Science at the Amusement Park

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What is up? What is down? What is a straight line? With beating heart we face the unusual movements.

An amusement park is a large hands-on physics laboratory, full of rotating coordinate systems, free-falling bodies and vector additions. It gives ample opportunity to experience Newton's laws with eyes, hands and body. The amusement park Liseberg in Göteborg is the largest amusement park of Scandinavia. It has long physics traditions - Albert Einstein gave a talk at Liseberg in 1923! Liseberg has many rides well suited for physics investigations, using simple equipment, as well as electronic accelerometers. Some investigations can easily be adapted to the local playground.

The heartbeat responds in different ways, both to the various accelerations and rotations of the body, but also to the thrill when in the queue. It can be monitored with electrodes on the body and the signal sent down to ground to be viewed in real-time by the classmates.

"Slänggungan" - carousel with swings

A good starting point is the carousel with swings shown in Figure 1. As the carousel rotates, the swings hang out from the vertical line, thereby enabling the chains to provide the force giving the required centripetal acceleration, while still counteracting the force of gravity. Take a moment to consider which swings will hang out the most: the empty ones or the ones loaded with a child or with a heavy adult! In this situation students often pick the most heavily loaded swings. They watch in amazement as the carousel starts - all swings (at the same radius) hang at the same angle, independent of load.

Figure 1. Which swings hang out the most as the carousel rotates? The empty ones or the heavily loaded ones?

This is an eye-catching example of the equivalence principle: the angle is determined by the ratio between the centripetal force and the weight. Since the intertial mass (entering the centripetal force) and the gravitational mass (entering the weight, mg), are equal, the angle is independent of the mass. Eötvös used the rotating earth as a giant merry-go-round by letting weights of different material balance from a rod suspended as a torsion balance. Refined Eötvös experiments are still performed, e.g. at the Eöt-Wash group at the University of Washington, giving lower and lower limits for possible deviations from the equivalence principle.[1]

Some exercises for the reader

- Estimate the acceleration by looking at the picture.
- What is the apparent weight of a person on the ride?
- Estimate the rotation time, using the information that the chains are 4.3 m.

Free fall

"Two seconds of weightlessness - can that solve the dieting problems for the summer", suggested the advertising when the "Space Shot" was introduced at Liseberg. Is it possible to be weightless in spite of temptations from candy floss or waffles with cream? What does weightlessness mean? Are astronauts weightless because they are so far from the gravitational field of the earth, as most new students suggest. (Try asking your group! Follow up by asking them to make a mental picture of the earth, the moon and the space shuttle. You could then ask them if and where there is a point where the gravitational attraction from the moon cancels that of the earth.) Or maybe they insist that weightlessness never occurs, since we cannot escape gravity? Most would, however, agree that an astronaut experiences weightlessness if the meatball on a fork hovers in front of the mouth. Meatball, astronaut and spaceship all fall towards earth with the same acceleration due to gravity. Similarly, an astronaut outside the space shuttle does not notice the effect of gravity, since he falls to earth with exactly the same acceleration as the orbiting space shuttle.

Many amusement parks now offer visitors the possibility to experience "two seconds of weightlessness". One example is the Space Shot, ("Uppskjutet") at Liseberg. After a quick tour up, the seats are decelerated to a stop before starting the free fall. Following the fall it lands softly on pressurized air. (The Free Fall e.g. at Gröna Lund in Stockholm, is instead decelerated by eddy currents produced by strong magnets.) The experience of weightlessness can be enhanced by taking along a small mug of water (1 cm of water is quite enough) and watch the water falling (don't pick a seat with headwind!). In the right conditions, the water seems to move slowly upward. Try it!

Often, the accelerations in an amusement park instead cause the rider to be significantly heavier than usual. "The Space Shot's emphasis is on the sudden blast upward from the bottom."[2] Figure 2 shows accelerometer data for the Space Shot, obtained with a "calculator based laboratory" (CBL) connected to a graphical calculator. The data can also be used to estimate the velocity at various points of the ride, and even the position. It is a good exercise in numerical sensitivity; the resolution of the accelerometer is about 0.013 g. What is the resulting uncertainty in the position after the ride (where, of course, we know that the rider is safely back to the starting point)?

A more visual accelerometer is provided by a slinky. Figure 3 shows three slinkies, one unloaded, one stretched by external forces, and one hanging free. Note how the spacing of the turns of the hanging slinky increases with the increasing load from the lower turns.

