GETTING STARTED WITH LOTUS SUSPENSION ANALYSIS

VERSION 4.03

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About This Guide

Welcome to Lotus Engineering Suspension Analysis. This product will allow you to design and analyse the vehicle suspension hard points to achieve the required suspension characteristics. The optional addition of compliant bushes and operating forces allow compliant characteristics to be calculated and bushes tuned to obtain the desired behaviour.

What You Need to Know

This guide assumes the following:

- Lotus Suspension Analysis is installed on your computer or network and you have permission to execute the relevant Lotus modules.

- The necessary password file is installed to allow you to run the necessary modules.

You have a basic understanding of vehicle suspension mechanisms, their loading regimes and functional operating requirements.

1 Introducing Lotus Suspension Analysis

1.1 Overview

This chapter introduces you to the Lotus Suspension Analysis Tool and explains the normal uses for it. It also introduces the tutorials that we've included in this guide to get you started working with Lotus Suspension Analysis (LSA).

This chapter contains the following sections:

- 1.1 Overview, 1
- 1.2 What is Lotus Suspension Analysis?, 2
- 1.3 Normal Uses of Lotus Suspension Analysis, 2
- 1.4 Overall Concepts, 2
- 1.5 Co-ordinate system, 3
- 1.6 Sign conventions, 3
- 1.7 About the Tutorials, 4

1.2 What is Lotus Suspension Analysis?

LSA is a design and analysis tool that can be used for both the initial layout of a vehicle suspensions hard points, and also the design and orientation of suspension bushes for the tuning of the complaint behaviour.

Models are created and modified through a 3d-viewing environment. This allows hard points and bushes to be ‘dragged’ on screen and graphical/numerical results updated in ‘real time’. A template-based approach to the modelling allows users to create their own suspension models, supplementing the ‘standard’ suspension templates provided.

1.3 Normal Uses of Lotus Suspension Analysis

LSA is used by both designers and analysts alike for the layout of the suspension hard point positions, in order that the required kinematic behaviour is achieved. Any number of results can be displayed graphically, (e.g. Camber angle, Toe angle), against bump motion, roll motion or steering motion. These results are updated in ‘real time’ as the suspension hard points are moved. The inclusion of compliant bushes to the kinematic model allows the tuning of bush properties to be carried out, to achieve required compliant response for items such as lateral force steer.

1.4 Overall Concepts

LSA has two main display and analysis modes, 2D and 3D, and it is possible to import a 2D model into 3D.

Suspensions can be articulated in bump/rebound, roll, steering and combined bump and steering (3D only) modes.

LSA uses templates to identify specific 3D suspension types. These templates define the number of parts, the number of points and connectivity of the parts. A large number of ‘standard’ templates are include with the installation, whilst users can create their own or modify existing ones to model kinematic suspension types not catered for.

3D models can be built as corner, axle or full vehicle suspension models.

LSA can be used just in Kinematic mode, (i.e. rigid bodies with ball joints), or in compliant mode where the deflection due to bushes is added to the kinematic results on an incremental basis, (note that the compliant module is licensed additionally to the kinematic module). The compliant mode includes modal analysis and forced damped capability.

1.5 Co-ordinate system

The LSA co-ordinate system is a right-handed system the origin of which must be in front of the car and coincide with the vehicle longitudinal centre line.

Y-axis is across the car track, and the +ve direction being towards the right side when sitting in the car.

X-axis is along the vehicle wheel base and positive toward the rear of the car.

Z-axis is the vertical height and positive upwards.

When inputting suspension hard point data you must ensure that all co-ordinates are constant with the origin you have selected and be aware that all suspension hard point output generated by LSA will be relative to that origin. The only restrictions are that the X-Z plane must pass through the centre of the car and the origin must be in front of the car. The co-ordinate system origin need not be coincident with the ground plane.

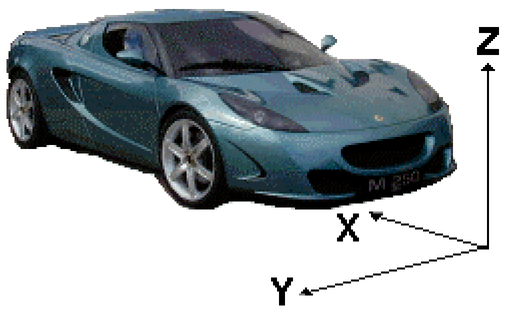


Figure 1.1 LSA co-ordinate System

1.6 Sign convention.

Camber - Inclination of the wheel plane to the vertical, negative when the wheel leans in at the top

King Pin Angle - The front view angle between the steering axis and the vertical. Positive when the steering axis leans inwards at the top.

Toe - Angle between the plane of the wheel and the forward direction, positive if the front of the wheel is “toed in” toward the centre of the car.

Castor - The angle in side view between the steering axis and vertical. Positive when the top of the steering axis is inclined toward the rear.

Steering Lock - Linear Y-axis displacement of the steering rack. Positive steering lock can produce negative or positive toe depending if the steering rack is in front or behind the steering axis.

Roll - Right hand rule applied to the vehicle positive x-axis. When sitting in the car roll to the left is positive.

1.7 About the Tutorials

The remainder of this guide is structured around a series of tutorials that introduce you to the features of Lotus Suspension Analysis. Each tutorial builds on what was learnt in those before it and are thus linked such that the user should work through them in the order presented. The essential steps required to complete the tutorial have been bulleted as shown below.

➢ ***Essential steps in the tutorial are bulleted and italic.***

To save time you can skip through the text and only do the essential steps. The rest of the text gives a more complete description.

- Tutorial 1 - Getting Started - Describes the layout and gives you an overview of the application, teaches you how to load existing files and introduces basic editing, viewing and saving concepts.
- Tutorial 2 - Full Vehicle Suspension – A double wishbone front and rear suspension model is setup in LSA. Target characteristics are defined and the tutorial gives step by step instructions to modify the suspension geometry so that a compromise suspension solution is achieved.

2 Tutorial 1 - Getting Started

2.1 Overview

This tutorial introduces the main features of the product and gives a summary of its base functionality.

This chapter contains the following sections:

- 2.1 Overview, 5
- 2.2 Starting the Application, 6
- 2.3 Creating a New Model, 8
- 2.4 Manipulating the Graphical View, 11
- 2.5 Displaying Graphical Results, 14
- 2.6 Displaying Text Results, 15
- 2.7 Bump, Steer and Roll Kinematics, 16
- 2.8 Animation Suspension Kinematics, 19
- 2.9 Saving Data File, 20
- 2.10 Closing the Application, 20

2.2 Starting the Application

To start Lotus Suspension Analysis from the main **Start** menu point to **Programs** and then **Lotus Engineering Software** and then **Lotus Suspension Analysis**. If the program fails to start or the menu item is missing from your start menu, firstly confirm that the software has been installed correctly. You can browse for the application directly, the executable file name is *Shark.exe*. As the program starts the start up 'splash' screen will be displayed, before the main application window is opened.

Start LSA from windows start menu

- ***Start -> Programs -> Lotus Engineering Software -> Lotus Suspension Analysis***

Figure 2.1 Start-up Splash Screen

On start-up the application will open with an empty 3D display window. A number of the menus and icons are disabled until either a new model has been started or an existing model has been loaded.

The settings of both the display and analysis modes is initially set either by the defaults, (if not previously run), or by the settings saved to the 'ini' file from the previous run.

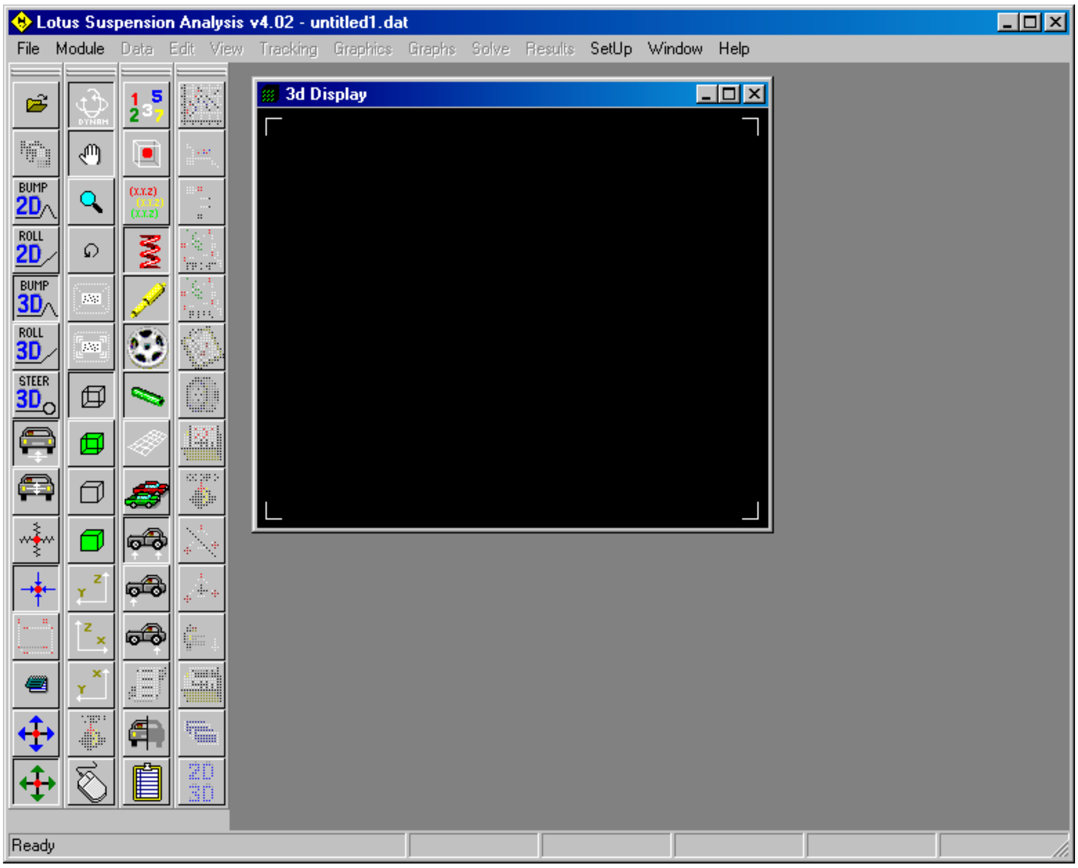


Figure 2.2 Layout of application

Additional context specific menu items are used throughout the application and can be accessed by clicking the right mouse on the window/graph of interest

2.3 Creating a New Model

To create a new model select the *File / New* menu option from the main menu bar, (note that we are in 3D module and will thus be creating a new 3D model creating a new model in the 2D module works in exactly the same way). The '*new model*' dialogue box is then displayed.

- ***File -> New***

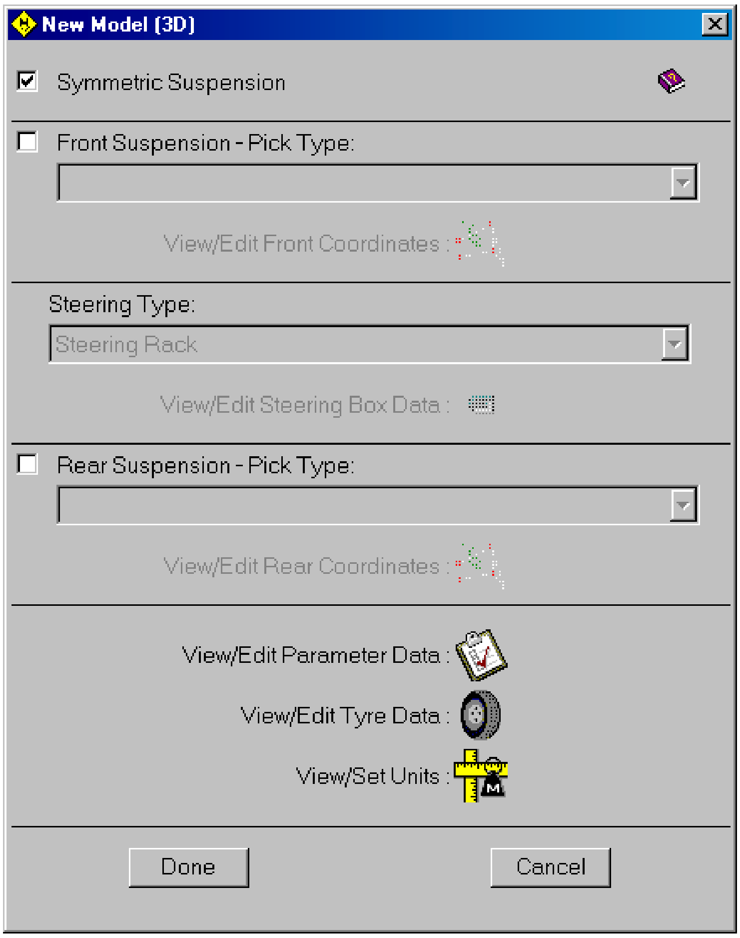


Figure 2.3 New Model Dialogue Box

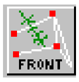
The dialogue box allows you to pick the required suspension type for the front or rear or both. For our example we will consider a model with only the front. Suspensions are modelled in LSA based on specific template types. Depending whether the template has been built with provision for a steering attachment point will dictate if it appears in the list of available front suspension types, (all defined templates are listed in the rear suspension list).

- ***Check 'Front Suspension- PickType'***

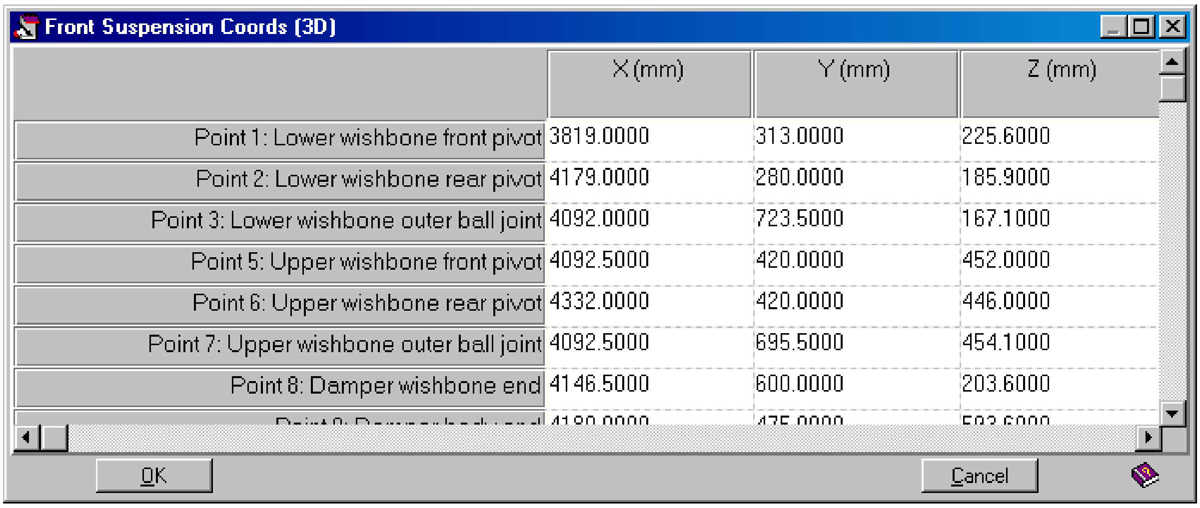
- ***From the front suspension drop down box select 'Type 1: Double Wishbone, damper to lower wishbone'***

- ***From steering type drop down box select 'steering rack'***

Once you have selected the front suspension type the 'View/Edit Front Co-ordinates' icon becomes enabled, allowing you to change the default hard point co-ordinate values.

- ***Click 'View/Edit Front Co-ordinates'*** 

to inspect the front suspension co-ordinate. Once done click OK to accept defaults

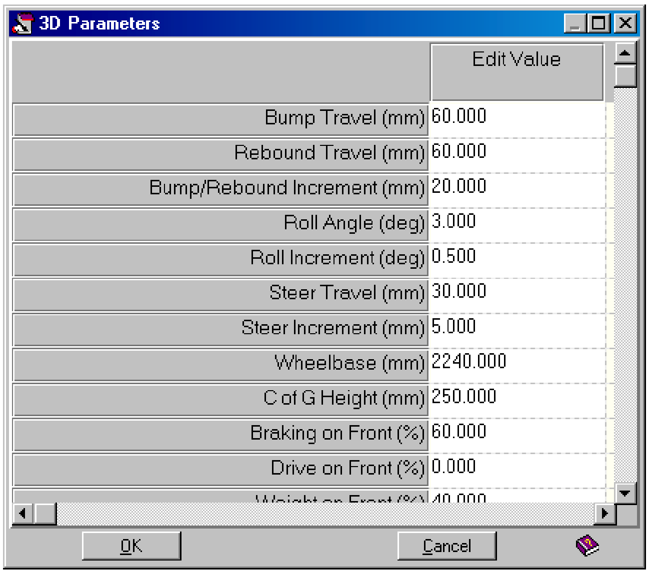


	X (mm)	Y (mm)	Z (mm)
Point 1: Lower wishbone front pivot	3819.0000	313.0000	225.6000
Point 2: Lower wishbone rear pivot	4179.0000	280.0000	185.9000
Point 3: Lower wishbone outer ball joint	4092.0000	723.5000	167.1000
Point 5: Upper wishbone front pivot	4092.5000	420.0000	452.0000
Point 6: Upper wishbone rear pivot	4332.0000	420.0000	446.0000
Point 7: Upper wishbone outer ball joint	4092.5000	695.5000	454.1000
Point 8: Damper wishbone end	4146.5000	600.0000	203.6000

Figure 2.4 Type 1 Default hard points display

For a front suspension you can choose between a conventional steering rack or a steering box, (a steering box requires additional hard point data to be defined). We will stick with the more normal steering rack.

From the 'new' dialogue box we can also view/change the 'Parameter' data associated with the model, (such as wheelbase, c of g height, bump travel, brake split etc and geometric data associated with the tyre). All of the model properties can also be modified at a later stage as required.



	Edit Value
Bump Travel (mm)	60.000
Rebound Travel (mm)	60.000
Bump/Rebound Increment (mm)	20.000
Roll Angle (deg)	3.000
Roll Increment (deg)	0.500
Steer Travel (mm)	30.000
Steer Increment (mm)	5.000
Wheelbase (mm)	2240.000
C of G Height (mm)	250.000
Braking on Front (%)	60.000
Drive on Front (%)	0.000

Figure 2.5 Parameter Data Lisiting

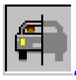
To complete the creation of a new front suspension model, select ‘Done’. This will now enable all the previously ‘greyed-out’ menus and icons. The created model is now displayed in the ‘3d display’ window.

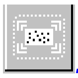
- ***Click ‘Done’ to open the model.***

Now that we have a model we will set up the 3D display. The first time LSA is opened the default view settings will be applied. Subsequently each time that LSA is closed, the current view setting are saved and will be used the next time LSA is opened (the default settings can only be restored by deleting the LSA initiation file ’SHARK.INI’ from the ‘WINNT directory).

- ***‘Graphics -> Screen Display -> Static Only’***

- ***‘Graphics -> Point Limits’, ensure neither ‘visible’ nor ‘use’ have a tick mark next to them.***

- ***Display both sides of the suspension by left clicking on the ‘Display Both Sides’ tool***  ***.***

- ***Auto scale the view with ‘Autoscale Display***  ***.***

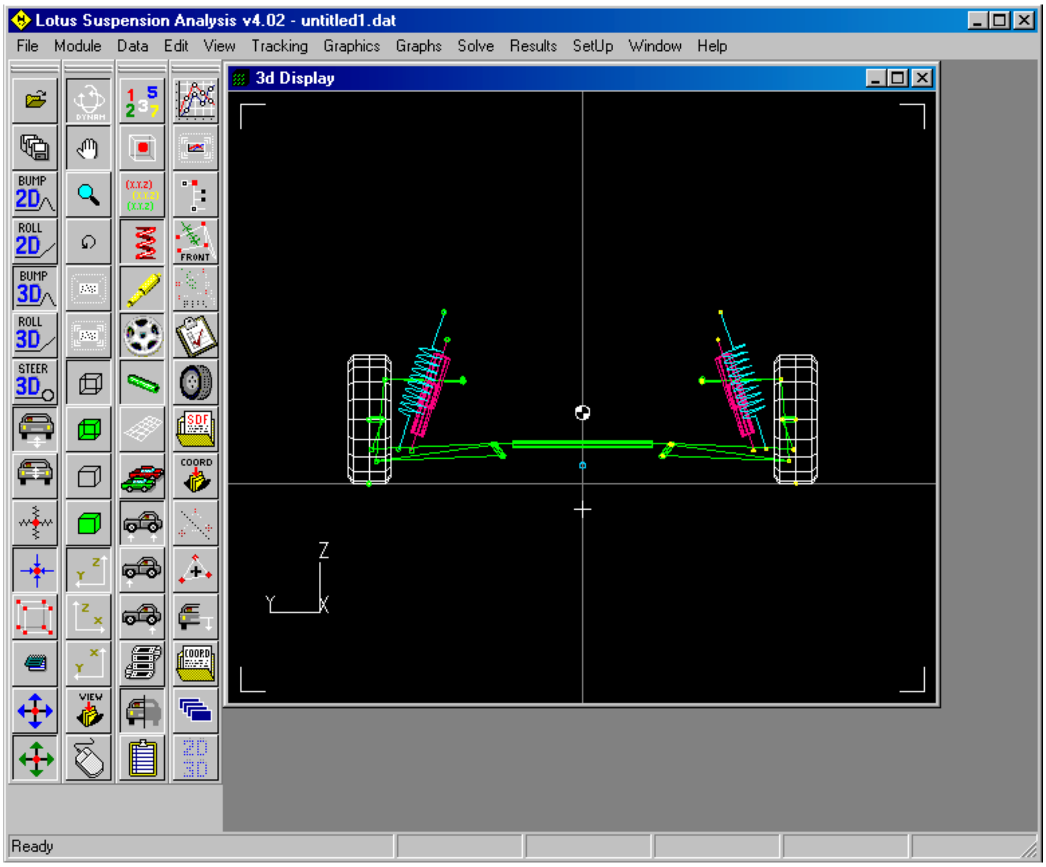


Figure 2.6 Screen shot of new front suspension model.

2.4 Manipulating the Graphical View

Use the Setup menu from the menu bar to display only the 'View' toolbar.

- ***From the 'SetUp' menu setup the toolbars so that only 'View Toolbar Visibilities' is displayed, as shown in the Figure 2.7.***

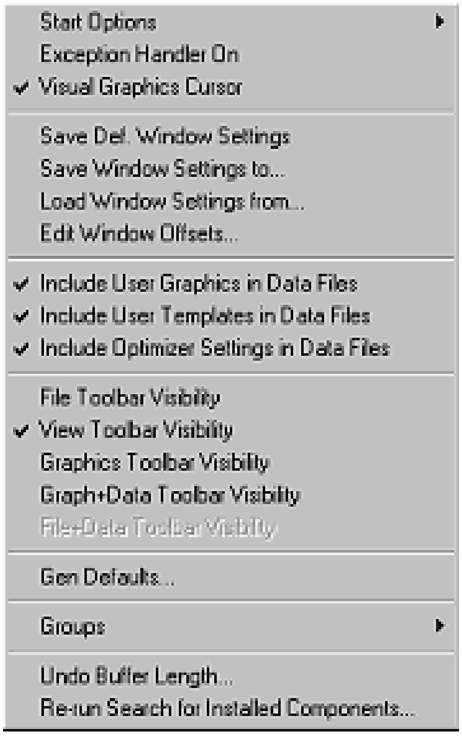


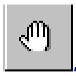
Figure 2.7 Selecting View Toolbar Visibilities from SetUp menu

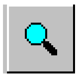
The suspension 3D display interface has two modes, 'Dynamic viewing' for manipulating the view and 'Edit' mode for modifying the suspension geometry. The left mouse button is clicked on the dynamic view icon to toggle between 'Viewing' and 'editing' mode. In viewing mode markers are displayed in each corner of the 3D suspension display window

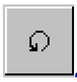
- ***Toggle the 'dynamic view icon'***  ***so that viewing mode is selected, ie markers displayed in each corner of the suspension 3D display window.***

The graphical display is manipulated through the mouse cursor and buttons. It allows you to rotate, translate and zoom in/out by the combination of holding the left mouse button down whilst moving the mouse. Specific menu options exist for 'autoscale', pick centre and setting the view to orthogonal projections.

If you are in the 'edit' mode selecting any one of the dynamic viewing options will change the mode to dynamic viewing. Alternatively selecting the dynamic view icon will cycle between edit and view modes.

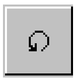
- ***Change to 'Translate view'*** ***. Select a point on the 3D-suspension window with the left mouse button, hold down and drag.***

- ***Change to 'Scale view'.***  ***Select with left mouse button, hold down and move down to zoom in, up to zoom out.***

- ***Change to 'Rotate view'*** ***. Select with left mouse button, hold down and move to rotate view. Picking towards the centre rotates the eye point around the object, picking towards the edge rotates around the object axis.***

(when in dynamic view mode, the Right Mouse button will cycle through the three dynamic view types, zoom, translate, rotate)

In some situations it is desirable to make frequent use of a particular user defined view. To achieve this LSA can save user define views for latter use.

- ***Use the rotate view tool***  ***to set a non-orthogonal view similar to figure 2.8.***

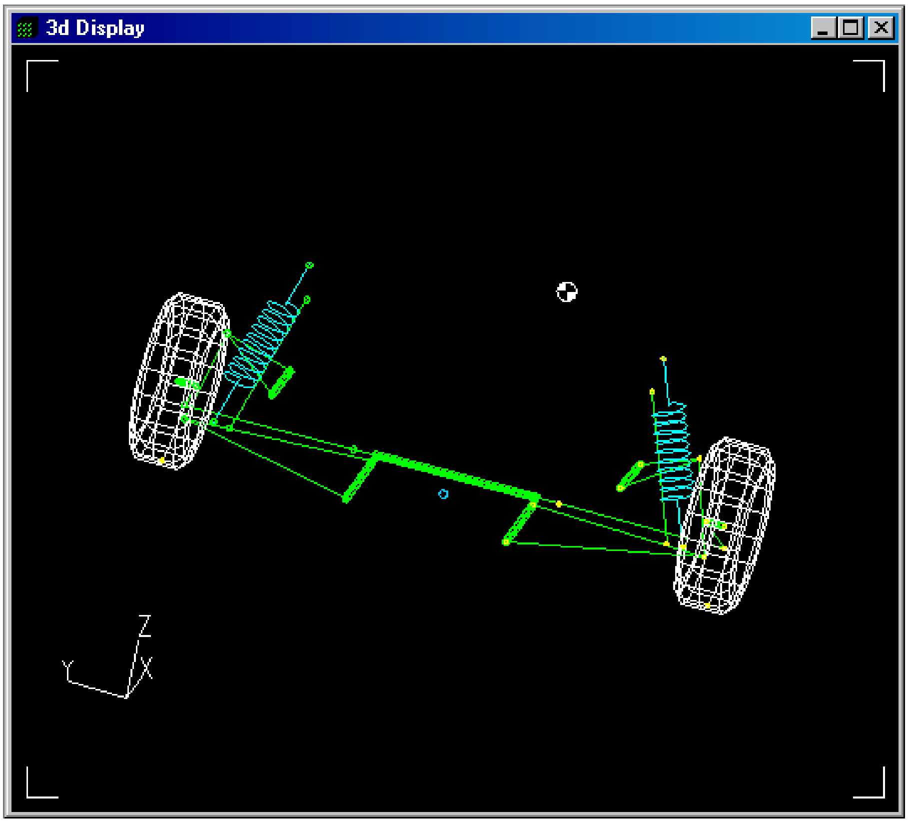
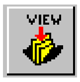
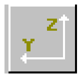
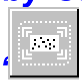


Figure 2.8 'Pictorial' view of front suspension.

- ***Select the 'Save Current View Settings'***  ***tool and enter a name for the view, click ok***

- ***Restore the front view by selecting the front view icon***  ***, then the 'Autoscale display' icon '***  ***'***

- ***The saved view can be used via the 'View' main menu . 'View - > Saved Views -> Recall Saved' and select the saved view from the list***

- ***To proceed re-set the suspension display to front view and ensure the view is fitted to the display window.***

2.5 Displaying Graphical Results

Graphs are used to display analysis results for any of the calculated results. To open a graph select *Graphs / New/Open*. The created window will show the current model results for a particular parameter, e.g. camber angle. To change the displayed parameter for a particular graph select the graph with the right mouse button and pick the required parameter from the displayed list. The right mouse menu also contains options for setting axis scales and general viewing options such as zoom and autoscale.

Any number of graphs can be open at the same time, the positions and sizes of which can be modified and saved by the user for future use, (see *SetUp / Save Window Settings To…*).

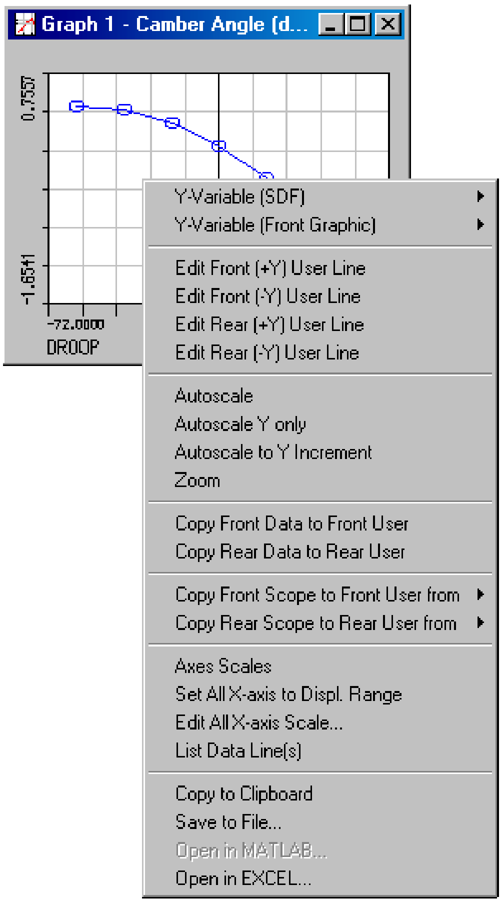


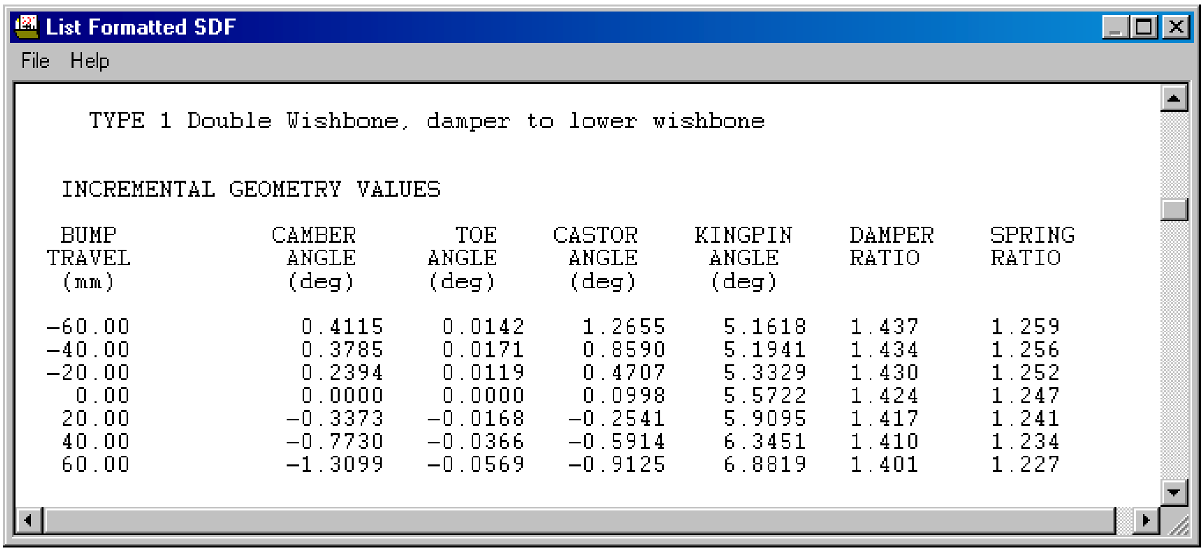
Figure 2.9 Graph showing right mouse menu

- ***From the menu bar select 'Graphs -> New/Open'***
- ***Set the graph to display camber angle by placing the cursor over the new graph then 'Right Click -> Y-Variable -> camber Angle'.***
- ***Open two more graphs for Toe Angle and Castor Angle and arrange the windows so you can view the suspension 3d display and each graph simultaneously.***

2.6 Displaying Text Results

The text results for the currently defined suspension model can be displayed in a scrollable text window, *Results / List Formatted SDF File…* This lists an echo of the input data and tabulated/headed suspension derivatives. This provides a convenient reporting medium for numerically summarising the suspension properties.

