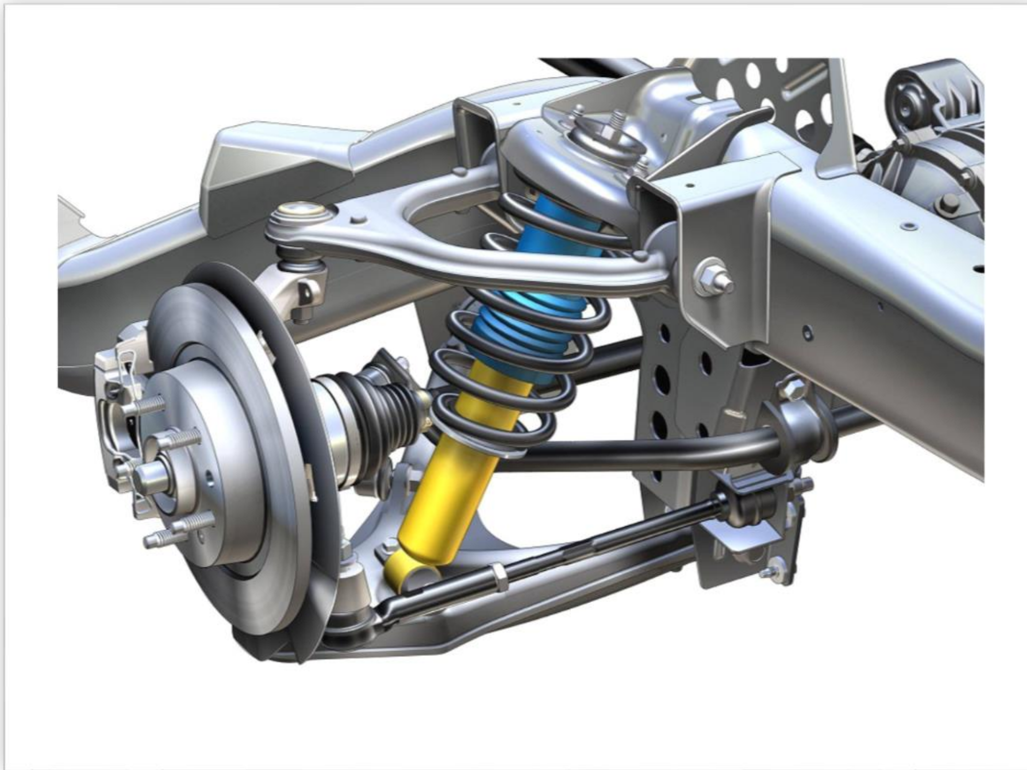

Designing A Suspension System

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ACKNOWLEDGEMENT

First of all, I would like to thank EISystems for providing me an opportunity to work on this project. I would also like to express my gratitude to Mr. Aditya Sharma for his constant support and guidance without whose help this project could not have been completed.

INTRODUCTION

The suspension system of a vehicle consists of tires, tire air, springs, dampers, shock absorbers and linkages that connects the chassis to the wheels and allows relative motion between the two. The suspension system affects the riding quality and the performance of the car which are complimentary to each other. So, for an optimum riding quality and performance the design of the suspension system should be well thought through. The suspension also helps the wheels to maintain contact with the road surface to maintain traction. The suspension also protects the vehicle itself and any cargo or luggage from damage and wear. The design of front and rear suspension may be different.

OVERVIEW

HISTORY

Henry Ford’s Model T used a torque tube to restrain this force, for his differential was attached to the chassis by a lateral leaf spring and two narrow rods. The torque tube surrounded the true driveshaft and exerted the force to its ball joint at the extreme rear of the transmission, which was attached to the engine. A similar method was used by the late-1930s Buick and by Hudson's bathtub car of 1948, which used helical springs which could not take fore-and-aft thrust.

The Hotchkiss drive, invented by Albert Hotchkiss, was the most popular rear suspension system used in American cars from the 1930s to the 1970s. The system uses longitudinal leaf springs attached both forward and behind the differential of the live axle. These springs transmit the torque to the frame. Although scorned by many European car makers of the time, it was accepted by American car makers because it was inexpensive to manufacture. Also, the dynamic defects of this design were suppressed by the enormous weight of US passenger vehicles before implementation of the Corporate Average Fuel Economy standard.

Another Frenchman invented the De Dion tube, which is sometimes called "semi-independent". Like a true independent rear suspension, this employs two universal joints or their equivalent from the centre of the differential to each wheel. But the wheels cannot entirely rise and fall independently of each other; they are tied by a yoke that goes around the differential, below and behind it. This method has had little use in the United States, though it does not evidence the bump steer that a more expensive, true independent suspension does. Its use around 1900 was probably due to the poor quality of tires, which wore out quickly. By removing a good deal of un-sprung weight, as independent rear suspensions do, it made them last longer.

OBJECTIVE

The main objective of this project is to design and analyze the entire double wishbone for improving stability, handling and safety of the performance car. Designing has been done considering the dynamics of the vehicle along with minimizing the sprung mass.

LITERATURE ASPECT

IMPORTANT TERMS

- ### Un-sprung Mass:

In a ground vehicle with a suspension the un-sprung mass or the un-sprung weight is the mass of the suspension, wheels or tracks (as applicable) and other components directly connected to them rather than supported by suspension. It includes mass of components like wheel axles, wheel bearings, wheel hubs, tires, and a portion of the weight of the driveshafts, springs, shock absorbers and suspension links

- ### Sprung Mass

The rest of the mass of the body which are supported by the spring system is called the sprung mass.

- ### Instantaneous Center

It is the imaginary point about which the un-sprung mass can be assumed to rotate during cornering.

- ### Roll Center

It is the imaginary point about which the sprung mass can be assumed to rotate during cornering. If there is a difference between the center of mass and the roll center, a moment arm is created. The size of the moment arm dictates how much the vehicle will roll.

Determination of roll center plays a very important role in deciding the geometry of the wishbones. Roll center and ICR is determined because it is expected that all three elements, the upper wishbone, the lower wishbone and the tie rod should follow the same arc of rotation during suspension travel. Initially the wishbone length is decided on the basis of trackwidth and chassis mounting. Height of roll center above or below the ground affects the camber change characteristics. Its position to the left or right of the centerline of the car will determine how the suspension will react to the dynamic forces which will influence the handling of the car while cornering.

- ### Camber Change Rate (CCR)

CCR is defined as the ratio of the change in the camber angle to the total wheel travel.

- ### Front View Swing Arm Length (FVSA length)

The FVSA length controls the roll center height, camber change rate and tire lateral scrub

$$\tan CCR = \frac{1}{FVSA}$$

THEORY

FUNCTIONS OF THE SUSPENSION SYSTEM

- Its supports the weight of the vehicle
- It allows the vehicle to maintain proper ground clearance
- It maintains proper alignment
- It reduces shock forces
- It helps to maintain traction between tire and road

TYPES OF SUSPENSION SYSTEMS

1. Independent Suspension

It allows each wheel on the same axle to move vertically i.e. react to a bump on the road independently of the others. This type of suspension usually offers better ride quality and handling due to less un-sprung weight e.g. Double Wishbones, MacPherson Strut

2. Dependent Suspension

There is a rigid linkage between the two wheels of the same axle. A force acting on one wheel will affect the opposite wheel. It is mostly employed in heavy vehicles. It can bear shocks with great capacity than independent suspension e.g. Solid Axle

3. Semi Independent Suspension

This system has the characteristics of both dependent and independent systems. The wheels move relative to one another as in independent suspension but the position of the wheel has some effect on the other wheel. This is done with the help of twisting suspension parts e.g. Twist Beam

TYPES OF SUSPENSION SYSTEM

- Double Wishbone Suspension with damper attached to upper wishbone
- Double Wishbone Suspension with damper attached to lower wishbone
- Steerable Macpherson Strut
- Steerable Twin Parallel Wishbones with knuckle
- Double Wishbone with rocker arm damper, anti-roll bar etc.

  There are several variations of the wishbone and Macpherson strut suspension system but in this design, we have used double wishbone setup with spring damper attached to lower wishbone.

DOUBLE WISHBONE SUSPENSION

It is an independent suspension design using two wishbone shaped arms to locate the wheels. Each wishbone or arm has two mounting points to the chassis and one joint at the knuckle. The shock absorber and coil spring mount to the wishbones to control the vertical movement. The upper arm is usually shorter to introduce negative camber as the suspension jounces. The two arms may be

- Equal and Parallel
- Unequal and Parallel
- Unequal and Non-Parallel

For equal and parallel wishbones, there is no change in camber angle as the links form a parallelogram. The roll center for this system is assumed to stay on the ground at all instants.

For unequal and parallel wishbones, the upper link is made shorter than the lower link. The links are parallel to each other only at ride height. As they have unequal length they cannot remain parallel during vertical movement.

With the help of unequal and non-parallel links the location of the instantaneous center can be altered. By raising and lowering the upper and lower pivots, suitable camber curves can be obtained.

FUNCTION OF ROLL CENTER

The height of the roll center above the ground and its proximity to the center of gravity controls the roll moment, riding quality and performance.

Closer is the Roll Center to the Center of Gravity less will be the roll moment of the net force acting at the CG about the roll axis.

Height of the roll center above the ground affects the riding quality and performance, with riding quality increasing with greater height above the ground and performance having an opposite effect. Some performance cars like Mercedes have their roll centers below the ground.

LONGITUDINAL LOAD TRANSFER

Load transfer refers to the shifting of weight to the front or back during braking or accelerating respectively. During accelerating, the pseudo force (=Ma, M is the mass of the vehicle, a is the acceleration) acts in the backward direction. Due to this force weight of the rear wheels increases while those of the front wheels increases. The opposite happens while braking. There is a load transfer to the front due to which the front wheels tend to dip and the rear wheels tend to rise. However, this dip and rise should be within the limit that the wheel remains in contact with the ground while maintaining proper ground clearance.

$$\Delta L = W * \frac{a}{g} * \frac{h}{l}$$

Where W is the gross vehicle weight, a is the longitudinal acceleration, h the height of the center of gravity from the ground and l is the wheel base.

PROCEDURE

To find length of control arms

- Draw the wheel with proper diameter, width including the KPI angle and knuckle mounting points
- From the center of the wheel mark distances equal to half the front track width and the FVSA length.
- With a suitable position of the roll center draw a line front the contact point of the wheel with the ground through the roll center and extend it up to the FVSA length to get the position of the IC
- Join the knuckle assembly points to the IC
- Draw the chassis with proper ground clearance and height.
- The points where the line joining knuckle assembly to IC intersects the chassis becomes the chassis assembly points.
- Length of the arms from the knuckle assembly point to the chassis assembly points gives the lengths of the control arms.

