6

Independent Suspension

A Kinematic Overview

(It's just not this simple!)

Before beginning the kinematic chapters I would highly recommend that anyone who is not thoroughly familiar with all aspects of racecar vehicle dynamics take time to build a series of models such as the spindle/upright model shown in Figures (6-1 & 6-2). They don't have to be pieces of artwork as long as they are closely representative of what you are studying and can have their various co-ordinates quickly changed. An accurately working model is worth its weight in gold. The hardest thing about building both representational and to-scale models is not creating unwanted moments - (Book Two).

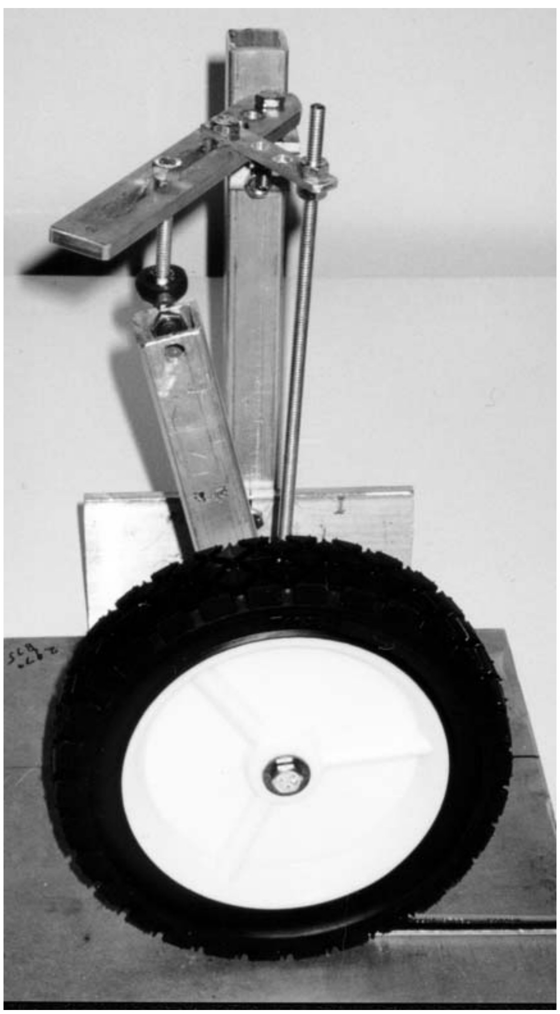


Figure 6-2

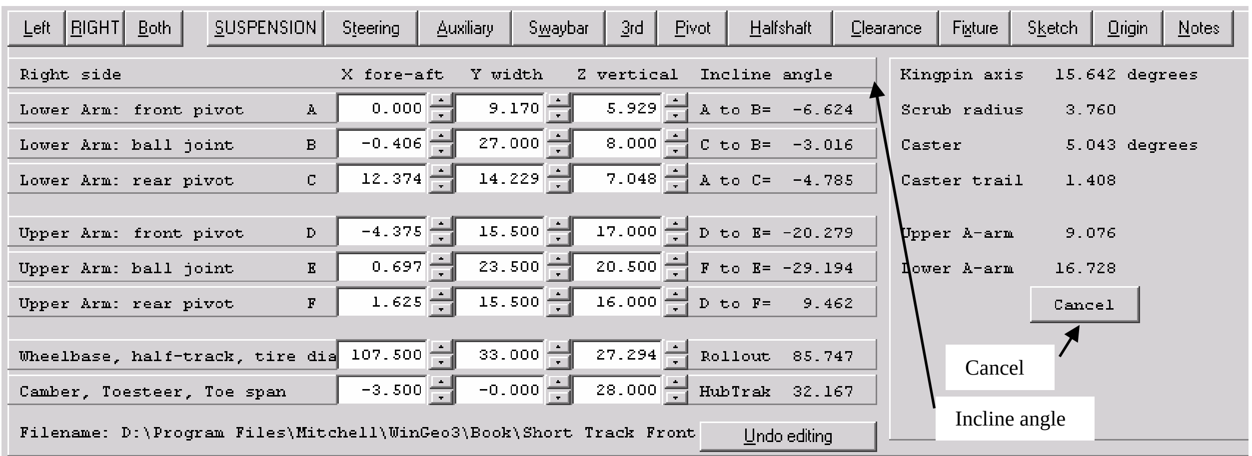
Figure 6-1 – Jig used to understand front suspension

Important Note: Many of the examples in this chapter, for the sake of clarity, are shown in single plane format which may not always represent the realities of three dimensional co-ordinate analysis. Points that intersect on a single plane do not **necessarily** intersect in three dimensional space. That is why the use of a three dimensional kinematics program such as WinGeo3 is so important.

A Quick WinGeo3 Review

- The **Edit menu** is where you enter measured data from an existing chassis as shown in Win 6-1. Until changes made in any of the WinGeo3 menus have been saved to a file, clicking on **cancel** will return the co-ordinates to their **original settings.**

- The user in this menu has the option of seeing either the incline angles or the distances between the various control arm co-ordinates. Win 6-1 shows the angle between the various points. Go to *Utility / Edit option* and click on *Check sums* to toggle between distance and *Incline angle*.



Win 6-1

- The **Design menu** is where the user can look at various design options i.e. create a suspension which meets specific design objectives and/or a component with specific characteristics (co-ordinates). The menu can also be used to design a new suspension. It can not be used to modify an existing suspension. The menu does **not allow** the user to start with a **predetermined part** such as a **spindle**.

- The **Build Menu** allows the user to create a suspension from existing parts.

- The **Compute Menu** allows the user to specify the problem to be solved.

Even if the user is involved in only one type of racing, he/she should use, at a minimum, both the short track and open wheel WinGeo3 examples when exploring each area of chassis kinematics. These chassis examples represent the two ends of the design spectrum. **Many** of the kinematic trends are not always immediately apparent when looking at one chassis type alone.

The three link short track suspension system, as emphasized in the live axle dynamics section of the book, is featured rather than the truck arm suspension because the live axle system is also commonly found on many GT road course chassis types, including the Trans Am series. If the user is involved in live axle truck arm suspension, they should **also** spend time looking at the WinGeo3 truck arm examples.

