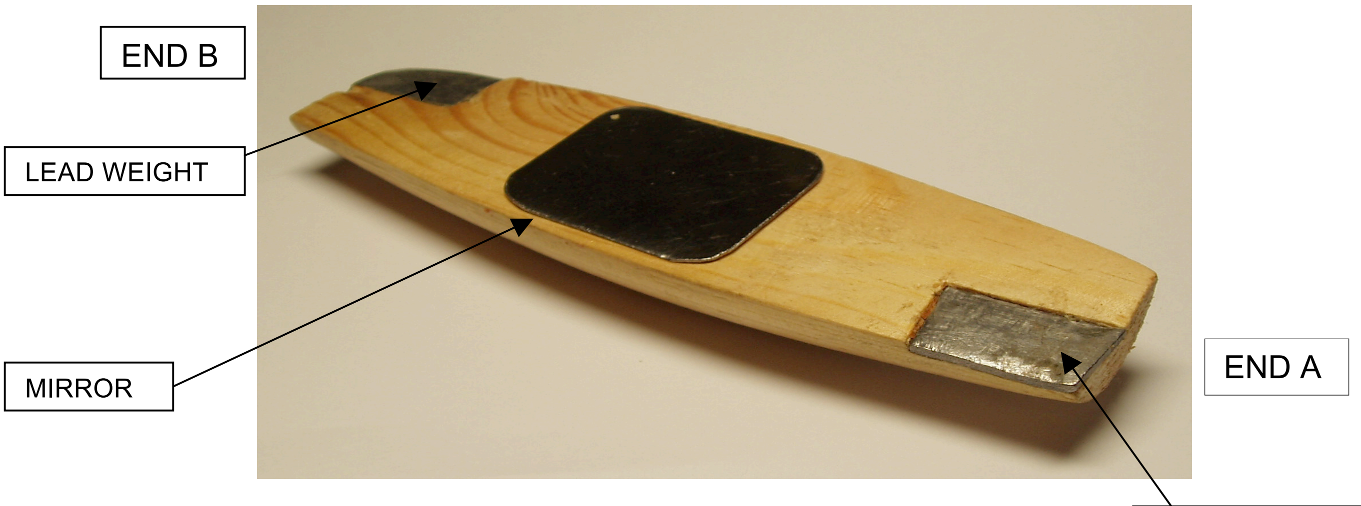
Some Ideas On How Rattlebacks Work

At the beginning of 2014, I saw a rattleback being demonstrated on a UK TV show called 'QI'. I was intrigued by the fact that that it would spin in one direction, but if spun in the other direction it would stop, rock and then reverse its spin direction. As there didn't seem to be an explanation of how it worked, I thought I would make a rattleback to experiment with.



MY RATTLEBACK

I decided to make my own, because I wanted to know exactly what it was made of and therefore there would be no hidden features, which might be in a commercial one. I turned the curved shape on a small work-working lathe and then cut it in half down the axis to make two rattlebacks. The size of the pair of rattlebacks was more or less determined by the piece of wood I used and I copied the general outline from pictures of rattlebacks on the internet. The dimensions are about 140mm long, 40mm across the widest part and 25mm across the ends. The narrow cross-section is semicircular and the lower part of the long cross-section is just a smooth convex curve judged by eye when I turned the wood. The size of the lead weights was chosen because it looked about right.

