “twist” of the spring mounting in plan view, and is usually zero for a symmetrical vehicle.

If the positive lateral axis is	and the positive longitudinal axis is	and the design side is	and the design side is further forward than the other side, then the angle is
LH	rearwards	RH	negative
		LH	positive
	forwards	RH	positive
		LH	negative
RH	rearwards	RH	positive
		LH	negative
	forwards	RH	negative
		LH	positive

10.5 Bellcrank mountings





This is only available if a pullrod or pushrod bellcrank has been specified.

From the Spring, Shock, ARB tab, select Bellcrank.

Enter the values for the bellcrank chassis pivot axis.

Point 1 is the chassis pivot point in the reference plane of the bellcrank (and this would usually be in the centre of the bellcrank bearing).

Point 2 is a reference point on the bellcrank pivot axis and can be any convenient point. Note that point 2 values are relative to the bellcrank pivot chassis location point 1. A positive lateral dimension means that point 2 is further outboard than point 1. If the vertical axis is positive upwards, a positive vertical dimension means that point 2 is above point 1; if the vertical axis is positive downwards, a positive vertical dimension means that point 2 is below point 1. If the longitudinal axis is positive rearward, a positive longitudinal dimension means that point 2 is rearward of point 1; if the longitudinal axis is positive forward, a positive longitudinal dimension means that point 2 is forward of point 1.

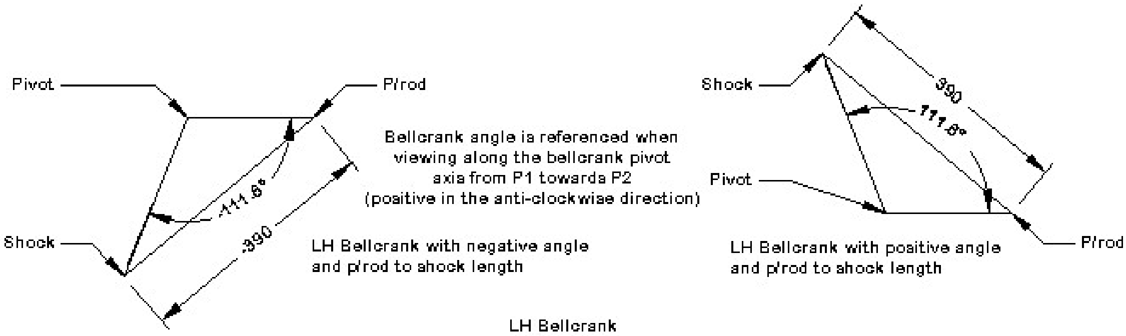
If the “Calc pivot 2?” checkbox is ticked, then the bellcrank pivot axis will be calculated such that a line from the shock absorber chassis mounting point to the bellcrank pivot axis forms a right angle; and a line from the pullrod (or pushrod) attachment point on the wishbone (or upright) to the bellcrank pivot axis forms a right angle.
This ensures that the shock absorber chassis mounting point lies on the rotational plane of the bellcrank shock arm; and the pullrod (or pushrod) attachment point on the wishbone (or upright) lies on the rotational plane of the bellcrank pushrod/pullrod arm. In the static position, this will eliminate any axial loading in the bellcrank bearings.
Additionally, the calculation uses the entered value of point 2 to determine the orientation of the bellcrank axis, and will update it with the calculated value.

If the calculated point 2 is not in the desired direction, then remove the -ve sign from the negative dimensions and add a negative sign the positive dimensions and then recalculate.

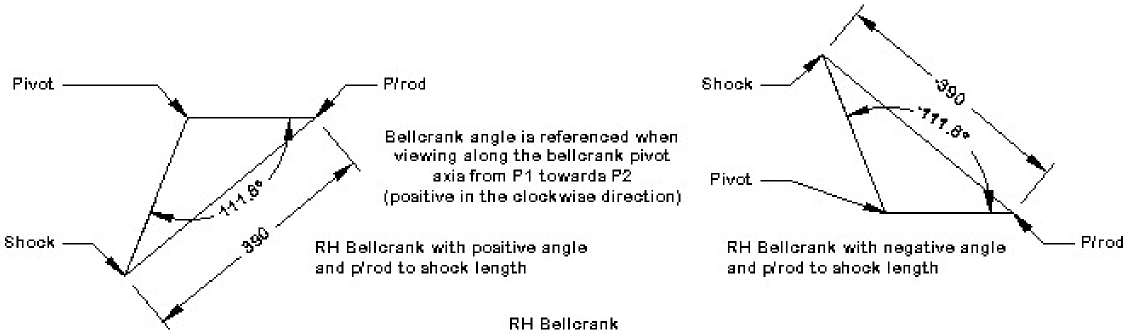
Note that this functionality is available for shockabsorber and bellcrank configurations.

Specify the direction of bellcrank rotation in bump.

Enter the bellcrank rotation direction when the wheel is moved into a bump position. The bellcrank rotation is referenced looking along the bellcrank pivot axis in the direction of point 1 towards point 2. Ensure that the car side shown in the dialog box title is the same as the vehicle side that you are "bumping", because the LH and RH bellcranks rotate in opposite directions in bump.



LH Bellcrank



RH Bellcrank

Enter the values for the bellcrank.

The bellcrank will have either two or three arms, one for each of the pull or pushrod, one for the shockabsorber (if specified) and one for the antirollbar (if specified).

For the pullrod or pushrod arm, enter the length and offset of the bellcrank arm.

If a bellcrank actuated shockabsorber is specified, enter the length and offset of the bellcrank arm, and either the distance between the shock mounting point and the rod mounting point, or the angle between the two arms. The other dimension will be calculated when the static calculation is done.
Note that if the pullrod calculation is specified as “Autocalc”, neither the distance nor the angle can be specified as both will be calculated.

If a bellcrank actuated antirollbar is specified, enter the length and offset of the antirollbar arm, and either the distance between the antirollbar mounting point and the rod mounting point, or the angle between the two arms. The other dimension will be calculated when the static calculation is done.

The arm lengths are measured in bellcrank plan view, and the offsets are relative to the bellcrank reference plane. The offsets are positive if in the same direction as the bellcrank pivot axis reference point, negative if in the opposite direction.

Shock to p/rod pivot length is the distance between the shock absorber connection point and the pushrod connection point.
For the LH bellcrank, the distance is positive when the shock mounting point is closest anti-clockwise, and negative when clockwise.
For the RH bellcrank, the distance is positive when the shock mounting point is closest clockwise, and negative when anti-clockwise.

The bellcrank angle will be 0 when all three points (rod, shock and pivot) are in a straight line with the rod and shock pivots on the same side of the bellcrank pivot.
The bellcrank angle will be 180 when all three points (rod, shock and pivot) are in a straight line with the rod and shock pivots on opposite sides of the bellcrank pivot.

Bellcrank angle is measured in the bellcrank reference plane, with pivot point 2 'away' and the p/rod point to the right.
Bellcrank angle is between -180 and +180 degrees.
For the LH bellcrank, the angle is positive when the shock mounting point is closest anti-clockwise, and negative when clockwise.
For the RH bellcrank, the angle is positive when the shock mounting point is closest clockwise, and negative when anti-clockwise.

Note that both the angle and the shock to p/rod distance will either be both negative, or both positive.

Usually, the LH and RH bellcrank angles and shock to p/rod pivot lengths will be equal and opposite.

Except for the pivot axis reference point, shock to p/rod distance, and pivot point offsets, all bellcrank dimensions are positive and are measured in bellcrank plan view.

For pullrod configurations, the bellcrank is more usually referred to as a lever although the menu input is the same.

Chassis mounting points:
Except for the pivot axis reference point, note that lateral values are horizontal measurements from the chassis centreline, vertical values are vertical measurements from the chosen chassis vertical datum, either ground based vertical datum, or chassis based vertical datum, and longitudinal values are horizontal measurements from the chosen chassis longitudinal datum.

10.6 Suspension actuation point

This will be the attachment point of the shockabsorber, spring, pushrod or pullrod to the A-arm, suspension link or upright depending on the spring type chosen.

Each of the configured shockabsorbers will require a linkage mounting point.

If a configured spring is not a ‘coilover’, then the spring will also require a linkage mounting point.

For struts with 'coilover', there is no linkage mounting input required, as that point is on the strut.

For a bellcrank actuated shock this will be the attachment point of the pull or pushrod. The attachment point of the shock to the bellcrank is specifed as part of the bellcrank. See Spring, Shock, ARB tab, then Bellcrank.

From the Spring, Shock, ARB tab, select Susp.

Note that for the bellcrank floating shockabsorber type, this input is for the pushrod mtg to the A-arm.

For each of the configured items, there will be a “tab”. If there is more than one “tab”, then select each in turn to enter the actuation point values.

For a transverse torsion bar where the arm is the lower link there is no linkage mounting input required, as that point is on the birdcage.

For a transverse torsion bar where the arm slides on the top of the axle tube, input the length of the arm. Measured from the centre of the torsion bar to the tip of the arm. The actual actuation point will be where the torsion bar arm contacts the axle tube.

After the static spring geometry has been calculated, the values relative to the suspension datums (if vehicle was specified) and vehicle (if a suspension item was specified) will be shown.

10.6.1 Actuation point on A-arm

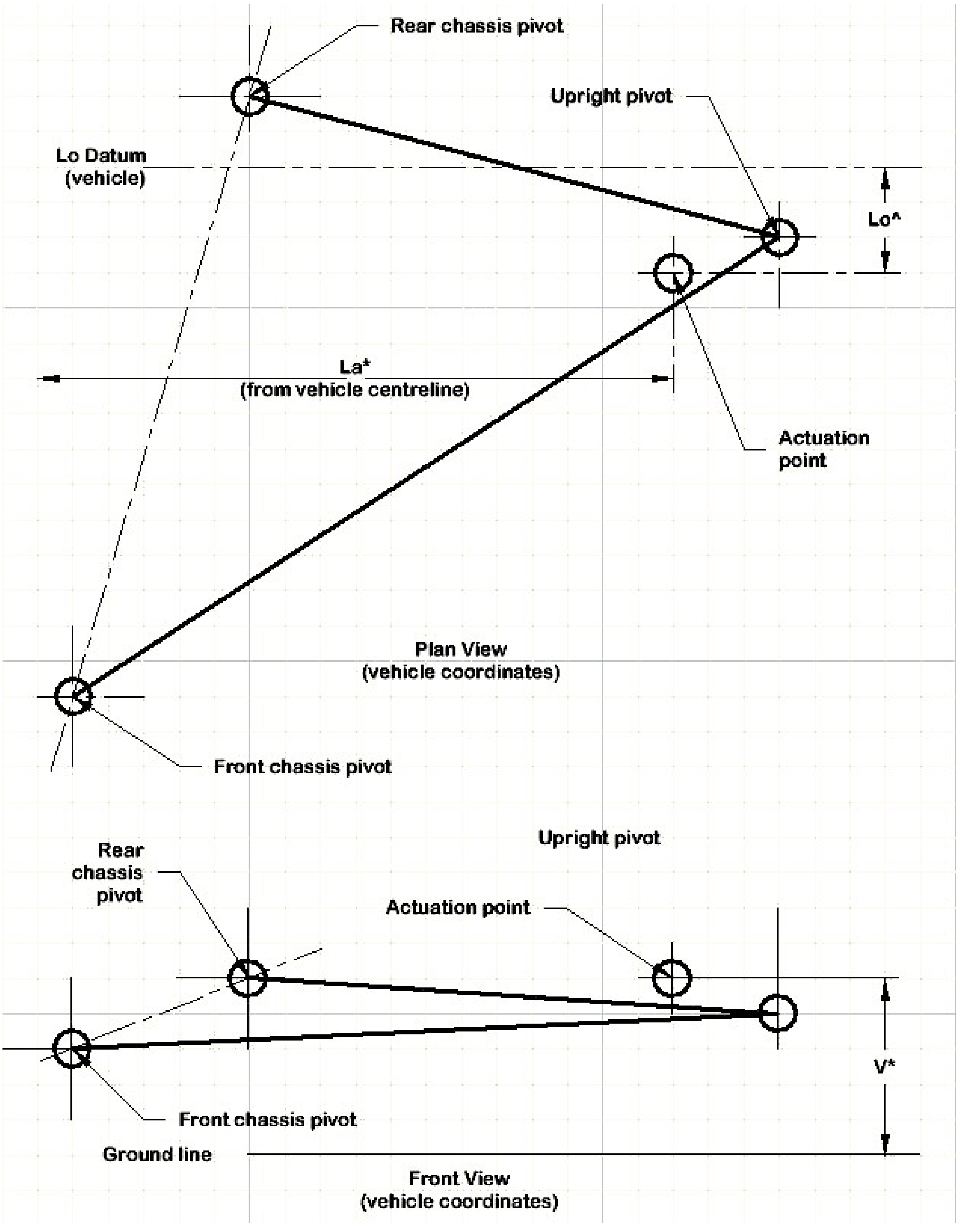
This will be the attachment point of the shockabsorber, spring, pushrod or pullrod to the A-arm.

After the static spring geometry has been calculated, the values relative to A-arm datums (if vehicle was specified) and vehicle (if A-arm was specified) will be shown.

Enter the values for the mounting point on the A-arm.

A choice is available allowing the actuation point to be specified relative to the A-arm itself, or to vehicle coordinates.

A-arm mounting using vehicle coordinates



When the A-arm pivot axis is not in line, or the A-arm is of an awkward shape, then the vehicle coordinates may be easier to measure.

The actuation point is measured relative to the vehicle datums. These datums are the vehicle centreline, the ground plane and the longitudinal reference plane.

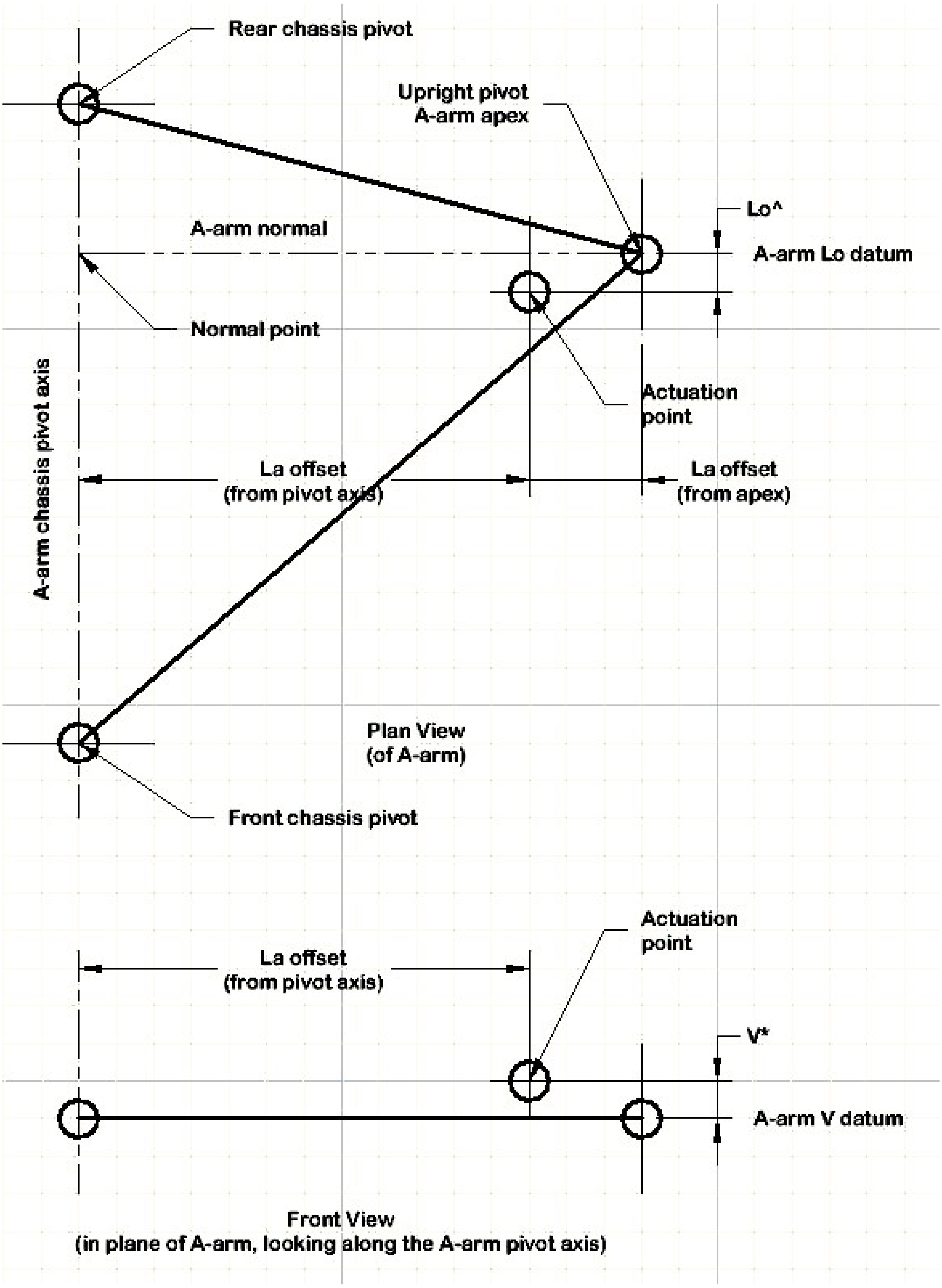
The lateral dimension is the distance from the vehicle centreline. Lateral dimension for one side will be positive (in the direction of the positive lateral axis), and negative for the other.

The vertical value is the distance above the ground. If the vertical axis is positive upward, then this will be positive; if the vertical axis is positive downward, then this dimension will be negative.

The longitudinal value is the distance behind or front the longitudinal reference plane. If the longitudinal axis is positive rearward, then a positive dimension is behind the longitudinal reference plane and a negative dimension is in front of the longitudinal reference plane; if the longitudinal axis is positive forward, then a positive dimension is in front of the longitudinal reference plane and a negative dimension is behind the longitudinal reference plane.

After calculation, the A-arm coordinates will be available, according to the specified options.

A-arm mounting using A-arm chassis pivot axis



When the A-arm "shape" is fixed, then this option is appropriate.

Specify the lateral dimension from "A-arm chassis pivot axis"

The actuation point is measured relative to the A-arm datums. These datums are the A-arm pivot axis (the base line joining the chassis front & rear pivot points), the line joining the upright pivot point to the normal pivot point (the A-arm normal link length) and the plane of the three pivot points.

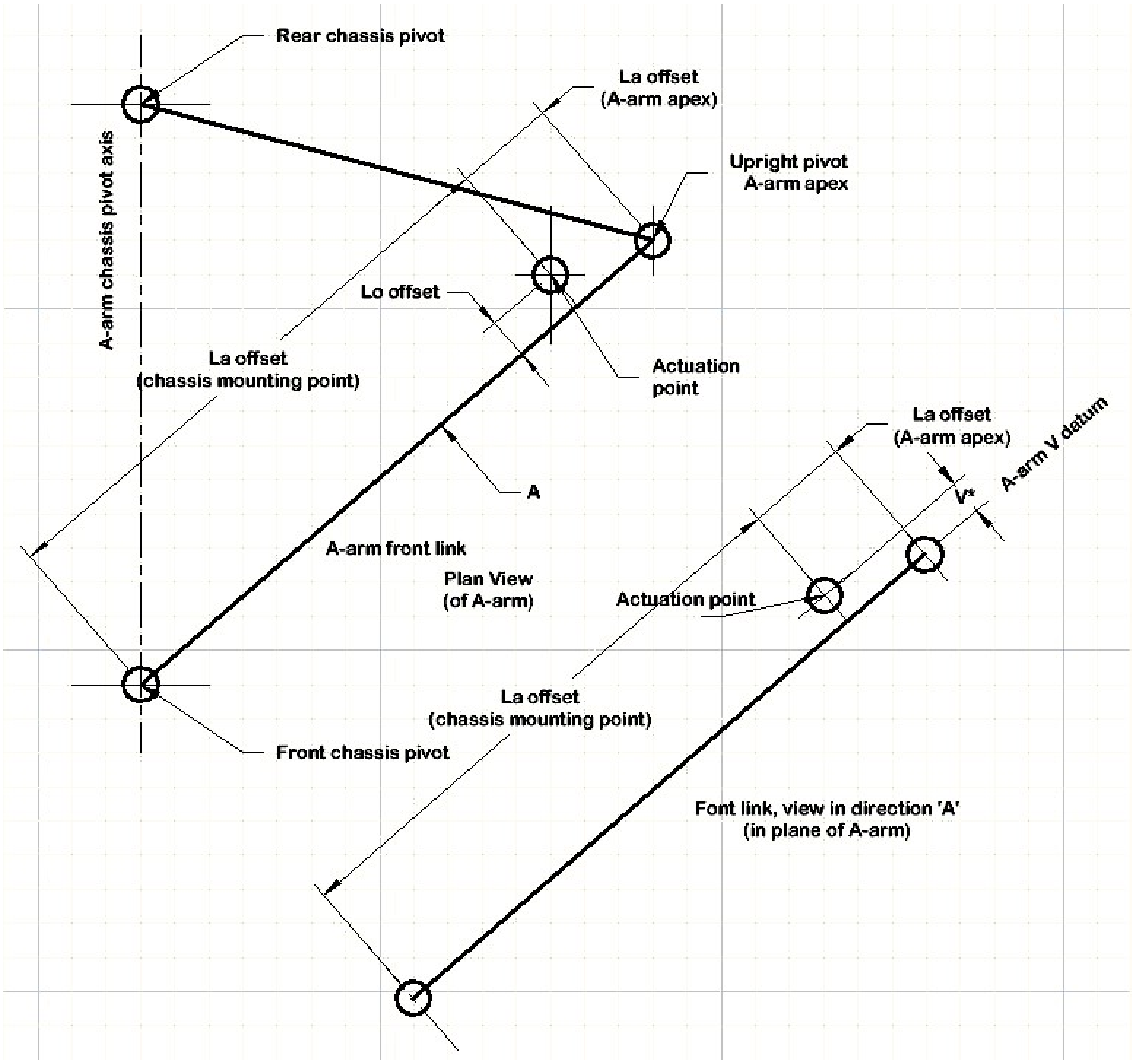
The lateral dimension is specified from the A-arm pivot axis.
If using the A-arm pivot axis, the lateral dimension is the distance from the A-arm pivot axis along the normal line to the A-arm apex. Positive dimensions are in the outboard direction (toward the upright), and negative dimensions are in the inboard direction (away from the upright). For the older style rocking top wishbone configuration, this dimension would be negative.

The vertical value is the distance above or below the plane of the A-arm. If the vertical axis is positive upward, then a positive dimension is above the A-arm plane and a negative dimension is below the A-arm plane; if the vertical axis is positive downward, then a positive dimension is below the A-arm plane and a negative dimension is above the A-arm plane.

The longitudinal value is the distance behind or front of the normal line. If the longitudinal axis is positive rearward, then a positive dimension is behind the normal line and a negative dimension is in front of the normal line; if the longitudinal axis is positive forward, then a positive dimension is in front of the normal line and a negative dimension is behind the normal line.

Instead of the 'normal line', a line normal to the A-arm pivot axis from either the front chassis pivot or the rear chassis pivot can be used.

A-arm mounting using A-arm apex or A-arm chassis pivot



When the A-arm is adjustable, especially when formed from two separate links, it is more appropriate to use one of the links as the reference datum.

The actuation point is measured relative to one of the A-arm links. The reference points are the link chassis mounting and upright mounting points. The vertical datum is the plane of the three pivot points.

The lateral dimension is measured along the link, and can be specified from either the A-arm chassis pivot or the A-arm apex (upright pivot).
If using the A-arm chassis pivot, the lateral dimension is the distance from the chassis pivot along the link centreline to the upright pivot. Positive dimensions are in the outboard direction (toward the upright), and negative dimensions are in the inboard direction (away from the upright). For the older style rocking top wishbone configuration, this dimension would be negative.
If using the A-arm apex (upright pivot), the lateral dimension is the distance from the upright pivot along the link centreline to the chassis pivot. Positive dimensions are in the inboard direction (away from the upright).

The vertical value is the distance above or below the plane of the A-arm. If the vertical axis is positive upward, then a positive dimension is above the A-arm plane and a negative dimension is below the A-arm plane; if the vertical axis is positive downward, then a positive dimension is below the A-arm plane and a negative dimension is above the A-arm plane.

The longitudinal value is the distance behind or front of the link centreline. If the longitudinal axis is positive rearward, then a positive dimension is behind the link centreline and a negative dimension is in front of the link centreline; if the longitudinal axis is positive forward, then a positive dimension is in front of the link centreline and a negative dimension is behind the link centreline.

Typical adjustable A-arm.

Adjusting the camber and or caster changes the link lengths, hence the shock mount moves relative to the A-arm chassis pivot axis. The shock mount remains fixed relative to the upright ball joint end of the camber control link. When the caster link is bolted to the camber link, the assembly is equivalent to a rigid A-arm.
In this example the mounts are referenced from the upright end of the rear link.
The shock mount X dimension will be positive (around 75mm), the Y dimension positive (around 50mm) and the Z dimension zero (because the mount is on the link centreline).
The antirollbar mount (it fixes with a horizontal bolt through the link) would have dimensions X = 110mm, Y = 0mm, Z = 40mm.
Image © 2010 Gary Rogers Motorsport. Used with permission.

10.6.2 Actuation point on trailing link

This will be the attachment point of the shockabsorber, spring, pushrod or pullrod to the suspension link.

After the static spring geometry has been calculated, the values relative to the link datums (if vehicle was specified) and vehicle (if link was specified) will be shown.

Enter the values for the mounting point on the suspension trailing link.

The actuation point is measured relative to either the link chassis mounting or the link suspension mounting, and the link centreline.

The lateral value is the distance from the link chassis pivot along the link centreline to the link axle pivot point.

The vertical value is the distance above or below the link centreline. If the vertical axis is positive upward, then a positive dimension is above the link centreline and a negative dimension is below the link centreline; if the vertical axis is positive downward, then a positive dimension is below the link centreline and a negative dimension is above the link centreline.

The longitudinal value is always 0.00.

10.6.3 Actuation point on upright

This will be the attachment point of the shockabsorber, spring, pushrod or pullrod to the upright.

After the static spring geometry has been calculated, the values relative to upright datums (if vehicle was specified) and vehicle (if upright was specified) will be shown.

Enter the values for the upright suspension actuation mounting point.

10.6.4 Actuation point on kingpin swivel

10.7 Pushrod, pullrod & shock absorber static lengths

This is only available for pushrod and pullrod bellcrank.

There are three alternative calculation methods.

1. Autocalc.
2. Specify the pullrod (or pushrod) length, or
3. Specify the shock absorber length, or

From the Spring, Shock, ARB tab, select Pullrod or Pushrod.

If a bellcrank actuated shock is specified (with or without a bellcrank antirollbar)

Option 1

Select ‘Autocalc” for AutoCalculation of the shock absorber and push/pullrod length.

This will adjust the bellcrank arm angle so that the centrelines of both the shock absorber and push/pullrod are at right angles to the bellcrank arms, and calculate the static shock length and the push/pullrod length.

This can be used for the initial design where the shock absorber and push/pullrod lengths may not be known, and provide a convenient starting point for the design refinement process. Note that this option does not guarantee that there is enough suspension linkage travel to allow the required suspension travel.

After calculation, the pushrod (or pullrod) and shock absorber lengths will be shown. The revised bellcrank dimensions can be seen in the bellcrank dialog box.

Option 2

Select “pullrod length”

Enter the pushrod (or pullrod) length at the static ride height.

The bellcrank dimensions must be fully specified and the bellcrank dimensions will remain unchanged.

After calculation, the static shock length will be shown.

Option 3

Select “shock length”.

Enter the shock absorber length at the static ride height.

The bellcrank dimensions must be fully specified and will remain unchanged.

After calculation, the pushrod (or pullrod) length will be shown.

If a bellcrank actuated antiroll is specified (without a bellcrank shock).

Option 1

Select ‘Autocalc” for AutoCalculation of the push/pullrod length.

This will align the bellcrank so that the centreline of push/pullrod is at right angles to the bellcrank arm.

This can be used for the initial design where the push/pullrod length may not be known, and provide a convenient starting point for the design refinement process. Note that this option does not guarantee that there is enough suspension linkage travel to allow the required suspension travel.

After calculation, the pushrod (or pullrod) length will be shown.

Option 2

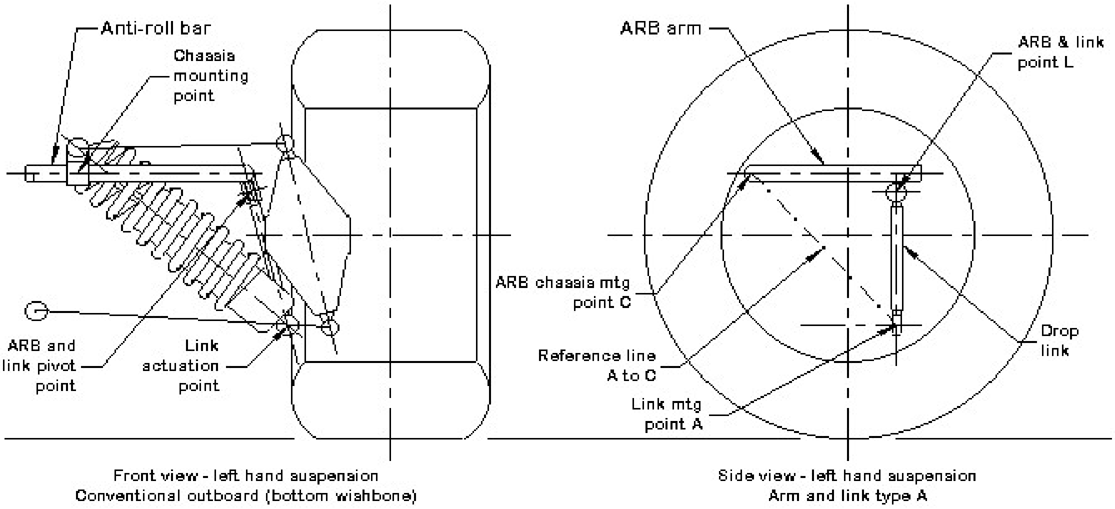
Select “pullrod length”

Enter the pushrod (or pullrod) length at the static ride height.