Remember that this first book is only able to scratch the kinematic surface. Obviously, the serious race engineer will take the opportunity to work past the surface on his/her own.

Note: Crews involved in different types of racing often use different terms to describe the same basic item. For example, open wheel and sports car crews will refer to an upright while stock cars and GT crews refer to the same type of thing as the spindle. It is my hope that this book will be user friendly for all types of racers so what to call each part has been rather problematic. I first tried combining names such as upright/spindle, toe-link/tie-rod and wishbone/A-Arm but nobody seemed to like that. I next tried using specific engineering terms for specific functions such as point of axial rotation to replace ball joint/rod end/ spherical bearing/ mono-ball and that didn't go over well either. In the end, if I am speaking in generic terms, I have decided to use just one or two names for each component type, provide a list of alternative names, and hope no one racing type gets too bent out of shape with my choices. If I am describing a specific type of car, I will use the most common name for that car type.

1. Spindle: Upright
2. Tie Rod: Toe link
3. Spherical bearing: Mono-ball
4. A-Arm: Wishbone - Control arm
5. Ball Joint: Rod end - Spherical bearing
6. Compression: Bump
7. Extension: Rebound
8. Understeer: Push
9. Oversteer: Loose

Track

- The front view distance from the center of the right side hub mounting surface to the center of the left side hub mounting surface is the most common method of measuring track - Figure (6-3 & 6-4). A trammel gauge is often used for this type of measurement.

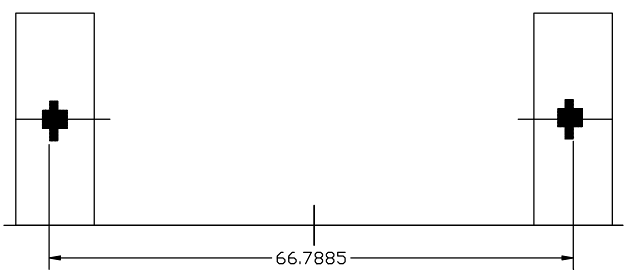


Figure 6-3

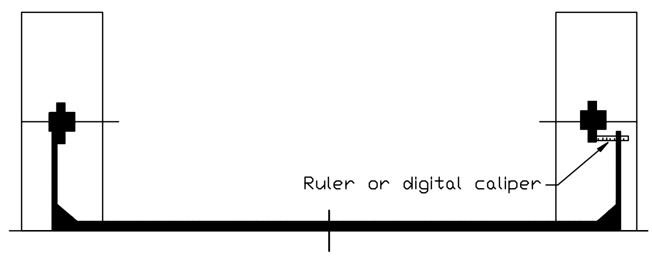


Figure 6-4

- Many race sanctioning bodies measure track from outer sidewall to outer sidewall at hub center height and at a specified psi. If the track is measured at the road surface, rim back spacing (offset), kingpin angle and camber angle need to be taken into consideration. This latter type of track measurement is used when working out the distance between contact patches.

*****Begin WinGeo3 Example*****

Utility: ***Track Option***

Track can be entered as *Full-track* or *Half-track*. *Full-track* is normally used for symmetric cars while *Half-track* is used for asymmetric cars. The Half-track measurement is from the centerline of the car (however that is determined) to the center of the tire contact patch.

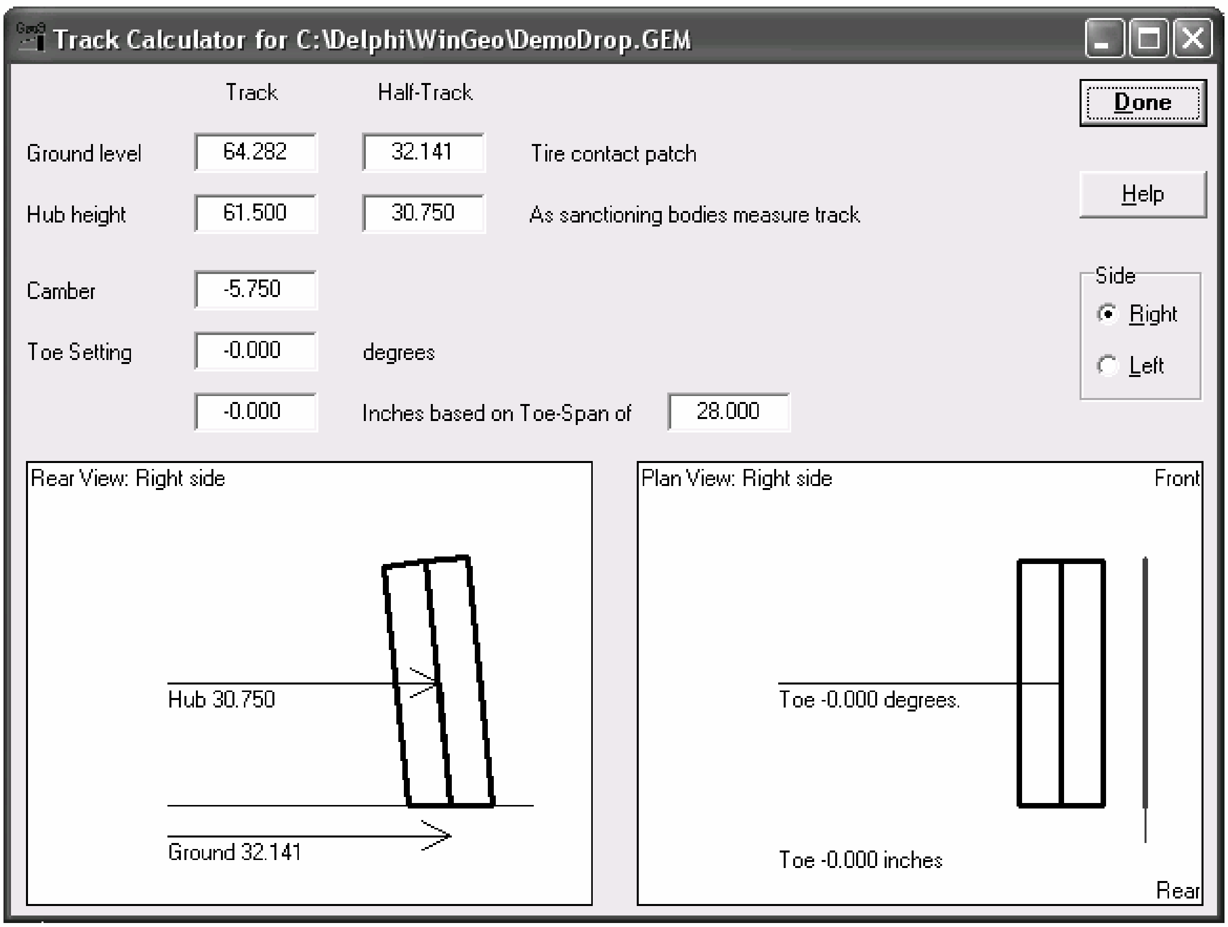
Edit: ***Track Calculator***

Track is entered under *Edit / Suspension*.

