
SUSPENSION AND STEERING GEOMETRY

Competences to be achieved for this skill area:

1. Analyse the characteristics of vehicle suspension geometry by a variety of methods and predict the effect that these characteristics will have on dynamic vehicle behaviour.

Range

effect of wheel alignment, caster, camber, kpi, roll centre height and steering offset on straight line stability, cornering behaviour and driver feedback.

camber, toe in and roll centre height changes that occur from bump to rebound wheel travel with different suspension systems.

how suspension travel induced geometry changes can be used to obtain specific cornering characteristics and driver feedback.

how anti-squat and anti-dive suspension geometry uses torque reaction on the suspension linkage to reduce vehicle attitude changes during braking and acceleration.

determination of vehicle roll centre and its influence on vehicle suspension behaviour .

2. Analyse the characteristics of vehicle steering geometry

Range

differentiation between oversteer and understeer.

use of a graphical technique to predict the cornering behaviour of a vehicle in terms of front and rear slip angles and yaw angle.

compromise involved in adopting true ackerman steering.

Learning exercise to enable these competences to be achieved

The assignments are designed as learning assignment as well as an assessment assignment on part of the content of this skill area

SUSPENSION AND STEERING GEOMETRY

Before and during the assignment you will be able given a number of lectures and class exercises to enable you to obtain the necessary skills and competences to successfully complete this skill area and complete the assignment.

Read the various references given in this handout as well as the notes on roll and steering geometry that are included. This will cover the basic information on suspension geometry that you will need.

Answer the various questions given in the handout and complete the exercise on roll centre geometry and steering geometry. The questions and your answers will then be discussed in class before the assignment begins.

Many of the references will cover the same information though different authors may have different view points on a particular subject. By reading a number of these references a clearer understanding of the problem can often be achieved..

Do not expect to always find the answer in the same form as the problems are set. It is possible that the answer may be obtainable only after combining several pieces of information.

You may find it helpful to use the simple wheel geometry models or drawing instruments to help you answer some of the questions.

Recommended reading

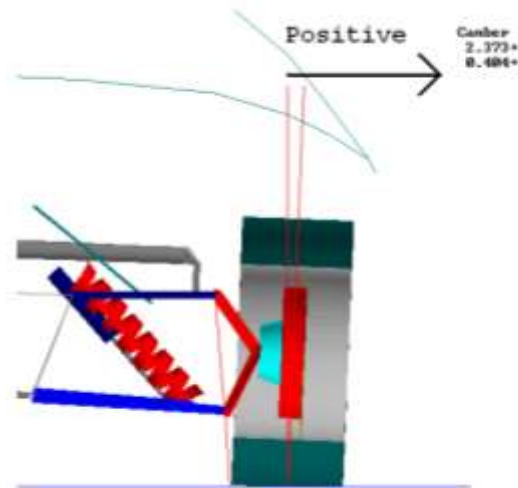
Advanced Vehicle Technology	Hienz Heisler	Sec. 10.1.1 to 10.1.5 Sec 10.2 Sec. 10.6.1 to 10.8.3
Automobile Suspensions	Colin Cambell	Ch. 4 and 5
Car Suspensions and Handling	Donald Bastow	Ch. 6 and 7
Fundamentals of Motor Vehicle Technology	Vic Hillier	
How to Make your Car Handle	Fred Puhn	
Race and Rally Source Book	Allan Staniforth	
Competition Car Suspension	Allan Staniforth	
Introduction to Race Car Engineering	Warren Rowley	Ch1

Questions on suspension geometry

1. What effect does KPI have on the camber of the wheel when it is:-
 - a. on the inside of a turn?
 - b. on the outside of a turn?
2. What effect does KPI have on the relative vertical position of wheel and body during steering?
3. How does positive and negative offset affect vehicle behaviour in the event of a puncture.
4. How will front wheel alignment affect vehicle stability when due to a side force one front wheel aligns with the direction of travel with:
 - a. toe out?
 - b. toe in?
5. What effect does castor have on wheel camber during a turn?
6. What effect will wheel camber have on cornering behaviour?
7. Describe the camber change behaviour of the following combinations of wishbones lengths and inclinations on both "bump" and "rebound" travel.
 - a. equal length parallel
 - b. equal length inclined inwards
 - c. equal length inclined outwards
 - d. unequal length parallel
 - e. unequal length inclined inwards
 - f. unequal length inclined outwards
8. What camber does the ideal suspension system aim to maintain at all times?
9. How might the fitting of over wide wheels with incorrect offset to a car effect its behaviour in the event of a puncture?
10. Explain how anti squat and anti dive characteristics can be incorporated into a wishbone type of suspension.

The following notes are taken from a variety of sources. WinGeo3 is used extensively and the source material for this can be found in the Values section of the WinGeo3 Help files.

Camber (from WinGeo3)



SAE: CAMBER ANGLE - The inclination of the wheel plane to the vertical. It is considered positive when the wheel leans outward at the top and negative when it leans inward.