For both options, the bellcrank dimensions must be fully specified and will remain unchanged.

The lengths to the bellcrank chassis pivot are shown for reference.

10.8 Anti-roll bar link dimensions



Typical anti-roll bar installation

From the Spring, Shock, ARB tab, select Link.

For all anti-roll bar types where the anti-roll bar mounts to the chassis, the anti-roll bar chassis mounting is point C, the link actuation is point A, (on the wishbone, upright or bellcrank as appropriate) and the anti-roll bar & link pivot is at point L.

For live axle rear suspensions with the anti-roll bar mounted on the axle, the anti-roll bar axle mounting is point C, the link actuation is point A, (on the chassis) and the anti-roll bar & link pivot is point L.

Initially these will be zero, but will be correct after Calculate Static. These should be checked to confirm that the anti-roll bar arm & link type is correctly specified.

Either enter the anti-roll bar link length and click "Specify", or leave it as 0.00 and specify “AutoCalc ”.

If “AutoCalc”, SusProg3D will calculate a link length so that the link will connect to the anti-roll bar arm at approximately right angles (in side view). This can be used for the initial design where the link length may not be known, and provide a convenient starting point for the design refinement process.

Specify the geometric relationship of the three anti-roll bar pivot points.

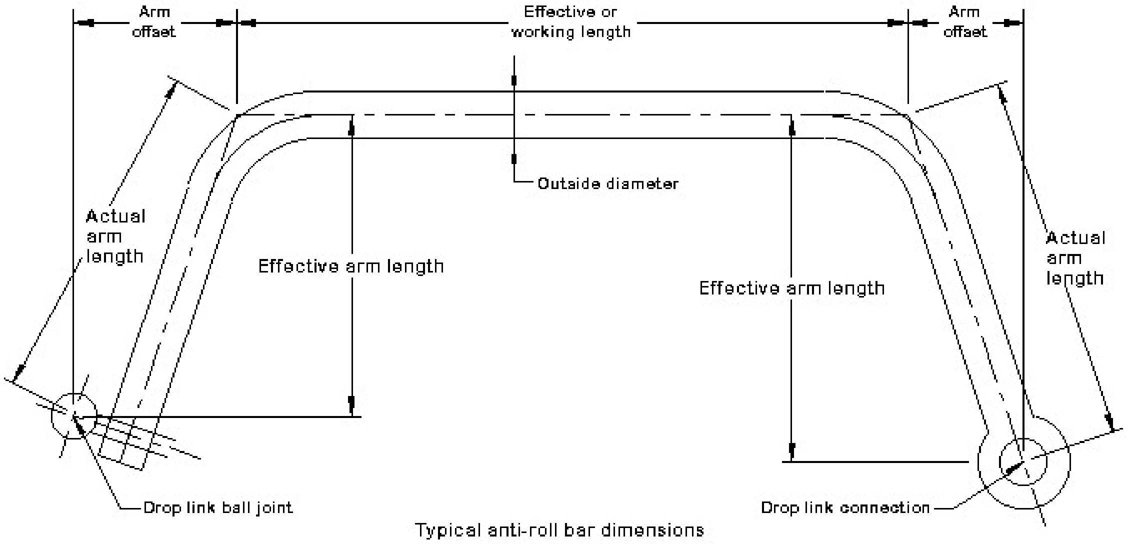
If you are designing the LH side of the vehicle, then in vehicle LH side view, with the front of the vehicle to the left, draw a line from point A to point C. If point L is to the right of this line (looking from A toward C) then specify arm & link type as "A". If point L is to the left of this line (looking from A toward C) then specify arm & link type as "B".

If you are designing the RH side of the vehicle, then in vehicle RH side view, with the front of the vehicle to the right, draw a line from point A to point C. If point L is to the left of this line (looking from A toward C) then specify arm & link type as "A". If point L is to the right of this line (looking from A toward C) then specify arm & link type as "B".

If the anti-roll bar attaches directly to the actuation point, specify the arm & link type as "no link".

Ensure that the car side shown in the dialog box title is the same as the vehicle side that you are referencing, because the LH and RH types will be opposite types.

10.9 Anti-roll bar dimensions

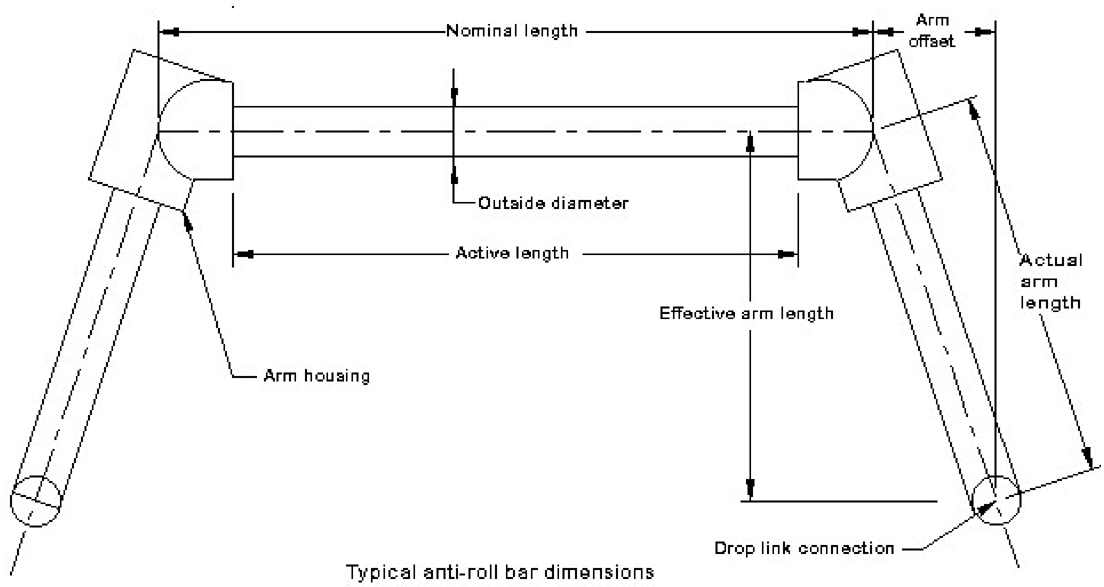


Typical anti-roll bar dimensions

From the Spring, Shock, ARB tab, select ARB.

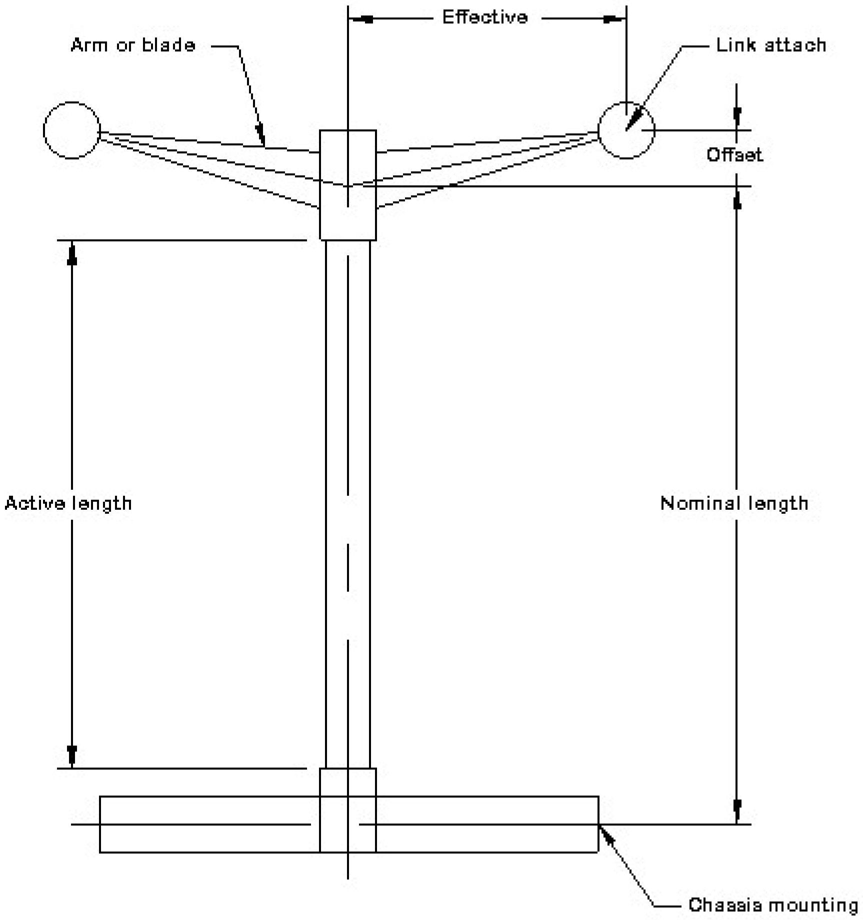
Enter the appropriate dimensions.

Active length is the effective or working length of the anti-roll bar.



Typical anti-roll bar dimensions

Nominal length is distance between the arm mountings (where the arms are attached to housings) or the distance between the arm bend points.



Typical Tbar anti-roll bar dimensions

For a T-bar anti roll bar, the active length is that length of the vertical section that actually twists under load. The nominal length is the distance from the chassis mounting centreline to the T-bar arm centreline.

If a solid bar, then leave the inside diameter as zero.

Enter the arm offset (if any) and either the actual or effective arm length. Use the choice box to indicate which dimension should remain as entered, and SusProg3D will calculate the other.

Specify whether the anti-roll bar arm is bent (from the same material as the anti-roll bar) or is a separately attached arm. A separate arm is considered rigid and has no effect on the anti-roll bar spring rate, a "bent arm" is considered to deflect and has the effect of softening the anti-roll bar spring rate.

Refer to the anti-roll bar rate calculations.

After Spring, Shock, ARB **|** Calculate, the calculated values will be correctly displayed.

Some anti-roll bar vendors test their bars on an "Intercomp Sway Bar Tester" or similar machine. If the vendor supplied spring rate does not agree with the SusProg3D calculated rate, use the "Cf" to specify a correction factor. There may be differences in the material specifications and heat treatment methods which cause differences between the theoretical and the actual spring rates.

10.10 Spring parameters

10.10.1 Coil spring parameters

From the “Spring, Shock, Arb” or the “Rates” tab, select Spring.

Spring calculation.

Choose either “Calculated” or “Specified”.

When calculating the spring parameters, “Calculated” will use the specified spring rate (that is, the spring rate that is specified in “Spring rate and load”) together with the specified spring seat dimensions, and will calculate a spring to provide the specified static load at that length.
This option is most appropriate when a custom wound spring is required.

When using the “Specified” option, the actual spring rate (that is, the spring rate that is specified on the spring design page) and free length will be used. This means that the spring length at the static load will be calculated, and the lower spring seat (the spring seat on the shock absorber body) will be adjusted to suit. In addition, when any dimensions are changed that would effect the static spring length, the spring seat will be adjusted. Also, this spring rate will be “back calculated” to determine the wheel rate.
This option is most appropriate when an “off the shelf” spring must be used.

Spring rate and load

Metric

If working in the metric system you can choose for spring data to be presented in SI (Metric) or US Customary (Imperial) units.
If you specify N/mm, spring rates are N/mm, spring loads are Newtons, and spring dimensions are mm.
If you specify lb/in, spring rates are lb/in, spring loads are lbs, and spring dimensions are inches.
Note that the spring mounting lengths and spring seats will remain in mm.
Hint. If you wish to use suspension frequency to calculate the spring rate, but also want to see the rates and loads in US Customary (Imperial) units, then 1) click on “lb/in” (to set up the rates and loads) and then 2) click on “Hz” to enable the frequency input.

Imperial

If working in the US Customary (Imperial) system, spring rates are in lb/in, spring loads are in lbs, and all linear measurements in inches.

Specify one of suspension frequency (Hz) or the spring rate (N/mm or lb/in) to be used in the calculation.

Specify the appropriate value for frequency or spring rate. When you finish inputting the value, the other values in this group will recalculate.

The static spring load is derived from the individual corner mass and the static spring motion ratio. These values are also used to calculate the frequency from the spring rate, and the spring rate from the frequency.

For a pushrod monoshock spring, the rates used are half the "real" spring rates.

For a Jaguar IRS with two coilover shock absorbers per side, the spring rate and all of the spring design data is for a single spring. It is assumed that both springs are identical.

For struts with 'coilover springs', the spring axis is assumed to be coaxial with the strut axis (ie the strut rod and tube centreline). This will be the situation for most race cars, particularly those with threaded adjustments for the bottom spring mount. Most production cars have the spring axis coaxial with the strut top mounting and the bottom ball joint or centreline of the wheel contact patch. This situation creates additional stresses within the spring as it undergoes an additional bending component as well as the usually axial length change. There is no allowance for this type of spring offset and with small amounts should have a negligible effect on calculated rates.

Spring seats

Enter the axial distance the spring seats are from the shock shaft and body mounting points.
If a main and tender spring combination, enter the thickness of the spacer between the two springs. If there is no spacer, enter zero.

The distance between the mounting points is shown for reference. For a coilover, these are the shock absorber mountings.

The resultant static spring length is shown for reference.
Note that this spring length is the distance between the spring seats. In the case of a main and tender spring combination it is the length of each of the springs in the static position plus the spacer thickness.

Specify the type of coil spring end. Both ends will be the same. For a main and tender spring combination, both springs will have the specified spring end type.

Spring system

For coilover spring, specify the type of spring. Either a single spring (constant rate) or dual springs (main and tender combination).

Non-coilover springs are all single springs (constant rate).

Coil spring design (single spring, constant rate).

The number of coils, wire size and inside diameter are used to display an appropriate looking spring.

There are various calculation options.

All options require appropriate values for the spring rate, static spring load and spring inside diameter. If the spring inside diameter is not specified, a value of 2.25" or 57mm will be used.

If the spring calculation is “Calculated”, the following options will calculate a spring to provide the static load at the static spring length. The spring free length will be calculated.
If the spring calculation is “Specified”, the following options will use the specified spring free length, and will calculate the static spring length at the static load, adjusting the position of the bottom spring seat to suit.
Generally the spring manufacturers offer a range of springs identified with the free length and rate, but may not indicate the wire diameter or coil count.
For example, the Eibach catalog does not indicate the wire diameter or the coil count, but does include the solid height. So you can use either “Coils” or “Wire dia” option and adjust the dimension until the solid height is correct.

If you choose "Auto", the number of active coils and wire diameter will be calculated to achieve the required spring rate with a minimum of 5 active coils and a maximum corrected static stress of 586 MPa (85,000 psi).

If you choose "Coils" and specify the number of active coils, the wire diameter and stress will be calculated.

If you choose "Wire dia" and specify the wire diameter, the number of active coils and stress will be calculated.

If you choose "Stress" and specify the corrected static stress, the number of active coils and wire diameter will be calculated. If the stress is not specified, a stress of 586 MPa (85,000 psi) will be used.

If you choose “Actual”, you must specify the inside diameter, wire diameter and active coil count and either the static length or the free length. The spring rate, free or static length, solid load and solid length will be calculated.
This is the option to use if the spring you have is not marked with the spring rate.

After calculating, the load-deflection graph can be viewed.
The horizontal axis is the spring deflection and the vertical axis the load.
Full droop is the dotted line, static is the solid line, and full bump is the dash dot dot line.
The diagonal line represents the spring rate. Steeper is stiffer.
If the droop load/deflection lines are not shown, then the spring is not loaded in the full

droop position.
If the bump load/deflection line intersection is off the end of the spring rate line, then this means that the spring has already gone solid before the full bump position.

Coil spring design, main and tender spring combinations.

The spring that becomes solid first is the “tender” spring; the other spring is the “main” spring. The “tender” spring is also known as the “helper” or “secondary”. It doesn’t matter in which order the springs are fitted to the shock absorber, the same spring will always become solid first.

The transition point is that point at which the tender spring becomes solid. Up to that point, the effective spring rate is always lower than either of the individual spring rates. At, and beyond, the transition point, the effective spring rate is that of the main spring.

The formula to determine the initial spring rate (ie up to the transition point, when both springs are “active”)

$$Ri = \frac{Rm \times Rt}{Rm + Rt}$$

The formula to determine the transition point between the initial and the final rate

$$TP = \frac{Fct}{Ri}$$

where Ri is the initial spring rate, Rm is the main spring rate, Rt is the tender spring rate, TP is the transition point, Fct is the tender spring solid load.

Generally speaking, there are two ways to employ tender springs, and it really depends at what point you want the spring rate to change.

1. The tender spring is solid before reaching the static position. At the static position the effective rate is the same as the main spring rate. Sometimes, if the main spring is free (ie has no deflection) in the droop position, then a very light tender spring is used to “fill the gap”. In this case the effective initial spring rate is very low, but serves to keep the main spring “in place”. More usually, the tender spring goes solid mid-way between full droop and static position. In this case the tender is stiffer than the main spring, so as to obtain an appropriate load-deflection curve.

2. The tender spring is effective through droop and into the initial bump travel. The tender spring only becomes solid after the static position. This gives a constant spring rate through droop and the first part of bump, with an increased spring rate approaching full bump.

As the initial step to designing a main – tender system, I would suggest first designing it as a single coil system. This will establish the minimum and maximum spring loads which are then useful for deciding on the tender spring solid loads.

When designing a main and tender spring combination, design the tender spring first.

Specify the solid load.
If the specified solid load is less than or equal to the static load, then the calculations will be option 1, if the specified load is greater than the static load then the calculations will be option 2.
As a starting point, for option 1 specify a load half way between minimum and the static load, and for option 2 a load half way between the static and maximum load.

Specify the tender spring rate.
For option 1, the tender spring rate can be any value; for option 2 the tender spring rate must be greater than the specified static spring rate (as the specified static spring rate is the initial spring rate of the combined tender and main springs).
As a starting point, for option 1 specify a rate equal to the specified static spring rate, and for option 2 a rate 2 to 3 times the specified static spring rate.

The combination of load and rate will be validated to ensure that they meet the above requirements.

If you choose "Auto", the number of active coils and wire diameter will be calculated to achieve the required spring rate, static spring length and solid load with a minimum of 2 active coils and a maximum corrected solid stress of 650 MPa (94,250 psi).

If you choose "Coils" and specify the number of active coils, the wire diameter and stress will be calculated.

If you choose "Wire dia" and specify the wire diameter, the number of active coils and stress will be calculated.

If you choose "Stress" and specify the corrected solid stress, the number of active coils and wire diameter will be calculated. If the stress is not specified, a stress of 650 MPa (94,250 psi) will be used.

If you are using Eibach ERS or other existing tender spring, calculate using “Actual ”. Specify the inside diameter, rate, solid length and solid load. This will calculate a spring with the appropriate number of coils and wire diameter, however the maximum stress may be much higher than the suggested 650 MPa (94,250 psi). There may be a difference in the calculated coil count and wire diameter compared to the actual spring, especially if the tender spring is made from non-circular wire or material with a different Modulus of Elasticity. This will not matter, as the important parameters are the rate, solid length and solid load. As long as these are correct, the combination rate and transition deflection and load will be correct.
Eibach refer to the solid length as “block length” and the solid load as “block load”.

Now that the tender spring solid load and length is known, the main spring static length, static load and spring rate will be adjusted.

Design the main spring. This is done the same way as for a single rate spring.

Whenever the tender spring is calculated, always recalculate the main spring.

After calculating both springs, the load-deflection graph can be viewed.
The horizontal axis is the spring deflection and the vertical axis the load.
Full droop is the dotted line, static is the solid line, and full bump is the dash dot dot line.
The transition point is shown with a dashed line.
The diagonal line represents the spring rate. Steeper is stiffer.
If the droop load/deflection lines are not shown, then the spring is not loaded in the full droop position.
If the bump load/deflection line intersection is off the end of the spring rate line, then this means that both springs have already gone solid before the full bump position.

Note that the main and tender springs may be “reversed”. When calculating the main – tender system characteristics, the tender spring is defined as that spring with the lowest solid load, ie it is the spring that will become solid first. If your transition deflection and load are not what you expect, then it is probable that the main spring has a lower solid load than the tender spring.
When designing the main spring, if the solid load of the main spring is less than that of the tender spring, a message will be shown asking if you wish to swap the springs around.

The solid load of the system (ie the load at which both springs are solid) is the same as the spring with the higher solid load.

The total deflection of the system is the sum of the maximum deflection (ie free length – solid length) of each spring.

Stress

The corrected torsional stress is calculated for three deflections of the spring, using the load calculated for that deflection. “Static” is the spring in the static ride height position, “full bump” is in the full bump position, and “solid” is when the spring is solid.
The main spring should not go solid at full bump. At the very least this will be a very abrupt transition to an “infinite” spring rate.

The tender spring is designed to be solid at some part of the usual suspension travel, hence the use of the solid stress when designing tender springs.

All calculated stress values include the Wahl factor.

This calculator is not intended as a comprehensive spring calculator. The number of coils, wire size and inside diameter are used to display an appropriate looking spring.

For detailed spring design refer to appropriate literature and manufacturers.

These calculations are based on SAE HS-795.

The allowable stress includes factors such as material, forming process, post-forming treatments, fatigue limits and surface finish. The values used are indicative only. Consult your spring supplier.

The Modulus of Elasticity – Shear, G, used in these calculations is 79300 MPa (11.5 x 10^6 psi) and is applicable for common cold wound spring materials.
For materials commonly used in hot coiled springs G is 76000 MPa (11.0 x 10^6 psi). This implies a 4% increase in wire diameter and corresponding decrease in the number of coils.

Do you need the spring to be preloaded in the full droop position?

If you don't get to full droop in your normal operating regime, then there is no reason to require that the spring is preloaded. In fact, it can make changing springs much easier, as when the car is jacked up and the suspension has dropped to full droop, the spring is free and can be more easily handled. If it has a significant preload in this position, either spring clamps or removal of suspension components may be required to assist in changing springs.

On the other hand, if you do get to full droop (and here I am thinking of off-road vehicles with long suspension travel and requiring effective springs at the full droop position, particularly after jumps) then it is better to have some preload.

For cars that get to full droop only in a pit stop situation (when the car is on jacks for wheel changes) and do not have any preload, then it would probably suffice to have some kind of spring guide or sleeve so that the spring seats correctly when the car is dropped back off the jacks.

Another consideration if you do not have preload and you have removable spring collars, then these may need to be lockwired or otherwise retained in position if they are not consistently located by the spring.

What do I need calculate?

Getting the required spring and wheel rates can be an iterative process.

1. Make sure that you have specified realistic limits for suspension travel, and that " Roll and Bump" has calculated.
2. Use the "Spring, Shock, ARB" selections to specify the chassis and suspension mounting points.
3. Make sure that the basic "Spring, Shock, ARB" calculates OK.
   Hint: Use ECalc and tick the "Geometry", "Roll and Bump" and "Spring, Shock, ARB". Leave the ECalc dialog open, and whenever you need to recalc, just click the "Calc" button.
4. Now use "Spring, Shock, ARB -> Spring" to specify and calculate the spring characteristics.
5. When you have a spring that looks OK, then "Apply" the spring.
6. And redo "Calc" to update all the "Results".
7. And then do "Rates" calculation to see the wheel rates.

If you need to change the geometry or travel limits, then repeat from step 1.

If you need to change the spring chassis or suspension mountings, then repeat from step 2.

If you need to change the spring characteristics, then repeat from step 4.

Which calculation option should I use?

This really depends on your requirements. If you are going to use an “off the shelf” spring, then use the “Specified” option. But, you might still start with the “Calculated” option if you are going to determine a starting spring rate based on suspension frequency. Enter a frequency and see what is the spring rate. Locate the adjustable spring seat in the centre of its adjustment range to get the static length. Then calculate a spring. Don’t worry about the number of coils or wire diameter, but note the free length. Now choose a spring close to this rate and free length from your preferred supplier. Switch to “Specified”, enter the spring dimensions and do the calculations.

As another example, if you have a vehicle with fixed spring seats then choose the “ Calculated” option, as this will not change the spring seat dimensions. But you still might want to try the “Specified” option. Particularly if you can use a “shorter” spring and add a custom spacer to the fixed spring seat to make up the difference.

You might have a number of alternative springs. Most vendors offer a range of spring rates with the same free length. Say you design for a 400lb/in 8” free length spring. What do you need to do when you swap in that set of 500lb/in 8” springs? So do the calculations with “Specified”, and note the 400lb/in spring seat dimension and the new 500lb/in spring seat dimension. Convert the difference to the number of turns of the spring seat adjuster. So now you know that swapping springs means turning the spring seat up or down by that number of turns, and the ride height will be maintained.
Alternatively, you can make up spacers of the appropriate thickness so that you do not need to adjust the spring seats. Basically what you are doing is compensating for the difference in static loaded length. This is an alternative to the approach suggested by Carroll Smith, which involves custom making each set of springs with the same static loaded length, and which would then have differing free lengths.

10.10.2 Torsion bar parameters

From the “Spring, Shock, Arb” or the “Rates” tab, select Spring.

Static spring rate

If working in the metric system you can choose for spring data to be presented in SI (Metric) or US Customary (Imperial) units.
If you specify N/mm, spring rates are N/mm, spring loads are Newtons, and all linear measurements are mm.
If you specify lb/in, spring rates are lb/in, spring loads are lbs, and all linear measurements are inches.
Hint. If you wish to use suspension frequency to calculate the spring rate, but also want to see the rates and loads in US Customary (Imperial) units, then 1) click on “lb/in” (to set up the rates and loads) and then 2) click on “Hz” to enable the frequency input.

If working in the US Customary (Imperial) system, spring rates are in lb/in, spring loads are in lbs, and all linear measurements in inches.

Specify one of suspension frequency (Hz) or the rectilinear spring rate (N/mm or lb/in) to be used in the calculation.

Specify the appropriate value for frequency or spring rate. When you finish inputting the value, the other values in this group will recalculate.

The static spring load is derived from the individual corner mass and the static spring motion ratio. These values are also used to calculate the frequency from the spring rate, and the spring rate from the frequency.

The static spring rate is the spring rate at the end of the lever, in a direction normal to the line from the centre of the torsion bar to the effective load point on the lever.

The torsional spring rate is for the torsion bar. It is calculated from the length and diameter.

There is a basic spring calculator.

The effective length and diameter are used to display an appropriate looking torsion bar.

There are five calculation options.

All options require appropriate values for the spring load and lever arm length.

Except for “Actual”, all options require appropriate values for the spring rate (either the rate or the frequency).

If you choose "Auto" or "Stress", the length and diameter will be calculated to obtain the required spring rate and static load with a maximum shear stress according to the Class selected. The Class number corresponds to the maximum operating shear stress, MPa

If you choose "Length" and specify the torsion bar length, the diameter will be calculated to obtain the required spring rate and static load. The shear stress and class number will be calculated.

If you choose "Dia" and specify the torsion bar diameter, the length will be calculated to obtain the required spring rate and static load. The shear stress and class number will be calculated.

If you choose "Actual", the effective length and diameter must be specified. The torsion bar rates, wind up angles, stress and class number will be calculated. The spring rate, frequency and wheel rate will be calculated.

Stress

The operating shear stress is calculated at three positions of the spring. The minimum stress is the when the spring is in the full droop position, the static stress is the spring in the static ride height position, and the maximum stress is in the full bump position.

The total operating stress range is the maximum stress minus the minimum stress. The smaller the total operating stress range the greater the fatigue life.

Ideally the spring should have a positive stress in the droop position. According to SAE HS-796 torsion bars with a maximum operating shear stress greater than 700 MPa should not be subject to reversal of load direction.

This calculator is not intended as a comprehensive spring calculator. The length and diameter are used to display an appropriate looking spring.
For detailed spring design refer to appropriate literature and manufacturers.

These calculations are based on SAE HS-796.

The allowable stress includes factors such as material, forming process, post-forming treatments, fatigue limits and surface finish. The values used are indicative only. Consult your spring supplier.

SAE H-796 suggests a maximum operating shear stress of 900MPa (130,500 psi) for passenger car suspensions. Operating shear stresses up to 1250MPa (181,000 psi) require close attention to material and production quality.

The Modulus of Elasticity – Shear, G, used in these calculations is 76000 MPa (11.0 x 10^6 psi) for torsion bars 16mm diameter and over, and 79300 MPa (11.5 x 10^6 psi) for diameters under 16mm.

10.10.3 Leaf spring parameters

From the “Spring, Shock, Arb” or the “Rates” tab, select Spring.

