the general science journal

The Rattleback and the Centrifugal Force

Frederick David Tombe,
Belfast, Northern Ireland, United Kingdom,
sirius184@hotmail.com
17th December 2010

Abstract. **The rattleback (Celtic stone) is the most mysterious phenomenon in classical mechanics. It freely undergoes a complete reversal of its angular momentum without the involvement of any apparent external torque. This mystery will now be investigated.**

Introduction

I. A rattleback is a special kind of spinning top, usually semi-ellipsoidal in shape, which when placed on a horizontal surface and rocked, will begin to rotate in a preferred direction. See this video,
https://www.youtube.com/watch?v=PydoEA5Jx5s

If we rotate the rattleback contrary to this preferred direction, any slight rocking will escalate at the expense of the rotation. The rotation axis will then precess 180 degrees until the rattleback is rotating in its preferred direction. It seems that a torque of some kind must be acting on the rattleback. Gravity acts vertically downwards and so this cannot be what is supplying the torque. Rolling friction is involved and it serves to dissipate the motion, but this is merely a resistive force which couldn't possibly cause a reversal torque. Static friction is also involved, and indeed without static friction a rattleback will not work. Static friction is necessary in order to avoid dissipation to dynamic (sliding) friction during the rocking stage of the motion, but static friction doesn't do any work and so it could not possibly cause a reversal torque.

Centrifugal Force

II. When an object is rotated, an inertial centrifugal expansion is induced, which in the case of solids is resisted by a reactive centripetal force that is in turn caused by the solid's inter-molecular bonds. When a rattleback rocks, the centrifugal force will act through the centre of mass in each limb, and a key feature of the rattleback is the fact that it is asymmetrically shaped. The position of the centre of mass in each limb is what will define the natural plane of rocking. If a rattleback is force-rocked about an axis, such that the centre of mass in each of the object's limbs lies outside the

plane of the forced-rocking, the reactive centripetal force will not then be in line with the inertial centrifugal force, and due to its asymmetrical shape, such a forced rocking will indeed occur naturally in the case of a rattleback. This means that only the component of the centrifugal force that is in line with the reactive centripetal force will be cancelled. There will still remain a residual component of centrifugal force acting transversely to the centre of rotation. During the rocking mode of a rattleback, in each limb, this transverse component of the centrifugal force acts out of the plane of the rocking motion, hence resulting in a torque which causes the rattleback to precess into a preferred horizontal plane of rotation.

Centrifugal force is therefore a real force despite the fact that modern textbooks claim otherwise, and this reality is the vital ingredient that is missing from all the standard analyses on rattlebacks [1].

The Two-Directional Rattleback

III. It's also possible to have a two-directional rattleback, so shaped that it can do a double reversal. We can see in this video, https://www.youtube.com/watch?v=puaif3OTJL4,

that the two-directional rattleback is more rounded in shape as compared to the long narrow boat-like shape of the one-directional rattleback, thus enabling the existence of more than one viable rocking axis. The nail attached to the edge of this rattleback ensures that if we have two principle rocking axes enclosing the nail between them, then these will induce a horizontal rotation in the opposite direction to each other.

The question then naturally arises as to why, when the rotation in the horizontal plane is in a specific direction, the rattleback would rock on one particular rocking axis, as opposed to the other. The reason for this relates closely to the behaviour of freely precessing bodies. When an irregularly shaped body freely rotates in space about an axis other than its first or third principal axis of inertia, it undergoes body precession about its axis of rotation. So, in the case of the two-directional rattleback, when rotated in the horizontal plane, the rocking axis will be chosen according to what stage of the precessional cycle it would be at if it weren't constrained by gravity and normal surface reaction. With the rocking axis so determined, once the rocking begins, then the horizontal transverse centrifugal force causes the reversal of the angular momentum to begin. The rotation axis will undergo a 360 degrees precessional cycle until such times as friction damps it out.

Conclusion

IV. The rattleback is mysterious because it is observed to reverse its angular momentum in the absence of any apparent torque. Friction is only resistive and never produces a recoil effect, while gravity only acts vertically downwards, so neither of these can be the cause. The inertial forces would appear to be the most obvious contenders, but the textbooks dismiss these as being merely fictitious artefacts that only arise when we make observations from a rotating frame of reference. However, unless conservation of angular momentum has broken down or there is a new force acting which has not yet been officially identified in physics, we must draw the conclusion that the textbooks have got it badly wrong in claiming that the inertial forces are merely fictitious **[1]**. The inertial forces are in fact as real as Newton's first law of motion from which they follow, and they are described in polar coordinates in an inertial frame of reference, **[2]**. Once we accept this reality, then the rattleback mystery is solved.

The precessional torque that acts on a rattleback is caused by centrifugal force acting transversely through the centre of mass on each limb. The two centres of mass are what define the natural plane of rotation. Due to the asymmetry in shape, when the rattleback rocks, the centres of mass in each limb are outside the plane of the rocking motion, and so the reactive centripetal force, which exists due to the inter-atomic bonds of the material, will then be out of line with the centrifugal force, and so it will only cancel with the radial component of the centrifugal force that it is in line with. The resultant transverse centrifugal force acting out of the plane of the forced rocking is the mysterious force in question that causes the reversal of the rattleback's angular momentum. In simple terms, the reversal torque is due to the fact that an inertial force has been partially blocked by a Newtonian force, leaving the remainder to cause an inertial torque. This torque acts transversely out of the plane of rotation, **[3]**.

References

[1] Tombe, F.D., ***"The Reality of Centrifugal Force"*** (2021)
https://www.researchgate.net/publication/350060937_The_Reality_of_Centrifugal_Force

[2] Tombe, F.D., ***"The Centrifugal Force Argument"*** (2014)
https://www.researchgate.net/publication/322445530_The_Centrifugal_Force_Argument

[3] Tombe, F.D., ***"The Importance of Centrifugal Force"*** (2022)
https://www.researchgate.net/publication/360933238_The_Importance_of_Centrifugal_Force