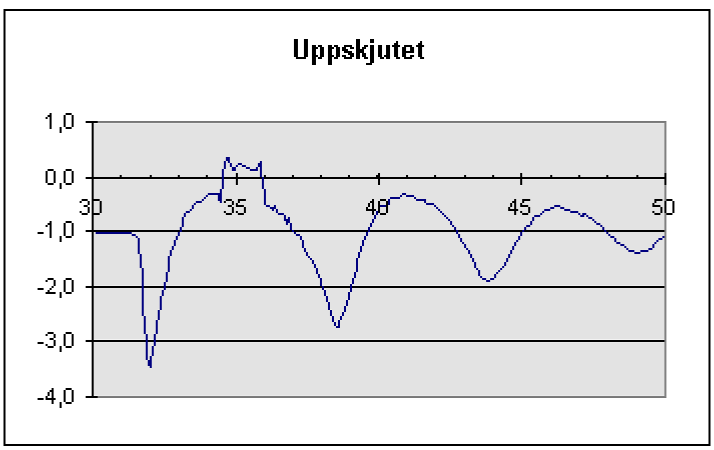

Figure 2. Accelerometer data for the Space Shot. The vertical axis is chosen so that standing on the ground gives "-1 g". From the figure we see that the rider experiences about 3.5 g for a short moment at the start and after 1.5 s of approximate weightlessness experiences 2.5 g, then 2.0 g etc. during the bouncing off the pressurised air.

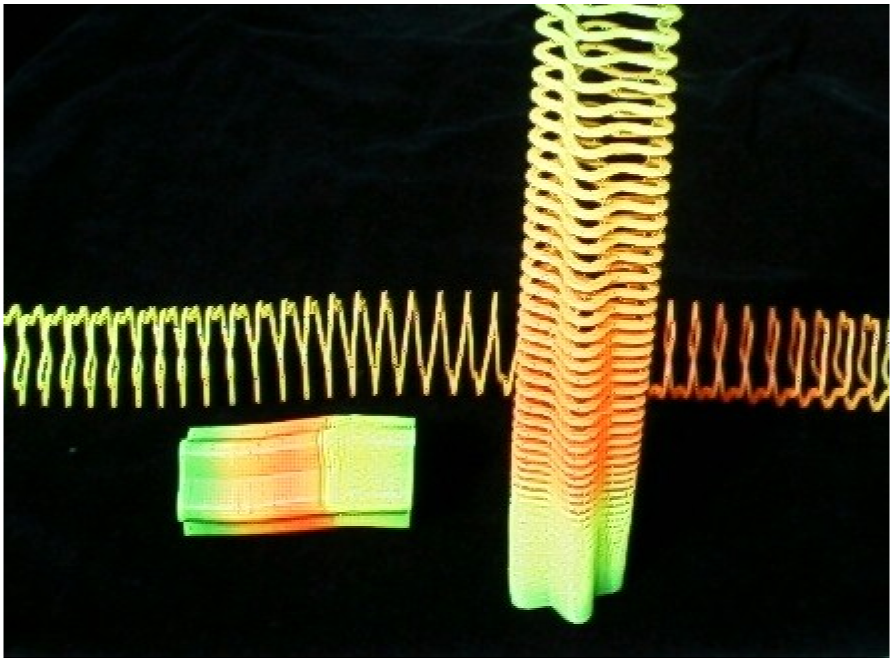

Figure 3. A "visual accelerometer": compare the spacing between the unloaded, the stretched and the free-hanging slinky. How will the spacing be affected by acceleration?

A few exercises for the reader

- What do you expect the slinky to look like at the top?
- How long would the slinky be with half the number of coils (more suitable to take along on a ride!)?
- How do you expect a (half) slinky to look at the start of the Space Shot?