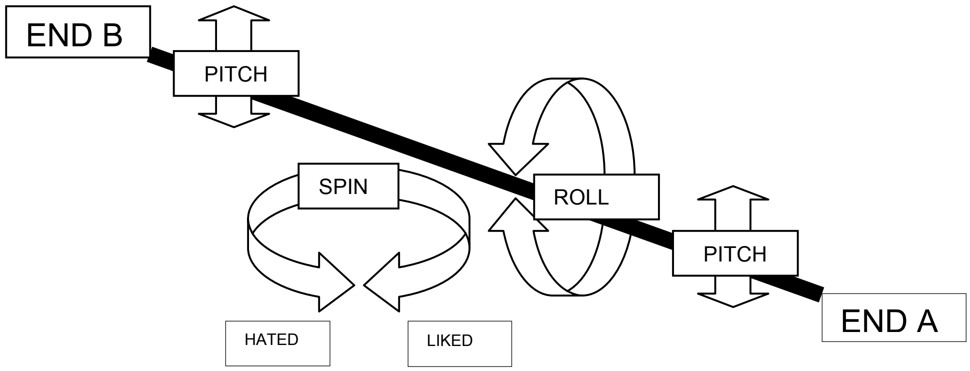
One of my rattlebacks is illustrated here. The other is similar, except that the lead weights are in the other corners. Both rattlebacks generally behave in the same way, except that the illustrated one reverses from anticlockwise spin to clockwise, whereas the other one reverses from clockwise to anticlockwise.

When stationary, my rattleback rests on the supporting surface with the upper face approximately horizontal. It is in stable equilibrium and, consequently, when tilted in any direction will naturally return by gravity to its horizontal state, after rocking once or twice.

The mirror is not a feature of the rattleback, but I show it in the illustration because it is used as part of my method of checking my ideas on the rattleback's motion and how it works.

In my explanation given below, I haven't included any mathematics because I'm not familiar with the techniques involved. Also, I realise that my simple explanation may not apply to other designs of rattleback, if, indeed, it adequately describes the action of my rattleback.

Particular Terms I Use in My Explanation



Pitch The up and down rocking motion from END A to END B. Because of the curved underside of the rattleback, the pivot point, where the rattleback rests on the supporting surface, moves from the mid-point to nearer the end that is down.

Roll The side-to-side rocking motion. As for Pitch, the point where the rattleback rests on the supporting surface is nearer to the side that is down.

Spin The horizontal rotation of the rattleback on the supporting surface. As for Pitch and Roll, the point where the rattleback rests on the supporting surface is nearer to the end and/or side that are down. I have used the term 'Hated' to indicate the direction of spin (anticlockwise as viewed from above) that my rattleback stops and then reverses. The term 'Liked' means that the rattleback continues to spin in this direction (clockwise) until slowed down and halted by friction.

Rattleback The illustrated rattleback.

How I Think the Rattleback Reverses Its Spin

If the supporting surface is VERY smooth, the rattleback will spin in the 'Hated' or 'Liked' direction until it is slowed and stopped by the small amount of friction between it and the supporting surface and by any wind resistance. No change of spin direction is initiated.
For this reason, I think that friction on the supporting surface is an essential feature of the spin-reversal action.

I think that the spin-reversal action takes place in the following stages:

1) The initial energy is given to the rattleback when the user spins it in the 'Hated' direction.

2) When the rattleback encounters friction in an off-centre contact between the bottom of the rattleback and supporting surface (let us assume that this is between the centre and End A) the rattleback then starts to roll clockwise as viewed from End A. This is because the lower part of the rattleback is retarded by the friction, whereas the stored energy, which is mainly in the weighted upper part of the rattleback, wants to keep the upper part going.

3) When the roll starts, the End A weight (which is trailing behind the friction point) initially moves upwards. The reaction to the force required to raise the weight causes End A to pitch further downwards thus increasing the frictional force. This slows or stops the spin as the spinning energy is transferred into a rolling and pitching motion. At End B, the weight initially moves downwards, temporarily lightening this end and increasing the pitching movement.

4) The stable equilibrium of the rattleback causes it to pitch back, bringing End B downwards. As part of the rattleback near End B comes into contact with the supporting surface, the friction causes the rattleback to roll clockwise as viewed from End B. A sequence similar in principle to that described for End A then takes place and the resultant pitching motion brings End A downwards..