The Camber Angle is measured in degrees.

SAE: RATE OF CAMBER CHANGE - The change of camber angle per unit vertical displacement of the wheel centres relative to the sprung mass.

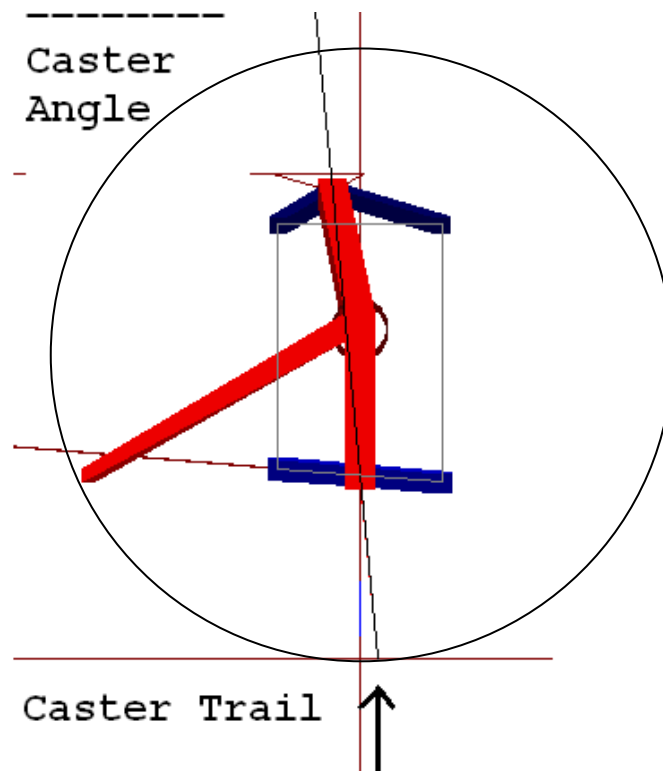
The Rate of Camber change is degrees per inch (standard) or degrees per mm (metric).

The static camber angle is entered in Edit: Suspension
The top value shown is the camber angle in degrees.

The lower value is the Rate of Camber Change, or $d\text{Camber} / d\text{Ride}$. This is not quite the same as the SAE definition because it is the change in camber per unit change in Ride, not the wheel centre. Because changes in camber will change the height of the wheel centre. This is a very small difference.

A tyre produces maximum braking or acceleration when it is flat on the ground, or camber = 0. A tyre produces maximum lateral force when it is leaned into the turn because that produces camber thrust. This would mean positive camber on the inside tyre and negative camber on the outside tyre. Designing a suspension to meet these conflicting goals is the art of the designer. For oval track cars the challenge is easier because the car only turns left (or right in Australia) and the car can have significant positive static camber on the inside tyre and negative static camber on the outside tyre.

Caster and Caster Trail (from WinGeo3)



SAE: CASTER ANGLE - The angle in side elevation between the steering axis and the vertical. It is considered positive when the steering axis is inclined rearward (in the upward direction) and negative when the steering axis is inclined forward.

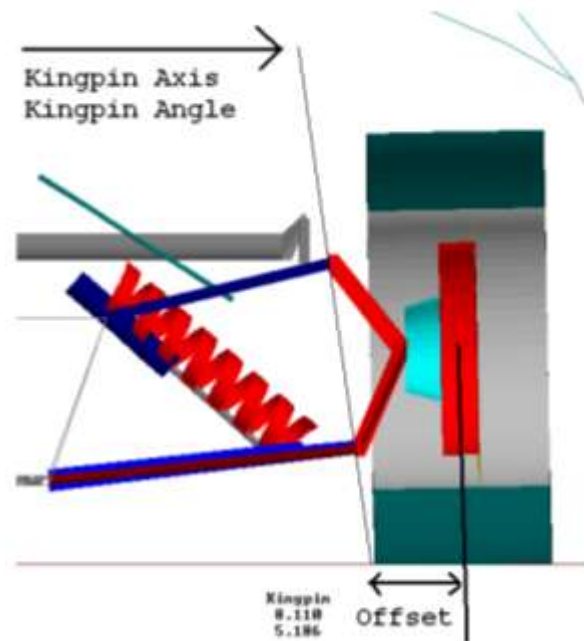
SAE: RATE OF CASTER CHANGE - The change in caster angle per unit vertical displacement of the wheel centre relative to the sprung mass.

SAE: CASTER OFFSET or TRAIL - The distance in side elevation between the point where the steering axis intersects the ground, and the centre of tyre contact. The offset is considered positive when the intersection point is forward of the tyre contact centre and negative when it is rearward.

The top value is the caster angle.

The lower value is the caster trail or caster offset.