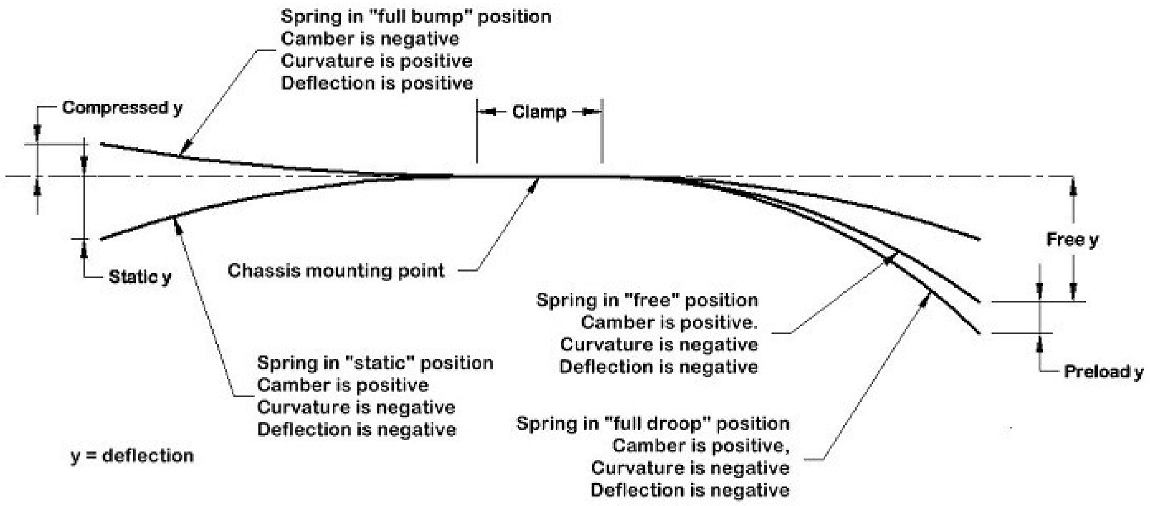
The spring effective length is the distance between the centres of the link holes (for plain end leaf) or the eyes (for eye end leaf), measured along the underside surface of the main leaf.

The leaf thickness is the thickness of the individual leaf.

The inactive length (aka clamp length) is the length of the spring rendered inactive by the action of the U-bolts or clamping bolts.

For metal-to-metal type spring seats, this length is usually assumed to be equal to the distance between the insides of the U-bolts.
For soft seats (using rubber type isolation, as in may passenger car installations) the inactive length may approach zero.

Currently, the only types of spring end are plain end (specifically where the spring is connected via a short tension link) and downturned eye (where the spring connects directly to the upright).



Leaf spring dimensions and terminology

The spring deflections shown in the static spring parameters and the spring deflections shown in the roll and bump data are relative to a flat spring.

The static spring deflection is the deflection of the main leaf from the “flat” position, fitted to the vehicle, in the normal static ride position.

The compressed spring deflection is the deflection of the main leaf from the “flat” position, fitted to the vehicle, in the maximum bump position. If this figure is positive, then the leaf spring has deflected past the flat position.

The free spring deflection is the deflection of the main leaf from the “flat” position in the unloaded position. This is the same as when the spring is removed from the vehicle.

The spring preload deflection is the deflection of the main leaf from the “free” position, fitted to the vehicle, in the maximum droop position. If this figure is negative, then either the main leaf is deflected this additional amount, or the suspension has to move this amount before the spring starts to take up the load.

AE-21 defines Camber as the arch height of the main leaf, and is positive or negative analogous to opening. For the usual automotive leaf springs, camber is positive in the free position. Curvature (1/R) is the reciprocal of radius (R). The curvature of a flat leaf is zero. Curvature is considered positive in the direction in which it increases with added load. Positive curvature corresponds with negative camber.

10.11 Calculate

This option will allow all the static values to be calculated and therefore available within the dialog boxes.

Before the spring calculations can be calculated, Roll Bump | Calculate and Steering | Calculate must complete without error.

From the Spring, Shock, ARB tab, select Calculate.

This will do all Geometry, Roll Bump and Steering calculations.

The status bar will display a message ‘Calculating...’ followed by either ‘OK’ or an error message.

On fast processors, the 'Calculating...' message may not remain long enough to be visible.

10.12 Display the results

From the Spring, Shock, ARB tab, select Result.

This will open a result window with all the calculated suspension values for the static position. The dialog boxes will also now show the updated static values.

```
SusProg3D SRD912.s3d Front Suspension

Vehicle lateral datum      (X): Vehicle centreline
Vehicle vertical datum     (Y): Ground
Vehicle longitudinal datum (Z):

LH and RH side identical

                             Wheel rate      Motion    Length    Spring
                          N/mm     lb/in     ratio              deflection
Shockabsorber                                 0.554    299.99
Coil spring               17.89    100.19     0.554    175.49     49.58
Antirollbar               51.12    286.25     0.554

Pullrod and bellcrank
- Pullrod mounting (wishbone)                   - X    550.00
                                                - Y    379.07
                                                - Z     10.90
- Pullrod length                                       365.15
                                                        Shock     P1 Bellcrank P2
Pullrod   Rollbar
- bellcrank pivots                              - X    331.47    250.00    307.99
252.67    331.47
                                                - Y    223.99    166.00     84.53
167.38    223.99
                                                - Z    100.01    100.00    100.42
0.05    100.06
- Pullrod arm length & offset                          100.00      0.00
- shockabsorber arm length & offset                    100.00      0.00
- Pullrod pivot to shockabsorber pivot                 139.31
- angle between arms                                    88.30
- anti-clockwise rotation in bump (LH)
- antirollbar link arm length & offset                 100.00      0.00
- Pullrod pivot to antirollbar link pivot              139.35
- angle between arms                                    88.33

Shockabsorber
- shockabsorber mounting (chassis)              - X    330.70
                                                - Y    225.00
                                                - Z    400.00
- length - compressed (full bump)                      250.95
-          static                                      299.99
-          extended (full droop)                       367.68
- stroke                                               116.74
- motion ratio (static)                                  0.55

Corner weight (unsprung)                                35.000 kg          77.16 lb
Corner weight (sprung)                                 160.000 kg         352.74 lb
Corner weight (total)                                  195.000 kg         429.90 lb
Suspension frequency                                     1.67 Hz          100.00 cpm

Coil spring parameters
- spring rate                                           58.22 N/mm       326.00 lb/in
- static load                                          288.614 kg         636.28 lb
- static length                                        175.49 mm           6.909 in
- spring seat (shockabsorber shaft)                     36.00 mm           1.417 in
- spring seat (shockabsorber body)                      88.50 mm           3.484 in
- free length                                          225.06 mm           8.861 in
- compressed length                                    126.45 mm           4.978 in
- preload                                              -18.12 mm          -0.713 in
- coil ID                                               57.15 mm           2.250 in
- wire dia                                              11.11 mm           0.437 in
- number of active coils                                 7.72
```

```
- type of ends                                      Closed and ground
- total number of coils                                   9.72
- coilbound (solid) length                              108.04 mm            4.253 in

Anti-roll bar
- arm length (actual)                                   165.00
- arm length (effective)                                165.00
- arm length (offset)                                     0.00
- drop link length                                      250.00
- antirollbar mounting (chassis)                 - X    300.00
                                                 - Y    383.00
                                                 - Z   -150.00
- arb arm/link pivot                             - X    300.00
                                                 - Y    218.01
                                                 - Z   -147.88

Anti-roll bar config is u-bar, actuated from bellcrank.
Shape is bent bar.Style B (LH side).
- active length                                         600.00 mm           23.622 in
- outside diameter                                       25.00 mm            0.984 in
- spring rate (nominal)                                 166.42 N/mm       931.92 lb/in

Chassis pivot points (from chassis X, Y, Z datum)         LH
- shockabsorber mounting                         - X    330.70
                                                 - Y    225.00
                                                 - Z    400.00
- bellcrank pivot (P1)                           - X    250.00
                                                 - Y    166.00
                                                 - Z    100.00
- bellcrank pivot axis (P2 offset from P1)       - X     57.99
                                                 - Y    -81.47
                                                 - Z      0.42
- antirollbar mounting                           - X    300.00
                                                 - Y    383.00
                                                 - Z   -150.00
Wishbone pivot points (X from chassis pivot, Y from plane, Z from apex normal)
- Pullrod mounting                               - X    250.00
                                                 - Y      0.00
                                                 - Z      0.00
```

10.13 ECalc

Allows several modules to be calculated from one point.

For example, if the shock absorber mounting is changed, you can recalculate all modules with one click.

See ECalc

11 Spring and anti-roll bar rate calculations

If the vehicle is configured with an anti-roll bar, both spring, shockabsorber and anti-roll bar must successfully calculate the static data before doing the rates calculation. If you wish to do only the spring rate calculations, the go to Spring, Shock, ARB | Config and set the anti-roll bar type to ‘ none’. You can later reset the anti-roll bar configuration to the correct type, and all previously entered data will still be retained.

11.1 Car end and car side

The [Front] or [Rear] tab choice will indicate the currently selected vehicle end.

The [LH] or [RH] tab choice will indicate the currently selected vehicle side.

These tabs acts as a toggle, and selecting this tab will switch between each of two.

Depending on the vehicle configuration, some menu bar items may not be available.

When a dialog box is opened, the title will include the currently selected car end and car side. If the car side is not shown, then the dialog box applies to both sides. If the car end is not shown, then the dialog box applies to both ends.

11.2 Vehicle mass

From the Rates tab, select Mass.

The unsprung corner mass are for the upright, tyre and wheel assembly. For a live axle, each rear corner will include half the mass of the axle.

The vehicle corner mass are the mass of each corner as measured by each individual corner scale. This includes both the sprung and unsprung mass.

The sprung corner mass are calculated.

Only the sprung mass (total, for the appropriate end of the vehicle under design) is used.

Once all the values have been entered, the totals and distributions can be calculated with the Calc button.

11.3 Maximum suspension travel in bump and droop

From the Rates tab, select Travel.

Enter the maximum suspension travel in bump and droop. Choose whether the allowable wheel travel should determine the related shock absorber lengths, or vice versa.

For the initial calculation, it is suggested that wheel travel be specified and the resultant shock absorber lengths calculated.

11.4 Do the calculations for the complete range of bump and droop travel

Before the full range of bump and droop calculations can be calculated, Roll Bump | Calculate, Steering **|** Calculateand Spring, Shock, ARB **|** Calculate must complete without error.

From the Rates tab, select Calculate.

This will do all Geometry, Roll Bump, Steering and Spring, Shock, ARB calculations.

The status bar will display a message ‘Calculating...’ followed by either ‘OK’ or an error message.

On fast processors, the ‘Calculating...’ message may not remain long enough to be visible.

Warning:

If specifying travel limits by choosing the shock absorber open and closed lengths, it is suggested that only small changes are made to the lengths as established by choosing the wheel travel limits. There is currently minimal checking that a requested shock absorber length is mechanically feasible, and consequently the calculations can fail. This is especially applicable to pushrod suspension where the bellcrank may be operating near its limits and the requested shock absorber length will not connect to the bellcrank. The indication of failure will typically be a status bar error message.

11.5 Display the results

From the Rates tab, select Result.

This will open a result window with all the calculated suspension values.

lh wheel	Spring wheel rate	Spring MR	Shock length	ARB wheel rate	ARB MR
100.00 bump	32.90	1.440	188.17	9.44	2.379
80.00 bump	32.74	1.443	202.06	10.16	2.294
60.00 bump	32.34	1.452	215.88	10.72	2.232
40.00 bump	31.88	1.462	229.61	11.17	2.187
20.00 bump	31.48	1.472	243.24	11.55	2.151
static	31.12	1.480	256.79	11.86	2.122
20.00 droop	30.92	1.485	270.27	12.19	2.093
40.00 droop	30.92	1.485	283.74	12.58	2.061
60.00 droop	31.28	1.476	297.24	13.11	2.019
80.00 droop	32.21	1.455	310.87 nsp	13.95	1.957
100.00 droop	34.19	1.412	324.80 nsp	15.42	1.861

Equivalent suspension travel due to chassis roll (right hand turn)

	outer (lh)	inner (rh)
1.00 roll	11.79	-11.77
2.00 roll	23.59	-23.50
3.00 roll	35.39	-35.17
2.00 roll	3.51	-43.37

with 20.00 droop

Motion ratio for shockabsorber/spring is calculated at each increment of bump and droop travel, and at each roll position. Motion ratio for anti-roll bar is calculated at each roll position.

If the motion ratio setting is Wheel:Shock then the motion ratio for the shockabsorber/spring is the ratio of wheel travel divided by the change in length of the shock absorber (produced by that same wheel travel).

If the motion ratio setting is Shock:Wheel then the motion ratio for the shockabsorber/spring is the ratio of the change in length of the shock absorber (produced by the wheel travel) divided by that same wheel travel.

Motion ratio for the anti-roll bar is the square root of the ratio of the nominal and actual wheel rates of the anti-roll bar. It is provided to enable a direct comparison to be made with the spring motion ratio.

If it is not possible to calculate the anti-roll bar linkage geometry, both the wheel rate and the motion ratio will be shown as zero. This can sometimes happen if the anti-roll bar actuation point moves so far (in bump or droop) that the anti-roll bar link cannot connect to the end of the anti-roll bar arm.

Spring preload length is the amount the spring is compressed when the suspension is in the full droop position. If this value is negative, then the free length of the spring is too short by this amount, and the spring is not compressed in full droop. The comment "nsp" may also appear if an intermediate droop position causes the spring to unload.

If designing for monoshock suspension, note that SusProg3D assumes two springs per vehicle end. The spring rates shown will need to be doubled to equal the actual (single) spring rate.

If designing for Jaguar suspension with two springs per wishbone, note that SusProg3D assumes two springs per vehicle end. The spring rates shown will need to be halved to equal the actual (single) spring rate.

For “live axles”, the wheel rates in bump are for equal movements on both wheels, ie pure heave.

For “live axles”, the spring and anti-roll bar rate in roll take into account the “spring base”. The roll rates will usually be much softer than bump rates.

11.6 ECalc

Allows several modules to be calculated from one point.

For example, if the spring rate is changed, you can recalculate all modules with one click.

See ECalc

12 Weight transfer & roll-stiffness calculations

This module can be used independently of all other modules, and the data required can be input using the Parameters and Mass dialog boxes. Data can also be saved. If using data which has been entered or calculated in other modules, note that changing those values in this module will also change them in their related modules. This may require that the other modules will need to be recalculated to maintain consistent results. The roll axis is based on the static front and rear roll centre heights.

Vehicle dynamic calculations are based on [BAST90, BAST93] and provide for the tyre spring rate, moments due to the unsprung weights, different front and rear tracks and separate suspension roll angles which are often not included in other calculations. For example, [COST80] does not include the tyre spring rate and only calculates a single chassis roll angle, and both [SMIT88] and [CAMP81] ignore the effects of the unsprung weights. The weight transfer calculations in [PUHN76] and [COST80] both agree closely with those of [BAST90].

In general, including the tyre spring rate decreases the overall roll stiffness and requires a greater vehicle roll angle, and including the unsprung weights generate additional roll moments and again lead to a greater vehicle roll angle.

Using the data for the Porsche 928, [CAMP81] calculates a chassis roll angle of 1.71°. Using the same data, [COST80] calculates a chassis roll angle of 1.84° and SusProg3D calculates a suspension roll angle of 1.85° (average of 1.62° front & 2.08° rear). For weight transfer, [SMIT88] calculates 317kg (split 76% front, 24% rear), [COST80] 429kg (68/32), [PUHN76] 425kg (67/33) and [BAST90] 429kg (63/37) The Porsche data shows that when the suspension spring rate is very high and approaches the tyre spring rate, then a significant amount of the vehicle roll is provided by the tyre deflection.

Frequencies are calculated for both the sprung and the unsprung masses using the bump spring rate.

If the tyre spring rate is entered as zero, it is treated as "infinitely stiff". In this case the sprung mass frequency is based on the sprung mass and the effective spring rate (at the wheel).

If the tyre spring rate is entered, then both the effective spring rate (at the wheel) and the tyre spring rate are used. This will generally lead to a lowering of the sprung mass frequency.

The calculations are based on [BAST93] Appendix A1.3 and A1.5.

12.1 Parameters

From the Dynamic tab, select Parameters.

Data values can be derived from two sources: Vehicle or Custom.

Vehicle data

> The values will be the current vehicle values.
> If any changes or calculations are done which effect the parameter values, they will be updated.
>
> Data can only be changed by updating and recalculating the underlying vehicle data.

Custom data

> All data can be updated in the Parameter input.
>
> No changes are made to the underlying vehicle data.

All spring rates (spring, anti-roll bar and tyre) are for one wheel only and are the effective wheel rates as measured at the tyre contact point. Either the spring or anti-roll bar rate may be zero, but not both. A typical tyre rate is 180-360 N/mm (1000-2000 lb/in).

The roll rates for “live axle” allow for the ‘spring base”, which is derived from the mounting points.

Note that if the tyre rate is zero, then this is assumed to be an "infinitely stiff" tyre with no deflection under load.

If using Metric units, all length dimensions are in mm, all weights are in kg, and all rates are in N/mm.

If using Imperial units, all length dimensions are in inches, all weights are in lb, and all rates are in lb/in.

Cornering force is the number of "g" lateral acceleration.

Sprung mass is the total sprung mass for each end of the vehicle.

Unsprung mass is the total unsprung mass (ie both wheels) for each end of the vehicle.

CofG height is for the complete vehicle, above the ground line. Refer CofG calculation for a description of a method to calculate CofG height.

To facilitate "What if?" calculations, a range can be entered for cornering acceleration, and, if in Custom mode, roll centre range.

Both front and rear roll centres allow for a minimum, step and maximum roll centre height.

If doing a calculation for a single roll centre, then specify the minimum as the the required roll centre and the step as zero. The maximum will be ignored.

To do a series of calculations for a range of roll centres, specify the minimum, step and maximum roll centres. Calculations will be done starting at the minimum roll centre, then increasing by the step amount until the maximum.

If both the front and rear roll centres have minimum, step and maximum values, the calculations will do all the rear roll centres for each front roll centre.

Similarly, a range of cornering accelerations can be specified.

The results will be shown in tabular form in the results output.

For subsequent analysis, it may be easier to export the results in CSV format. This can be directly imported by Excel.

In this case, after entering the values, use the Apply button to load the values and keep the dialog open. Then, after doing the "DynamicCalc" you can use the "Open" or "Open with" button to open the CSV file.

12.2 Calculate

Prior to calculation, and if the Parameter data is specified as "Vehicle data", then the parameter data will be refreshed from the vehicle data.
This ensures that any changes to vehicle data input or calculated values are always used when calculating.

From the Dynamic tab, select DynamicCalc.

The status bar will display a message ‘Calculating...’ followed by either ‘OK’ or an error message.

On fast processors, the ‘Calculating...’ message may not remain long enough to be visible.

12.3 Display the results

From the Dynamic tab, select DynamicResult.

This will open a result window with all the calculated weight transfer and chassis roll values.

```
C of G - above ground (vehicle)           305.00 mm
       - above ground (sprung mass)       308.59 mm
       - from front axle cl              1348.15 mm
```

```
       - height above roll axis           232.65 mm
Single wheel rate - front - tyre          175.00 N/mm    979.95 lb/in
                          - spring         17.89 N/mm    100.18 lb/in
                          - arb             6.80 N/mm     38.08 lb/in
                          - combined       43.27 N/mm    242.33 lb/in
                  - rear  - tyre          174.00 N/mm    974.35 lb/in
                          - spring         31.12 N/mm    174.26 lb/in
                          - arb             0.00 N/mm      0.00 lb/in
                          - combined       52.80 N/mm    295.65 lb/in
Anti-roll stiffness - front - on tyres   29936.76 kg-cm/degree   2152.76 ft-lb/degree
                            - susp       4223.65                  303.72
                            - total      3701.43                  266.17
Anti-roll stiffness - rear  - on tyres   27677.54 kg-cm/degree   1990.29 ft-lb/degree
                            - susp       4950.14                  355.97
                            - total      4199.13                  301.96
Anti-roll stiffness - car   - on tyres   57614.30 kg-cm/degree   4143.05 ft-lb/degree
                            - susp       9173.79                  659.69
                            - total      7900.56                  568.13
Weight transfer - front axle               92.81 kg       204.62 lb
                - rear axle               114.33 kg       252.05 lb
Roll couple distribution                   44.81% front
Roll angle - front - on tyres               0.43 degree
                   - suspension             2.05 degree
                   - total                  2.49 degree
           - rear  - on tyres               0.56 degree
                   - suspension             1.93 degree
                   - total                  2.49 degree
```

12.4 Notes

In these calculations it has been presumed that the roll angle for the plane of the front axle is equal to that for the plane of the rear axle. This in general presupposes a high figure for chassis torsional rigidity. [PUHN76] suggests that the chassis stiffness should be at least 10 times the total suspension roll stiffness. [VALK92] suggests a minimum of 3000 ft-lbs/deg for light road-racing cars.

Some typical examples include the Ford GT40 Mk1 at 12500 ft-lb/deg [CAMP76], the '62 Lotus 24 at 700 ft-lb/deg and the Lotus 25 at 2400 ft-lb/deg with engine installed [BAMS90], the '94 FIA Class 1 DTM Opel Calibra at 30000 N-m/deg (22124 ft-lb/deg) which is three times the stiffness of the production car [RACE43], and the '93 F1 Lola T93/30 with a design stiffness of 30000 ft-lb/deg [MACK93].

Avon quote the following spring rates for their ACB10 1994-96 Formula Ford tyres when fitted to 5.5Jx13 rims.

The vertical spring rate of the 7317M (6.0/21.0-13) front tyre is 175 N/mm at 18psi, increasing to 183 N/mm at 20psi and 190 N/mm at 22psi. For the 7319M (7.0/22.0-13) rear tyre it is 174 N/mm at 18psi, 181 N/mm at 20psi and 189 N/mm at 22psi [RACE36]

The CofG height as entered, is the height of the CofG of the complete vehicle above the static ground plane. This is recalculated to provide the sprung mass CofG height (above static ground plane), the distance of the CofG from the front axle cl and its height above the roll axis.

Weight transfer is the amount of weight transferred from the inner to the outer wheels. It should always be remembered that the total weight transfer from the inside wheels to the outside wheels of a vehicle is determined by the total weight of the vehicle, its track, the height of the centre of gravity and the cornering force. It is only possible by means of anti-roll bars, etc, to alter the fore-and-aft distribution of the weight transfer.

The vehicle roll angle consists of two components; the roll angle due to the deflection of the tyres, plus the roll angle due to suspension movement. For example, if the tyre roll angle is 0.67° and the suspension roll angle is 2.18° then to obtain a vertical outer wheel the suspension geometry should provide -0.67° camber at 2.18° roll. The total vehicle roll angle is 2.25°.

13 Longitudinal pitch centre calculations

The longitudinal pitch centre is the theoretical point about which the chassis will rotate in side view.

It is identical in concept and geometrical construction to the roll centre. The difference is that the roll centre is defined in the vertical plane of the axle, and the longitudinal pitch centre in the the plane of the front and rear wheel wheel pair.

One specific application is to see how the longitudinal pitch centre moves when the front suspension bumps and the rear suspension droops, typically under braking.

The original function did a calculation for each combination of front axle bump and droop and rear axle bump and droop and presented to data in a tabular format.
Use the Dynamic -> PitchCalc to do the set of calculations and then Dynamic -> PitchResults to see the data.

Because the data was somewhat confusing, a new interactive graphical function has been added.

The suspension bump and droop data is entered in Dynamic -> PitchData and then the pitch centre is calculated and the location shown graphically in Dynamic -> PitchGraphic.

The older functionality has been retained but will probably be removed in a future release.

13.1 PitchCalc

From the Dynamic tab, select PitchCalc.

The status bar will display a message ‘Calculating...’ followed by either ‘OK’ or an error message.

On fast processors, the ‘Calculating...’ message may not remain long enough to be visible.

13.2 PitchResults

From the Dynamic tab, select PitchResult.

This will open a result window with all the calculated longitudinal pitch centre values.

13.3 PitchData

From the Dynamic tab, select PitchCalc.

There is space for 20 data points, each point having a front suspension travel and a rear suspension travel. Each data point has a trackbar, with the slider indicating the relative suspension travel. The upper section is wheel bump, the lower section wheel droop, with the static position in the centre.

The trackbar has a resolution of 1% of the bump or droop value. So if the bump is 125mm (5") then each "click" of the slider will be 1.25mm (0.050")

Data can be entered by using the trackbar slider to set a value. When the mouse is over a trackbar, the values will display.
If you click on the central part of the trackbar, the slider will move.
To select a trackbar without changing the value, click outside the central section. When selected, the trackbar will have a dotted line border. The data point number and value will show in the data input box.
When the trackbar is selected, the arrow keys will move the slider up and down.

When a trackbar is selected, the data value can be entered in the numerical input box. Use the TAB key to exit the input box.

Data can be entered into each trackbar individually. Or specify the first and last data point, then use the "join ends" button to calculate and set each intermediate data point.

The data is available to the graphical display as it is entered. The input can be left open while the graphic is calculated and displayed. Clicking "OK" will close the dialog.

13.4 PitchGraphic

From the Dynamic tab, select PitchGraphic.

The graphic will display the front and rear wheels on a ground line. There is a vertical line representing the front axle centreline.

The panel showing the pitch centre data can be moved with the mouse. It will show the current values for the suspension travel together with the vertical and longitudinal co-ordinates of the pitch centre. You can choose to show the LH, RH or both points.

The pitch centre vertical dimension is relative to the ground plane; the longitudinal dimension is relative to the front axle centreline.

The initial calculation and display will be the first data set.

Use the ">" button to calculate the next data point, the "<" button to calculate the previous data point. The "<<" and ">>" buttons will go to the first and last data points respectively.

Use the "+" and "-" buttons to zoom in or out.

If you have specified an undertray, this will be shown, and will give a more visual indication of the vehicle movement.

14 AutoCalc

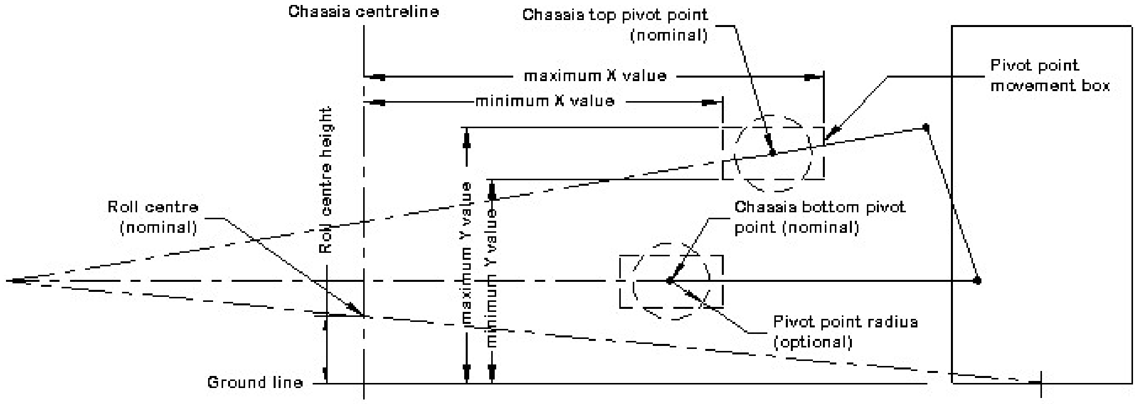
What if, or what combination of suspension chassis mounting points will give the desired geometry. This is AutoCalc.

Before using AutoCalc, the suspension geometry data must be entered and successfully Roll&Bump. This data set is the base or reference data.

AutoCalc will inherit all existing settings for chassis pivot point calculation and wheel alignment adjustment.

Be careful specifying the Geometry Configuration option. If an option is specified which requires that a wishbone link length is fixed, and the associated chassis pivot point is moved, then this will vary the track by the required distance, to maintain the specified link length. This may not be the required action. It is safest to use the “Wheel location and alignment” option (ie keeping a constant track) before using AutoCalc. If no other values are changed, this will not affect the calculations other than allowing the suspension link lengths to vary as required. The option of still having fixed link lengths may be useful in the case where the fixed length link has little or no lateral variation and the resultant track variation is acceptable, or the appropriate vehicle regulations require that the link length(s) remain unchanged (but do allow relocation of the pivot point). If fixed link lengths are specified and the base wishbone axis is not in-line, then this will change the basic suspension geometry accordingly.

It is also suggested that toe-in be set to zero before running AutoCalc.



AutoCalc chassis pivots

14.1 Config

From the AutoCalc tab, select Config.

Use the "Vehicle" button to load the initial calculation values from the Vehicle design values.

If the lateral and vertical values for the front and rear pivot points are the same, the “inline” option will be specified. If they are different, the “offset” option will be specified.

The chassis pivot point closest to the axle centreline (in plan view) will be specified as the “control” point.

Select the required calculation option for both top and bottom wishbone.

Inline (front reference)	The front and rear wishbone pivot points are set to the same lateral and vertical values and consequently the wishbone pivot axes are in-line. The “ control” values are the front pivot point.
Inline (rear reference)	The front and rear wishbone pivot points are set to the same lateral and vertical values and consequently the wishbone pivot axes are in-line. The “ control” values are the rear pivot point.

Offset (front ref) Offset (rear ref)	If the front and rear wishbone pivots are not in-line, then the ‘offsets’ between the two points will be maintained. The individual lateral and vertical offsets are calculated from the base data, where the ‘offset’ is the difference between the front and rear dimension. For 'Offset (front ref) the front pivot point will range between the specified minimum and maximum lateral and vertical values. For 'Offset (rear ref) the rear pivot point will range between the specified minimum and maximum lateral and vertical values. The 'other' pivot point will maintain the base 'offset', and both pivot points will move in the same direction. For example, if the base configuration has the front pivot lateral = 300 and rear pivot lateral = 320 (this gives a rear lateral offset of 20), and lateral Min = 290 and Max = 310 and 'Offset - (front ref) is specified, then the front pivot will range from 290 to 310 and the rear pivot point will range from 310 to 330 with the rear pivot always 20 greater than the front.
Front (rear fixed)	Only the front pivot point will vary through the specified range. The rear pivot point will be fixed at the existing position. The front pivot lateral and vertical values will vary within the specified minimum and maximum lateral and vertical values.
Rear (front fixed)	Only the rear pivot point will vary through the specified range. The front pivot point will be fixed at the existing position. The rear pivot lateral and vertical values will vary within the specified minimum and maximum lateral and vertical values.

