# Leaning Trikes using Rear Axle Pedal Crank Mechanism

By Stephen Nurse, Melbourne, Australia, November 2013

## Summary & Background

*Tilting Delta Trikes with a rear axle made from standard cycle cranks were invented by Mr. Vi Vuong, who calls them "iLean trikes". He has developed several such versions with family and friends and mainly builds from recycled materials. The trikes can be built in many different ways. This article introduces these trikes, shows their relationship to other human-powered vehicles, and considers the maths of their tilting and suspension performance.*

## Current versions: Photos

iLean trikes by: S. Alexander Petraj, Stephen Nurse and Vi Vuong

## Introduction

Recent internet videos [2, 3] posted by Mr. Vi Vuong astonished the human-powered-vehicle community. He had mounted cycle wheels "in the place of pedals" on cranks on a working bottom bracket and used the resulting assembly as the rear axles of a self-leaning delta trike. The mechanism was seen to work well by thousands of viewers. Vi's use of the mechanism has been on front-wheel-drive, centre-steer trikes in the Python family.

Since seeing the videos I have built my own version of the trike. Riding it feels just like my equivalent bike [1] with the rear wheels letting the vehicle lean in corners, cope with camber on roads and give a suspension effect. The rear axle makes it feel like there's a "virtual rear wheel" midway between the actual rear wheels.

This rear-wheel mechanism makes braking or driving of the rear wheels difficult, however it seems to be suitable as a variation on most front-wheel-drive recumbent bikes. These include Python and moving-bottom-bracket (Cruzbike) styles as well as fixed-bottom-bracket direct styles (Bevo bike). There's no reason it should not work as well on indirect-drive and other front-wheel-drive recumbents (e.g. Zox, Raptobike, Handcycles).