The Advanced WinGeo3 program measures track at ground level at the center of the tire contact patch. Most sanctioning bodies measure track at hub height by measuring from the outside of one tire to the outside of the opposite tire. These measurements can be quite different when either or both of the tires have static camber. The Track Calculator allows the user to toggle between the contact patch track and the track at the hub.

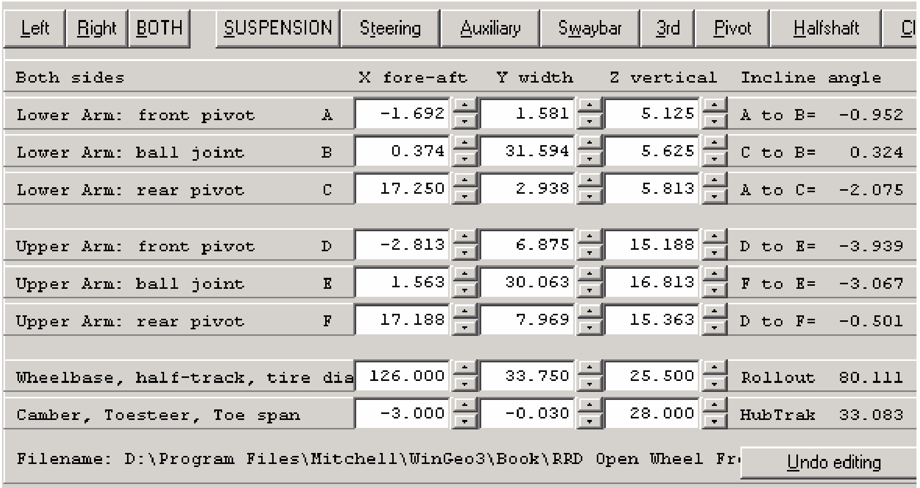
In the example from DemoDrop.gem file, the right side camber is -5.750 degrees. The half-track at ground level is 32.141 inches. At hub height the value is 30.750.

The Track Calculator, as shown in Win 6-2, allows you to specify a hub-height value and a static camber value and see the corresponding ground level value. It will do both right and left sides. However, when using the Advanced WinGeo3 version, the results of these calculations are not automatically applied to the suspension. You must manually enter the desired track value.



Win 6-2

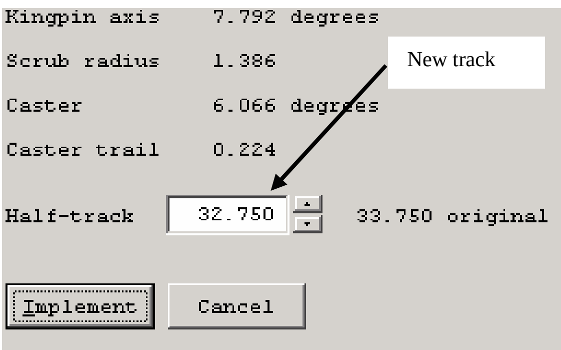
Build: Track Width - Changing the track width moves the ball joints and changes the track. The track is changed by altering the A-arms and preserving the hub/upright and the kingpin parameters. Only the Y-axis (lateral) value is changed. Win 6-3 shows the upper and lower A-arm co-ordinates before the track is changed. Win 6-4 shows both the new track and original track. Once the track has been altered in the track box the *Implement* box must be clicked in order to implement the change. Win 6-5 shows the resulting change in the A-arm **y** co-ordinates. When using *Build Track width* both the upper and lower control arms' y components are changed by the same amount.



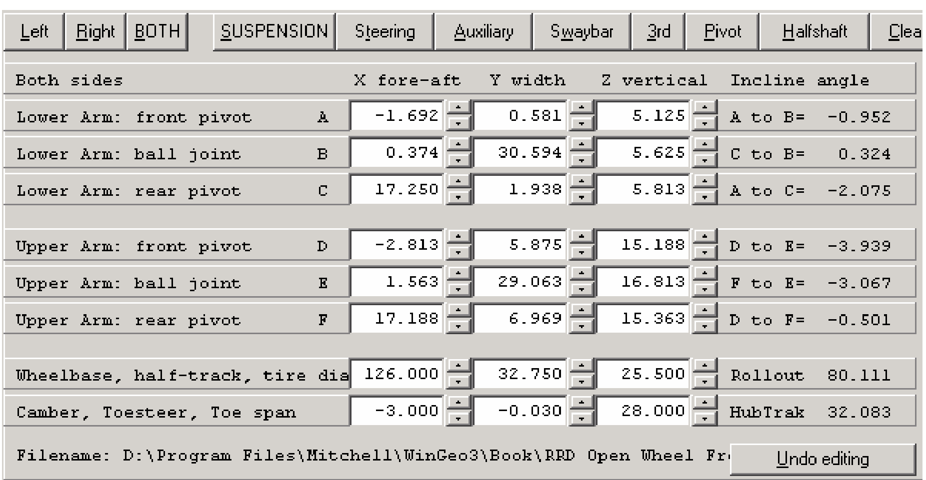
Both sides		X fore-aft	Y width	Z vertical	Incline angle
Lower Arm: front pivot	A	-1.692	1.581	5.125	A to B= -0.952
Lower Arm: ball joint	B	0.374	31.594	5.625	C to B= 0.324
Lower Arm: rear pivot	C	17.250	2.938	5.813	A to C= -2.075
Upper Arm: front pivot	D	-2.813	6.875	15.188	D to E= -3.939
Upper Arm: ball joint	E	1.563	30.063	16.813	F to E= -3.067
Upper Arm: rear pivot	F	17.188	7.969	15.363	D to F= -0.501
Wheelbase, half-track, tire dia		126.000	33.750	25.500	Rollout 80.111
Camber, Toesteer, Toe span		-3.000	-0.030	28.000	HubTrak 33.083

