Satellites and Orbits

Age Range: 8-18 by tailoring depth
Number of Students: 10-30
Equipment: Tennis ball, short tube, string, weights, 3xtorch (flashlight) - optional
Duration – Around 1-2 hours depending on detail and understanding

Introduction

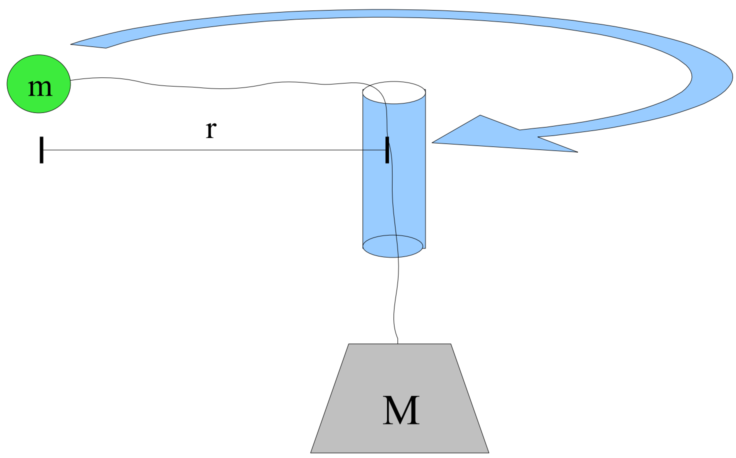
Find out how much is known about satellites – what are they – can we think of examples? How do they stay up? How high are they?

Check how much maths the students have done – are they comfortable with algebra? (If not, equations should be avoided, or given in their arranged forms with values to substitute.)

We are going to look at orbits and satellites, and some of their uses.

Orbits - period vs. altitude.

Use string with tennis ball and tube. A pen barrel seems to work as a tube. (A Tennis ball can be attached by piercing a small hole and pushing the string through with a pen/screwdriver, and then cutting a slot on the other side so that pliers can be used to pull the string through. Tie a big knot. The same technique can be used to create the weight.) Get student to swing it and lift different weights with same radius. Note that for a stronger force inwards, the ball must move faster.



Now try one weight at different radii. Does it go faster or slower when further out? Need to be careful with definitions – ask the students whether it goes around more times in a second, or travels a greater distance per second.

More Detail

Given 2*pi*r, and a stop watch, they should be able to check this over, say, 10 revolutions. Get them to guess first. Mark two or more positions on the string for the swinger to maintain. The quantitative part of this can be skipped if desired – the qualitative description seems to be sufficient.

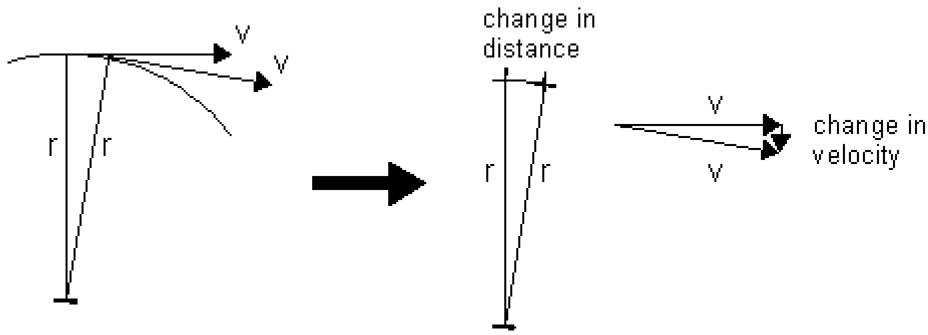
This is a good time to discuss how orbits are maintained. Remind the students of Newton's First Law – force is needed to change the velocity. Velocity is speed with direction. The force acts at right angles to the motion, so the direction changes, but the speed does not. It may be useful to discuss the idea of a cannon firing balls with successively more speed until they travel around the earth.

If only doing change of radius with fixed weight, raise the fact that gravitational force dies away with distance from the centre of mass. The toy is not an accurate model, but the idea that larger orbits take longer to complete is still valid.