Kingpin Angle and Offset (from WinGeo3)



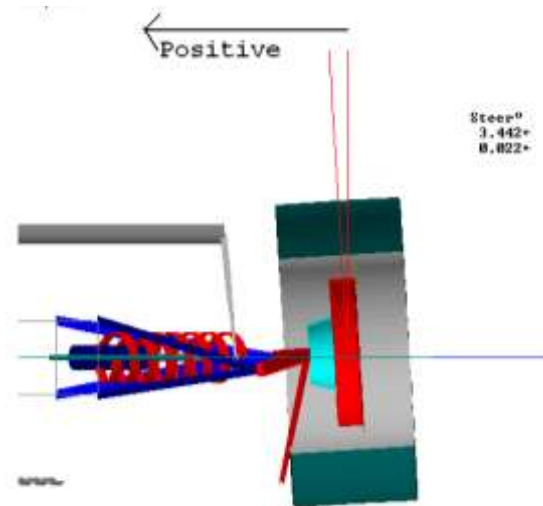
SAE:KINGPIN INCLINATION - The angle in front elevation between the steering axis and the vertical.

SAE: KINGPIN OFFSET - Kingpin offset at the ground is the horizontal distance in front elevation between the point where the steering axis intersects the ground and the centre of tyre contact.

The kingpin offset at the wheel centre is the horizontal distance in front elevation from the wheel centre to the steering axis.

The top value is the kingpin inclination in degrees, 8.110 degrees in the example
The lower value is the kingpin offset at the ground, 5.186 inches in the example
This is sometimes called **scrub radius**.

Toesteer (from WinGeo3)



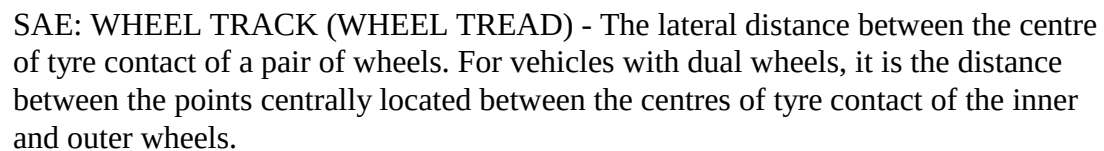
SAE: STATIC TOE ANGLE (Degrees) - The static toe angle of a wheel, at a specified wheel load or relative position of the wheel centre with respect to the sprung mass, is the angle between a longitudinal axis of the vehicle and the line of intersection of the wheel plane and the road surface. The wheel is in “toed-in” if the forward portion of the wheel is turned toward a central longitudinal axis of the vehicle, and “toed-out” if turned away.

SAE: STATIC TOE (inches or millimeters) - Static toe-in or toe-out of a pair of wheels, as a specified wheel load or relative position of the wheel centre with to the sprung mass, is the difference in the transverse distances between the wheel planes, taken at the extreme rear and front points of the tyre treads. When the distance at the rear is greater, the wheels are “toed-out” by this amount; and when smaller, the wheels are “toed-out”.

Note that the SAE definition of STATIC TOE matches the RbyN definition when you select to measure toe in inches or millimeters, and when the Toe-Span is the same as the tyre diameter.

SAE does not assign a sign to STATIC TOE ANGLE. I have assumed positive steer angles denote a “toed-in” condition on both wheels.

The right wheel in a left turn is shown. The upper number is toe in degrees. The lower number is $d\text{Steer} / d\text{Ride}$, the rate of change of steer. This reflects bump-steer.



SAE: RATE OF TRACK CHANGE: - The change in wheel track per unit vertical displacement of both wheel centres in the same direction relative to the sprung mass.

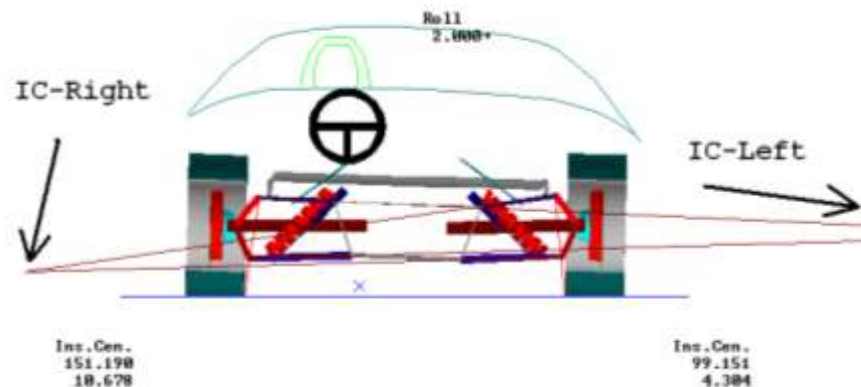
Scrub is track change; the lateral movement of the tyre contact patch. The top number is Scrub

The lower value is the Rate of Scrub Change, or $d\text{Scrub} / d\text{Ride}$. This is not quite the same as the SAE definition because it is the change in track change per unit change in Ride, not the wheel centre. Because changes in camber will change the height of the wheel centre. This is a very small difference.