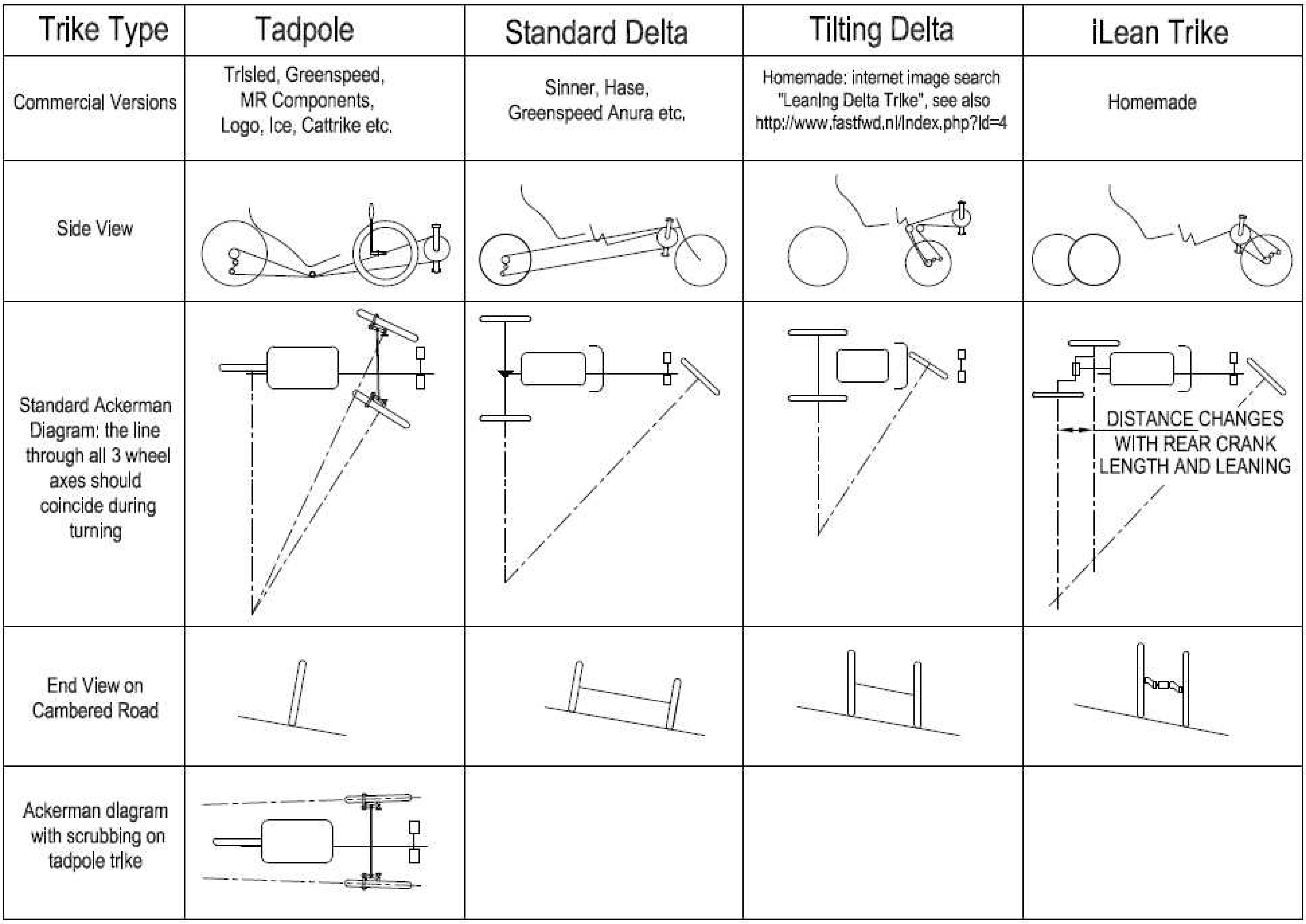
## Handling

The layout and steering arrangement of these new iLean tilting trikes is shown in fig.1 together with those of other leaning delta trikes and non-leaning delta and tadpole trikes.

In curves, the axes of all three wheels should meet at a single point. This principle is called Ackermann steering [4], and unless this condition is fulfilled, the tires scrub and resist forward motion. A frequent demonstration of wheel scrub is in a tadpole trike with poorly aligned (toed in or toed out) front wheels. Most delta trikes have innate Ackermann steering, however iLean trikes do not. They have "good enough" Ackermann which is dynamic and depends on the lean of the trike as well as the trike's geometry. With good geometry, the trike's wheel alignment improves when cornering at speed. Handling and behaviour of these trikes include:

- **On flat ground, straight ahead**, the rider is constantly turning and balancing, just as in normal bike operation.
- **On cambered roads**, seat and rider stay upright as the back wheels assume different heights. Height differences between wheels are often small.

- **Leaning during turns**, the rider leans and the rear wheels assume significantly different “heights” when seen from a plane parallel to the rear wheels. When seen from the side, the horizontal distance between the back wheels is foreshortened, reducing the wheel-scrub effect of the geometry.
- **Suspension.** When one rear wheel hits a bump, it raises the back of the trike in a lever motion. The rear-wheel bottom-bracket assembly goes up only half the height of the bump, and this is what the rider feels. On 20” (500mm OD) wheels on a 10mm bump, the average rate of rise the rider feels is close to that of a 2000mm wheel and the effective height of the bump is still halved. This seems to indicate an effective suspension. (Refer to Appendix for calculations)
- **Simultaneous Actions.** When riding, none of these behaviours occur in isolation. They all happen simultaneously, but the mechanism seems to cope.




# Fig 1: Trike Comparison and Steering.

Front-wheel-drive bikes and their iLean-trike equivalents

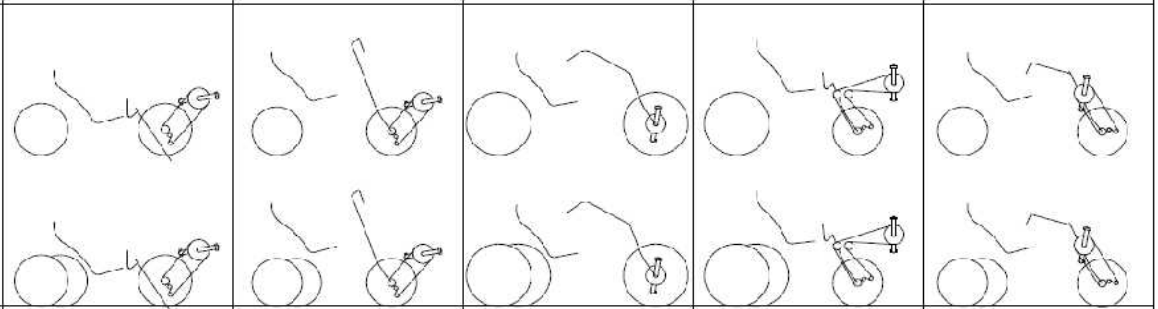
| | Centre Steer | Moving Bottom Bracket | In-Hub Pedals and Gears | Fixed Bottom Bracket, with Pulley on Chain tension side | Fixed Bottom Bracket, no Pulley on Chain tension side |
|---|---|---|---|---|---|
| Commercial Versions | Flevobike | Cruzbike | Penny Farthings, no modern commercial versions | Zox, Raptobike etc, | Bevo, Ming |
| Bike Diagram |  | | | | |
| Trike Diagram | | | | | |
| Trike Versions by | Vi Vuong, USA | S. Alexander Petraj, Greece | None Known | None Known | Stephen Nurse, Australia |