There are several versions of eye-catching towers in different parks. For example, the "Turbo Drop"[2] (available e.g. at Liseberg where it takes the rider 100 m above sea level - how far away is the horizon?) lets the rider fall with 2 g, causing an apparent "upward fall" of the water (don't hold the mug under your chin!). The "Free Fall" at Gröna Lund in Stockholm, on the other hand, really is a free fall following a long wait at the top. Thus, the water should be expected to remain in the mug, but it doesn't. Biology catches up with the physics in the form of a "Moro Reflex", familiar to parents of small children: a baby under sudden moves attempts to cling on to the mother, to avoid falling. Similarly, the rider feeling the seat drop, for an instant raises the hand, giving the water a small push upwards.[3]

With the heart upside down

In an amusement park, the body is exposed to a large variety of unusual movements. How does it respond? One obvious measure is the pulse. For attractions, like the Space Shot, where the largest accelerations happen within time scales of seconds or shorter, the resolution of the heartbeat is somewhat low. The slow pendulum shown in Figure 4 is ideal for studying the reactions of the heart. Figure 5 shows accelerometer data from the ride (with the accelerometer pointing straight down to the seat throughout the ride). As seen from the data, the swing goes from one side to the other in about 10 seconds, until it finally makes it slowly over the top and completes a few full turns. The baroreceptors in the body sense the higher pressure in the head. Standing on the ground, the observer can watch the heartbeat dropping significantly about 2 seconds after the rider passed the top. One example is shown in Figure 6. (Note: not all rides are identical and the accelerometer data in Figure 5 were not recorded at the same time as the heartbeat in Figure 6.)

Figure 4. A giant pendulum with a counter weight. Additional energy is provided every time the pendulum passes the lowest point until it makes a full turn with riders hanging upside down.

Exercises for the reader

- Using the accelerometer data, estimate the maximum angle at every turn.
- How does the period depend on the amplitude?
- The distance from the centre is about 12 m. What would be the period of a mathematical pendulum of this length? What would be the length of a mathematical pendulum with the period of this attraction?

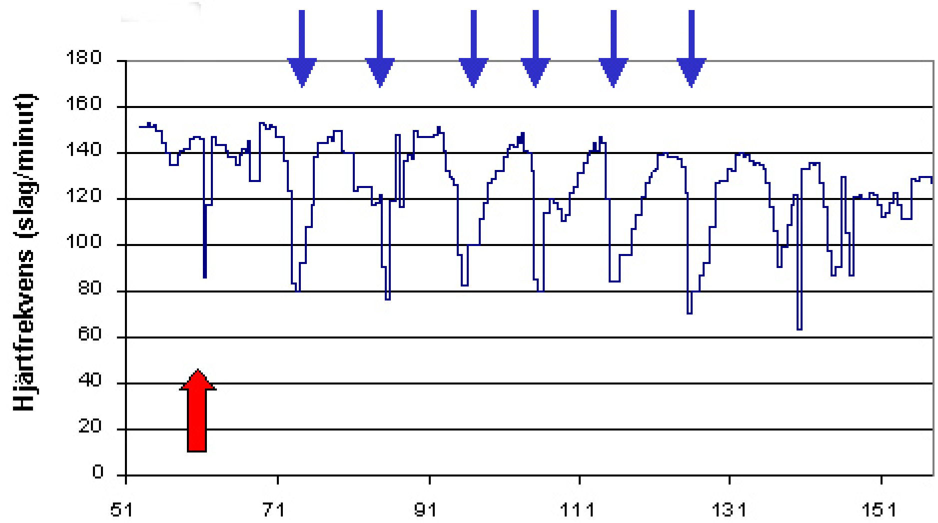

Figure 5. Accelerometer data from the ride

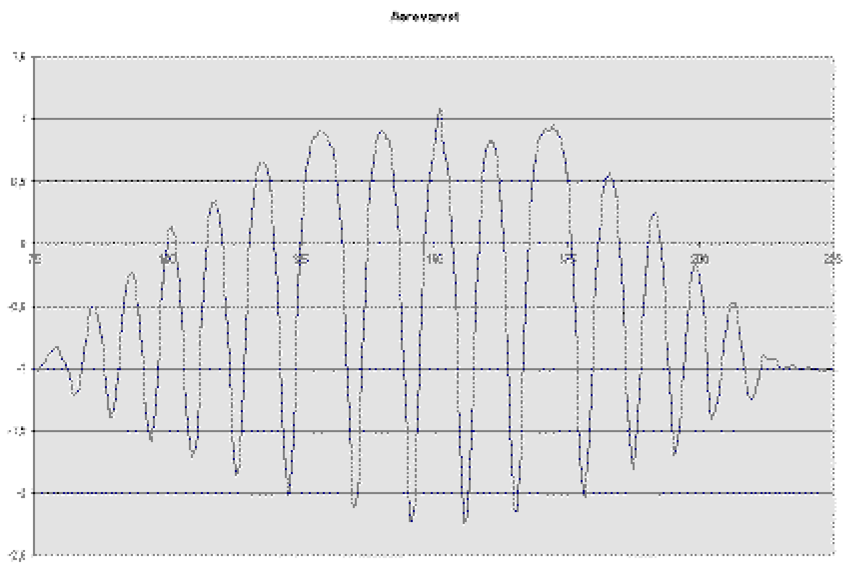

Figure 6. Example of heartbeat variations during the "Aerovarvet" ride

The roller coaster

Figure 7. The roller coaster: How much energy is lost during the ride? What forces do the riders experience?