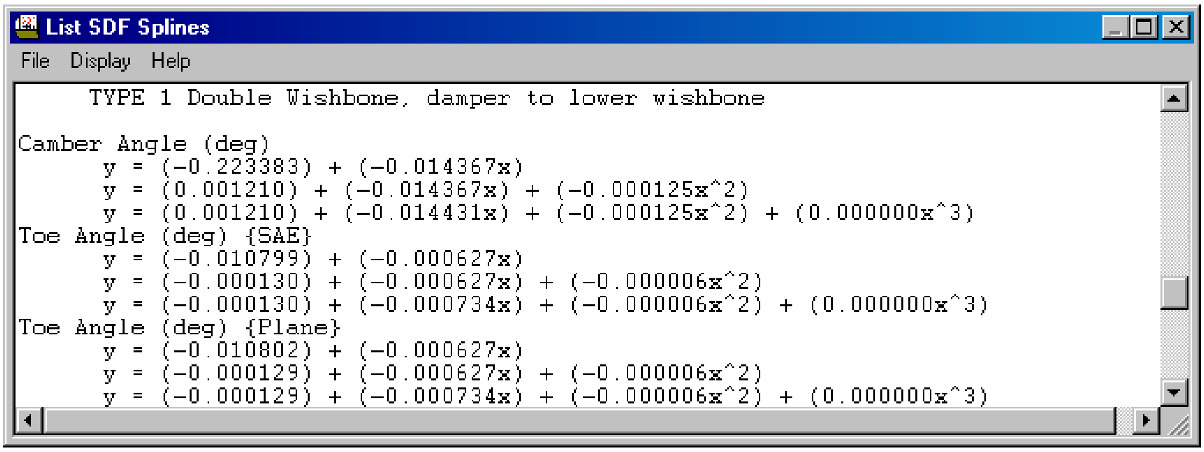
➢ ***From the main menu select 'Results -> List SDF File'. When done inspecting results close the text results window***



BUMP TRAVEL (mm)	CAMBER ANGLE (deg)	TOE ANGLE (deg)	CASTOR ANGLE (deg)	KINGPIN ANGLE (deg)	DAMPER RATIO	SPRING RATIO
-60.00	0.4115	0.0142	1.2655	5.1618	1.437	1.259
-40.00	0.3785	0.0171	0.8590	5.1941	1.434	1.256
-20.00	0.2394	0.0119	0.4707	5.3329	1.430	1.252
0.00	0.0000	0.0000	0.0998	5.5722	1.424	1.247
20.00	-0.3373	-0.0168	-0.2541	5.9095	1.417	1.241
40.00	-0.7730	-0.0366	-0.5914	6.3451	1.410	1.234
60.00	-1.3099	-0.0569	-0.9125	6.8819	1.401	1.227

Figure 2.10 Sample Formatted SDF Display

The text results can also be listed as a series of spline fits rather than tabulated data. The user having control of which splines to list and the power of the spline fits. This provides a method of exporting suspension properties to external spline based full vehicle handling applications.




```
     TYPE 1 Double Wishbone, damper to lower wishbone

Camber Angle (deg)
      y = (-0.223383) + (-0.014367x)
      y = (0.001210) + (-0.014367x) + (-0.000125x^2)
      y = (0.001210) + (-0.014431x) + (-0.000125x^2) + (0.000000x^3)
Toe Angle (deg) {SAE}
      y = (-0.010799) + (-0.000627x)
      y = (-0.000130) + (-0.000627x) + (-0.000006x^2)
      y = (-0.000130) + (-0.000734x) + (-0.000006x^2) + (0.000000x^3)
Toe Angle (deg) {Plane}
      y = (-0.010802) + (-0.000627x)
      y = (-0.000129) + (-0.000627x) + (-0.000006x^2)
      y = (-0.000129) + (-0.000734x) + (-0.000006x^2) + (0.000000x^3)
```

Figure 2.11 Sample Spline Results Display

2.7 Bump, Steer and Roll Kinematics

➢ ***Display the File Toolbar from the SetUp menu by selecting 'SetUp -> File Toolbar Visibility'***

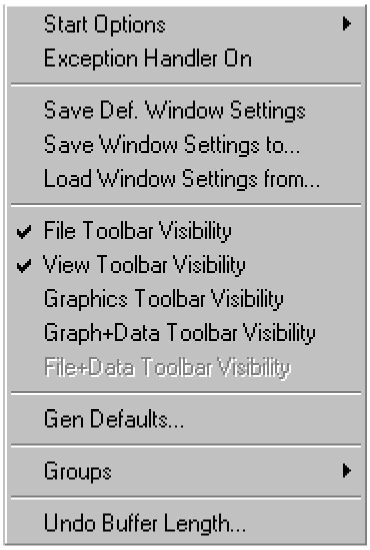


Figure 2.12 Displaying the File Toolbar

The suspension articulation type can be bump/rebound, roll or steering. Steering articulation is applicable to 3D front suspension models only. The articulation type can be changed via the relevant toolbar icons or the Module / Shark pull down menu options.

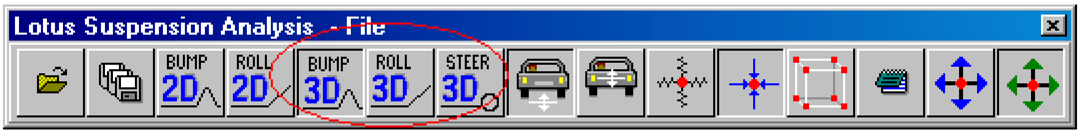


Figure 2.13 3D articulation type icons ringed

Changing the articulation type will change any displayed result graphs to show the same variables but over the new articulation motion range (roll, bump, steer). Graph axis scales may need to be re-set to show the new results.

➢ ***In turn select each of the '3D bump' '3D Roll, and '3D Steer' articulation Icons on the File Toolbar and note how the results displayed on each graph change for each motion type.***

An additional combined bump and steering mode is available. Users define each point separately through an interactive display.

Each articulation type range is controlled by user defined limits. These can be changed via the 'Data -> Parameters' main menu. The bump/rebound travel can also be set for specific positions.

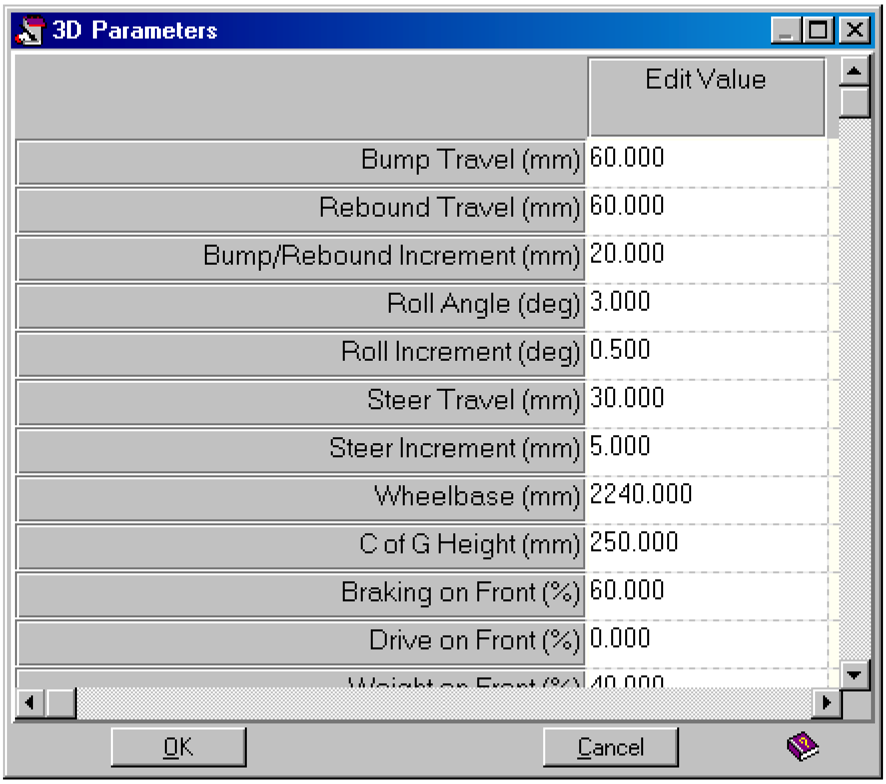
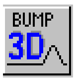
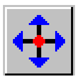


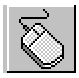
Figure 2.14 Parameters Data Display

Now we can move the suspension hard points and see the effect on the suspension kinematics.

Suspension hard points can be modified by one of three ways, using input edit boxes, using the keyboard arrow keys or by dragging hard points with the mouse

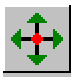
- ***Select the 'Change to 3D bump Module' icon***  ***from the file toolbar.***

- ***Click the 'Set to Joggle Mode' icon***  ***on the File Toolbar and left click on one of the left inboard suspension ball joints.***

- ***Left Click on the 'Toggle Tracking Setting' icon***  ***on the 'View' toolbar until both up/down and left/right arrows are displayed over the suspension point you have selected.***

- ***Manipulate the suspension hard point by holding down the 'Ctrl' key then pressing the arrows on the keyboard.***

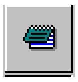
As the suspension point is moved the suspension geometry graphs will be continuously updated and the position of the suspension roll centre will move on the 3D display. The roll centre is displayed as a blue circular dot on the display. Toggling between 3D bump, steer and roll using the 'File' Toolbar icons will update the graphs for each of the kinematic motion types.

- ***Select the 'Set To Drag Mode' icon*** 

- ***From the main menu select 'Tracking -> Length' and set the '3D Drag Line Length' to 50 mm.***

- ***Now left click and hold a suspension hard point. This can now be dragged around the screen and the results will be continuously updated on the graphs as you move the suspension.***

The suspension hard point can each be moved in the front, plan and side views. The suspension is modelled symmetrically, any change to one side is mirrored on the opposite hard point.

- ***Select the 'Set to Edit' icon***  ***on the File toolbar and left click on a lower inboard suspension point.***

- ***In the edit box add 5 mm to the 'y' co-ordinate and click 'OK'. The suspension will now have moved to the new location.***

When in edit mode 'tracking lines' are drawn to indicate the current 'tracking' direction(s). This is not relevant to the hard point-editing mode as tracking only applies to the dragging and joggle edit modes. To change the current tracking direction the right mouse button will cycle through the available tracking direction options. A similar action is achieved by selecting the mouse icon from the 'view' toolbar.

Hard point joggling operates in a similar way to dragging with regard to available directions. The drawn joggle symbol indicates the number of joggle directions available. To use joggle select either Ctrl + Arrow Key for coarse joggle or Shift + Arrow Key for fine joggle. The joggle fine size is a tenth of the coarse size, the coarse size can be set via SetUp / Gen Defaults…

For a full description of the suspension hard point editing options refer to the help file, 'Overview – Hard Point Editing' and 'Overview – Hard Point Dragging'.

LSA can also be set up to retain the length of suspension parts when modifying the suspension. In this mode the whole suspension moves to satisfy the new hard point location without changing any suspension part lengths.

- ***From the menu bar select 'Edit -> Change mode -> Retain Part Length'. Now try dragging suspension hard points with the mouse.***

- ***Return 'Change mode' to 'Change part lengths'***

2.8 Animation Suspension Kinematics

The suspension can now be animated to give a movie of the suspension movement in bump, roll and steer. The movement of the roll centre is also displayed in the animation and the suspension hard points can be edited during the animation.

- ***Display the graphics tool bar by using the SetUp menu 'SetUp -> Graphics Toolbar Visibility'***
- ***Left click the 'Animate mechanism' icon***  ***on the graphics toolbar.***
- ***Whilst the animation is displayed switch between bump, roll and steer modes.***
- ***As the suspension is animating try dragging suspension hard points and see the effect on the roll centre location in roll, bump and steer.***

2.9 Saving Data Files

Models can be saved in the conventional way using *File / Save* or *File / SaveAs* menu items. You will always be warned about overwriting existing model files. Data files will include all suspension hard point data, compliant bush properties and model parameters. What it does not necessarily include is the template definition. A data file can in refer to the template via an entry number if the 'include User Templates in Data File' option is not checked. For further information on the definition and storing of suspension templates see the template sections in this document.

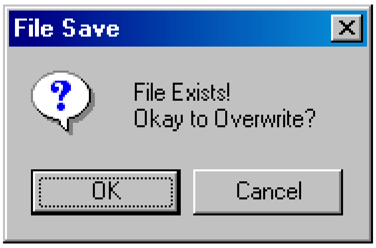


Figure 2.15 Okay to Overwrite dialogue

2.10 Closing the Application

To close the program select '*File -> Exit'* from the main menu, and then confirm the 'okay to exit' prompt. Alternative methods to close the application include the conventional 'X' from the windows top right corner, Alt+F4 or close from the main windows top left menu. In addition the 'esc' key will close the application, (subject to accepting the prompt).

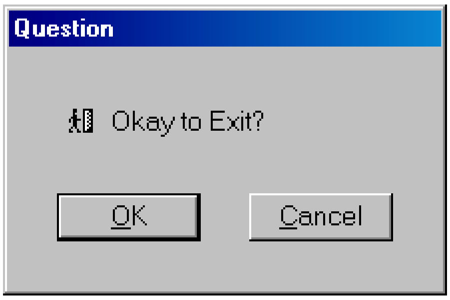


Figure 2.16 Okay to Exit Prompt

3 Tutorial 2 - Full Suspension Model

3.1 Overview

In this tutorial we will develop separate front and rear suspensions in two separate files then combine the two to create a full vehicle suspension kinematic model.

A target hypothetical suspension characteristics has been set in Section 3.2 and we will attempt to achieve a design that gives the best compromise solution. The target does not necessary represent desirable kinematics nor have other limitations such as packaging been considered. The suspension specification shown in Table 3.1 is a subset of all the dimensions / specifications required. All other data has been left as LSA default values.

This chapter contains the following sections:

- 3.1 Overview, 21
- 3.2 Target Suspension Design, 22
- 3.3 Tutorial 2.a, 23
- 3.4 Tutorial 2.b, 27

3.2 Target suspension design

Front suspension: Type 1: double wish bone
Steering: Steering rack
Rear suspension: Type 1: double wish bone

Table 3.1 Suspension specifications.

Settings

	Front	Rear
Toe	0	0
Camber	-1.5	-1.5
Castor	3	0
KPI	5	5
Anti-dive	40	-
Anti-squat	-	44
Ackerman	80%	-
% braking	60%	40%
Roll centre height	75	100

Suspension travel

	Front	Rear
Bump	40	40
Rebound	40	40
Roll	2.5	2.5
Steering	30	-

Tire

	Front	Rear
Rolling radius	225	225
Width	150	150

Goals:

- Minimise roll and bump steer.
- Minimise movement of roll centre.
- Keep roll centre above ground at maximum bump.
- Camber less than zero at maximum body roll angle.
- Minimise tire scrub with bump

3.3 Tutorial 2.a

Open new front suspension model

- ***From the file main menu select 'File -> New' to bring up the new model dialog box.***

- ***Select front suspension only with Type 1: double wishbone suspension and steering rack.***

- ***On the 'New Model' dialog left click on the 'View/Edit parameter data' icon***  ***.***

- ***Go through the list of parameters and modify: Bump travel, Rebound travel, Roll angle and Steer travel to match the data in table 3.1***

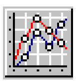
- ***Left click 'Ok' to close parameter dialog box then 'Done' to generate the new model.***

- ***To set the static toe and camber angles from the main menu select 'Data -> Set Static Angles…' and input 0.0 for toe and –1.5 for camber, then click 'ok'.***

- ***Check that all of the 4 toolbars are displayed. If any are missing they can be displayed from 'setup' on the main menu.***

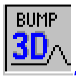
The model parameter and static settings have now been set up. We will now proceed to set up graphs to display the results as we manipulate the suspension geometry. Our goal is to manipulate the hard points to give kinematic motion in bump/rebound, steer and roll that gives the best compromise compared with our design goals. The static toe angle has been set to zero for now to avoid confusion when analysing the steering Ackerman geometry. If the toe angle is non-zero then the % Ackerman steering is ill-defined and the LSA Ackerman output cannot be used.

Open Graphs

- ***Left click on the 'open new results graph' icon***  ***on the graphics+data toolbar to open a new results graph.***

- ***Right click on the new graph and select 'Y-Variable -> Camber angle'***

- ***Open another 5 graphs for toe angle(deg) {SAE}, castor angle (deg), King Pin Angle (deg), Roll Centre Height {To Grnd} (mm) and Half Track change. Once all the graphs are open arrange the 3d display window and the graphs so they can all be viewed simultaneously.***

- ***Select 3D Bump mode by left clicking the icon*** 

.

- ***Right click on each graph in turn and select 'AutoScale to Y increment' to auto scale each graph. (The axis scale and y increment size can be set to your own custom values by right clicking on the graph and selecting 'Axes Scales').***

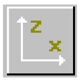
The castor angle and KPI will be modified first to achieve the specified values. For this tutorial we will modify the upper ball joint on the suspension upright.

- ***Turn off display of the wheels by clicking on the 'Toggle Enhanced Wheel Vis' icon*** ***.***

- ***Select joggle mode and left click on the top upright ball joint. You can now move the ball joint in the y direction. As you move the hardpoint (keyboard keys 'ctrl' + '->') the KPI graph will be updated. Move the ball joint to give 5 degrees KPI at zero bump as shown on the KPI graph.***

With the ball joint selected the mouse right click will toggle through the available joggle directions in that view

- ***Right click on the KPI graph and select 'List data line(s)' to verify angle. Close the dialog when done.***

- ***Change the view to z-x*** 

- ***Move the top upright ball joint in the x-direction to give 3 degrees castor angle.***

The castor and KPI are now set and you can manipulate the views to visually verify that the top of the king pin axis is inclined inwards towards the centre line of the car and backwards toward the rear. The castor and KPI are also listed in the SDF output file available in the 'results menu'. Return to front view and 3d roll mode when done.

- Next we will manipulate the inboard suspension hard points to achieve desired suspension kinematics in bump and roll.

To achieve these characteristics we will move the inboard suspension hard points on the upper and lower suspension wishbones and the inner and outer steering ball joints. Before proceeding experiment with moving these 6 suspension hard points and see if you can achieve a compromise between the target suspension kinematic characteristics. As movement of any one hard point can effect all of the characteristics we are interested in you will need to iteratively move and adjust each hard point in front and side view until you have reached a best compromise. Figures 3.1 and 3.2 give an indication of one hard point configuration that satisfies this condition. Once you have finished experimenting continue with the tutorial to input the suspension hard points manually.

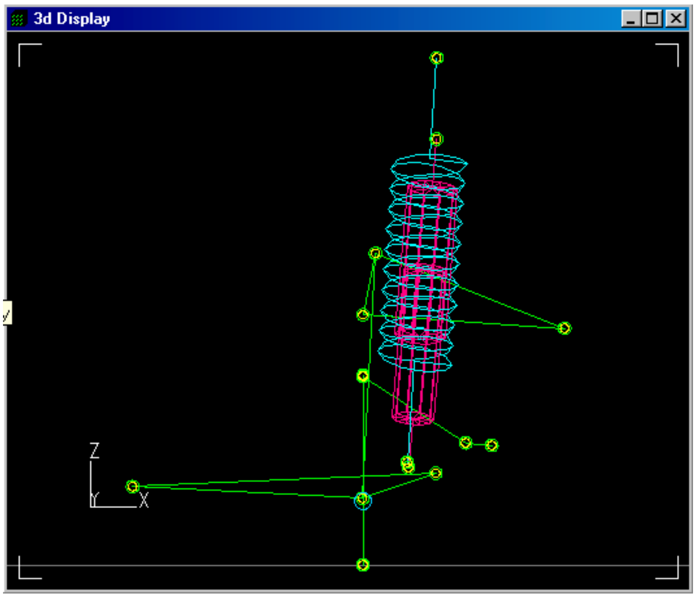


Figure 3.1

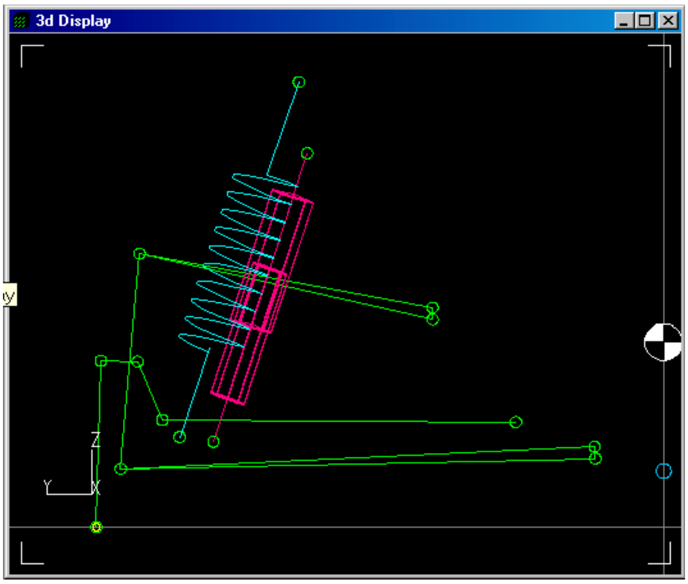
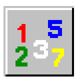
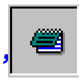


Figure 3.2

- ***Set viewing mode to front view y-z***



- ***Turn hard point numbering on by toggling the 'Point Nos Visibility' tool.***

- ***Select the 'Set to Edit Mode'***  ***icon and select the lower front inboard pivot: 'Point 1' and type in the hard point location shown in Figure 3.3***

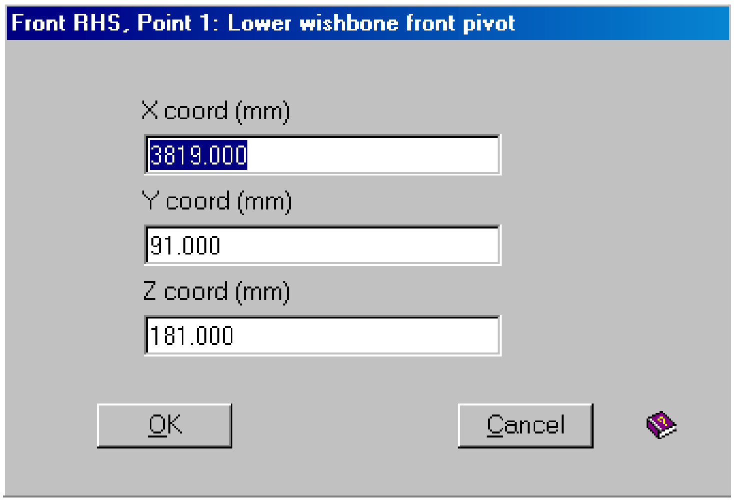


Figure 3.3

- ***Now go through each of the hard points listed in table 3.2 and use the same method to set the hard point locations listed in the table.***

Table 3.2 Suspension hard points that require modification.

Point	Name	X (mm)	Y(mm)	Z(mm)
1	Lower wishbone front pivot	3819	91	181
2	Lower wishbone rear pivot	4179	92	197
5	Upper wishbone front pivot	4092	308	385
6	Upper wishbone rear pivot	4332	308	369
11	Outer track rod ball joint	4214	668	233
12	Inner track rod ball joint	4245	197	230

With the suspension now located toggle between 3D bump roll and steer modes and verify that the design criteria are satisfied. Note that the calculation for Ackerman is based on having zero static toe. If the static toe is non-zero the output for % Ackerman is not properly defined and cannot be used.

- ***You can now verify yourself from the graphs and animating the suspension in steering, bump and roll that a compromise solution to the targets set out in section 3.2 has been achieved.***

- ***From the main menu select 'File -> Save As' and save the model as 'Tutorial 2a'.***

Now we have setup the graphs we can also save window setting which will save which output graphs are displayed. The next time you use the model you can load the windows setting file to reset the graphs.

- ***From the main menu select 'SetUp -> Save Window settings To…'. Enter 'Tutorial 2a' as the file name and save the widows settings file.***

This completes tutorial one. The solution obtained is a compromise between all the desired and sometimes conflicting requirements of the suspension. You may want to experiment to see if you can improve the design. Also notice that the camber and castor angles achieved are not an exact match to the targets.

3.4 Tutorial 2.b

Open New Rear Suspension Model

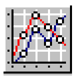
- ***From LSA menu select 'File -> New'.***

- ***Check the rear suspension tick box and select Type 1 Double wishbone, damper to lower wishbone (we will add the front suspension later).***

- ***Check that the parameter data and tyre data are correct (you may need to modify Bump travel, Rebound travel, Roll angle and Steer travel to match the data in table 3.1) then click done on the 'New Model' dialog to open the new rear suspension model.***

Now we have a new rear suspension model open we will setup a new graph to display % anti-squat for the rear suspension.

- ***From the main menu select 'Setup -> Load Windows settings From….'. Select the settings file 'Tutorial 2a' that we saved earlier and open.***

- ***Add another graph by clicking on the 'Open New Results Graph' tool***  ***and position the graph so it does not obstruct any of the other graphs.***

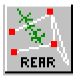
- ***Right click on the new graph and select 'Y-Variable -> Anti-Squat (%)'.***

- ***Auto scale the Y-axis. Right click on graph and select 'Autoscale To Y Increment'.***

The new graph settings can be now saved to the windows settings file.

- ***From the main menu select 'SetUp -> Save Window settings To…'. Enter 'Tutorial 2b' as the file name and save the widows settings file.***

Setup of the rear suspension follows the same procedure as the front therefore we will omit manipulating the suspension hard points and edit the rear suspension co-ordinates table directly. At this point you can experiment for yourself to see if you can meet the suspension characteristic targets then continue from this point once you are done (you may want to save your own model before you proceed).

- ***Click on the 'View/Edit rear co-ordinates'*** 

icon to bring up the rear suspension co-ordinates table.

- ***Now you can manually edit each of the suspension hard point locations by directly editing the (X,Y,Z) co-ordinates of each hard point. Use table 3.3 for input data. Click 'OK' when finished.***

Table 3.3 Rear suspenion hardpoints co-ordinate table.

Rear Suspension Coords (3D)

	X (mm)	Y (mm)	Z (mm)
Point 1: Lower wishbone front pivot	6446.5000	245.0000	197.1000
Point 2: Lower wishbone rear pivot	5980.5000	213.0000	221.1000
Point 3: Lower wishbone outer ball joint	6331.5000	724.0000	167.1000
Point 5: Upper wishbone front pivot	6239.5000	469.0000	396.1000
Point 6: Upper wishbone rear pivot	6568.5000	501.0000	384.1000
Point 7: Upper wishbone outer ball joint	6332.5000	701.0000	420.1000
Point 8: Damper wishbone end	6386.5000	600.0000	204.1000
Point 9: Damper body end	6419.5000	475.0000	594.1000
Point 11: Outer track rod ball joint	6454.5000	666.0000	269.1000
Point 12: Inner track rod ball joint	6485.5000	340.0000	263.1000
Point 16: Upper spring pivot point	6419.5000	486.0000	690.1000
Point 17: Lower spring pivot point	6384.5000	645.0000	210.1000
Point 18: Wheel spindle point	6332.5000	701.0000	311.8169
Point 19: Wheel centre point	6332.5000	750.0000	313.1000

OK Cancel

You can check for yourself that the new rear suspension co-ordinates give a 'good' compromise solution compared to the targets set out in Section 3.2. To complete the full suspension model we will now proceed to add the front suspension from tutorial 2.a.

➢ ***From the main menu select 'File -> Add End From File' and select the front suspension model developed in tutorial 2a.***

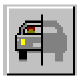
You now have a full vehicle suspension kinematic model with satisfies the target kinematic characteristics.

When working with full suspensions, displaying both the front and rear suspensions can be visually confusing. LSA allows you to display only the front or rear suspension and also only one side of the suspension.

 Displays only the front suspension.

 Displays only the rear suspension.

 Displays both front and rear suspension.

 Toggles between displaying one side and both sides.

In this tutorial you have learnt all the basic operations for setting up, manipulating and analysing suspension kinematics. To complete this tutorial save your file and quit LSA.

➢ ***Save model as 'Tutorial 2b' and close Lotus Suspension Analysis to end tutorial 2.***

4 Tutorial 3 - User Templates (1)

4.1 Overview

This chapter describes the structure of the model Templates used by Lotus Suspension Analysis to define and solve each suspension type. This then details how users can create their own templates and make them available as extra 'default' templates or share them with other users.

This chapter contains the following sections:

- 4.1 Overview, 31
- 4.2 Description of User Templates, 32
- 4.3 The 'Parts' Data Set, 33
- 4.4 The 'Points' Data Set, 34
- 4.5 The 'Settings' Data Set, 36
- 4.6 Settings - 'Parts', 36
- 4.7 Settings - 'General Types', 37
- 4.8 Settings – 'Bushes', 44
- 4.9 Settings – 'Point Solution Type', 44
- 4.10 Template Validation, 54
- 4.11 Exercise1 – 'Modifying an Existing Template', 56
- 4.12 Exercise 1 – 'Solution', 57

4.2 Description of User Templates

All suspension types used in LSA (Shark) are defined using a template structure. This structure uses a combination of data sets separated up into ‘Parts’, ‘Points’, ‘Settings’ and ‘Graphics’. A significant number of the most common suspension types are ‘hard coded’ into the application as defaults, but the user can modify these ‘defaults’ or add their own through the template editing tool, (*File / Edit Templates)*.

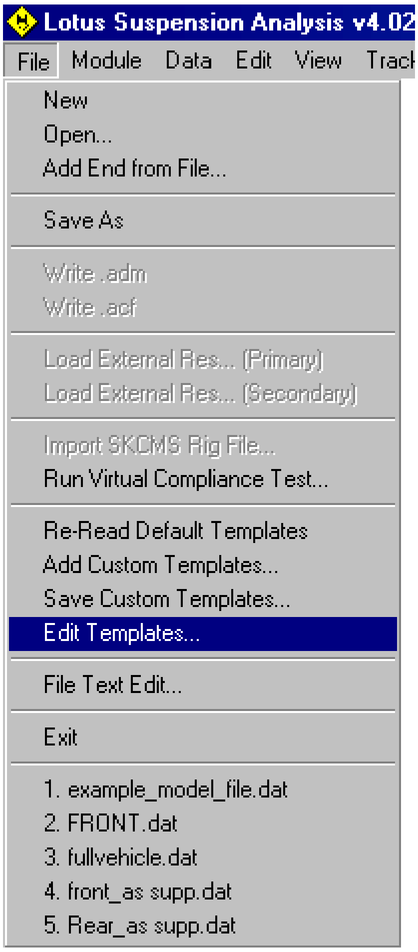


Figure 4.1 Opening the template editor

Each template is given a location number in the templates’ database, (for example the default double wishbone suspension is stored in location number 1). The template is also given a descriptive string to make recognition of each type easier.

Data values in the various data sets within the template editor are grouped into four further categories. These are ‘compulsory’, level 1, level 2 and level 3. Each category is identified by a colour. These are used to illustrate which values **must** be defined by the user and which can be filled via the ‘auto-fill’ routines. The auto-fills can be used to assist in identify missing template values through a series of menu options.

4.3 The 'Parts' Data Set

The Parts data set defines how many parts are in the suspension corner (or axle) model. Parts include wishbones, tie rods, uprights and rockers. There is no need to add a part for the vehicle body, (this is taken as part number –1), spring/dampers or the tyre. Each of these are implicitly included later by 'Point' definition.

By convention the upright **must** be the last part in the list. The only data fields for a part is an identifying label. This label is used in the other data sets to ease part recognition/selection.

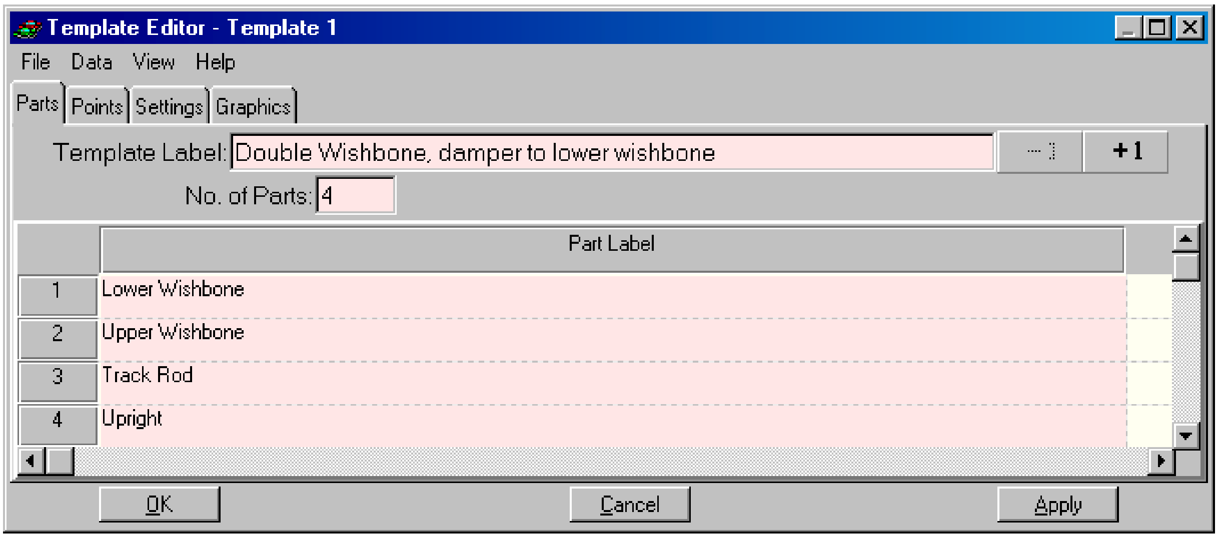


Figure 4.2 'Parts' Data Set editing – Default template 1 shown

Part Numbers and Part Labels for the defined model can be displayed on the model using the visibility switches, *Graphics / Part Nos* and *Graphics / Part Labels.*

All data values in the 'Parts' data set are in the 'Compulsory' category.

4.4 The 'Points' Data Set

The Points data set defines how many 'hard points' are include in the suspension corner/axle model. The data fields for each point is a descriptive label, (again used to aid identification/selection) and the default x, y and z co-ordinate values. The default co-ordinate values are those that are applied to a 'new' model using the particular template. The 'SHARK' co-ordinate system is a right handed system with the Y-axis across the car track, the origin of which is assumed to be on the vehicle centre line and the +ve direction being towards the offside suspension (Right hand Corner sitting in car). The X-axis is along the vehicle wheelbase, normally with the origin in front of the vehicle with the +ve direction towards the rear. The Z-axis is the vertical height, which for the 3D mode can be at any height position. The +ve direction is taken as upwards.