Fig 2: Front wheel drive bikes and their ilean trike equivalents

## Dimensions and Geometry

The relevant dimensions of iLean trikes are:

- Lateral distance between the rear-wheel ground-contact points, "Q" after the familiar pedal distance.
- Wheel diameter, "D"
- Crank length, "P"
- Longitudinal distance between the rear-wheel ground-contact points, "B"

Notable, changeable influences on the geometry are:

- "Q" can be made wide by splitting the crank axle and bottom bracket of the simple "pedal" construction. The resulting wide space can allow for a large load-carrying platform and improve the steering characteristic by allowing "B" to reduce dramatically when the trike leans in corners.
- "P" can be made short to improve wheel-scrub performance without much compromise to suspension performance. This shortening was done on the author's trike and wheel scrub (drift) disappeared when 170mm cranks were swapped for 90mm cranks.
- Suspension seems good enough that "increasing the effect of a bump" by moving the rear axle close to the rider would not compromise comfort.
- At least on paved roads, suspension seems good enough that reducing the rear-wheel size from 20" to 16" would not compromise comfort.

## Construction

A trike using Vi's rear axle design needs a small number of mostly standard parts. My trike has 20" wheels adapted to include pedal axles as the main non-standard parts. Note that for the back wheels to achieve the same direction of rotation relative to the cranks as normal pedals, the drive crank should be mounted on the left-hand side as shown in Fig 3.

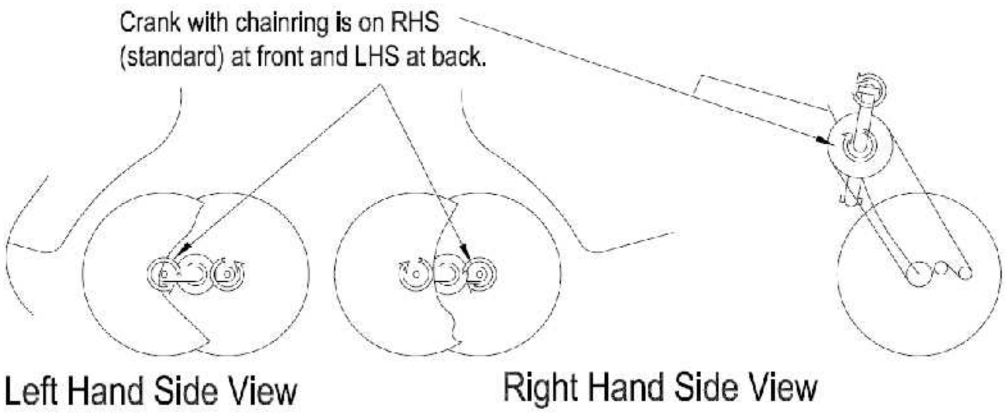



Fig 3 Rotation of pedal and rear wheel relative to crank at front and rear of iLean trike.

The axle assembly attaches straight onto a frame and includes

- 2 wheels with axles designed to mount to pedals (modified wheelchair or trike hubs or other)
- Standard cranks
- Bottom-bracket shell and bearing assembly.

Unicycle cranks are generally shorter and more economical than conventional bike cranks, and they make good components for iLean Trikes. Some unicycle cranks come with disc brake mounts as standard and these could be used for braking the pedal mechanism in an iLean trike assembly for static stability (see below).

To summarise, the iLean trike uses an unconventional but simple set of parts. They are simpler than other leaning delta trike types, most of which require several specially made components.