To find length of axis of control arms

- Draw 4 lines with heights equal to height of the lower chassis point, upper chassis point, lower ball joint and upper ball joint respectively at a distances away from each other which can be obtained from the front view drawing
- Draw the front view of the wheel and the side view of the wheel at sufficient distances from each other
- Join upper chassis point to upper ball joint and extend it up to the center line of the front view wheel. Similarly, for the lower pair of mountings
- Project this point of intersection to the center line of the side view
- Project the upper and lower ball joint to the side view
- For outboard arrangement draw a line through the ground contact making an angle ø with the horizontal. Take a suitable SVSA length and find the corresponding IC
- Join the IC with the point of intersection of the center line of the side view and the projection of line joint the ball joint to the chassis point
- Extend these lines backwards to a suitable point. Mark these points as P,Q
- Project these points backwards to the line representing the chassis points
- From these projections draw a horizontal line
- Intersection of these lines with the line joining P and the projection of the corresponding ball joint gives the corresponding arm axis length

DESIGN

Design of the suspension system follows the following steps

1. Tire design
2. Break Disc design
3. Hub and Knuckle Design
4. Rim Design
5. Spring and Damper Design

TIRE DESIGN

The model considered uses tire of the specification 245/45R19

Width of tire=245/25.4=9.65 in

Aspect ratio=0.45

So, section height=0.45*9.65=4.34 in

Rim diameter=19 in

Outer diameter of tire= 2*4.34+19=27.68 in

Tire Diameter=27.68 inch

Tire Width= 9.65 inch

Rim Diameter= 19 inch

Static Front Camber Angle=-0°

Static Rear Camber Angle=-0°

Front Wheel Caster Angle=0.1°

Static Front Wheel Toe-In=0°

Static Front Wheel Toe-Out=0°

Rear Wheel Toe-In=0.20

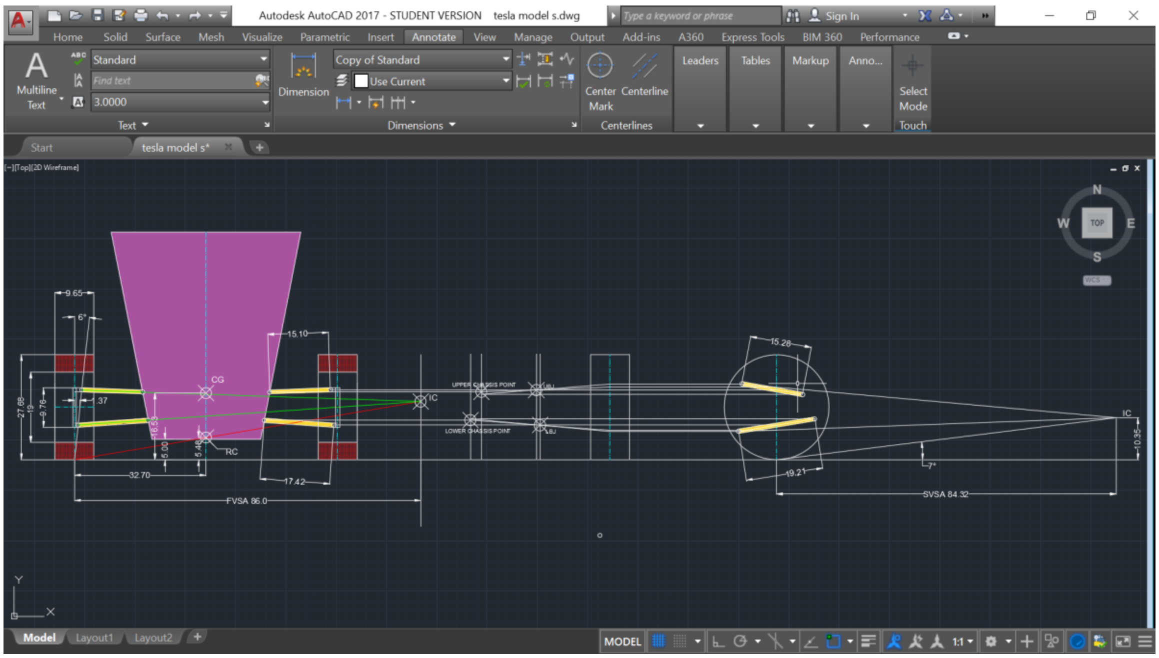
King Pin Inclination=5.57°

Scrub Radius=7.91 mm

Mechanical Trail=0.83 mm

SUSPENSION DESIGN

Double wishbone suspension with spring damper assembly connected to the lower control arm has been used for the design. Outboard braking system with independent front and rear suspension and rack type steering accumulation has been used.



Change in camber in jounce=1°

Change in camber in bounce=1°

Total Wheel Travel= 3”

Camber Change Rate (CCR)= 2/3

FVSA=$\frac{1}{\tan CCR} = \frac{1}{\tan\frac{2}{3}} = 86”$

Height of Center of gravity=16.5”

We assume that the roll center is located at a height 3.33”

Upper Control Arm Length=15.10”

Lower Control Arm Length=17.42”

$$\%Anti\ Dive = \%Front\ Breaking * \tan\theta * \frac{l}{h}$$

$$\%Anti\ Lift = \%Rear\ Breaking * \tan\theta * \frac{l}{h}$$

We assume 60% anti dive for our design.

Wheel base=116.5”

CALCULATING PERCENTAGE FRONT BRAKING

Weight on front wheels(x)= 4967.48 N

Weight on rear wheels(y)= 5381.44 N

Longitudinal Load Transfer on each of the front wheels (L)=1273 N

Front braking=$\frac{x+L}{x+y} = \frac{4967.48+1273}{4967.48+5381.44} = 0.603$

So percentage front braking=60%

Therefore, by substituting in the above equation we get, $\tan\theta = 0.1416$

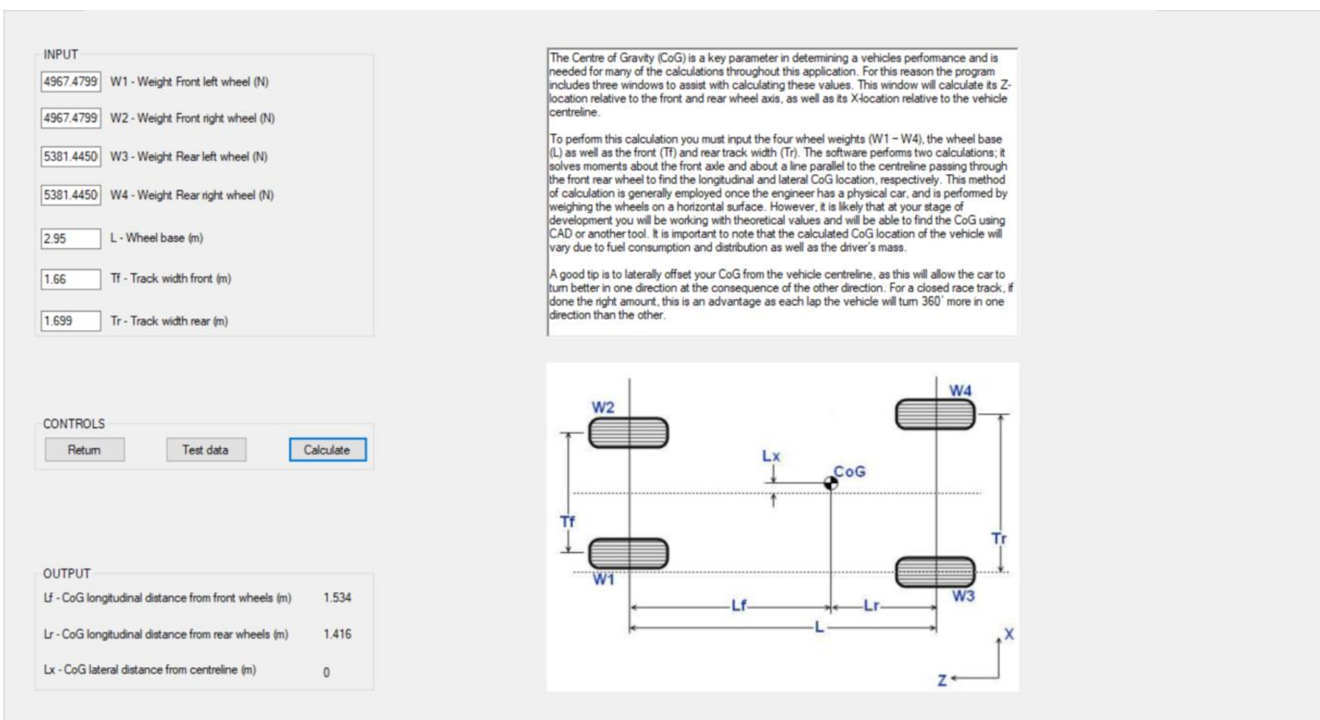
$$\theta = 8.061°$$

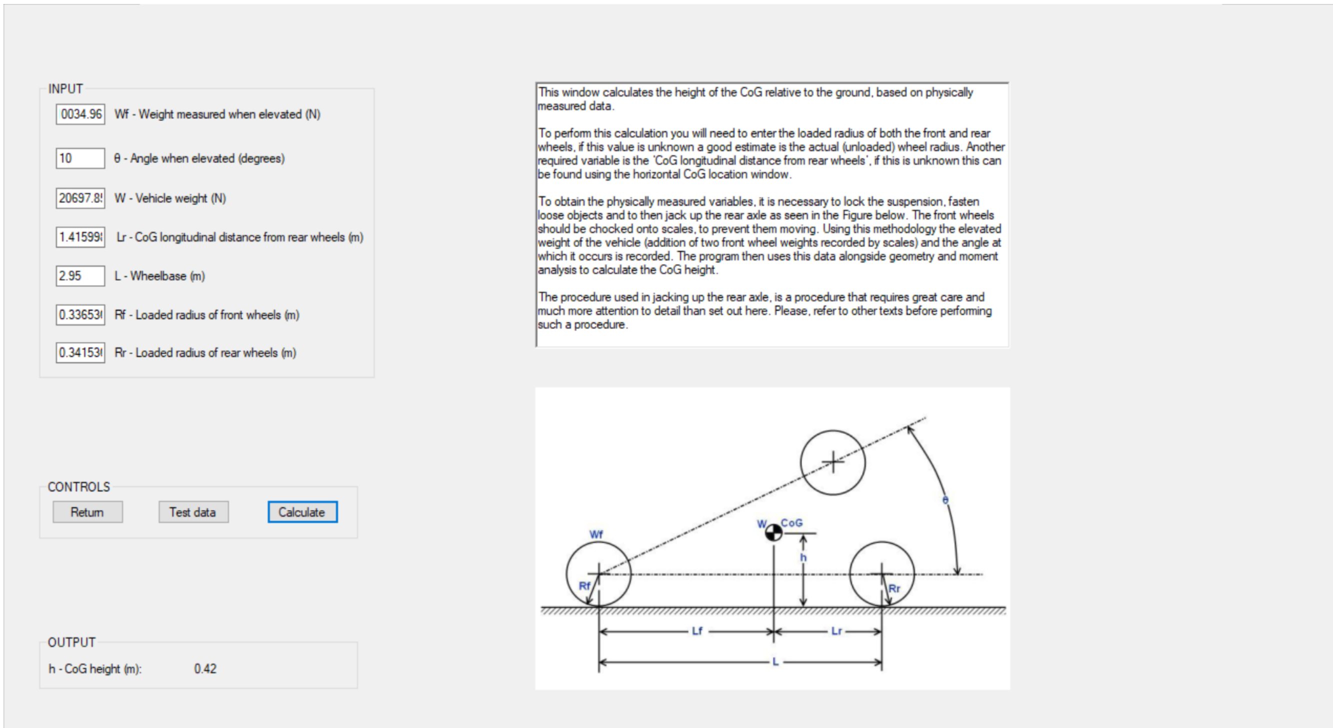
Assuming a suitable value of SVSA length we get the position of IC as 10.35”