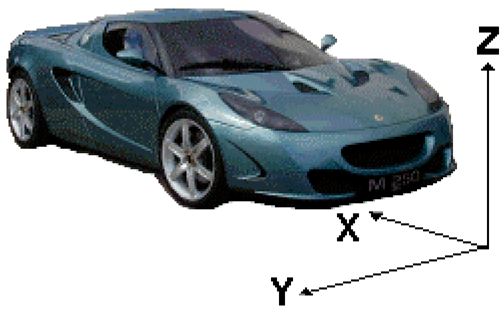


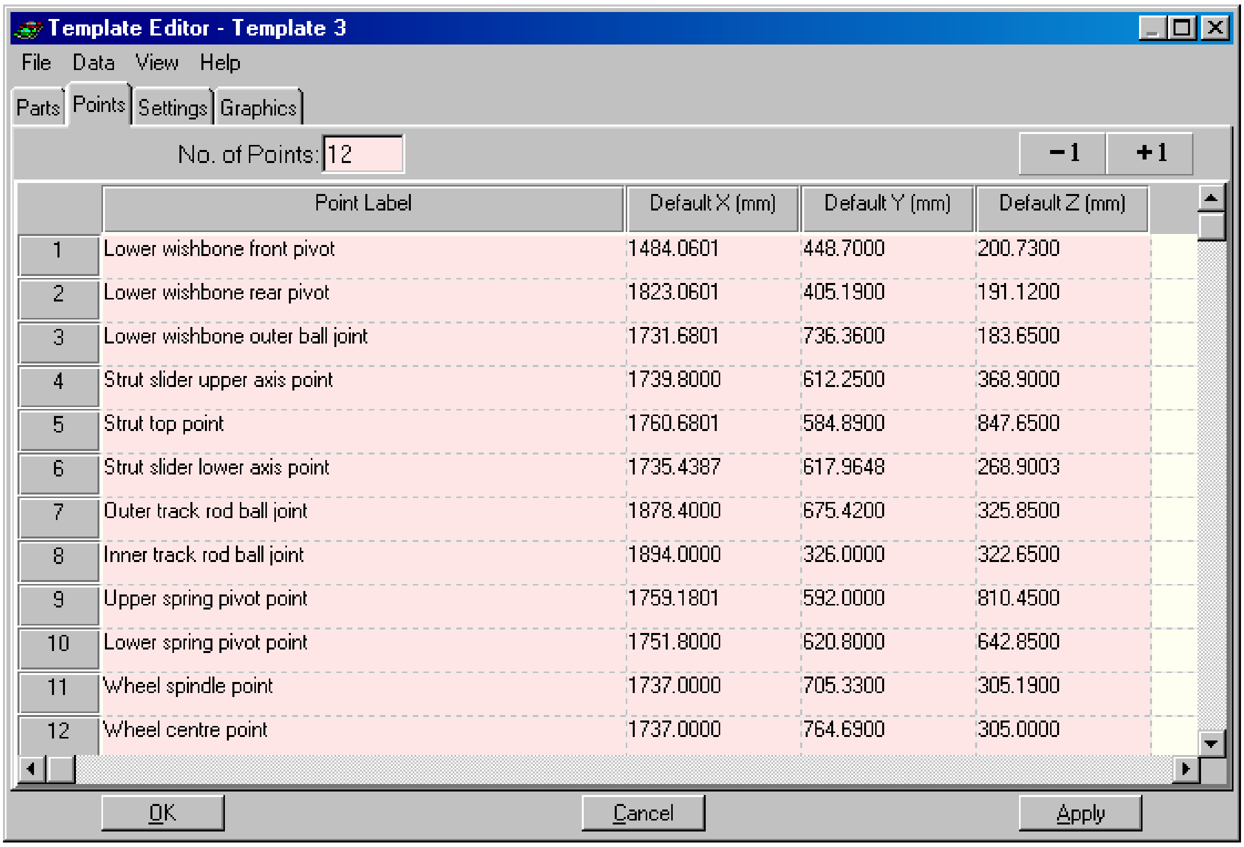
Figure 4.3 'Shark' Co-ordinate System

Connections between Parts are made at points, (i.e. wishbone ball joint). These connection points should only be entered once in the list of points, (the association to two parts is made later). Remember to add points for springs and damper connection points. You need to include points for both the suspension attachment point of the spring (or damper) and the attachment to the body.

If you have a combined spring/damper unit that employs common attachment points, you need not define the spring and damper points separately. We can associate both the spring and damper to the same connection point later.

For strut type suspensions the strut is defined by three points, the strut top mount point and two further points on the slider axis. These later two points would normally be placed at the upper and lower bearing centres to ensure the correct moments/forces. These three points will always be forced to lie along a single 3D line and thus get updated/corrected by the application.

Two points are always used to define the wheel spindle axis. The first is the wheel centre and the second is a point on the wheels rotational axis. This second spindle point can be either inboard or outboard of the wheel centre, although it is usually placed inboard of the wheel centre since its is the normal convention to draw between these two, a graphical element representing the spindle shaft.



	Point Label	Default X (mm)	Default Y (mm)	Default Z (mm)
1	Lower wishbone front pivot	1484.0601	448.7000	200.7300
2	Lower wishbone rear pivot	1823.0601	405.1900	191.1200
3	Lower wishbone outer ball joint	1731.6801	736.3600	183.6500
4	Strut slider upper axis point	1739.8000	612.2500	368.9000
5	Strut top point	1760.6801	584.8900	847.6500
6	Strut slider lower axis point	1735.4387	617.9648	268.9003
7	Outer track rod ball joint	1878.4000	675.4200	325.8500
8	Inner track rod ball joint	1894.0000	326.0000	322.6500
9	Upper spring pivot point	1759.1801	592.0000	810.4500
10	Lower spring pivot point	1751.8000	620.8000	642.8500
11	Wheel spindle point	1737.0000	705.3300	305.1900
12	Wheel centre point	1737.0000	764.6900	305.0000

Figure 4.4 'Points' Data Set editing – Default template 3 shown

Although we have given each point a descriptive label, they can also be referenced by a simple number. This number is defined in the 'settings' data set when the templates is not in 'full list' mode. This number need not be the same as its numerical position in the list. The use of this number is somewhat historical relating back to earlier version of the program when points were only referenced by number rather than by label. The visibility of both 'number' and 'label' on the model is set using the visibility switches, *Graphics / Point Nos.* and *Graphics / Point Labels.*

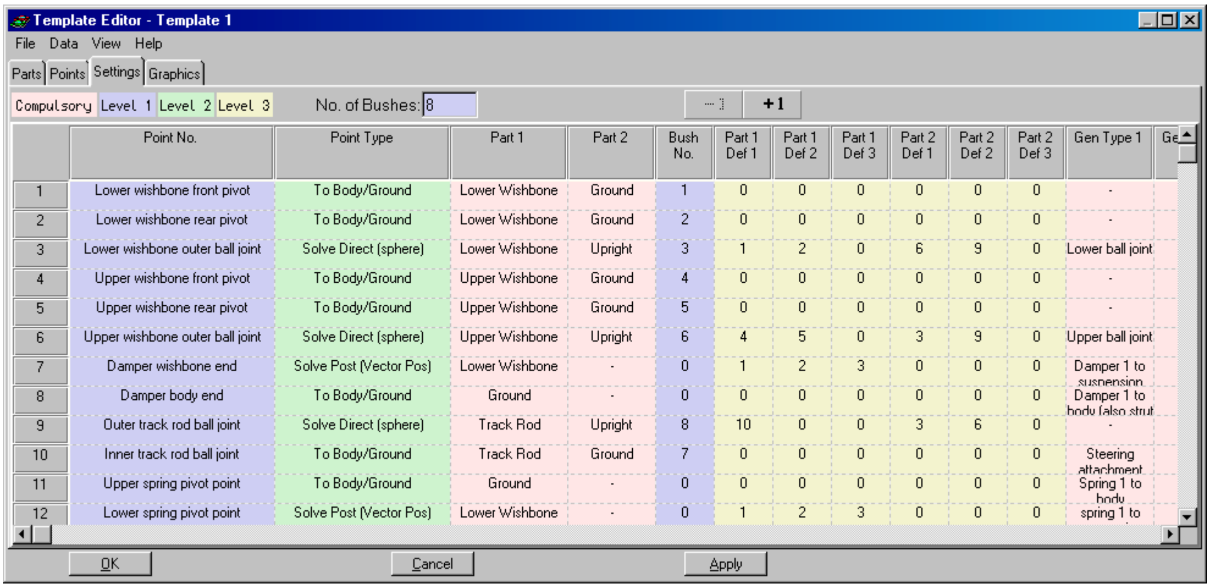
You do **not** define a point for the tyre contact point. This is calculated automatically from the tyre properties and the wheel spindle points. It is given the internal point No. of 99.

All data values in the 'Points' data set are in the 'Compulsory' category.

The 'Points' data set does have some optional identification labels that are used for the import/export options to some specific file formats. These can be seen in the right hand columns of the spread sheet.

4.5 The ‘Settings’ Data Set

The ‘Settings’ data set has a row entered for each point defined in the ‘Points’ data set. It is through the Settings data set that we identify the association of points to a part, (or Parts), the solution method to solve for each point, a bush No. and any special function that the point has. Some of these data fields are compulsory others may be filled through the ‘auto-fill’ options. It should be noted that the ‘auto-fill’ routines are not foolproof and thus should be applied with care. Auto-fill routines should only be used once all the compulsory data fields have been filled.

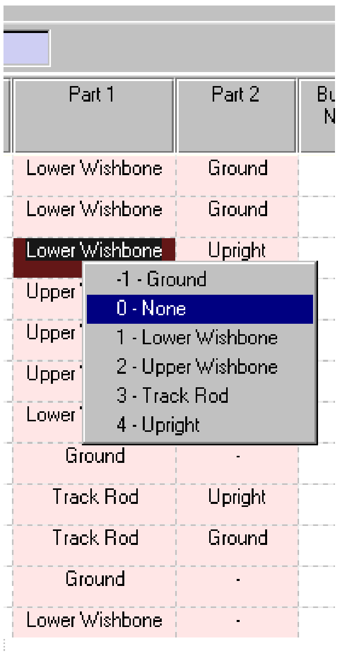


	Point No.	Point Type	Part 1	Part 2	Bush No.	Part 1 Def 1	Part 1 Def 2	Part 1 Def 3	Part 2 Def 1	Part 2 Def 2	Part 2 Def 3	Gen Type 1
1	Lower wishbone front pivot	To Body/Ground	Lower Wishbone	Ground	1	0	0	0	0	0	0	-
2	Lower wishbone rear pivot	To Body/Ground	Lower Wishbone	Ground	2	0	0	0	0	0	0	-
3	Lower wishbone outer ball joint	Solve Direct (sphere)	Lower Wishbone	Upright	3	1	2	0	6	9	0	Lower ball joint
4	Upper wishbone front pivot	To Body/Ground	Upper Wishbone	Ground	4	0	0	0	0	0	0	-
5	Upper wishbone rear pivot	To Body/Ground	Upper Wishbone	Ground	5	0	0	0	0	0	0	-
6	Upper wishbone outer ball joint	Solve Direct (sphere)	Upper Wishbone	Upright	6	4	5	0	3	9	0	Upper ball joint
7	Damper wishbone end	Solve Post (Vector Pos)	Lower Wishbone	-	0	1	2	3	0	0	0	Damper 1 to suspension
8	Damper body end	To Body/Ground	Ground	-	0	0	0	0	0	0	0	Damper 1 to body (also strut
9	Outer track rod ball joint	Solve Direct (sphere)	Track Rod	Upright	8	10	0	0	3	6	0	-
10	Inner track rod ball joint	To Body/Ground	Track Rod	Ground	7	0	0	0	0	0	0	Steering attachment
11	Upper spring pivot point	To Body/Ground	Ground	-	0	0	0	0	0	0	0	Spring 1 to body
12	Lower spring pivot point	Solve Post (Vector Pos)	Lower Wishbone	-	0	1	2	3	0	0	0	spring 1 to

Figure 4.5 ’Settings’ Data Set editing – Default template 1 shown

4.6 ‘Settings’ - Parts

Columns 3 (‘part 1’) and 4 (‘part 2’) define the parts that a point is associated with. These are compulsory data fields. A point can at most be associated with two parts, (this would be a connection between parts and requires a bush) and a minimum of one. In the case of a point associated to one part, always fill column 3 in preference to column 4. Note that additional part options, ‘Ground’ and ‘None’ are added to the available parts list.



4.7 'Settings' - General Types

Column 12 ('Gen Type 1') which, whilst it is a compulsory data field, it can be left blank, (the equivalent of 'none' from the menu options). This column defines whether a point performs one of the 'General Types' functions. These functions identify to the solver and the template builder that a point has specific properties. Column 13 ('Gen Type 2') is a repeat of column 12 and is used if a point has more than one General Type classification. There are currently 27 different 'General Types'. Each is discussed below.

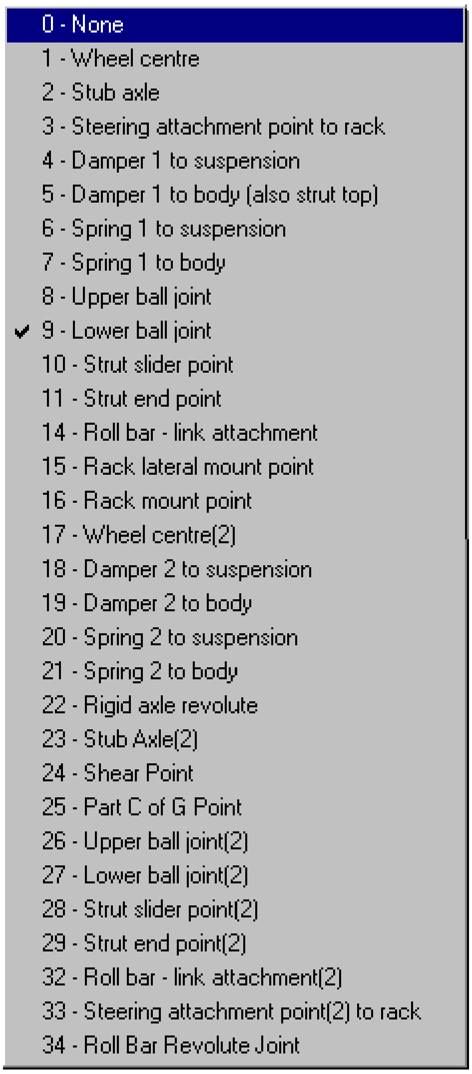


Figure 4.6 General Types Menu

0 = None: Identifies that the point has no specific type. This could include points such as wishbone attachment points to ground.

1 = Wheel Centre: One point must always be identified as 'wheel centre'. Identifies that the point is the wheel centre.

2 = Stub Axle: One point must always be identified as ‘stub axle’. Identifies that the point is the second point on the wheel spindle which together with the ‘wheel centre’ define the stub axle and hence all wheel related parameters.

3 = Steering Attachment Point to Rack: This optional point identifies that the template has a point at which steering input can be applied, (either rack or steering box). It is also used to determine whether the template will appear in the list of available ‘Front’ suspensions on the *File/New* option, (all templates appear in the list of ‘Rear; suspensions irrespective of this general type).

4 = Damper 1 to Suspension: This optional point identifies that the specified point is the position in the template at which the damper is attached to the moving suspension. This is used to determine damper travel, damper ratio etc. To work correctly it will need general type 5 to also be defined. This would also be used to identify the point at the upper bearing position on the slider of a McPherson-strut suspension. The reference to ‘Damper 1’ in the description is a recognition for potential future expansion to include multiple damper templates.

5 = Damper 1 to Body (also Strut Top): This optional point identifies that the specified point is the position in the template at which the damper is attached to the body. It is used in conjunction with general type 4 above. This would also be used to identify the point at the top of the slider for a McPherson-strut suspension.

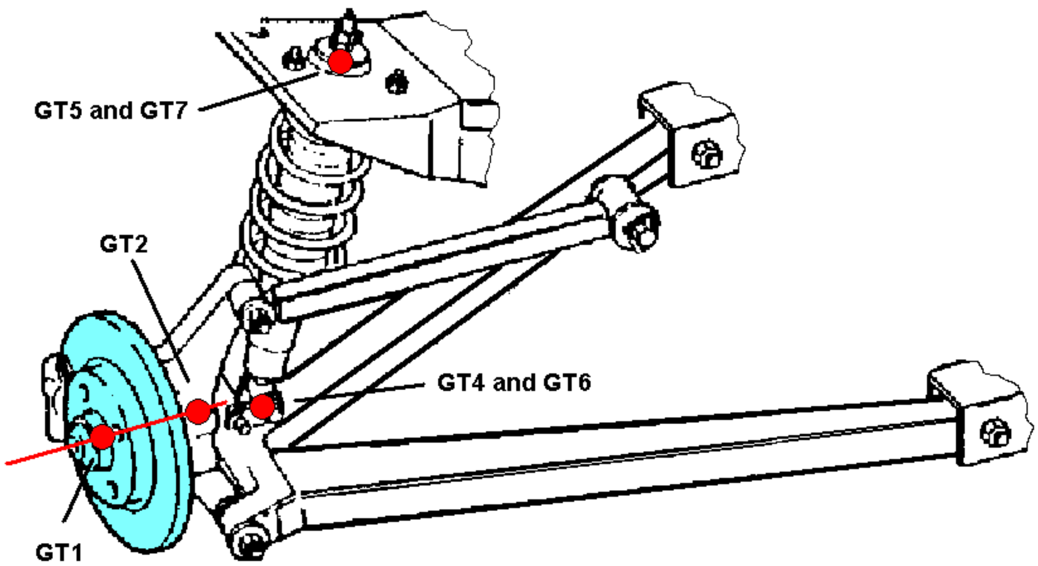


Figure 4.7 Example Rear Suspension – Showing General Types 1,2,4,5,6 and 7

6 = Spring 1 to Suspension: This compulsory point identifies that the specified point is the position in the template at which the spring is attached to the moving suspension. This is used to apply suspension spring forces to the template and determine spring travel, spring ratio etc. To work correctly it will need general type 7 to also be defined. The reference to ‘Spring 1’ in the description is a recognition for potential future expansion to include multiple spring templates.

7 = Spring 1 to Body: This optional point identifies that the specified point is the position in the template at which the spring is attached to the body. It is used in conjunction with general type 6 above.

8 = Upper Ball Joint: This optional point identifies that the specified point is the upper ball joint on the steering axis. Whilst this is optional if it exists and can be identified this will improve the calculation speed/accuracy. Together with general type 9 it defines the steering axis. If a steering axis can not be defined but a steering attachment point has been identified, (see default template No. 20), then additional calculations are used involving a small steering perturbation to identify the 'effective' steering axis. This normally involves suspension types that have twin outer ball joints rather than a single one.

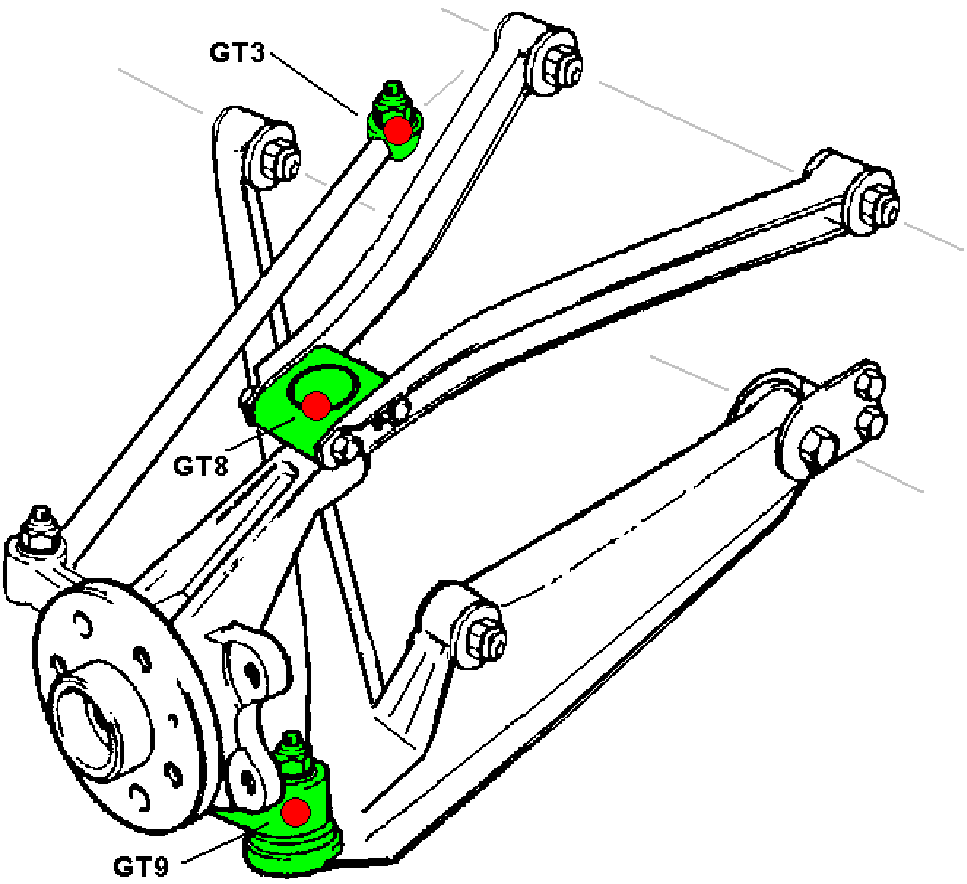


Figure 4.8 Example Front Suspension – Showing General Types 3,8 and 9

9 = Lower Ball Joint: This optional point identifies that the specified point is the lower ball joint on the steering axis, (see comments for type 8 above).

10 = Strut Slider Point: This optional point identifies that the template is a strut type suspension and the specified point is the strut body upper bearing position. This should not be confused with the strut top mount, (which is identified via general type 5). This point moves with the strut body and is used as the sliding connection between the slider and the strut body, (see also type 11 below).

11 = Strut End Point: This optional point identifies that the template is a strut type suspension and the specified point is the strut slider end bearing. This point moves with the strut slider and is used as the sliding connection between the slider and the strut body.

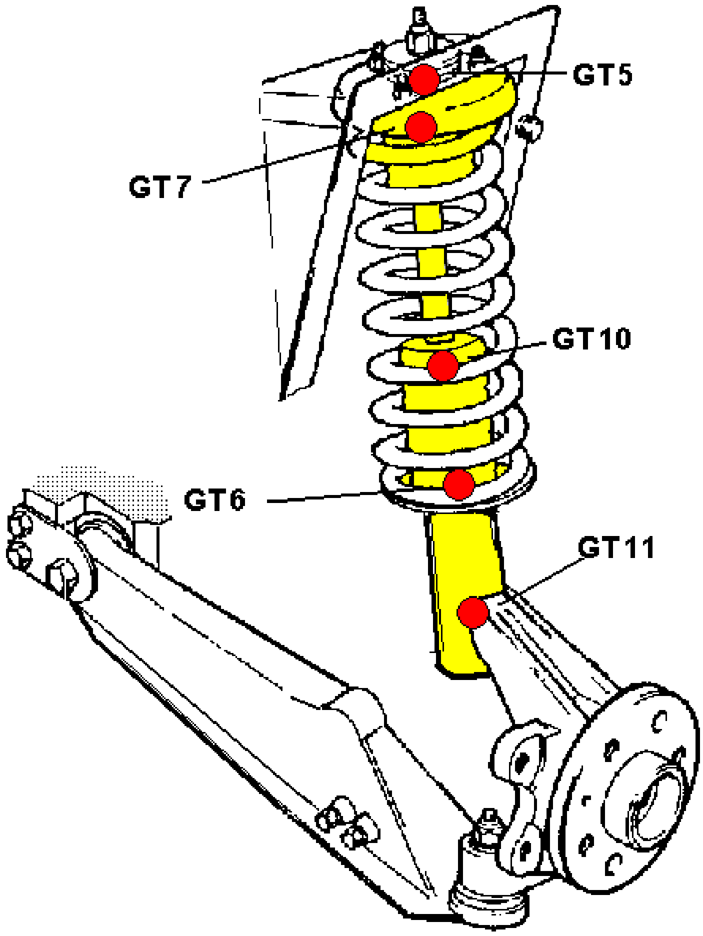


Figure 4.9 Example McPherson Strut – Showing General Types 5,6,7,10 and 11

14 = Roll Bar – Link attachment: This optional point identifies the point where the roll bar drop link is attached to the anti-roll bar. This is used to identify the amount of twist in the bar and hence the force applied to the suspension.

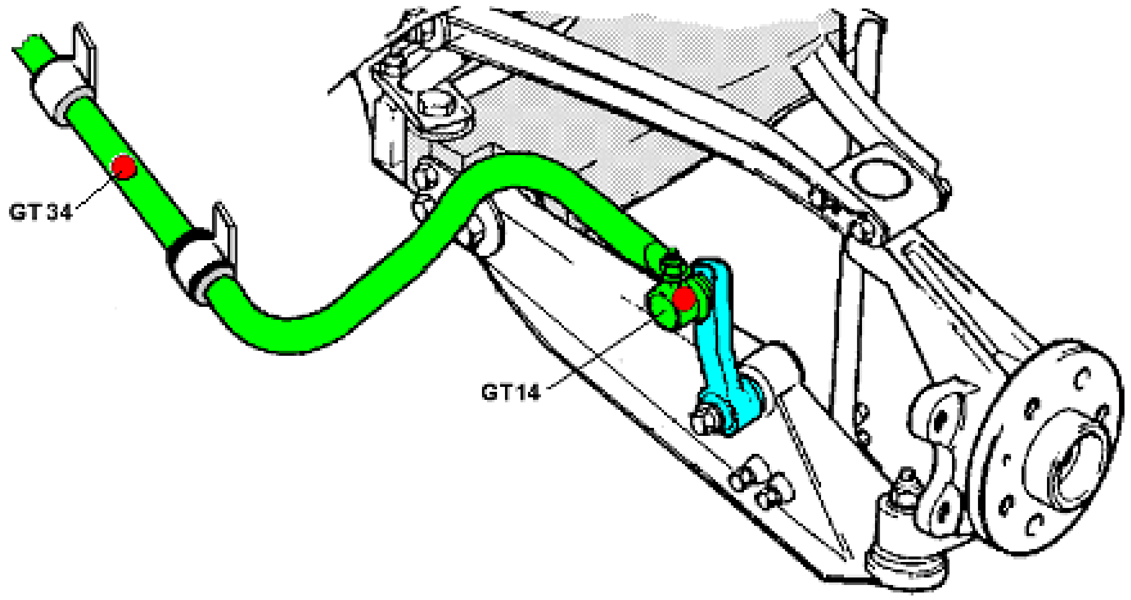


Figure 4.10 Example Front Suspension – General Types 14 and 34

15 = Rack Lateral Mount point: This optional point identifies the point as being a the rack attachment point that also takes the axial reaction load. User defined bush properties should be defined accordingly.

16 = Rack Mount Point: This optional point identifies the point as being the second rack attachment point. No axial load is carried by this point when using the default bush settings.

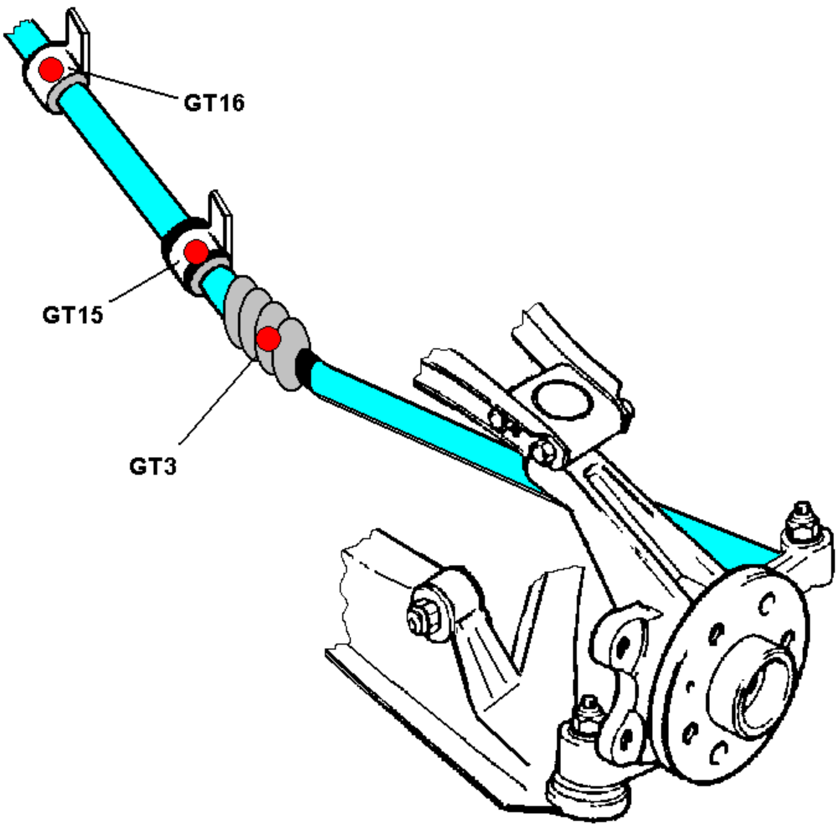


Figure 4.11 Example Front suspension – General Types 3, 15 and 16

17 = Wheel Centre(2): This optional point identifies the point as being the second wheel centre for rigid axle and full axle templates.

18 = Damper 2 to suspension: This optional point identifies the point as being the second dampers' attachment point to the suspension. It may be a second damper on a single corner model or the opposite side on a full axle model.

19 = Damper 2 to body: This optional point identifies the point as being the second dampers' attachment point to the body. As for point 18 above it may be one of two cases.

20 = Spring 2 to suspension: This optional point identifies the point as being the second springs' attachment point to the suspension. It may be a second spring on a single corner model or the opposite side on a full axle model.

21 = Spring 2 to body: This optional point identifies the point as being the second springs' attachment point to the body. As for point 20 above it may be one of two cases.

22 = Rigid axle revolute: This optional point identifies the point as being a revolute joint at the centre of a rigid axle. It is required for rigid axle templates to enable them to pre-solve in kinematic mode when in roll mode.

23 = Stub Axle(2): This optional point identifies the point as being the second wheel stub axle point. This is needed for full axle models.

24 = Shear Point: Used just for twist beam suspensions to identify the different pivot point position used in bump and roll. (Optional).

25 = Part C of G Point: Used to identify a point as being the C of G point for its primary part. It is normal for this point to not be used except as the C of G point, i.e. no involved in any joints. (Optional).

26 = Upper Ball Joint(2): Identifies a point as being the upper ball joint for the steering axis on full axle templates only. This must be a connection between two parts to conform with the concept of a steering axis. It is an optional setting in that if it (and the lower ball joint) are not defined the steering axis is determined via a small perturbation of the steering input mechanism. If it can be defined it will lead to faster solution times than the small perturbation method. (Optional).

27 = Lower Ball Joint (2): Identifies a point as being the lower ball joint for the steering axis on full axle templates only. This must be a connection between two parts to conform with the concept of a steering axis. It is an optional setting in that if it (and the upper ball joint) are not defined the steering axis is determined via a small perturbation of the steering input mechanism. If it can be defined it will lead to faster solution times than the small perturbation method. (Optional).

28 = Strut Slider Point(2): Sets the point for a Macpherson strut suspension type that is considered to be the location of the top bush for the strut for full axle templates only, (attached to the strut body). (Required for Struts).

29 = Strut End Point(2): Sets the point for a Macpherson strut suspension type that is considered to be the location of the strut lower bush for full axle templates only, (attached to the strut slider). (Required for Struts).

32 = Roll Bar – Link Attachment(2): Identifies the point as being the second connection between the roll bar drop link and the suspension. (Optional). Roll bars can only be added to full axle templates so a template must have both this and point 14 defined.

33 = Steering Attachment Point(2) to Rack: T Identifies which suspension link end point should be used for the steering input from the rack or steering box for the second end in a full axle model only. See also point 3 above. This point should be the inboard end of the track rod, i.e. link point connected to body or rack. (Optional). For a compliant rack to be added to the model this point must be defined together with point 3 above.

34 = Roll Bar, Revolute Joint: Identifies the point as being the centre point of a two part roll bar. In kinematic mode this is treated as a simple revolute allowing roll motion. In compliant mode the roll bar stiffness is applied to this point to simulate the effect of the roll bar stiffness. (Optional). Roll bars can only be added to full axle templates so a template must have this point and points 14 and 32 defined.

4.8 'Settings' - Bushes

The settings data set is where we define the number of bushes in the model and assign a bush number to each connection, (column 5). A bush is added at any point that is a connection between two parts and at a point that is the connection of a part to ground. Bush Nos. are primarily used for internal identification and need not be sequential.

4.9 'Settings' – Point Solution Type

Column 2, ('Point Type') defines for each point the solution type used to solve its incremental position. This controls the number of equations and the values used in solving the set of simultaneous equations. Some solution definitions can be post solved. That is determined after the set of simultaneous equations are solved. Ten different point solution types are available although by far the most common is the use of the 'sphere' equation. A description of each solution type is given below. Depending on the solution type selected the values required in columns 6 to 11 alter. These level 3 data fields identify the relevant points for the selected solution type.

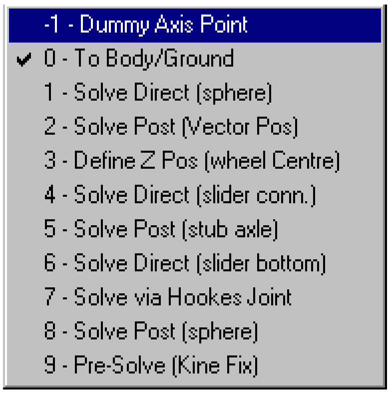


Figure 4.12 Point 'Type' options list

-1 = Dummy Axis Point: This option would not normally be used. It was added to deal with a specific issue identified for backward compatibility with default template type 12. It had in its original formulation an additional undefined point used to restrain the upright and enable the use of a steering knuckle. It is not envisaged that users would need to use this special option, as it is perfectly feasible to build this suspension template without recourse to this point solution type.