5) The pitching and rolling are kept going for as long as the rattleback keeps spinning in its 'Hated' direction, and the sequence is:
   i) End A is down [see Stage 2]
   ii) End A rolls clockwise (as viewed from that end) [see Stages 2 & 3]
   iii) End B pitches downwards [see Stage 4]
   iv) End B rolls clockwise (as viewed from that end) [see Stage 4]
   v) End A pitches downwards [see Stage 4]
   vi) Return to Step ii) if the rattleback is still spinning.

   When the rattleback stops spinning, Stage 6 starts.

6) After the spinning energy of the rattleback is exhausted, the rolling motion described in Stage 5 is no longer perpetuated by the nudges given to the rattleback as each end meets the supporting surface. However, the pitching motion continues and, because the weighted corners of the rattleback have more energy, they overshoot when the pitching motion changes direction. This overshoot causes the rattleback to roll, and the rattleback adopts its natural sequence which is:
   i) End A pitches downwards
   ii) End A rolls anticlockwise (as viewed from that end)
   iii) End B pitches downwards
   iv) End B rolls anti-clockwise (as viewed from that end)
   v) Return to Step i).

7) Provided there is enough energy left, the rattleback's natural sequence continues. The anticlockwise rolling motion at each end, whenever it is down and thus in contact with the supporting surface, kicks the rattleback into spinning in the 'Liked' direction. This effect continues until the pitching and rolling energy has been transferred into spinning motion.

8) The rattleback is now spinning freely in the 'Liked' direction.

9) If excessive friction is encountered, for example, when End A is slightly down, End A starts to roll anticlockwise. When the roll starts, the weight (which is leading the friction point) initially moves downwards. The reaction to this movement is temporarily to lighten End A which causes End A to pitch upwards. This decreases or eliminates the effect of the friction and allows the rattleback to continue spinning.

A Method of Checking the Pitch and Roll Sequences

After having developed my hypothesis on how my rattleback worked, I wanted to observe whether the pitching and rolling sequences were, indeed, as I had predicted. At first, I found it impossible to visually observe the interrelationship between pitch and roll in the sequences, because they are so fast and the movements are quite small. After some thought, I devised the following methods. I found that these checks confirmed the sequences are as described above. I hope you get the same result.

To carry out the checks, you need the following bits of gear:

- A small piece of mirror that is lightweight and can be cut to size, if necessary. Stick or fasten it to the top centre of your rattleback.
- A small (key-ring) torch. The sort with just a single LED bulb.

This is the method for checking the sequence that occurs as the 'Hated' spin is stopped:

1) Position the rattleback on the surface you intend to spin it on.

2) Switch on the torch and hold it about 25 mm above the mirror. From almost directly above the mirror, look into it and hold the torch so that the image of the torch bulb is near the centre of the mirror.

3) Spin the rattleback in its 'Hated' direction. As it starts its pitching and rolling, you should see the image of the bulb move in a circular or elliptical path. Persistence of vision should give you the impression that the bulb leaves a trail, and this enables you to tell whether the path was traced in a clockwise or anticlockwise direction. Sometimes you might see a large initial circle followed by a small circle traced in the opposite direction. The second circle is produced by the rattleback's natural sequence, which starts the rattleback spinning in the 'Liked' direction.

4) To determine the pitch and roll relationship indicated by a traced path, you can manually tilt the stationary rattleback in a pitch and roll sequence that makes the bulb image rotate in the same direction.
   (My rattleback, which has an anticlockwise 'Hated' spin, produces an anticlockwise trace in the mirror.)

This is the method for checking the rattleback's natural sequence:

1) Place the rattleback on a tray and observe the bulb image in the mirror, as above.

2) Gently vibrate the tray with a rocking motion until the rattleback starts spinning in its 'Liked' direction. You should see a smaller circular or elliptical path traced in the opposite direction to the path traced in the previous check.
   (My rattleback, which has a clockwise 'Liked' spin, produces a clockwise trace in the mirror.)

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