The dialog will also show the following calculation settings.

The datum side. This is the side of the vehicle used for base chassis dimensions. The chassis dimensions for the other side of the vehicle will be set identical.

The geometry instant centre location, either fixed chassis points or swing axle and roll centre.

The geometry wheel location and alignment.

The roll and bump roll centre location.

The roll and bump roll axis alignment.

All of these are all set in the Geometry **|** Config and RollAndBump **|** Config.

14.2 Car end and car side

The [Front] or [Rear] tab choice will indicate the currently selected vehicle end.

The [LH] or [RH] tab choice will indicate the currently selected vehicle side.

These tabs acts as a toggle, and selecting this tab will switch between each of two.

Depending on the vehicle configuration, some menu bar items may not be available.

When a dialog box is opened, the title will include the currently selected car end and car side. If the car side is not shown, then the dialog box applies to both sides. If the car end is not shown, then the dialog box applies to both ends.

14.3 Chassis limits

From the AutoCalc tab, select Chassis Limits.

14.3.1 Double wishbone

Use the "Vehicle" button to load the initial calculation values from the Vehicle design values.

Enter the desired minimum, maximum and step values. Initially the minimum and maximum are set to the base values (either the front or the rear pivot point). The default step value is 1.0mm or 0.050”.

For wishbone suspension, it will apply to both top and bottom wishbones. For struts, it will only apply to the bottom wishbone.

For 'fixed chassis pivot points' the lateral and vertical co-ordinates will vary as described. For 'fixed swing axle and roll centre' the lateral co-ordinates will vary as described, and the vertical co-ordinate will always be calculated to achieve the required swing axle and roll centre.

14.3.2 Strut

Certain values are not applicable to strut suspensions.

If fixed chassis pivot points are specified, then the chassis top pivot vertical value will remain constant (Maximum and minimum values can be input, but will default to the nominal value before execution).

Similarly, if fixed swing axle and roll centre is specified, then the swing axle values are not used, only the roll centre values.

If a range of chassis top pivot lateral values are specified, these will only be used if the camber adjustment location is the chassis top pivot, otherwise they will be ignored and the appropriate value calculated which may lie outside the specified range. To avoid unnecessary calculations, do not specify a chassis top pivot vertical value range (unless you also specify that the camber adjustment location is the chassis top pivot).

14.4 Upright limits

From the AutoCalc tab, select Upright Limits or Strut Limits

Use the "Vehicle" button to load the initial calculation values from the Vehicle design values.

Enter the desired minimum, maximum and step values. Initially the minimum and maximum are set to the base values. The default step value is 1.0mm or 0.050”.

For wishbone suspension, it will apply to both top and bottom upright wishbone pivot points. For struts, it will only apply to the bottom wishbone pivot point.

14.5 Specify the test and reporting requirements

From the AutoCalc tab, select Test Limits.

Use the "Vehicle" button to load the initial calculation values from the Vehicle design values.

The ‘print’ column checkbox is used to control the report output, the ‘test’ column checkbox is used to determine the successful pivot point combinations.

Check the appropriate ‘test’ column checkbox to choose which values will be used to determine if a particular combination of pivot points meets your requirements. If nothing is selected, nothing will be checked.

If more than one test is to be checked, then the calculation is aborted when the first test fails. For example, if the Roll Centre is checked and Roll Centre is out of limit, then bump and droop camber is not calculated or checked. This is done to speed up the process. Conversely, a successful combination must pass all the tests specified.

The pivot location radius selections allow for specifying that the pivot point must not move further than the specified distance from the base point. Both front and rear pivot points will be tested, and both must be within the specified distance.

If the roll centre location is checked, enter the maximum and minimum height for the static roll centre.

The static roll centre is recalculated for each combination of chassis pivot points and/or swing axle lengths and that roll centre movement is measured from this new static roll centre location.

If the roll centre movement is checked, enter a value for the maximum distance that the roll centre can migrate from the static roll centre while the chassis rolls through the total roll amount. Roll increments are set in Roll&Bump | Increments. The roll centre travel shown in the results will be the maximum roll centre travel, which could be at any of the roll positions.

If “min” is checked, then the maximum roll centre movement for each test combination will be compared with the previous results, and if it is less, then that combination will be added to the test results. This can be used to answer the question “I don’t know the actual value, I want the minimum roll centre movement”. If a value for roll centre movement is specified, this will be the starting value, otherwise the roll centre movement of the first combination will be used.

Specify if the roll centre movement is to be calculated as the distance between the actual and static roll centres, or as the difference in heights between the actual and static roll centres. If the geometry calculations are being done with “dynamic” roll centres, then the former may be the most appropriate choice; if “semi-dynamic” then the later may be the most appropriate choice.

If the Bump Camber is checked, enter the values that the wheel camber at the maximum bump position must be within. The maximum value is the numerically larger of the two values. For example, if the wheel must camber to at least -3.00° but no more than -3.35°, then maximum bump camber will be -3.00° and minimum bump camber will be -3.35°. (Values are inclusive). The maximum bump distance is set in Geometry | Travel.

If the Droop Camber is checked, enter the values for which the wheel camber at the maximum droop position must be within. For example, if the wheel must camber to between -1.00° and +1.00° on full droop, then maximum droop camber will be +1.00° and minimum droop camber will be -1.00°. (Values are inclusive). The maximum droop distance is set in Geometry | Travel

All pivot location data plus the tested items will be included in the report output. If you wish to include additional items, then check the appropriate ‘print’ column checkbox.

An output line will only be created for test point combinations that meets the test limits.

14.6 Do all the iteration calculations

From the AutoCalc tab, select Calculate.

Before calculating, check that the output file is correctly specified.

Specify the output file format.

- If 'Text' is specified, the output will be written as plain ASCII text.
- If 'CSV' is specified, the output will be formatted in Comma Separated Variable format. This format can be imported into most spreadsheet packages. A single header line plus multiple detail lines will be written.

If the suggested file name or directory location is not appropriate, use "Save as" to specify the file locations and file name.

Press “Calc” to start the calculations.

A progress box will appear with two bar graphs. The top one is titled "Combinations tested" and will indicate the progress in calculating all the combinations requested. The bottom one is titled "Combinations within specified limits" and will indicate the number of combinations that meet the required parameters.

If you get excessive (or not enough) acceptable results, then change the test limit values.

If you wish to exit the calculation process, press [Halt]. The calculation will immediately stop and the output file will contain all those tests completed.

The progress box will show the number of combinations tested, the number within the specified limits and the output file name.

When the calculations have completed you can view the results.

Use the "Open" to view the output file using the associated application.
For example, if the output file is 'Text' then it will be opened with the application associated with .txt files. This is usually NotePad.
If the output file is 'CSV' then it will be opened with the application associated with .csv files. This is usually Microsoft Excel.
If you want to use an application not associated with that particular file type, then use "Open with..." and choose the application.

14.7 View the results file

This file will be created when the ‘Text’ option is specified.

The file has a suffix of ".TXT".

Use the "Open" button to view the output file using the associated application. This is usually NotePad.
If you want to use an application not associated with ".txt", then use "Open with..." and choose the application.

Abbreviations used are ‘ctf’ for chassis top front pivot point, ‘ctr’ for chassis top rear pivot point, ‘cbf ’ for chassis bottom front pivot point, ‘cbr’ for chassis bottom rear pivot point, ‘rc’ for roll centre, ‘bc’ for bump camber and ‘dc’ for droop camber.

Both front & rear pivot point lateral and vertical values will be printed.

```
AutoCalc2D Nominal Chassis Dimensions
Wishbone: Fixed chassis pivots with Fixed Track (Adjustable top and bottom links
Chassis pivot point -top    -from car cl            300.00
(virtual)                    -from ground            377.87
                    -bottom -from car cl            250.00
                             -from ground            165.85
Upright pivot point -top    -from wheel flange      150.00
(on upright)                 -from hub cl            120.00
                             -from axle cl             0.00
                    -bottom -from wheel flange      100.00
                             -from hub cl           -120.00
                             -from axle cl             0.00
Upright pivot point -top    -from car cl            546.68
(from car datums)            -from ground            383.23
                    -bottom -from car cl            598.70
                             -from ground            144.57
Virtual swing axle length (static)                   3000.00
Roll centre height                                     75.00
Track (actual, at specified settings)                1400.00
Top link length (end view)                            246.74
Bottom link length (end view)                         349.35
Tyre rolling radius                                   265.00
Wheel offset                                            0.00
```

```
Camber                                                -0.50
Upright pivot inclination and offset         12.30    69.78
Castor angle and trail                        5.00    22.71
Wheel toe reference length                           330.00
Static toe in, mm                                      1.00

AutoCalc check limits
Maximum and minimum wheel camber in bump     -2.70    -2.75


      Test    ct.x      ct.y      cb.x      cb.y
         1    295.00    377.00    240.00    165.00
        22    295.00    377.00    250.00    166.00
484 combinations tested, and 139 within specified limits
```

14.8 Read the CSV results file with Excel

This file will be created when the ‘CSV’ option is specified.

The file has a suffix of ".CSV".

Use the "Open" button to view the output file using the associated application. This is usually Microsoft Excel.
If you want to use an application not associated with ".csv", then use "Open with..." and choose the application.

The number of columns will depend on the selected ‘print’ and ‘test’ options selected. The number of rows will be the number of combinations within the specified limits plus a header and trailer row.

There may be limitations in the number of rows that a spreadsheet can hold. For example, Excel 7.0 has a limit of 16,384 rows. Later versions have increased this limit to 65,536 rows.

15 Display

When the main SusProg3D display has focus, the F6 key or Ctrl-C will copy the display (as a bitmap image) to the clipboard. This image can be pasted (using Ctrl-V or the Paste command) into various applications such as Paint or Wordpad.

The Print button will print the graphic direct to the printer. See Print the graphic for details.

15.1 Display settings

From the menu bar, select Settings then Display.

Background.

The background colour can be specified.

The reference lines can be “anti-aliased”. This may improve the appearance of the lines, but there is a performance penalty.

The control panel format can be either “Vertical” or “Horizontal”.

The colours and spacing of the grid lines can be specified.

The major grid lines will be drawn the specified distance apart in the major colour, and the minor grid lines will be drawn in between at the specified interval in the minor colour.

For metric systems, major grid spacing of 100mm with 5 or 10 divisions is a good choice. This gives a grid of 20mm or 10mm squares.
For imperial systems, major grid spacing of 10inches with 10 divisions is a good choice. This gives a grid of 1inch squares.
Both imperial and metric dimensions are stored. This means that when you switch between metric and imperial, the appropriate grid spacing will be used.

When the dialog is opened the grid display will be turned on. Note that the grid is only visible when the view is along one axis. When the dialog is closed, the grid display will revert to the currently specified Control Panel setting.

Zoom

Specify the “zoom percentage”. This is the amount that the graphic will be increased by (when the “+” key is pressed) or decreased by (when the “-“ key is pressed).

15.2 Control

The control panel contains the controls to allow manipulation of the display. The panel can be shown in either a horizontal or vertical format. See Display settings.

The display can then be manipulated and viewed as required.

The ‘+’ (plus) and ‘-‘ (minus) keys will zoom the display out and in.

Note that the graphic will be centered at the specified “Centre of Rotation” and that all zooming and rotations will be about this point. Initially this is the centre of axle hub centreline. See View orientation.

Attitude

Rotate the suspension graphic by “clicking” the appropriate arrow button.

The yaw axis is the vertical axis. This corresponds to turning the vehicle.

The pitch axis is the lateral horizontal axis. This corresponds to the vehicle nosing up or down.

The roll axis is the longitudinal axis. This corresponds to rolling the vehicle.

Attitude delta

Choose the amount, in degrees, by which each click will rotate the vehicle.

The “Reset” button will reset all rotations back to zero.

Bump, droop and turn

There are five buttons (for the front suspension) and three buttons (for the rear suspension).
“Clicking” the “+” button, or pressing the up arrow key, will bump the chassis, one bump increment at a time. When the maximum bump is reached, the button will be “greyed out”.
“Clicking” the “0” button will reset the chassis to the static position.
“Clicking” the “-” button, or pressing the down arrow key, will droop the chassis, one droop increment at a time. When the maximum droop is reached, the button will be “greyed out”.

In the static position, for the front suspension, the turn buttons will be enabled.
“Clicking” the “>” button, or pressing the right arrow key, will turn the wheels right one turn increment at a time. When the maximum right turn is reached, the button will be “greyed out”.
“Clicking” the “0” button will reset the chassis to the straight ahead position.
“Clicking” the “<” button, or pressing the left arrow key, will turn the wheels left one turn increment at a time. When the maximum left turn is reached, the button will be “greyed out”.

The caption will indicate the current bump, droop or turn position.

Roll

There are three buttons.
“Clicking” the “+” button, or pressing the right arrow key, will roll the chassis right, one roll increment at a time. When the maximum right roll is reached, the button will be “greyed out”.
“Clicking” the “0” button will reset the chassis to the 0 roll position. Note that this position may not be the same as the Static ride height position.
“Clicking” the “-” button, or pressing the left arrow key, will roll the chassis left, one roll increment at a time. When the maximum left roll position is reached, the button will be “greyed out”.

The caption will indicate the current roll position.

Car Side

Choose LH, RH or both sides

To aid in distinguishing sides, LH construction lines are red, RH construction lines are green.

Fixed

Choose either Wheel or Chassis as the fixed item.

If the Wheel is fixed, then the chassis will drop in bump and rise in droop while the wheel remains in contact with the ground plane.

Conversely, if the Chassis is fixed, then the wheel will rise in bump and drop in droop while the chassis remains at a constant height relative to the ground plane.

Note that selecting the “roll points” will automatically switch to “Fixed Wheel”.

Include

For each of the items, tick the checkbox to include the item in the suspension graphic, and clear it to exclude it.

With the exception of “Wheel”, all checkbox items will display the appropriate item when selected, and not display it when cleared. For “Wheel”, when selected will display a full wheel and tyre and when cleared will display three circles (corresponding to the centreline and the tyre tread width).

Colours

The background and grid colours can be specified. See Display settings.

The default colours used for the various items are

Red	Wishbone front links
	LH construction lines
Green	Wishbone rear links
	RH construction lines
Blue	Toe control link (wishbone and strut suspensions only)

15.3 ECalc

Select the Display tab, then ECalc.

Specify which calculations are required. Some calculations are dependent on other calculations. Where this is the case, the dependent calculations will also be selected.

The “Select all” button will select all items (if some items have not been selected). The “Clear all” button will “unselect” all items (except for the basic Geometry).

Geometry	will calculate and display the basic static geometry. In the display control, Travel will be limited to ‘Static’ only, and Include will select Construction lines only.
Roll and Bump	will calculate and display the full Roll and Bump geometry, including the maximum travel points. In the display control, Travel will include the full range, and Include will select Construction lines only.
Steering	will include the steering in the geometry Roll and Bump calculations. In the display control, Include will include the toe control link. Note that this is only applicable to wishbone and strut suspension types.
Driveline	If there is a Driveline, this will include the Driveline in the geometry calculations. In the display control, Include will include the Inner UJ, Outer UJ and Driveline.
Spring, Shock, ARB	will calculate and display the static position of the specified suspension components; bellcrank, shockabsorber, spring and anti-roll bar. In the display control, Travel will be limited to ‘Static’ only, and Include will select Spring, Shock, Anti-roll bar and Construction lines. If the spring does not display, see below.
Rates	will calculate and display the full spring data for the full suspension travel. In the display control, Travel will include the full range, and Include will select Spring, Shock, Anti-roll bar and Construction lines.

Make sure that all the required data is input.

The calculations can be initiated in either of two ways:

- Press "Calc"
- If ECalc is open when a dialog Apply button is clicked, then the data will be updated and all the ECalc selected calculations will be performed

The data will be recalculated (the specified suite of calculations will be done) and if all calculations complete without error the display will be refreshed.

If any of the calculations fail, then an error message like this will be raised. '[Front] Spring, Shock, ARB calculation failure. Incomplete or invalid input data.'
You may need to close ECalc and use the individual section Calcs until they complete correctly.

Spring not displaying.

If the spring does not display, it is probably because it has not been specified. Make sure that the spring has been specified, specifically that the number of coils, wire diameter and coil inside diameter are all greater than zero.

Shockabsorber body length.

When the Static calculations are done, and the shockabsorber compressed length has not been calculated, a nominal shockabsorber body length of 2/3 of the static length will be used.

When the Rates are calculated and the shockabsorber compressed length is known, the shockabsorber body length is calculated so that the shockabsorber is fully closed in the maximum bump position.

15.4 View orientation

There are five view orientation tab buttons – Front, Left, Rear, Right, Plan↑ and Plan↓.

These will show the front view, left side view, rear view, right side view and plan view respectively.
Plan↑ will be oriented so that the front of the vehicle is "up", with the left side of the vehicle on the left side of the screen. The view is from above the vehicle.
Plan↓ will be oriented so that the front of the vehicle is "down", with the right side of the vehicle on the left side of the screen. The view is from above the vehicle.

There is a button to control the way the graphic is drawn. Clicking this button will switch between [Full] and [Lines].

If it is [Full], then the graphic will be drawn in full with representations of the suspension elements.
If it is [Lines], then all graphics will be drawn as single lines with the mounting or actuation point drawn as a dot.

There is a button to turn the display of the grid on or off. Clicking this button will switch between [Grid] and [NoGrid].

When [Grid] is on, a grid will be drawn. The colour and spacing of the grid can be specified. See Display settings. Note that the grid is only visible when the view is along one axis.

There is a button to hold the current graphic orientation on a recalculation. Clicking this button will switch between [Hold] and [NoHold].

If "Hold" is selected, then whenever the vehicle data is recalculated and the display redrawn, the vehicle will remain in the same position. If "NoHold" is selected, then the vehicle will always be redrawn in front view, with the graphic centred on the axle hub centreline.

There is a Reset button.

Clicking this will reset the "Centre of Rotation" to the centre of the axle hub centreline, resize the graphic to fit in the display screen, and redraw in front view, centred in the display screen.

Zoom in and out

The "+" and "-" keys will zoom the graphic in and out. See Display settings.
The graphic is zoomed about the "Centre of Rotation"

Show me the coordinate.

"Axis aligned" means that one of the axis is pointing straight out of, or straight into, the screen, eg font, left, right, rear and plan. In the Control panel, when two of the axes are at 0, 90, 180, or 270 then this is "axis aligned". The third axis can be any value.

When the graphic is "axis aligned", and the [Grid] button is on, the grid will be shown.

When the graphic is "axis aligned" (with or without the grid showing), when the left mouse button is clicked a hint widow will show with the vehicle coordinates of the pixel at the cursor. The values will be shown for the two axes in the plane of the graphic.

The hint window will display about 0.5 seconds after the mouse click, and will remain for about 2.5 seconds. The values will also show on the status line (bottom left hand corner) and will remain until another hint needs to be shown.

Centre of Rotation

The Centre of Rotation (CoR) is the point about which the graphic will be zoomed and rotated.

The graphic will be positioned so that the CoR is always in the centre of the display.

Initially the CoR is in the centre of the axle hub centreline (and this is the way the previous versions worked).

To change the CoR, the graphic must be “axis aligned”. Position the cursor at the required location, hold down the Control key and click the left mouse button. The graphic will be reposition with the “clicked point” now in the centre of the display. All subsequent zoom and rotation will take place around the new Centre of Rotation.

Note that the CoR is relocated only in the two axes in the plane of the graphic. If you need to relocate the CoR in all three axes, then you will need to do it twice.
For example, to reposition the CoR on the top a-arm front chassis pivot point, first show the graphic in Front view. The Control-click on the top a-arm front chassis pivot point. This will centre the graphic in front view and set the CoR vertical and lateral coordinates. Now switch to any of the left, Right or Plan views. Again Control-click on the top a-arm front chassis pivot point. This will centre the graphic, and also set the CoR longitudinal coordinate. Now when you zoom or rotate, the top a-arm front chassis pivot point will always be in the centre of the display. If you get lost, use the Reset tab button.

16 Tools

16.1 Create Chassis Datum from vehicle coordinates

From the Tool tab, select Datum then "Create from vehicle coordinates".

The intended use of this tool is to convert vehicle (ie ground based) coordinates to chassis datum coordinates.

Before using this tool, all the required calculations should be done, as the calculated vehicle coordinates will be used to create the chassis datum referenced mounting points.

Chassis datum (description):

Vertical datum	Identify the vertical datum plane by name. Typically "Undertray" or "Chassis build datum"
Longitudinal datum	Identify the longitudinal datum reference point by name. This could be a suspension mounting point or any convenient hard point on the chassis structure.

Chassis datum (vehicle coordinates):

The chassis datum surface is defined by three points:

- Two points define the longitudinal centreline, one at the front and one at the rear.
  While these two point will usually be on the vehicle centreline, that is not essential. But the two points will be used to define the centreline of the chassis datum surface.
- The third point defines the "twist" or "side rake" in the chassis datum plane as seen from front or rear view.

The chassis longitudinal datum is controlled by specifying a fourth point, the longitudinal datum reference point.

This is a convenient point from which all longitudinal dimensions are taken. This point need not be on the chosen chassis datum surface, and can be at any height.

All four points are dimensioned from the vehicle ground datum.

Centreline reference point - front	This point defines the chassis datum surface longitudinal centreline. Any convenient point, but it must be in the chassis datum plane, and should be on the chassis centreline. Ideally this point will be somewhere around the front axle, or the front edge of the actual chassis datum plane.
Centreline reference point - rear	This point defines the chassis datum surface longitudinal centreline. Any convenient point, but it must be in the chassis datum plane, and should be on the chassis centreline. Ideally this point will be somewhere around the rear axle, or therear edge of the actual chassis datum plane.
Lateral reference point	This point must be in the chassis datum plane, and offset to one side from the chassis datum longitudinal centreline. It is used to specify the amount of "twist" or "side rake". If there is no "twist" or "side rake" then specify this point the same as the centreline reference point - rear, but with a lateral value about the same as half the track.
Longitudinal reference point	This point defines the zero datum for all longitudinal dimensions. It may be a convenient chassis point (the back edge of the chassis datum plane), a fixed chassis feature (the front edge of the front bulkhead), or a legislated reference point (a particular chassis frame

reference hole).

Chassis datum surface:

This defines the size of the chassis datum surface. If using a ground based datum, then leave all these dimensions zero. If using a actual chassis datum, like a surface plate or a build table or jig, then this will define a rectangular surface representative of the actual chassis datum surface.

Front edge of datum surface	The distance the front edge of the chassis build surface is from the longitudinal datum.
Rear edge of datum surface	The distance the rear edge of the chassis build surface is from the longitudinal datum.
Datum surface width	The chassis build surface width.

Now click the "Apply" button.

All the chassis mounting points (suspension, shock, spring, steering) will be calculated.

For further details on using a ground based vertical datum.

For further details on converting from a ground based to a chassis based vertical datum.

For further details on using a chassis based vertical datum.

16.2 Realign Datum Location

From the Tool tab, select Datum, then "Move vertically and/or longitudinally".

The intended use of this tool is to move either or both the vertical and longitudinal datums, and recalculate all chassis pickup points so they are referenced from the new datum plane(s).

Chassis datum (description):

Vertical datum	Identify the vertical datum plane by name. Typically "Undertray" or "Chassis build datum"
Longitudinal datum	Identify the longitudinal datum reference point by name. This could be a suspension mounting point or any convenient hard point on the chassis structure.
Realign existing chassis datum	Initially, both these dimensions should be zero. Following the initial calculations, you may decide that the chassis datum originally specified is no longer appropriate. To move the vertical datum in the +ve direction, enter a positive value for the vertical axis; to move the vertical datum in the –ve direction, enter a negative value for the vertical axis. To move the longitudinal datum in the +ve direction, enter a positive value for the longitudinal axis; to move the longitudinal datum in the –ve direction, enter a negative value for the longitudinal axis. Update the vertical and longitudinal datum comments to describe the new datum locations. Use the ‘Apply’ button to recalculate the chassis vertical and longitudinal values accordingly. Finally, do a complete recalculation so that all the dimensions in the various result outputs are updated.

Note that the longitudinal datum reference point dimensions do not change as the point is referenced relative to the datums, and has effectively moved with them.

For further details on using a ground based vertical datum.

For further details on converting from a ground based to a chassis based vertical datum.

For further details on using a chassis based vertical datum.

16.3 Coordinate Measuring Machine to SusProg

This tool converts vehicle coordinates to the SusProg3D upright, strut or trailing arm datum coordinates.

A 3D Coordinate Measuring Machine (CMM) is often used to measure a complete vehicle, providing dimensional data in CMM or world coordinates.

The current vehicle configuration and car end will determine the available conversion tool.

CMM upright, CMM strut, CMM Trailing Arm, CMM Axle, or CMM A-arm / Control arm will do all the required conversion calculations.

If your CMM produces output in an Excel format, the CMM data can be imported from an Excel spreadsheet. See CMM input data Excel names for details.

Although this section specifically refers to a 3D Coordinate Measuring Machine (CMM), the tool can also be used to convert from "ground based" dimensions to upright, strut, a-arm or trailing arm datum based dimensions.

16.3.1 CMM Setup

If the CMM coordinate origin is not on the vehicle centreline, or on the ground line, then specify the offset of the CMM datum.

For example, if the vertical datum is a chassis reference point, then this point will be above the ground. If the vertical datum is positive upwards (usually the case), the this offset will also be positive.

It is seldom necessary to allow for the longitudinal offset.

A comment can be added.

Before using this tool, the following data must be specified:

Wheel data	the rim mounting offset (as this determines the relationship between the wheel/spindle centre and the wheel mounting flange), the toe reference length (as this is used to determine the wheel toein dimension).
Geometry type	the geometry type, set in Vehicle -> Config, determines the upright type and the number and location of the linkage mounting points.
Suspension type	the suspension type, set in Spring, Shock, ARB -> Config determines the number and function of the various suspension mounting points which are directly attached to the upright, strut, trailing arm or A-arm. Currently, only the CMM data for a single shockabsorber and spring is supported.

From the Tool tab set the [CarEnd] and the [CarSide].

It is easiest if the [CarSide] is set to the side which has the positive lateral dimensions, then you don’t have to enter all negative dimensions.

If the vehicle is symmetrical, then tick the “identical” box, and then this will update both LH and RH dimensions.
If the vehicle is not symmetrical, then leave this box unticked. You will then need to switch sides, open a second copy of the tool, and input the CMM data for the other side. Remember that if you are doing the side which is the negative lateral axis, then all the lateral dimensions must be entered as negative.

16.3.2 CMM Upright

Select CMM, then the Upright tab.

If the CMM origin is not on the ground plane, or not on the vehicle centreline, then go to Setup and specify the CMM origin offset.

The following data points are required:

Spindle/wheel centre	This is the CMM coordinate of a point in the centre plane of the wheel, on the spindle (or axle) centreline.
Spindle reference	This is the CMM coordinate of a point on the spindle (or axle). It must not be the same as the spindle/wheel centre point, and is usually the end of the axle. It can be either inboard or outboard of the spindle/wheel centre point. The greater the distance between this point and the spindle/wheel centre point, the more accurate the calculations.
Upright mounting points	This is the CMM coordinate of the centre of the linkage mounting ball joint or bearing. The number of points will vary according to the particular upright type.
Steering arm balljoint (front suspension only)	This is the CMM coordinate of the centre of the steering arm ball joint. If you don’t have this coordinate, then leave it as zero. The tool will still calculate a value, but it will be inaccurate. You will not be able to do any steering calculations.
Shock mounting	This is the CMM coordinate of the shock mounting on the upright.
Spring mounting	This is the CMM coordinate of the spring mounting on the upright.
Anti-roll bar mounting	This is the CMM coordinate of the anti-roll bar mounting on the upright.
Pull or pushrod mounting	This is the CMM coordinate of the pull or pushrod mounting on the upright.

Now press “Calc”.
This will calculate all the upright data points, relative to the upright datums; the tyre rolling radius; and the wheel alignment and location.

If the upright has a single ball joint for the top A-arm and a single ball joint for the bottom A-arm, the caster will be calculated (from the CMM data), then the upright will be “rotated” to the zero caster position, and all upright dimensions will be calculated relative to a vertical king pin axis (in side view). If the wheel spindle is not on the king pin axis (in side view) then this dimension will be noted as “King pin axis to spindle offset”.

If the upright has a multiple ball joints, or “virtual” pivot points, the caster will be assumed to be zero.
The upright dimensions are all calculated relative to this “zero caster” orientation (in side view).

If you want to use these calculated values to update the vehicle data, then press “Vehicle”.
The upright dimensions will be carried over to the Geometry | Upright input dialog.
The tyre rolling radius will be carried over to the Geometry | Wheel input dialog.
The wheel alignment and location will be carried over to the Geometry | Alignment input dialog.
If appropriate, the suspension mounting point will be carried over to Spring, Shock, Arb | Suspension input dialog.

16.3.3 CMM Strut

Select CMM, then the Strut tab.

If the CMM origin is not on the ground plane, or not on the vehicle centreline, then go to Setup and specify the CMM origin offset.