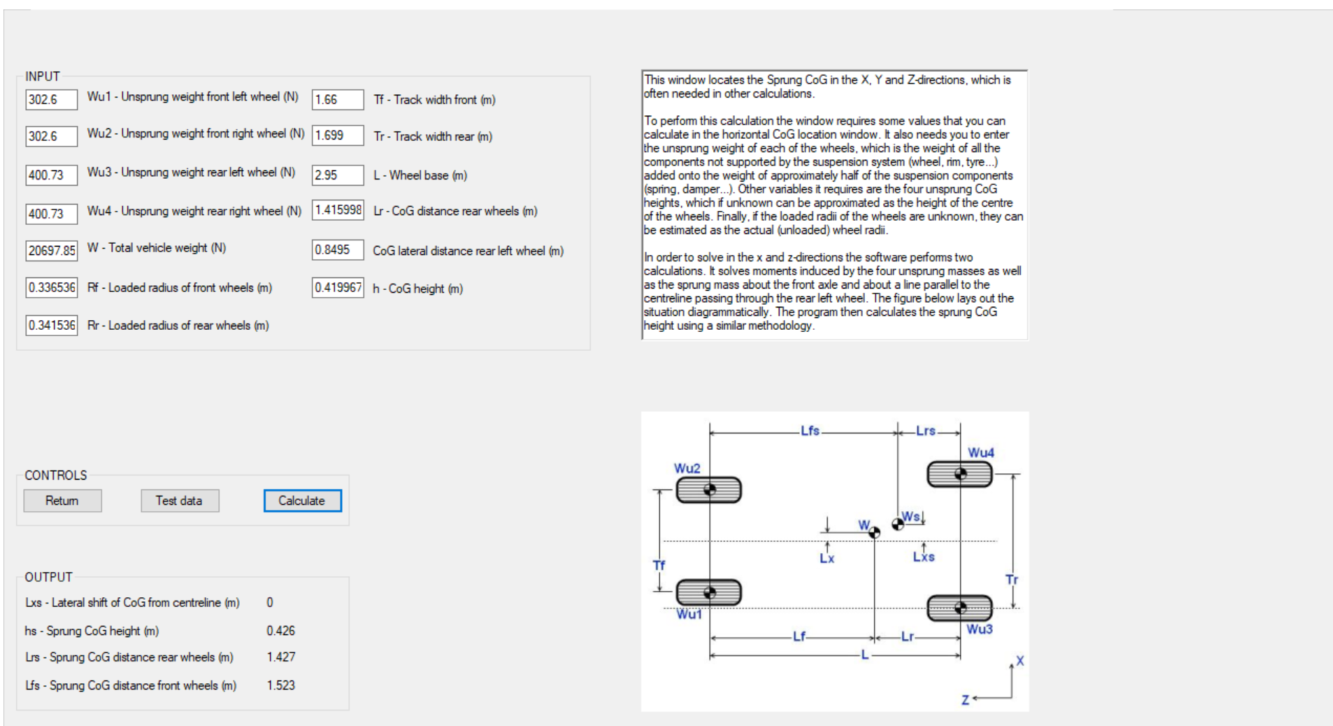
Now taking projections of the corresponding points, we get the length of the axis of the two arms

Length of axis of upper control arm=15.28”

Length of axis of lower control arm=19.21”




INPUT
0034.96 Wf - Weight measured when elevated (N)
10 θ - Angle when elevated (degrees)
20697.8 W - Vehicle weight (N)
1.41599 Lr - CoG longitudinal distance from rear wheels (m)
2.95 L - Wheelbase (m)
0.33653 Rf - Loaded radius of front wheels (m)
0.34153 Rr - Loaded radius of rear wheels (m)
CONTROLS
Return
Test data
Calculate
OUTPUT
h - CoG height (m): 0.42
This window calculates the height of the CoG relative to the ground, based on physically measured data.
To perform this calculation you will need to enter the loaded radius of both the front and rear wheels, if this value is unknown a good estimate is the actual (unloaded) wheel radius. Another required variable is the 'CoG longitudinal distance from rear wheels', if this is unknown this can be found using the horizontal CoG location window.
To obtain the physically measured variables, it is necessary to lock the suspension, fasten loose objects and to then jack up the rear axle as seen in the Figure below. The front wheels should be chocked onto scales, to prevent them moving. Using this methodology the elevated weight of the vehicle (addition of two front wheel weights recorded by scales) and the angle at which it occurs is recorded. The program then uses this data alongside geometry and moment analysis to calculate the CoG height.
The procedure used in jacking up the rear axle, is a procedure that requires great care and much more attention to detail than set out here. Please, refer to other texts before performing such a procedure.
Wf
W
CoG
θ
h
Rf
Rr
Lf
Lr
L


INPUT
302.6 Wu1 - Unsprung weight front left wheel (N)
302.6 Wu2 - Unsprung weight front right wheel (N)
400.73 Wu3 - Unsprung weight rear left wheel (N)
400.73 Wu4 - Unsprung weight rear right wheel (N)
20697.85 W - Total vehicle weight (N)
0.336536 Rf - Loaded radius of front wheels (m)
0.341536 Rr - Loaded radius of rear wheels (m)
1.66 Tf - Track width front (m)
1.699 Tr - Track width rear (m)
2.95 L - Wheel base (m)
1.415998 Lr - CoG distance rear wheels (m)
0.8495 CoG lateral distance rear left wheel (m)
0.419967 h - CoG height (m)
CONTROLS
Return
Test data
Calculate
OUTPUT
Lxs - Lateral shift of CoG from centreline (m) 0
hs - Sprung CoG height (m) 0.426
Lrs - Sprung CoG distance rear wheels (m) 1.427
Lfs - Sprung CoG distance front wheels (m) 1.523
This window locates the Sprung CoG in the X, Y and Z-directions, which is often needed in other calculations.
To perform this calculation the window requires some values that you can calculate in the horizontal CoG location window. It also needs you to enter the unsprung weight of each of the wheels, which is the weight of all the components not supported by the suspension system (wheel, rim, tyre...) added onto the weight of approximately half of the suspension components (spring, damper...). Other variables it requires are the four unsprung CoG heights, which if unknown can be approximated as the height of the centre of the wheels. Finally, if the loaded radii of the wheels are unknown, they can be estimated as the actual (unloaded) wheel radii.
In order to solve in the x and z-directions the software performs two calculations. It solves moments induced by the four unsprung masses as well as the sprung mass about the front axle and about a line parallel to the centreline passing through the rear left wheel. The figure below lays out the situation diagrammatically. The program then calculates the sprung CoG height using a similar methodology.
Lfs
Lrs
Wu2
Wu4
W
Ws
Lx
Lxs
Tf
Tr
Wu1
Wu3
Lf
Lr
L
X
Z

INPUT

90469718	Az - Longitudinal acceleration (g)
20697.85	W - Vehicle weight (N)
0.4199670	h - CoG height (m)
2.95	L - Wheelbase (m)

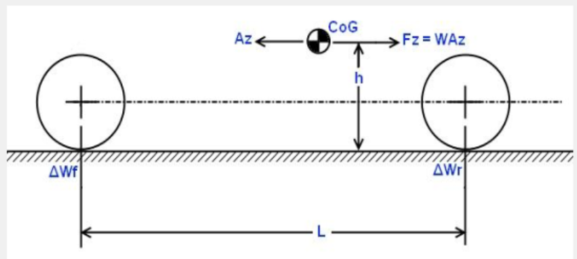
This window allows you to calculate the load transfer on the front and rear wheels due to longitudinal acceleration or braking.

The input values are rather simple and few, with perhaps the exception of two. The longitudinal acceleration value is entered in the units of 'g', if you have an acceleration in the units of 'm/s' you can convert to 'g' by dividing that value by 9.81. The CoG height entered should be the dynamic value, this may be quite different to the static value due to effects such as that of longitudinal acceleration.

The way in which the software calculates the load transfers is by solving moments about the point where the front and rear axles are in contact with the ground. The moment due to the wheels at a distance L should be equal to the moment caused by the vehicle weight at a perpendicular distance h.

CONTROLS

Return | Test data | Calculate



OUTPUT

ΔW1 - Front left wheel load change (N)	-723
ΔW2 - Front right wheel load change (N)	-723
ΔW3 - Rear left wheel load change (N)	723
ΔW4 - Rear right wheel load change (N)	723

INPUT

.5730987	Ax - Lateral acceleration (g)
20697.85	W - Vehicle total weight (N)
2.95	L - Wheelbase (m)
1.534001	Lf - CoG longitudinal distance from front wheels (m)
0.419967	h - CoG height (m)
1.66	Tf - Track width front (m)
1.699	Tr - Track width rear (m)
0.139192	FRch - Front roll centre height (m)
0.14	RRch - Rear roll centre height (m)
44	% front roll rate distribution (0-100)

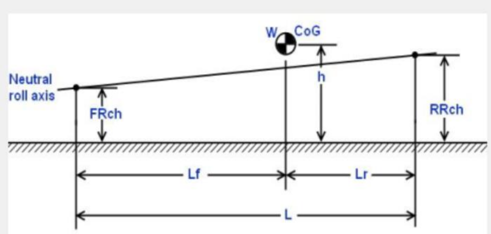
This window calculates the lateral load transfer due to a lateral acceleration for a vehicle cornering in a steady turn. The analysis used is a 1-mass model analysis, which is less accurate than a 3-mass model because it approximates the front and rear unsprung weights as well as the sprung weight by a single overall vehicle weight. As such, the analysis is not as accurate, but should be used if either the front/rear unsprung weight magnitude or location cannot be accurately approximated.

In order to perform the calculation the software requires you to enter values for the 10 fields shown, 5 of which can be found quite easily. Two of the remaining five relate to the CoG, and can be found using the CoG buttons if they are unknown. Another one is the "% front roll rate distribution' which can be found using the 'roll & ride rates' button. Finally, the last two relate to the front and rear roll centre heights. This calculator does not provide any help in finding these, so if unknown you should refer to a textbox for the relevant theory.

The theory used for this calculation is quite complex, but mainly consists of solving moments. A diagrammatic layout of the situation is included below, to help visualize the situation.