Filename: D:\Program Files\Mitchell\WinGeo3\Book\RRD Open Wheel Fr

Win 6-3



Win 6-4



Both sides		X fore-aft	Y width	Z vertical	Incline angle
Lower Arm: front pivot	A	-1.692	0.581	5.125	A to B= -0.952
Lower Arm: ball joint	B	0.374	30.594	5.625	C to B= 0.324
Lower Arm: rear pivot	C	17.250	1.938	5.813	A to C= -2.075
Upper Arm: front pivot	D	-2.813	5.875	15.188	D to E= -3.939
Upper Arm: ball joint	E	1.563	29.063	16.813	F to E= -3.067
Upper Arm: rear pivot	F	17.188	6.969	15.363	D to F= -0.501
Wheelbase, half-track, tire dia		126.000	32.750	25.500	Rollout 80.111
Camber, Toesteer, Toe span		-3.000	-0.030	28.000	HubTrak 32.083

Filename: D:\Program Files\Mitchell\WinGeo3\Book\RRD Open Wheel Fr

Win 6-5

*****End WinGeo3 Example*****

Wheelbase - Wheelbase is measured in the longitudinal or side view plane from the center of the front wheel to the center of the rear wheel - Figure (6-5). Using WinGeo3 the wheelbase is entered under *Edit / Suspension*.

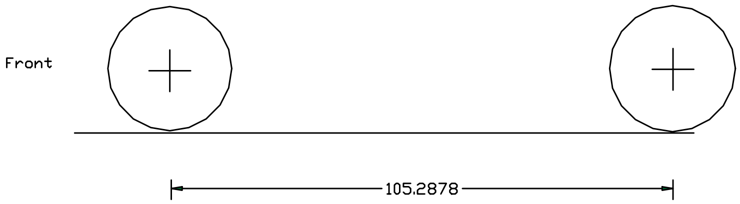


Figure 6-5

Backspacing - Backspacing is the distance from the back face of the center section (the hub mounting surface) to the inboard surface of the rim (the rim surface nearest the chassis centerline) minus the bead width - Figure (6-6).

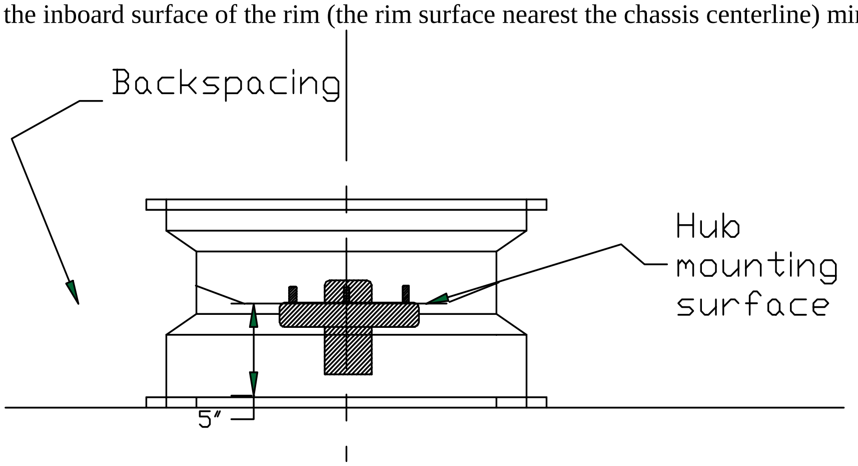


Figure 6-6

Offset - Offset is the distance the hub mounting surface is from the center of the rim - Figure (6-7). If the back face of an 8" rim is in the center of the rim, you have 0 offset and 4" backspacing. If on an 8" rim the backspacing is 3", the offset is 1" out/positive. Rim width is always measured from inside of bead to inside of bead.

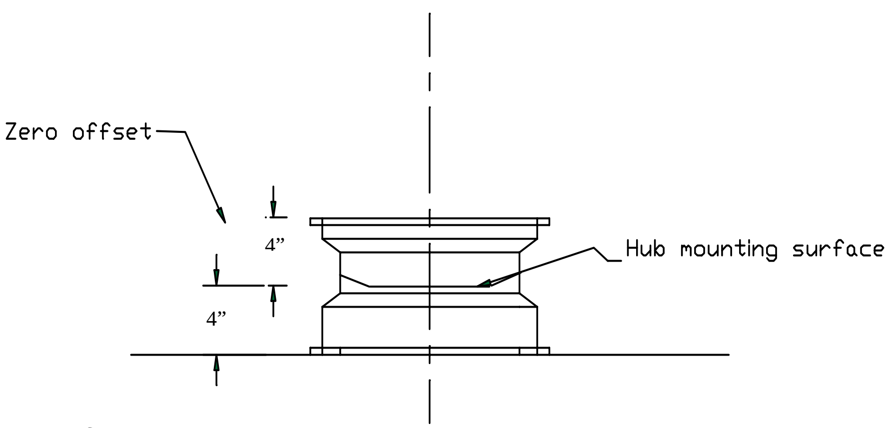


Figure 6-7

****WinGeo3**** – Refer to *Build / Fixture / Enter fixture/spindle point* to work with rim offset.

Uprights and Spindles

The spindle/upright is the heart of the independent suspension system. All suspension design characteristics begin with the spindle co-ordinates. When designing an independent suspension system, if the spindle design is free, the instant centers (as discussed shortly) are most likely the first points the designer will locate. If the spindle co-ordinates are predetermined by the sanctioning body, previous design restraints and/or financial restraints, the instant center locations will, to some extent, be restricted by the current upright/spindle design.

Kingpin Axis and Inclination Angle - The angular difference between true vertical and a line drawn through the center of the upper and lower ball joints as viewed from the front is referred to as the kingpin angle ("Kingpin axis" is a line not an angle)- Figure (6-8). Positive kingpin **angle** has the top ball joint moved towards the chassis and the bottom ball joint moved towards the tire. Kingpin inclination angle is a compromise between scrub radius and weight jacking as will be discussed later in this and subsequent chapters. Adding kingpin angle is used to reduce the kingpin offset moment. Changing the kingpin inclination can also change the steered camber and caster angles, which, in turn, can raise the spindle and lower the chassis or lower the spindle and raise the chassis. This, in turn, changes the amount the springs, bars and dampers are compressed, and, ultimately, the loads at each contact patch. Changing anything changes everything else to some degree or other.