## Braking the pedal mechanism

Preventing the rotation of the rear pedal mechanism around the bottom bracket can make the rear wheels act as a stand and allow the rider to be stable on the trike when stopped at traffic lights or going very slowly. These are normal, desirable characteristics of recumbent trikes. The iLean trikes seen so far are not yet equipped with this ability.

## Conclusion

A pedal-mechanism rear axle provides a simple alternate construction for front-wheel-drive bikes. The construction

- can use mostly standard parts,
- can compare to other constructions in cost,
- can compare to other constructions in weight, and
- is spectacular, interesting and has the potential to be used on many human-powered and other vehicles.

## Scope

This study only considers trikes where the cranks making up the rear axle are mounted on opposite sides. Other mounts are possible and these can deliver different trike dynamics. One is with the cranks mounted at 90 degrees to each other as shown in S. Alexander Petraj's video.

This study details front-wheel-drive leg-driven recumbents as candidates for use as iLean delta trikes. However the pedal-rear-axle mechanism could also be used on scooters, handcycles and motor- or engine-assisted / driven vehicles.

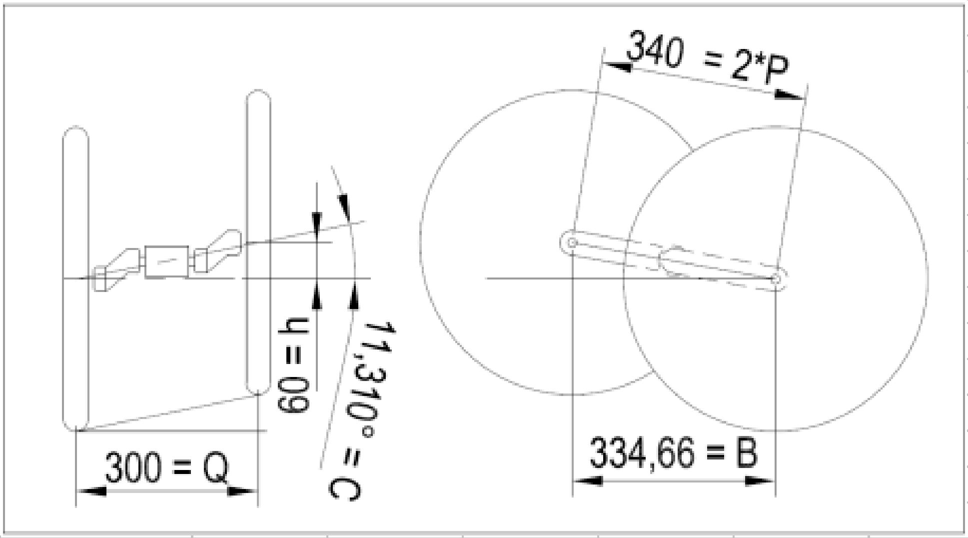
## References


1. An Illustrated Guide to the Cycle Zoo by Stephen Nurse. ISBN 978-1-921488-08-5 published / available through http://modularbikes.com.au/
2. http://en.openbike.org/wiki/~iLean by Vi Vuong. This website includes photos and links to videos and should be used in conjunction with this article.
3. Video of Vi Vuong's iLean trike https://www.youtube.com/user/TheFutonExpress
4. http://en.wikipedia.org/wiki/Ackermann_steering_geometry.


## Appendices

Spreadsheet allowing calculations of performance of trikes in corners and over bumps. Screenshots of this spreadsheet are included below.

### Appendix 1: Combined Effect of Cambered Road & Leaning in Corners




The angle of the rear bottom bracket to the ground is the combination of the camber on the road and the leaning of the trike.
Its easier to work out the maths if the rear bottom bracket is shown as horizontal although in practice this only happens instantaneously and when riding in a straight line.