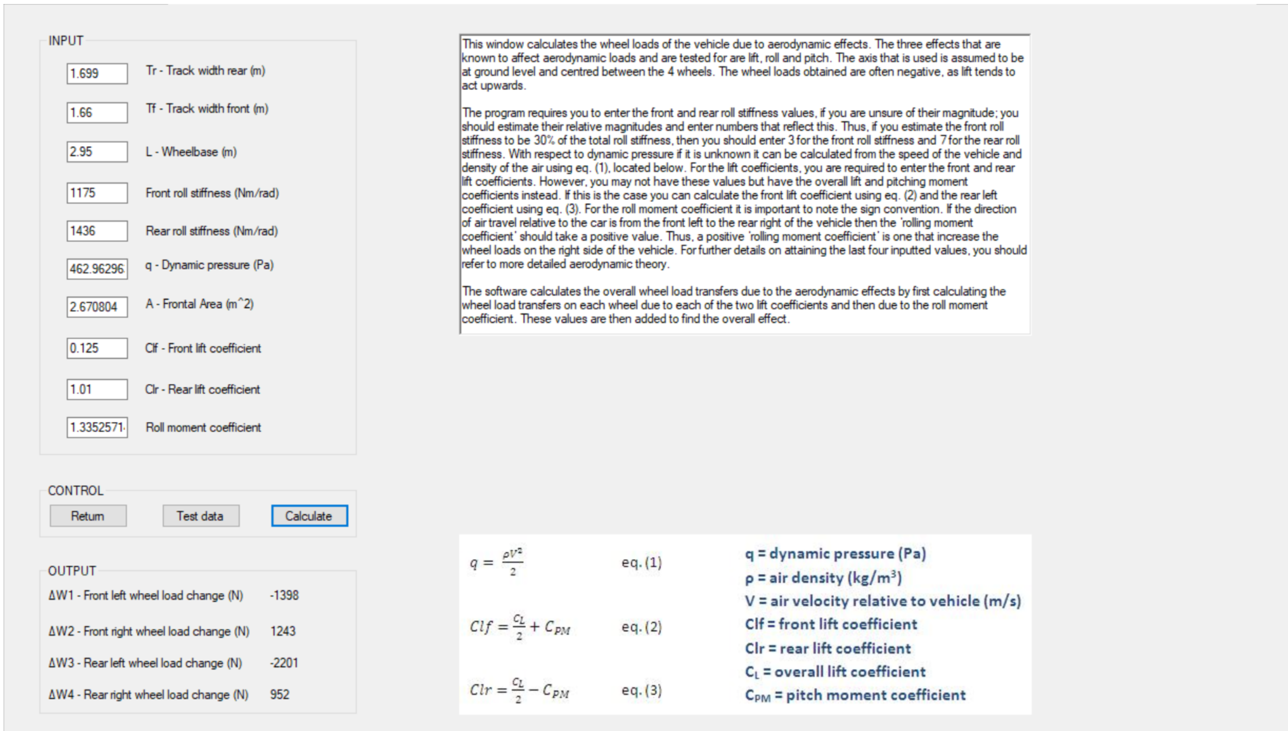
CONTROLS

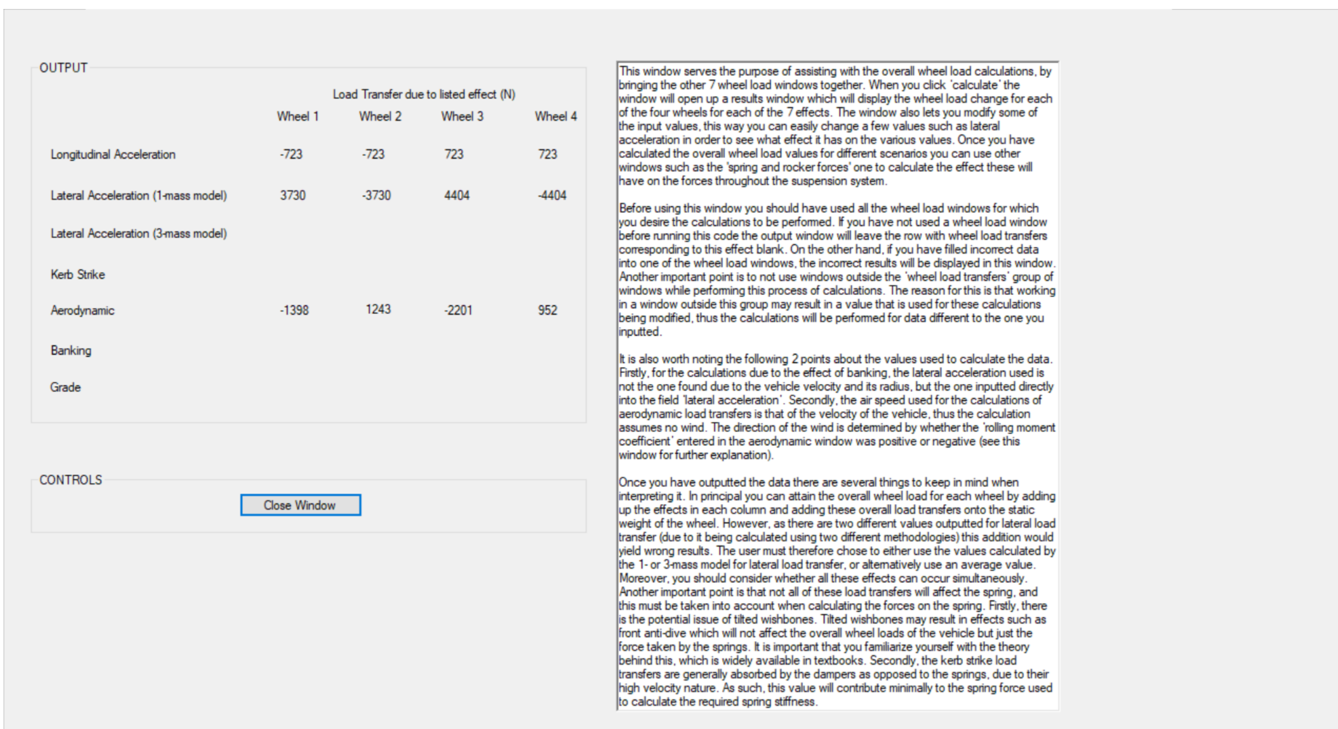
Return | Test data | Calculate



OUTPUT

ΔW1 - Front left wheel load change (N)	3730
ΔW2 - Front right wheel load change (N)	-3730
ΔW3 - Rear left wheel load change (N)	4404
ΔW4 - Rear right wheel load change (N)	-4404


INPUT
1.699
Tr - Track width rear (m)
1.66
Tf - Track width front (m)
2.95
L - Wheelbase (m)
1175
Front roll stiffness (Nm/rad)
1436
Rear roll stiffness (Nm/rad)
462.96296
q - Dynamic pressure (Pa)
2.670804
A - Frontal Area (m^2)
0.125
Clf - Front lift coefficient
1.01
Clr - Rear lift coefficient
1.3352571
Roll moment coefficient
CONTROL
Return
Test data
Calculate
OUTPUT
ΔW1 - Front left wheel load change (N) -1398
ΔW2 - Front right wheel load change (N) 1243
ΔW3 - Rear left wheel load change (N) -2201
ΔW4 - Rear right wheel load change (N) 952
This window calculates the wheel loads of the vehicle due to aerodynamic effects. The three effects that are known to affect aerodynamic loads and are tested for are lift, roll and pitch. The axis that is used is assumed to be at ground level and centred between the 4 wheels. The wheel loads obtained are often negative, as lift tends to act upwards.
The program requires you to enter the front and rear roll stiffness values, if you are unsure of their magnitude; you should estimate their relative magnitudes and enter numbers that reflect this. Thus, if you estimate the front roll stiffness to be 30% of the total roll stiffness, then you should enter 3 for the front roll stiffness and 7 for the rear roll stiffness. With respect to dynamic pressure if it is unknown it can be calculated from the speed of the vehicle and density of the air using eq. (1), located below. For the lift coefficients, you are required to enter the front and rear lift coefficients. However, you may not have these values but have the overall lift and pitching moment coefficients instead. If this is the case you can calculate the front lift coefficient using eq. (2) and the rear left coefficient using eq. (3). For the roll moment coefficient it is important to note the sign convention. If the direction of air travel relative to the car is from the front left to the rear right of the vehicle then the 'rolling moment coefficient' should take a positive value. Thus, a positive 'rolling moment coefficient' is one that increase the wheel loads on the right side of the vehicle. For further details on attaining the last four inputted values, you should refer to more detailed aerodynamic theory.
The software calculates the overall wheel load transfers due to the aerodynamic effects by first calculating the wheel load transfers on each wheel due to each of the two lift coefficients and then due to the roll moment coefficient. These values are then added to find the overall effect.
$q = \frac{\rho V^2}{2}$ eq. (1)
$Clf = \frac{C_L}{2} + C_{PM}$ eq. (2)
$Clr = \frac{C_L}{2} - C_{PM}$ eq. (3)
q = dynamic pressure (Pa)
ρ = air density (kg/m³)
V = air velocity relative to vehicle (m/s)
Clf = front lift coefficient
Clr = rear lift coefficient
C_L = overall lift coefficient
C_{PM} = pitch moment coefficient


OUTPUT
Load Transfer due to listed effect (N)
Wheel 1 Wheel 2 Wheel 3 Wheel 4
Longitudinal Acceleration -723 -723 723 723
Lateral Acceleration (1-mass model) 3730 -3730 4404 -4404
Lateral Acceleration (3-mass model)
Kerb Strike
Aerodynamic -1398 1243 -2201 952
Banking
Grade
CONTROLS
Close Window
This window serves the purpose of assisting with the overall wheel load calculations, by bringing the other 7 wheel load windows together. When you click 'calculate' the window will open up a results window which will display the wheel load change for each of the four wheels for each of the 7 effects. The window also lets you modify some of the input values, this way you can easily change a few values such as lateral acceleration in order to see what effect it has on the various values. Once you have calculated the overall wheel load values for different scenarios you can use other windows such as the 'spring and rocker forces' one to calculate the effect these will have on the forces throughout the suspension system.
Before using this window you should have used all the wheel load windows for which you desire the calculations to be performed. If you have not used a wheel load window before running this code the output window will leave the row with wheel load transfers corresponding to this effect blank. On the other hand, if you have filled incorrect data into one of the wheel load windows, the incorrect results will be displayed in this window. Another important point is to not use windows outside the 'wheel load transfers' group of windows while performing this process of calculations. The reason for this is that working in a window outside this group may result in a value that is used for these calculations being modified, thus the calculations will be performed for data different to the one you inputted.
It is also worth noting the following 2 points about the values used to calculate the data. Firstly, for the calculations due to the effect of banking, the lateral acceleration used is not the one found due to the vehicle velocity and its radius, but the one inputted directly into the field 'lateral acceleration'. Secondly, the air speed used for the calculations of aerodynamic load transfers is that of the velocity of the vehicle, thus the calculation assumes no wind. The direction of the wind is determined by whether the 'rolling moment coefficient' entered in the aerodynamic window was positive or negative (see this window for further explanation).
Once you have outputted the data there are several things to keep in mind when interpreting it. In principal you can attain the overall wheel load for each wheel by adding up the effects in each column and adding these overall load transfers onto the static weight of the wheel. However, as there are two different values outputted for lateral load transfer (due to it being calculated using two different methodologies) this addition would yield wrong results. The user must therefore chose to either use the values calculated by the 1- or 3-mass model for lateral load transfer, or alternatively use an average value. Moreover, you should consider whether all these effects can occur simultaneously. Another important point is that not all of these load transfers will affect the spring, and this must be taken into account when calculating the forces on the spring. Firstly, there is the potential issue of tilted wishbones. Tilted wishbones may result in effects such as front anti-dive which will not affect the overall wheel loads of the vehicle but just the force taken by the springs. It is important that you familiarize yourself with the theory behind this, which is widely available in textbooks. Secondly, the kerb strike load transfers are generally absorbed by the dampers as opposed to the springs, due to their high velocity nature. As such, this value will contribute minimally to the spring force used to calculate the required spring stiffness.

MATERIAL SELECTION

As the wishbone arms are the critical components in suspension because they are going to take all the loads which could be of the vehicle or load acting during bumps and droops. For this design, the material selected is AISI 4130. For the spring and damper system, material used is ASTM A228.

SIMULATION AND TOOLINGS

Simulation of the suspension system was done using the Suspension Calculator and Lotus Shark software. Appropriate data were taken as input and the results were obtained. Each data was then plotted on graphs with bump and droop as one of the parameters.

The Lotus Suspension analysis data is attached below.

```
********************************************************************
****************
    18/06/18
19:16:40
      LOTUS SUSPENSION ANALYSIS v4.03

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

     FRONT SUSPENSION       FILENAME: untitled1.dat

     TYPE 1 Double Wishbone, damper to lower wishbone

         X          Y          Z
       (mm)       (mm)       (mm)
   3819.00    313.00    225.60    POINT (   1 ) = Lower wishbone
front pivot
   4179.00    280.00    185.90    POINT (   2 ) = Lower wishbone
rear pivot
   4092.00    723.50    167.10    POINT (   3 ) = Lower wishbone
outer ball joint
   4092.50    420.00    452.00    POINT (   5 ) = Upper wishbone
front pivot
   4332.00    420.00    446.00    POINT (   6 ) = Upper wishbone
rear pivot
   4092.50    695.50    454.10    POINT (   7 ) = Upper wishbone
outer ball joint
   4146.50    600.00    203.60    POINT (   8 ) = Damper wishbone
end
   4180.00    475.00    593.60    POINT (   9 ) = Damper body end
   4214.50    740.50    208.00    POINT (  11 ) = Outer track rod
ball joint
   4245.50    308.00    227.00    POINT (  12 ) = Inner track rod
ball joint
```

```
   4180.00    486.00    690.00    POINT (  16 ) = Upper spring pivot
point
   4145.00    645.00    210.00    POINT (  17 ) = Lower spring pivot
point
   4092.50    701.00    313.10    POINT (  18 ) = Wheel spindle
point
   4092.50    750.00    313.10    POINT (  19 ) = Wheel centre point
   4030.00    440.00    195.00    POINT (  20 ) = Part 1 C of G
   4170.00    520.00    450.00    POINT (  21 ) = Part 2 C of G
   4230.00    525.00    220.00    POINT (  22 ) = Part 3 C of G
   4130.00    720.00    275.00    POINT (  23 ) = Part 4 C of G
```