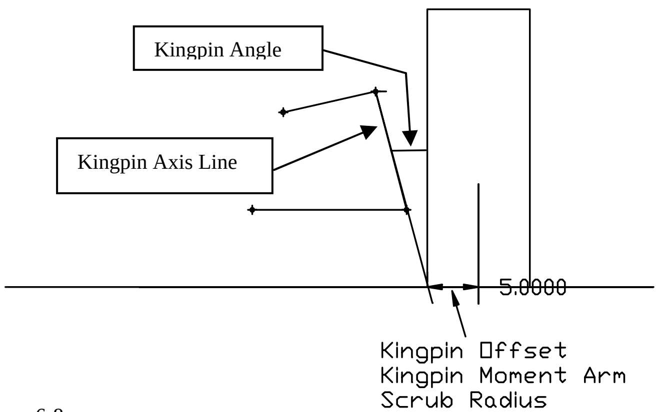
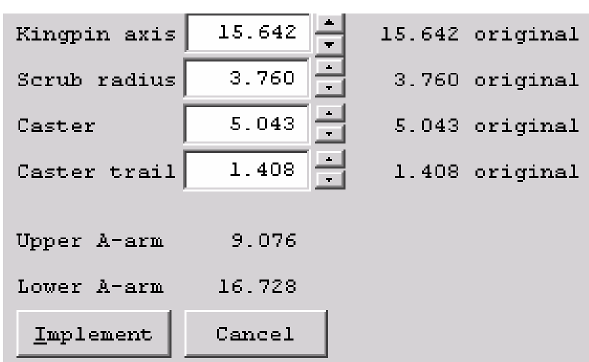


Figure 6-8

*****Begin WinGeo3 Example*****

Design: **Kingpin, Scrub and Caster**

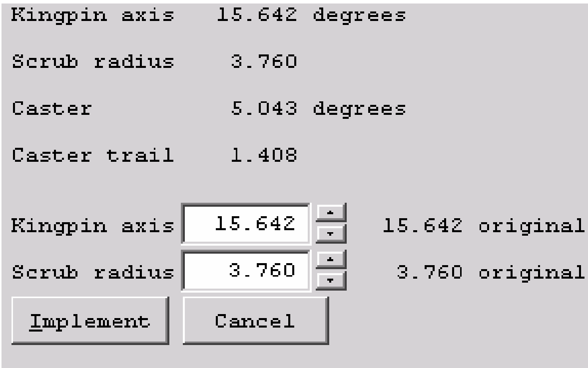
Using this menu, the spindle kingpin axis, scrub radius, caster and caster trail can be modified by modifying the numbers in the upper right hand corner of the page as seen in Win 6-6. Because it **maintains** the original **camber** angle both the spindle and control arm co-ordinates are modified. Going to *Build* / *Fixture* is the best place to view the changes in suspension and upright/spindle co-ordinates. **Changes** made in *Design / Kingpin, Scrub and Caster* **change** the suspension co-ordinates in Edit / Suspension.



Win 6-6

Build: **Caster Angle and Trail**

In this menu the control arms are altered to move the kingpin axis while **preserving** the spindle/upright – Win 6-7. The ball joints are moved **and** the static **camber** is **changed**. Changes made in *Build / Caster angle and trail* changes the control arm co-ordinates in *Files / Edit*.



WinGeo3 6-7

*****End WinGeo3 Example*****

Most designers and race engineers understand the importance of the kingpin offset moment arm. Not as many realize how the very small changes in camber, caster and steering as the result of changing the kingpin angle can dramatically change the loads seen at the contact patches. As we will see later in the book, a change of even 10 lb. of normal load at a contact patch can change the balance of the chassis. A 20 lb. load change can make a considerable change in a chassis' handling. The following tables are a quick first look at how dramatic small changes can be. Table (6-1) has a kingpin angle of 7 degrees and is used as the base setting. Table (6-2) has a larger kingpin angle of 12 degrees and Table (6-3) has a smaller kingpin angle of 2 degrees. Though the resulting camber, caster and steering changes are quite small, the resultant load changes are quite considerable. Once again, this type of exploration is impossible without computers and appropriate software. Later in the book, we will spend time examining actual on track data suspension acquisition.

Table 6-1

Effect of Kingpin Angle Change. **Base Setting** (RF Spring = 900 lb. - LF Spring = 800 lb. - Bar = 268 lb.)						
Kingpin Angle <u>7 Degrees</u> (Base Setting)	Zero Suspension Motion	-1" of Ride Motion (Dive)	1^0 of Roll Motion (Left Turn)	-1^0 of Left Steering Motion (8.395 Dg)	Ride, Roll & Steer Combined	Change From Base Setting
Camber RF	-3.500	-4.465	-3.027	-4.052	-4.740	
Caster RF	5.007	-4.465	5.390	4.921	5.894	
Steering RF	-0.125	-0.348	-0.270	8.395	7.993	
Load RF	-0.000	545.931	1516.434	-325.077	1511.902	
Load LF	-0.000	429.091	-1535.76 *	319.194	-611.511	
Spring RF	0.000	-0.844	-0.489	0.101	-1.199	
Spring LF	0.000	-0.835	0.860	-0.009	-0.476	
Bar Twist	0.000	0.111	5.667	-1.213	4.227	

(* Actual force depends on spring preload)

