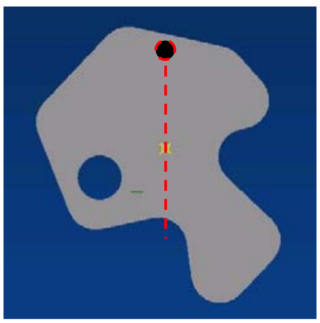
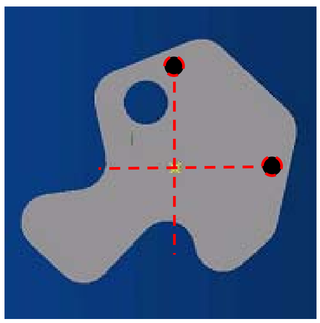
Measuring center-of-gravity height on a Formula Car

James Hakewill, June 2007

In order to calculate weight transfers during braking and cornering, a number of pieces of information are required. Many of these are simple to use in equations but rather hard to come by in practice – the position of the vehicle center of gravity in three dimensions being one example.

The center of gravity (c.g.) of an arbitrary shape can be found either by laborious calculation or by asking the CAD tool, if accurate models are available. It can also be found by hanging the shape from various points – the center of gravity will lie directly below the point of suspension. Drawing vertical lines from

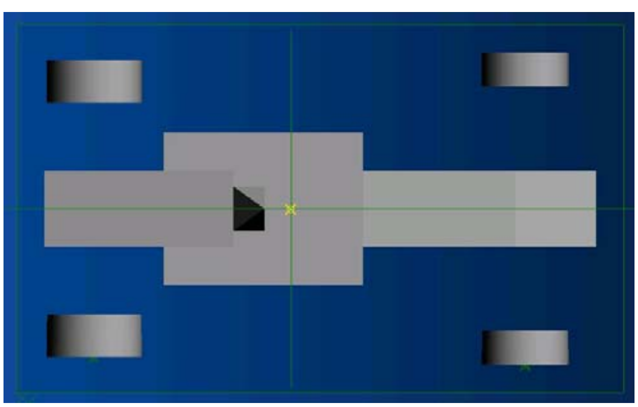




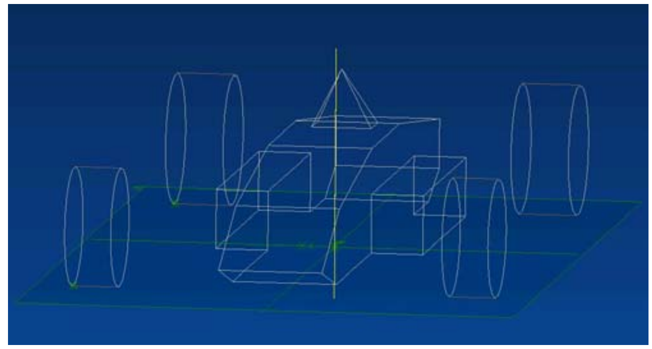
each point of suspension will reveal the c.g. at the point where the lines cross.

For a two-dimensional shape, the minimum number of lines (axes) required to produce the position of the c.g. is two. For three dimensions, three axes are required.

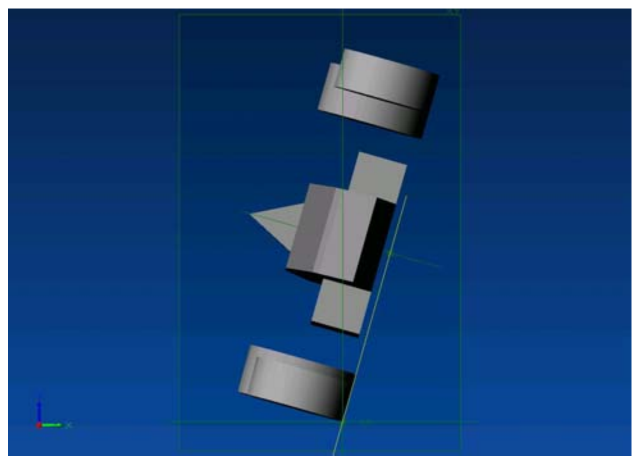
For a car, two of the three axes can be readily calculated using corner weight data, – and the plan-area position of the center of gravity located.



The vertical axis passing through the plan-area position must pass through the three-dimensional center of gravity. The challenge then is to find the point along the vertical axis where the center of gravity lies.



The approach chosen in this case was to balance the car on two points – the front and rear tire sidewalls of one side of the car. The vertical plane rising from these points must pass through the center of gravity.



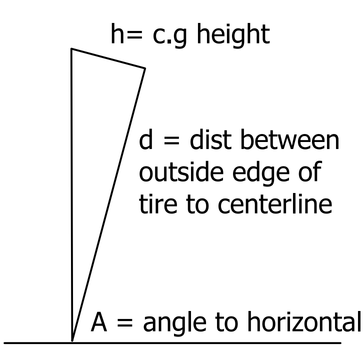
Before the car was balanced in this way, the spring/damper units were removed and replaced with solid bars ('dummy shocks') to place the car at the static ride height. Bags of cement were strapped into the car to simulate the weight of the driver. Strangely enough, the usual driver was not keen to sit in the car whilst the experiment was performed.

Once the car has been got into a position of balance, it should be possible to keep it there with just a couple of fingers whilst the angle is measured.