The following data points are required:

Spindle/wheel centre	This is the CMM coordinate of a point in the centre plane of the wheel, on the spindle (or axle) centreline.
Spindle reference	This is the CMM coordinate of a point on the spindle (or axle). It must not be the same as the spindle/wheel centre point, and is usually the end of the axle. It can be either inboard or outboard of the spindle/wheel centre point. The greater the distance between this point and the spindle/wheel centre point, the more accurate the calculations.
Strut rod (top)	This is the CMM coordinate of the top end of the strut rod. Usually the strut rod has a threaded end and a pilot section which protrudes through the strut mounting, and where the retaining nut is fitted. Although it is not intended that this point is the same as the strut mounting point, the strut mounting coordinates can be used.
Strut rod (bottom)	This is the CMM coordinate of the bottom end of the strut tube.
Bottom balljoint (wishbone)	This is the CMM coordinate of the centre of the suspension linkage ball joint.
Steering arm balljoint	This is the CMM coordinate of the centre of the steering arm ball joint. If you don’t have this coordinate, then leave it as zero. The tool will still calculate a value, but it will be inaccurate. You will not be able to do any steering calculations.
Strut mounting (on chassis)	This is the CMM coordinate of the centre of the strut top chassis mounting.

Now press “Calc”.
This will calculate all the strut data points, relative to the strut datums; the tyre rolling radius; and the wheel alignment and location.

If the wheel spindle is not on the strut rod axis (in side view) then this dimension will be noted as “ Strut rod axis to spindle offset”.
The strut dimensions are all calculated relative to a vertical strut rod axis (in side view).

If you want to use these calculated values to update the vehicle data, then press “Vehicle”.
The strut dimensions will be carried over to the Geometry | Strut input dialog, the strut type will be set to “Fixed knuckle/strut A” and the steering arm location will be set to “knuckle”.
The tyre rolling radius will be carried over to the Geometry | Wheel input dialog.
The wheel alignment and location will be carried over to the Geometry | Alignment input dialog.

16.3.4 CMM Trailing Arm

Select CMM, then the Trailing Arm tab.

If the CMM origin is not on the ground plane, or not on the vehicle centreline, then go to Setup and specify the CMM origin offset.

The following data points are required:

Spindle/wheel centre	This is the CMM coordinate of a point in the centre plane of the wheel, on the spindle (or axle) centreline.
Spindle reference	This is the CMM coordinate of a point on the spindle (or axle). It must

	not be the same as the spindle/wheel centre point, and is usually the end of the axle. It can be either inboard or outboard of the spindle/wheel centre point. The greater the distance between this point and the spindle/wheel centre point, the more accurate the calculations.
Trailing arm mounting points	This is the CMM coordinate of the centre of the chassis or linkage mounting ball joint or bearing.
	The number of points will vary according to the particular trailing type.
Shock mounting	This is the CMM coordinate of the shock mounting on the trailing arm.
Spring mounting	This is the CMM coordinate of the spring mounting on the trailing arm.
Anti-roll bar mounting	This is the CMM coordinate of the anti-roll bar mounting on the trailing arm.
Pull or pushrod mounting	This is the CMM coordinate of the pull or pushrod mounting on the trailing arm.

If the vehicle is symmetrical, then tick the “identical” box, and then this will update both LH and RH uprights.
If the vehicle is not symmetrical, then leave this box unticked. You will then need to switch sides, open a second copy of the tool, and input the CMM data for the other side. Remember that if you are doing the side which is the negative lateral axis, then all the lateral dimensions must be entered as negative.

Now press “Calc”.
This will calculate all the trailing arm data points, relative to the trailing arm datums; the tyre rolling radius; and the wheel alignment and location.

The trailing arm vertical datum plane will be located through the two axle reference points and the outer (or front) trailing arm chassis pivot point.
The trailing arm lateral datum plane will be located on the wheel mounting flange, normal to the axle centreline.
The trailing arm longitudinal datum plane will be located on the axle centreline, normal to the other two planes.

The trailing arm dimensions are all calculated relative to this “zero inclination” orientation (in side view).

If you want to use these calculated values to update the vehicle data, then press “Vehicle”.
The upright dimensions will be carried over to the Geometry | Trailing Arm input dialog.
The tyre rolling radius will be carried over to the Geometry | Wheel input dialog.
The wheel alignment and location will be carried over to the Geometry | Alignment input dialog.
If appropriate, the shock mounting point will be carried over to Spring, Shock, Arb | Suspension input dialog.

16.3.5 CMM Axle

This tool converts 3D Coordinate Measuring Machine (CMM) data to the SusProg3D axle datum coordinates.

This function will be implemented on request.

Due to the number of alternative live axle designs, and in particular the way in which camber and toe are provided, it is not practical to develop a single tool that will allow for all foreseeable combinations and variations.

Should you have a need for this functionality, we will be pleased to incorporate it and make sure that it meets your requirements.

16.3.6 CMM A-arm / CMM Control arm

Select CMM, then the A-arm or the Control arm tab.

If the CMM origin is not on the ground plane, or not on the vehicle centreline, then go to Setup and specify the CMM origin offset.

The following data points are required:

Chassis mounting points	These are the CMM coordinates of the centre of the front and rear A-arm / Control arm chassis mounting ball joints or bearings.
Upright mounting points	These are the CMM coordinate of the centre of the front and rear A-arm / Control arm upright mounting ball joint or bearing.
Shock mounting	This is the CMM coordinate of the shock mounting on the A-arm / Control arm
Spring mounting	This is the CMM coordinate of the spring mounting on the A-arm / Control arm
Anti-roll bar mounting	This is the CMM coordinate of the anti-roll bar mounting on the A-arm / Control arm
Pull or pushrod mounting	This is the CMM coordinate of the pull or pushrod mounting on the A-arm / Control arm
Caster link mounting	This is the CMM coordinate of the caster control link mounting on the Control arm

Now press “Calc”.
This will calculate all the A-arm / Control arm data points, relative to the A-arm / Control arm datum.

If you want to use these calculated values to update the vehicle data, then press “Vehicle”.
The A-arm / Control arm dimensions will be carried over to the appropriate Spring, Shock, Arb | Suspension input dialog.

16.4 Mumford linkage

The tool is based on some simplified assumptions.

The view and calculations use the static vehicle coordinates for all calculations, and the orientation is normal to both ground and the vehicle centreline. This plane is located fore and aft on the bellcrank pivot point.

The tool assumes that the bellcrank and lever pivot axes are both normal to this plane. If your pivot axes are not parallel to the ground (in side view), and parallel to the vehicle centreline (in plan view) there will be slight differences between the results calculated by the tool, and the results calculated by the geometry calculations, when using the data provided by the tool.

Before using the tool, the basic geometry must be entered and calculated. It is probably easiest to specify the geometry configuration settings with Instant centre location set to “Roll centre height” and Wheel location and alignment set to “Wheel location + axle alignment”. This will calculate the Mumford linkage to generate the specified roll centre, with the bellcrank, lever and links dimensioned so that the levers are 90 degrees to the lateral links.

The data will refresh after each Geometry calculation. If you need to change the axle mounting points, or the chassis linkage mounting points, then these must be done in the Geometry section, followed by a calculation. The calculated coordinates will then be updated in the tool.

The tool can be used to investigate the changes to the Mumford linkage as one of the parameters is changed. These parameters are the bellcrank angle, lever lengths, and the linkage instant centre height. Generally one dimension can be changed while holding another fixed, and all other dimensions will be recalculated accordingly.
The recalculation will be done after entering a new value and then pressing the Tab key, or by selecting the "Normalise linkage" option.

It is then easy to see the effect of changing one dimension, and the interaction with the other linkage components.

The tool uses the following rules.

1. Only the static position is calculated.
2. All the bellcrank arm lengths and lever lengths are identical.
3. The bellcrank is positioned so that the two link pivot points are the same height above the ground (ie the line joining the ends of the bellcrank arms is parallel to the ground).
4. The lever is positioned so that it is parallel to the bellcrank arm (that connects to the intermediate link).
   In all cases, the intermediate link length will be calculated.
5. If the roll centre height is being changed, it is assumed that the roll centre is in the axle plane, on the vehicle centreline.

The graphic is provided to give a better feedback and visualisation of how the various components “fit”. It is sometimes difficult to appreciate these relationships from numbers only.

When a solution has been developed, use the Vehicle button to transfer the data back to the main geometry. Now that the geometry is being provided with the complete Mumford linkage specification, update the geometry configuration settings and change the Instant centre location to “Suspension link chassis mounting points” and Wheel location and alignment to “All top and bottom links + Mumford linkage”. This will use the Mumford linkage to generate the roll centre. Note that there may be differences in the calculated roll centre, and the lateral and intermediate link lengths from those shown in the tool, for the reasons discussed above.
In particular, if the suspension roll axis is not parallel to the ground, then there will be significant differences in the location of the Mumford linkage instant centre, and the roll centre. The steeper the roll axis, and the further the plane of the Mumford linkage is from the axle centreline, the greater this difference.

16.5 Upright shim calculator

This tool enables the wheel camber to be calculated for the range of shims.
The basic geometry must be calculated before using this tool.

The wheel alignment is shown for the nominal shim stack. This is the number of shims and the shim thickness as specified in the upright input.

Enter the minimum number of shims used (which is usually none) and the maximum number of shims.
Then "Calc".

The graph will update and show the number of shims (along the X axis) and the wheel camber (along the Y axis).

The grid will also update and show the camber for each shim stack.

16.6 Crossmember

This tool is available in the "Tools" menu, under "Xmbr"

Some older unit body vehicles, and contemporary hot rod conversions, utilize a separate front suspension crossmember. Typically this crossmember is a self contained assembly with suspension a-arm mounts, spring and shock mounts and steering rack mounts. In turn, the crossmember is bolted or welded to the chassis side frame.

This tool provides the mapping between the mounting points on the crossmember (relative to the crossmember datums) and the same points on the chassis (relative to the chassis datums).

The relationship between the crossmember and the chassis is defined by three points, P1, P2 and P3. These three points are specified for both chassis and crossmember.

P1 is used as the primary location; P2 and P3 are used as secondary locations.

Together, P1 and P2 locate the crossmember in plan view and front view.
Ideally P1 is a point on the positive lateral axis, and P2 is a point on the negative lateral axis. The line P1-P2 should be horizontal in front view, at right angle to the chassis centreline in plan view, and centred about the chassis centreline.

If the distance between the chassis P1 and P2 points is not identical to the distance between the crossmember P1 and P2 points, then the crossmember will be located with both P1 points coincident, and with the two P2 points on the same line.

Point P3 then controls the side view "tilt" of the crossmember. The crossmember is "tilted" so that the crossmember P3 point is in the plane of the three chassis points.

Crossmember chassis mounting points P1, P2 and P3.
These are the mounting points on the crossmember for the chassis.
Note that these points are relative to the crossmember datums. The lateral dimensions must include the minus sign if the point is on the negative lateral axis.
What are the crossmember datums? They can be any convenient surfaces. It largely depends on the design of the crossmember and/or the crossmember build jig. Where the centre portion of the crossmember is made from a length of RHS, it is convenient to use the top and back faces of the RHS as the vertical and longitudinal datums.

Chassis crossmember mounting points P1, P2 and P3.
These are the mounting points on the chassis for the crossmember.
Note that these points are relative to the chassis datums. The lateral dimensions must include the minus sign if the point is on the negative lateral axis.

Crossmember suspension mounting points.
Note that these will be the LH or the RH side points according to the description.
These points are relative to the crossmember datums.
As per the usual way of defining the chassis mounting points, the lateral dimension will always be shown as positive (even though it may be on the "negative" side of the chassis).

Chassis suspension mounting points.
Note that these will be the LH or the RH side points according to the description.
These points are relative to the chassis datums.
As per the usual way of defining the chassis mounting points, the lateral dimension will always be shown as positive (even though it may be on the "negative" side of the chassis).

The buttons between each pair of mounting points specifies if a mounting point is chassis "C" or crossmember "X" located. If it is located on the chassis, there is no input (as the point is not transferred to or from the crossmember).

The calculation option specifies which data is calculated: "Calculate crossmember" will calculate the crossmember mounting points from the chassis mounting points; and "Calculate chassis" will calculate the chassis mounting points from the crossmember.

Each of the crossmember and chassis data sets contains an "Import", "Export XX" and "Export symmetric" button.
"Import" will read the data from the current vehicle, and "Export XX" will update the current vehicle data for the one side only, and "Export symmetric" will update the current vehicle data for both sides with the same data.

Application note - an existing crossmember.

We have an existing crossmember and need to see where it should be fitted to the chassis side frames.
A set of mounting points is defined for the chassis, locating the crossmember at an appropriate height and with no "tilt".
The crossmember is measured up using the centre section as the datum, and all points entered.
All applicable "C or X" buttons are clicked onto "X".
We then click "Calculate chassis" and then "Calc".
This maps the crossmember suspension mounting points onto the chassis.

Open up the chassis input dialog and the alignment dialog.
Back to the crossmember tool, and click the "Export symmetric" button. This updates the chassis input dialog with the appropriate values. Now do a geometry calc.
Now we can see where the suspension mounts are, and the suspension characteristics.

We now decide that the caster needs to be changed.

We decide that it is easiest to simply tilt the crossmember, so we change the chassis P3 point. Repeat the crossmember to chassis calculation, export the results, then do the geometry calc, and see that the caster has changed.

Maybe we need to drop the suspension a bit. So just adjust the chassis P1 and P2 points a bit lower. Now redo all the calcs. See how the crossmember points remain unchanged, but the chassis points are now lower.

Finally, export the crossmember points (use "Export symmetrical") so that they will be saved with the data file.

Application note - design a new crossmember

We have previously designed our double a-arm suspension (perhaps copied from another vehicle) but need to have all the a-arm, rack, and shock mounts on a separate crossmember.

We are going to use a section of RHS as the centre section and will use the top and back surfaces as the crossmember datums. The RHS is positioned to clear the engine and this establishes all the P1, P2 and P3 points.

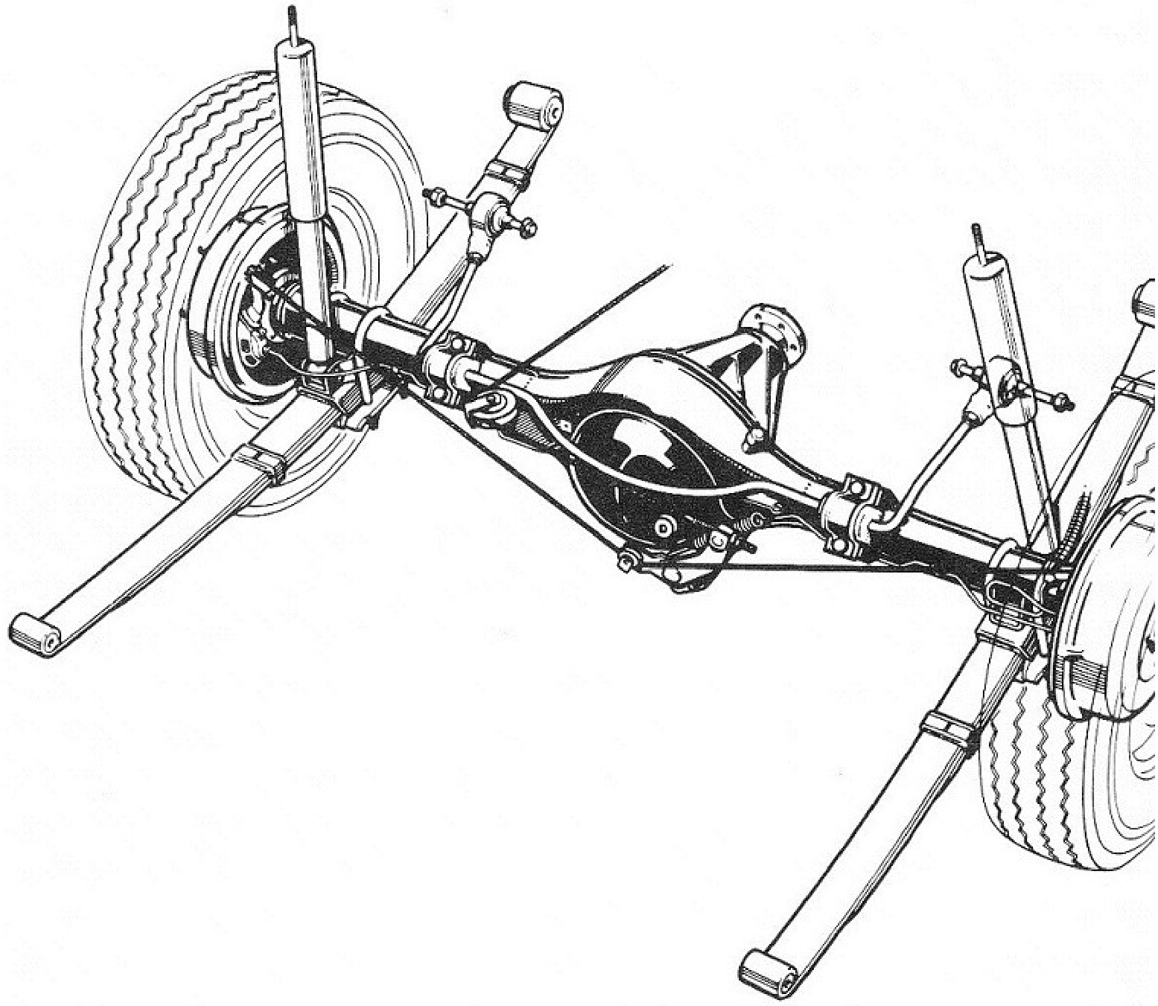
We then "Import" the chassis mounting points.
All applicable "C or X" buttons are clicked onto "X".

We then click "Calculate crossmember" and then "Calc".
This maps the chassis suspension mounting points onto the crossmember.

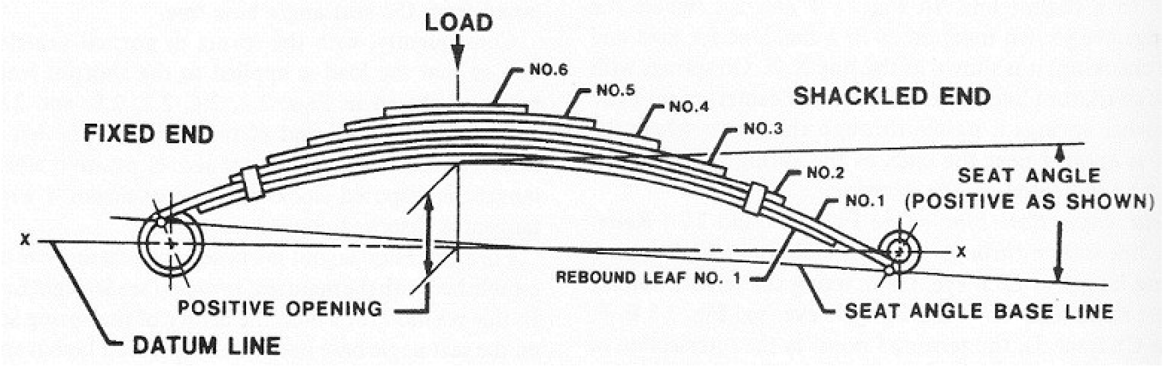
Now we can use those crossmember dimensions to build our crossmember.

Remember to export the crossmember points (use "Export symmetrical") so that they will be saved with the data file.

16.7 Leaf spring design



Typical leaf spring rear suspension - Ford Capri.
Underslung spring with upturned eye at both ends.



Typical underslung spring as positioned in a load testing machine (upside down from the installed vehicle position). Note that the datum line is between the spring eye centres. In this example, the fixed eye is upturned, and the shackled eye is downturned.

The SAE load test specifies that when the load is measured, the spring ends shall be free to move in the direction of the datum line. The ends are usually mounted on carriages with rollers. The spring shall be supported on its ends, such that the datum line is horizontal.
The load shall be applied from above to the shortest leaf. [The load] shall be transmitted from the

testing machine head through a standard SAE loading block. The loading block shall be centered over the centre bolt with the legs of the V resting on the spring.

Choose to work in either metric (SI) or imperial units.
Metric units are mm, N, N/mm and Mpa.
Imperial units are inch, pound, pound/inch and psi.

Spring eye.
Specify either plain, upturned, downturned or berlin eye. Currently any combination of upturned and downturned eyes, both eyes berlin, or both ends plain are supported.
Specify the inside diameter of the eye.

Specify the spring type.

Single	This is a single leaf of constant width and constant thickness.
Multi	This is a uniform strength spring with leaves of "common curvature".
TwoStage	This is a dual rate spring. The first stage is a uniform strength spring with leaves of "common curvature", the second stage is a uniform strength spring with flat leaves. The rate change point is when the first stage leaves are flat, and then engage the second stage leaves.

Stiffening factor (SF).
Selection of the correct SF value in the final spring design is predicated on factors gained from experience, since the value may vary from less than 1.10 to 1.50, depending on the design specifications.
For passenger car springs with tapered leaf ends and more or less "uniform" stress design, use SF = 1.10
For passenger car springs with tapered leaf ends and extended leaf lengths, use SF = 1.15
If you are testing an existing spring and have the actual load required to produce the specified static deflection, then adjust the SF so that the calculation returns the required static load.

Specify the number of leaves.
For a single leaf spring this will always be 1.
For a multi leaf spring enter a number between 1 and 10 (inclusive).
For a two stage spring enter a number for the number of leaves in the first stage, and the number of leaves in the second stage. Each stage must have at least 1 leaf, and the total number of leaves cannot exceed 10.

Specify the leaf width.
All leaves are the same width.

Specify the leaf thickness.
Each leaf can have a different thickness. Thickness for each leaf must be entered.

Main leaf length is measured along the tension side of the leaf, to a point perpendicular to the centre of the eye. Ideally measured with the main leaf flat.

Specify the length from the centre of the fixed eye to the centre bolt. Usually the centre bolt is closer to the fixed eye.

Inactive length.
Length of the spring rendered inactive by the action of the U-bolts or clamping bolts. For metal-to-metal type spring seats, this length is usually assumed to be equal to the distance between the insides of the U-bolts, except for some curved seats where it is apt to be slightly shorter. For soft seats (using rubber type isolation, as in many passenger car installations) the inactive length may approach zero.
As the inactive length is increased, both the spring rate and stress will increase. For a given deflection, the load will increase; for a given load, the deflection will decrease.

Specify the design opening height. Measured in the design load position from the datum line to the tension side of the main leaf. As shown in the above diagram, the opening height is positive.

Specify either the design load or the design deflection. The design deflection is the deflection from the free position (ie no load on the spring) to the design opening height.

Specify the metal to metal clearance. This is the maximum distance the spring can deflect from the design position. Usually until the spring or the axle contacts the vehicle chassis.

Do the calculation, using the appropriate button.

The vertical spring rate will be calculated. For a two-stage spring both the initial and the final spring rates will be shown.

The design and full bump stress will be calculated.
For automotive suspensions, the design load stress is usually in the range of 600 - 750 MPa (87000 - 109000 psi) for passenger cars. The maximum stress should not exceed the minimum yield stress of the spring material. For properly heat treated alloy steel, the minimum yield stress is generally accepted as 1200 Mpa (174000 psi).
When a spring is subjected to windup under engine or brake torque or any other forced external means, stresses in addition to those due to the vertical load may be present and should be considered in computing the stress.

Spring control Φ
If the axle is not mounted in the centre of the spring then this indicates the amount the axle will rotate in bump and droop.

After the spring has been calculated, click on the 'load-deflection graph' tab to see the graphical representation of the load vs deflection. The solid line is the design load and deflection; the dashed line is the load and deflection when the main leaf is flat. For a two-stage spring this is the transition point from the initial rate to the final rate.

If the currently loaded vehicle data file has a leaf spring, then use the 'Load data' button to get the spring dimensions.
Similarly, the 'Save data' button will save the spring data into the currently loaded vehicle data file.

For a complete explanation and additional calculations refer to AE-21 or HS-788

17 Excel import and export

From the Tool tab, there are several functions available to export SusProg3D data to Excel, and to import SusProg3D data from Excel.

- Calc2Excel enables calculated data (ie roll and bump values, spring rates, etc) to be exported to an Excel spreadsheet.
  While the Calc2Excel dialog and the Excel workbook are open, any calculations (ie Calc, ECalc or VCalc) will automatically update Excel.
  The available data is listed under Calculated data Excel names.
- Input2Excel enables input data (ie chassis mounting points, upright dimensions, etc) to be exported to an Excel spreadsheet.
  Data is exported when the "Export" button is clicked.
  The available data is listed under Input data Excel names.
- Excel2Input enables input data (ie chassis mounting points, upright dimensions, etc) to be imported from an Excel spreadsheet.
  Data is imported when the "Import" button is clicked.
  The available data is listed under Input data Excel names.
- Excel2CMM enables input data (ie chassis mounting points, upright dimensions, etc) to be imported from an Excel spreadsheet.
  Data is imported when the "Import" button is clicked.
  The available data is listed under CMM input data Excel names.

There are three ways to link SusProg3D to an Excel workbook:

1. Open the Excel workbook (by any of the Windows methods), then select the appropriate Excel tool; or
2. Select the appropriate Excel tool, and use the “Open Excel” button to choose the Excel workbook; or
3. Select the appropriate Excel tool, and open the Excel workbook (by any of the Windows methods).

If multiple tools are open at the same time, they can each reference the same Excel workbook.

Clicking "Show Excel log" will display a log of the basic Excel interaction results. It may be helpful if the calculation doesn't update Excel as expected.

If the "Close Excel on exit?" is ticked, then Excel will close when the Excel tool is closed, or, if there are multiple Excel tools open, when the last Excel tool is closed.

If the "Close Excel on exit?" is not ticked, then Excel will remain open when the Excel tool is closed, or, if there are multiple Excel tools open, when the last Excel tool is closed.

The following versions of Excel are supported

V9.0	Excel2000 (not officially supported, but should work OK)
V10.0	Excel2002
V11.0	Excel2003
V12.0	Excel2007
V14.0	Excel2010
V15.0	Excel2013
V16.0	Excel2016

To determine your Excel version,
click on Help, then click on About Microsoft Excel, or
click on the Office button, then click on Excel Options, then click on Resources, or
enter the following formula into a cell =INFO("release")

17.1 Creating worksheets

A single Excel workbook (usually a data file with the .xls or .xlsx suffix) can contain multiple worksheets.

If you want to create a single vehicle workbook, with data for both front and rear suspensions, then you will need to create two named worksheets: one named ‘Front’ for the front suspension, and a second named ‘Rear’ for the rear suspension. Sheet names are not case sensitive.

Exporting data from SusProg3D to Excel

When calculating the front suspension, the Excel tool will look for a sheet named ‘Front’ and make that the active worksheet. If there is not a sheet named ‘Front’, then the current sheet will be the active worksheet. Similarly when calculating the rear suspension, it will look for a sheet named ‘Rear’, and make that the active worksheet.

If you only create one of the pair of named worksheets (for example ‘Front’) and this is the active worksheet when calculating ‘Rear’, then this sheet will not be considered as the active worksheet, and will not be updated.

Only the named ranges on the active worksheet will be updated.

Then, when calculating and updating the Excel data, the appropriate end will always be updated.

Which worksheets are updated depends on the way the worksheets are named, and which calculation method is used.

For all calculation methods, if the active workbook does not contain any worksheets named 'Front' or 'Rear' then only the active worksheet will be referenced. The data for the calculated end (or for the current end in the case of VCalc) will be used.

For all the individual "Calcs", and for ECalc, if the active workbook contains a worksheet name that matches the the currently specified end, ie 'Front' or 'Rear', then that worksheet will become the active worksheet. Only the currently specified car end will be calculated, and that data will be used.
If the worksheet names include the LH and/or RH suffix, then each worksheet will become the active worksheet in turn.
For example, if you have worksheets "Front" and "Rear" and you calculate the front suspension, then only worksheet "Front" will be updated.
For example, if you have worksheets "FrontLH", "FrontRH", "RearLH" and "RearRH" and you calculate the front suspension, then worksheets "FrontLH" and "FrontRH" will be updated.

For VCalc, if the active workbook contains worksheet names 'Front' or 'Rear', then each worksheet will become the active worksheet in turn.
If the worksheet name includes the LH and/or RH suffix, then each worksheet will become the active worksheet in turn.
For example, if you have worksheets "Front" and "Rear" and you use VCalc to calculate both front and rear suspension, then both worksheets will be updated.
For example, if you have worksheets "FrontLH", "FrontRH", "RearLH" and "RearRH" and you use VCalc to calculate both front and rear suspension, then all worksheets will be updated.

Importing data from Excel to SusProg3D

The Excel import tool will look for a sheet with a matching name, ie ‘Front’ or 'Rear' and only import data from that worksheet. If there are no sheets named 'Front' or 'Rear' then the currently active sheet will be used.

If the worksheet name includes the LH and/or RH suffix, then each side of the vehicle will be updated with the appropriate data.

If the worksheet name does not include the LH and/or RH suffix, then the range name must include the car side, or, if omitted, the data will be assumed symmetric and the data will be applied to both sides of the vehicle.

One advantage to having individual LH and RH sheets is that the named ranges do not need the LH or RH suffix. If the worksheet name does not have the LH or RH suffix then then named ranges must include the LH or RH suffix, if not the data for the current vehicle side will be used.

17.2 Creating named ranges - 1

In Excel, you will need to create named ranges.

Excel2007 and later

To name a group of cells, select the cells, then Formulas -> Define Name. Change the Scope from "Workbook" to the name of the sheet.

Use Formulas -> Name Manger to see all the named ranges. Note that all names should be scoped to their specific sheets.

Excel2003 and earlier

To name a group of cells, select the cells, then Insert -> Name -> Define.

To print a list of all named ranges on a sheet, go to Insert -> Name -> Paste and then "Paste List". The names and the cell references will be pasted into two columns, starting with the currently selected cell.