If you visit Liseberg, you must not miss the "Lisebergbanan". The train is first pulled up to 65 m over sea level, giving a good view over the city of Göteborg and over the building site for the new Science Center "Universeum", to be inaugurated in June 2001. The train takes you on a 2.7 km and 2.5 minute ride, to a large extent using the natural hills in the park, to a lowest point of 20 m and a maximum speed of 95 km/h. A roller coaster is a prime example of the energy principle, where the potential energy provided as you pass the highest point is all you have to take you round the track. How well is the energy conserved? A visual indication is provided by the nearby "Hangover", where the train makes a return trip on the same track. Before starting on the return journey, the train reaches *nearly* its original height, before being pulled the last few metres to the top.

A roller coaster also provides good examples of vector addition, as the train slopes and curves in different directions. In several places the tracks are built to imitate the free fall parabola.

The acceleration can be measured in several different ways. A "horizontal accelerometer" is provided by a little mass on a string, e.g. a Liseberg rabbit from one of the shops. It will bounce considerably, and needs to be stopped now and then, e.g. passing over the top of a hill. Watch the angle the rabbit makes to the track! (Remember, you and the rabbit undergo the same acceleration, but the rabbit hanging from the string does not feel the "normal force" from the seat.) The slinky can again be taken along as a vertical accelerometer, or more precise data can be recorded using electronic devices.

Exercises for the reader

- Neglecting friction, what speed would you expect from 45 m height difference?
- At every instant all parts of the train have the same speed. Nevertheless, the ride in the front, back and middle are different. Why? In which seat will you feel the lightest? The heaviest?
- How do you expect the "rabbit-on-a-string" to hang as the train accelerates down a hill? As it turns to the left?
- Is the reading from a vertical accelerometer sufficient to provide information about "g-forces"?

Before leaving the park

Visit one of the shops and get a helium balloon (take the smallest you can find) for experiments during the trip home. It works best in the large space provided in a bus, but works reasonably well also in a car. What happens to the balloon as the vehicle starts? As it turns? As it brakes in front of a traffic light?

Using an amusement park in courses

Liseberg has been used in the introductory physics course for students in the educational programme "Problem Solving in Natural Sciences" at Göteborg University since its start in 1995. The Liseberg visit takes place within their first month at the University. Each of the 5-6 groups of about 6 students is assigned 3 different attractions of different types, with the task to describe the motion, figure out e.g. how energy is provided and, where applicable, the point where the rider would feel the heaviest and the lightest (how heavy? how light?) In some cases detailed data was made available by the amusement park. If a force is worked out with the wrong sign it becomes immediately obvious when confronted with the experience of the body. The observations and results from each group are then presented and discussed with the rest of the class in a session of about three hours, usually very enjoyable.

After the first year, more systematic instructions and information were presented on the Web, with help enlisted from a few students in a summer project, paid by the science faculty at Göteborg University. The pages have since been revised and extended, in view of experiences gained from working with the material in subsequent courses, and, of course, as new attractions have been added to the park. These pages, available at http://www.matnat.gu.se/slagkraft/, are now used by many schools from various parts of Sweden in their preparation for excursions to Liseberg. During the year 2000, the "FRN" provided support to enable graduate students to direct visits for school classes - and giving all of us easier access to children's thoughts.

During a visit to an amusement park the equations come alive. Second derivatives are felt throughout the body. The block on the inclined plane is replaced by a train in the slope of a roller coaster and "Gedanken experiments" from the textbooks can be realised in one of the most attractive hands-on laboratories available.

Acknowledgements

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References

1. The Eöt-Wash group at University of Washington: http://mist.npl.washington.edu:80/eotwash/
2. http://www.s-spower.com/, Manufacturer Information about the "Space Shot" and the "Turbo Drop"
3. See the presentation of experiments at Gröna Lund at http://www.physto.se/gronalund/

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