0 = To Body/Ground: This sets the point solution type as being pre-filled, (by bump, rebound or roll articulation) and hence no equations are added to the solver for this point. No arguments are required in columns 6 to 11 for this solution type. Points that use this type are usually those that are attached directly to the body.

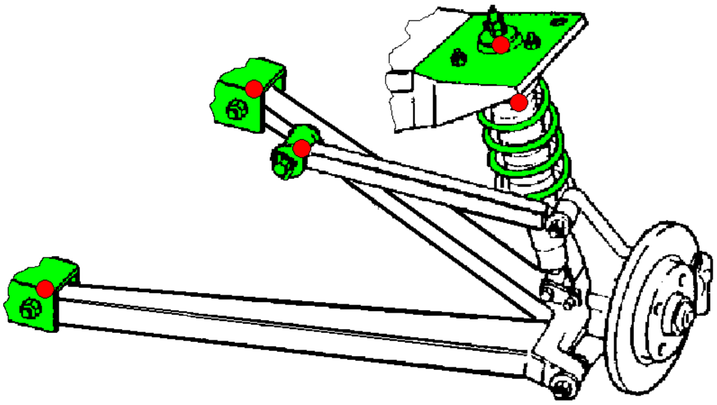


Figure 4.13 Typical Point Type 0's, To Body/Ground

1 = Solve Direct (sphere): This sets the point solution type to be based on the equation of a sphere. A spherical equation is added to the list of simultaneous equations for each point referenced in columns 6 to 11. The sphere equation controls the 3D distance between two points. The two points being the current rows point and the column 6 to 11 data field values.

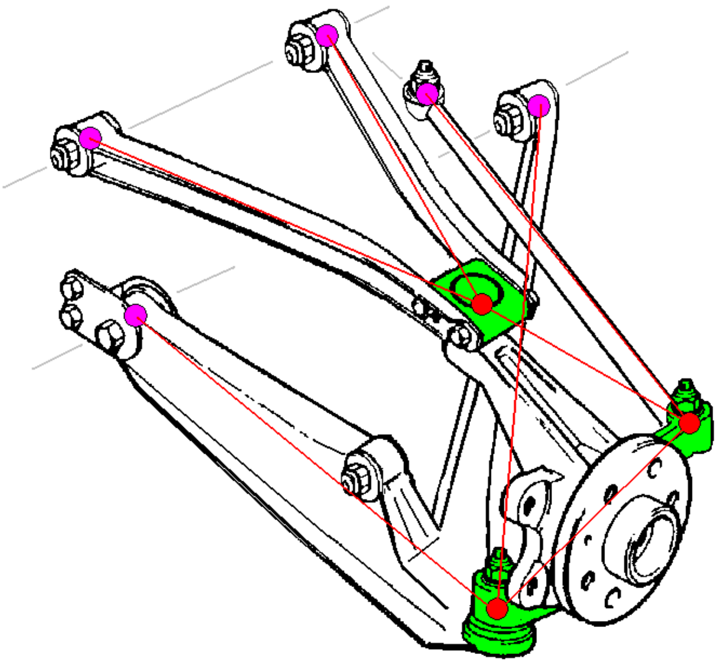


Figure 4.14 Typical Double Wishbone Type 1's, Solve direct (Sphere)

Data entry in columns 6 to 11 can be completed using the 'auto-fill' routines. The auto fill routines tend to add duplication but these are checked for and ignored by the solver.

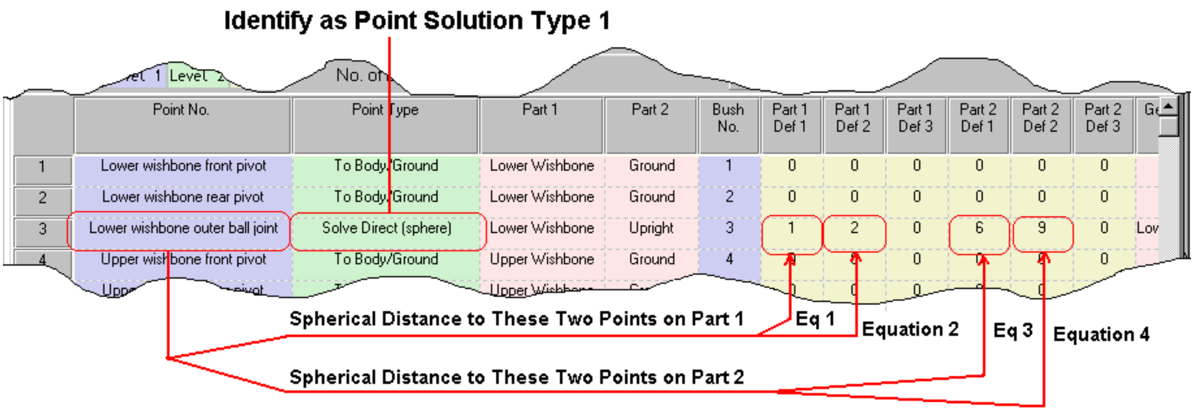


Figure 4.15 Screen Shot for settings on solution type 1, Adds 4 Equations

2 = Solve Post (Vector Pos): This sets the point solution type to be based on a fixed position relative to three other points on the same body. It is a 'post' simultaneous equation solution calculation and as such has no control on the suspension articulation. Typical cases where this solution type is applied would be the case of a simple damper attachment to a wishbone. By definition it requires a minimum of four points to be associated with the relevant part. It is used where possible in preference to type 1 above, to increase the overall calculation speed by not adding three more sphere equations to the list. This solution type should not be used on push-rod or pull-rods since additional mechanism positions rely on it.

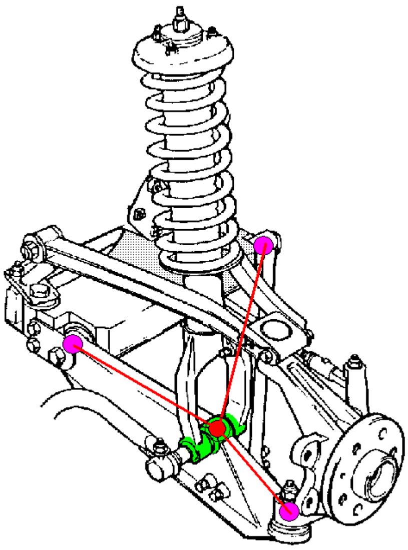


Figure 4.16 Example Solver Point Type 2.

Define in columns 6,7 and 8 the three point No's of points on the same part as this point. No numbers are required for columns 9 to 11.

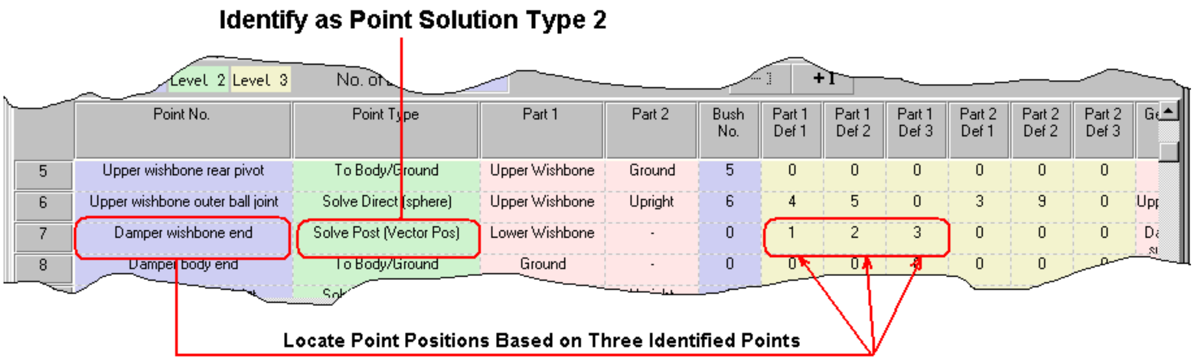


Figure 4.17 Screen Shot for settings on solution type 2

3 = Define Z Pos (Wheel Centre): This point solution type is specific to wheel centre points. A point that has already been identified as the wheel centre would be given this point solution type by the ‘auto-fill’ routines. It requires in columns 6,7 and 8 three other reference points to be identified on the same part. One of these points should not be the wheel spindle point since that point is always post calculated and therefore not available to use in defining the wheel centre. This point solution type adds one equation to the simultaneous equation list. No values are required in columns 9,10 and11.

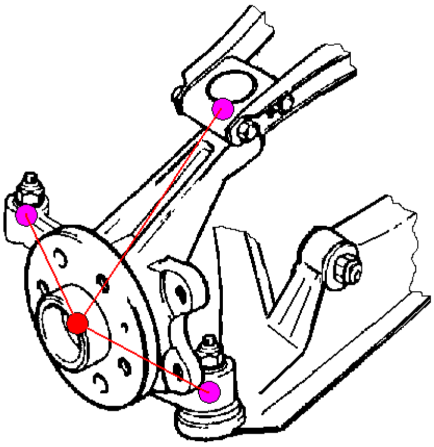
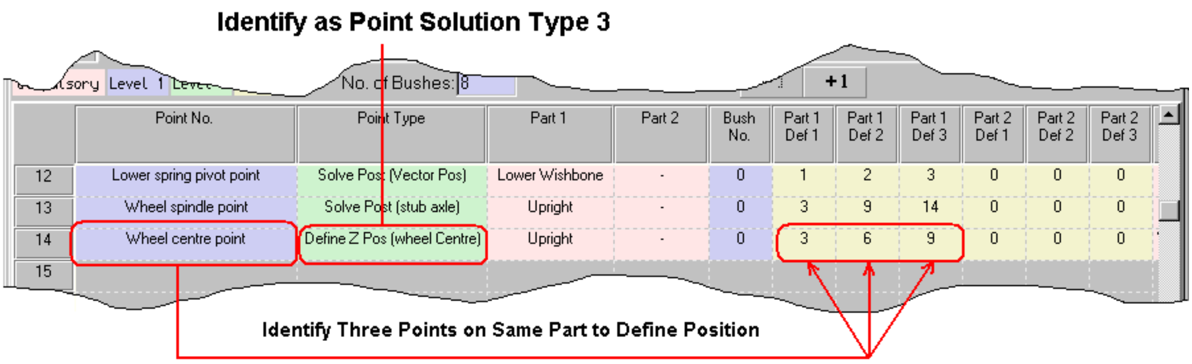


Figure 4.18 Example Solver Point Type 3, Typical point dependency



	Point No.	Point Type	Part 1	Part 2	Bush No.	Part 1 Def 1	Part 1 Def 2	Part 1 Def 3	Part 2 Def 1	Part 2 Def 2	Part 2 Def 3
12	Lower spring pivot point	Solve Pos (Vector Pos)	Lower Wishbone	-	0	1	2	3	0	0	0
13	Wheel spindle point	Solve Post (stub axle)	Upright	-	0	3	9	14	0	0	0
14	Wheel centre point	Define Z Pos (wheel Centre)	Upright	-	0	3	6	9	0	0	0
15											

Figure 4.19 Screen Shot for settings on solution type 3, Adds 1 Equation

4 = Solve Direct (Slider Conn): This point solution type is specific to Strut slider points. A point that has already been identified as the 'Strut slider point', (general type 10), would be given this point solution type by the 'auto-fill' routines. It requires in columns 6 and 7 the two other strut slider points to be identified, (general types 5 and 11). This adds two equations to the simultaneous equations list.

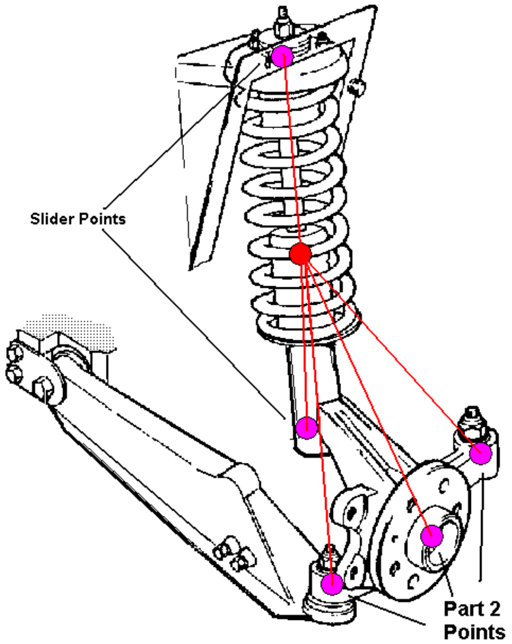
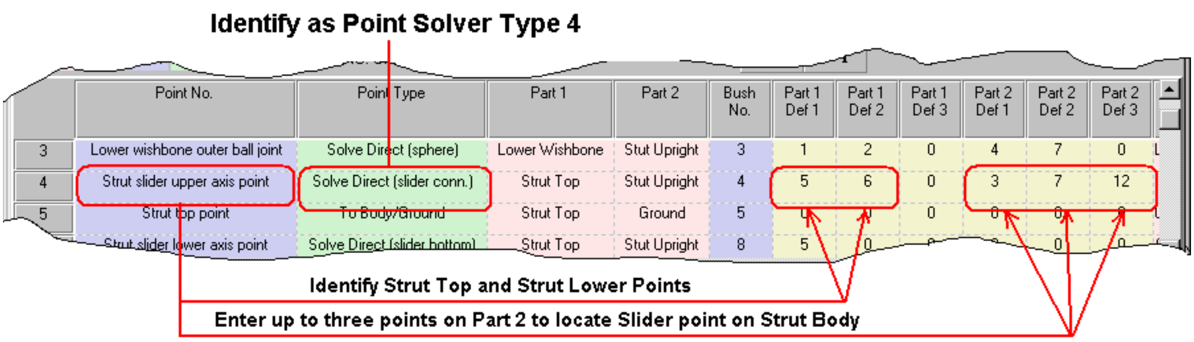


Figure 4.20 Example Solver Point Type 4, Shows both part definitions.

No value is required for column 8. In columns 9,10 and 11 point No's are required for up to three other points on the Strut Upright part, that define the location of it on that part. Each point number adds a sphere constraint equation between it and the strut slider point. The auto-fill routine will always add three points, any subsequent duplication in spherical constraints is ignored.



	Point No.	Point Type	Part 1	Part 2	Bush No.	Part 1 Def 1	Part 1 Def 2	Part 1 Def 3	Part 2 Def 1	Part 2 Def 2	Part 2 Def 3
3	Lower wishbone outer ball joint	Solve Direct (sphere)	Lower Wishbone	Stut Upright	3	1	2	0	4	7	0
4	Strut slider upper axis point	Solve Direct (slider conn.)	Strut Top	Stut Upright	4	5	6	0	3	7	12
5	Strut top point	To Body/Ground	Strut Top	Ground	5	0	0	0	0	0	0
	Strut slider lower axis point	Solve Direct (slider bottom)	Strut Top	Stut Upright	8	5	0	[illegible]	[illegible]	0	[illegible]

Figure 4.21 Screen Shot for settings on solution type 4, Adds 5 Equations

5 = Solve Post (Stub axle): This point solution type is specific to the point general type 2 'Stub Axle'. A point that has already been identified as the 'Stub axle point', (general type 2), would be given this point solution type by the 'auto-fill' routines. It requires three points to be defined through columns 6,7 and 8 that are also on the upright part. This is a post simultaneous solution method and so does not add any equations to the list.

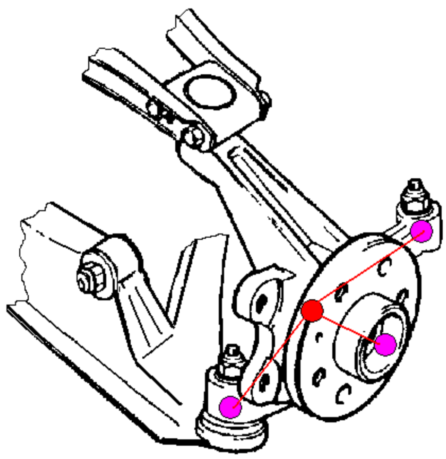


Figure 4.22 Example Solver Point Type 5, Shows typical three point definition.

The normal point selection would include the wheel centre point. Because this is a Post simultaneous equation solver type it can use any three points on the body that have already been solved in the main simultaneous equation solution, this is typically major defining points such as all ball joints. It can not use points that are also post solved since depending on the solver order sequence they may not yet have been evaluated.

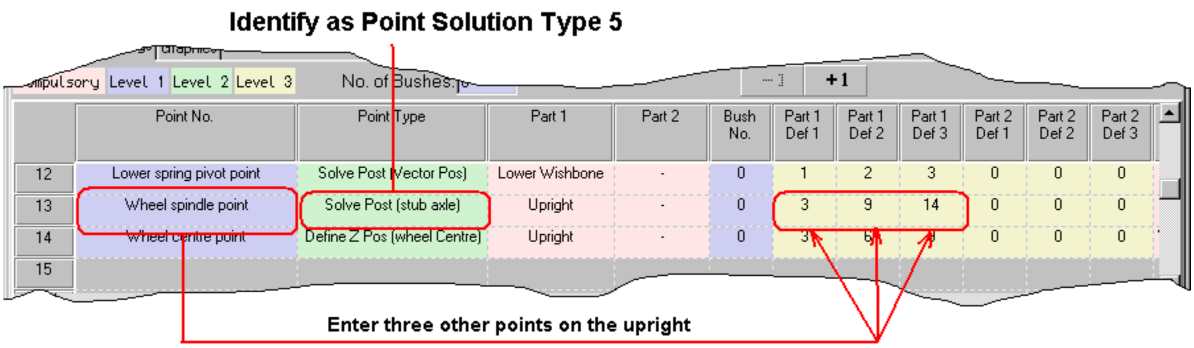


Figure 4.23 Screen Shot for settings on solution type 5.

6 = Solve Direct (Slider Bottom): This point solution type is specific to Strut End Points. A point that has already been identified as the 'Strut End Point', (general type 10), would be given this point solution type by the 'auto-fill' routines. It requires in column 6 the strut top point to be identified, (general types 5). This adds one equation to the simultaneous equations list.

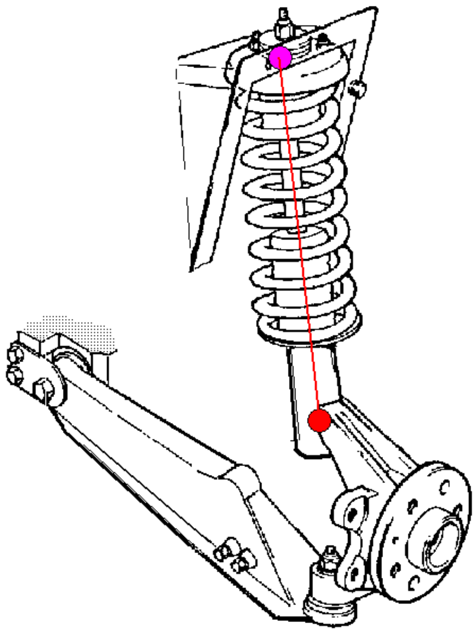
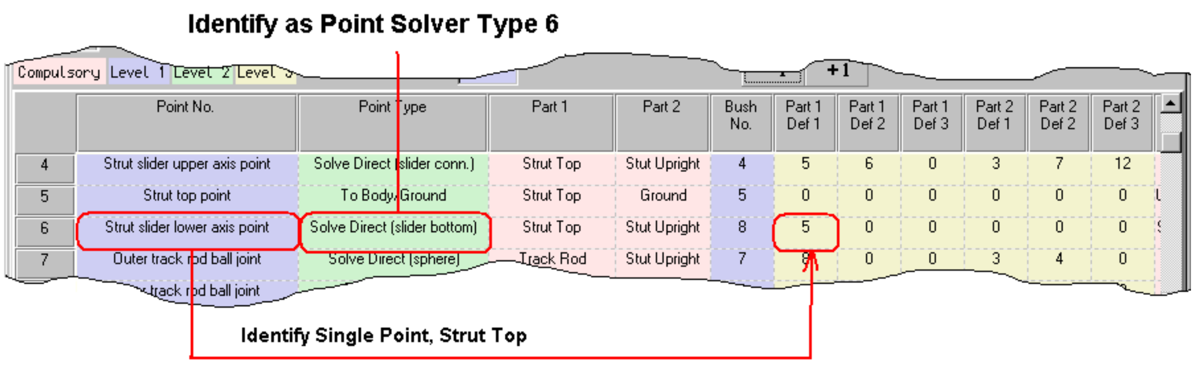


Figure 4.24 Example Solver Point Type 6, Shows single point identification.

No values are required for columns 7 and 8 or columns 9,10 and 11.



	Point No.	Point Type	Part 1	Part 2	Bush No.	Part 1 Def 1	Part 1 Def 2	Part 1 Def 3	Part 2 Def 1	Part 2 Def 2	Part 2 Def 3
4	Strut slider upper axis point	Solve Direct (slider conn.)	Strut Top	Stut Upright	4	5	6	0	3	7	12
5	Strut top point	To Body/Ground	Strut Top	Ground	5	0	0	0	0	0	0
6	Strut slider lower axis point	Solve Direct (slider bottom)	Strut Top	Stut Upright	8	5	0	0	0	0	0
7	Outer track rod ball joint	Solve Direct (sphere)	Track Rod	Stut Upright	7	8	0	0	3	4	0
	…track rod ball joint										

Figure 4.25 Screen Shot for settings on solution type 6, Adds 1 Equation

7 = Solve via Hookes Joint: This point solution type is a post calculation solution type that was added to handle the specific case of an under constrained kinematic model. The normal use for this solution type is when a spring or damper is attached to a tie rod. Kinematically a tie rod having just two attachment points provides a single spherical constraint to the model but in itself it has a degree of freedom left, rotation about the axis joining the two ends. When a damper is attached to this link, unless it is placed exactly on the tie rod axis, this degree of freedom means that the new position of the damper attachment cannot be solved. By placing a Hookes joint at one end of the tie rod this rotational degree of freedom is removed and a kinematic solution can be identified.

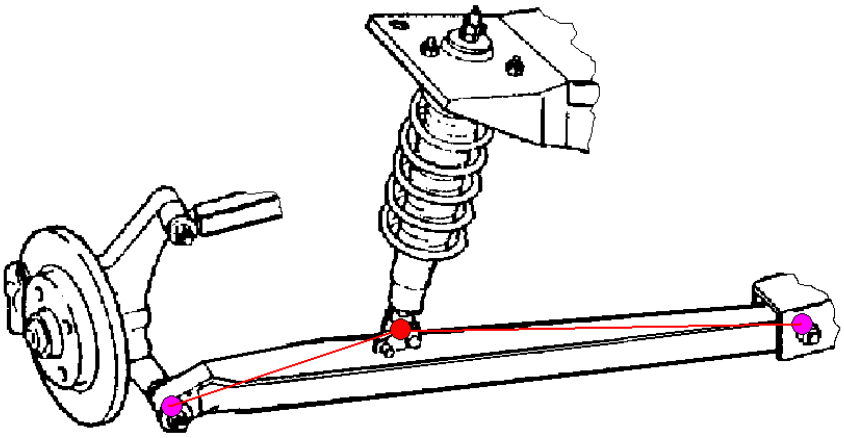


Figure 4.26 Example Solver Point Type 7, Two points identified.

The use of a Hookes joint in the kinematic model does not effect the fully bushed compliant solution. The rotational degree of freedom in the complaint case is taken out via suitable bush properties. An example of the Hookes joint point solver can be found in default template 19.

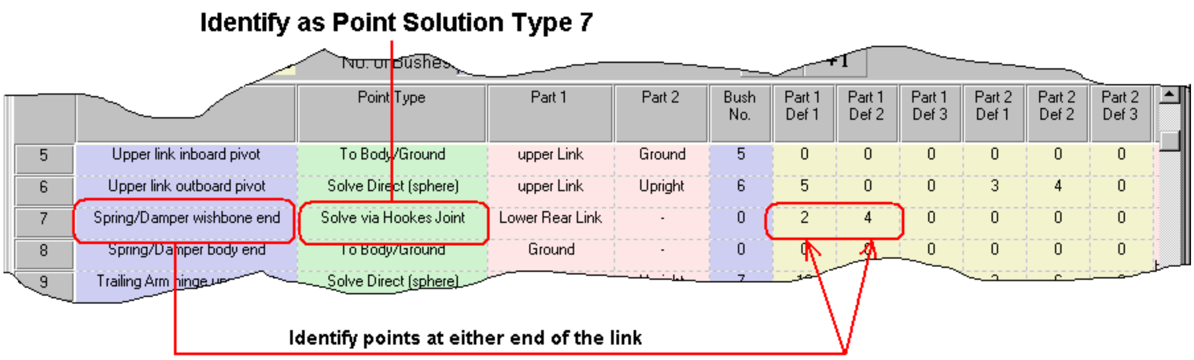
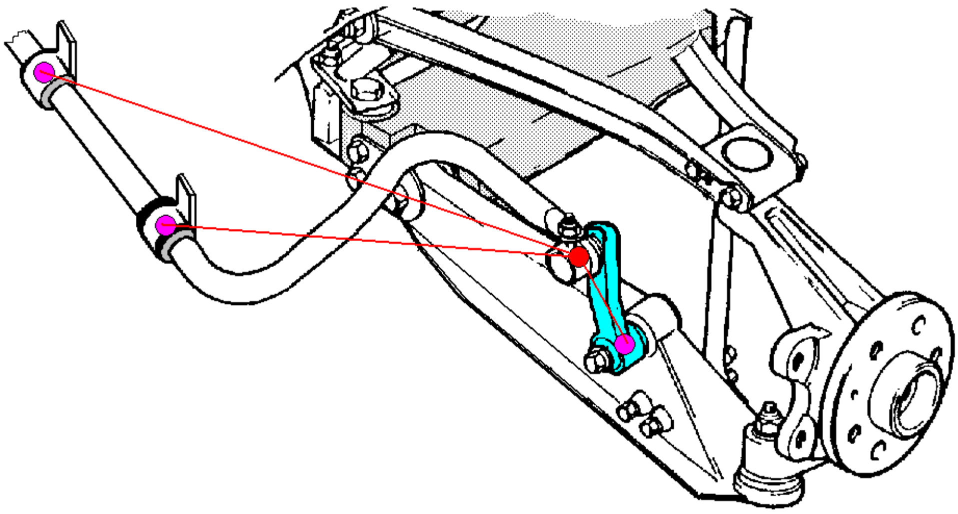


Figure 4.27 Screen Shot for settings on solution type 7, Example template 19.

8 = Solve Post (sphere): This point solution type is a post calculation solution type and as such adds no equations to the simultaneous equation list. It is used as an alternative to point solution type 2 in special cases. It is always preferable to use point solution type 2 rather than this one. Since the sphere equation always has more than one solution which can lead to errors when two solutions are similar.

Default template 23 uses this solution type for the anti roll bar drop link attachment. As with the conventional ‘Solve Direct (sphere)’ solution type up to three points are listed in columns 6,7 and 8 a spherical constraint equation added for each point number. All points entered must be on the same part as the point being solved. No data points need be defined in columns 9,10 and 11.



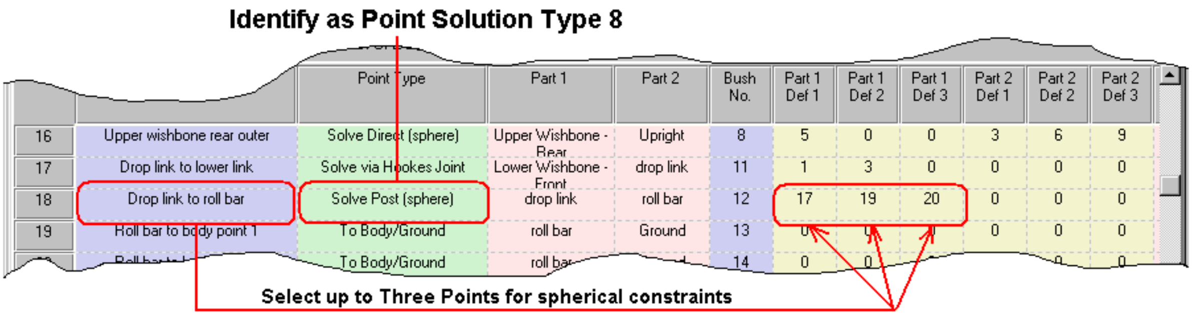
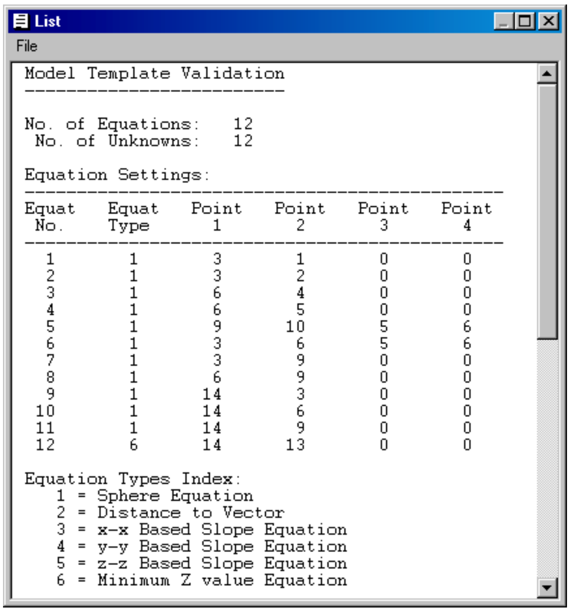


Figure 4.28 Screen Shot for Settings on solution type 8.

9 = Pre-Solve (Kine Fix): A pre main solver option calculation. Requires no defining points since the point is assumed to be inactive in kinematic mode. It remains fixed to the part it is defined on (normally ground or a ground fixed part). It is used to add additional compliance effects for parts such as rack mounts and sub frames that are assumed to have no kinematic effect but are included in the compliance matrix.

4.10 Template Validation

The definition of a template is used to identify unknown point positions, (x, y and z), and the number of equations. For a successful template definition the number of equations must equal the number of unknowns. A utility is provided to test the unknown to equations count. From the template window select *Data / Run Validation Test…* The produced display lists the number of unknowns and the number of equations. Each equation is listed by type and with the associated point numbers.



List
File

Model Template Validation

No. of Equations: 12
No. of Unknowns: 12

Equation Settings:

Equat No.	Equat Type	Point 1	Point 2	Point 3	Point 4
1	1	3	1	0	0
2	1	3	2	0	0
3	1	6	4	0	0
4	1	6	5	0	0
5	1	9	10	5	6
6	1	3	6	5	6
7	1	3	9	0	0
8	1	6	9	0	0
9	1	14	3	0	0
10	1	14	6	0	0
11	1	14	9	0	0
12	6	14	13	0	0

Equation Types Index:
1 = Sphere Equation
2 = Distance to Vector
3 = x-x Based Slope Equation
4 = y-y Based Slope Equation
5 = z-z Based Slope Equation
6 = Minimum Z value Equation

Figure 4.29 Example Template validation for default template type 1

This list can be compared with expected equations to debug new template problems. Remember that it will not list 'post' calculation unknowns or equations only those that are solved as the list of simultaneous equations. If we compare the validation list with the template 'settings' we can identify the source of each equation. The validation of template 1, shows 12 unknowns. Looking at the conventional double wishbone suspension we can identify these, (we will ignore additional points that are post calculated);

Lower Wishbone Outer Ball Joint, X, Y and Z co-ordinates, (x3, y3, z3)

Upper Wishbone Outer Ball Joint, X, Y and Z co-ordinates, (x6, y6, z6)

Steering Arm Outer Ball Joint, X, Y and Z co-ordinates, (x9, y9, z9)

Wheel Centre Point, X, Y and Z co-ordinates, (x14, y14, z14)

These 12 unknowns are illustrated on the image below.