**Nomenclature**

From the conventional letter for pedal spacing, Q is the distance between rear wheel centres in the bottom bracket axle direction.
P is the pedal radius
B is the distance between wheel centres as projected onto the road surface
C is the angle of the rear wheel axes relative to the road
h is the height distance between rear wheels when the wheel axes are horizontal

**Derivation**

$h = Q\ (\tan C)$ and $h^2+B^2 = (2P)^2$

So $h^2= (2P)^2-B^2$ or $h= ((2P)^2-B^2)^{0.5}$

So we have $h = Q\ (\tan C) = ((2P)^2-B^2)^{0.5}$ or $Q\ (\tan C) = ((2P)^2-B^2)^{0.5}$

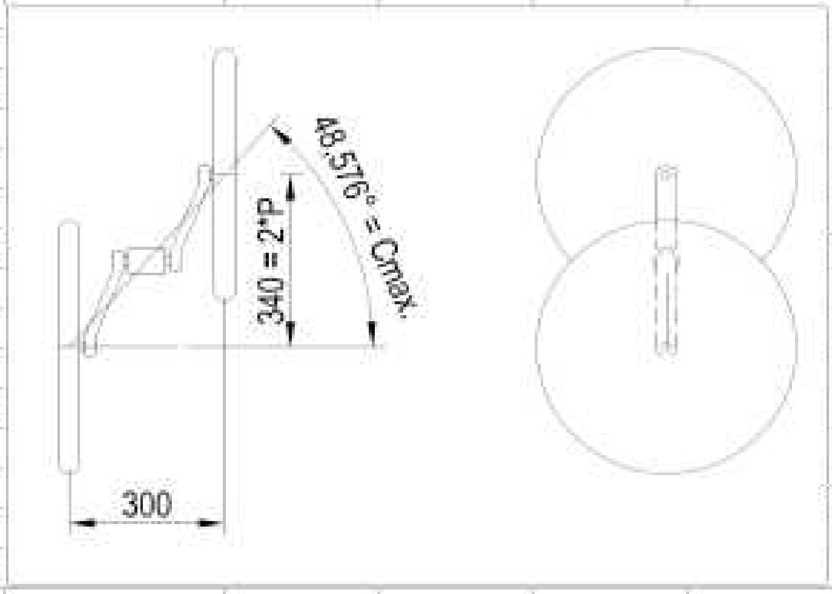
Squaring both sides, $Q^2\ (\tan^2 C) = (2P)^2-B^2$

So $B^2 = (2P)^2 - Q^2\ (\tan^2 C)$, or $B = ((2P)^2 - Q^2\ (\tan^2 C))^{0.5}$

**Calculation**

| Q | C deg | C rad | P | B |
|---|---|---|---|---|
| 300 | 11.31 | 0.197397 | 170 | 334.6639 |

## Special Case, "Maximum Tilt on 3 wheels"




ners.

iLean trikes can reach a point of "maximum trike tilt" when the rear cranks are vertical.

**When does that happen?**

From the above, $B^2 = (2P)^2 - Q^2 (\tan^2 C)$ so for B = 0, 2P = Q tan C

or C = atan (2P/Q)

**Calculation**

| P | Q | C rad | C deg |
|---|---|---|---|
| 170 | 300 | 0.847817 | 48.57633 |

**What happens after that?**

Depending on the trike geometry, speed and turn radius,

* All the weight of the back of the trike can rest on the inside wheel and the trike runs on 2 wheels, ie the front and inside wheel contact the ground
* If Q is wide, the trike stays put, it doesn't tip, it just can't lean at a greater angle.

## Further Scope

The above calculations assume the cranks which mount the front wheels are diametrically opposed. This doesn't have to be the case and mounting cranks and wheels at (say) a 90 degree angle to each other