We will return to this later. *(Later on, we can show that T^2 prop R^3 if they can do the maths.)* Point is: The further out it is, the faster it will be travelling, but it has to cover more distance, so goes round fewer times in a minute.

More Advanced Maths

May want to introduce F=mv^2/r as force for maintaining a circular orbit. Derivation of this is as follows:



The speed around the orbit remains constant – only its direction changes such that the direction of the speed is always the tangent to the circle (i.e. its radial velocity changes). Similarly, the radius of the circle is constant. This means that a pair of similar (isosceles) triangles can be formed – one from the radius of the orbit (r) and the change in distance over a given time (d), the other from the speed of the orbit (v) and the radial change in velocity (Δv) over the same time.

From similar triangle rules:

$$\frac{\Delta v}{v}=\frac{d}{r}$$

$$\Delta v=\frac{(v*d)}{r}=\frac{(v*v*t)}{r}$$

dividing by time gives:

$$\frac{\Delta v}{t}=\frac{v^2}{r}$$

$\Delta v/t$ is acceleration, and $f=ma$ so:

$$f=\frac{mv^2}{r}$$

Quick game:

Get ten students to link arms to form an outwards facing circle. - now ask them to rotate at a constant speed (quite slowly and anti-clockwise). They represent the Earth rotating.

I (or another student) orbits round them, close in and going faster than them - what do they each see? (rising and setting from right to left = west to east)
The satellite orbits round far out and with a larger period - what do they see? (rising and setting the other way round)

I come in between and orbit at same pace (angular velocity) - what do they each see? (I'm always in front of one of them - some of them never see me)
This is geostationary. (Explain origin of the word.)

Discuss Telecommunications

Now a change in topic – but only slight.

How can we send messages?

- Radio - OK for short distances - one to many – mostly just line of sight
    - Two volunteers get torches – tell them to flash once for "how are you?" twice for "fine" three times for "bad". Can they communicate?
- Telephone - OK for short to medium distances, but need lots of junctions and cables.
- Internet - same as telephone.
- Satellite - One to one or one to many - high cost for launch, but low maintenance, one time only.
    - Could talk about different generations - e.g. reflection, amplification, error correction.

Game Reprise

Gather ten students as before and get them to rotate. Have two neighbouring students send messages using their torches. Now try to get two students about a third of the way round to do this. No line of sight means no message.

Now give the satellite a torch and have him/her repeat the signal from student to student. This is like modern satellites communicaions.

If there are no torches, just repeat spoken messages from student to student via the "satellite".

Analysis

How high up is a geostationary orbit? If the students are up for some maths, they can find out now.

Probably want to give them:

(1) Force needed to maintain circular orbit is given by $F = mv^2/r$

(2) Force due to gravity is given by $F = GMm/r^2$

(3) $G \sim= 6.67E\text{-}11\ m^3\ kg^{-1}\ s^{-2}$, They may need M_earth (5.97E24 kg), but if they're keen, can work this out from knowing the force on a single kilo at R_earth (see other modules – 3600 km)

If they're less advanced, rearrange the equations for them and give them the numbers – just let them work the arithmetic. Desired altitude of geostationary orbit is 35 786 km.

How long would a radio signal take to go up and come down? ($c=3E8\ m\ s^{-1}$) Answer is ~.25 seconds. This is quite a big delay if talking to someone.

Further discussions

- How does one communicate via radio? AM vs. FM? Different polarisations? Different frequencies? Phase Modulation? Digital vs.

Analogue? Retransmission at different frequencies (e.g. if the two students communicating with torches had different colours and so did the retransmission person – or if speaking, use a different tone of voice).

- Handle earth observation. Why? What sort of information? What advantages/disadvantages compared to earth based?
- Science Missions e.g. Hubble
- Show some pictures from earth observation
- Have a brain-storming session on what the components of a satellite would be – e.g. transmitter/receiver, control computer, rocket motor, gyroscopes, solar panels, batteries (for earth-shadow), cooling systems, insulation etc.