Table 6-2

Effect of Kingpin Angle Change. **12 Degrees** (RF Spring = 900 lb. - LF Spring = 800 lb. - Bar = 268 lb.)						
Kingpin Angle 12 Degrees	Zero Suspension Motion	-1" of Ride Motion (Dive)	1 Degree of Roll Motion (Left Turn)	-1 of Left Steering Motion (8.395 Dg)	Ride, Roll & Steer Combined	Change From Combined Base Setting
Camber RF	-3.500	-4.778	-3.203	-3.962	-5.122	0.382 (more)
Caster RF	5.007	5.589	5.338	4.931	5.780	0.114 (less)
Steering RF	-0.125	-0.331	-0.261	8.391	7.978	0.015 (less)
Load RF	-0.000	490.832	1351.981	-321.964	1281.862	230.04 (less)
Load LF	-0.000	342.621	-1382.69	316.097	-496.480	-115.03 (less)
Spring RF	0.000	-0.812	-0.473	0.097	-1.152	0.047 (less)
Spring LF	0.000	-0.791	0.461	-0.116	-0.474	0.002 (less)
Bar Twist	0.000	0.184	5.459	-1.289	3.949	0.278 (less)

Table 6-3

Effect of Kingpin Angle Change. **2 Degrees** (RF Spring = 900 lb. - LF Spring = 800 lb. - Bar = 268 lb.)						
Kingpin Angle 2 Degrees	Zero Suspension Motion	-1" of Ride Motion (Dive)	1 Degree of Roll Motion (Left Turn)	-1 of Left Steering Motion (8.395 Dg)	Ride, Roll & Steer Combined	Change From Base Setting
Camber RF	-3.500	-4.235	-2.899	-4.134	-4.475	0.265 (less)
Caster RF	5.007	5.721	5.431	4.915	5.984	0.009 (more)
Steering RF	-0.125	-0.336	-0.264	8.403	8.072	0.079 (more)
Load RF	-0.000	561.399	1562.667	-302.661	1627.851	116.0 (more)
Load LF	-0.000	472.839	-1563.580	291.511	-680.215	- 69.0 (more)
Spring RF	0.000	-0.852	-0.492	0.101	-1.215	0.016 (more)
Spring LF	0.000	-0.851	0.484	-0.082	-0.463	0.013 (less)
Bar Twist	0.000	0.065	5.713	-1.103	4.402	0.175 (less)

All spindles and uprights are designed to have a prescribed kingpin angle built in - Figures (6-9/6-11).

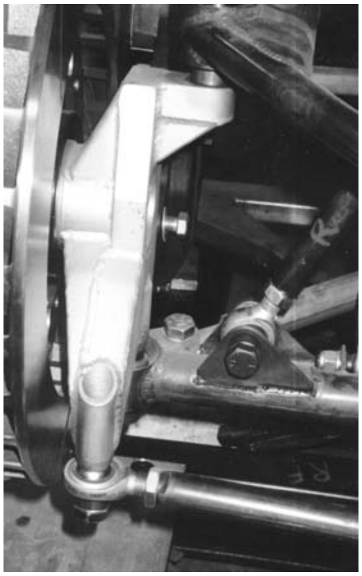


Figure 6-9 – GT Chassis

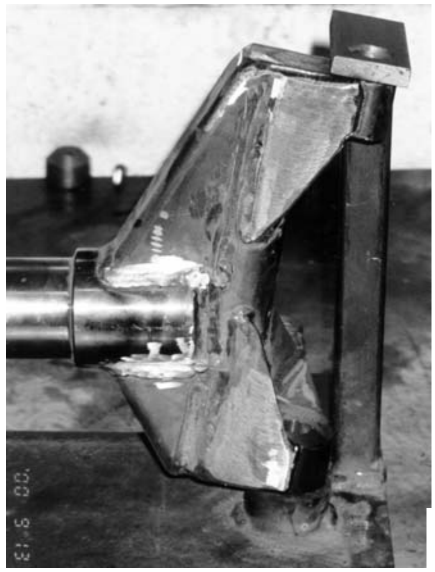


Figure 6-10 – 5x5 Stock Car Spindle

Figure 6-11 – Formula Upright

Kingpin Offset - Kingpin offset is determined by first projecting a line through the upper and lower ball joints to the ground and then measuring the distance from where this line intersects the ground to the center of the tire contact patch (front view) - Figures (6-12). The kingpin offset creates a front view moment arm extending from the center of the tire contact patch to the intersection of the spindle/upright axis with the road surface.

The angle of the kingpin axis will determine the type of force seen at the center of the hub. If the spindle/upright has zero kingpin inclination, the forces at the hub center line will be purely vertical. If the upright/spindle kingpin axis is inclined at some angle other than vertical, the hub will see a resultant force. *Key tuning tool*.

The center of the tire contact patch will not necessarily be at the center of the tire depending on rim offset, suspension geometry and /or lateral forces. The center of the tire contact patch will also move with changes in the tire's rolling radius, shear angle and shear percentage, which, in turn, changes the length of the kingpin offset moment arm.

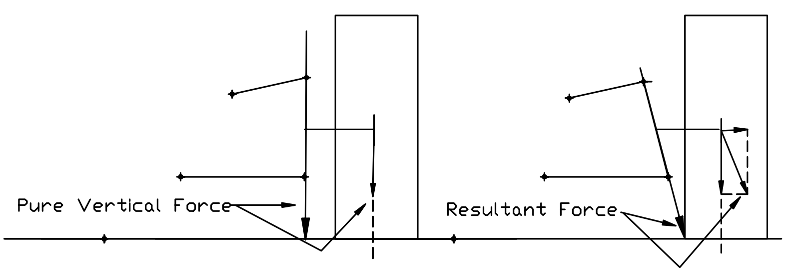


Figure 6-12

- The contact patch turning axis is directly below a point at the vertical centerline of the hub and the rim mounting surface.

- The kingpin offset moment arm and scrub radius are one and the same.

****WinGeo3 Example**** - Use the same WinGeo3 examples as in Kingpin Axis.

Stock Car Spindles - Spindles used on many modern stock cars can be purchased in a semi-finished form from companies such as **Speedway**. All spindle shaft machining is completed but both the lower and upper portions of the spindle are extended and meatier so the team can place the upper ball joint and steering arm/lower ball joint mount co-ordinate anywhere within a prescribed range. Both the upper height and kingpin angle can be changed within a prescribed area with the excess material machined off. Similarly, the lower ball joint and steering arm can be moved up or down a prescribed amount with the excess material machined off - Figure 6-13.