Scrub is the only suspension value that depends upon the rotation point. Moving the rotation point vertically and then rolling the chassis causes a lateral movement that shows up as scrub. See Rotation Point form

Scrub can be predicted from the location of the instant centre. See Fundamental Analysis form

Instant Centre (from WinGeo3)



SAE: SWING CENTRE: - That instantaneous centre in the transverse vertical plane through any pair of wheel centres about which the wheel moves relative to the sprung mass.

SAE: SWING-ARM RADIUS: - The horizontal distance from the swing centre to the centre of tyre contact.

For Double A-arm suspensions the Instant Centre is determined by drawing one line from the upper ball joint through the upper A-arm perpendicular to the centreline of the car. Another line is drawn from the lower ball joint through the lower A-arm perpendicular to the centreline of the car. The intersection of these lines is the Instant Centre. This point has implications for kinematics and for force computations.

Please note that the instant centre of the right side wheel is usually on the left side of the vehicle. The values for the right side wheel are shown below the right tyre. In the example shown below the right side wheel has a swing arm distance of 99.151 inches and an instant centre height of 4.304 inches. The swing arm distance is not quite the same as the SAE swing-arm radius because the distance is from the centre of tyre contact to the instant centre, not the horizontal distance. The distance is the square root of the radius squared plus the height squared.

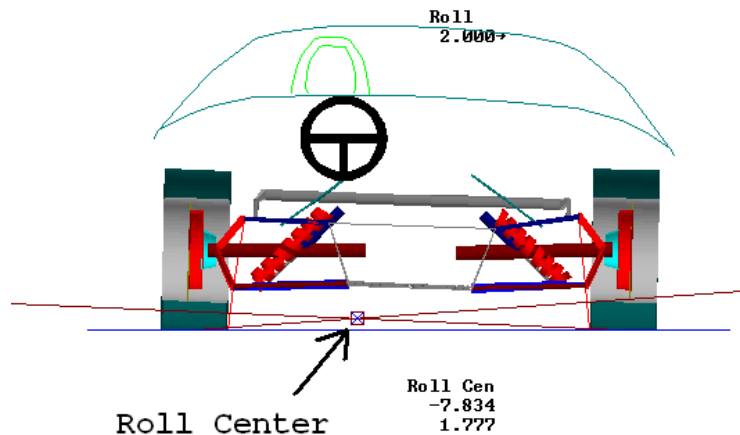
In the example shown below:

Instant Centre height	4.304
Swing Arm Radius	99.058
Swing Arm Distance	99.151

The left side wheel has a swing arm distance of 151.190 inches and a height of 10.678 inches.

Instant Centre height	10.678
Swing Arm Radius	150.812
Swing Arm Distance	151.190

Kinematic Roll Centre (from WinGeo3)



SAE - ROLL CENTRE - The point in the transverse vertical plane through any pair of wheel centres at which lateral forces may be applied to the sprung mass without producing suspension roll.

This SAE definition is generally considered the force roll centre. The example below shows the kinematic roll centre, which is the intersection of lines drawn from the tyre contact point to the respective instant centre. This is the point about which the sprung mass can roll without

See Values: Force-Based Roll Centre

The top value is the Y-axis (lateral) location of the kinematic roll centre. Positive values are right of the vehicle centreline. Negative values are to the left. In the example below the kinematic roll centre is 7.834 inches to the left.

The lower value is the Z-axis (vertical) location of the kinematic roll centre. In the example below the kinematic roll centre is 1.777 inches above ground.

NOTE: These locations are in the RbyN coordinate system, not the user's coordinate system.

DETERMINATION OF ROLL CENTRE POSITION

The **KINEMATIC ROLL CENTRE** of a vehicle can be defined as the instantaneous centre of rotation of the body assuming that the wheels are rigid and do not move sideways on the road.

The Society of Automotive Engineers (SAE) define the roll centre as the point in the transverse vertical plane through any pair of wheel centres at which lateral force may be applied to the sprung mass without producing suspension roll this constitutes an idealised concept and does not represent a true instantaneous centre of rotation of the sprung mass.

The **ROLL AXIS** is the line joining the front and rear roll centres of the car. Work through the exercise following to determine the roll centre of various suspension systems using the techniques demonstrated in class.

Then consider the effect on geometry and vehicle behaviour of having the roll centre:-

- at high level or coincident with the CG
- at ground level
- below ground level

To determine the Roll Centre of a suspension system

Refer to Fig. 1

A suspension system can be considered as 3 linked objects:

- the wheel **W**
- the body **B**
- the ground **G**

Each pair of objects is linked by an instantaneous centre of rotation or centro **I**.

I_{BG} is the centro of the body relative to the ground more commonly known as the **Kinematic Roll Centre**.

I_{WB} is the centro of the wheel relative to the body which is the swing arm pivot.

I_{WG} is the centro of the wheel relative to the ground which is the centre of contact between tyre and ground. It therefore forms a pivot permitting the top of the wheel to pivot inwards or outwards.

The Kennedy Arronhold theorem states that :-

"The centros of each of the three pairs selected from three objects lie on a straight line".