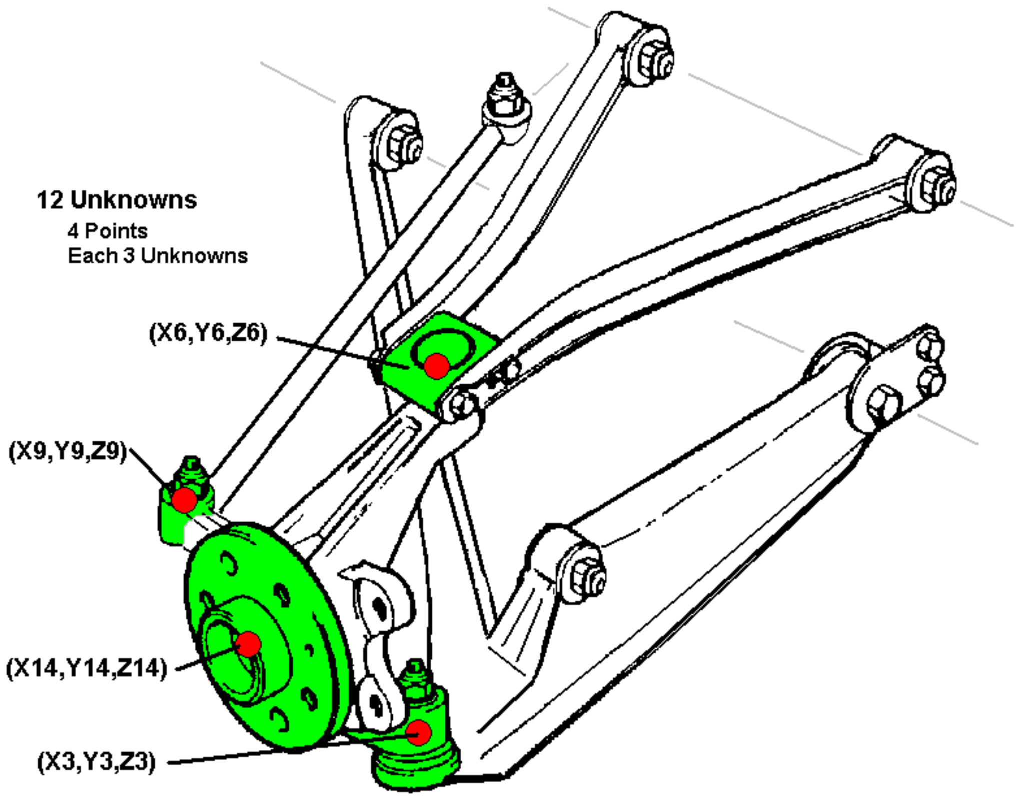
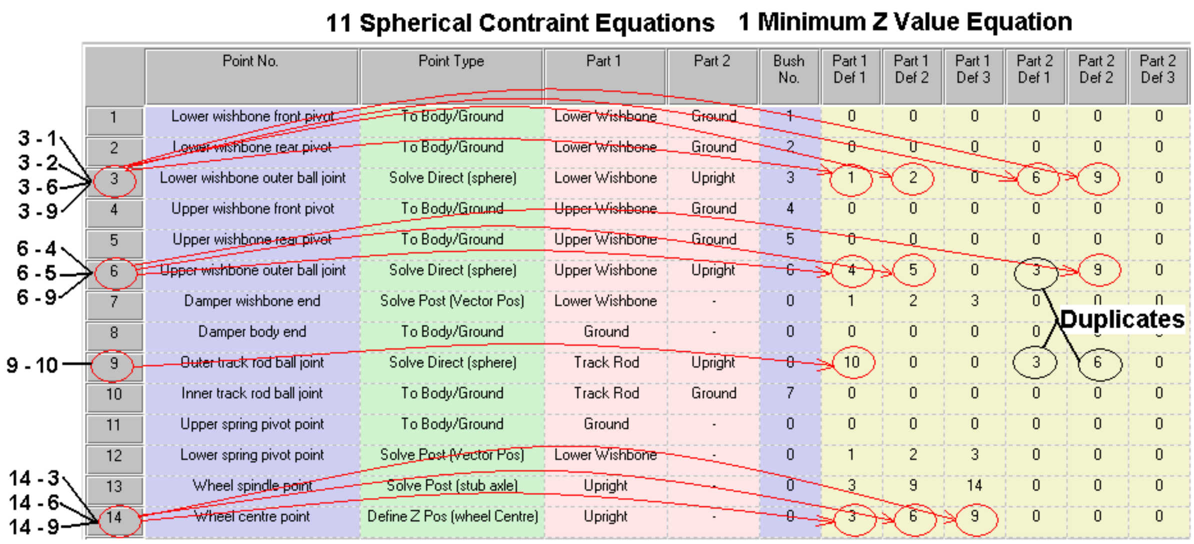


Figure 4.30 Default Template Type 1, 12 unknowns indicated

If we now look at the data in the 'Settings' display we can identify the origin of the 12 equations used to solve for the 12 unknowns.



	Point No.	Point Type	Part 1	Part 2	Bush No.	Part 1 Def 1	Part 1 Def 2	Part 1 Def 3	Part 2 Def 1	Part 2 Def 2	Part 2 Def 3
1	Lower wishbone front pivot	To Body/Ground	Lower Wishbone	Ground	1	0	0	0	0	0	0
2	Lower wishbone rear pivot	To Body/Ground	Lower Wishbone	Ground	2	0	0	0	0	0	0
3	Lower wishbone outer ball joint	Solve Direct (sphere)	Lower Wishbone	Upright	3	1	2	0	6	9	0
4	Upper wishbone front pivot	To Body/Ground	Upper Wishbone	Ground	4	0	0	0	0	0	0
5	Upper wishbone rear pivot	To Body/Ground	Upper Wishbone	Ground	5	0	0	0	0	0	0
6	Upper wishbone outer ball joint	Solve Direct (sphere)	Upper Wishbone	Upright	6	4	5	0	3	9	0
7	Damper wishbone end	Solve Post (Vector Pos)	Lower Wishbone	-	0	1	2	3	0	0	0
8	Damper body end	To Body/Ground	Ground	-	0	0	0	0	0	[illegible]	[illegible]
9	Outer track rod ball joint	Solve Direct (sphere)	Track Rod	Upright	8	10	0	0	3	6	0
10	Inner track rod ball joint	To Body/Ground	Track Rod	Ground	7	0	0	0	0	0	0
11	Upper spring pivot point	To Body/Ground	Ground	-	0	0	0	0	0	0	0
12	Lower spring pivot point	Solve Post (Vector Pos)	Lower Wishbone	-	0	1	2	3	0	0	0
13	Wheel spindle point	Solve Post (stub axle)	Upright	-	0	3	9	14	0	0	0
14	Wheel centre point	Define Z Pos (wheel Centre)	Upright	-	0	3	6	9	0	0	0

Figure 4.31 Screen shot of settings for default template type 1

Compare the paired numbers with those given in the validation list, they will match. Minimum Z equation added automatically for wheel centre point. Three duplicate spherical constraints ignored by the solver.

4.11 Exercise 1 – Modifying an Existing Template

As a simple exercise in modifying a template we will take default template 1 and change the component that the spring/damper is attached too. To validate that we have changed the connection point of the spring we will use the compliant analysis force display.

Open a new front-end only model and use default template type 1. Turn the compliance 'on' and note the calculated force display, (see front view screen shot below).

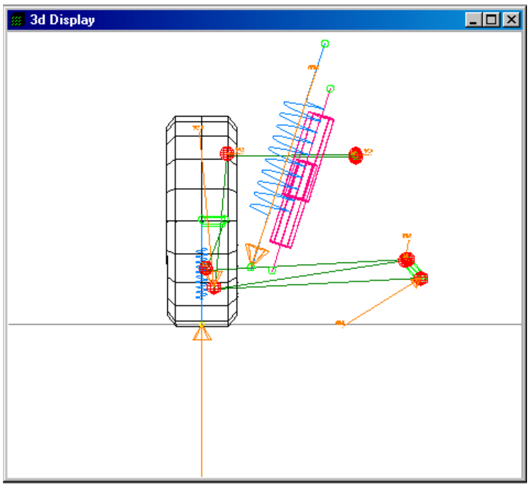


Figure 4.32 Standard templates calculated forces.

Now modify the points 'Damper wishbone end' and 'lower spring pivot point' such that they are attached to the upright rather than the lower wishbone.

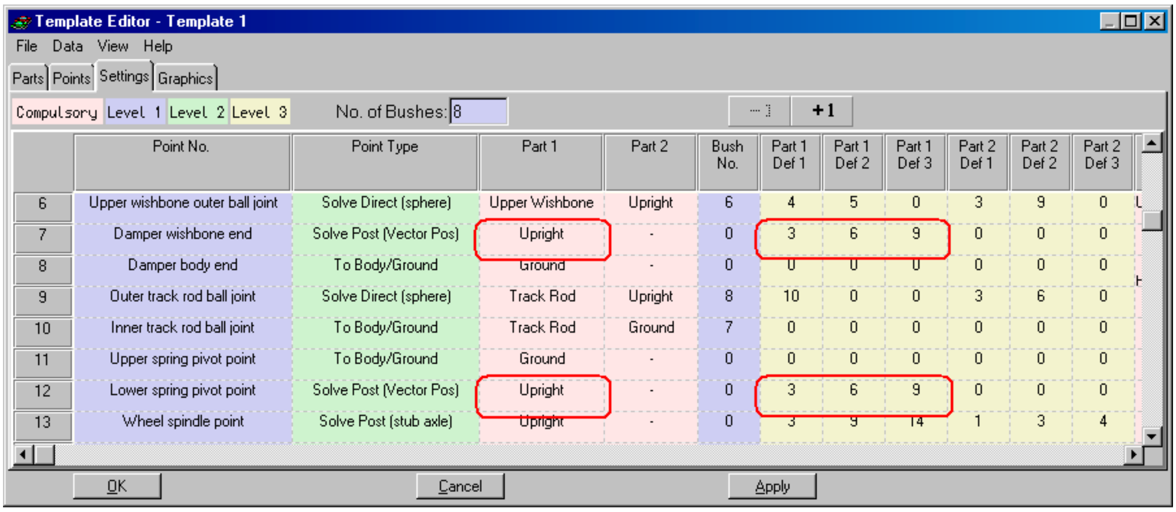
Remember to set any required changes to the new points in columns 6 to 11. For the purpose of this exercise do not use the 'auto-fill' routines we will cover these later.

Make the require template changes and confirm the difference by checking for a change in the calculated forces.

Hint: Use the 'apply' button to apply the changes to the current model. Otherwise you will need to use the *File / New* option to pick up the changes to the template.

4.12 Exercise 1 – Solution

You should have made changes to the 'Part 1' settings for points 7 and 12. You will also have needed to change columns 6, 7 and 8 for both of them to reference three points, (other than themselves), on the upright. Could pick any three from points 3, 6, 9 or 14.



	Point No.	Point Type	Part 1	Part 2	Bush No.	Part 1 Def 1	Part 1 Def 2	Part 1 Def 3	Part 2 Def 1	Part 2 Def 2	Part 2 Def 3
6	Upper wishbone outer ball joint	Solve Direct (sphere)	Upper Wishbone	Upright	6	4	5	0	3	9	0
7	Damper wishbone end	Solve Post (Vector Pos)	Upright	-	0	3	6	9	0	0	0
8	Damper body end	To Body/Ground	Ground	-	0	0	0	0	0	0	0
9	Outer track rod ball joint	Solve Direct (sphere)	Track Rod	Upright	8	10	0	0	3	6	0
10	Inner track rod ball joint	To Body/Ground	Track Rod	Ground	7	0	0	0	0	0	0
11	Upper spring pivot point	To Body/Ground	Ground	-	0	0	0	0	0	0	0
12	Lower spring pivot point	Solve Post (Vector Pos)	Upright	-	0	3	6	9	0	0	0
13	Wheel spindle point	Solve Post (stub axle)	Upright	-	0	3	9	14	1	3	4

Figure 4.33 Modified template 1, Changes ringed.

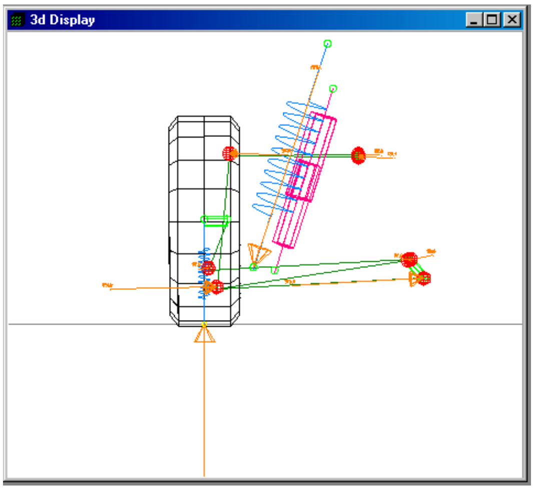


Figure 4.34 Revised model illustrating the change in calculated forces.

If this was required to be a permanent change we would probably change the default x,y,z co-ordinates for points 7 and 12 to make them more realistic and change some of the point descriptions to be inline with our new template.

Unless we save this modified template, our changes will be lost when we close the application. In this instance we do not want to retain the changes to this default template. In the next section we will look at creating and saving new templates such that they are available for future use.

5 Tutorial 4 - User Templates (2)

5.1 Overview

This chapter we extend the previous chapters description of the data structure for templates, by creating a new template and making this available for subsequent analysis runs.

This chapter contains the following sections:

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5.2 Template Sources

Each template is stored in a particular template 'slot', (normally referred to as template type). So the conventional double wishbone suspension with damper attached to the lower wishbone is stored in slot 1 by the hard coded default templates.

Each saved model data file references the appropriate template slot via this number. The data file itself does not necessarily have a copy of the template structure only the slot number, (you can optionally save the template(s) with the data file *SetUp / Include User Templates in Data Files)*. Thus it is important to remember that if you make a change to a template the safest approach is to save it to a new 'free' slot number.

Templates are stored at four levels. Each subsequent level can overwrite the current slot template with a new template, if it defines a template slot number that is already defined by a previous level.

The first template source level is the 'hard-coded defaults'. These are built into the program at compile time and thus whilst they can be modified or over-written by subsequent levels, (as identified above), they cannot be directly changed by the user. The 'hard-coded defaults' at release version 4.03c are:-

Slot 1 Double Wishbone, damper to lower wishbone

Slot 2 Lower H frame, single upper link

Slot 3 Steerable Macpherson Strut

Slot 4 Non-Steerable Macph Strut, two lower ball joints, tie to ground

Slot 5 5-Link Rigid Axle (Panhard Rod)

Slot 6 Double Wishbone, damper to upper wishbone

Slot 7 Non/Steerable Macpherson Strut, steering arm to lower wishbone

Slot 8 4-Link Rigid Axle (Panhard Rod)

Slot 9 4-Link Rigid Axle (Twin Upper)

Slot 10 Trailing Arm with Two Cross Car Links

Slot 11 Semi/Trailing Arm

Slot 12 Steerable Twin Parallel Wishbones with Steering Knuckle

Slot 14 Double Wishbone with Push Rod Suspension

Slot 15 Double Wishbone, Rocker Arm Damper

Slot 16 Non/Steerable Lower 'A' Arm with Toe Link

Slot 17 Double Wishbone, Push Rod, Mono-shock

Slot 18 Double Wishbone, Upper Toe Link, Drop 'S' Link

Slot 19 Hinged Trailing Arm, Twin lower Link

Slot 20 Double Wishbone, Twin Outer Ball Joints

Slot 21 5-Link Rigid Axle (Watts Linkage)

Slot 22 Double Wishbone, Twin Outer Ball Joints, Spring Front

Slot 23 Double Wishbone, Anti-Roll Bar

Slot 24 Steerable Macpherson Stut, Twin Outer Ball Joints

Slot 25 Double Wishbone, Twin Lower Outer Ball Joints

Slot 26 Double Wishbone, Damper to Lower Wishbone, Compliant Rack

Slot 27 Steerable Macpherson Strut, Twin Lower Link

Slot 28 4-Link Rear, Transverse Control Link

Slot 29 Twist Beam – Twin Wheel

The second template source level is the ‘User defined Templates’. The user defined templates are stored in a specific file, (_user_templates.dat), in the same folder as the software is installed in. On program start-up this file is checked for and if found any user defined template information stored in it is loaded into the application. As discussed above if the same slot number as one of the ‘hard coded defaults’ is used the user template will overwrite the hard coded default. This file will only exist if the user has previously selected to save a template from within the template editor.

The third template source level is the ‘Custom Templates’. These are stored by the user into a user defined file, (disc location, folder location and name). They are only loaded from the file into the relevant template slots when the users scans for and reads the required file. Thus custom templates can be stored in any number of separate files, these files can be passed between users or stored on a central repository. As identified previously slot numbers referenced by the custom templates will overwrite any existing default or user template definition. If you use custom templates the template properties must be loaded before you load a data file that references this custom template.

The fourth template source is from within a loaded data file. If the template has been saved with the data file, this will be loaded into its respective slot when the data file is opened. Note that these changes to the template will continue to reside in the loaded slot until it in turn is overwritten, the program is restarted or one of the *File / Re-Read* menu options is run.

Slot No.	1 - Hard-coded defaults	2 - User Defined Templates	3 – Custom Templates	4-Data Files
1	Double Wishbone, damper to lower wishbone.			
2	H-frame Lower, single upper link.			
3	Steerable Macpherson Strut.			
4	Non-Steerable Macpherson Strut, twin lower link.			
5	5-Link Rigid Axle (Panhard Rod)			
6	Double Wishbone, damper to upper wishbone.			
7	Non-Steerable Macph strut, toe link to wishbone.	Would overwrite hard coded	Would overwrite defined	
8	4-Link Rigid Axle (Panhard Rod)			
9	4-link Rigid Axle (Twin Upper)		Would overwrite hard coded	
10	Trailing Arm, upper and lower rear links.			
11	Semi Trailing Arm.			
12	Steerable Twin Parallel Wishbones and knuckle.			
13		Free slot to use		
14	Double Wishbone, Push Rod to damper.			
15	Double Wishbone, Rocker arm damper.			
16	Non Steerable lower A with toe link.			
17	Double Wishbone, pushrod mono-shock.			
18	Double Wishbone, Upper toe link + S link.			
19	Hinged Trailing Arm, Twin Lower Link.			
20	Double Wishbone, twin outer ball joints.			
21	5-Link Rigid Axle (Watts Linkage)			
22	Double Wishbone, twin outer ball joints Spring front.			
23	Double Wishbone, twin outer ball anti roll bar.			
24	Steerable Macpherson Strut, twin outer ball joints.			
25	Double Wishbone, twin lower outer ball joints.			
26	Double Wishbone, damper to lower, comp rack.			
27	Steerable Macpherson Strut, Twin lower Link			
28	4-Link Rear, Transverse Control Link			
29	Twist Beam - Twin Wheel			
30….		Free slot to use		
….		Free slot to use		
…50		Free slot to use		

Figure 5.1 Schematic of Template Levels and Slot Nos.

The schematic above illustrates the templates levels. ‘Cyan’ shows the ‘free’ slots where new ‘user’ or ‘custom’ templates could be stored. The ‘Red’ boxes indicate example slots for ‘user’ and ‘custom’ templates that would overwrite the ‘Hard-coded’ defaults. The ‘mauve’ box indicates an example ‘custom’ template slot that would have overwritten the ‘Red’ box ‘user’ template.

5.3 Storing and Saving Templates

As identified previously the user can save templates either as ‘User’ templates, ‘Custom’ templates or within the data file. Saving templates involves writing the specified template slot number to a file.

The ‘user’ templates file is a predefined file name and location, whilst the ‘custom’ templates are saved to user specified files. ‘Custom’ templates can be saved either singularly or as a complete capture of all currently defined templates including unaltered ‘default’ templates.

5.4 Saving to the User Templates File

A templates is saved to the user templates file from the template editor. Open the template editor, *File / Edit Templates*. You would then display the required template by selecting the ‘+’ and ‘-‘ icons. Once displayed select the menu *Data / Save Template to User File*. You will be warned about the data change and overwrite existing users file, (if found).

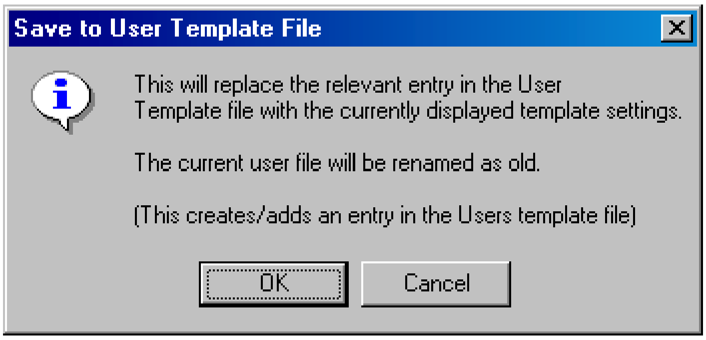


Figure 5.2 Saving current template to user template file

The user templates file, (_User_Templates.dat), will only exist if a previous template has been saved to the user templates file. If the user templates file already contains an entry for the slot number selected, this will be replaced with the current settings. If no entry exists in the User templates file for the selected slot number then this template definition will be added to the User templates file.

When adding/over writing the contents of the User templates file the existing file is renamed to _User_Templates.dat.old.

If you choose to delete the user templates file all templates revert back to the hard coded settings.

At any time during a program run you can revert back to the hard coded defaults + saved user templates by selecting the main menu item, *File / Re-Read Default +User Templates*. If the user templates has been deleted this will effectively set all template settings back to the hard-coded defaults.

5.5 Saving Custom template Files

A modified template data settings can be saved to a separate file as a 'Custom' template. On subsequent analysis runs this file would need to be re-read before this custom template can be used. From within the template editor the currently displayed template can be saved to a custom file by selecting *Data / Custom Template Save…* Confirm the information message and use the file browser to identify the required file location and name, (this could be on a remote/central server).

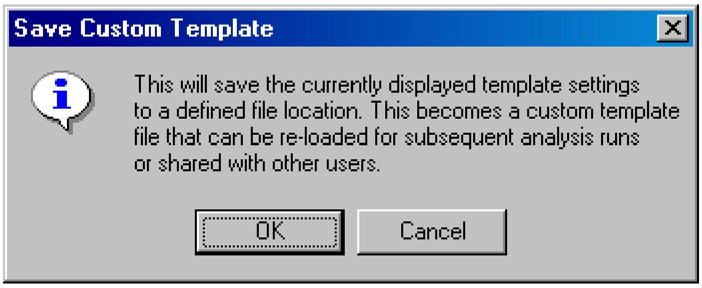


Figure 5.3 Save Custom Template file message

Templates loaded from custom files will overwrite any existing data in the specified slot number.

It is also possible to take a 'snap-shot' copy of all defined template data settings and save them to a single 'custom' templates file. From the main menu select *File / Save Custom Templates (All)*, then use the displayed file browser to locate the required file location and name.

If you require to on subsequent runs use a Custom template, these must be re-loaded as unlike 'user' templates they are not automatically loaded when starting the application. To load a 'custom' template from the main menu select *File / Add Custom Templates…* Use the displayed file browser to locate the required custom templates file.

5.6 Creating New Templates

If you need to create a new template you would normally pick a currently free 'slot' to avoid overwriting an existing template. In the template editor step through until you find a Slot identified as 'Not Defined'.

To assist in building a template that is only a slight change from an existing one you can pre-fill your new template from an existing one by using the *File / Fill current Template From /…* menu option.

We will create a new template completely from scratch via the following exercise.

5.7 Exercise 2 – Creating a New Template

As an exercise in understanding the structure of user defined templates we will create from scratch a new template for the generic five link rear suspension illustrated below.

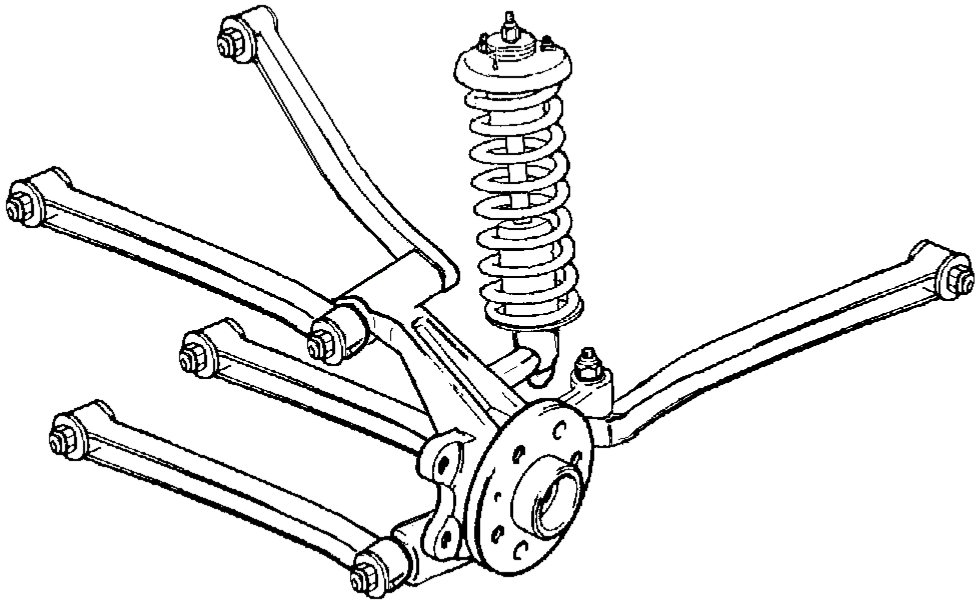


Figure 5.4 Example five link rear suspension

To create the new template, open the template editor, (*File / Edit Templates).* Find a convenient empty slot, (the screen shots shown with this examples use slot number 8). But you may wish to select a free slot such as number 30.

Step 1: Starting at the 'Parts' tab we need to;

1) Give the template a label
2) Identify the number of parts
3) Give each part a descriptive label.

Remember to make the upright the last part. No need to define a part for 'Ground'.

See overleaf for example 'Parts' data values.

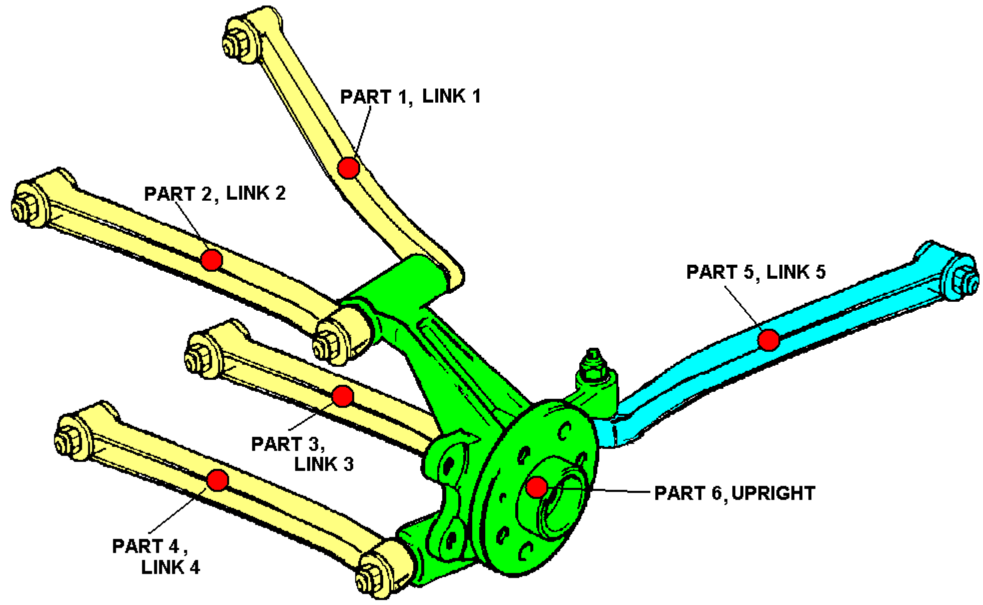


Figure 5.5 Identification of Parts, Six in Model

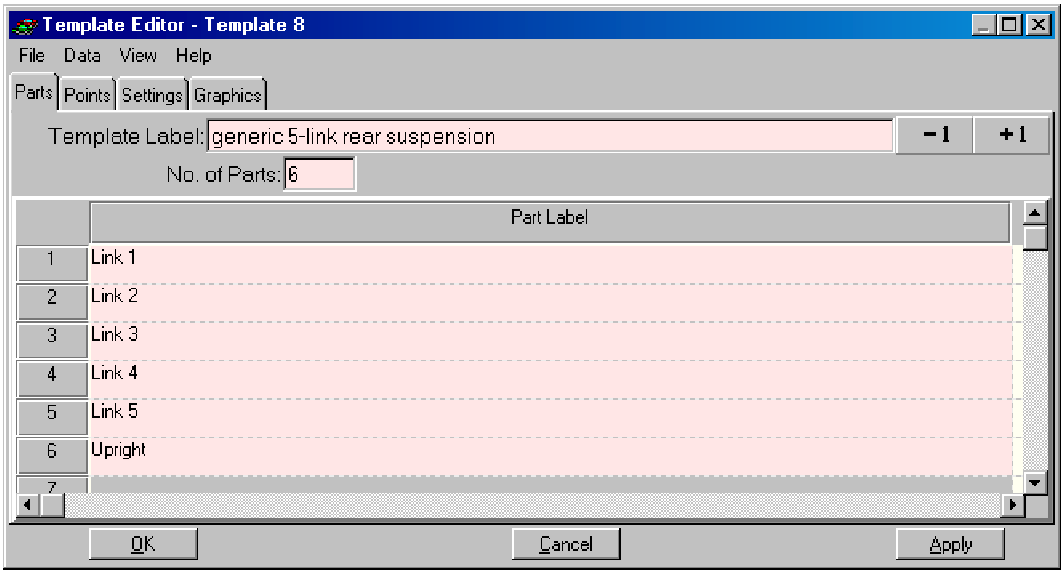


Figure 5.6 Screen shot with 'Parts' data values entered

Step 2: Change to the 'Points' tab. Now we need to;

1) Identify the number of points
2) Give each point a descriptive label
3) Supply the default x, y and z values for each point.

Remember you don't need to define a point for the tyre contact point and we can make the spring-damper attachment points as coincident.

See overleaf for example 'Points' data values.

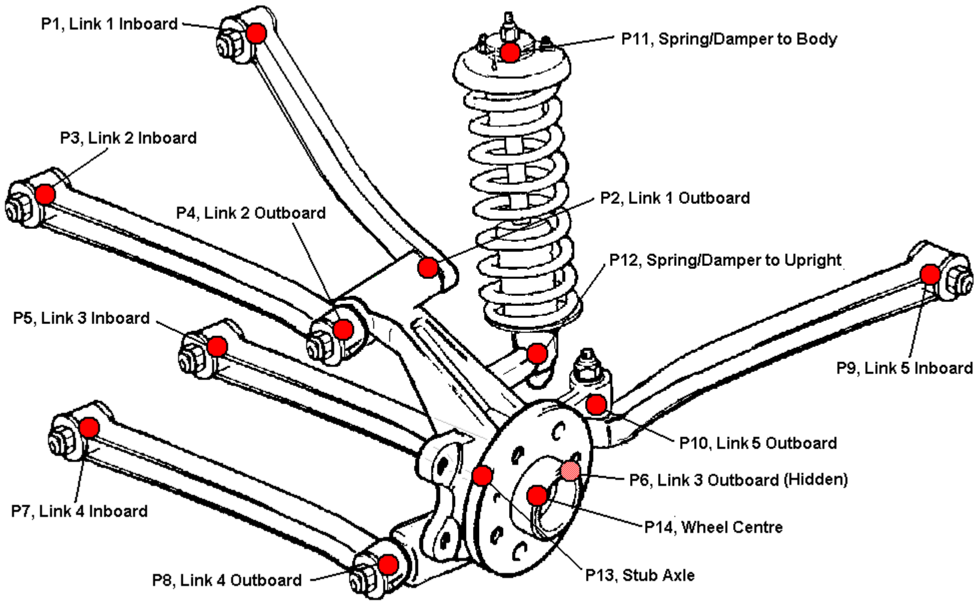
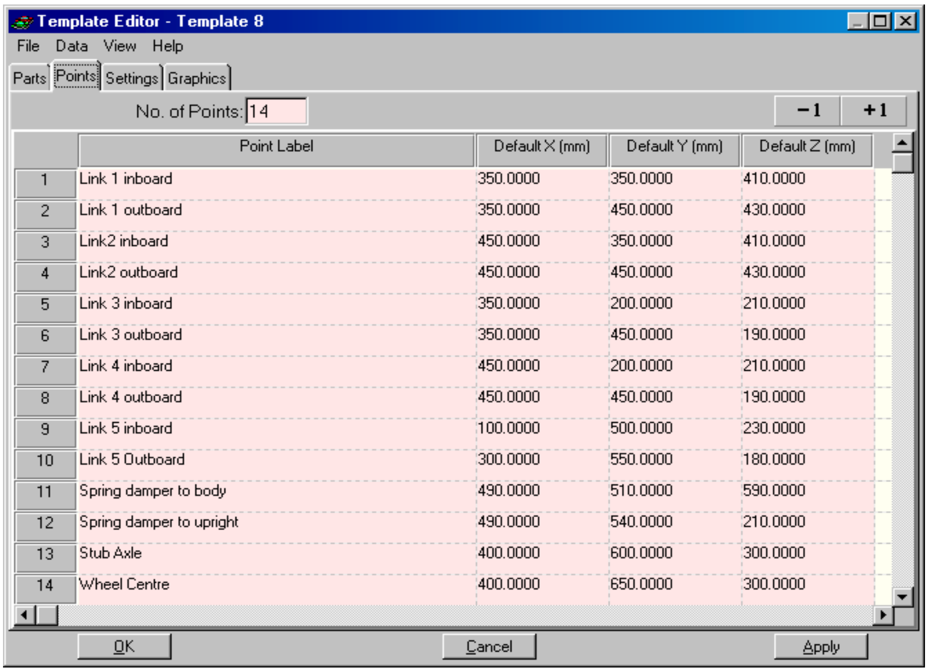


Figure 5.7 Identification of Points, 14 in Model



	Point Label	Default X (mm)	Default Y (mm)	Default Z (mm)
1	Link 1 inboard	350.0000	350.0000	410.0000
2	Link 1 outboard	350.0000	450.0000	430.0000
3	Link2 inboard	450.0000	350.0000	410.0000
4	Link2 outboard	450.0000	450.0000	430.0000
5	Link 3 inboard	350.0000	200.0000	210.0000
6	Link 3 outboard	350.0000	450.0000	190.0000
7	Link 4 inboard	450.0000	200.0000	210.0000
8	Link 4 outboard	450.0000	450.0000	190.0000
9	Link 5 inboard	100.0000	500.0000	230.0000
10	Link 5 Outboard	300.0000	550.0000	180.0000
11	Spring damper to body	490.0000	510.0000	590.0000
12	Spring damper to upright	490.0000	540.0000	210.0000
13	Stub Axle	400.0000	600.0000	300.0000
14	Wheel Centre	400.0000	650.0000	300.0000

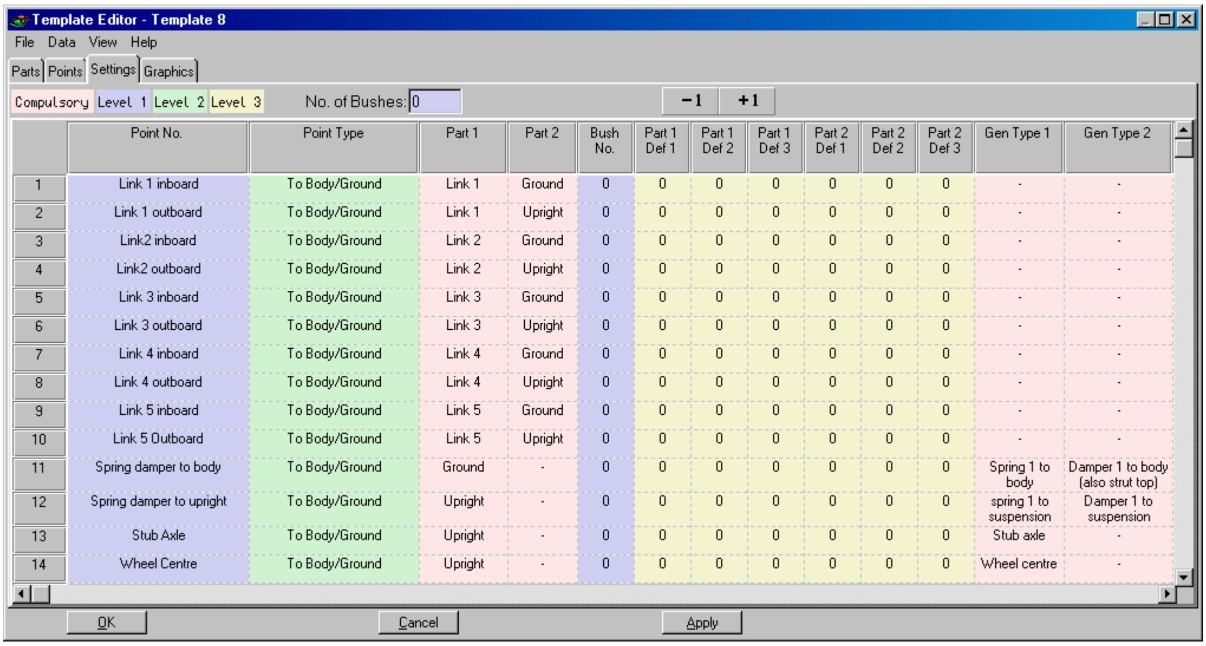
Figure 5.8 Screen shot with 'Points' data values entered

Step 3: Change to the 'Settings' tab. Now we need to;

1) Identify the 'Part 1' and 'Part 2' settings for each point.
2) Define any General types for each point.