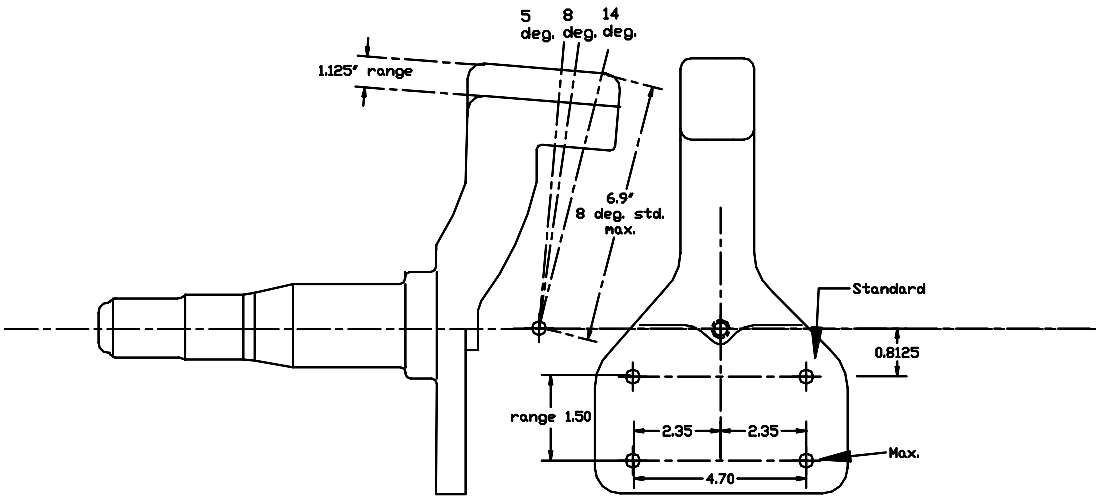


Figure 6-13

The steering arms can also be purchased in a number of different configurations including standard and dropped. Figures 6-14 & 6-15 show a spindle that began life as semi-finished. The steering arm is a dropped design.

Figure 6-14

Figure 6-15

Camber

Camber - The inward or outward tilt of the wheel relative to a vertical line projected through the center of the contact patch is referred to as camber. Negative camber has the top of the tire pointed inwards towards the chassis - Figure 6-16.

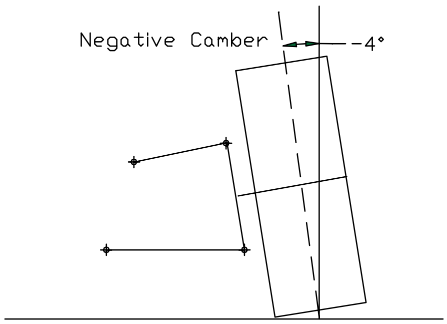


Figure 6-16

Camber Gain (Change in Either Direction) - Camber gain is the amount camber changes in relation to chassis bump and roll. A flat track requires more camber gain (positive at the inside wheel, negative at the outside wheel) than a banked track primarily because on a banked track, you have less body roll i.e. stiffer roll rates and lower overturning moments. When a wheel is moved up in relation to the chassis (bump), it normally results in negative camber gain i.e. both the inside and outside wheels see an increase in negative camber. However, body roll normally results in positive rather than negative outside wheel camber gain and negative gain at the inside wheel. Even when bump and roll are combined, the result may well be a positive and not negative gain at the outside wheel. A computer is needed to run through all the required iterations.

Bump Camber Gain - The direction and rate of camber change during bump is determined by the suspension co-ordinates. The two primary factors which determine camber gain in bump are A-arm/wishbone length and angle.

Bump Camber Gain - A-Arm/Wishbone Length - A shorter upper A-Arm length will result in the arc tightening (horizontal distance between the outer and inner upper control arm mounts decreasing), which, in turn, increases the camber gain rate. Whether the gain is positive or negative depends on the placement of the arc - Figures 6-17 & 6-18.

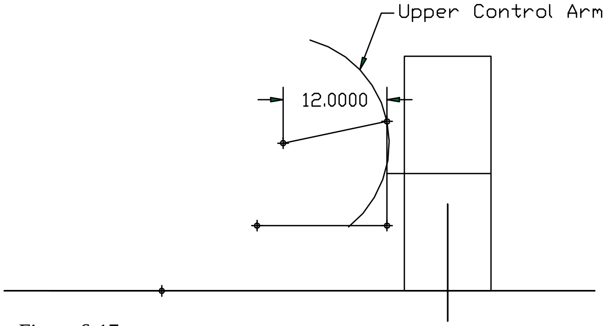


Figure 6-17

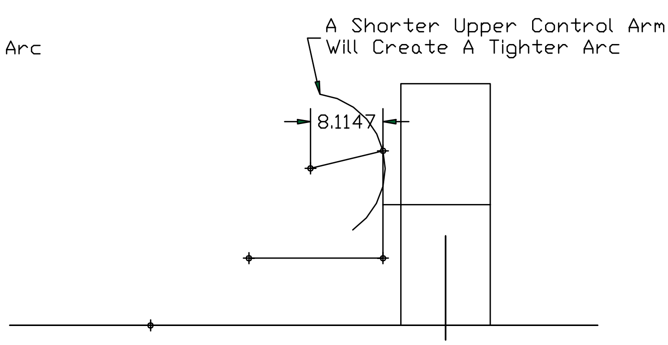


Figure 6-18

Bump Camber Gain - A-Arm/Wishbone Angle - The angle of the upper and/or lower A-Arm, in turn, determines the instant center height and length. Instant centers as discussed later in this chapter are a point of intersection between lines drawn through the upper outer and inner suspension points and the lower outer and inner suspension points (two-dimensional front view) – Figures 6-19 & 6-20.

- As the instant center length is increased, camber gain due to bump slows down i.e. the swing arm (distance between the instant center and the spindle's point of axial rotation) radius increases. The shorter the swing arm radius, the tighter the arc.

- Changing the height of the instant center has somewhat less effect on bump camber change than changing the instant center length.