It can be seen therefore that the Kinematic Roll Centre (RC) I_{BG} must lie on the same line as I_{WB} and I_{WG}

To find the RC for the short swing arm suspension shown in Fig 1.

Draw a line through I_{WG1} and I_{WB1} . The roll centre must lie on this line.

Repeat for I_{WG2} and I_{WB2} and where the lines intersect must be the roll centre .

For more complex suspension systems the centro I_{WB} must first be found by determining the intersection of lines drawn through inclined links or, if linear movement is produced, by assuming the centro is at infinity. See Fig. 2a and 2b.

Using the same technique find the roll centre for the common independent suspension systems shown in Fig 3.

Sketch in the roll centres for the rigid axle layouts in Fig 4

Consider the following roll centre positions :

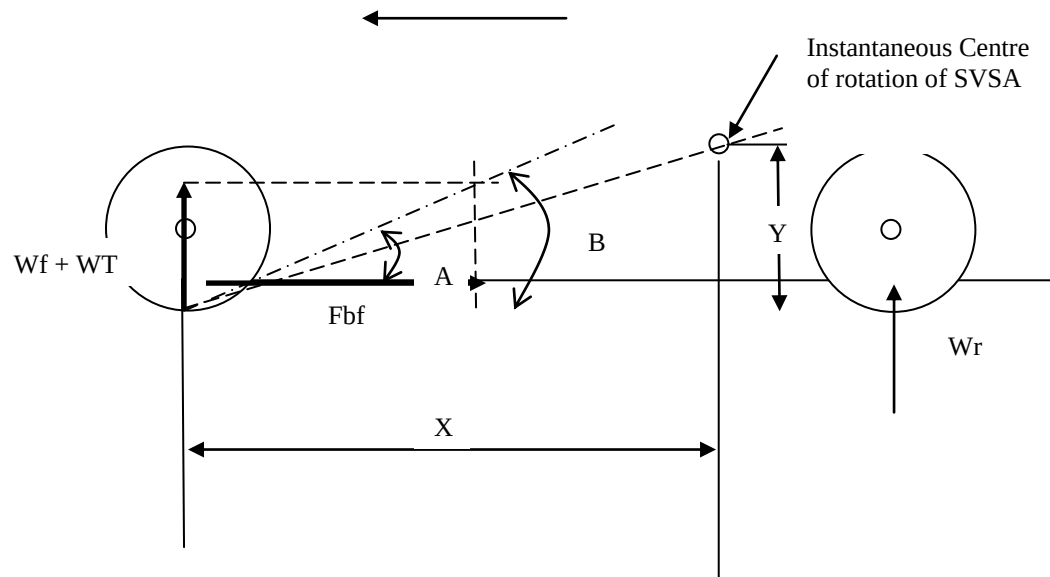
- around wheel centre height
- at ground level
- below ground level

and then comment on the effect that they would have on the suspension behaviour in terms of :

- camber change during bump to rebound suspension travel
- lateral movement of the centre of gravity
- lateral scrub of the tyre during bump to rebound suspension travel

ANTI DIVE GEOMETRY

Determination of proportion of antidive for normal outboard brakes



W_f and W_r = static loads

WT = Weight transfer

$$\tan A = Y/X$$

$$\tan B = (W_f + WT_f) / F_{bf}$$

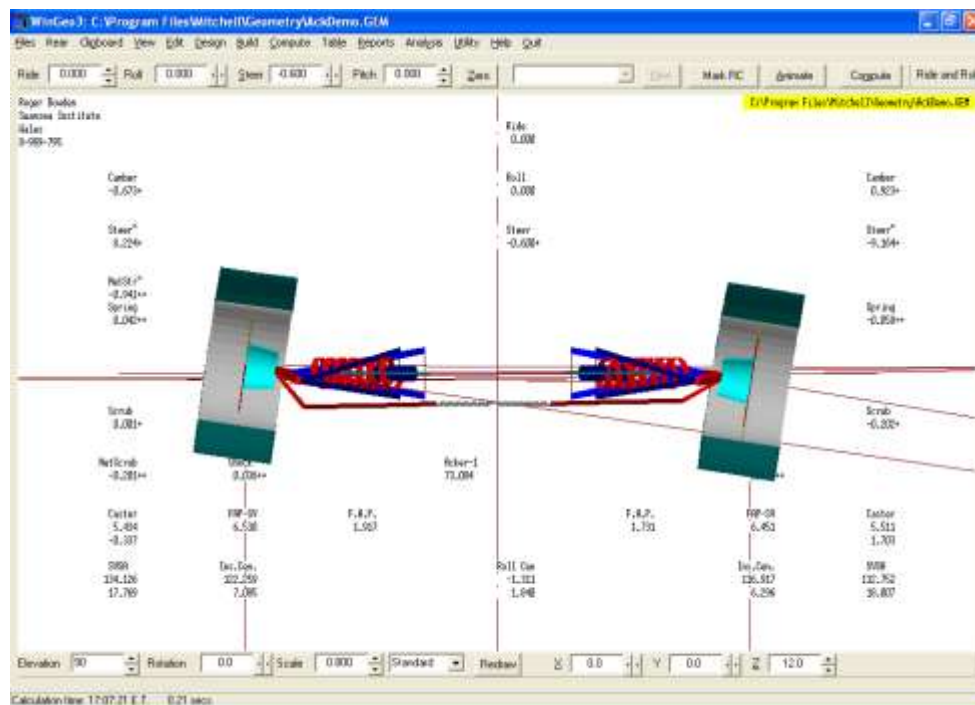
$$\text{Anti-dive \%} = (\tan A / \tan B) \times 100$$