STATIC VALUES

CAMBER ANGLE	**(deg):**	**0.00**
TOE ANGLE (SAE) (+ve TOE IN)	**(deg):**	**0.00**
TOE ANGLE (PLANE OF WHEEL)	**(deg):**	**0.00**
CASTOR ANGLE	**(deg):**	**0.10**
CASTOR TRAIL (HUB TRAIL)	**(mm):**	**-0.25**
CASTOR OFFSET	**(mm):**	**0.83**
KINGPIN ANGLE	**(deg):**	**5.57**
KINGPIN OFFSET (AT WHEEL)	**(mm):**	**40.74**
KINGPIN OFFSET (AT GROUND)	**(mm):**	**7.91**
MECHANICAL TRAIL	**(mm):**	**0.83**
ROLL CENTRE HEIGHT	**(mm):**	**84.57**

GENERAL DATA VALUES

TYRE ROLLING RADIUS	**(mm):**	**336.54**
WHEELBASE	**(mm):**	**2959.10**
C OF G HEIGHT	**(mm):**	**419.86**
BREAKING ON FRONT AXLE	**(%):**	**60.00**
DRIVE ON FRONT AXLE	**(%):**	**0.00**
WEIGHT ON FRONT AXLE	**(%):**	**48.00**
OUTBOARD FRONT BRAKES:		
OUTBOARD REAR BRAKES:		
INDEPENDENT FRONT SUSPENSION:		
INDEPENDENT REAR SUSPENSION:		
RACK TYPE STEERING ARTICULATION:		

```
                              RUN DETAILS
                             FULL MODEL:
         BUMP TRAVEL   (mm):        38.10           INCREMENT   (mm):
20.00
      REBOUND TRAVEL   (mm):        38.10           INCREMENT   (mm):
20.00
          ROLL ANGLE  (deg):         3.00      ROLL INCREMENT  (deg):
0.50
     STEERING TRAVEL   (mm):        30.00  STEERING INCREMENT   (mm):
5.00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REAR SUSPENSION FILENAME: untitled1.dat

TYPE 1 Double Wishbone, damper to lower wishbone

X (mm)	Y (mm)	Z (mm)	
6778.10	313.00	230.42	POINT (1) = Lower wishbone front pivot
7138.10	280.00	190.72	POINT (2) = Lower wishbone rear pivot
7051.10	723.50	171.92	POINT (3) = Lower wishbone outer ball joint
7051.60	420.00	456.82	POINT (5) = Upper wishbone front pivot
7291.10	420.00	450.82	POINT (6) = Upper wishbone rear pivot
7051.60	695.50	458.92	POINT (7) = Upper wishbone outer ball joint
7105.60	600.00	208.42	POINT (8) = Damper wishbone end
7139.10	475.00	598.42	POINT (9) = Damper body end
7173.60	740.50	212.82	POINT (11) = Outer track rod ball joint
7204.60	308.00	231.82	POINT (12) = Inner track rod ball joint
7139.10	486.00	694.82	POINT (16) = Upper spring pivot point
7104.10	645.00	214.82	POINT (17) = Lower spring pivot point
7051.60	701.00	317.92	POINT (18) = Wheel spindle point
7051.60	750.00	317.92	POINT (19) = Wheel centre point
6989.10	440.00	199.82	POINT (20) = Part 1 C of G
7129.10	520.00	454.82	POINT (21) = Part 2 C of G
7189.10	525.00	224.82	POINT (22) = Part 3 C of G
7089.10	720.00	279.82	POINT (23) = Part 4 C of G

STATIC VALUES

CAMBER ANGLE	(deg):	0.00
TOE ANGLE (SAE) (+ve TOE IN)	(deg):	0.00
TOE ANGLE (PLANE OF WHEEL)	(deg):	0.00
CASTOR ANGLE	(deg):	0.10
CASTOR TRAIL (HUB TRAIL)	(mm):	-0.25
CASTOR OFFSET	(mm):	0.84
KINGPIN ANGLE	(deg):	5.57
KINGPIN OFFSET (AT WHEEL)	(mm):	40.74

```
        KINGPIN OFFSET (AT GROUND)   (mm):     7.44
                  MECHANICAL TRAIL   (mm):     0.84
                ROLL CENTRE HEIGHT   (mm):    85.48

                         GENERAL DATA VALUES
               TYRE ROLLING RADIUS   (mm):   341.36
                         WHEELBASE   (mm):  2959.10
                      C OF G HEIGHT  (mm):   419.86
            BREAKING ON FRONT AXLE    (%):    60.00
               DRIVE ON FRONT AXLE    (%):     0.00
              WEIGHT ON FRONT AXLE    (%):    48.00
                     OUTBOARD FRONT BRAKES:
                      OUTBOARD REAR BRAKES:
             INDEPENDENT FRONT SUSPENSION:
              INDEPENDENT REAR SUSPENSION:

                               RUN DETAILS
                              FULL MODEL:
         BUMP TRAVEL   (mm):       38.10          INCREMENT   (mm):
20.00
      REBOUND TRAVEL   (mm):       38.10          INCREMENT   (mm):
20.00
          ROLL ANGLE  (deg):        3.00     ROLL INCREMENT  (deg):
0.50
     STEERING TRAVEL   (mm):       30.00  STEERING INCREMENT   (mm):
5.00


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     FRONT SUSPENSION     -    BUMP TRAVEL
            RHS WHEEL (+ve Y)

     TYPE 1 Double Wishbone, damper to lower wishbone


   INCREMENTAL GEOMETRY VALUES

      BUMP             CAMBER       TOE    CASTOR   KINGPIN
DAMPER    SPRING
     TRAVEL             ANGLE     ANGLE     ANGLE     ANGLE
RATIO     RATIO
      (mm)              (deg)     (deg)     (deg)     (deg)
[-]       [-]
```

```
-40.0000000      0.378500015      0.171000008E-01  0.859099984
5.19399977        1.43400002       1.25600004
-20.0000000      0.239399999      0.119000003E-01  0.470699996
5.33290005        1.42999995       1.25199997
0.000000000E+00  0.000000000E+00  0.000000000E+00  0.997999981E-01
5.57219982        1.42400002       1.24699998
 20.0000000      -.337300003      -.167999994E-01  -.254000008
5.90950012        1.41799998       1.24100006
 40.0000000      -.772700012      -.366000012E-01  -.591199994
6.34490013        1.40999997       1.23500001


  INCREMENTAL SUSPENSION PARAMETER VALUES

      BUMP       ANTI       ANTI       ROLL       ROLL       HALF
WHEELBASE    DAMPER    SPRING
    TRAVEL       DIVE      SQUAT    CENTRE    CENTRE     TRACK
CHANGE    TRAVEL    TRAVEL
      (mm)        (%)        (%)    HEIGHT    HEIGHT    CHANGE
 (mm)       (mm)       (mm)
                                  TO BODY   TO GRND       (mm)
                                     (mm)       (mm)

-40.0000000      -73.6299973      0.000000000E+00   88.7799988
128.779999       -5.71999979       2.86999989       27.9799995
31.9500008
-20.0000000      -73.9499969      0.000000000E+00   86.6699982
106.669998       -2.55999994       1.41999996       14.0200005
16.0100002
0.000000000E+00  -74.3499985      0.000000000E+00   84.5699997
84.5699997       0.000000000E+00  0.000000000E+00  0.000000000E+00
      0.000000000E+00
 20.0000000      -74.8199997      0.000000000E+00   82.6600037
62.6599998        1.96000004      -1.38000000      -14.0799999
      -16.0799999
 40.0000000      -75.3499985      0.000000000E+00   81.1399994
41.1399994        3.32999992      -2.71000004      -28.2199993
      -32.2400017


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     FRONT SUSPENSION     -    BUMP TRAVEL
            LHS WHEEL (-ve Y)

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

INCREMENTAL GEOMETRY VALUES

BUMP TRAVEL (mm)	CAMBER ANGLE (deg)	TOE ANGLE (deg)	CASTOR ANGLE (deg)	KINGPIN ANGLE (deg)	DAMPER RATIO [-]	SPRING RATIO [-]
-40.0000000	0.378500015	0.171000008E-01	0.859099984	5.19399977	1.43400002	1.25600004
-20.0000000	0.239399999	0.119000003E-01	0.470699996	5.33290005	1.42999995	1.25199997
0.000000000E+00	0.000000000E+00	0.000000000E+00	0.997999981E-01	5.57219982	1.42400002	1.24699998
20.0000000	-.337300003	-.167999994E-01	-.254000008	5.90950012	1.41799998	1.24100006
40.0000000	-.772700012	-.366000012E-01	-.591199994	6.34490013	1.40999997	1.23500001

INCREMENTAL SUSPENSION PARAMETER VALUES

BUMP TRAVEL (mm)	ANTI DIVE (%)	ANTI SQUAT (%)	ROLL CENTRE HEIGHT TO BODY (mm)	ROLL CENTRE HEIGHT TO GRND (mm)	HALF TRACK CHANGE (mm)	WHEELBASE CHANGE (mm)	DAMPER TRAVEL (mm)	SPRING TRAVEL (mm)
-40.0000000	-73.6299973	0.000000000E+00	88.7799988	128.779999	-5.71999979	2.86999989	27.9799995	31.9500008
-20.0000000	-73.9499969	0.000000000E+00	86.6699982	106.669998	-2.55999994	1.41999996	14.0200005	16.0100002
0.000000000E+00	-74.3499985	0.000000000E+00	84.5699997	84.5699997	0.000000000E+00	0.000000000E+00	0.000000000E+00	0.000000000E+00
20.0000000	-74.8199997	0.000000000E+00	82.6600037	62.6599998	1.96000004	-1.38000000	-14.0799999	-16.0799999
40.0000000	-75.3499985	0.000000000E+00	81.1399994	41.1399994	3.32999992	-2.71000004	-28.2199993	-32.2400017

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      REAR SUSPENSION      -    BUMP TRAVEL
            RHS WHEEL (+ve Y)

     TYPE 1 Double Wishbone, damper to lower wishbone


   INCREMENTAL GEOMETRY VALUES

      BUMP              CAMBER       TOE    CASTOR   KINGPIN
DAMPER    SPRING
    TRAVEL               ANGLE     ANGLE     ANGLE     ANGLE
RATIO     RATIO
      (mm)               (deg)     (deg)     (deg)     (deg)
[-]       [-]

-40.0000000      0.378500015      0.171000008E-01  0.859099984
5.19399977        1.43400002       1.25600004
-20.0000000      0.239399999      0.119000003E-01  0.470699996
5.33290005        1.42999995       1.25199997
0.000000000E+00  0.000000000E+00  0.000000000E+00  0.997999981E-01
5.57219982        1.42400002       1.24699998
 20.0000000      -.337300003      -.167999994E-01  -.254000008
5.90950012        1.41799998       1.24100006
 40.0000000      -.772700012      -.366000012E-01  -.591199994
6.34480000        1.41100001       1.23500001


  INCREMENTAL SUSPENSION PARAMETER VALUES

      BUMP       ANTI       ANTI       ROLL       ROLL       HALF
WHEELBASE    DAMPER    SPRING
    TRAVEL       DIVE      SQUAT    CENTRE    CENTRE     TRACK
CHANGE     TRAVEL    TRAVEL
      (mm)        (%)        (%)    HEIGHT    HEIGHT    CHANGE
(mm)        (mm)        (mm)
                                  TO BODY   TO GRND       (mm)
                                     (mm)       (mm)

-40.0000000       49.5200005       47.5800018       89.0500031
129.050003       -5.75000000      -2.86999989       27.9799995
31.9500008
-20.0000000       49.7299995       48.3499985       87.2699966
107.269997       -2.57999992      -1.41999996       14.0200005
16.0100002
```

```
0.000000000E+00   49.9900017       49.2099991       85.4800034
85.4800034       0.000000000E+00  0.000000000E+00  0.000000000E+00
      0.000000000E+00
 20.0000000       50.3100014       50.1300011       83.8899994
63.8899994       1.98000002       1.38000000      -14.0799999
      -16.0799999
 40.0000000       50.6599998       51.0999985       82.6800003
42.6800003       3.39000010       2.71000004      -28.2199993
      -32.2400017


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      REAR SUSPENSION      -    BUMP TRAVEL
            LHS WHEEL (-ve Y)