Remember any point that is a connection between two parts, or a connection between a part and ground, requires two parts to be defined.

See overleaf for example point 'Settings'.



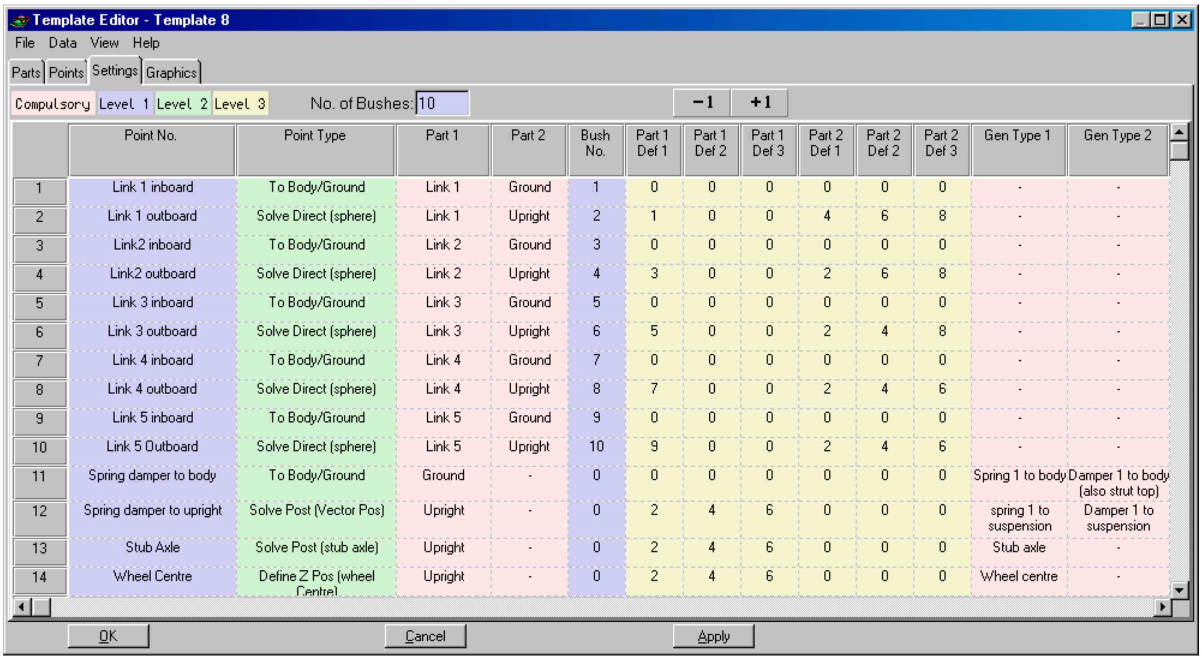
	Point No.	Point Type	Part 1	Part 2	Bush No.	Part 1 Def 1	Part 1 Def 2	Part 1 Def 3	Part 2 Def 1	Part 2 Def 2	Part 2 Def 3	Gen Type 1	Gen Type 2
1	Link 1 inboard	To Body/Ground	Link 1	Ground	0	0	0	0	0	0	0	-	-
2	Link 1 outboard	To Body/Ground	Link 1	Upright	0	0	0	0	0	0	0	-	-
3	Link2 inboard	To Body/Ground	Link 2	Ground	0	0	0	0	0	0	0	-	-
4	Link2 outboard	To Body/Ground	Link 2	Upright	0	0	0	0	0	0	0	-	-
5	Link 3 inboard	To Body/Ground	Link 3	Ground	0	0	0	0	0	0	0	-	-
6	Link 3 outboard	To Body/Ground	Link 3	Upright	0	0	0	0	0	0	0	-	-
7	Link 4 inboard	To Body/Ground	Link 4	Ground	0	0	0	0	0	0	0	-	-
8	Link 4 outboard	To Body/Ground	Link 4	Upright	0	0	0	0	0	0	0	-	-
9	Link 5 inboard	To Body/Ground	Link 5	Ground	0	0	0	0	0	0	0	-	-
10	Link 5 Outboard	To Body/Ground	Link 5	Upright	0	0	0	0	0	0	0	-	-
11	Spring damper to body	To Body/Ground	Ground	-	0	0	0	0	0	0	0	Spring 1 to body	Damper 1 to body (also strut top)
12	Spring damper to upright	To Body/Ground	Upright	-	0	0	0	0	0	0	0	spring 1 to suspension	Damper 1 to suspension
13	Stub Axle	To Body/Ground	Upright	-	0	0	0	0	0	0	0	Stub axle	-
14	Wheel Centre	To Body/Ground	Upright	-	0	0	0	0	0	0	0	Wheel centre	-

Figure 5.9 Initial Settings for Part 1, Part 2 and Gen Type values.

We can now use the auto-fill routines to complete the other required data values. Alternatively you may want to try completing them by hand and then check them with the auto-fill settings. To use the auto-fill select *Data / Test Auto Fill* and if you then select *Level 1* you can note the changes level by level.

Using the *Test* auto-fill routines allows you to visual review the differences and accept or reject the changes.

Repeat the Test Auto-fills for Levels 2 and 3 such that you have a fully defined template, (check with results on following page).



	Point No.	Point Type	Part 1	Part 2	Bush No.	Part 1 Def 1	Part 1 Def 2	Part 1 Def 3	Part 2 Def 1	Part 2 Def 2	Part 2 Def 3	Gen Type 1	Gen Type 2
1	Link 1 inboard	To Body/Ground	Link 1	Ground	1	0	0	0	0	0	0	-	-
2	Link 1 outboard	Solve Direct (sphere)	Link 1	Upright	2	1	0	0	4	6	8	-	-
3	Link2 inboard	To Body/Ground	Link 2	Ground	3	0	0	0	0	0	0	-	-
4	Link2 outboard	Solve Direct (sphere)	Link 2	Upright	4	3	0	0	2	6	8	-	-
5	Link 3 inboard	To Body/Ground	Link 3	Ground	5	0	0	0	0	0	0	-	-
6	Link 3 outboard	Solve Direct (sphere)	Link 3	Upright	6	5	0	0	2	4	8	-	-
7	Link 4 inboard	To Body/Ground	Link 4	Ground	7	0	0	0	0	0	0	-	-
8	Link 4 outboard	Solve Direct (sphere)	Link 4	Upright	8	7	0	0	2	4	6	-	-
9	Link 5 inboard	To Body/Ground	Link 5	Ground	9	0	0	0	0	0	0	-	-
10	Link 5 Outboard	Solve Direct (sphere)	Link 5	Upright	10	9	0	0	2	4	6	-	-
11	Spring damper to body	To Body/Ground	Ground	-	0	0	0	0	0	0	0	Spring 1 to body	Damper 1 to body (also strut top)
12	Spring damper to upright	Solve Post (Vector Pos)	Upright	-	0	2	4	6	0	0	0	spring 1 to suspension	Damper 1 to suspension
13	Stub Axle	Solve Post (stub axle)	Upright	-	0	2	4	6	0	0	0	Stub axle	-
14	Wheel Centre	Define Z Pos (wheel Centre)	Upright	-	0	2	4	6	0	0	0	Wheel centre	-

Figure 5.10 Data Fill Complete to Level 3 using auto-fill routines.

We could now use this template to create a new model using the *File / New* option in the normal way, (remember that because we have not identified a input steering point it will only appear in the *Rear* suspension list).

If we did use this template in its current form, because we haven't associated any graphics with this template, we would only see the hard points, tyre graphic and spring/damper graphic. We need to define template graphics.

Before we cover template graphics, save the currently defined values for our new template to a user file. From the template editor select, *Data / Custom Template Save*. Confirm the 'save' event and locate the required file folder and name using the standard browser

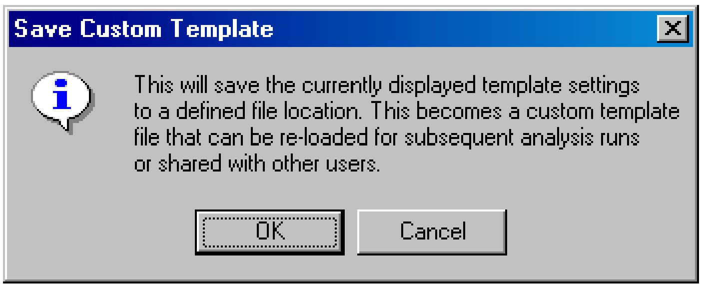


Figure 5.11 Save custom template message.

5.8 Template Graphics

When a template is used within a model, each has its own associated 3D graphics. Apart from the generic graphics items such as the wheel/tyre, spring and damper the remainder such as links and wishbones are specified by the fourth data set of the template specification 'Graphics'.

Currently nine basic graphics primitives are available, Line, Cylinder, Circle, Sphere, Facet, Plane, Distance, Component and Angle. Each of these graphical types is drawn based on hard point co-ordinates. Each primitive type has its own set of property values and some may be defined in a number of ways. A full list of the current options is given below, with further details of some specific examples following this list.

Line Graphic Classes:

Pnt-Pnt Line: Adds a new Line graphical element to the selected ends' template. Two hard point picks are required, points need not be on the same part.

Pnt-Vector Line: Adds a new Line graphical element to the selected ends' template. Three hard point picks are required, a line is drawn through the first point who's direction is set by the vector defined by the second and third picks, points need not be on the same part. The first and second picks can be the same point. The line is drawn to a global clipped length.

Pnt-Xvector Line: Adds a new Line graphical element to the selected ends' template. One hard point pick is required, a line is drawn through the picked point in the global X axis direction. The line is drawn to a global clipped length.

Pnt-Yvector Line: Adds a new Line graphical element to the selected ends' template. One hard point pick is required, a line is drawn through the picked point in the global Y axis direction. The line is drawn to a global clipped length.

Pnt-Zvector Line: Adds a new Line graphical element to the selected ends' template. One hard point pick is required, a line is drawn through the picked point in the global Z axis direction. The line is drawn to a global clipped length.

Pnt-Plane-Norm: Adds a new Line graphical element to the selected ends' template. A line is drawn through the selected point in a direction normal to the selected plane. The plane is identified by three point picks. The line is drawn to a global clipped length.

Pnt-UserVector: Adds a new Line graphical element to the selected ends' template. A line is drawn through the selected point in a direction defined by a user vector. The line is drawn to a global clipped length.

Cylinder Graphic Classes:

Pivot: Adds a new Pivot graphical element to the selected ends' template. Two hard point picks are required, both points need not be on the same part.

Tube: Adds a new Tube graphical element to the selected ends' template. Two hard point picks are required, both points need not be on the same part.

Vector-Radius-Length: Adds a new cylinder graphical element to the selected ends' template. Drawn through the selected point in a direction defined by the second and third point picks. The radius and length of the cylinder are defined directly.

Circle Graphic Class:

Pnt-Pnt-Pnt: Adds a new Circle graphical element to the selected ends' template. Three hard point picks are required through which is drawn a circle, both the circle centre and radius are calculated and displayed as part of the graphical display.

Cntr-Rad-Norm: Adds a new Circle graphical element to the selected ends' template. Three hard point picks are required. The circle is drawn centered at the first point of a defined radius and who's normal is defined by the second and third picks. The first and second picks can be the same point.

Cntr-Pnt-Plane: Adds a new Circle graphical element to the selected ends' template. Three hard point picks are required. The circle is drawn centered at the first point and is drawn through the second point, (i.e. defines the radius), in a plane that contains the third picked point. All picked points must be different.

Pnt-Normal: Adds a new Circle graphical element to the selected ends' template. Three hard point picks are required. The circle is drawn through the first point about the defined normal vector. All picked points must be different. The derived circle centre and radius is drawn as part of the graphical element display.

Sphere Graphic Class:

Pnt-Pnt Radius: Adds a new Sphere graphical element to the selected ends' template. Two unique hard point picks are required. The sphere is centered at the first pick and the radius is set by the second pick.

Pnt Radius: Adds a new Sphere graphical element to the selected ends' template. One hard point pick is required. The sphere is centered at the pick and given the radius specified by the user.

Pnt-Pnt Dia: Adds a new Sphere graphical element to the selected ends' template. Two unique hard point picks are required. The sphere is centered at the mid point of the two picks, the radius being half the distance between them.

Pnt-Pnt-Pnt-Pnt: Adds a new Sphere graphical element to the selected ends' template. Four unique hard point picks are required. The sphere is drawn through the selected four points. Four points will define a unique sphere who's calculated radius and centre position is identified as part of the drawn graphical element.

Facet Graphic Class:

Pnt-Pnt-Pnt Facet: Adds a new Triangular Facet graphical element to the selected ends' template. Three hard point picks are required, points need not be on the same part.

Pnt-Pnt-Pnt-Pnt Facet: Adds a new Four noded Facet graphical element to the selected ends' template. Four unique hard point picks are required, points need not be on the same part. Whilst points need not be in a plane, any facet drawn of non-planar nodes is not fully define

Plane Graphic Class:

Pnt-Pnt-Pnt Plane: Adds a plane graphical element to the selected ends' template. Three unique hard point picks are required, points need not be on the same part. All plane elements are drawn clipped to a global value, (which the user can edit).

Pnt-X-Y Plane: Adds an X-Y plane graphical element to the selected ends' template drawn through the selected pick. All plane elements are drawn clipped to a global value, (which the user can edit).

Pnt-X-Z Plane: Adds an X-Z plane graphical element to the selected ends' template drawn through the selected pick. All plane elements are drawn clipped to a global value, (which the user can edit).

Pnt-Y-Z Plane: Adds an Y-Z plane graphical element to the selected ends' template drawn through the selected pick. All plane elements are drawn clipped to a global value, (which the user can edit).

Pnt-UserVector Plane: Adds an plane graphical element to the selected ends' template drawn through the selected pick. The orientation of the plane is controlled by two user defined vectors. All plane elements are drawn clipped to a global value, (which the user can edit).

Distance Graphic Class:

Pnt-Pnt Dist: Adds a point to point distance graphical element to the selected ends' template. Any two hard point picks are required, both points must be on the same suspension corner. The display shows the total distance between the two points.

Pnt-Line Dist: Adds a point to line distance graphical element to the selected ends' template. Any three hard point picks are required, all points must be on the same suspension corner. The last two picks define the required line. The display shows the total perpendicular distance between the point and the line.

Line-Line Dist: Adds a minimum distance between two lines graphical element to the selected ends' template. Any four hard point picks are required, all points must be on the same suspension corner. The first two picks define one line whilst the last two picks define the other required line. The display shows the minimum normal distance between the two lines as a total distance.

Pnt-Plane Dist: Adds a points' distance from a plane as a graphical element to the selected ends' template. Any four hard point picks are required, all points must be on the same suspension corner. The first point is the required point whilst the last three picks define the required plane. The display shows the normal distance between the point and the plane as a total distance.

Component Graphic Class:

Pnt-Pnt Comps: Adds a point to point distance graphical element to the selected ends' template. Any two hard point picks are required, both points must be on the same suspension corner. The display shows the distance between the two points in its x, y and z components.

Pnt-Line Comps: Adds a point to line distance graphical element to the selected ends' template. Any three hard point picks are required, all points must be on the same suspension corner. The last two picks define the required line. The display shows the perpendicular distance between the point and the line in its x, y and z components.

Line-Line Comps: Adds a minimum distance between two lines graphical element to the selected ends' template. Any four hard point picks are required, all points must be on the same suspension corner. The first two picks define one line whilst the last two picks define the other required line. The display shows the minimum normal distance between the two lines in its x, y and z components.

Pnt-Plane Comps: Adds a points' distance from a plane as a graphical element to the selected ends' template. Any four hard point picks are required, all points must be on the same suspension corner. The first point is the required point whilst the last three picks define the required plane. The display shows the normal distance between the point and the plane in its x, y and z components.

Angle Graphic Class:

Pnt-Pnt-Pnt Angle: Adds an angle between three points graphical element to the selected ends' template. Any three hard point picks are required, all points must be on the same suspension corner. The middle picks is the point for which the angle is given. The display shows the angle created by the three point picks in degrees.

'Line' Graphic:

This is a simple line joining two hard points. It could be representing a simple link or be part of a wishbone, the graphics of which are built up using a number of 'lines'. The properties of a 'Line' are;

Point 1 Hard point at start of line, (pick from list).

Point 2 Hard point at end of line, (pick from list).

Position 1	Sets association with either first or second part, (if applicable).
Position 2	Sets association with either first or second part, (if applicable).
Property 1	Offset in Global 'x' from Point 1 x-value
Property 2	Offset in Global 'y' from Point 1 y-value
Property 3	Offset in Global 'z' from Point 1 z-value
Property 4	Offset in Global 'x' from Point 2 x-value
Property 5	Offset in Global 'y' from Point 2 y-value
Property 6	Offset in Global 'z' from Point 2 z-value
Colour	Optional colour setting, (numerical 1-n).

The 'position' settings are used to show compliance deflections. A hard point that is associated with two parts, (by virtue of being the connection between them), can have in compliance solution mode two positions. The ability to pick either the first or second parts allows a visual representation of deflection of a bush by the separation of two graphics points.

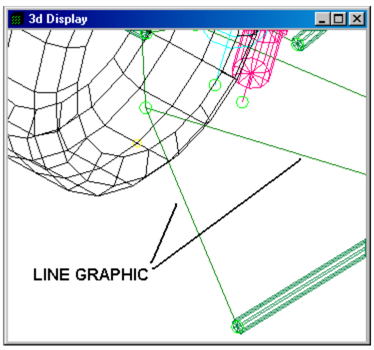


Figure 5.12 Examples of 'Line' graphics

‘Cylinder - Pivot’ Graphic:

This is a simple cylinder joining two hard points. Normally used to indicate a pivot axis, (also added automatically joining the wheel centre and the spindle point). The properties of a ‘Pivot’ are;

Point 1	Hard point at start of line, (pick from list).
Point 2	Hard point at end of line, (pick from list).
Position 1	Sets association with either first or second part, (if applicable).
Position 2	Sets association with either first or second part, (if applicable).
Property 1	Offset in Global ‘x’ from Point 1 x-value
Property 2	Offset in Global ‘y’ from Point 1 y-value
Property 3	Offset in Global ‘z’ from Point 1 z-value
Property 4	Offset in Global ‘x’ from Point 2 x-value
Property 5	Offset in Global ‘y’ from Point 2 y-value
Property 6	Offset in Global ‘z’ from Point 2 z-value
Colour	Optional colour setting, (numerical 1-n).

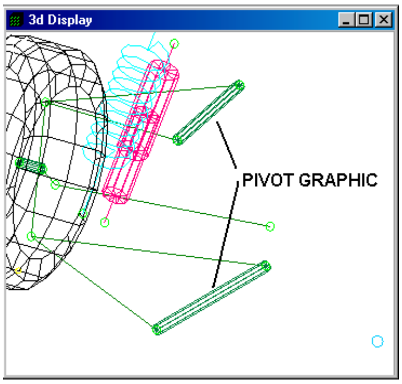


Figure 5.13 Examples of ‘Pivot’ Graphics

‘Cylinder - Tube’ Graphic:

This is a tube joining two hard points. Normally used to indicate a bar or tubular link. The difference between this and the ‘Pivot’ graphic is that the properties of the tube allow you to control the diameter and the axial offsets from the ends. The properties of a ‘Tube’ are;

Point 1	Hard point at start of line, (pick from list).
Point 2	Hard point at end of line, (pick from list).
Position 1	Sets association with either first or second part, (if applicable).
Position 2	Sets association with either first or second part, (if applicable).
Property 1	Outer diameter of tube.
Property 2	Offset of tube start from point 1 position, along the tube axis.
Property 3	Offset of tube end from point 2 position, along the tube axis.
Colour	Optional colour setting, (numerical 1-n).

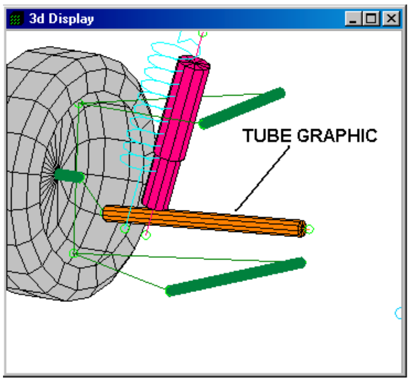


Figure 5.14 Example of 'Tube' Graphics.

'Facet - Triangular' Graphic:

This is a triangular facet joining three hard points. Normally these would be on the same body and used to indicate a face of a solid link. It will only appear as a 'filled' facet when the view fill style is set to something other than wire frame. In wire frame mode only the boundary of the facet is drawn. The properties of a 'Tri Facet' are;

Point 1	Hard point at first corner of the facet, (pick from list).
Point 2	Hard point at second corner of the facet, (pick from list).
Point 3	Hard point at third corner of the facet, (pick from list).
Position 1	Sets association with either first or second part, (if applicable).
Colour	Optional colour setting, (numerical 1-n).

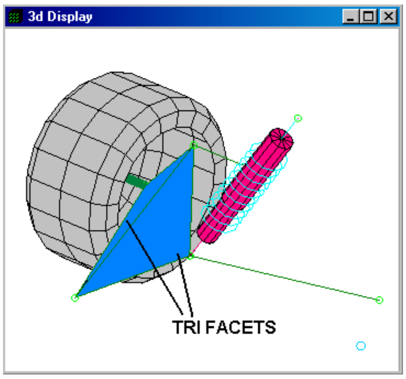


Figure 5.15 Examples of 'Tri Facets' Graphics

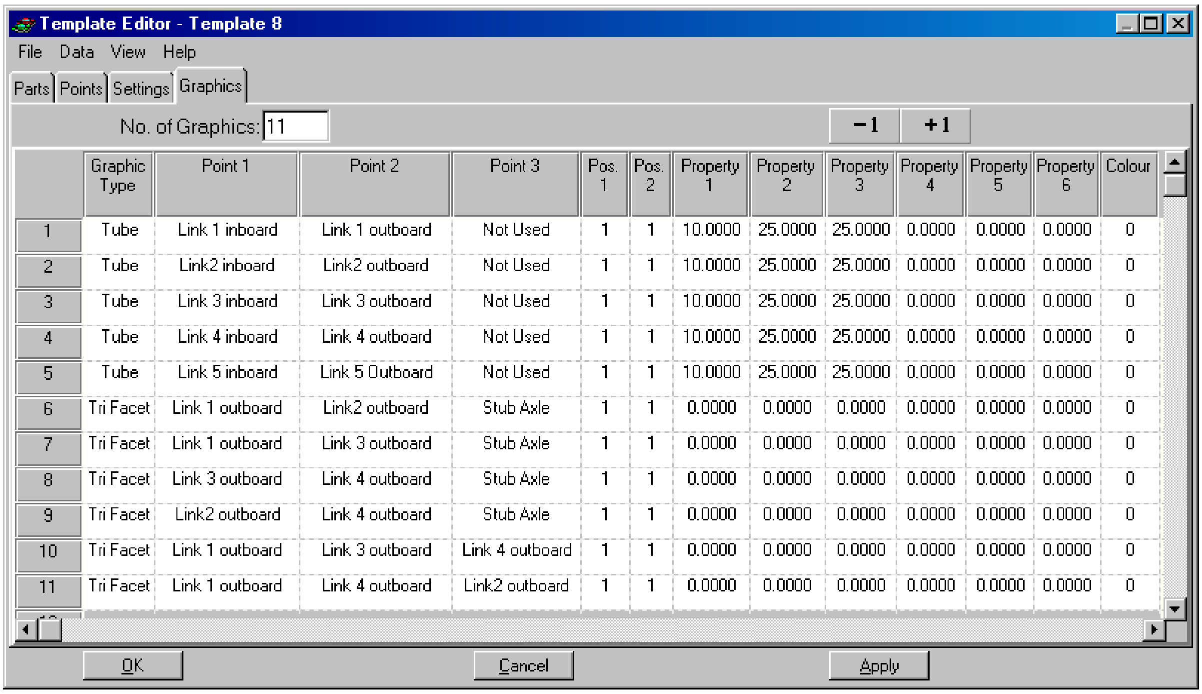
5.9 Exercise 3 – Adding Graphics to a Template

To complete the template we created earlier, we will know add some graphics to the template. Open the template editor and select the correct template and change to the ‘Graphics’ tab. Currently the number of graphical elements is set to zero.

For our template add a ‘Tube’ graphic for each of the five links, and fill the upright with 6 triangular facets. Remember we do not need to add graphics for the spring, damper, spindle axis or tyre as these are automatically drawn, using our point ‘gen type’ settings.

Remember to identify the required properties for each element, and select the relevant points.

Once complete compare to the solution overleaf and re-save the completed custom template.



	Graphic Type	Point 1	Point 2	Point 3	Pos. 1	Pos. 2	Property 1	Property 2	Property 3	Property 4	Property 5	Property 6	Colour
1	Tube	Link 1 inboard	Link 1 outboard	Not Used	1	1	10.0000	25.0000	25.0000	0.0000	0.0000	0.0000	0
2	Tube	Link2 inboard	Link2 outboard	Not Used	1	1	10.0000	25.0000	25.0000	0.0000	0.0000	0.0000	0
3	Tube	Link 3 inboard	Link 3 outboard	Not Used	1	1	10.0000	25.0000	25.0000	0.0000	0.0000	0.0000	0
4	Tube	Link 4 inboard	Link 4 outboard	Not Used	1	1	10.0000	25.0000	25.0000	0.0000	0.0000	0.0000	0
5	Tube	Link 5 inboard	Link 5 Outboard	Not Used	1	1	10.0000	25.0000	25.0000	0.0000	0.0000	0.0000	0
6	Tri Facet	Link 1 outboard	Link2 outboard	Stub Axle	1	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0
7	Tri Facet	Link 1 outboard	Link 3 outboard	Stub Axle	1	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0
8	Tri Facet	Link 3 outboard	Link 4 outboard	Stub Axle	1	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0
9	Tri Facet	Link2 outboard	Link 4 outboard	Stub Axle	1	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0
10	Tri Facet	Link 1 outboard	Link 3 outboard	Link 4 outboard	1	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0
11	Tri Facet	Link 1 outboard	Link 4 outboard	Link2 outboard	1	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0

Figure 5.16 Graphical Element Settings for Five Link Template

The screen shot above shows the settings used, values have been entered for the tube diameters and end offsets, all other property values are left as zero.

Make any alterations as necessary and re-save you're custom template.

We can now use our template to create a model.

Note: You can add extra points to your templates that are used purely for applying graphical elements too. These 'dummy' points can be included to the template in the same way as any other point. Remember, because these points do not have any influence on the kinematic mechanism, they do not need to use one of the Pre-solve options that adds to the simultaneous equations set. Since this would lead to a increase in solution time. These dummy points would normally be solved using 'Solve Post (Vector Pos)', Solve Post (Sphere) or 'Solve via Hookes joint'.

Whilst the method outlined above is perfectly valid, the addition of convenience menus under sub-menu *Graphics / Add* it is far easier to add graphical elements to templates by using the graphical interface to identify required graphics primitive and then select points directly from the 3D view.

5.10 Using the New Template

We can now use our new template. Open a new model in the normal way, *(File / New*), and select our new template from the rear suspension list.

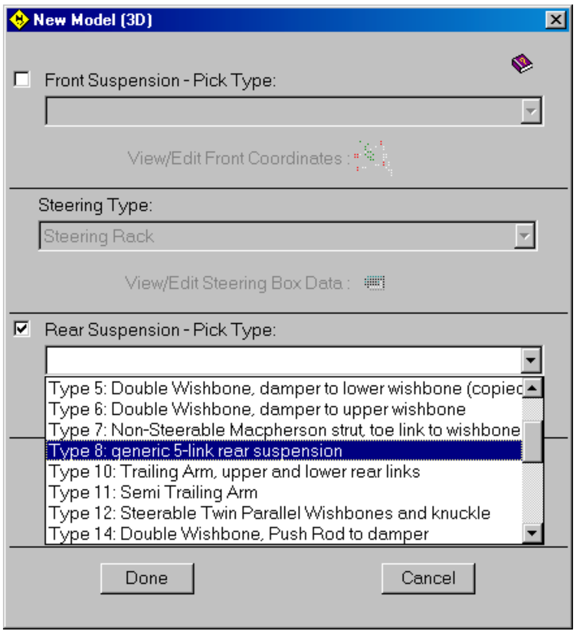


Figure 5.17 Selecting the new template.

Your new model should look like that shown below. This new template can be used as a generic template for all 5-link rear suspensions. We could with a small change to the template make it available for use as a steerable front suspension.

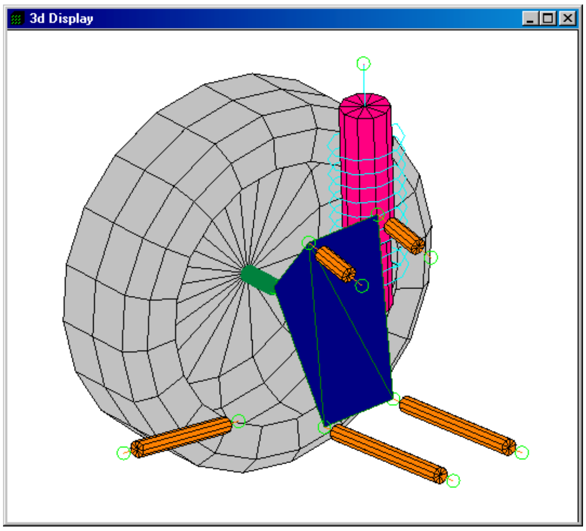


Figure 5.18 Screen Shot of Generic 5-link rear suspension template

Try modifying the template for use as a steerable front 5-link suspension.

6 Tutorial 5 - Compliant Analysis

6.1 Overview

Up to now we have only considered the pure kinematics of the suspension system. The suspension members and joints have been considered rigid and any deflection of the suspension due to force compliance has been ignored. In this chapter the compliant bush analysis features of Lotus Suspension Analysis are introduced. The suspension arms are still modelled as rigid members but the bushes joining the suspension arms are compliant.

Lotus Suspension Analysis solves for compliant bushes by superposition of kinematic and compliant bush solutions. First the kinematic solution for any particular suspension displacement is calculated then a linearised bush compliance calculation is performed at that kinematic position. The two results are then superimposed to give the final result.

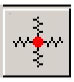
For any particular suspension displacement the effect of bush compliance is assumed to give a small perturbation of the position of the suspension members from the pure kinematic position. The system equations defining the bush compliance can then be linearised by assuming that the change in angle between suspension members due to compliance is very small and can be taken as being negligible. Doing this makes the compliance equations linear and gives direct solution that executes very quickly allowing suspension compliance results to be updated onscreen as the suspension design is manipulated with mouse and keyboard input.

This chapter contains the following sections:

- 6.1 Overview, 79
- 6.2 Enabling compliance calculation, 80
- 6.3 Editing compliant bush properties, 82
- 6.4 Adding external forces, 84
- 6.5 Displaying compliance results, 88

6.2 Enabling compliance calculation

For this tutorial we will work with a front suspension model to illustrate compliant bush analysis.

- **Use the 'File' menu and select 'New'. *Create a new default 'type 1' double wishbone front suspension model.***
- ***Turn on compliance calculation by clicking on 'Toggle 3D Compliance Solver'*** 

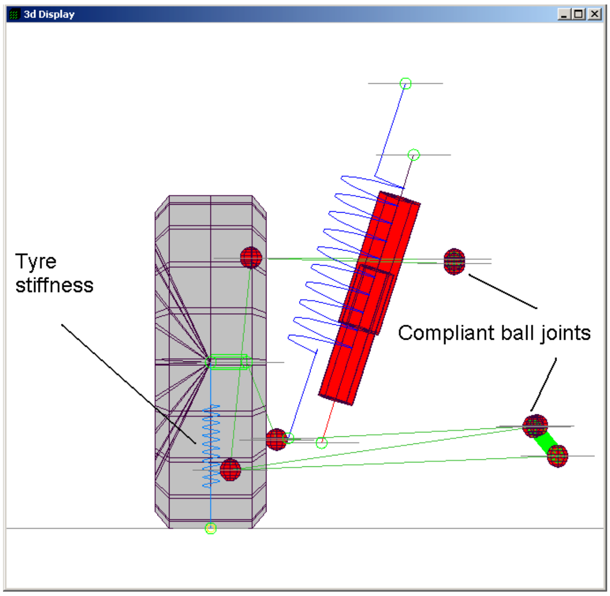


Figure 6.1 Screen shot of front suspension with compliant joints.