On the track the car pulls up to 2G laterally during cornering, so balancing the full weight of the car on one side of the suspension was not a great concern – although naturally it was done very carefully!

The car was lifted into position using an engine crane and an I-section beam between the wheels. Don't try this at home – or if you do it's at your own risk!

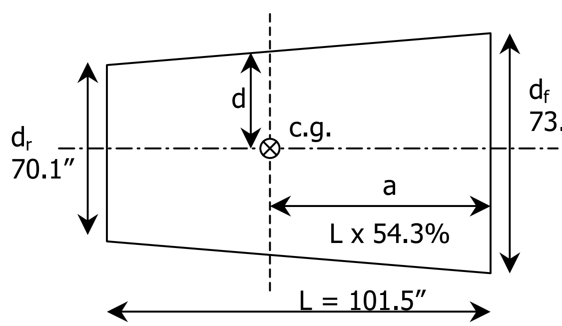
When the car was balanced on its wheels – able to be held in place with just a couple of fingers and the crane straps slack, the difference in angle from the horizontal was measured.



$$h = d \tan(90-A)$$

If the track were equal front and rear, the calculation would be very simple trigonometry.

On the car in question – a Van Diemen RF03 Zetec, the width of the front end is wider than the rear. As a result it is necessary to work out the width of the car at the slice along the centerline of the car that contains the c.g.:



df = Between outside edges of front wheels: 73.6″
dr = Between outside edges of rear wheels: 70.1″
Wr = Weight on rear axle – 54.3%
L = Wheelbase: 101.5″
a = Front axle to c.g.: 54.3% x 101.5″ = 55.1″
A = Angle at which the car balanced: 74.2 degrees

width at c.g. d = df + ((dr – df) * Wr)
= 73.6 + ((70.1-73.6) * 0.543)
= 71.7″

c.g. height h = (d / 2) * tan (90 – A)
= 10.1″

<u>Quick & dirty estimation of errors:</u>
df: ±0.25″
dr – df: ±0.25″
A: ± 0.2 degrees
Wr – calculated from corner weights at ± 1lb per corner over 1270lbs, hence approx 0.3%.

Max positive error,
d: 0.25 + (0.25 * 0.003) = 0.25075

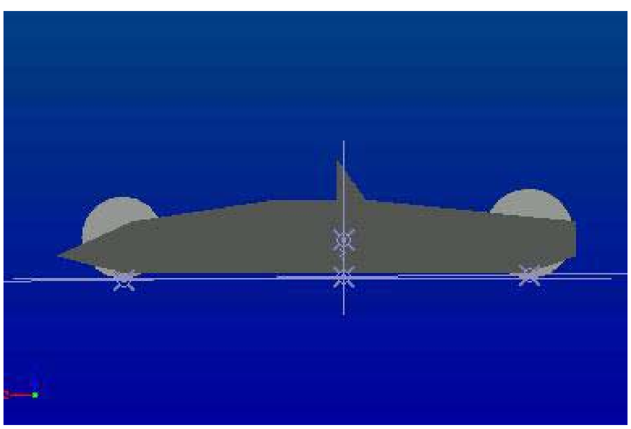
Result with max positive errors
h = (71.7 + 0.25075)/2 * tan(90 – 74.2 – 0.2)
= 10.0″

Hence the total error is ± 0.1″ or thereabouts.

Claude Rouelle described this method of calculating CG in one of his vehicle dynamics seminars.

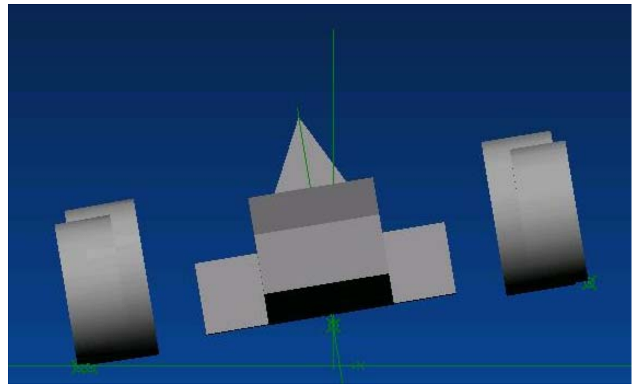
Using the CG height

The roll axis passes through the front and rear roll centers. The height H of the CG above the roll axis at the plane containing the CG is used in kinematic weight transfer calculations.



Alternative scheme #1

One possible scheme is to place the car on scales, take corner weights and then raise one side or one end of the car by a significant amount and take corner weights again.



The theory goes that the center of gravity will be shifted towards the low side/end of the car, which will then weigh heavier. The height of the c.g. can then be worked out from the change in measured weights.

However – the relatively small changes in corner weights mean that the measurement error from the scales may become a large factor in the overall result.

This method is described in Race Car Vehicle Dynamics – Milliken/Milliken, section 18.2.

Alternative scheme #2

If the car were suspended from a single point, the vertical axis from the point of suspension would pass through the center of gravity.

The roll hoop is the most obvious point from which it would be possible to suspend the car. However – if the c.g. is far from the roll bar, suspending the car from the roll hoop may require a fair amount of height. If the c.g is close to the roll bar, the angle taken by the car may be very small.

Assuming that the car is symmetrical and the c.g. lies on the center plane, the c.g. position can be calculated from the angle at which the car is hanging. However, getting the car stable enough to measure this angle could be tricky since it is a very large pendulum.