     TYPE 1 Double Wishbone, damper to lower wishbone


   INCREMENTAL GEOMETRY VALUES

      BUMP              CAMBER       TOE    CASTOR   KINGPIN
DAMPER    SPRING
    TRAVEL               ANGLE     ANGLE     ANGLE     ANGLE
RATIO     RATIO
      (mm)               (deg)     (deg)     (deg)     (deg)
[-]       [-]

-40.0000000      0.378500015      0.171000008E-01  0.859099984
5.19399977       1.43400002       1.25600004
-20.0000000      0.239399999      0.119000003E-01  0.470699996
5.33290005       1.42999995       1.25199997
0.000000000E+00  0.000000000E+00  0.000000000E+00  0.997999981E-01
5.57219982       1.42400002       1.24699998
 20.0000000      -.337300003      -.167999994E-01  -.254000008
5.90950012       1.41799998       1.24100006
 40.0000000      -.772700012      -.366000012E-01  -.591199994
6.34480000       1.41100001       1.23500001


  INCREMENTAL SUSPENSION PARAMETER VALUES

      BUMP       ANTI       ANTI       ROLL       ROLL       HALF
WHEELBASE    DAMPER    SPRING
    TRAVEL       DIVE      SQUAT    CENTRE    CENTRE      TRACK
CHANGE    TRAVEL    TRAVEL
```

```
      (mm)        (%)        (%)     HEIGHT    HEIGHT    CHANGE
(mm)       (mm)       (mm)
                                    TO BODY   TO GRND      (mm)
                                       (mm)      (mm)

-40.0000000       49.5200005       47.5800018       89.0500031
129.050003       -5.75000000      -2.86999989       27.9799995
31.9500008
-20.0000000       49.7299995       48.3499985       87.2699966
107.269997       -2.57999992      -1.41999996       14.0200005
16.0100002
0.000000000E+00   49.9900017       49.2099991       85.4800034
85.4800034       0.000000000E+00  0.000000000E+00  0.000000000E+00
      0.000000000E+00
 20.0000000       50.3100014       50.1300011       83.8899994
63.8899994        1.98000002       1.38000000      -14.0799999
      -16.0799999
 40.0000000       50.6599998       51.0999985       82.6800003
42.6800003        3.39000010       2.71000004      -28.2199993
      -32.2400017


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     FRONT SUSPENSION     -    ROLL
            RHS WHEEL (+ve Y)

     TYPE 1 Double Wishbone, damper to lower wishbone


   INCREMENTAL GEOMETRY VALUES

      ROLL              CAMBER       TOE    CASTOR   KINGPIN
DAMPER    SPRING
     ANGLE               ANGLE     ANGLE     ANGLE     ANGLE
RATIO     RATIO
     (deg)               (deg)     (deg)     (deg)     (deg)
[-]       [-]

-3.00000000       2.24270010      -.368999988E-01  -.578299999
3.32940006        1.40499997       1.23000002
-2.50000000       1.89559996      -.300999992E-01  -.469900012
3.67650008        1.40799999       1.23199999
-2.00000000       1.53779995      -.233999994E-01  -.359699994
4.03439999        1.41100001       1.23500001
```

```
-1.50000000       1.16919994      -.170000009E-01  -.247600004
4.40290022        1.41400003       1.23800004
-1.00000000      0.790099978      -.109000001E-01  -.133699998
4.78210020        1.41700006       1.24100006
-.500000000      0.400299996      -.520000001E-02  -.178999994E-01
5.17189980        1.42100000       1.24399996
0.000000000E+00  0.000000000E+00  0.000000000E+00  0.997999981E-01
5.57219982        1.42400002       1.24699998
0.500000000      -.410899997      0.469999993E-02  0.219400004
5.98309994        1.42799997       1.25000000
 1.00000000      -.832300007      0.879999995E-02  0.340999991
6.40450001        1.43099999       1.25300002
 1.50000000      -1.26440001      0.121999998E-01  0.464500010
6.83659983        1.43499994       1.25600004
 2.00000000      -1.70720005      0.148999998E-01  0.589999974
7.27950001        1.43799996       1.25899994
 2.50000000      -2.16079998      0.167999994E-01  0.717499971
7.73320007        1.44200003       1.26300001
 3.00000000      -2.62540007      0.179999992E-01  0.847100019
8.19789982        1.44500005       1.26600003


  INCREMENTAL SUSPENSION PARAMETER VALUES

      ROLL         ROLL CENTRE POSITION       HALF WHEELBASE
DAMPER    SPRING
     ANGLE          X          Y          Z     TRACK    CHANGE
TRAVEL    TRAVEL
     (deg)       (mm)       (mm)       (mm)    CHANGE       (mm)
(mm)       (mm)
         (+ve Y to outer wheel: Z rl to Grnd)  (mm)

-3.00000000       4092.50000      -33.1100006       84.7200012
      -.109999999      -2.67000008      -27.7700005      -31.7199993

-2.50000000       4092.50000      -28.2000008       84.6699982
      -.799999982E-01  -2.24000001      -23.1100006      -26.3999996

-2.00000000       4092.50000      -22.9699993       84.6299973
      -.500000007E-01  -1.79999995      -18.4699993      -21.1000004

-1.50000000       4092.50000      -17.4500008       84.5999985
      -.299999993E-01  -1.36000001      -13.8400002      -15.8100004

-1.00000000       4092.50000      -11.7399998       84.5800018
      -.999999978E-02  -.910000026      -9.21000004      -10.5200005

-.500000000       4092.50000      -5.90000010       84.5699997
      0.000000000E+00  -.460000008      -4.59999990      -5.26000023

0.000000000E+00   4092.50000      0.000000000E+00   84.5699997
      0.000000000E+00  0.000000000E+00  0.000000000E+00
      0.000000000E+00
```

```
0.500000000       4092.50000       5.90000010       84.5699997
     0.000000000E+00  0.460000008       4.59000015       5.23999977

 1.00000000       4092.50000       11.7399998       84.5800018
     -.999999978E-02  0.930000007       9.17000008       10.4700003

 1.50000000       4092.50000       17.4500008       84.5999985
     -.299999993E-01   1.39999998       13.7399998       15.6899996

 2.00000000       4092.50000       22.9599991       84.6299973
     -.500000007E-01   1.87000000       18.2900009       20.8899994

 2.50000000       4092.50000       28.2000008       84.6699982
     -.799999982E-01   2.34999990       22.8400002       26.0799999

 3.00000000       4092.50000       33.1100006       84.7200012
     -.119999997       2.82999992       27.3700008       31.2600002


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     FRONT SUSPENSION     -    ROLL
           LHS WHEEL (-ve Y)

     TYPE 1 Double Wishbone, damper to lower wishbone


   INCREMENTAL GEOMETRY VALUES

      ROLL              CAMBER       TOE    CASTOR   KINGPIN
DAMPER    SPRING
     ANGLE               ANGLE     ANGLE     ANGLE     ANGLE
RATIO     RATIO
     (deg)               (deg)     (deg)     (deg)     (deg)
[-]       [-]

-3.00000000      -2.62540007      0.179999992E-01  0.847100019
8.19789982        1.44500005       1.26600003
-2.50000000      -2.16079998      0.167999994E-01  0.717499971
7.73320007        1.44200003       1.26300001
-2.00000000      -1.70720005      0.148999998E-01  0.589999974
7.27950001        1.43799996       1.25899994
-1.50000000      -1.26440001      0.121999998E-01  0.464500010
6.83659983        1.43499994       1.25600004
```

```
-1.00000000      -.832300007      0.879999995E-02  0.340999991
6.40450001        1.43099999       1.25300002
-.500000000      -.410899997      0.469999993E-02  0.219400004
5.98309994        1.42799997       1.25000000
0.000000000E+00  0.000000000E+00  0.000000000E+00  0.997999981E-01
5.57219982        1.42400002       1.24699998
0.500000000      0.400299996      -.520000001E-02  -.178999994E-01
5.17189980        1.42100000       1.24399996
 1.00000000      0.790099978      -.109000001E-01  -.133699998
4.78210020        1.41700006       1.24100006
 1.50000000       1.16919994      -.170000009E-01  -.247600004
4.40290022        1.41400003       1.23800004
 2.00000000       1.53779995      -.233999994E-01  -.359699994
4.03439999        1.41100001       1.23500001
 2.50000000       1.89559996      -.300999992E-01  -.469900012
3.67650008        1.40799999       1.23199999
 3.00000000       2.24270010      -.368999988E-01  -.578299999
3.32940006        1.40499997       1.23000002


  INCREMENTAL SUSPENSION PARAMETER VALUES

      ROLL         ROLL CENTRE POSITION       HALF WHEELBASE
DAMPER    SPRING
     ANGLE          X          Y          Z     TRACK    CHANGE
TRAVEL    TRAVEL
     (deg)       (mm)       (mm)       (mm)    CHANGE       (mm)
(mm)       (mm)
         (+ve Y to outer wheel: Z rl to Grnd) (mm)

-3.00000000       4092.50000      -33.1100006       84.7200012
      -.119999997       2.82999992       27.3700008       31.2600002

-2.50000000       4092.50000      -28.2000008       84.6699982
      -.799999982E-01   2.34999990       22.8400002       26.0799999

-2.00000000       4092.50000      -22.9699993       84.6299973
      -.500000007E-01   1.87000000       18.2900009       20.8899994

-1.50000000       4092.50000      -17.4500008       84.5999985
      -.299999993E-01   1.39999998       13.7399998       15.6899996

-1.00000000       4092.50000      -11.7399998       84.5800018
      -.999999978E-02  0.930000007       9.17000008       10.4700003

-.500000000       4092.50000      -5.90000010       84.5699997
      0.000000000E+00  0.460000008       4.59000015       5.23999977

0.000000000E+00   4092.50000      0.000000000E+00   84.5699997
      0.000000000E+00  0.000000000E+00  0.000000000E+00
      0.000000000E+00
```

```
0.500000000       4092.50000       5.90000010       84.5699997
     0.000000000E+00  -.460000008       -4.59999990      -5.26000023

 1.00000000       4092.50000       11.7399998       84.5800018
     -.999999978E-02  -.910000026       -9.21000004      -10.5200005

 1.50000000       4092.50000       17.4500008       84.5999985
     -.299999993E-01  -1.36000001       -13.8400002      -15.8100004

 2.00000000       4092.50000       22.9599991       84.6299973
     -.500000007E-01  -1.79999995       -18.4699993      -21.1000004

 2.50000000       4092.50000       28.2000008       84.6699982
     -.799999982E-01  -2.24000001       -23.1100006      -26.3999996

 3.00000000       4092.50000       33.1100006       84.7200012
     -.109999999      -2.67000008       -27.7700005      -31.7199993


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      REAR SUSPENSION     -    ROLL
            RHS WHEEL (+ve Y)

     TYPE 1 Double Wishbone, damper to lower wishbone


   INCREMENTAL GEOMETRY VALUES

      ROLL              CAMBER       TOE    CASTOR   KINGPIN
DAMPER    SPRING
     ANGLE               ANGLE     ANGLE     ANGLE     ANGLE
RATIO     RATIO
     (deg)               (deg)     (deg)     (deg)     (deg)
[-]       [-]

-3.00000000       2.24259996      -.368999988E-01  -.578299999
3.32949996        1.40499997       1.22899997
-2.50000000       1.89559996      -.300999992E-01  -.469900012
3.67650008        1.40799999       1.23199999
-2.00000000       1.53779995      -.233999994E-01  -.359699994
4.03439999        1.41100001       1.23500001
-1.50000000       1.16919994      -.170000009E-01  -.247600004
4.40290022        1.41400003       1.23800004
```