Depending on the individual item, the required range will be either a single cell, or an appropriately sized range of cells.

Items in the Linkage, WheelAlignment and WheelAndTyre groups require a either a named single cell (for a specific item) or an appropriately sized named range of cells (for all items).
If the range size is smaller than the total number if items in that group, then the number of data items will be truncated to fit in the range.

Items in the Datum groups require either a named single cell or, for XYZ items, an appropriately sized range of 1, 2 or 3 cells.

For item requiring a group of cells, the required range size is determined by your roll and bump travel and increment setting.
For example, if the maximum bump is 85mm and the bump increment is 10mm, there will be 9 bump points; if the maximum droop is 75mm and the droop increment is 10mm, there will be 8 droop points; for a total of 18 bump and droop points (9 bump + 1 static + 8 droop).
Similarly, if the maximum roll is 4 degrees and the roll display increment is 0.5 degree, there will be 9 roll points (for versions prior to V4.600) and 17 (for V4.600 and later).
In this example, the total number of points is 27 (for versions prior to V4.600) or 35 (for V4.600 and later).
These numbers are shown as the “Excel range size required”.

Prior to V4.600 the number of bump and droop points was limited to 31 and the number of roll points to 11. V4.600 increased both these limits, and also now rolls in both directions.
If you are using an Excel data sheet designed for the previous data point limits, using the new data point limits could result in truncated data.
Option 1: Increase the size of all named ranges to suit the new number of data points.
Option 2: Name a single cell as "S3D_Aandra" and the contents of that cell should contain the number of bump, droop and roll data points. Note that the sum of the bump and droop should be one less that the total bump and droop points as it excludes the static data point. The roll includes the static roll data point. Enter the three numbers using either a full stop or a comma to separate the three numbers, for example, if bump = 5, droop = 4 and roll = 6 then enter 5,4,6 or 5.4.6

The range should cover the required number of contiguous cells, and can be either in one row or in one column.
If the range is only a single cell, then the “static” data will be exported.
If the range is three cells, and the number of bump and droop points is greater than three, then the maximum bump, static, and maximum droop data will be exported.
If the range is less than the number of bump and droop points, all cells will be blank.
If the range is greater than the total number of points, the “extra” cells will be blank.

If the range is equal to the number of bump and droop points, then only the bump and droop data will be exported.
If the range is greater than the number of bump and droop points, but smaller than the total number of points, then only the bump and droop data will be exported, and the “extra” cells will be blank.

Name the Excel range as follows:

Name syntax: S3D_Group_Item[_CarSide]

All names start with “S3D”. This is to ensure that there is no clash with any other named ranges in your workbook. Items in square brackets are optional. Names are not case sensitive. The separation character is an underline "_".

All names shall include a group identifier.
Versions prior to V4.605A allowed for the group identifier to be omitted, and defaulted to “Point”. This is now deprecated.

All names shall include an item identifier.

The CarSide is optional. If specified it must be either “LH” or “RH”. If it is not specified, data will be provided for the datum side.

For example, to include the LH camber, the name will be “S3D_Point_Camber_LH”.

Any item identifier suffixed with XYZ means that all three orthogonal dimensions are available. The axis character will have the same meaning as the specified axis settings. You can specify 1, 2 or 3 of the axis characters, and they can be in any order (eg XY, ZYX, ZX, etc). The cell range must match the number of axis characters.
If a single axis character is specified (eg X, Y or Z) then the cell range must be either a single row (of the appropriate number of columns) or a single column (of the appropriate number of rows).
If two axis characters are specified (eg XY, YZ or ZX) then the cell range must be a rectangle of either two rows (of the appropriate number of columns) or two columns (of the appropriate number of rows).
If three axis characters are specified (eg XYZ) then the cell range must be a rectangle of either three rows (of the appropriate number of columns) or three columns (of the appropriate number of rows).
If you omit the axis characters, then they will default to XYZ, ordered in the lateral, vertical and longitudinal directions.

Warning! If you are specifying XYZ items (ie all three coordinates) and the the number of data points is also 3, then the data will be exported with the X Yand Z values in rows, with the data points in columns.

With the exception of the “Datum” group items, all XYZ coordinates default to “ground based”, and bump means that the chassis is closer to the ground (ie the wheels have “bumped” and hence the chassis has lowered relative to the ground plane).
Alternatively, calculated data can be exported as coordinates relative to the chassis datum.
To specify that data should be relative to the chassis datum, name a single cell as "S3D_RefDatum" and the contents of that cell should contain some descriptive text that contains the word "Chassis". If the name "S3D_RefDatum" is not found, or it does not contain the word "Chassis", then all data will default to vehicle (ground) datum.
For the “Datum” group items, all XYZ coordinates are “datum based”.

Note that not all items are applicable for a particular suspension configuration.

For the shock and spring group names, “Shock” and “Shock1”, “Spring” and “Spring1” refer to the primary (or only) shock and spring; “Shock2” and “Spring2” refer to the secondary shock and spring for that corner of the vehicle.

Either “Center” or “Centre”, “Tire” or “Tyre” spellings are OK.

17.3 Creating named ranges - 2

Generally, you will want to have separate worksheets for the front and rear suspensions.

For this, you will need to create two Excel worksheets as "Front" and "Rear".
Each worksheet will need the same set of named ranges.

The easiest way is to create the front worksheet first with all the named ranges, then just copy it to create the rear worksheet.

Excel2007 and later

- If you haven't already done so, rename 'Sheet1' to 'Front'. Make sure you are on worksheet 'Front'.

- Now create all the named ranges (as described in the previous topic). Specify Scope as 'Front'.

- Now create a 'Rear' worksheet by copying the 'Front' sheet.

  Click on the 'Front' sheet tab (to make sure that is the current sheet).
  On the Home tab, in the Cells group, click Format and then under Organize Sheets, click Move or Copy Sheet.
  You can also right-click on a selected sheet tab, and then click Move or Copy.
  Where the dialog says 'Before sheet', select 'Sheet2'.
  Then 'tick' the 'Create a copy' box, then OK.

- Excel will copy the 'Front' sheet, and create a new sheet called 'Front (2)'. Rename it to 'Rear'.

- To see a complete list of the named ranges

  Use Formulas -> Name Manger to see all the named ranges. Note that all names should be scoped to their specific sheets.

If you have existing front and rear worksheets, and need to add a named range to one or both sheets

- If you need to add a name range to a sheet later on, then make that sheet the current sheet. Add the named range (as described in the previous topic) ensuring that the Scope as the sheet name.

- This technique can also be used to create bespoke LH and RH sheets, so that the workbook contains four worksheets, FrontLH, FrontRH, RearLH and RearRH. One advantage to having individual LH and RH sheets is that the named ranges do not need the LH or RH suffix.

Excel2003 and earlier

- If you haven't already done so, rename 'Sheet1' to 'Front'. Make sure you are on worksheet 'Front'.

- Now create all the named ranges (as described in the previous topic).

- Now create a 'Rear' worksheet by copying the 'Front' sheet.

  Make sure that 'Front' is the current sheet.
  Click on the 'Edit' menu, then the 'Move or Copy sheet' command. The shortcut is Alt+E, Alt+M
  Where the dialog says 'Before sheet', select 'Sheet2'.
  Then 'tick' the 'Create a copy' box, then OK.

- Excel will copy the 'Front' sheet, and create a new sheet called 'Front (2)'. Rename it to 'Rear'.

- To see a complete list of the named ranges

  Now, in the Rear sheet, go to Insert, Name, Define and you will see all the named ranges, but with 'Rear' on the right hand side.

If you have existing front and rear worksheets, and need to add a named range to one or both sheets

- If you need to add the name range to one sheet only, then make that sheet the current sheet. If you need to add the named range to both sheets, then make the front sheet the current sheet.

- Create the name range (as described in the previous topic), but make sure that the name is prefixed with the sheet name and an exclamation mark.
  For example, if you want to create a name "S3D_Point_Camber" on the 'Front' worksheet, then the name will be "Front!S3D_Point_Camber". Note the exclamation mark. There are no spaces in the name.
  Then click "Add".
  You should see the name added, together with its sheet name on the right.

- Now, to add the same "S3D_Point_Camber" to the 'Rear' worksheet.
  Make the 'Rear' worksheet the current worksheet.
  Create the name range (as described in the previous topic), prefixed with the sheet name and an exclamation mark.
  For example, if you want to create a name "S3D_Point_Camber" on the 'Rear' worksheet, then the name will be "Rear!S3D_Point_Camber".
  Then click "Add".
  You should see the name added, together with its sheet name on the right.

- This technique can also be used to create LH and RH sheets, so that the workbook contains four worksheets, FrontLH, FrontRH, RearLH and RearRH. One advantage to having individual LH and RH sheets is that the named ranges do not need the LH or RH suffix.

17.4 Calculated data Excel names

Name the Excel range as follows:

Name syntax: S3D_Group_Item[_CarSide]

All names start with “S3D”. This is to ensure that there is no clash with any other named ranges in your workbook. Items in square brackets are optional. Names are not case sensitive. The separation character is an underline "_".

All names shall include a group identifier.
Versions prior to V4.605A allowed for the group identifier to be omitted, and defaulted to “Point”. This is now deprecated.

All names shall include an item identifier.

The CarSide is optional. If specified it must be either “LH” or “RH”. If it is not specified, the data will be used for both sides.

When using one set of data for both sides, it is usual for the lateral dimensions to be positive for one side of the vehicle, and negative for the other. In this case it is suggested that positive dimensions are used, and that the default car side is also set to the same side. This will ensure that the other side of the vehicle is assigned the negative dimensions.

Calculated data can be exported as coordinates relative to the vehicle (ie ground) datum, or relative to the chassis datum.

Unless otherwise specified, all data will be relative to vehicle (ground) datum.

To specify that data should be relative to the chassis datum, name a single cell as "S3D_RefDatum" and the contents of that cell should contain some descriptive text that contains the word "Chassis". If the name "S3D_RefDatum" is not found, or it does not contain the word "Chassis", then all data will default to vehicle (ground) datum.

Group identifier	Item identifier	LH and RH values	Description
Point	AccelAnti	Yes	Anti-lift percentage. For the front suspension with front wheel drive, reduces droop travel under forward acceleration
	AccelAnti or AntiSquat	Yes	Anti-squat percentage. For the rear suspension with rear wheel drive, reduces bump travel under forward acceleration.
	Axle*XYZ (where * is 1 to 9)	Yes	The available values will vary according to the specific geometry type. See Axle mounting points below for itemised descriptions.
	BrakeAnti or AntiDive	Yes	Anti-dive percentage. For the front suspension, reduces bump travel under forward braking.
	BrakeAnti or AntiLift	Yes	Anti-lift percentage. For the rear suspension, reduces droop travel under forward braking.
	Bump	Yes	Wheel travel. Positive values are bump, negative values are droop.
	Camber	Yes	Wheel camber, degrees
	Caster	Yes	Wheel caster, degrees
	Chassis*XYZ (where * is 1 to 9)	Yes	The available values will vary according to the specific geometry type. See Chassis mounting points below for itemised descriptions.
	Description	Yes	Wheel travel / chassis roll description
	FrontICLength	Yes	Front view swing axle length. Instant centre to wheel contact centre, along the ground
	FrontICXYZ	Yes	Front view instant centre.
	KPBXYZ	Yes	King pin bottom pivot point (or equivalent). If the upright has a single bottom pivot point, then this will the same point. If the upright has two bottom pivot points, then this will be the virtual pivot point.
	KPGXYZ	Yes	Where the line of the king pin, from the KPT

Group identifier	Item identifier	LH and RH values	Description
			to the KPB (or equivalent) intersects the ground plane.
	KPI	Yes	King pin inclination (or equivalent), degrees
	KPTXYZ	Yes	King pin top pivot point (or equivalent). If the upright has a single top pivot point, then this will the same point. If the upright has two top pivot points, then this will be the virtual pivot point.
	Pinion	Yes	Pinion angle, degrees (relative to ground plane)
	RCHeight	No	Roll centre vertical position (from ground)
	RCOffset	No	Roll centre lateral position (from vehicle centreline)
	RideHeightXYZ	Yes	Ride height reference point location. Vehicle datum: The vertical dimension is the actual ride height. Chassis datum: The vertical dimension is the vertical location of the ride height reference point from the chassis datum.
	Roll	Yes	Chassis roll, degrees. Positive values are LH roll, negative values are RH roll.
	Scrub	Yes	Wheel lateral movement from Static position In front view
	ScrubRadius or KPIOffset	Yes	Distance from the intersection of the king pin (or equivalent) and the wheel contact centre, in front view. Positive offset is when the KPI line intersects inboard of the wheel contact patch centreline.
	SideICAngle	Yes	Angle of the line joining the side view IC and the wheel contact patch from horizontal
	SideICAxleHeight	Yes	Where the line joining the side view IC and the wheel contact patch “crosses” the “other” axle. Height above ground.
	SideICHeight	Yes	Side view pitch centre height. Instant centre to ground
	SideICLength	Yes	Side view pitch centre length. Instant centre to wheel contact centre, along the ground

Group identifier	Item identifier	LH and RH values	Description
	SpindleRefPointXYZ	Yes	Location of the wheel spindle reference point
	SteeringOffset	Yes	The radial distance from the wheel contact point to the steering axis (extended to the ground plane)
	Toe or ToeDegree	Yes	Wheel toe, degrees (toe in is positive) (Versions prior to V4.87A reported toe in as negative)
	ToeIn or ToeOffset	Yes	Wheel toe in, in mm or inches (toe in is positive) (Versions prior to V4.87A reported toe in as negative)
	Tramp	Yes	Wheel longitudinal movement from Static position In side view
	Trail	Yes	Distance from the intersection of the king pin (or equivalent) and the wheel contact centre, in side view. Positive trail is when the KPI line intersects ahead of the wheel contact patch centreline.
	Upright*XYZ (where * is 1 to 6)	Yes	The available values will vary according to the specific geometry type. See Upright mounting points below for itemised descriptions.
	WheelCentreXYZ	Yes	Location of the spindle/wheel centre.
	WheelContactXYZ	Yes	Location of the wheel centreline on ground The lateral value is the “half track” The longitudinal value is the distance to the longitudinal datum. Vehicle datum: The vertical value will always be zero (ie on ground) Chassis datum: The vertical value will be distance above or below the chassis datum.
ToeOutInTurn			The toe out in turn data. This is only available for the front suspension. All of the data for each turn angle will be included. This data requires a single range of cells, N rows by 24 columns, where N is the number of calculated points. See toe-out in turn increment to calculate N. If the Excel range is larger than the calculated data, the 'excess' cells will be noted '#N/A'.

Group identifier	Item identifier	LH and RH values	Description
			If the Excel range is smaller than the calculated data, only that data which will fit within the range will be shown. The data will be presented in the following sequence. Steering turn angle Toe out in turn Wheel toe angle LH and RH Rack travel Ackermann percentage Camber (actual) LH and RH Camber (change) LH and RH Caster (actual) LH and RH Caster (change) LH and RH Jacking effect LH and RH Steering ratio LH and RH Caster trail LH and RH KPI offset LH and RH Steering offset LH and RH
Shock* Spring* (where * is 1 or 2. If omitted, defaults to 1)	ChassisXYZ	Yes	Chassis mounting point. For a “coilover” spring, this is the shock chassis mounting point.
	Length	Yes	For a shockabsorber, length is the distance between chassis and suspension mounting points. For a spring, it is the actual spring length between the spring abutments.
	MotionRatio	Yes	Motion ratio.
	SuspensionXYZ	Yes	Suspension mounting point. For a “coilover” spring, this is the shock suspension mounting point.
Spring* (where * is 1 or 2. If omitted, defaults to 1)	Deflection	Yes	Spring deflection from the free length
	WheelRate	Yes	Wheel rate
AntiRollBar	ArmLinkXYZ	Yes	The antirollbar arm and link pivot point.
	ChassisXYZ	Yes	Chassis mounting point.
	MotionRatio	Yes	Motion ratio.
	SuspensionXYZ	Yes	Suspension mounting point.

Group identifier	Item identifier	LH and RH values	Description
	Twist	Yes	Twist angle (degrees)
	WheelRate	Yes	Wheel rate
Bellcrank	AntirollBarXYZ	Yes	Bellcrank anti-roll bar link pivot
	PivotAxis1XYZ	Yes	Bellcrank pivot axis on chassis - P1
	PivotAxis2XYZ	Yes	Bellcrank pivot axis on chassis - P2
	Rod2Bellcrank	Yes	Angle between the pushrod or pullrod and the bellcrank arm
	RodXYZ	Yes	Bellcrank pull or push rod pivot
	Rotation	Yes	Bellcrank rotation angle (from static)
	Shock2Bellcrank	Yes	Angle between the shock and the bellcrank arm
	ShockXYZ	Yes	Bellcrank shock pivot
	SuspensionXYZ	Yes	Pushrod or pullrod actuation point on the suspension
Driveline (for driveshafts)	ChassisXYZ	Yes	Driveshaft universal joint - chassis
	Item* (where * is 1 to 4)	Yes	1 is the driveshaft or CV joint plunge, 2 is the inner joint angle, 3 is the outer joint angle, 4 is the driveshaft length.
	SuspensionXYZ	Yes	Driveshaft universal joint - suspension. For independent suspension, usually on the upright, strut or trailing arm
Driveline (for propshaft)	Item* (where * is 1 to 6)	No	1 is the spline travel, 2 is the centre bearing plunge, 3 is the gearbox universal joint angle (for torque tube), 4 is the gearbox universal joint angle (to propshaft) 5 is the centre bearing universal joint angle (2-piece shafts) 6 is the axle pinion universal joint angle (to propshaft)
Vehicle	PitchCentre	Yes	Longitudinal pitch centre data All of the pitch centre data will be included. This data requires a single range of cells,

Group identifier	Item identifier	LH and RH values	Description
			2N+1 rows by M+1 columns, where N is the number front suspension bump and droop points and M is the number of rear suspension bump and droop points. The data will be presented in the same format and sequence as output in the PitchResults. If the Excel range is larger than the calculated data, the 'excess' cells will be noted '#N/A'. If the Excel range is smaller than the calculated data, only that data which will fit within the range will be shown.
Aandra		No	Range limit specification for models created prior to V4.600 See Creating named ranges

The following items are common with input data Excel names

Group identifier	Item identifier	LH and RH values	Description
Vehicle	RideHeight		Static ride height, distance from ground to reference point. Ride height can be specified using a combination of 2 or 3 points on LH and/or RH sides of the vehicle. See Specifying Ride Height. When exporting data to Excel, data will be output into the appropriate cells, with the unused cells blank. If the range size is incorrect an error message "CHECK RANGE" will display. When importing data from Excel, data will be read from all cells.
		No	If the CarSide is not specified, and the worksheet is for both sides. Requires a 4 cell range (2 rows, 2 columns). First row is the front ride height, LH and RH. Second row is the rear ride height, LH and RH.
		Yes	If the CarSide is specified, or the worksheet is for a specific car side. Requires a 2 cell range (2 rows, 1 column). First row is the front ride height. Second row is the rear ride height.
WheelAlignment	Item* (where * is 0 to 6) If blank, will default to Item00	Yes	0 or 00 means "all items" and requires a 6 cell range. 1 or 01 is the camber, 2 or 02 is the caster,

Group identifier	Item identifier	LH and RH values	Description
			3 or 03 is the toe, 4 or 04 is the wheel location (lateral), 5 or 05 is the wheel location (longitudinal), 6 or 06 is the toe reference length.
WheelAndTyre	Item* (where * is 0 to 11) If blank, will default to Item00	Yes	Note that all dimensions will be in the preferred units. When using inch dimensions, all values will be in "inches". When using metric dimensions, values will be either "mm" or "inches" according to the preference used in the wheel input. 0 or 00 means "all items" and requires an 11 cell range. 1 or 01 is the rim diameter, 2 or 02 is the rim width, 3 or 03 is the mounting offset, 4 or 04 is the tyre tread width, 5 or 05 is the tyre width, 6 or 06 is the tyre radius, 7 or 07 is the tyre rate, 8 or 08 is the toe reference length, 9 or 09 is the description, 10 is the tyre diameter, 11 is the wheel spacer thickness.
Linkage	Link* (where * is 0 to 9) If blank, will default to Link00	Yes	The available values will vary according to the specific geometry type. See Suspension link lengths below for itemised descriptions. 0 or 00 means "all items" and requires a 9 cell range.

17.5 Input data Excel names

Name the Excel range as follows:

Name syntax: S3D_Group_Item[_CarSide]

All names start with “S3D”. This is to ensure that there is no clash with any other named ranges in your workbook. Items in square brackets are optional. Names are not case sensitive. The separation character is an underline "_".

All names shall include a group identifier.

All names shall include an item identifier.

The CarSide is optional. If specified it must be either “LH” or “RH”. If it is not specified, the data will be used for both sides.

When importing data from Excel, if an item is not found, then the value in the data file will remain unchanged.

Group identifier	Item identifier	LH and RH values	Description
DatumPoint	Axle*XYZ (where * is 1 to 9)	Yes	The available values will vary according to the specific geometry type. See Axle mounting points below for itemised descriptions.
	Chassis*XYZ (where * is 1 to 9)	Yes	The available values will vary according to the specific geometry type. See Chassis mounting points below for itemised descriptions.
	RideHeightXYZ		Ride height reference point location. Ride height can be specified using a combination of 2 or 3 points on LH and/or RH sides of the vehicle. See Specifying Ride Height. When exporting data to Excel, data will be output into the appropriate cells, with the unused cells blank. If the range size is incorrect an error message "CHECK RANGE" will display. When importing data from Excel, data will be read from all cells and loaded into the input data.
		No	If the CarSide is not specified, and the worksheet is for both sides. Requires a 12 cell range (2 rows x 6 columns). First row is the front ride height reference point, LH and RH. Second row is the rear ride height reference point, LH and RH.
		Yes	If the CarSide is specified, or the worksheet is for a specific car side. Requires a 6 cell range (2 rows x 3 columns). First row is the front ride height reference point. Second row is the rear ride height reference point.
	Strut*XYZ (where * is 0 to 10 or 0 to 11)	Yes	0 or 00 means "all items" and requires either a 3 x 10 or 3 x 12 cell range depending on the strut type. The available values will vary according to the specific geometry type. See Strut datum dimensions below for itemised descriptions. If "all items" is not used, and individual items are specified, then S3D_DatumPoint_Strut01 must be specified so that the type of strut can be identified.

Group identifier	Item identifier	LH and RH values	Description
	Upright*XYZ (where * is 0 to 6)	Yes	0 or 00 means "all items" and requires a 3 x 6 cell range. The available values will vary according to the specific geometry type. See Upright mounting points below for itemised descriptions
DatumShock* DatumSpring* (where * is 1 or 2. If omitted, defaults to 1)	ChassisXYZ	Yes	Chassis mounting point. For a “coilover” spring, this is the shock chassis mounting point.
	Length	Yes	Shock absorber or Spring length (static)
DatumBellcrank	PushrodArmLength or PullrodArmLength	Yes	Pushrod or pullrod arm length.
	PushrodArmOffset or PullrodArmOffset	Yes	Pushrod or pullrod arm offset
	ShockArmLength	Yes	Shock arm length
	ShockArmOffset	Yes	Shock arm offset
	Pushrod2ShockLength or Pullrod2ShockLength	Yes	Distance between pullrod (or pushrod) and shock pivots
	Pushrod2ShockAngle or Pullrod2ShockAngle	Yes	Angle between pullrod (or pushrod) and shock arms, degrees
	Pushrod2ShockCalc or Pullrod2ShockCalc	Yes	Specify 0 to calculate using distance, 1 to calculate using angle
	ArbArmLength	Yes	Antirollbar arm length
	ArbArmOffset	Yes	Antirollbar arm offset
	Pushrod2ArbLength or Pullrod2ArbLength	Yes	Distance between pullrod (or pushrod) and antirollbar pivots

Group identifier	Item identifier	LH and RH values	Description
	Pushrod2ArbAngle or Pullrod2ArbAngle	Yes	Angle between pullrod (or pushrod) and antirollbar arms, degrees.
	Pushrod2ArbCalc or Pullrod2ArbCalc	Yes	Specify 0 to calculate using distance, 1 to calculate using angle
	PivotAxis1XYZ	Yes	Bellcrank pivot axis on chassis - P1
	PivotAxis2XYZ	Yes	Bellcrank pivot axis on chassis - P2
	PivotAxisCalc	Yes	Specify 1 to calculate pivot axis on chassis - P2 If not found, or is not 1, then pivot axis on chassis - P2 must be input
	RotationDirection	Yes	Bellcrank rotation direction in bump, 0 for clockwise, 1 for anti-clockwise
	PushrodLength or PullrodLength	Yes	Pushrod or pullrod length
	LinkCalc	Yes	Specify 0 for Autocalc, 1 for Pushrod (or pullrod) length, 2 for shock length.
DatumAntiRollBar	ChassisXYZ	Yes	Chassis mounting point.
	LinkCalc	Yes	Specify 1 for Autocalc, 0 for Specify
	LinkLength	Yes	Antirollbar link length
	LinkType	Yes	Specify 0 for type A, 1 for no link, 2 for type B

The following items are common with calculated data names

Group identifier	Item Identifier	LH and RH values	Description
Vehicle	RideHeight		Static ride height, distance from ground to reference point. Ride height can be specified using a combination of 2 or 3 points on LH and/or RH sides of the vehicle. See Specifying Ride Height.

Group identifier	Item Identifier	LH and RH values	Description
			When exporting data to Excel, data will be output into the appropriate cells, with the unused cells blank. If the range size is incorrect an error message "CHECK RANGE" will display. When importing data from Excel, data will be read from all cells and loaded into the input data.
		No	If the CarSide is not specified, and the worksheet is for both sides. Requires a 4 cell range (2 rows, 2 columns). First row is the front ride height, LH and RH. Second row is the rear ride height, LH and RH.
		Yes	If the CarSide is specified, or the worksheet is for a specific car side. Requires a 2 cell range (2 rows, 1 column). First row is the front ride height. Second row is the rear ride height.
WheelAlignment	Item* (where * is 0 to 6) If blank, will default to Item00	Yes	0 or 00 means "all items" and requires a 6 cell range. 1 or 01 is the camber, 2 or 02 is the caster, 3 or 03 is the toe, 4 or 04 is the wheel location (lateral), 5 or 05 is the wheel location (longitudinal), 6 or 06 is the toe reference length.
WheelAndTyre	Item* (where * is 0 to 11) If blank, will default to Item00	Yes	Note that all dimensions will be in the preferred units. When using inch dimensions, all values will be in "inches". When using metric dimensions, values will be either "mm" or "inches" according to the preference used in the wheel input. 0 or 00 means "all items" and requires an 11 cell range. 1 or 01 is the rim diameter, 2 or 02 is the rim width, 3 or 03 is the mounting offset, 4 or 04 is the tyre tread width, 5 or 05 is the tyre width, 6 or 06 is the tyre radius, 7 or 07 is the tyre rate, 8 or 08 is the toe reference length, 9 or 09 is the description, 10 is the tyre diameter, 11 is the wheel spacer thickness.

Group identifier	Item Identifier	LH and RH values	Description
Linkage	Link* (where * is 0 to 9) If blank, will default to Link00	Yes	The available values will vary according to the specific geometry type. See Suspension link lengths below for itemised descriptions. 0 or 00 means "all items" and requires a 9 cell range.

17.6 CMM input data Excel names

Name the Excel range as follows:

Name syntax: S3D_Group_Item[_CarSide]

All names start with "S3D". This is to ensure that there is no clash with any other named ranges in your workbook. Items in square brackets are optional. Names are not case sensitive. The separation character is an underline "_".

All names shall include a group identifier.

All names shall include an item identifier.

The CarSide is optional. If specified it must be either "LH" or "RH". If it is not specified, the data will be used for both sides.

When using one set of data for both sides, it is usual for the lateral dimensions to be positive for one side of the vehicle, and negative for the other. In this case it is suggested that positive dimensions are used, and that the default car side is also set to the same side. This will ensure that the other side of the vehicle is assigned the negative dimensions.

Group identifier	Item identifier	LH and RH values	Description
CMM	Chassis*XYZ (where * is 1 to 5)	Yes	The available values will vary according to the specific geometry type. See Chassis mounting points below for itemised descriptions.
	Comment	No	Comment text
	DatumXYZ	No	CMM datum offset from vehicle datum
	SpindleXYZ	Yes	Spindle reference point
	StrutAxisTXYZ	Yes	A point on the top of the strut rod. Must be on the rod axis.
	StrutAxisBXYZ	Yes	A point on the bottom of the strut rod or tube. Must be on the rod or slider axis. Together, StrutAxisT and StrutAxisB define the strut rod axis.
	Suspension*XYZ (where * is 1 to 8)	Yes	Suspension mounting on the upright / trailing arm / A-arm 1 is the shockabsorber mounting point

Group identifier	Item identifier	LH and RH values	Description
			2 is the spring mounting point 3 is the anti-roll bar link mounting point 4 is the pull or pushrod mounting point 5 is the second shockabsorber mounting point (if there are 2 shockabsorbers) 6 is the second spring mounting point (if there are 2 springs) 7 is the caster control link (for Ford Integral Link) 8 is the toe link mounting (for A-arm mounted toe control links)
	Upright*XYZ (where * is 1 to 6)	Yes	The available values will vary according to the specific geometry type. See Upright mounting points below for itemised descriptions.
	WheelCentreXYZ	Yes	Spindle / wheel centre

The following items are common with calculated data names

Group identifier	Item identifier	LH and RH values	Description
WheelAndTyre	Item* (where * is 0 to 11)	Yes	Note that all dimensions will be in the preferred units. When using inch dimensions, all values will be in "inches". When using metric dimensions, values will be either "mm" or "inches" according to the preference used in the wheel input. 0 or 00 means "all items" and requires an 11 cell range. 1 or 01 is the rim diameter, 2 or 02 is the rim width, 3 or 03 is the mounting offset, 4 or 04 is the tyre tread width, 5 or 05 is the tyre width, 6 or 06 is the tyre radius, 7 or 07 is the tyre rate, 8 or 08 is the toe reference length, 9 or 09 is the description, 10 is the tyre diameter, 11 is the wheel spacer thickness.