The ball joints are now represented by red wire frame spheres denoting that the compliant solver module is active. You will also note that the tyre stiffness has also been included in the solver and it is graphically represented by a spring connecting the stub axle to the contact patch. Although the suspension forces are calculated the joints remain rigid until their individual compliance is activated. It is now possible to load external forces onto the model and view the resulting loads on each of the points within the model. To start we will add the force due to spring compression.

- ***Load the model with the spring force by selecting 'Solve -> Suspension Spring Force'. Ensure all other forces are removed from the model by un-checking; 'External Forces', 'Suspension Roll Bar Force' and 'Rack Cross-link Forces' in the 'Solve' menu.***
- ***If not already displayed, the force vectors can be added to the graphical display from the menu by selecting 'Graphics -> Compliance visibility -> Calculated Forces'.***

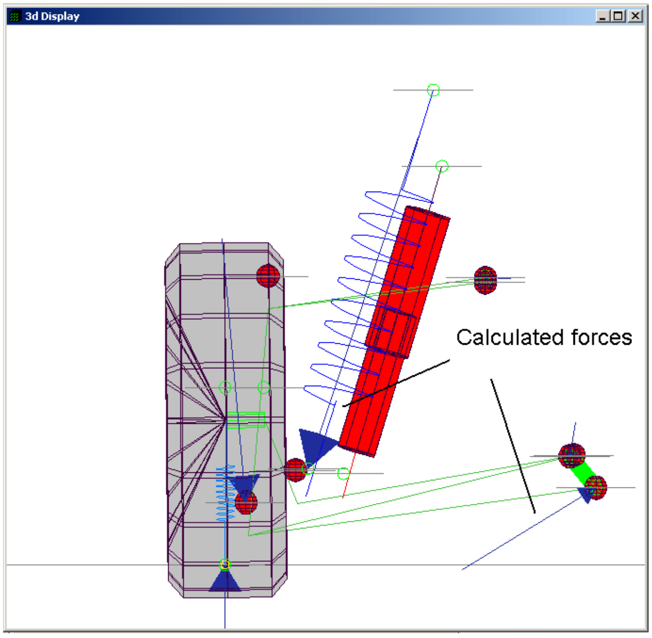
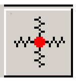


Fig 6.2 Calculated compliance forces due to spring force

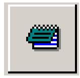
Arrows now appear on the model representing the load vector exerted by the suspension members on each ball joint/bush in the model. To compare the results of the kinematic solution to the combined kinematic and compliant model the deflection due to force/load can be magnified by selecting '*View -> Deformed Geometry Scale'* and increasing the magnification factor.

- ***Toggling between the kinematic and compliant model using the 'Toggle 3D compliance tool'***  ***now shows a clear difference between the two models due to deflection of the tire.***

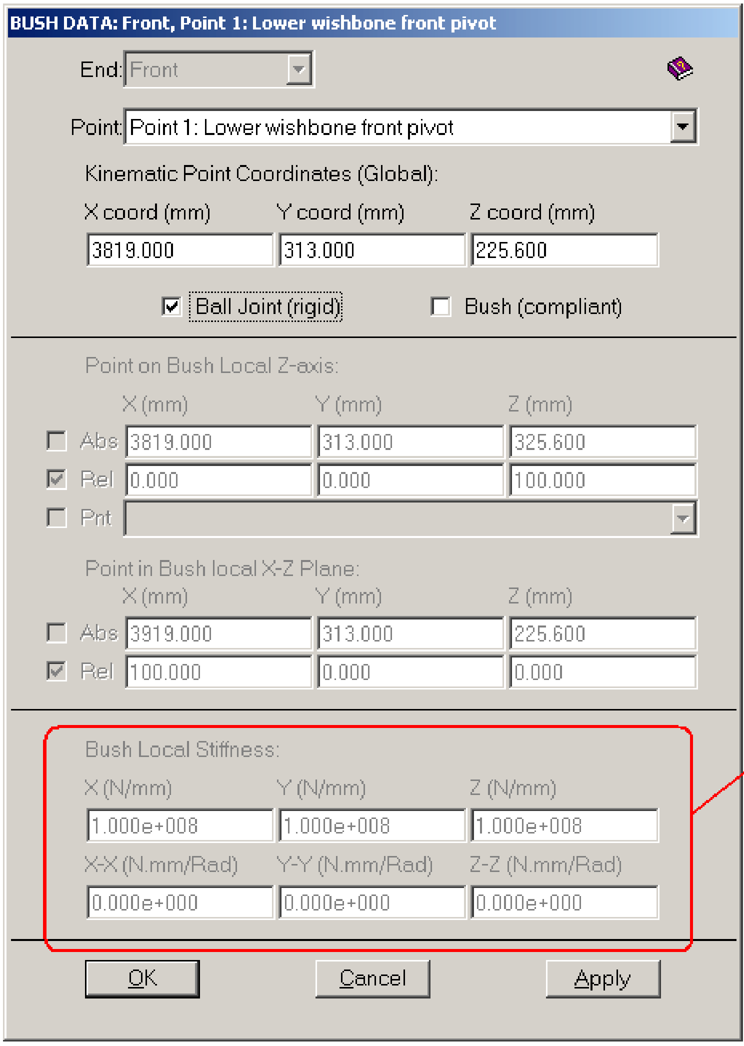
- ***To animate the deflection due to compliance select 'Graphics -> Screen Display -> Animate (deformed Geom)' from the main menu bar.***

6.3 Editing compliant bush properties

The LSA 3D compliance solver treats rigid and compliant bushes the same. The only difference between ‘rigid’ and ‘compliant’ bushes is the value of stiffness used for each degree of freedom of the joint. A rigid ball joint is defined as a compliant bush that has a zero stiffness in rotation about the x, y and z axes but a very high stiffness in translation along the x, y and z axes (can be thought of as approaching infinity) i.e. the joint is free to rotate in all directions but has a fixed x, y, z position. The only change that occurs when the rigid ball joint is switched to a compliant bush is the stiffness in each degree of freedom changes to represent a real bush.

- ***Set the view to the ‘x-y view’ then select ‘Set to Edit mode’***  ***and click on the front lower wishbone pivot.***

A bush data table will be brought up displaying the current ball joint/ bush setting and the stiffness of the bush in all directions.



Ball joint stiffness
Note: -

Large x, y, z values
Zero x-x, y-y, z-z values

- ***Select 'Bush (compliant)'. The greyed out boxes are now active and the bush axis are set relative to the centre of the bush.***

To define bush compliance the local co-ordinate system of the bush first needs to be specified. This is achieved by specifying a point that lies on the local z axis and a second point that lies within the local x-z plane of the local co-ordinate system. These two points and the location of the bush uniquely define a local co-ordinate system. These two points can be defined in a number of ways.

1) Absolute (Abs). Defines a point in the absolute global co-ordinate system.
2) Relative (Rel). Defines a point along the axes of the global co-ordinate system but relative to the location of the bush.
3) Point (Pnt). Uses another suspension point.

- ***From the 'point' drop down select 'Point 1: Lower Wishbone Front Pivot' and set the bush to 'Bush (compliant)'.***
- ***Set the 'Point on Bush Local Z-axis' to Pnt and select 'point 2: Lower Wishbone Rear Pivot'.***
- ***Set the 'Point on Bush Local x-z Plane' to relative and select x = 0, y = 100, z = 0***
- ***Accept default bush stiffness and click 'Apply'***
- ***From the 'point' drop down select 'Point 2: Lower Wishbone Rear Pivot' and set the bush to 'Bush (compliant)'.***
- ***Set the 'Point on Bush Local Z-axis' to Pnt and select 'Point 1: Lower Wishbone Front Pivot'.***
- ***Set the 'Point on Bush Local x-z Plane' to relative and select x = 0, y = 100, z = 0***
- ***Accept default bush stiffness and click 'OK'***

A slight deflection of the lower wishbone rear bush has occurred due to the effect of compliance. Also note that this slight bush movement has caused toe out of the wheel, illustrating the effect of the small deflection caused by this compliance and the resultant effect on the suspension system as a whole.

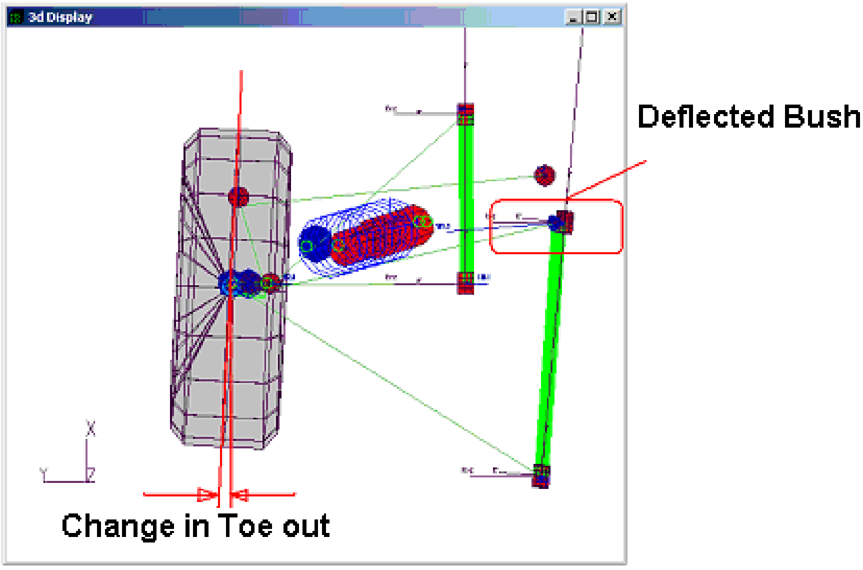


Fig 6.3 Deflection of compliant bush due to spring force

6.4 Adding external forces

In addition to the spring force LSA allows application of force vectors to any suspension member. Combination of force vectors can be used to simulate any arbitrary road load condition. LSA contains a number of force sets that can be applied to the system and also allows user defined forces. Each force set is applied separately to the suspension. To investigate the effect of multiple forces on a suspension all the forces must be combined within the one force set. LSA does not simultaneously apply more than one force set at a time however more than one force set can be turned on and LSA will then calculate results for each force set applied separately. The suspension graphic display window always displays the compliant results for the default force set that is set by the user.

- ***From the main menu select 'Data -> Compliance Data -> External Forces'.***

Now both *'Spring force'* and *'External forces'* should be active.

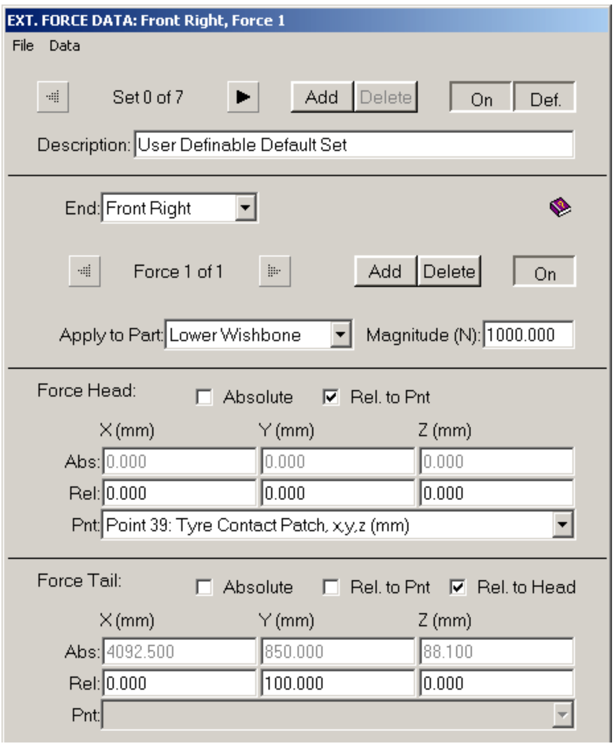


Fig 6.4 External Force Data edit screen

Set up a 1000N inward acting lateral load applied to the upright acting at the centre of the front contact patch.

- ***Select 'Set 0', 'User Definable Default Set'***
- ***Click the 'Add' button next to the force selector to add a force to the force set.***
- ***Check that front right is selected for 'end' and select 'upright' in the 'Apply to Part' drop down box.***
- ***Give the force a magnitude of 1000 N.***

The force can be turned on and off using the 'On' button in the second box. Multiple forces can be added to each component in turn by adding additional forces in the same Force Set.

- ***Define the point where the force is acting by setting up the 'Force Head' so that it acts at the 'Tyre Contact Patch x, y, z (mm)' by selecting it from the 'Pnt' drop down box.***
- ***Define the 'Force Tail' relative, Rel, to the Force Head at y = 100.***
- ***Click 'OK' to close the external force dialog box when done.***

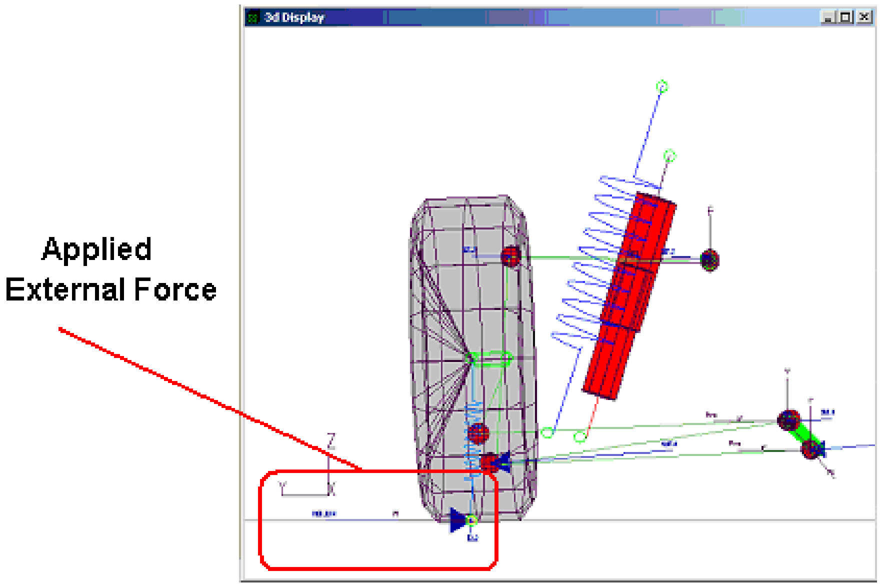


Fig 6.4 External force applied to upright at Contact Patch.

As with the bushes axes each of the force vectors can be defined using two reference points. The force head can be defined as acting at a pre-defined point selected from the drop down menu or by giving it an absolute value expressed as a global Cartesian co-ordinate.

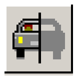
The force tail, can also be set using several reference points. It can be defined as an absolute point defined in 3D space, as a point relative to another selected point or can be given a co-ordinate relative to the force head .

We will now add more forces to force set 0 using table 6.1 for input data. Once each of the external forces have been included in the model the effect of these forces both individually and combined can be calculated.

- ***Use table 6.1 to setup 4 forces in force 'Set 0'.***

Force	End	Apply to part	Magnitude (N)	Force Head	Force Tail (Rel.To Head)
1	Front Right	Upright	1000	Tyre Contact Patch	Y = 100
2	Front Right	Upright	1000	Tyre Contact Patch	X = -100
3	Front Left	Upright	1000	Tyre Contact Patch	Y = 100
4	Front Left	Upright	1000	Tyre Contact Patch	X = -100

Table 6.1

- ***Turn both halves of the model on using the***  ***button.***

The model now reflects the systems reaction to a series of forces that would typically be exerted as the vehicle enters a right hand corner under slight braking. Similar forces acting on the system due to other conditions can be added in other force sets to represent say, braking or accelerating.

6.5 Displaying compliance results

➢ ***Select 'Results -> Display Compliance Values' from the main menu bar.***

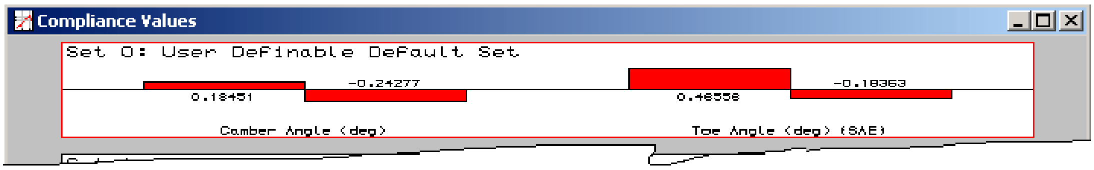


Fig 6.5 Compliance Values

The Compliance Values (figure 6.5) show the change in the displayed values due to application of the force Set. By default the two displayed variables are Camber angle and Toe Angle but other variables can be added by left clicking on the force set background then right clicking, selecting *'Add Extra Variable'*. The variable displayed on any particular graph can also be changed by left clicking on the particular graph then right clicking to select the variable from the '*Y-Variable'* menu. Each force set can be turned off as required or all force sets can be turned on by right clicking and selecting *Turn Force Set 'Off'* and *Turn All Force Sets 'On'* respectively. Similarly the spring force set, can also be added or removed. Note that the Graphic suspension display will only display the deformed suspension geometry for the user selected default force set.

➢ ***Add the 'Castor Trail' variable to the Force Set 0 results by first left clicking on the background of the force set 0 display then right clicking, select 'Add Extra Variable'.***

➢ ***Left click on the new graph then Right click and select 'Y-Variable -> Castor Trail (mm)'.***

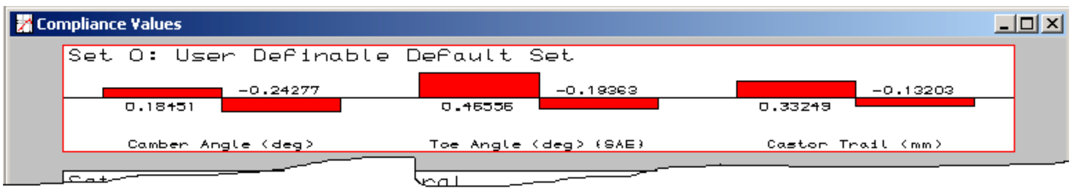
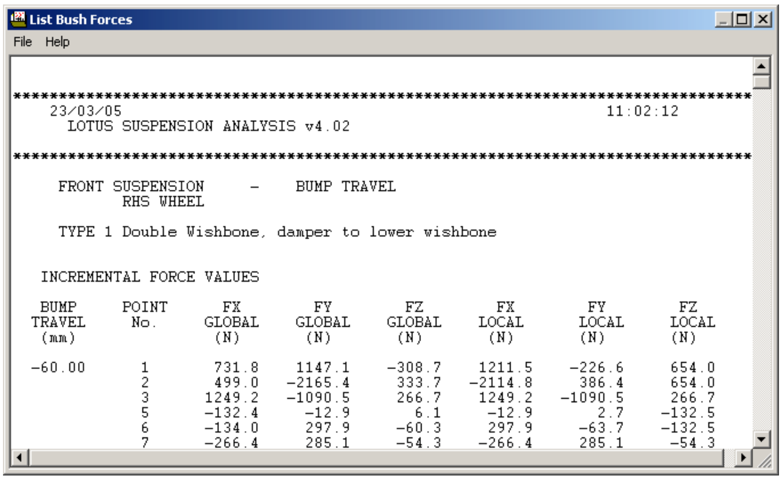


Fig 6.6 Compliance Variables relevant to External Forces

Compliance data can also be displayed numerically in the form of 'Bush Forces' and 'Bush Deflections' by selecting *Results > List Bush Forces…* and *Results > List Bush Deflections…* from the main menu bar. The list of values display deflection and forces for all three modes i.e. Bump, Steer and Roll. In addition, they are displayed over a range for each of these three modes.



List Bush Forces

File Help

```
******************************************************************************
    23/03/05                                                        11:02:12
      LOTUS SUSPENSION ANALYSIS v4.02

******************************************************************************

     FRONT SUSPENSION     -    BUMP TRAVEL
            RHS WHEEL

     TYPE 1 Double Wishbone, damper to lower wishbone


   INCREMENTAL FORCE VALUES
```

BUMP TRAVEL (mm)	POINT No.	FX GLOBAL (N)	FY GLOBAL (N)	FZ GLOBAL (N)	FX LOCAL (N)	FY LOCAL (N)	FZ LOCAL (N)
-60.00	1	731.8	1147.1	-308.7	1211.5	-226.6	654.0
	2	499.0	-2165.4	333.7	-2114.8	386.4	654.0
	3	1249.2	-1090.5	266.7	1249.2	-1090.5	266.7
	5	-132.4	-12.9	6.1	-12.9	2.7	-132.5
	6	-134.0	297.9	-60.3	297.9	-63.7	-132.5
	7	-266.4	285.1	-54.3	-266.4	285.1	-54.3

Fig 6.7 Compliance Data expressed as numeric values

➢ ***Tutorial Done.***

7 Using the Optimiser

7.1 Overview

This chapter describes the use of the internal optimiser to provide a numerical method of identifying an 'optimum' solution. The requirements for this optimum solution are defined as a series of kinematic and/or compliant targets. The solution can be achieved by moving identified points within a defined limited space, and/or varying bush properties, again within a limited variation.

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- **Introduction**

The optimiser is a fully integrated solution technique for quickly and efficiently identifying 'optimum' solutions. The approach used is not based on a design of experiment or Taguchi type techniques. It instead uses a combination of scoring, sensitivity and trends to identify the optimum.

The scoring technique is used to convert the deviation of the current solution from all desired characteristics and values to a single number (or score). The objective of the optimisation process is to reduce this score to zero.

The score is determined by summing the deviation of each point on the calculated curve (e.g. camber angle against bump travel) or value when compared to a defined target curve. Any number of characteristics can be included in this way, the summation of each made with reference to a weighting factor. It does rely on the user knowing what target responses they require for each included characteristic. Increasing the number of characteristics does not significantly alter the analysis time of the optimisation process.

The variables for the optimisation are identified as point positions and/or bush properties. Whilst the optimisation can include both kinematic and compliant variables they are more normally performed in isolation of each other. Each included variable has a user-defined range to contain the solution within sensible bounds. Also within these bounds a minimum resolution is specified to limit the number of solution steps. The number of variables included directly affects the run time for the optimisation so it should be kept to the minimum possible.

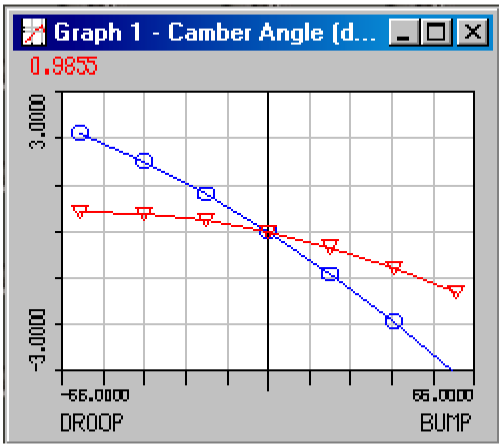
The optimiser assess each variable to identify a sensitivity value. This is the amount the score changes over the defined range at the specified step size. This then sets the order that each variable is adjusted to produce its minimum value before moving on to the next variable in the sensitivity order list. The user can run the optimisation either from the most to the least sensitive or more successfully from the least sensitive to the most sensitive.

Thresholds can be set to ignore variables whose sensitivity is significantly less than the most sensitive, as well as an solution acceptance tolerance on getting the deviation score down to zero.

At the end of the optimisation process the user is presented with the original score and the best position score. The user can then optionally accept the new 'optimised' solution or return to the original models data.

7.2 Setting Kinematic Targets via User Lines

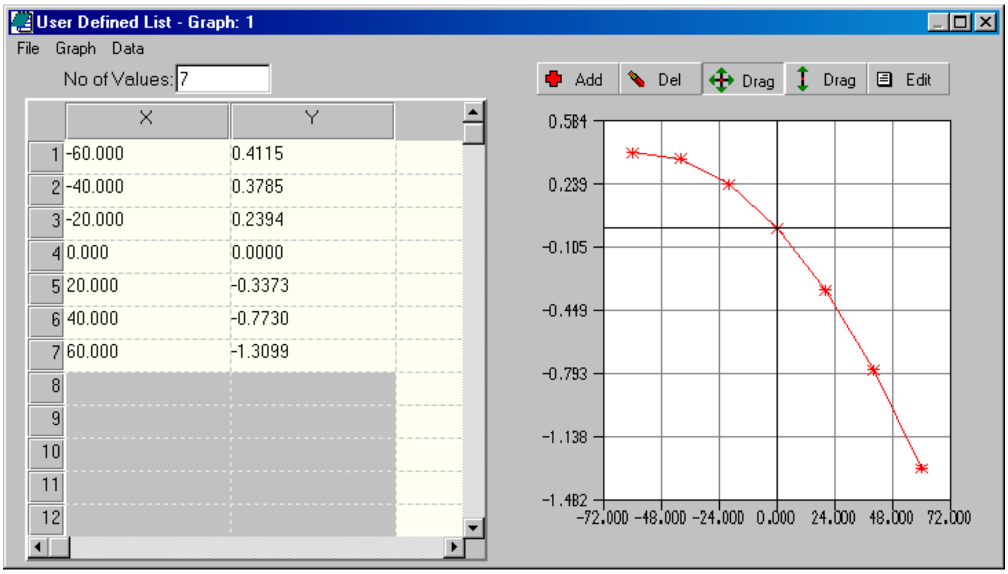
The kinematic targets for the optimiser, such as camber, toe and roll centre height are defined via user lines, defined for each of the required suspension derivatives graphs. (Note that although graphs can display graphical element properties, they cannot be used for the optimisation, as you cannot define user lines for them). User lines can be defined directly or extracted from user line data sets. These data sets are managed through a series of menu options that allow the user to add too, edit or remove user line data from data sets. Each dataset can have any number of complete sets of user lines stored in them, and any number of datasets can be referenced by the application at any one time. These data set files are stored by their full pathname in the users ini file such that they a searched for at program start up and added to the relevant menu tree. In a similar manner to 'add' datasets can be removed from the available list. These dataset files can thus be shared between users, either through a central server type location or by local copies of the same file.



Example Graph showing User Line and deviation 'score'

A convenience menu function is provided, *Graphs / Copy Front-2D data to User* for copying the current result line values to the user line. This menu function performs a copy not just for the currently visible graph parameters but all available results, (some 45 different parameters). Thus for a given target model this function provides a complete set of user line curves, that could be stored/added to a dataset for use as a future target for an alternative model.

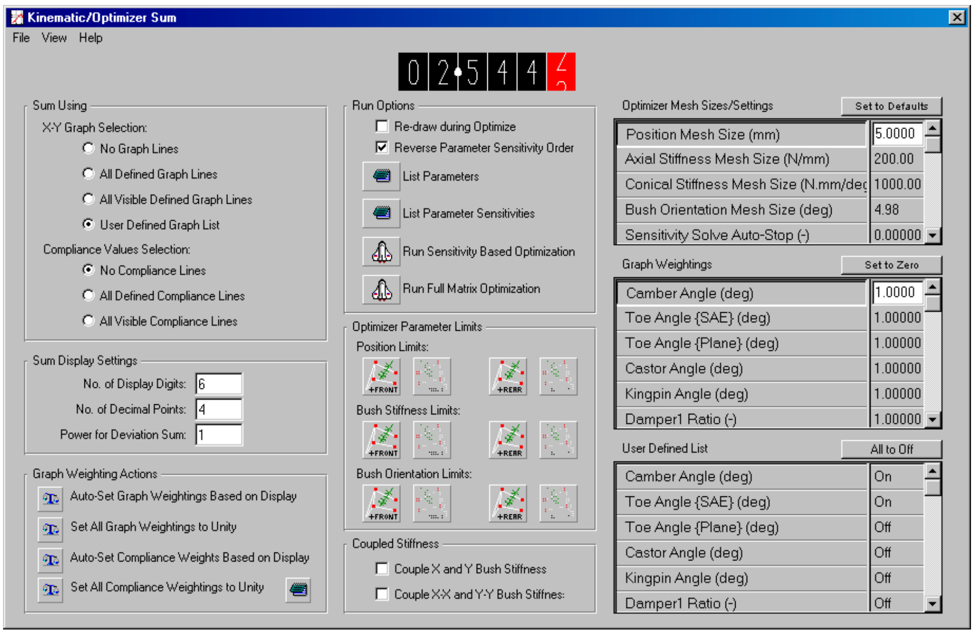
Individual graphs user lines can be edited directly through the right mouse menu option on the chosen graph. Note that user lines are stored and edited by corner. This is to support asymmetric model options.



Example user line edit

7.3 Weighting Settings for Kinematics

Each graph/curve used in summing the total deviation from its respective user line is included via its own weighting factor. This allows the user to balance the numerical differences between say an angle such as camber and a distance such as roll centre height. A number of convenience functions are available to automatically set these but before we can look at these we need to review how we specify which graphs we wish to include in the optimisation process. It doesn't necessarily follow that because a particular graph is visible it will be included in the optimisation score.

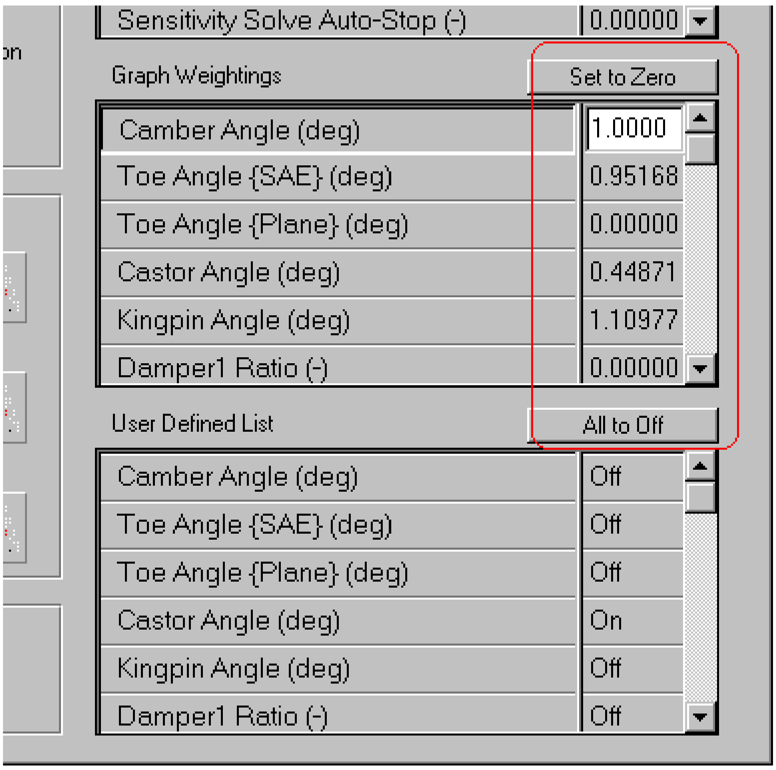


Optimiser Display Screen

All optimiser settings are accessed through the *Results / Display Kinematic Sum/Optimizer* display. This display can be with or without 'details'. The screen shot on the previous page illustrates the 'with details' display.

Through this display you can specify which graphs to include into the sum. The top left corner shows the 'sum using' options. We can choose to include, No Graph lines, All defined (i.e. any with a user line specified visible or not), All visible defined graph lines, (i.e. as per the previous option but must also be visible), or a user defined list. The user defined list is set graph by graph in the lower right hand corner. Note that the top left hand box also has the compliance sum options that we will cover later.

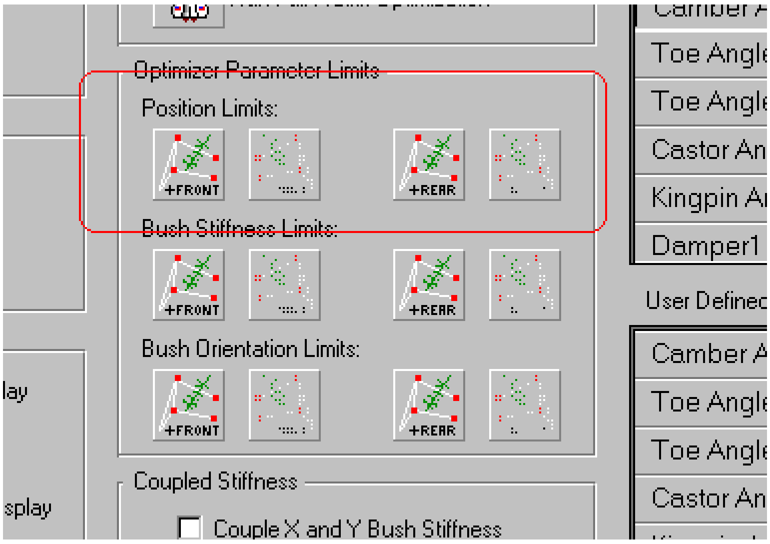
Once we have identified which Graph selection to include we can then set the appropriate weightings. The 'Graph weightings' panel shows the current value for each graph. We can either edit them directly or use one of the menu options (lower left). This will either set them all to zero, all to unity or to a weighted value based on the individual graphs y-range. The latter option attempts to provide a convenience weighting regime without recourse to lengthy editing of each graphs value. These weighting numbers will directly influence the optimisation process, in both the order and final achieved model. When using this auto-weight option it is import to have the graph y-axes correctly set. This may be nothing more than using the graph autoscale option or may involve more specific axis setting.