```
-1.00000000      0.790099978      -.109000001E-01  -.133699998
4.78210020        1.41700006       1.24100006
-.500000000      0.400299996      -.520000001E-02  -.178999994E-01
5.17189980        1.42100000       1.24399996
0.000000000E+00  0.000000000E+00  0.000000000E+00  0.997999981E-01
5.57219982        1.42400002       1.24699998
0.500000000      -.410899997      0.469999993E-02  0.219400004
5.98309994        1.42799997       1.25000000
 1.00000000      -.832300007      0.879999995E-02  0.340999991
6.40450001        1.43099999       1.25300002
 1.50000000      -1.26440001      0.121999998E-01  0.464500010
6.83659983        1.43499994       1.25600004
 2.00000000      -1.70720005      0.148999998E-01  0.589999974
7.27950001        1.43799996       1.25899994
 2.50000000      -2.16079998      0.167999994E-01  0.717499971
7.73320007        1.44200003       1.26300001
 3.00000000      -2.62540007      0.179999992E-01  0.847100019
8.19789982        1.44500005       1.26600003


  INCREMENTAL SUSPENSION PARAMETER VALUES

      ROLL         ROLL CENTRE POSITION       HALF WHEELBASE
DAMPER    SPRING
     ANGLE          X          Y          Z      TRACK    CHANGE
TRAVEL    TRAVEL
     (deg)       (mm)       (mm)       (mm)    CHANGE       (mm)
(mm)        (mm)
         (+ve Y to outer wheel: Z rl to Grnd) (mm)

-3.00000000       7051.60010      -27.2900009       85.6900024
      -.900000036E-01   2.67000008      -27.7700005      -31.7199993

-2.50000000       7051.60010      -23.3500004       85.6200027
      -.700000003E-01   2.24000001      -23.1100006      -26.3999996

-2.00000000       7051.60010      -19.0799999       85.5699997
      -.399999991E-01   1.79999995      -18.4699993      -21.1000004

-1.50000000       7051.60010      -14.5400000       85.5299988
      -.199999996E-01   1.36000001      -13.8400002      -15.8100004

-1.00000000       7051.60010      -9.81000042       85.5000000
      -.999999978E-02  0.910000026      -9.21000004      -10.5200005

-.500000000       7051.60010      -4.94000006       85.4800034
      0.000000000E+00  0.460000008      -4.59999990      -5.26000023

0.000000000E+00   7051.60010      0.000000000E+00   85.4800034
      0.000000000E+00  0.000000000E+00  0.000000000E+00
      0.000000000E+00
```

```
0.500000000       7051.60010       4.94000006       85.4800034
     0.000000000E+00  -.460000008       4.59000015       5.23999977

 1.00000000       7051.60010       9.81000042       85.5000000
     -.999999978E-02  -.930000007       9.17000008       10.4700003

 1.50000000       7051.60010       14.5400000       85.5299988
     -.299999993E-01  -1.39999998       13.7399998       15.6899996

 2.00000000       7051.60010       19.0799999       85.5699997
     -.500000007E-01  -1.87000000       18.2900009       20.8899994

 2.50000000       7051.60010       23.3500004       85.6200027
     -.700000003E-01  -2.34999990       22.8400002       26.0799999

 3.00000000       7051.60010       27.2900009       85.6900024
     -.100000001      -2.82999992       27.3700008       31.2600002


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      REAR SUSPENSION     -    ROLL
            LHS WHEEL (-ve Y)

     TYPE 1 Double Wishbone, damper to lower wishbone


   INCREMENTAL GEOMETRY VALUES

      ROLL              CAMBER       TOE    CASTOR   KINGPIN
DAMPER    SPRING
     ANGLE               ANGLE     ANGLE     ANGLE     ANGLE
RATIO     RATIO
     (deg)               (deg)     (deg)     (deg)     (deg)
[-]       [-]

-3.00000000      -2.62540007      0.179999992E-01  0.847100019
8.19789982        1.44500005       1.26600003
-2.50000000      -2.16079998      0.167999994E-01  0.717499971
7.73320007        1.44200003       1.26300001
-2.00000000      -1.70720005      0.148999998E-01  0.589999974
7.27950001        1.43799996       1.25899994
-1.50000000      -1.26440001      0.121999998E-01  0.464500010
6.83659983        1.43499994       1.25600004
```

```
-1.00000000      -.832300007      0.879999995E-02  0.340999991
6.40450001        1.43099999       1.25300002
-.500000000      -.410899997      0.469999993E-02  0.219400004
5.98309994        1.42799997       1.25000000
0.000000000E+00  0.000000000E+00  0.000000000E+00  0.997999981E-01
5.57219982        1.42400002       1.24699998
0.500000000      0.400299996      -.520000001E-02  -.178999994E-01
5.17189980        1.42100000       1.24399996
 1.00000000      0.790099978      -.109000001E-01  -.133699998
4.78210020        1.41700006       1.24100006
 1.50000000       1.16919994      -.170000009E-01  -.247600004
4.40290022        1.41400003       1.23800004
 2.00000000       1.53779995      -.233999994E-01  -.359699994
4.03439999        1.41100001       1.23500001
 2.50000000       1.89559996      -.300999992E-01  -.469900012
3.67650008        1.40799999       1.23199999
 3.00000000       2.24259996      -.368999988E-01  -.578299999
3.32949996        1.40499997       1.22899997


  INCREMENTAL SUSPENSION PARAMETER VALUES

      ROLL         ROLL CENTRE POSITION       HALF WHEELBASE
DAMPER    SPRING
     ANGLE          X          Y          Z     TRACK    CHANGE
TRAVEL    TRAVEL
     (deg)       (mm)       (mm)       (mm)    CHANGE       (mm)
 (mm)       (mm)
         (+ve Y to outer wheel: Z rl to Grnd) (mm)

-3.00000000       7051.60010      -27.2900009       85.6900024
      -.100000001      -2.82999992       27.3700008       31.2600002

-2.50000000       7051.60010      -23.3500004       85.6200027
      -.700000003E-01  -2.34999990       22.8400002       26.0799999

-2.00000000       7051.60010      -19.0799999       85.5699997
      -.500000007E-01  -1.87000000       18.2900009       20.8899994

-1.50000000       7051.60010      -14.5400000       85.5299988
      -.299999993E-01  -1.39999998       13.7399998       15.6899996

-1.00000000       7051.60010      -9.81000042       85.5000000
      -.999999978E-02  -.930000007       9.17000008       10.4700003

-.500000000       7051.60010      -4.94000006       85.4800034
      0.000000000E+00  -.460000008       4.59000015       5.23999977

0.000000000E+00   7051.60010      0.000000000E+00   85.4800034
      0.000000000E+00  0.000000000E+00  0.000000000E+00
      0.000000000E+00
```

```
0.500000000       7051.60010       4.94000006       85.4800034
      0.000000000E+00  0.460000008      -4.59999990      -5.26000023

 1.00000000       7051.60010       9.81000042       85.5000000
      -.999999978E-02  0.910000026      -9.21000004      -10.5200005

 1.50000000       7051.60010       14.5400000       85.5299988
      -.199999996E-01   1.36000001      -13.8400002      -15.8100004

 2.00000000       7051.60010       19.0799999       85.5699997
      -.399999991E-01   1.79999995      -18.4699993      -21.1000004

 2.50000000       7051.60010       23.3500004       85.6200027
      -.700000003E-01   2.24000001      -23.1100006      -26.3999996

 3.00000000       7051.60010       27.2900009       85.6900024
      -.900000036E-01   2.67000008      -27.7700005      -31.7199993


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     FRONT SUSPENSION     -    STEERING TRAVEL

     TYPE 1 Double Wishbone, damper to lower wishbone

   INCREMENTAL GEOMETRY VALUES

      RACK                 TOE       TOE    CAMBER    CAMBER
ACKERMANN   TURNING
    TRAVEL               ANGLE     ANGLE     ANGLE     ANGLE
(%)    CIRCLE
      (mm)                 RHS       LHS       RHS       LHS
RADIUS
                          (deg)     (deg)     (deg)     (deg)
(mm)