17.7 Chassis mounting points

For a double A-arm suspension: 1 = top front link
2 = top rear link

	3 = toe control link (usually the rack end ball joint) 4 = bottom front link 5 = bottom rear link 6 = top wishbone virtual pivot point 7 = top wishbone normal pivot point 8 = bottom wishbone virtual pivot point 9 = bottom wishbone normal pivot point Virtual and normal points (6, 7 ,8 & 9) are calculated data only, and are not applicable for Datum groups
For a strut suspension	1 = strut top mounting 3 = toe control link (usually the rack end ball joint) 4 = bottom front link 5 = bottom rear link 8 = bottom wishbone virtual pivot point 9 = bottom wishbone normal pivot point Virtual and normal points (8 & 9) are calculated data only, and are not applicable for Datum groups
Ford Integral Link	2 = camber control link 3 = toe control ink 4 = lower control a-arm front 5 = lower control a-arm rear 8 = lower control a-arm virtual pivot point 9 = lower control a-arm normal pivot point Virtual and normal points (8 & 9) are calculated data only, and are not applicable for Datum groups
For a 3 or 4 link live axle	1 = top link mounting, 2 = bottom link mounting
For twin trailing arm live axle	2 = arm mounting
For a torque tube live axle	2 = torque tube mounting
For a torque arm live axle	1 = torque arm mounting, 2 = bottom link mounting
For a Mumford link	5 = Mumford bellcrank (or lever) pivot point 6 = Mumford bellcrank (or lever) axis reference point
For a Panhard rod	4 = Panhard rod chassis mounting
For a Watts linkage, with the Watts lever pivoting on the chassis	5 = Watts lever pivot point 6 = Watts lever axis reference point
For a Watts linkage, with the Watts lever pivoting on the axle	4 = Watts lateral link mounting

17.8 Upright mounting points

For the typical independent suspension upright

Item	Value	Description
01	XYZ	Top mounting for an upright with single top mounting, or Top front mounting for an upright with two top mountings.
02	XYZ	Top rear mounting for an upright with two top mountings. Leave blank if not applicable.
03	XYZ	Toe control link mounting
04	XYZ	Bottom mounting for an upright with single bottom mounting, or Bottom front mounting for an upright with two bottom mountings.
05	XYZ	Bottom rear mounting for an upright with two bottom mountings. Leave blank if not applicable.
06	Single number	Spindle reference point

Ford integral link

Item	Value	Description
01	XYZ	Caster control link mounting.
02	XYZ	Camber control link mounting
03	XYZ	Toe control link mounting
04	XYZ	Lower control a-arm mounting.
05	XYZ	Not applicable, leave blank.
06	Single number	Spindle reference point

For the typical independent suspension strut. Note that these are calculated data items for Calc2Excel export only. For strut input data see Strut datum dimensions.

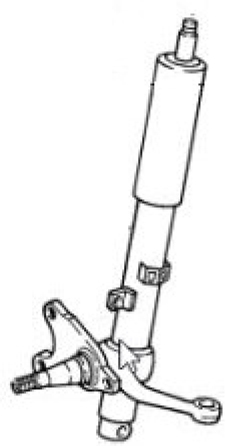
Item	Value	Description
01	XYZ	Not applicable, will default to zero
02	XYZ	Not applicable, will default to zero
03	XYZ	Toe control link mounting
04	XYZ	Bottom mounting for a strut with single bottom mounting, or Bottom front mounting for a strut with two bottom mountings.

Item	Value	Description
05	XYZ	Bottom rear mounting for a strut with two bottom mountings. If not applicable will default to zero
06	Single number	Spindle reference point

17.9 Strut datum dimensions

There are two different styles of strut, and each has a different way to specify dimensions.

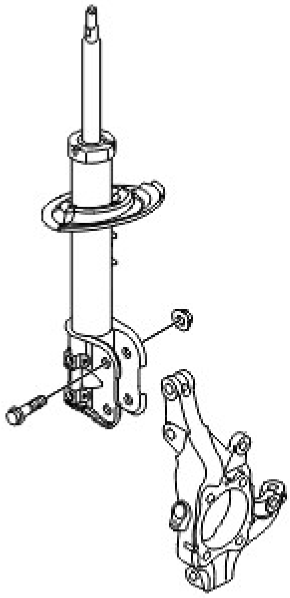
For fixed knuckle/strut types



Item	Value	Description
01	Single character	Strut type, either "A" or "B"
02	XYZ	Strut rod top Not used for strut type B when importing from Excel. Will default to zero.
03	XYZ	Strut rod bottom
04	Single number	Strut axis length Not used for strut type A when importing from Excel. Will default to zero.
05	Single number	Strut axis angle Not used for strut type A when importing from Excel. Will default to zero.
06	XYZ	Bottom A-arm mounting (for a single A-arm mount), or Bottom front link mounting (for the double ball joint bottom mount)
07	XYZ	Bottom rear link mounting (for the double ball joint bottom mount) Leave blank if not applicable.
08	Single number	Steering arm ball joint location, either 0 (on knuckle) or 1 (on strut tube) If not specified when importing from Excel will default to 0
09	XYZ	Steering arm ball joint

10	Single number	Spindle reference point

For the "bolted on" knuckle to strut tube type



Item	Value	Description
01	Single character	Strut type, either "C" or "D"
02	XYZ	Strut tube (knuckle mounting) A
03	XYZ	Strut tube (knuckle mounting) B Not used for strut type D when importing from Excel. Will default to zero.
04	XYZ	Knuckle (strut mounting) A
05	XYZ	Knuckle (strut mounting) B Not used for strut type D when importing from Excel. Will default to zero.
06	Single number	Strut axis length
07	Single number	Adjustment angle for Strut type C Strut axis angle for strut type D
08	XYZ	Bottom A-arm mounting (for a single A-arm mount), or Bottom front link mounting (for the double ball joint bottom mount)
09	XYZ	Bottom rear link mounting (for the double ball joint bottom mount) Leave blank if not applicable.
10	Single number	Steering arm ball joint location, either 0 (on knuckle) or 1 (on strut tube) If not specified when importing from Excel will default to 0
11	XYZ	Steering arm ball joint
12	Single number	Spindle reference point

17.10 Axle mounting points

For a 3 or 4 link live axle

1 is the top link mounting,
2 is the bottom link mounting

For twin trailing arm live axle	2 is the arm mounting
For a torque tube live axle	2 is the torque tube mounting
For a torque arm live axle	3 is the torque arm mounting effective point
For a Mumford link	5 is the Mumford lateral link mounting
For a Panhard rod	5 is the Panhard rod axle mounting
For a Watts linkage, with the Watts lever pivoting on the chassis	5 is the Watts lateral link mounting
For a Watts linkage, with the Watts lever pivoting on the axle	6 is the Watts lever pivot point 7 is the Watts lever axis reference point

17.11 Suspension link lengths

For A-arm and multi-link independent suspension	1 = top front link 2 = top rear link 3 = top A-arm base length (for top A-arm only) 4 = top A-arm normal length (for top A-arm only) 5 = toe control link 6 = bottom front link 7 = bottom rear link 8 = bottom A-arm base length (for bottom A-arm only) 9 = bottom A-arm normal length (for bottom A-arm only)
Ford Integral Link	2 = camber control link 5 = toe control link 6 = lower control a-arm, front link 7 = lower control a-arm, rear link 9 = lower control a-arm, normal link
For a 3 or 4 link live axle	1 = top link, 2 = bottom link
For twin trailing arm live axle	2 = trailing arm
For a torque arm live axle	2 = bottom link
For a Mumford link	4 = Mumford lateral link 5 = Mumford intermediate link
For a Panhard rod	4 = Panhard rod
For a Watts linkage	4 = Watts lateral link

18 Technical and implementation notes

This section contains additional information and calculation notes.

18.1 Suspension geometry

Even for inline suspension pivots where the upright moves strictly vertically, castor shown in the chassis bump segments will vary slightly in bump and droop. This is a consequence of the apparent change of upright height in vehicle side view as the wheel is cambered, and consequently the castor angle appears to change. Changes to static castor require the wishbone upright pivot points to move fore and aft. There is a similar effect due to toe-in and toe-out which move the upright pivots forward and backward. Toe-in tends to increase the castor, toe-out to reduce it. This readily illustrates the way in which a change to one wheel setting can introduce slight variations into the other settings. Although these variations are extremely small, SusProg3D automatically compensates for them, and the wheel is always set to the exact static setting specified, and the adjustable link lengths calculated accordingly.

There are two linkage instant centres (IC).

The front view instant centre is in the vertical plane of the axle centreline. This IC then defines the roll centre and swing axle length. Camber change and wheel track variations are a function of the position of the front view IC.

The side view instant centre is in the vertical plane of the wheel centreline. Caster change and anti -dive or anti-squat characteristics are a function of the position of the side view IC.
If the suspension linkages are such that they are parallel and do not intersect at an instant centre, then the instant centre height and length will be zero.
Side view instant centre locations are referenced to the specific axle, and for the front axle, will be positive in the rearward direction, and negative in the forward direction. For the rear axle, will be positive in the forward direction, and negative in the rearward direction.
The side view “anti-line” is that line joining the tyre contact point to the instant centre, or, if there is no intersection point, is the line from the tyre contact point parallel to the plane of the wishbone. If the instant centre location is negative, then the “anti-line” will be extended in the opposite direction.
The “axle height” dimension is where the “anti-line” cuts the vertical line from opposite axle tyre contact point.
The “anti-line” angle is the angle between the “anti-line” and the ground line.

The front and rear side view instant centres can be combined to produce a vehicle pitch centre. This is analogous to the front view roll centre which combines the left and right instant centres. The vehicle pitch centre is calculated as part of the PitchCalculation.

For a more detailed discussion, see [MILL95] and [REIM96].

In a similar fashion, the suspension roll axis is defined.

For a typical independent suspension, there is an “instant plane” defined by the wheel contact centre point, the front view instant centre, and the side view instant centre. Where the “instant planes” of the left and right suspensions intersect, then this is the suspension roll axis. The suspension roll axis line intersects the plane of the axle at the roll centre.

For a typical live axle suspension, the suspension roll axis is determined by the linkage intersection points. Again, the roll centre is where this axis intersects the plane of the axle.

The suspension roll axis inclination is shown as a percentage (ie the roll axis inclination angle, in radians, times 100). If the suspension roll axis is inclined downwards (towards the front of the vehicle) then this is shown as a negative value.

For a more detailed discussion, see [MILL02]

SusProg3D uses the specified wheel alignment settings, and either the specified track and wheel axle centreline offset from the datum, or the specified wishbone link lengths to position the upright and wheel. This then determines the lengths of the wishbone links or the remaining wishbone links and both the track and wheel axle centreline offset from the datum.

For the rear suspension, the term castor is applied differently to that when used for the front suspension. In the settings dialog box, the value for castor is taken to be the inclination of the upright from the vertical, and is consistent with accepted usage. This is the value shown as "Castor angle" in the various displays and printouts.

As noted elsewhere, bump and droop travels are measured at the centreline of the tyre. This can sometimes cause the calculations to fail for maximum droop, where at first glance, there is adequate suspension travel. Typically what happens is that as the wheel approaches full droop it assumes an increasing amount of negative camber. This raises the wheel contact point relative to the upright bottom pivot point, requiring more upright droop travel to compensate. Eventually a situation can be reached where the distance the bottom upright pivot has to be dropped to achieve the required wheel travel is such that the length of the top wishbone is shorter than the distance to the top upright pivot. This is usually only a problem with short top links (especially if they have little or no inclination above horizontal in the static position) and large amounts of droop travel. A similar situation can also arise on large bump travel.

For wishbone and strut type suspensions, the steering calculations are decoupled from the roll and bump calculations. This means that when doing the roll & bump calculations, the wheel toe setting is fixed (ie there is no toe change in bump and droop). The steering calculations, however, use the specified (or calculated as the case may be) steering arm and rack pivot locations to calculate the toe change in bump and droop. These toe changes are also applied to the roll and bump data, and if the roll & bump data is redisplayed, these toe changes will be shown. If, however, after doing the steering, the roll & bump is recalculated, then the roll & bump display will again be based on fixed toe-in. By decoupling the toe change from the basic geometry calculations, it means that toe control pivot points do not need to be continually changed as changes are made to upright and or chassis pivot points.

18.2 Instant centres

How instant centres are calculated for the different suspension types.

18.2.1 Semi-trailing arm

There is no option to specify swing axle length and roll centre.

Swing axle length is determined by the intersection of the chassis pivot point axis and the vertical plane of the axle centreline.

18.2.2 Trailing arm, upper and lower lateral links

The geometry instant centres and swing arm lengths are defined by the intersection of two planes. The bottom lateral link and the trailing arm pivot point define one of the planes, and the top lateral link and the trailing arm pivot point define the other. The instant centre axis is the intersection of these two planes.

The two instant centres are the roll centre (in front view) and the pitch centre (in side view).

The front view instant centre, roll centre and swing arm length are calculated where the instant centre axis intersects the plane of the axle.

The side view instant centre and swing arm length are calculated where the instant centre axis intersects the plane of the wheel.

The instant centres will be calculated. All required chassis mounting point lateral, vertical and longitudinal dimensions must be specified. The instant centre values shown in Geometry | ICs will all be “read only”.

18.2.3 Strut

The geometry instant centres and swing arm lengths are defined by the intersection of two planes. The strut rod slider axis and the chassis top mounting point together define one of the planes, and the three pivot points of the bottom wishbone define the other. The two instant centres are the roll centre (in front view) and the pitch centre (in side view).

The front view instant centre, roll centre and swing arm length are calculated from the strut slider axis and the wishbone pivot to bottom ball joint line, in the plane of the axle.

The side view instant centre and swing arm length are calculated from the strut slider axis and the wishbone pivot axis, in the plane of the wheel.

From the Geometry tab, select Config to specify how the instant centre will be calculated.

The instant centres can be either

- derived from the specified chassis mounting points, or
- specified directly, and will determine the chassis mounting points.

From the Geometry tab, select ICs to specify or check the instant centre dimensions.

The strut rod slider axis and the chassis top mounting point together define one of the projection planes which determine the instant centre locations. If the anti-squat is specified as “Strut” then the anti-squat will be calculated from the strut rod inclination and a horizontal bottom wishbone.

If the instant centre location is determined by “Suspension link chassis mounting points” then the instant centres will be calculated. All required chassis mounting point lateral, vertical and longitudinal dimensions must be specified. The instant centre values shown in Geometry | ICs will all be “read only”.

If the instant centre location is determined by “Swing axle lengths and roll/pitch centre heights” then the bottom wishbone chassis mounting lateral and longitudinal dimensions must be specified, and the appropriate instant centre and swing arm length dimensions must be specified in Geometry | ICs

- either the front view swing axle length or roll centre height can be specified (but not both), and
- either the side view swing axle length or the side view instant centre height or the anti angle can be specified (but not more than one of them).

This option will calculate the bottom wishbone chassis mounting vertical dimensions.

18.2.4 Tri-link strut

The geometry instant centres and swing arm lengths are defined by the intersection of two planes. The strut rod slider axis and the chassis top mounting point together define one of the planes, and the lateral links and the trailing link define the other. The two instant centres are the roll centre (in front view) and the pitch centre (in side view).

The front view instant centre, roll centre and swing arm length are calculated from the strut slider axis and the lateral link pivots, in the plane of the axle.

The side view instant centre and swing arm length are calculated from the strut slider axis and the trailing link pivots, in the plane of the wheel.

From the Geometry tab, select Config to specify how the instant centre will be calculated.

The instant centres can be either

- derived from the specified chassis mounting points, or
- specified directly, and will determine the chassis mounting points.

From the Geometry tab, select ICs to specify or check the instant centre dimensions.

If the instant centre location is determined by “Suspension link chassis mounting points” then the instant centres will be calculated. All required chassis mounting point lateral, vertical and longitudinal dimensions must be specified. The instant centre values shown in Geometry | Ics will all be “read only”.

If the instant centre location is determined by “Swing axle lengths and roll/pitch centre heights” then the bottom wishbone chassis mounting lateral and longitudinal dimensions must be specified, and the appropriate instant centre and swing arm length dimensions must be specified in Geometry | ICs

- either the front view swing axle length or roll centre height can be specified (but not both), and
- either the side view swing axle length or the side view instant centre height or the anti angle can be specified (but not more than one of them).

This option will calculate the bottom lateral link chassis mounting vertical dimensions.

18.2.5 Live axle

There is no option to specify the roll centre. The roll centre is determined by the Watts linkage pivot point, the Panhard rod or the 4 trailing links, depending on the particular location style.

18.3 Strut application

A common requirement for vehicles with strut suspension is the relocation of the chassis link pivot points (or changing the length of the lower link) to provide the required wheel camber, particularly when the vehicle ride height and/or different wheel and tyre sizes have been fitted.

1. Ensure the vehicle is sitting at the required ride height and the correct wheel and tyres are fitted.
2. Measure all the required values and input.
3. Run the calculations and verify.

To relocate the lower control arm pivot point to achieve a specific static negative camber and keep original lower control arm length.

1. Specify the instant centre location as “Suspension link chassis mounting points”
2. Note the chassis lower lateral control arm pivot lateral value.
3. Specify the configuration option as “Bottom wishbone + strut top mounting + wheel toe”. This will keep the strut top mounting and the bottom wishbone lower lateral control arm length fixed.
4. If you require more (less) negative camber, increase (decrease) the chassis pivot point lateral dimension of the mounting for the lower lateral control arm.
5. Calculate, and check the wheel alignment.
6. Repeat 4 and 5 until the wheel alignment camber is the dimension required.

Change the length of the lower control arm and keep the original pivot point.

1. Specify the instant centre location as “Suspension link chassis mounting points”
2. Note the lower lateral control arm length.
3. Specify the configuration option as “Bottom wishbone + strut top mounting + wheel toe”. This will keep the strut top mounting and the bottom wishbone lower lateral control arm mounting fixed.
4. If you require more (less) negative camber, increase (decrease) the link length of the lower lateral control arm.
5. Calculate, and check the new lower lateral control arm length.

6. Repeat 4 and 5 until the wheel alignment camber is the dimension required.

Now use the Steering module to determine the required adjustments to achieve the desired bump steer and toe-out in turn characteristics.

When measuring a strut, particularly when still fitted to the vehicle, be particularly careful to measure from the correct strut datums and centrelines. After calculating all the static values, you can verify all points from vehicle coordinates and adjust if necessary. The steering ball joint and the strut rod axis bottom point will often be the most difficult points to dimension accurately.

18.4 Tri-strut application

A common requirement for vehicles with strut suspension is the relocation of the chassis link pivot points (or changing the length of the lateral links) to provide the required wheel camber, particularly when the vehicle ride height and/or different wheel and tyre sizes have been fitted.

As an example, it may be required to relocate of the lateral link chassis pivot points to achieve a specific static negative camber.

1. First ensure the vehicle is sitting at the required ride height and the correct wheel and tyres are fitted.
2. Measure all the required values and input.
3. Run the calculations and verify.

To relocate the lateral link chassis pivot points to achieve a specific static negative camber and keep original link lengths.

1. Specify the instant centre location as “Suspension link chassis mounting points”
2. Note both chassis lower lateral control arm pivot lateral value.
3. Specify the configuration option as “All links + strut top mounting (fixed wheel alignment)”. This will keep the strut top mounting and the lateral link lengths fixed.
4. If you require more (less) negative camber, increase (decrease) the chassis pivot point lateral dimension of both lateral links.
5. Calculate, and check the wheel alignment.
6. Repeat 4 and 5 until the wheel alignment camber is the dimension required.

Change the length of the lateral links and keep the original pivot points.

1. Specify the instant centre location as “Suspension link chassis mounting points”
2. Note both chassis lower lateral control arm lengths.
3. Specify the configuration option as “All links + strut top mounting (fixed wheel alignment)”. This will keep the strut top mounting and the lateral link mountings fixed.
4. If you require more (less) negative camber, increase (decrease) the length of both lateral links.
5. Calculate, and check the wheel alignment.
6. Repeat 4 and 5 until the wheel alignment camber is the dimension required.

Now use the Steering module to check the desired bump steer characteristics.

When measuring a strut, particularly when still fitted to the vehicle, be particularly careful to measure from the correct strut datums and centrelines. After calculating all the static values, you can verify all points from vehicle coordinates and adjust if necessary. The strut rod axis bottom point will often be the most difficult point to dimension accurately.

18.5 Semi-trailing arm application

A common requirement for vehicles with semi-trailing arms is to establish the bump steer characteristics if the arm is located in a different static position from the initial design position, for example by lowering the chassis (where the pickup points are fixed on the chassis structure) or by fitting different tyre sizes (which moves the axle up or down) and maintaining the vehicle ride height.

- First ensure the vehicle is sitting at the initial ride height and the correct wheel and tyres are fitted.
- Measure all the required values and input.
- Run the calculations and verify.
- Specify the configuration option as “Chassis mounts + semi-trailing arm”. This will keep the trailing arm chassis mountings and lengths fixed.
- If the requirement is to lower the chassis (say 50mm) and retain the same tyre size, subtract 50mm from the static ride heights. Recalculate the geometry, roll & bump and steering. The geometry and bump steer characteristics of the lowered vehicle will be displayed.
- If the requirement is to change the tyre size (say by fitting a lower profile tyre with a 15mm smaller rolling radius) and adjusting the spring abutments to maintain the original chassis ride height, subtract 15mm from the tyre rolling radius. Recalculate the geometry, roll & bump and steering. The geometry and bump steer characteristics of the lowered vehicle will be displayed.

Note that in both cases the distance of the axle centreline from the Z datum will change slightly in order to keep the arm link lengths unchanged.

18.6 Upper transverse leaf spring, lower reversed A-arm and trailing link

Currently the only spring eye supported is the downturned eye. This is the standard TriumphGT6 spring.

Although specified as a symmetric half elliptic leaf spring, geometrically it is equivalent to a pair of back-to-back quarter elliptic springs.

The centre of the spring (the centre of the clamped section) is considered to be rigidly fixed to the chassis.

The position of the centre of the spring eye is calculated by assuming a circular arc for the active section of the main leaf.
There is no lateral or torsional deflection.

18.7 Dimensioning chassis points using ground based vertical datum

Before measuring, the vehicle should be in the static ride position.

All chassis point vertical dimensions are measured vertically from the ground.

The chosen datum should be identified, eg "ground".

A point on the chassis is chosen as the longitudinal datum reference, and all longitudinal dimensions are measured horizontally forward and backward from a vertical line through this point.

The chosen datum should be identified, eg "rear corner of front wheel arch".

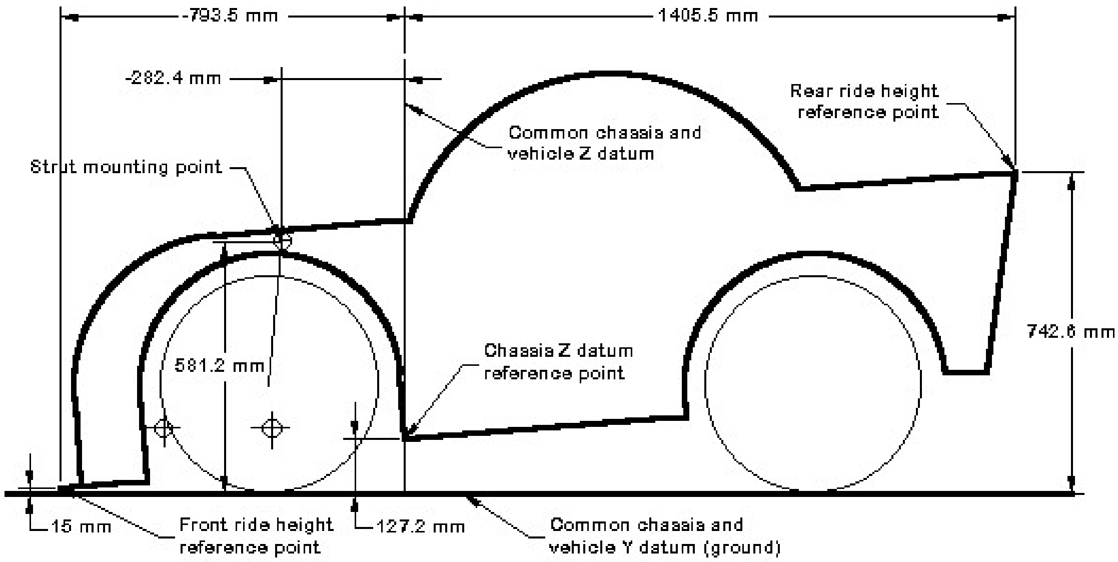


Fig 1 Chassis dimensions based on ground datum with vehicle in static ride position

In the figure above, the vehicle is in the static ride position.

A point on the corner of the rear edge of the front wheel arch and chassis undertray line is chosen as the longitudinal datum point.

The top strut mounting point lateral, vertical and longitudinal are then measured.

The lateral dimension is from the vehicle centreline.

The vertical dimension is from the ground, 581.2mm (approx 22.881").

The longitudinal dimension is forward from the longitudinal datum vertical, -282.4mm (approx 11.118").

In the same way, all the other chassis points are measured.

It is also necessary to specify two ride height reference points. For this vehicle, one point is the front splitter, the other is the rear deck lid. Any convenient point can be used, but they must be one front and the other rear, ideally at least the length of the wheelbase apart.

In the same way as before, the two points are measured.

Front ride height reference point vertical and longitudinal measurements are 15.0mm and -793.5mm (approx 0.590" and -31.217").

Rear ride height reference point vertical and longitudinal measurements are 742.6mm and 1405.5mm (approx 29.236" and 55.335").

The static ride heights must also be specified.

Since the vehicle is already in the static ride position, the static ride heights are the same as the ride height reference point vertical dimensions, 15.0mm and 742.6mm respectively. Note that ride height dimensions are always positive.

In the above example, the vertical axis is positive upwards and the longitudinal axis is positive rearwards.

18.8 Convert from ground based to chassis based vertical datum.

This may be useful where the initial design is done with ground based dimensions, but to facilitate chassis construction, it may be more convenient to reference dimensions to fixed chassis planes (for example, the chassis undertray and front bulkhead). The "Create from vehicle coordinates" datum tool can be used to move both the vertical and longitudinal datums, and recalculate all chassis pickup points so they are dimensioned from the new datum planes.

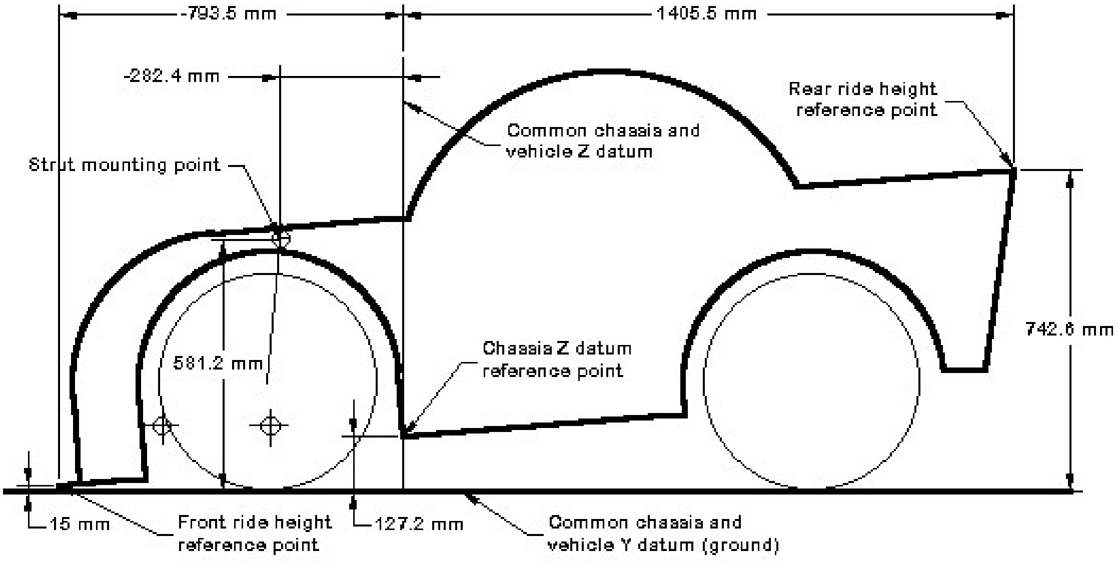


Fig 1 Chassis dimensions based on ground datum with vehicle in static ride position

Firstly, the vehicle should be calculated so that all the vehicle coordinates are correct. Make sure that the appropriate ride heights have been correctly specified.

Now, identify the surface that is to be used as the new chassis datum. In this example we will use the flat section of chassis between the wheels as our chassis datum. Our build surface will be a flat surface approx 2.4m x 1.2m (8' x 4').

We will use a point central between the two front side sill edges, and a point central between the two rear side sill edges, as our centreline reference points, and the right hand front side sill edge as out lateral reference point. There is rake in side view, but no side rake in end view.

We will be using the front edge of the side sill as our longitudinal reference point.