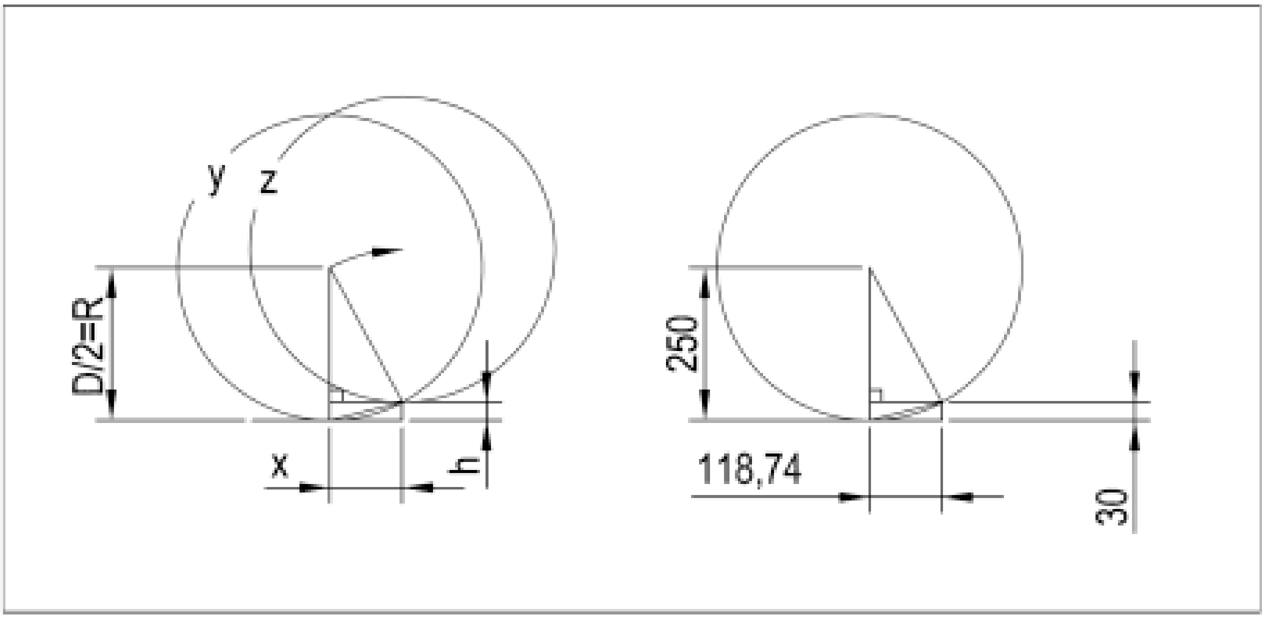
* should have interesting effects on the trike's stability and handling.

* has the immediate effect of reducing the effective crank axle length by a factor of $1 / 2^{0.5}$

S. Alexander Petraj has used this configuration on his trike and reports good results.

# Suspension effects

## Bumps on standard wheels




| | Nomenclature | | Sample Values |
|---|---|---|---|

This is an illustration of what happens when a bike wheel hits a bump.
This is a start point for the calculation of the effect of offset axle suspension.

As a wheel approaches a bump of height "h", it moves from position y to z.
The start of the rise is distance "x" away from the bump.

**Derivation**

$R^2 = x^2 + (R-h)^2 = x^2 + R^2 - 2Rh + h^2$

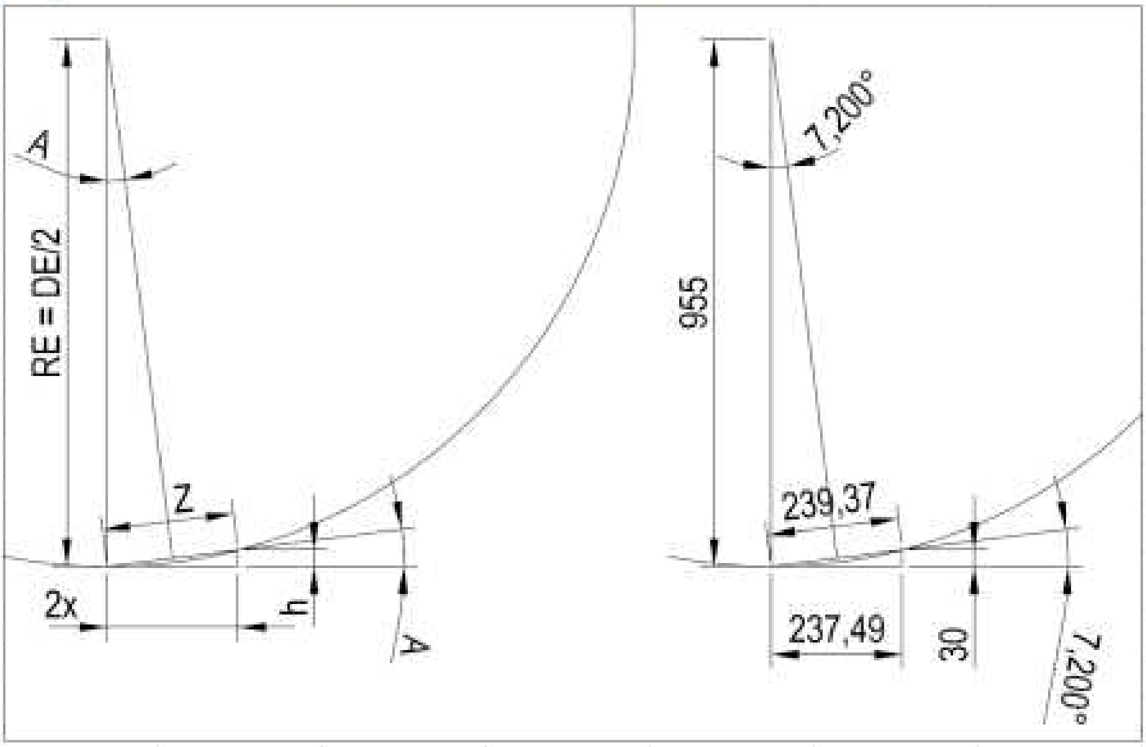
Removing $R^2$, we get $0 = x^2 - 2Rh + h^2$

