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# Roller coaster loop shapes revisited

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## The original paper

In ‘Rollercoaster loop shapes’, (Pendrill 2005 *Phys. Educ.* **40** 517) the author started from the observation that although textbook loops are often circular, real rollercoaster loops are not. In this paper the mathematical description of various possible loop shapes, as well as their riding properties was discussed and also how a study of loop shapes can be used in physics education.

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## The commentary

Roller coasters are classical examples of energy conservation and continue to provide excellent illustrations of the interplay between gravitational potential energy and kinetic energy, with some – small – losses to thermal energy. Even when the lift hill is replaced by one (or more) launch sections, the principle for the motion remains the same.

Energy considerations in roller coaster loops are always good examples for quantitative exercises, allowing students to discover that the initial elevation needs to be about  $r/2$  to move essentially weightlessly over the highest part of the loop with radius  $r$  in the highest points. Higher elevations, of course, lead to higher speeds and stronger downward force from the track to provide the acceleration required for the motion in the loop. Energy considerations also show that the force at the bottom of a circular loop becomes 6 mg (or ‘6 g’ for short), which is permissible according to standards, but most modern roller coasters stay below 5 g.

The problem with the circular loop is not only the strong force at the bottom, but also the sudden transition from a track section with a much larger radius of curvature, and smaller forces. In addition, the body would be exposed to a very rapid change in angular velocity, with the head tending to continue along a straight line (Newton’s first law) while the lower part of the body starts to rotate – a setup for whiplash. It is thus important to find ways for smoother transitions, which can be achieved in different ways, as discussed in the original paper. Werner Stengel introduced the clothoid loop, where a part of a Cornu (Euler) spiral connects track parts with different radii of curvature. Another common approach is to design loops with a constant centripetal acceleration. The paper from 2005 also introduced the possibility of loops with constant force on the rider. An analytical solution for this type of loop was subsequently obtained by Nordmark and Essen [1], and this achievement was reported by Fox News.

In roller coaster queues, there are often discussions about which is the best seat. These discussions can be brought into the classroom, with discussions about how the location of the center of mass of the train influences the speed for the train to move over the top, and the size of the effect for different train lengths. This is one of the student investigations discussed in a later paper [2], with modified free-body diagrams to take length and position into account, and also comparisons of modelling, video and electronic data from riding in the loop.

Subsequent papers involved the use of dataloggers to monitor acceleration in 3 dimensions [3]

## References

1. Nordmark A B and Essen H 2010 The comfortable roller coaster – on the shape of tracks with a constant normal force *Eur. J. Phys.* **31** 1307
2. Pendrill A-M 2013 Student investigations of forces in a roller coaster loop *Eur. J. Phys.* **34** 1379
3. Pendrill A-M 2008 Acceleration in 1, 2, and 3 dimensions in launched roller coasters *Phys. Educ.* **43** 483–91

## Biography

Ann-Marie Pendrill is director of the Swedish National Resource Centre for Physics Education since 2009 and also professor (since 2015) in science communication and physics education, at Lund University. Her research background is in computational atomic physics, but her more recent work has focused on various aspects of physics and science education. She has used examples from playgrounds and amusement parks in her teaching in physics, teaching and engineering programmes. (Photo credit: Maja Kristin Nylander.)