Using the Tool | Datum dialog, and "Create from vehicle coordinates".

Enter the chassis datum vehicle coordinates:

Centreline reference point - front	0.0, 127.2, 0.0
Centreline reference point - rear	0.0, 135.5, 783.0
Lateral reference point	600.0, 127.2, 0.0
Longitudinal reference point	600.0, 127.2, 0.0
Front edge datum surface	-600.0
Rear edge datum surface	1800.0
Width datum surface	1200.0

Now "Apply".

All the chassis coordinates will be recalculated relative to the new chassis datum.

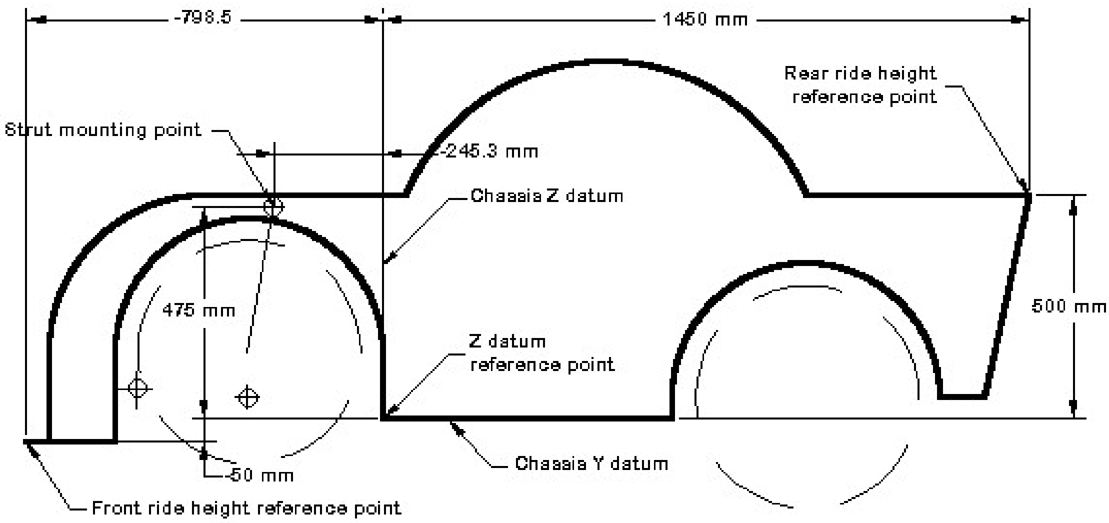


Fig 2a Chassis dimensions based on undertray line and rear of front wheel arch

Note that the ride height reference points will be recalculated, but the ride heights will remain unchanged.

In this example, because we use the vehicle sill section for our new chassis datum, the front spoiler is now below the build table surface. This means that we must limit the length of the build table, or remove the spoiler before putting the chassis on the build table. Or we can move the chassis datum surface down 50mm. This would mean that we need 50mm blocks to support the side sills, but we can have the complete chassis and bodywork on the build table.

This time we will use the "Move vertically and/or longitudinally" datum tool.

To move the vertical datum in the direction of the positive vertical axis, enter a positive value for ‘ vertically’; to move the vertical datum in the direction of the negative vertical axis, enter a negative value for ‘vertically’.

Enter realign chassis datum value as -50.0, 0.0

Use the ‘Recalc’ button to recalculate the chassis vertical and longitudinal values accordingly.

Now do a complete vehicle calculation. All of the calculated vehicle coordinates should remain unchanged. It is only the chassis datum defined inputs that have been changed.

In the above example, the vertical axis, Y, is positive upwards and the longitudinal axis, Z, is positive rearwards.

18.9 Dimensioning chassis points using chassis based vertical datum

Before measuring, the chassis should be positioned such that the chosen vertical datum plane is horizontal. This is usually the chassis undertray or major structure. Most often this will also correspond to the position of the chassis in the build jig or mounted on a surface plate.

All chassis points vertical dimensions are measured vertically from the datum.

The chosen datum should be identified, eg "chassis undertray".

A point on the chassis is chosen as the longitudinal datum reference, and all longitudinal dimensions are measured horizontally forward and backward from a vertical line through this point.

The chosen datum should be identified, eg "rear corner of front wheel arch".

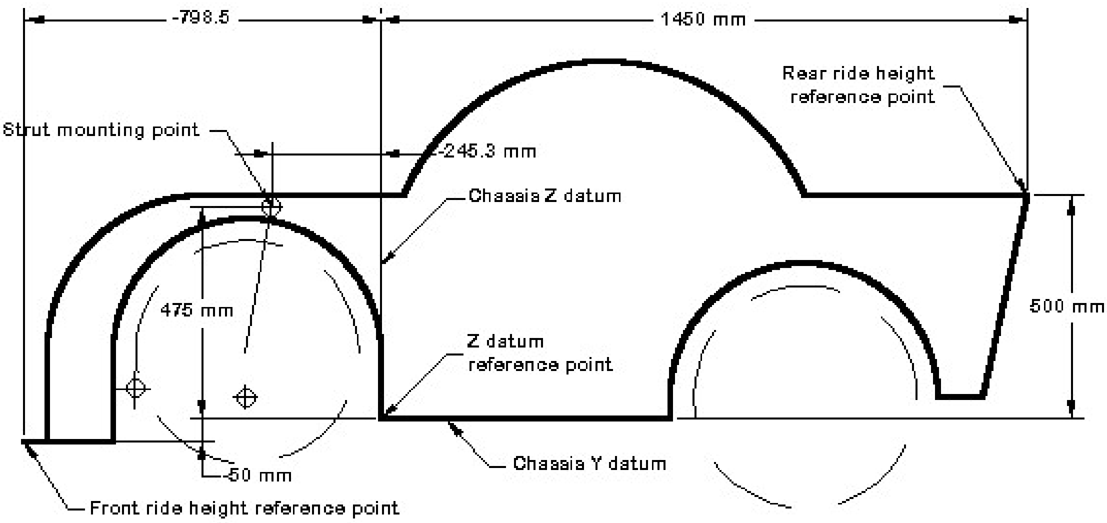


Fig 2a Chassis dimensions based on undertray line and rear of front wheel arch

In the figure above, the chassis is in the build position with the undertray level.

A point on the corner of the rear edge of the front wheel arch and chassis undertray line is chosen as the longitudinal datum point.

The top strut mounting point lateral, vertical and longitudinal dimensions are then measured.

The lateral dimension is from the vehicle centreline.

The vertical dimension is from the chassis vertical datum (the undertray line), 475.0mm (approx 18.701").

The longitudinal dimension is forward from the longitudinal datum vertical, -245.3mm (approx 9.657").

In the same way, all the other chassis points are measured.

It is also necessary to specify two ride height reference points. For this vehicle, one point is the front splitter, the other is the rear deck lid. Any convenient point can be used, but they must be one front and the other rear, ideally at least the length of the wheelbase apart.

In the same way as before, the two points are measured.

Front ride height reference point vertical and longitudinal measurements are -50.0mm and -798.5mm (approx -1.969" and -31.437").

Rear ride height reference point vertical and longitudinal measurements are 500mm and 1450.0mm (approx 19.685" and 57.087").

The static ride heights must also be specified.

It is required that the vehicle adopt a similar position to that shown in fig 2b below, so the static ride heights are specified as 15.0mm and 742.6mm respectively (approx 0.590" and 29.236").

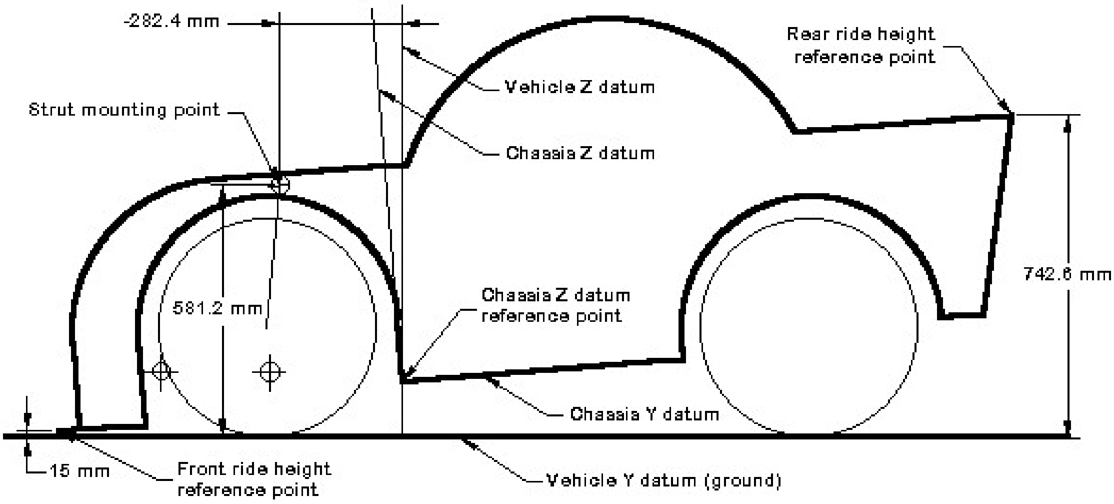


Fig 2b Chassis dimensions based on ground datum with vehicle in static ride position

As part of the static geometry calculations, the chassis points are referenced to the vehicle vertical datum (ground) and the vehicle longitudinal datum.

The vehicle longitudinal datum is a vertical line through the longitudinal datum reference point, but is now normal to the ground (instead of normal to the undertray line as it is in fig 2a).

Consequently, the top strut mounting point vertical and longitudinal dimensions are 581.2mm (approx 22.881") and -282.4mm (approx 11.118"), measured from the vehicle vertical and longitudinal datum.

In the above example, the vertical axis, Y, is positive upwards and the longitudinal axis, Z, is positive rearwards.

18.10 Asymmetric suspension

Full provision for asymmetric suspension, including linkage geometry, suspension elements, wheel and tyre sizes or the wheel alignment settings is provided.

Symmetry is controlled at the individual input form level.

When the input form is displayed, the current LH and RH data values are compared and, if identical, the "identical" check box is ticked. If there is a difference between any of the current LH and RH data values, then the "identical" check box will be cleared.

To apply the input data values to both sides of the vehicle, select or "tick" the "identical" check box.

To apply the input data values only to one side of the vehicle, and to leave the other side with the current values, then clear the "identical" check box.

18.11 Motion ratio calculations

Shock absorber and spring motion ratios are calculated as the ratio between the wheel travel and the shock or spring travel.

Depending on the combination of geometry settings, and the method of calculation, there can be slight differences in the reported motion ratios.

This situation only occurs for those suspension types where the steering (or toe control) can be specified and calculated separately from the geometry.
For example, with double a-arm suspension it is possible to do the geometry and roll&bump calculations without specifying any of the toe control coordinates or link lengths, and then the

calculations are done without any toe change. This simplifies the calculations when the main priority is the establishment of instant centres, roll centres and camber change without having to be concerned with toe control links.

When the steering is specified, and a steering calc is done, then the toe control link will be included in the calculation and the appropriate toe change calculated.

Another way to include the toe change in the calculations is to use a geometry configuration wheel location and alignment setting that includes the steering or toe control linkage.

The following examples are for a double a-arm suspension

Using the individual calculations

If the geometry config wheel location and alignment is any except "Top and bottom wishbones + steering linkage + turn"	Geometry static calculation will use the specified wheel toe setting. Roll&bump calculations will hold the specified wheel toe setting. In other words, no bump steer. If the shock and spring calculations are now done, the motion ratio calculations will be using the "no bump steer" wheel alignment settings.
If the geometry config wheel location and alignment is any except "Top and bottom wishbones + steering linkage + turn"	Geometry static calculation will use the specified wheel toe setting. Roll&bump calculations will hold the specified wheel toe setting. In other words, no bump steer. Steering calculation will redo the Roll&Bump calculations and the correct bump steer will be recalculated. If the shock and spring calculations are now done, the motion ratio results will be slightly out because the motion ratio calculations will be using partly "bump steer" data and partly "no bump steer" data.
If the geometry config wheel location and alignment is "Top and bottom wishbones + steering linkage + turn"	Geometry static calculation will calculate the wheel toe setting. Roll&bump calculations will calculate the wheel toe setting. In other words, the correct bump steer. If the shock and spring calculations are now done, the motion ratio calculations will be using the "bump steer" wheel alignment settings.

The ECalc dialog is a way of doing multiple calculations from a single point.

Using ECalc

If the geometry config wheel location and alignment is any except "Top and bottom wishbones + steering linkage + turn"	If the Steering is excluded from the calculation options, the shock and spring motion ratio calculations will be using the "no bump steer" wheel alignment settings.
All geometry config wheel location and alignment options	If the Steering is included in the calculation options, the shock and spring motion ratio calculations will be using the "bump steer" wheel alignment settings.

For the most accurate motion ratio calculations, use ECalc with steering selected.

It is suggested that when the basic geometry and steering have been established, the geometry config wheel location and alignment be changed to "Top and bottom wishbones + steering linkage + turn". This will ensure that all calculations are then done with the full bump steer wheel alignment.

18.12 Pushrod and pullrod suspension.

When the Bellcrank pivot axis, point 2 “Calc?” box is checked, reference values for the bellcrank pivot axis point 2 will be calculated.

- If the static chassis longitudinal values for the pushrod (or pullrod) actuation point, bellcrank pivot axis point 1 and chassis shock absorber mounting are identical, then these components are considered as operating in the vertical plane with the bellcrank pivot axis parallel to both the car cl and ground plane.

- If the static chassis longitudinal values for the pushrod (or pullrod) actuation point, bellcrank pivot axis point 1 and chassis shock absorber mounting are different, then these components are considered as operating in the plane of those three points, with the bellcrank pivot axis normal to that plane.

When the Bellcrank pivot axis, point 2 “Calc?” box is cleared, then entered values for the bellcrank pivot axis point 2 will be used to determine the bellcrank pivot axis. The distance between point 1 and 2 does not matter, and can be any convenient value.

The bellcrank pivot axis (either calculated or specified) is then considered fixed for all subsequent bump and droop calculations.

Bellcrank rotation direction in bump is the bellcrank rotation direction when the wheel is moved into a bump position. The bellcrank rotation is referenced looking along the bellcrank pivot axis in the direction of point 1 towards point 2. Ensure that the car side shown in the dialog box title is the same as the vehicle side that you are "bumping", because the LH bellcrank and RH bellcrank rotate in opposite directions in bump.

The bellcrank angle is similarly defined as the **anti-clockwise** angle between the two arms, viewed along the bellcrank pivot axis, in the direction of point 1 towards point 2.

18.13 Anti-roll bar calculations

The anti-roll bar nominal rate is measured at the arm actuation point normal to the arm,

$$\theta = \frac{32 \times 360}{2\pi^2} \times \frac{TL}{GD^4}$$

$$\text{Let } \theta = 1 \text{ then } T = \frac{2\pi^2 \times G \times D^4}{32 \times 360 \times L}$$

$$\text{Force on end of arm, } F = \frac{T}{Arm_{eff}} = \frac{2\pi^2 \times G \times D^4}{32 \times 360 \times L \times Arm_{eff}}$$

$$Rate_{arb} = \frac{\text{Force}}{\text{distance end moves for 1 degree}}$$

$$= F \times \frac{360}{Arm_{eff} \times 2\pi}$$

$$= \frac{\pi \times G \times D^4}{32 \times L \times Arm_{eff}^2}$$

The value of Shear Modulus, G, is 79290 MPa (11.5×10^6 psi) for the usual spring steels.

To include the bending of the arms (for the "bent bar" type of anti-roll bar),

$$Rate_{arm} = \frac{F}{\delta} = \frac{3EI}{Arm_{act}^3} \text{ where } I = \frac{\pi D^4}{64}$$

$$= \frac{3 \times E \times \pi \times D^4}{64 \times Arm_{act}^3}$$

$$\frac{1}{Rate_{corrected}} = \frac{1}{Rate_{arb}} + \frac{2}{Rate_{arm}}$$

The value of Young's Modulus, E, is 206800 MPa (30×10^6 psi) for the usual spring steels.

For a hollow anti-roll bar, $D^4 = (D^4 - d^4)$.

The effective rate of the anti-roll bar at the wheel,

$$Rate^{w}_{arb} = \frac{Rate_{arb}}{MR^{2}_{arb}}$$

The effective rate of the suspension spring at the wheel,

$$Rate^{w}_{spring} = \frac{Rate_{spring}}{MR^{2}_{spring}}$$

The wheel rate due to the spring and the anti-roll bar is the sum of each wheel rate acting in parallel,

$$Rate^{w}_{susp} = Rate^{w}_{spring} + Rate^{w}_{arb}$$

For a single wheel in bump, the rate is determined by the main spring on the side involved, added to the spring rate of the anti-roll bar acting in series with the main spring on the other side of the car,

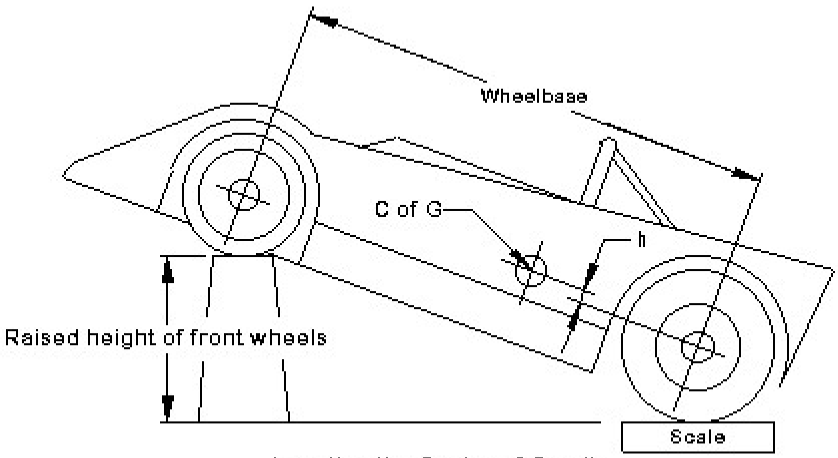
$$Rate^{w}_{bump} = Rate^{w}_{spring} + \frac{Rate^{w}_{spring} \times Rate^{w}_{arb}}{Rate^{w}_{spring} + Rate^{w}_{arb}}$$

When the tyre rate is included, the combined wheel rate is the sum of the suspension wheel rate and tyre rate acting in series,

$$\frac{1}{Rate^{w}_{combined}} = \frac{1}{Rate^{w}_{suspension}} + \frac{1}{Rate^{w}_{tyre}}$$

In the above equations, θ is the angle of twist (degrees) of the anti-roll bar, T is the torque (Newton -mm), L is the length of the anti-roll bar (mm), G is the Shear Modulus (MPa), D and d are the outside and inside diameter of the anti-roll bar (mm), F is the force on the end of the arm (Newtons), Arm_{eff} and Arm_{act} are the effective and actual length of the anti-roll bar arm (mm), $Rate_{arb}$ is the "spring rate" at the arm end due to the twisting of anti-roll bar only, $Rate_{arm}$ is the "spring rate" at the arm end due only to the arm bending, $Rate_{corrected}$ is the combined rate due to the twisting of the anti-roll bar and bending of both arms acting in series (all rates in Newtons/mm), and E is Young's Modulus (MPa).

18.14 Centre of gravity calculation



Locating the Centre of Gravity

The CofG height is the vertical location of the CofG, measured above the ground. A method for measuring the CofG height is as follows. Fill all liquids (oil, water & fuel) to the required levels and make a note. Ensure that fluids cannot leak when the vehicle is elevated. Be aware that any fluid movement or leakage during a test can falsify the results. Replace the springs and/or shock absorbers with rigid links so that any suspension movement is prevented. Set the vehicle up on a level with the rear wheels on a pair of scales, and note the readings. Then elevate the front wheels with blocks, hoist or forklift ensuring that the vehicle is supported by the front wheels, and not the chassis. The higher the front wheels can be raised, the more accurate the calculations and measurements, but the more unstable the vehicle will become. **BE CAREFUL.** Note the new rear wheel weights. The rear wheels may be blocked on the scales, but the front wheels must be free rolling to avoid any weight effect on the scales.

$$h = \frac{\Delta W \times L \times \sqrt{L^2 - X^2}}{W_t \times X}$$

$$CofG_{height} = R_r + h$$

SusProg3D will calculate the CofG height of the sprung mass only, with the assumption that the CofG of each unsprung wheel assembly is located at the centre of the wheel. This gives reasonably accurate answers for most suspension systems, as almost all the heavy unsprung items are centred about the wheel centreline.

$$CofG_{height\ sprung} = \frac{(W_t \times CofG_{height}) - (W_{uf} \times R_f) - (W_{ur} \times R_r)}{W_t - (W_{uf} + W_{ur})}$$

In the above equations, W_t is the total vehicle weight (kg, vehicle level), W_{uf} & W_{ur} are the front & rear unsprung weight (kg), ΔW is the increase in weight on rear wheels (kg, vehicle elevated), h is the height of CofG above horizontal through rear axle centreline (mm), L is the wheelbase (mm), X is the distance the front tyres are elevated (mm) and R_f & R_r are the front & rear tyre rolling radius (mm). If using FPS units, all weights are in lbs and all dimensions are in inches.

There is a inter-dependency between mass, wheelbase, track, ride height, centre of gravity location, and tyre size. Changing any one of these has an influence on the CofG location.

Vehicle and Chassis CofG

The Vehicle CofG height is specified in the Mass input, and is calculated as described above.

To calculate the Vehicle CofG lateral and longitudinal location, the coordinate location of each the four wheels (specifically the tyre contact point) must be known. This is done by either specifying the Datum location, the wheel alignment location, or by doing the static geometry calculation. Both front and rear must be known.
As a quick check, the calculated longitudinal location should be equal to the wheelbase times the rear distribution percentage.

Now that the Vehicle CofG location is known, it can be used to calculate the Chassis CofG (ie the CofG of the sprung mass). This calculation requires the same data as the Vehicle CofG calculation, but uses the sprung masses rather than the total masses, and also requires the tyre rolling radius for all four wheels.
As a quick check, the longitudinal location should be equal to the wheelbase times the rear axle sprung mass divided by the total sprung mass. If the Vehicle CofG is higher than the axle centreline heights (ie the tyre rolling radius), then the Chassis CofG will be slightly higher than the Vehicle CofG; if the Vehicle CofG is lower than the axle centreline heights (ie the tyre rolling radius), then the Chassis CofG will be slightly lower than the Vehicle CofG.

When the Vehicle CofG height is specified, it will always be used to recalculate the Chassis CofG height.

Both of the Vehicle and Chassis CofG locations are referenced to the front axle centreline, the vehicle centreline, and the ground plane.

SusProg3D also needs to calculate the Chassis CofG referenced to the chassis datums.
To do this it needs the ride height data, so you should ensure that the ride height settings correspond to the ride heights used in the above calculations.
As a quick check, the longitudinal location should be the same as the distance from the front axle centreline, plus the distance the front axle centreline is from the longitudinal datum.

For all of the above calculations, if the calculated location is not close to the “quick check” location, or the longitudinal location is zero, then one or more of the required reference dimensions is probably missing.

Now SusProg3D has the required data (ie the mass and CogG location of each of the four wheel assemblies, and the main sprung mass) it can "back calculate" the Vehicle CofG for any changes in ride height, track, wheelbase or tyre size. The CofG of each of the wheel assemblies is assumed to be at the centre of the wheel.

For example, if you change the ride height, both the Vehicle and Chassis CofG height will change.

18.15 Braking anti geometry

The front anti-dive % and the rear anti-lift % are calculated as part of the geometry and roll and bump calculations.

- Anti-dive in the front suspension reduces bump travel under forward braking.
- Anti-lift in the rear suspension, reduces droop travel under forward braking.

The vehicle wheelbase, centre of gravity height and brake split ratio are used in these calculations.

The wheelbase is calculated from the specified datum positions and wheel locations. See Wheelbase and Datum.

The centre of gravity height is specified, see Mass.

Enter the front wheel brake percentage, see Configuration.

Note that if the % figures are negative, then this is the opposite condition. Negative anti-dive would increase front bump travel, and negative anti-lift would increase rear droop travel.

For a more detailed discussion, see [GILL92] Chapter 7 and [MILL95] Section 17.3.

18.16 Acceleration anti geometry

The anti-squat % and anti-lift % are calculated as part of the geometry and roll and bump calculations.

- Anti-lift in the front suspension only occurs with front wheel drive, and reduces droop travel under forward acceleration.
- Anti-squat in the rear suspension only occurs with rear wheel drive, and reduces bump travel under forward acceleration.

The vehicle wheelbase, centre of gravity height and torque split ratio are used in these calculations.

The wheelbase is calculated from the specified datum positions and wheel locations. See Wheelbase and Datum.

The centre of gravity height is specified, see Mass.

Enter the front axle torque percentage, see Configuration.

Note that if the % figures are negative, then this is the opposite condition. Negative anti-lift would increase front droop travel, and negative anti-squat would increase rear bump travel.

For a more detailed discussion see [GILL92] Chapter 7 and [MILL95] Section 17.3.

18.17 Longitudinal pitch centre calculations

The front and rear side view instant centres can be combined to produce a vehicle pitch centre. This is analogous to the front view roll centre which combines the left and right instant centres.

Because the vehicle pitch centre requires both the front and rear side view instant centres, the roll and bump calculations must be done for each end of the vehicle. The vehicle pitch centre will be calculated for each combination of front and rear suspension bump and droop travel, and will show the distance of the vehicle pitch centre from the front axle centreline (positive rearward, and negative forward) and the height of the vehicle pitch centre above the ground line. The ground line will be the line joining the front and rear wheel tyre contact points.

18.18 Measurements

When making measurements, particularly on existing vehicles, it is very important that they be to the dead centre of the actual connecting point. It may be necessary to look at spares or disassemble components to decide exactly where these pivot points are. Remember that the accuracy of your measurements is critical in getting accurate answers.

18.19 Units and conversions

25.40 mm = 1.000 inch

1 kg = 9.80665 Newton = 2.204622 lb

1 kg/cm ≈ 0.981 N/mm ≈ 5.6 lb/in

1 MPa ≈ 145 psi

1 g = 9.80665 m/s2 ≈ 32.174 fps2

G = 79290 MPa ≈ 11.5 x 10^6 psi (Shear Modulus for 4130 & 4340 steel)

E = 206800 MPa ≈ 30 x 10^6 psi (Young's Modulus for typical steel)

For metric users, all spring and wheel rate calculations are now using SI units. Rates are N/mm (Newtons per mm), loads are N (Newtons). Vehicle weights are in kg (kilograms).

18.20 Bibliography

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18.21 Display the SusProg program version

Select Help | About to open a message box displaying details about SusProg3D and operating system version.

18.22 Consulting and development services

If you are having difficulties or want help in achieving certain goals, call or write me to discuss your particular problem. Full consulting and development services are available along with custom programming to meet your needs, particularly if your required spring location/actuation design is not supported by the standard SusProg3D package.

Your comments and opinions are appreciated.

19 Licence agreement

This manual and software are protected by both Australian copyright law and International treaty provisions, with the following single exception. R D Small authorises you to make archival copies of the software for the sole purpose of backing-up this software and protecting this software from loss.

This software is licensed to run on a single computer.

Suspension designs that you independently generate using the SusProg3D software may be used, given away, or sold without additional licence or fees. You are not required to say that your suspension designs were developed using SusProg3D.

The sample suspension designs on the SusProg3D distribution provide a demonstration of the various features of SusProg3D. They are intended for educational purposes only. R D Small grants you (the registered owner of this copy of SusProg3D) the right to edit or modify these sample designs for your own use, but you may not give them away or sell them.

Warranty

With respect to the physical media and the physical documentation enclosed, R D Small warrants the same to be free of defects in materials and workmanship for a period of 60 days from the date of purchase. In case of notification within the warranty period of defects in material or workmanship, R D Small will replace the defective media or documentation. If you need to return a product, call R. D. Small. The remedy for breach of this warranty shall be limited to replacement and shall not encompass any other damages, including but not limited to loss of profit, and special, incidental, consequential, or other similar claims.

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Modifying road car suspension systems may result in the vehicle failing the requirements of the relevant state Road Traffic Authority and therefore being declared unroadworthy and unregistered.

The price of man in motion is the occasional accident and/or collision. Testing vehicle performance may be dangerous. Motor racing is dangerous. This software package is about improving the performance of the motor vehicle. It deals with developing and changing suspension characteristics. Anyone who uses this program and or manual as a guide for vehicle modification does so entirely at their own risk.

In no event shall R D Small be liable for any loss of profit or any other commercial damage, including but not limited to special, consequential or other damages arising from the application of any information, dimensional changes or data because of using this package.

Governing Law

This statement shall be construed, interpreted, and governed by the laws of the State of Queensland, Australia.

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20 Evaluation version

The Evaluation version of SusProg3D provides both fixed upright or strut dimensions, and fixed wheel and tyre sizes.

Front upright (wishbone suspension)

The toe control point can be varied as required. Both the top and bottom pickup points are fixed.

Rear upright (wishbone suspension)

Both the toe control point and the universal joint location can be varied as required. Both the top and bottom pickup points are fixed.

Front & Rear Strut

Both the toe control point and the universal joint location can be varied as required. Both the strut rod axis (top and bottom points) and the wishbone bottom pickup points are fixed. The strut dimensions are identical for front and rear.

Front & Rear Wheel & Tyre

All wheel and tyre dimensions are fixed.

21 Network licensing

Network licensing is available for fixed LAN networks using TCP/IP.

A single SusProg3D licence server is required.

Multiple SusProg3D clients are supported, but must remain connected (via the LAN) to the SusProg3D licence server for the duration of the SusProg3D session.

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