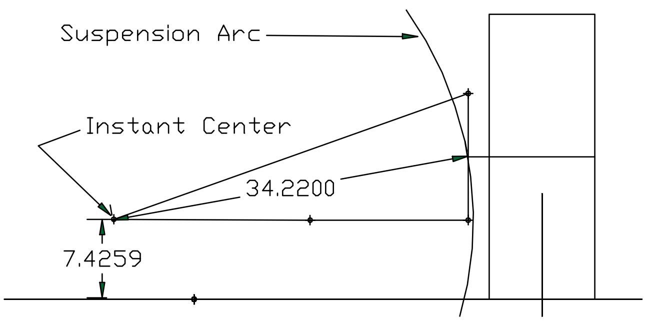


Figure 6-19

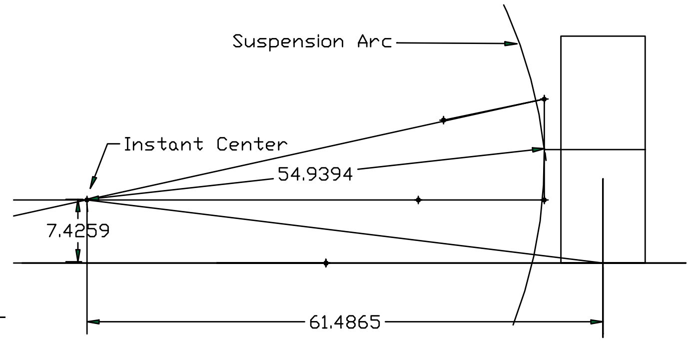


Figure 6-20

Figures 6-21 & 6-22 show portable jigs used to build control arms of different lengths and offsets. Portable jigs are often used during a test session when the team is away from home base and the race engineer wants to try a new control arm length.

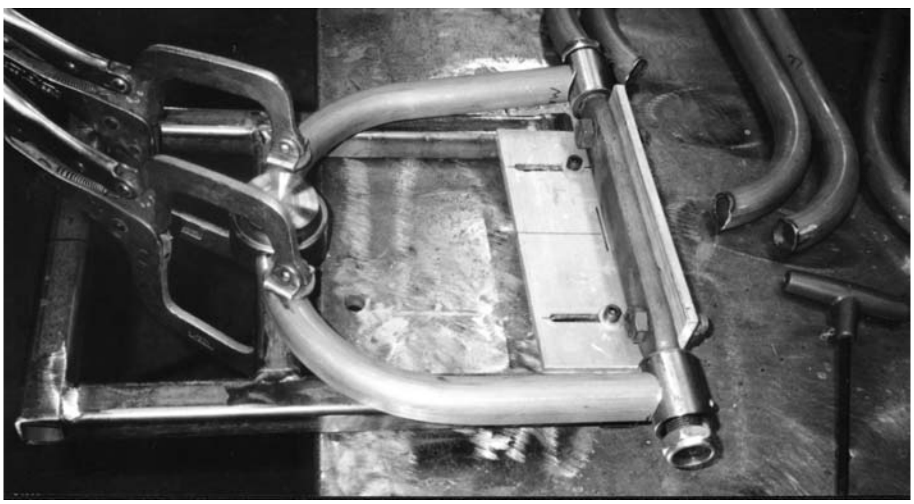


Figure 6-21 – In a five day test session, this jig was used to build eighteen different stock car upper suspension A-Arms.

Figure 6-22 – This portable jig was set up to build all the upper and lower A-Arms for a formula car. One side was designed for the left side suspension while the other side was used for the right side suspension.

Roll Camber Gain - Body roll at the chassis centerline affects camber gain or loss in the opposite direction to suspension bump - Figures 6-23. In this instance, body roll produces positive camber gain on the outside and negative camber gain on the inside. Outside bump would produce negative camber gain while outside droop would produce positive camber gain.

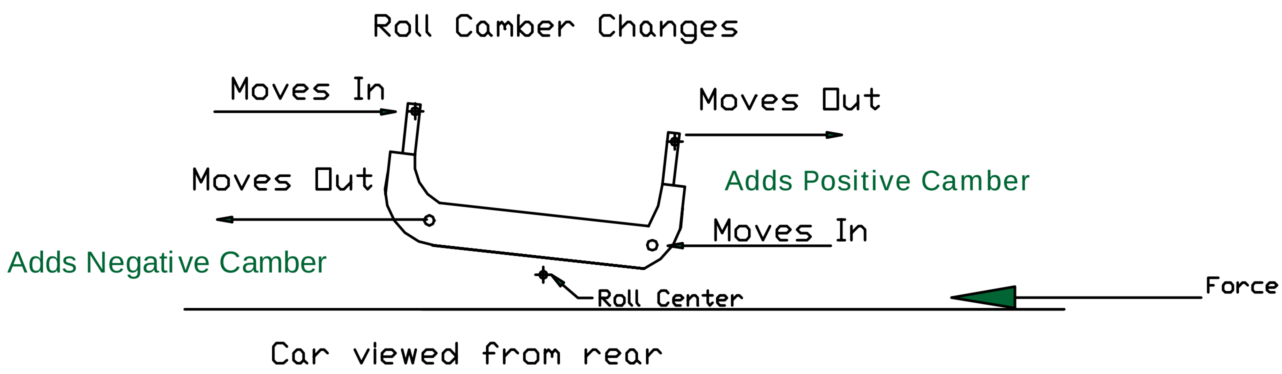


Figure 6-23

Instant Center Location Effects on Camber during Roll:

- Body Roll Camber Change - Instant Center Beyond the Center Line of the Chassis

- Camber angle decreases as the result of body roll when the instant center point is beyond the centerline of the chassis.

- Body Roll Camber Change - Instant Center at the Center Line of the Chassis

    - Camber angle does not change appreciably as the result of body roll when the instant center point is at the centerline of the chassis.

- Body Roll Camber Change - Instant Center Before the Center Line of the Chassis

    - Camber angle increases as the result of body roll when the instant center point is before the centerline of the chassis.

Steering Iterations and Camber Change - Steering angle iterations in combination with bump and/or roll introduces an additional set of camber change iterations.

The amount of camber a car requires depends on the track surface, banking, wheel rates, scrub or lateral displacement, tire width to rim width, tire sidewall height and stiffness (more negative camber is needed with a softer and/or taller sidewall), air pressure, tire compound, car weight, driver style, track temperature etc. To determine the right amount of camber needed, look at tire temperatures, tire surface patterns and tire wear. In spite of what many people think, this is not that easy to do. The only accurate way to observe tire temperature during cornering is with real time infrared data. The bottom line for determining the required camber is the stopwatch versus tire degradation rate. Optimum tire operating temperature is far more important than whether you have a textbook camber temperature profile.