or $x = (Dh-h^2)^{0.5}$

**Calculation**

| h | D | x | h/x |
|---|---|---|---|
| 30 | 500 | 118.7434 | 0.252646 |
| 30 | 400 | 105.3565 | 0.284747 |

# Equivalent Wheel Size Calculation




Nomenclature

Sample Values

This shows a calculation of the "effective diameter" of the wheel which produces the same rate of rise as the offset axle suspension shown above.
In this case it is very large and about 4 times as big as the original 500mm wheel.
Note that this calculation only takes into account the rate of rise
The amplitude of rise is also halved.

**Derivation**

Angle A = atan (h/2x)

and $z^2 = h2 + (2x)^2$ or $z = (h^2 + (2x)^2)^{0.5}$

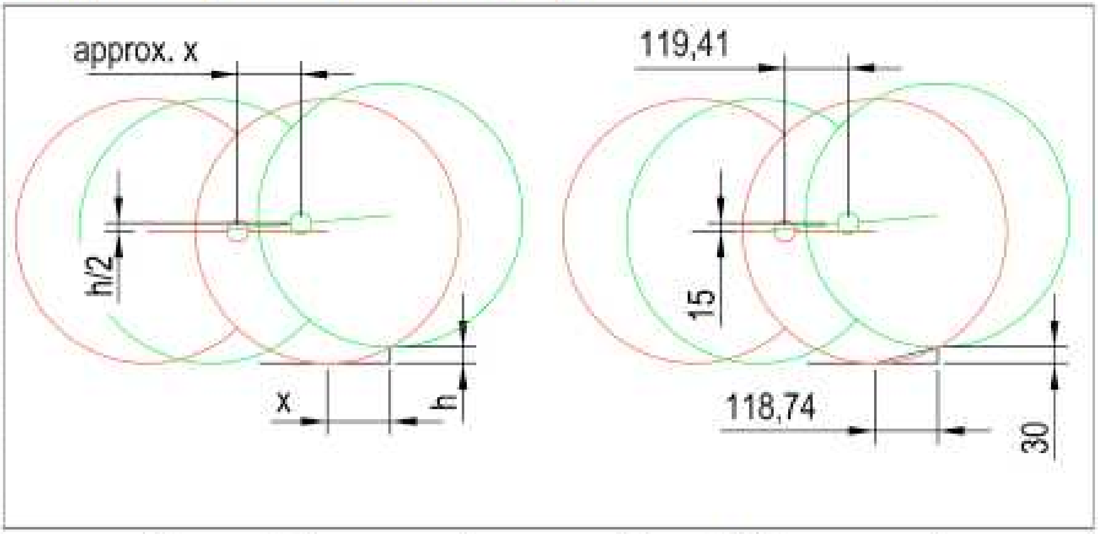
and REsinA = z/2

so $DE = 2RE = (h^2+(2x)^2)^{0.5}/\sin(\mathrm{atan}(h/2x))$

**Calculation**

| h | x | DE |
|---|---|---|
| 30 | 118.74 | 1909.892 |
| 30 | 105.35 | 1509.816 |

## Bumps on pedal axle rear suspension




Nomenclature

Sample Values

This shows an offset axle suspension setup before and at the end of the same size bump.
The trike frame is mounted on the bottom bracket (small circle)
To a very close approximation, the rider feels half the height rise over the same distance, when compared to an unsuspended wheel

So now we have a rate of rise over a bump that is half that of the single wheel.
We are used to the feel of an unsuspended bike and its possible to rate the suspension of a bike in terms of its wheel diameter.