Graph weightings ringed - Set by Auto-weight routine

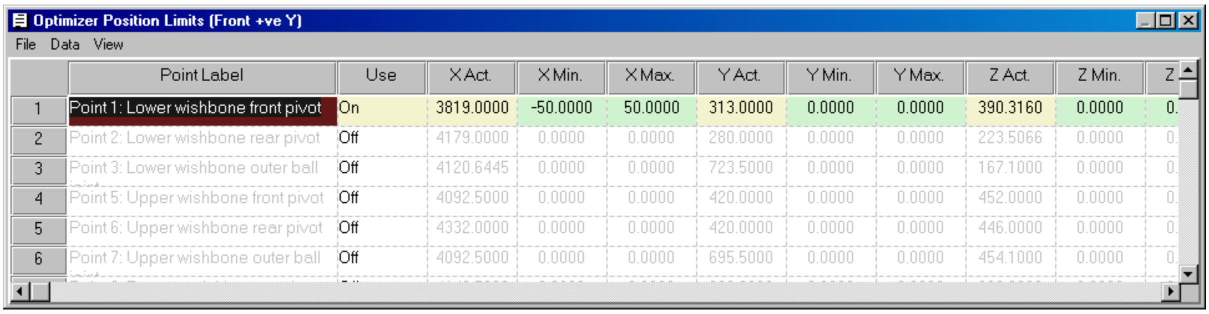
7.4 Identifying Positional Optimiser Parameters

Having specified how we are to determine the targets and summation we need to identify which hard point positions we intend to move. We can set positional parameter limits by individual corner. In the simplest single corner symmetrical model we would only be interested in one corners points set.



Accessing the positional parameters settings

Within each corner set we identify which points are to be included with a simple on/off selection. On the same line we also define the limits of motion in each axis for the selected point. Menu options are available to set the limits as the current position, or the current points tolerance limits. As a display option we can either view the parameter limits as absolute or deltas.



Optimizer Position Limits (Front +ve Y)

File Data View

	Point Label	Use	X Act.	X Min.	X Max.	Y Act.	Y Min.	Y Max.	Z Act.	Z Min.	Z
1	Point 1: Lower wishbone front pivot	On	3819.0000	-50.0000	50.0000	313.0000	0.0000	0.0000	390.3160	0.0000	0.
2	Point 2: Lower wishbone rear pivot	Off	4179.0000	0.0000	0.0000	280.0000	0.0000	0.0000	223.5066	0.0000	0.
3	Point 3: Lower wishbone outer ball	Off	4120.6445	0.0000	0.0000	723.5000	0.0000	0.0000	167.1000	0.0000	0.
4	Point 5: Upper wishbone front pivot	Off	4092.5000	0.0000	0.0000	420.0000	0.0000	0.0000	452.0000	0.0000	0.
5	Point 6: Upper wishbone rear pivot	Off	4332.0000	0.0000	0.0000	420.0000	0.0000	0.0000	446.0000	0.0000	0.
6	Point 7: Upper wishbone outer ball	Off	4092.5000	0.0000	0.0000	695.5000	0.0000	0.0000	454.1000	0.0000	0.

Example Parameter setting - Point 1 selected viewed as deltas

The above screen shot shows just point 1 as having been selected, and only the x-axis will be considered since the limits for y and z are set to 0. This display has been switched to show delta's and thus the zero's imply no change from the current actual value.

Once we have set all our required parameters we can list them through the 'List parameters' button. Our simple case of a single parameter is shown below.

Parameter Listing

Label	Axis	Current	MinVal	MaxVal
Front +ve Y, Point 1: Lower wishbone front pivot	Xpos	3819.000	3769.000	3869.000

Parameter listing - single point position single axis

In a similar display we can list the parameters in sensitivity order. This can be useful in identifying parameters that have a small impact on the solution and they can thus either be removed from the list, or used to identify a value for the 'sensitivity ignore ratio'. The objective being to reduce the number of parameters to produce a quicker solution time.

Sensitivity Listing

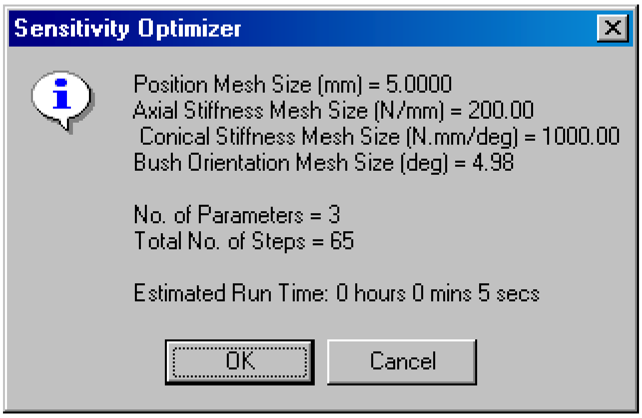
Label	Axis	Current	MinVal	MaxVal	Sensitivity
Front +ve Y, Point 1: Lower wishbone front pivot	Zpos	390.316	340.316	440.316	0.32664
Front +ve Y, Point 1: Lower wishbone front pivot	Xpos	3819.000	3769.000	3869.000	0.21203
Front +ve Y, Point 1: Lower wishbone front pivot	Ypos	313.000	263.000	363.000	0.06669

Sensitivity listing - three parameters shown, Y insensitive.

7.5 Running a Kinematic Optimisation

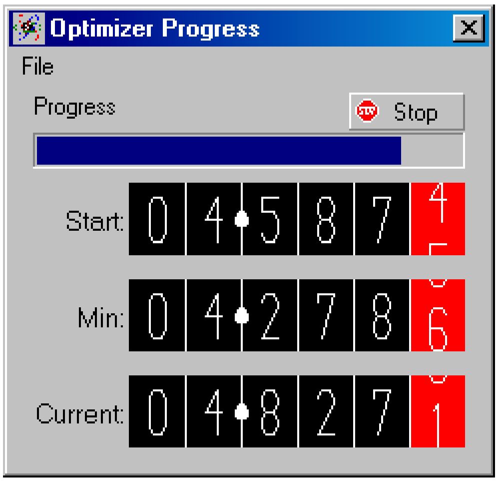
With the targets defined and the parameters specified we can run the optimiser. As stated previously the solver will run through each parameter in a sensitivity based order selecting the setting for each parameter that gives the lowest deviation, this positional setting for minimum score is retained as the solver moves to the next parameter. During this process the user can view the intermediate steps in the graphical window as well as the animated score. Two optimisation options are available, one of which is a simple full matrix solution. This full matrix option is impractical for all but the most simple cases, (simple in terms of few variables). The normal solution method is the 'Sensitivity Based Optimization'.

When you first select the optimisation button a summary display is shown listing the step size resolutions, number of parameters, total number of steps and an estimate of the run time.



Optimisation summary

Selecting Ok will start the optimisation and display the progress display shown below. The display shows the progress and three scores. The scores are the value at the start, the minimum value found so far and the score for the last iteration.



Progress display

7.6 Kinematic Tutorial

To illustrate the previous discussion we will run a simple example involving three graph curves and three parameters.

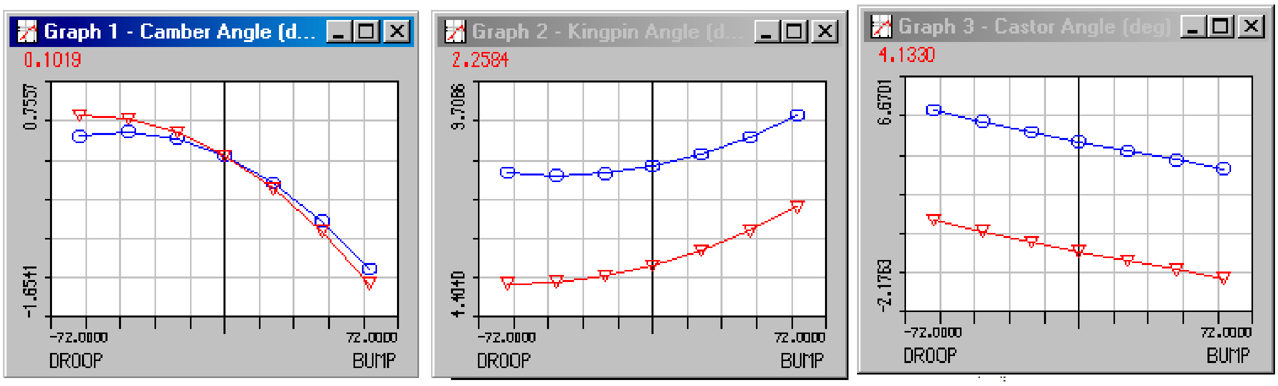
Create a new single corner front model based on default type 1.

Open three graphs, Camber Angle, Kingpin Angle and Castor Angle, *Graphs / New*. Ensure you are set to 3d bump module and that bump/rebound is set to +-60mm with a 20mm increment, *Data / Parameters*.

Use the graph convenience menu item to pre-fill the user lines with the current data values, *Graphs / Copy Front-2D data to User*.

Edit point 3, the outer lower ball joint to a new position, X=4072, Y=733.5, Z=177.0

Before opening the optimiser display autoscale the graphs. They should now appear as below. Note deviation scores visible.



Graph screen shot for tutorial

Open the Optimiser display, *Results / Display Kinematic Sum/Optimiser*, and set the display to show details. For this simple example we will use a fine positional increment, so set 'Position Mesh Size' to 1.0 mm.

We are going to have point 3's X,Y and Z position as variables so open the relevant 'Position Limits' display and set them 'on' and range to the current tolerances. Check by comparing your parameter list with that shown below.

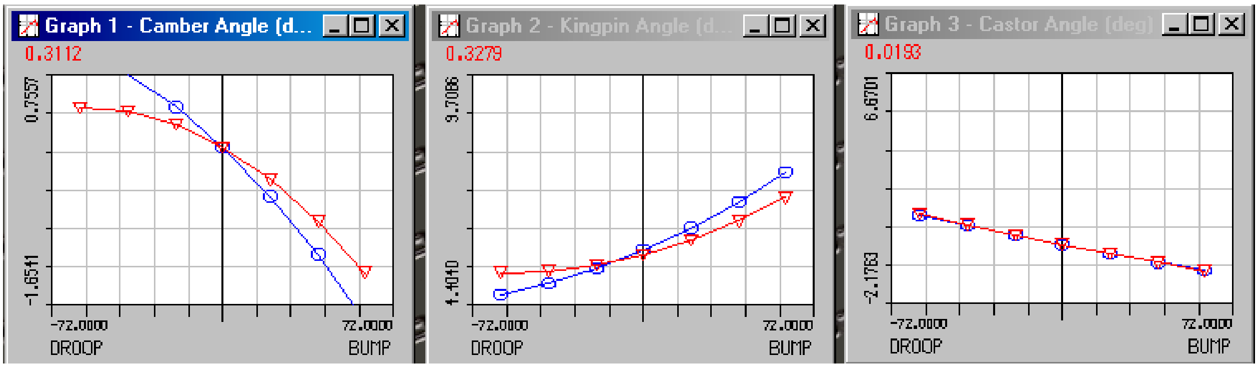
Parameter Listing

Label	Axis	Current	MinVal	MaxVal
Front +ve Y, Point 3: Lower wishbone outer ball...	Xpos	4072.000	4067.000	4117.000
Front +ve Y, Point 3: Lower wishbone outer ball...	Ypos	733.500	698.500	748.500
Front +ve Y, Point 3: Lower wishbone outer ball...	Zpos	177.000	142.100	192.100

Parameter Listing

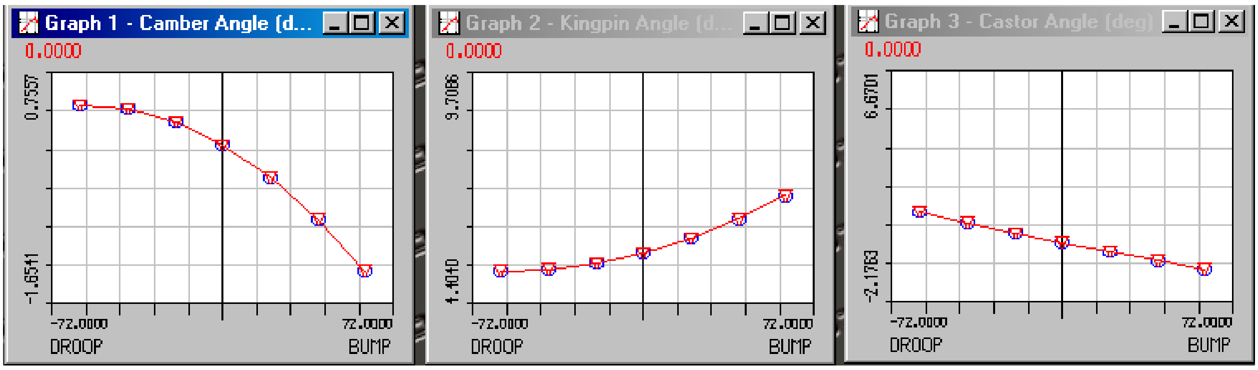
Before we can run the analysis we need to define what weightings we will apply. Initially try the 'Auto-Set weightings based on display' option. This should give 1.0 (camber), 0.2724 (castor) and 0.4543 (kingpin) for our three graphs.

Try running the optimiser with these weightings…



Auto-Weightings Result - Score = 0.4654

The auto-weightings do not produce a very effective solution. In particular the Camber curve is not very close. Try re-running but this time double the camber weighting, i.e. 2.0, 0.2724, 0.4543. No need to reload the original values can re-run from this new position.

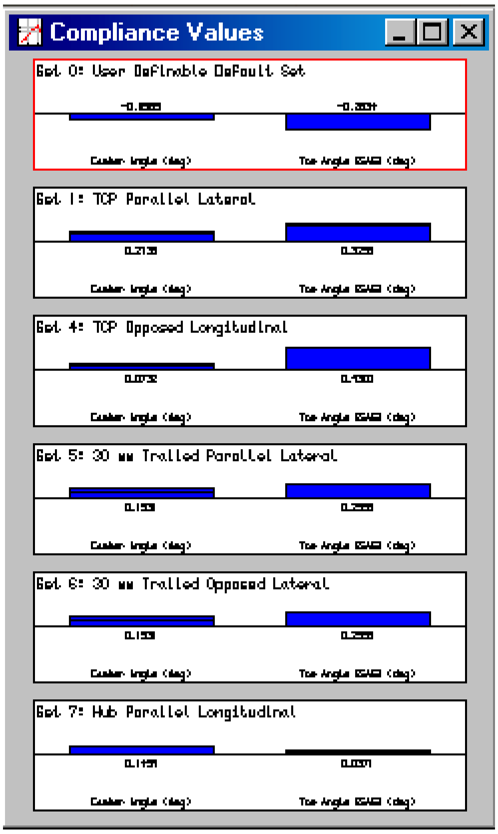


Revised Weighting Graphs

In this case we get a much-improved match and a score of zero. Are the co-ordinates for point 3 the same as originally? Would we have got here in one step had we set the weightings to 2.0 etc. from the start?

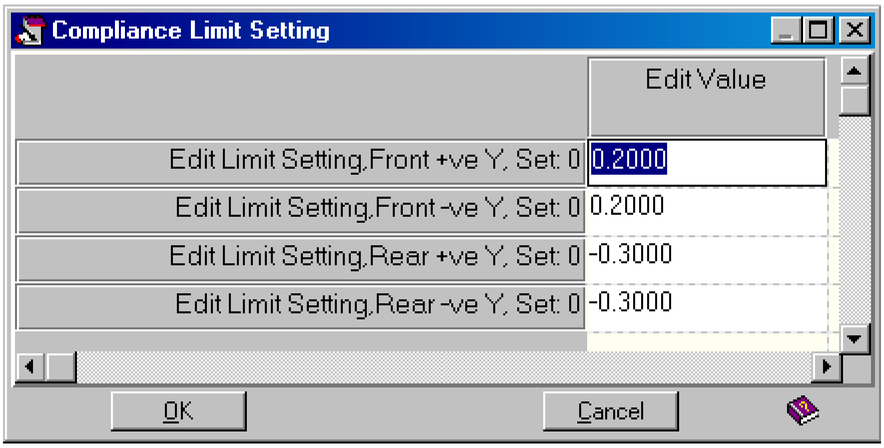
7.7 Setting Compliant Targets via Compliance Coefficients.

To extend the use of the optimiser into the use of tuning compliant properties such as bush stiffness and orientation we need to have a additional compliant results scoring method similar to that used with our derivative graphs. We can of course use the graph curves user lines as targets for compliant bush optimisation, but it is more normal to use the 'Compliance Values' bar chart display, (*Results / Display Compliance Values*) as this allows us to use compliant specific results under a range of different load cases.



Example Screen Shot - Compliance Values

Each bar on the display has an associated target or limit setting. These are drawn as horizontal lines across each bar display. We can use the sum of differences from these 'limit' settings to control our optimisation process in a similar way to the x-y graph user lines. To set the limit values for a particular bar select it with the right mouse button and then edit as required. Alternatively to edit them all through a single display select from the right mouse menu on the compliance values graph the menu option *Edit All Line Limits/Scale/Weights…*



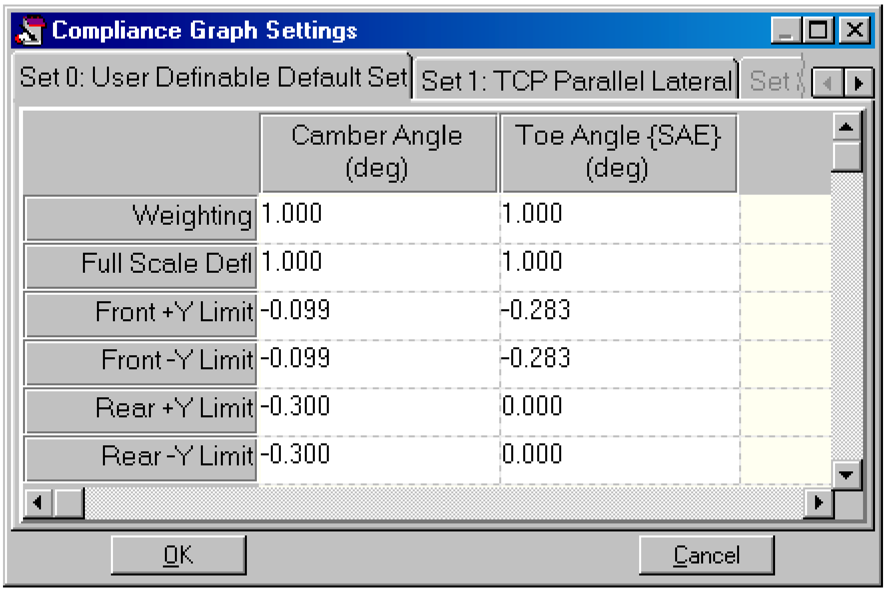
Limit Setting for Individual Bar

In a similar manner to user line setting a convenience menu option is available, *Set All Limit Values to Current*, from the right mouse menu to take the current values as required limits.

No database system exists for these limit settings but they are saved into the users ini file.

7.8 Weighting Settings for Compliance Targets

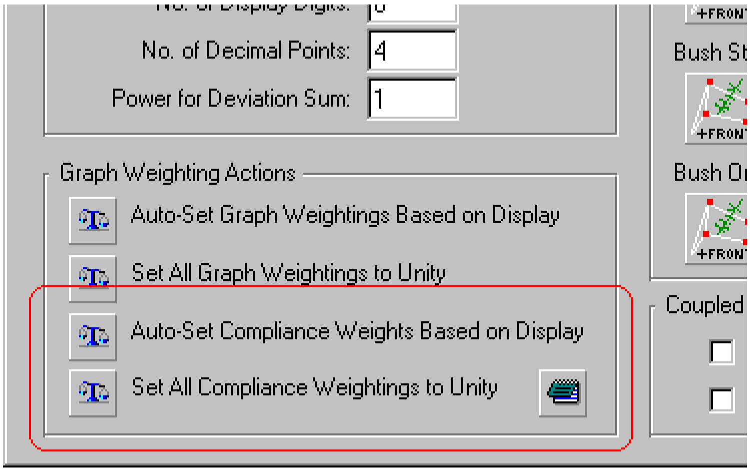
As with the kinematic user lines we need to apply a weighting factor to each compliant bar graph. We can either edit them individually using the right mouse menu item *Edit Weighting Setting…* or use the *Edit All* option.



Setting Weighting Values via the edit all display

Individual weighting values are applied to each separate bar in each load set, although the same value is used for each corner within a single bar variable, though each corner can have a separate target/limit.

The optimiser display has two convenience options for auto-setting the bar weighting values. The lower left panel has *Auto-Set Compliance Weights Based on Display* and *Set All Compliance Weightings to Unity*. They function as implied to provide one-click settings for the weightings.



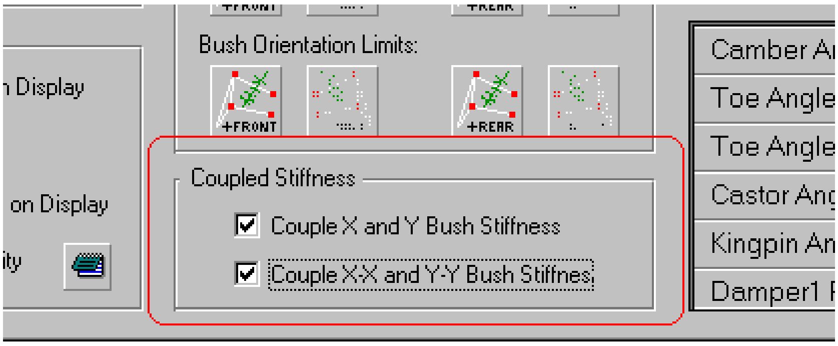
Compliance Weighting Settings

7.9 Specifying Compliant Optimiser Parameters and Limits.

The compliant properties available as parameters for the optimiser are the bush X, Y and Z axial stiffness, the bush X-X, Y-Y and Z-Z rotational rates and the bush orientation. The bush orientation is controlled by the optimiser through an Euler sequence of local axis rotations about the X, Y and Z axes.

Obviously compliant optimisation can only be applied to model points that are either a connection to ground or a connection between parts. They must also have been identified as 'compliant' rather than 'rigid'.

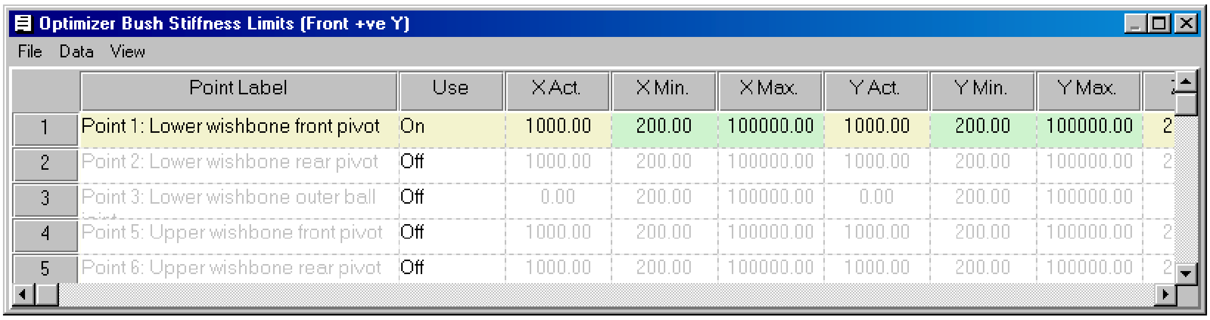
Because of the often symmetric nature of bushes special options are provided to couple the X and Y stiffness, (i.e. no need to set both the X and Y axial stiffness as a parametric variable just change one and the other will be automatically made the same). A similar option is available for the x-x and y-y rotation rates.



Coupling the X and Y Stiffness parameters

To select the required bushes to optimise select the 'Bush Stiffness Limits' icon. Within this display toggle on the required bushes, and set the x, y and z limits in a similar manner to that performed previously for point position.

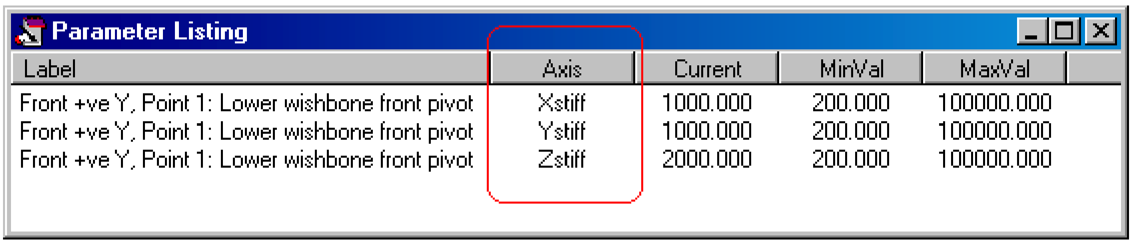
You can pre-fill all the stiffness values using the two convenience menu items, *Pre-Fill Min/Max Using Defined Values* and *Pre-Fill Using Actual Values*. The first of these two options requires the user to specify what the min and max limits should be.



	Point Label	Use	X Act.	X Min.	X Max.	Y Act.	Y Min.	Y Max.
1	Point 1: Lower wishbone front pivot	On	1000.00	200.00	100000.00	1000.00	200.00	100000.00
2	Point 2: Lower wishbone rear pivot	Off	1000.00	200.00	100000.00	1000.00	200.00	100000.00
3	Point 3: Lower wishbone outer ball	Off	0.00	200.00	100000.00	0.00	200.00	100000.00
4	Point 5: Upper wishbone front pivot	Off	1000.00	200.00	100000.00	1000.00	200.00	100000.00
5	Point 6: Upper wishbone rear pivot	Off	1000.00	200.00	100000.00	1000.00	200.00	100000.00

Single Bush enabled, limits set for x, y and z

Once all the required parametric bush properties are defined they can be viewed via the list parameters option. The axis will be identified as 'Xstiff', 'Ystiff' and 'Zstiff' as applicable.

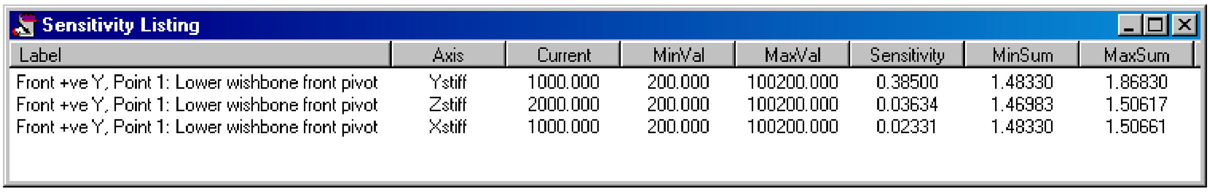


Label	Axis	Current	MinVal	MaxVal
Front +ve Y, Point 1: Lower wishbone front pivot	Xstiff	1000.000	200.000	100000.000
Front +ve Y, Point 1: Lower wishbone front pivot	Ystiff	1000.000	200.000	100000.000
Front +ve Y, Point 1: Lower wishbone front pivot	Zstiff	2000.000	200.000	100000.000

Parameter listing, stiffness variables indicated.

We can similarly review sensitivities of the defined parameters. The step size used between minimum and maximum stiffness is defined in the top right panel entries. Here you define both the step sizes for both the axial and rotational stiffness.

The same process can be applied to set up bush rotations as parametric variables. Identify the points, set the limits and step the step size.



Sensitivity Listing

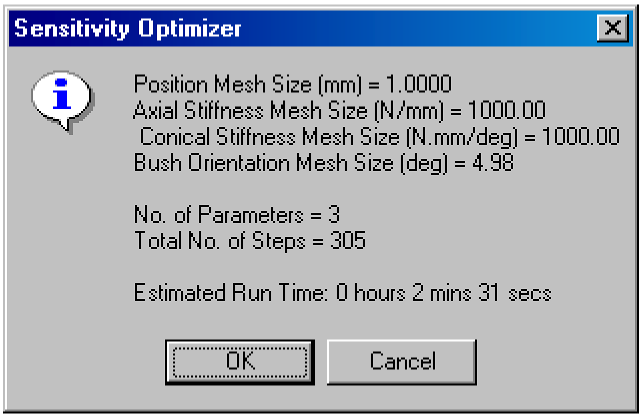
Label	Axis	Current	MinVal	MaxVal	Sensitivity	MinSum	MaxSum
Front +ve Y, Point 1: Lower wishbone front pivot	Ystiff	1000.000	200.000	100200.000	0.38500	1.48330	1.86830
Front +ve Y, Point 1: Lower wishbone front pivot	Zstiff	2000.000	200.000	100200.000	0.03634	1.46983	1.50617
Front +ve Y, Point 1: Lower wishbone front pivot	Xstiff	1000.000	200.000	100200.000	0.02331	1.48330	1.50661

Sensitivity listing - note min and max sums given

7.10 Running a Compliant Optimisation.

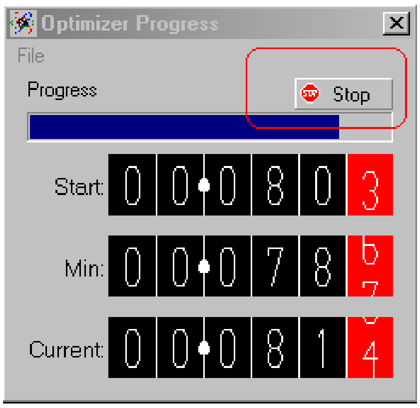
With the variables, limits and parameters defined we can no run the optimisation in exactly the same way as for the previous kinematic only example.

Because this is a compliant solve the solution run times will be longer than previously. Check the total number of steps and run time for sensible values before submitting the optimisation run. You may need to revise the step size to reduce the run time.



check run time before submitting

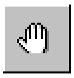
You can stop a optimiser run before it finishes and still have the option to take the lowest score solution already found. This can be useful when in a long run a suitable solution has already been found. Alternatively you could set the 'Auto-Stop' value to be higher.



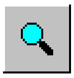
Stop button identified

8 Command Reference Card

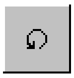
Change between dynamic **Viewing** mode and dynamic **Point Picking**. Shortcut **Alt+Z**



Change to **Translate** view. Select with left mouse button, hold down and drag.

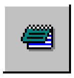


Change to **Scale** view. Select with left mouse button, hold down and move down to zoom in, up to zoom out.

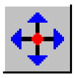


Change to **Rotate** view. Select with left mouse button, hold down and move to rotate view. Picking towards the centre rotates the eye point around the object, picking towards the edge rotates around the eye to object axis.

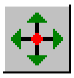
(when in dynamic view mode, the **Right Mouse** button will cycle through the three dynamic view types)



Point-pick mode set to **Edit**. Selecting a point with the left mouse button brings up a dialogue box to edit the points values.



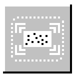
Point pick mode set to **Joggle**. Selecting a point draws the 'joggle' symbol on the selected point. **Ctrl+Arrow** keys joggles the points position in coarse steps, **Shift+Arrow** keys joggles the point in fine steps. Joggle is affected by current tracking direction.



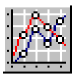
Point pick mode set to **Drag**. Select a point with the left mouse button hold down and drag along current tracking axis direction(s).

(when in dynamic point pick mode, the **Right-Mouse** button will cycle through the **Tracking** directions)

Cycles through the available tracking directions. The current **Tracking** direction(s) is indicated on screen by visible lines drawn through each hard point, along the relevant axis.



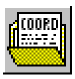
Autoscales the 3D graphical display. Shortcut **Ctrl+A**.



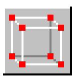
Opens a new **Graph**. The displayed variable can be changed by selecting the graph with the **Right-Mouse** button, and picking the required parameter.

Animates the suspension over the currently selected articulation type, Bump, Roll or Steer.

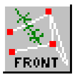
Displays the Suspension Derivatives listing (**SDF**'s) in a pop-up dialogue box.



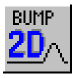
Displays the suspension **Co-ordinates** for a specified bump and steer position in a pop-up dialogue box.



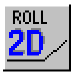
Enables the **Tolerance** analysis. In the first instance the point to run the tolerance analysis on must be defined.



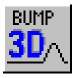
Display for editing the current front/rear suspension hard points.



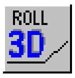
Change solver to **2D Bump** module.



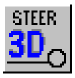
Change solver to **2D Roll** module.



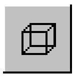
Change solver to **3D Bump** module.



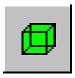
Change solver to **3D Roll** module.



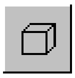
Change solver to **3D Steer** module.



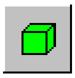
Set view mode to **Wire Frame**.



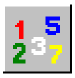
Set view mode to **Solid Fill**.



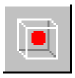
Set view mode to **Hidden Line**. This view mode only works correctly with the graphics frame type set to OpenGl, (see View/Graphics Frame Type).



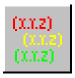
Set view mode to **Depth Buffered** solid fill. This view mode only works correctly with the graphics frame type set to OpenGl, (see View/Graphics Frame Type).



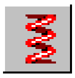
Toggles the visibility of the hard **Point Reference No's.**



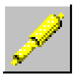
Toggles the use of the **Limit Bboxes** for the hard points. Limits can also be either visible or invisible. Turning limit boxes on will always make them visible.



Toggles the visibility of the hard point (x,y,z) **Co-ordinates.**

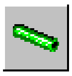


Toggles the visibility of the **Spring** enhanced graphics display. When off spring is drawn as a simple line.

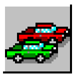


Toggles the visibility of the **Damper** enhanced graphics display. When off damper is drawn as a simple line.

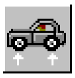
Toggles the visibility of the **Wheel** enhanced graphics display. When off wheel is drawn as a simple line.



Toggles the visibility of the **Pivot Axes** enhanced graphics display. When off is drawn as simple line.

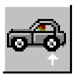


Toggles the visibility of the any **Body** graphics currently selected, (see Data / Body Type).

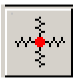


Displays both **Front** and **Rear** suspensions, (if in current model).

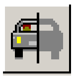
Displays **Front** suspension only.



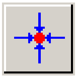
Display **Rear** suspension only.



Toggle 3D compliance solver. Toggles between compliant joints with resultant forces and pure kinematic joints.



Toggles between **Display both sides** of the suspension and right-hand side only.



Toggle 3D Compliance Forces. Toggles the model to display compliance forces such as Spring Forces, External Forces, Compliance Forces ETC.

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