Steering geometry

Georges Langensperger is attributed with solving the steering geometry problem needed to maintain the wheels perpendicular to their arc of motion for stub-axle steering for carriages in 1816. Ackermann recognized the importance of this and, acting as an agent of Langensperger, took out British patents. And as a consequence the term Ackermann steering is universally associated with this type of steering geometry

Both sides		X fore-aft	Y width	Z vertical	Check distance		
Lower Arm: front pivot	A	-3.000	3.800	8.500	A to B= 17.757	Kingpin axis	6.983 degrees
Lower Arm: ball joint	B	0.000	27.000	6.750	C to B= 17.757	Scrub radius	5.173
Lower Arm: rear pivot	C	3.000	9.500	7.000	A to C= 6.021	Caster	5.466 degrees
Upper Arm: front pivot	D	-3.000	12.800	16.000	D to E= 13.578	Caster trail	0.646
Upper Arm: ball joint	E	1.000	25.720	17.200	F to E= 13.129	Upper A-arm	12.976
Upper Arm: rear pivot	F	3.000	12.800	16.000	D to F= 6.000	Lower A-arm	17.500
Wheelbase, track, tire diameter		100.000	66.000	24.500	Rollout 76.969	Track at ground	66.000
Camber, Toesteer, Toe span		0.000	0.000	28.000	HubTrak 29.000	Track at hub	66.000
Tire contact patch		0.000	33.000	0.000	B to E= 10.575		

Filename: C:\Program Files\Mitchell\Geometry\AckDemo.GEM Undoing



Ackermann Steering

There are two different ways to calculate Ackermann. The classic constructs lines perpendicular to the wheels and determines a turn centre. This has problems when there is static toesteer, so it is calculated to correct for static toesteer. The other uses the percentage of classic Netsteer. The user can select one or both from

Turn Centre perpendicular Acker-1

Percentage of classic Netster Acker -2

Turn Centre perpendicular Acker-1

The traditional way of constructing Ackermann based on the use of the intersection of the steering arms is no longer used in the current WinGeo3 software.

These values show the Ackermann values for a pair of files. The black value of 74.98% represents the Ackermann for AckDemo1. The red value of 97.296% represents the Ackermann for AckDemo2.

Acker-1 is the Ackermann value constructed by drawing lines perpendicular to the wheels. Their intersection is the projected back to the wheelbase of the chassis and is selected on the utility menu of WinGeo3

Ackermann Analysis

The classic definition constructs perpendiculars from both front wheels. Their intersection is the instant centre. This point is then projected back to the centreline of the chassis. If the projection is at the rear axle then there is 100% Ackermann.

Example of Ackermann Analysis:

Wheelbase is 2540 mm

Turn radius 9808 mm

Ackermann (based on turn centre)

Assume the turn centre is at $x = 2290\text{mm}$ and $y = 8779\text{ mm}$.

With the turn centre inside the wheelbase this vehicle has more than 100% classic Ackermann.

The actual value is $\text{Ackermann \%} = 100 * \text{Wheelbase} / \text{Position of turn centre}$
 $= 100 \times (2540/2290) = \mathbf{110.891\%}$

If the intersection is beyond the rear axle where is less than 100% classic Ackermann. This definition was changed in the Mitchell WinGeo3 software on April 30, 2006.

The circles represent the wheelbase. If the Toesteer perpendicular projects back to the rear axle there is 100% Ackermann. The graphic scale can be changes with a multiple value.

Percentage of Classic Netsteer Acker-2

An alternative analysis constructs the steer angle for the inside wheel to achieve classic Ackermann. This provides a netsteer value for classic Ackermann. The Netsteer Ackermann value is the percentage difference between actual and classic Netsteer.

The proper way to examine relative steering is to examine Netsteer over a range of chassis motion and steering inputs. Ackermann analysis provides a quick answer but is not the ultimate answer.

