FORCES

Losing weight: the physics diet

The perfect answer to obesity—a person can lose around 10% of their weight by stepping into a special room found in many shops, offices and apartment buildings. No, this is not an advert for the latest weight-loss craze. It is the basic physics of forces.

When a lift is stationary (or moving at a constant speed), let us consider the forces acting on a person inside—weight (mg) downwards and the normal reaction force upwards ($R = mg$). When the lift accelerates downwards, the person's weight (mg) still acts downwards, but the normal reaction force is reduced ($R_{min} = mg - ma$), leaving a resultant force acting downwards. This resultant downwards force must be causing the person to accelerate downwards. When the lift accelerates upwards, the person's weight (mg) continues to act downwards, but this time the normal reaction force is increased ($R_{max} = mg + ma$), leaving a resultant force acting upwards. This resultant upwards force must be causing the person to accelerate upwards.

The experiment I performed with a small group of 16–17-year-old pupils involved a lift, a normal reaction force detector (i.e. digital bathroom scales) and a Wii-controller datalogger [1]. The pupils used the scales to find their mass (m) in kg before getting into the lift. When in the lift, the pupils stood on the scales and recorded the highest reading the scales reached as the lift accelerated upwards (because the scales read in kg, multiplying this by g gives R_{max}, although it is also possible to buy scales which read in Newtons). The lowest reading as the lift decelerated was also recorded (multiplying this by g gives R_{min}).

The mass readings taken by the pupils from the scales were used to find the acceleration of the lift,

$$a = \frac{R_{max} - R}{m} \quad \text{or} \quad a = \frac{R - R_{min}}{m}.$$

A Wii remote control can be connected by Bluetooth to a laptop and used as a datalogger, as described by Wheeler [1]. The WiiMote Physics software was used to record data from the accelerometer. It displays a value of acceleration measured in g, so a value of 1 corresponds to an acceleration of 9.81 m s^{-2}. The resolution of the data is 0.04 g. The Wii remote control was placed horizontally on the floor of the lift during the journey. The recorded data are shown in figure 1, which shows that the acceleration increases at the beginning of the journey as the lift ascends. The acceleration is zero during the middle part of the journey. As the lift decelerates towards the second floor of the building a reduction in acceleration is seen.

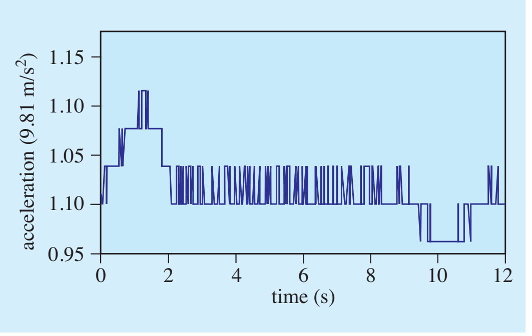

Figure 1. *Acceleration–time graph for a journey in a lift. Recorded with a Wii controller and WiiMote Physics software.*

The background measurement of acceleration when stationary fluctuates between 1 g and 1.04 g, spending approximately 50% of the time at each reading. Thus the stationary (or constant velocity) reading should be 1.02 g.

Taking a reading of the maximum acceleration on the upwards journey gives a value of 1.12 g. This corresponds to an additional upwards reaction force of (1.12 – 1.02) = 0.1 g = 0.98 m s^{-2}. This matched up well with the results obtained by the pupils from calculations using measurements from the scales.

Integrating acceleration with respect to time gives the velocity reached by the lift. Thus the area under the graph is the velocity reached. Considering the initial acceleration and approximating the area as a triangle gives the velocity reached as

$$0.5 \times 2 \times (1.12 - 1.02) \times 9.81 = 0.98 \text{ m s}^{-2}.$$

Digital meters often have an integration time over which they average the raw readings, leading to an increased response time. This can be estimated as < 0.3 s by rapidly flipping the controller over. While this is a sizeable portion of the time over which the lift is accelerating, it appears not to affect the results significantly because the distance travelled can be approximated in close agreement with the pupils' (tape-measure) measurements by assuming that the lift travels at the calculated velocity (0.98 m s^{-2}) for a time of 10.2 – 1.2 = 9.0 s, giving a distance travelled of 8.8 m.

Further comparisons could be drawn by calculating the change of velocity during the deceleration at the end of the upwards journey. Additionally, the downwards journey could be recorded and analysed in the same way. The times of the upwards and downwards journeys could be compared.

Reference

[1] Wheeler M D 2011 Physics experiments with Nintendo Wii controllers *Phys. Educ.* **46** 57

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