-30.0000000      -13.9099998       14.1999998      0.189999998
      0.150000006      -16.5599995       11824.4102
-25.0000000      -11.5799999       11.7799997      0.129999995
      0.100000001      -16.7399998       14318.0996
-20.0000000      -9.26000023       9.39000034      0.900000036E-01
      0.599999987E-01  -16.8899994       18028.3691
-15.0000000      -6.94000006       7.01999998      0.500000007E-01
      0.299999993E-01  -17.0100002       24172.5996
```
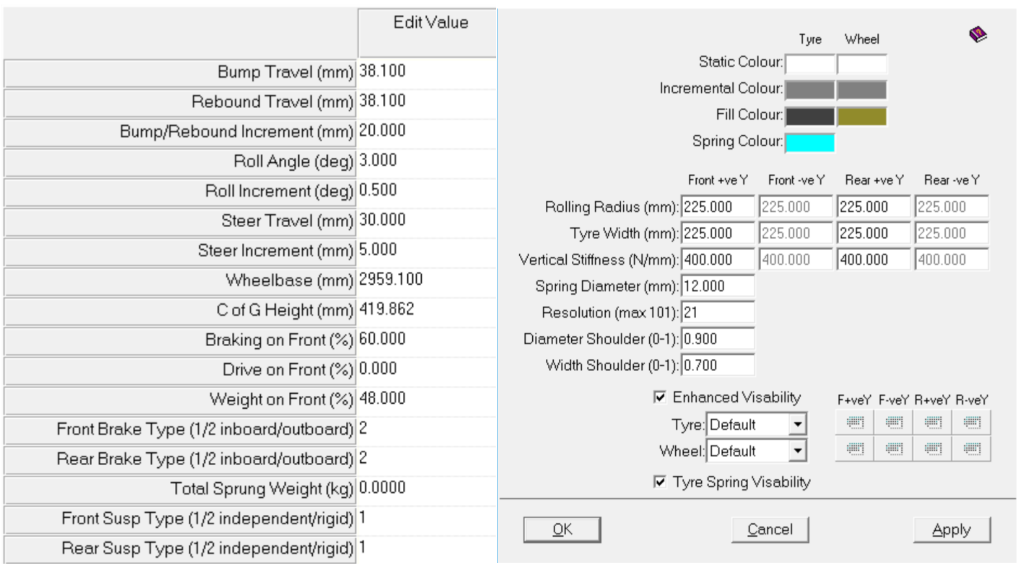
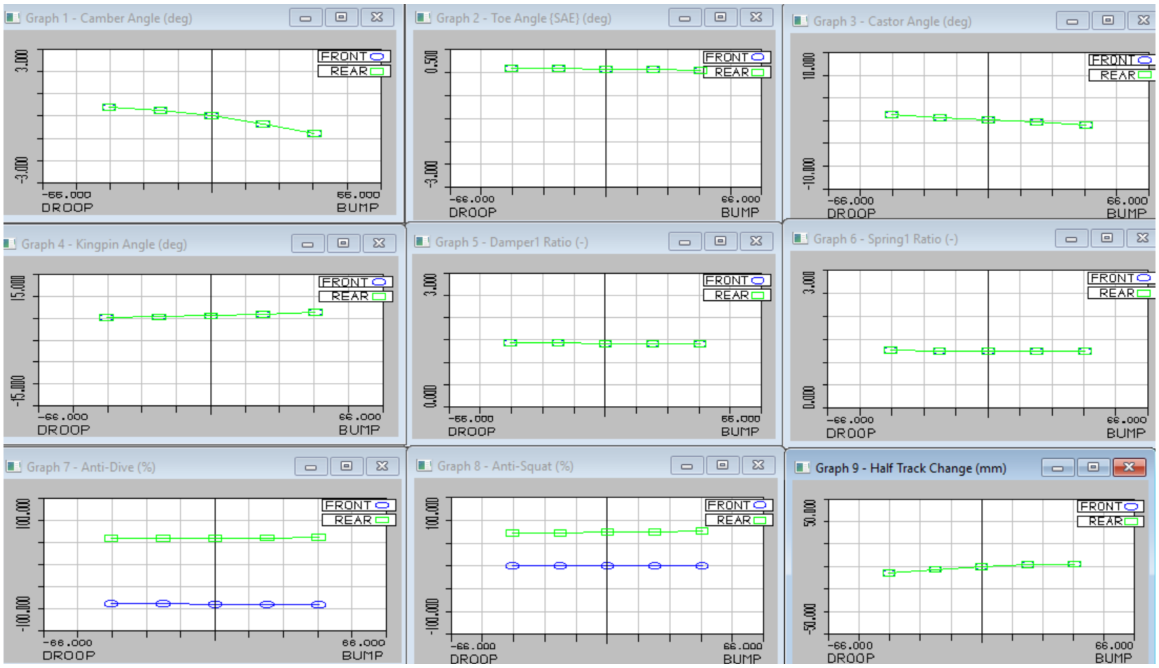
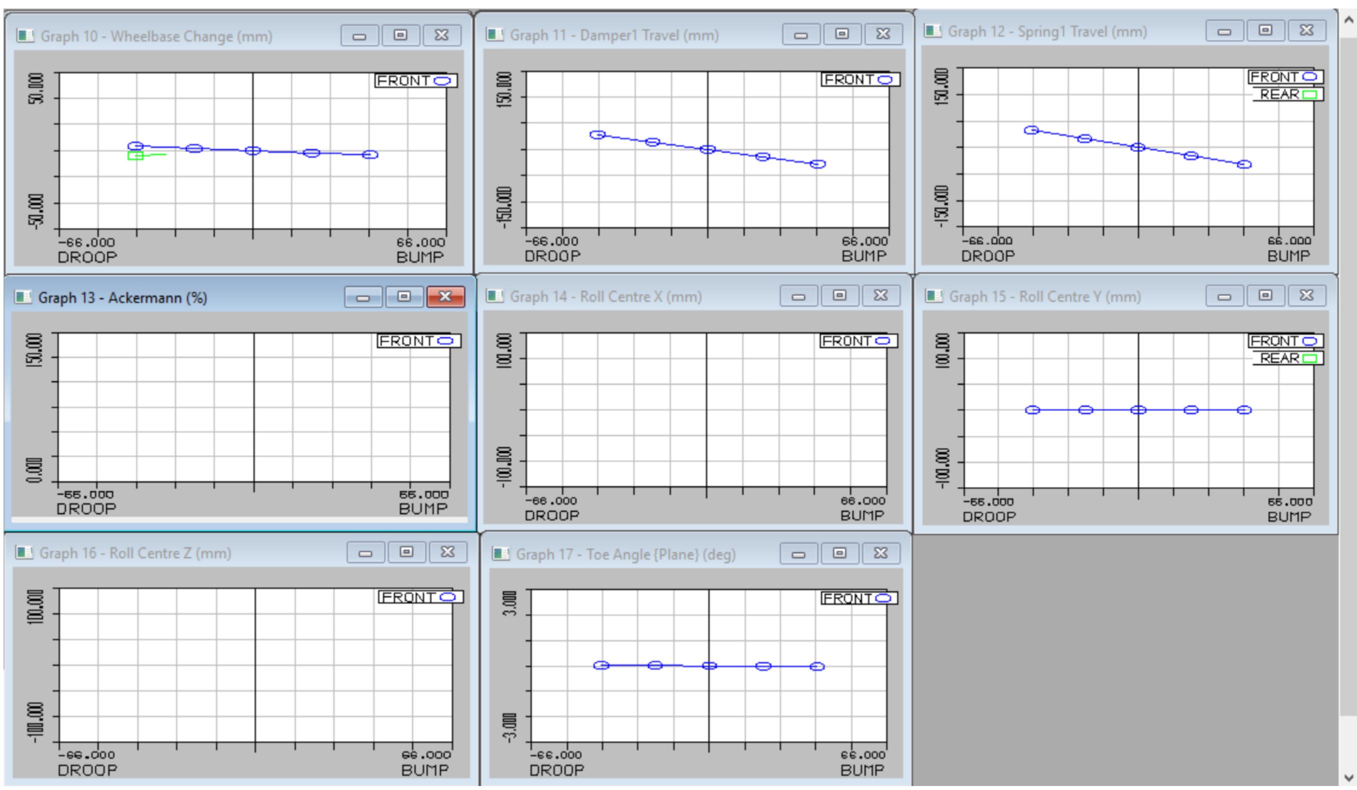
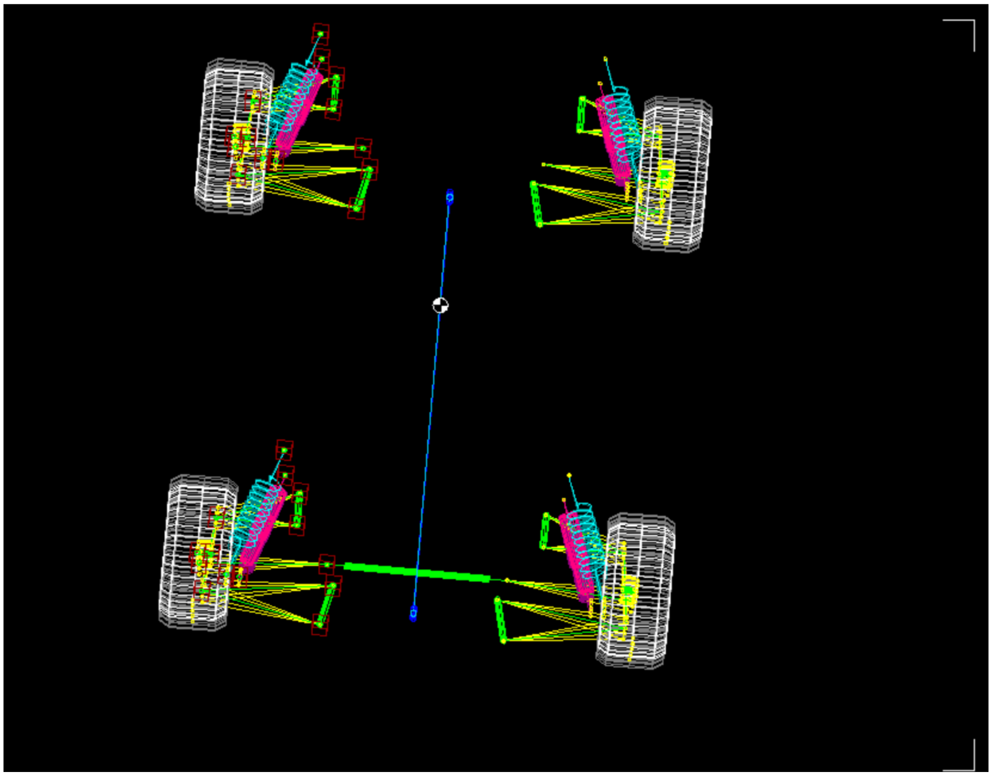
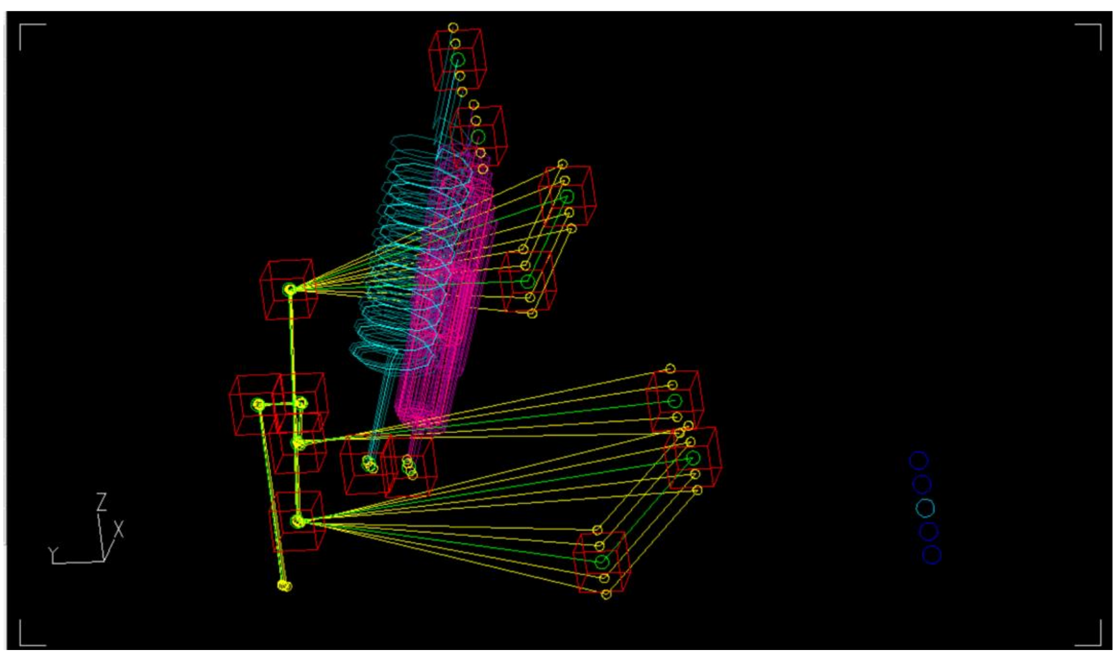

```
-10.0000000       -4.63000011       4.65999985       0.299999993E-01
      0.999999978E-02   -17.0900002        36402.6719
-5.00000000       -2.31999993       2.32999992       0.999999978E-02
      0.000000000E+00   -17.1499996        72977.3438
0.000000000E+00   0.000000000E+00  0.000000000E+00   0.000000000E+00
      0.000000000E+00   -16.5599995       0.000000000E+00
 5.00000000        2.32999992      -2.31999993       0.000000000E+00
      0.999999978E-02   -17.1499996        72977.3438
 10.0000000        4.65999985      -4.63000011       0.999999978E-02
      0.299999993E-01   -17.0900002        36402.6719
 15.0000000        7.01999998      -6.94000006       0.299999993E-01
      0.500000007E-01   -17.0100002        24172.5996
 20.0000000        9.39000034      -9.26000023       0.599999987E-01
      0.900000036E-01   -16.8899994        18028.3691
 25.0000000        11.7799997      -11.5799999       0.100000001
      0.129999995       -16.7399998        14318.0996
 30.0000000        14.1999998      -13.9099998       0.150000006
      0.189999998       -16.5599995        11824.4102
```




Graph 1 - Camber Angle (deg)
3.000
-3.000
FRONT
REAR
-66.000
DROOP
66.000
BUMP
Graph 2 - Toe Angle (SAE) (deg)
0.500
-3.000
Graph 3 - Castor Angle (deg)
10.000
-10.000
Graph 4 - Kingpin Angle (deg)
15.000
-15.000
Graph 5 - Damper1 Ratio (-)
3.000
0.000
Graph 6 - Spring1 Ratio (-)
3.000
0.000
Graph 7 - Anti-Dive (%)
100.000
-100.000
Graph 8 - Anti-Squat (%)
100.000
-100.000
Graph 9 - Half Track Change (mm)
50.000
-50.000


Graph 10 - Wheelbase Change (mm)
50.000
-50.000
FRONT
-66.000
DROOP
66.000
BUMP
Graph 11 - Damper1 Travel (mm)
150.000
-150.000
Graph 12 - Spring1 Travel (mm)
150.000
-150.000
REAR
Graph 13 - Ackermann (%)
150.000
0.000
Graph 14 - Roll Centre X (mm)
100.000
-100.000
Graph 15 - Roll Centre Y (mm)
100.000
-100.000
Graph 16 - Roll Centre Z (mm)
100.000
-100.000
Graph 17 - Toe Angle (Plane) (deg)
3.000
-3.000




Z
Y
X

CONCLUSION

The objective of designing the suspension system of a 5-seater performance car with high safety and production costs seems to be accomplished. The design is first conceptualized based on personal experience and intuition. The design process includes the use of software like AutoCAD, Suspension Calculator and Lotus Shark.

REFERENCE

- John.C.Dixon, Suspension Analysis and Computation Geometry
- Thomas D. Gillespie, Fundamentals of Vehicle Dynamics
- www.google.com
- www.cardekho.com