Calculation of Ackermann %

Wheel base = 2540 mm

Centre of turn x dimension = 2290 mm

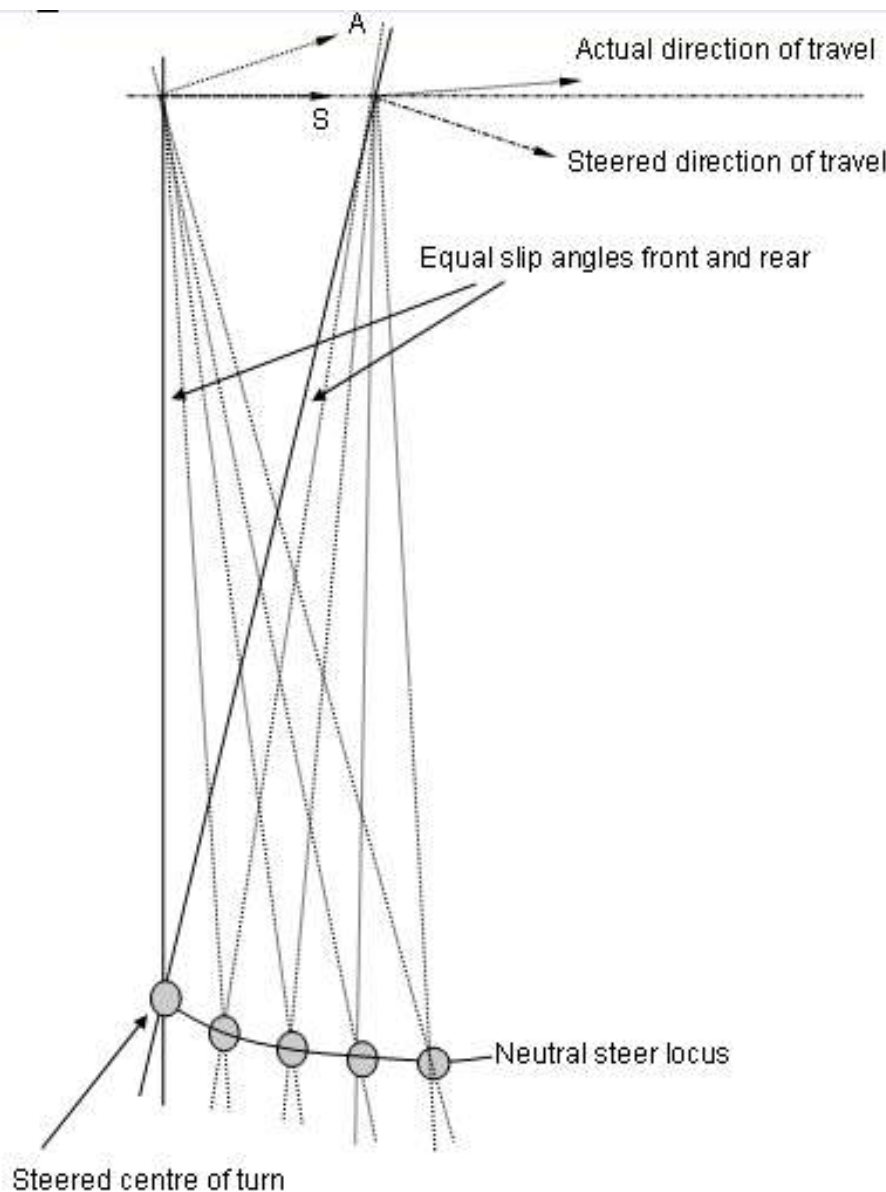
Ackermann = $100 \times (2540/2290) = 110.891\%$

