BACK TO SCHOOL

By Ann-Marie Pendrill - SWEDEN

Ann-Marie Pendrill is a professor at the Gothenburg University physics department, and the director of Sweden's National Resource Centre for Physics Education, oh – and a Club member. She has endeavoured to use roller coasters, and rides in general, as part of the physics syllabus since 1995, and has organised several amusement park physics days for schools. She has published many papers on the subject. They include "Stopping a roller coaster train," "Acceleration in school, in everyday life and in amusement parks" and "Isotope shift in the electron affinity of chlorine." To be honest, this last one didn't really find a link to any amusement rides, although I am sure Ann-Marie tried. She also wrote the nomination for the honorary doctorate given to Werner Stengel in 2005.

Here Ann-Marie looks at the forces applied to a rider on *Helix*, comparing how various seats differ during the ride. She also explains some of the questions put to students in Sweden.

Justin Garvanovic

Ann-Marie with Werner Stengel at the Helix Board of Governors event

An amusement park can be seen as a large physics laboratory, where the forces required for acceleration can be experienced, providing a very concrete experience of concepts often considered abstract and difficult. Here I present examples of the forces in the inverted top hat of *Helix*, which was the topic for one of the problems in the theory part of the final for the Swedish physics olympiad team, which took place one week after the opening of *Helix*.

After the second launch, where the train attains the speed (v_0) of 23.5m/s at an elevation (h_0) of 42.4m it reaches the highest point (h) of 68.1m in the Inverted Top Hat. The track section over the top is 13.1m while the slope changes from 62.1° uphill to 54.1° downhill. This information makes it possible to calculate the forces on a rider in a couple of steps.

Q) What is the speed of the train as it passes the highest point?
A) Neglecting energy losses (and train length) to keep it simple, the speed v at the top can be obtained by noting the increase in potential energy, $mgh - mgh_0$, leads to a corresponding reduction in kinetic energy, $mv^2/2 - mv_0^2$. This gives: $v^2 = v_0^2 - 2g(h - h_0)$.
With the values inserted, this gives: $v^2 = 23.5\text{m/s}^2 - (2 \times 9.82\text{m/s}^2) \times (68.1\text{m} - 42.4\text{m})$.
Taking the square root gives $v \approx 6.9$m/s or 25km/h.

Q) Estimate the radius of curvature, R, in the highest point.
A) A circle with radius R has a circumference $2\pi R$. The track can be approximated by circular arc with L = 13.1m, over an angle $\theta = 54.1° + 62.1° = 116.2°$ compared to the angle 360° for a full circle. This gives $2\pi R = L \times (360 / 116.2)$, or R = 6.5m.

Q) Estimate the centripetal acceleration.
A) The centripetal acceleration is given by $v^2/R \approx 7.3\text{m/s}^2 \approx 0.7g$, directed downwards.

Q) What forces act in the highest point on a rider with mass m?
A) The forces on a person with mass m accelerating 0.7g downwards are 1mg from gravity and 0.3mg upwards from the train. Since you are upside down, this force comes from the restraints pushing you and will count as -0.3G.

How do the theoretical values compare to the experience when you ride? While the jury was grading the solutions, the finalists had a chance to experience the forces first hand, and also to collect data (using the WDSS sensor from Vernier). Three sets of data were taken during the same ride, from rows two and nine. The diagram shows the "vertical acceleration" (i.e. the "g force" in the direction along the spine of the rider) as well as the measured elevation, where the highest point is easily identified.

The measured data show values closer to 0g in the top hat – close to weightlessness. This means that the downwards acceleration is slightly larger than obtained in the simplified calculation. This can be understood by noting, for a start, that the train travels under the track at the top, giving both a smaller radius and a higher speed. In addition, due to the train length (12.5m for the *Helix*), the centre of mass of the train is slightly lower than the middle of the train.

How does the place in the train influence the ride? Although the whole train travels with the same speed at any given time, the riders will be in different positions. The front and back of the train both pass the high points faster than the middle of the train. On the other hand, the train moves fastest through a valley when the middle of the train is lowest, so a rider in the middle will experience the largest G force in the valleys. Since the train moves slower over the high points, the time difference for the graphs is larger there than in the valleys when the train moves faster.

An interesting comparison for *Helix* is when the train leaves the second launch on the way up to the highest point of the track, the inverted top hat. Obviously, the back of the train moves slower than the front through the part where the track turns upwards, so whereas a rider in the front experiences 4G at that point, a rider in the back only reaches 3G.

Passing over the large airtime hump following the inverted top hat, the front of the train has a higher speed in the beginning of the hump than at the end, resulting in more negative Gs in the beginning, whereas a rider at the back instead experiences more negative Gs at the end of the hump, giving the extra lift from the seat that many enthusiasts treasure.

A few articles about forces in amusement rides can be found here: tivoli.fysik.org/english/articles/