Oversteer and Understeer

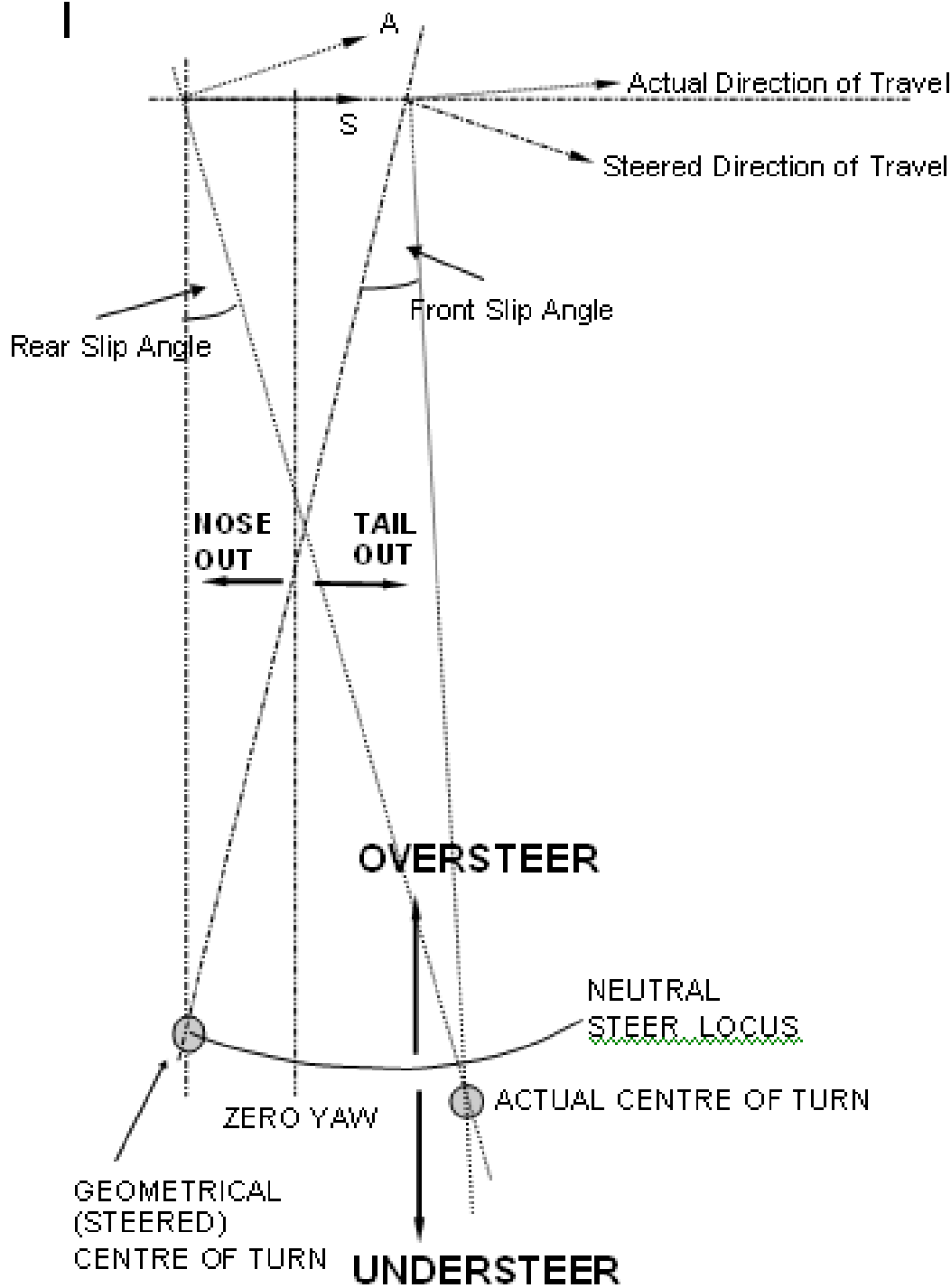
The techniques you will need for this exercise will be explained in class.

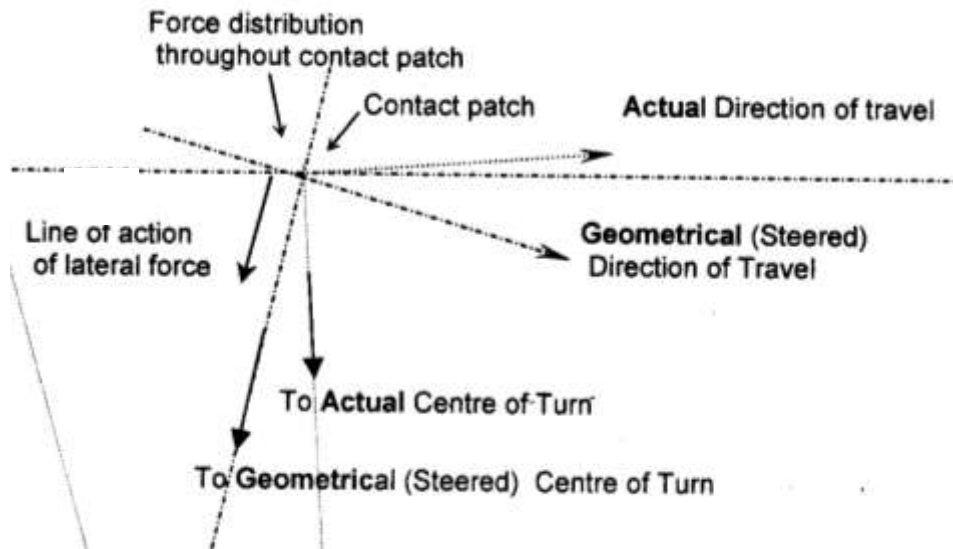
The basic relationship between front and rear slip angles, yaw and steering attitude is summarised in the diagram of Steering Geometry. The construction of the neutral steer locus shown in that diagram is demonstrated below and is produced from a range of equal front and rear slip angles

Construction of Neutral Steer Locus



Steering Geometry





Detail of distribution of lateral force in the cornering tyre

Steering Geometry Class Exercise

Draw the steering geometry diagrams for the following cases to determine the missing information required to complete the following table:-

Case No.	1	2	3	4
Wheel base (m)	3	3	3	3
Turn Radius (m)	20	20	20	20
Yaw Angle	2 T.O.	2 N.O.	2 N.O.	*
Front Slip Angle	*	2	*	8
Rear Slip Angle	8	*	2	6.5
Steering Mode	*	*	*	U.S.

T.O. = Tail Out
 N.O. = Nose Out
 U.S. = Understeer
 O.S. = Oversteer