

Investigation 7: Timing for a catch

It is a common misconception that the trapeze is only for very slight young women, as is becoming the case in gymnastics. It is not the case that trapeze artists fall into a particular stereotype in this way, yet on the trapeze, tricks are performed which seem to require immense strength or extreme suppleness.

It is certainly true that on a static trapeze, or a pull-up bar in the gym, it does require some degree of strength to lift your legs up over your head etc. But there is a major difference between these stationary bars and the flying trapeze: the swing. The fact that the performer is swinging when he moves his body into these positions means that he often has components of his momentum that will help 'pull' his body into a desired position. This is most easily explained with an example.

The Knee-Hang



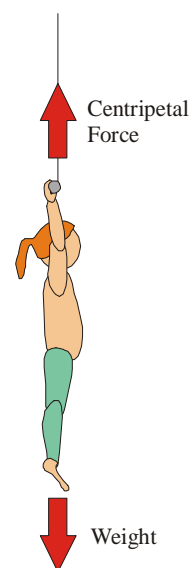
The knee-hang is considered one of the easiest tricks on the flying trapeze and is therefore the first that most people try. For this investigation, we will concern ourselves only with the very first stage of this trick: getting your legs up at the front end, pushing them between your arms, and hooking them over the bar.

During the swing forwards, since the performer is moving in part of a circle, he experiences a centripetal force by the bar on his hands, pulling him towards the centre of the circle. This force opposes the tendency for his body and legs to move tangentially. Although this is the correct scientific explanation for what is occurring, the performer would probably talk about feeling a 'centrifugal force' pulling down on his feet.

Patrick Fullick, in his 'Physics' textbook explains that the illusion of a centrifugal force comes from viewing the system from the inside (i.e. while moving), rather than from the outside, where any observers would be stationary.

The centripetal force on the man's legs (assumed again to be half his weight - 35kg) is given by:

$$F = ma \text{ (to centre)} = m \frac{v^2}{r}$$



Therefore the greatest force on the man occurs when the speed is greatest.

From Investigation 1, we know that the maximum speed occurs at the bottom of the swing, and at this point he has speed 5.4ms⁻¹.

$$F = m \frac{v^2}{r} = 35\text{kg} \times (5.4)^2 / 4.6\text{m} \text{ (see diagram in Investigation 1)}$$

$$F = 221.9\text{N}$$

Although this force is to the centre, the performer will feel this force as though it is pulling him to the ground (for reasons mentioned above). Therefore in addition to the 350N with which gravity pulls on his legs, he feels an extra 222N. If he were to try to pull his legs up at this point, he would have to be very strong, since they would feel much heavier than normal!

Once he reaches the last part of his forward swing, his speed decreases (as all the KE changes to PE), and so the force which he feels pulling him outwards decreases.

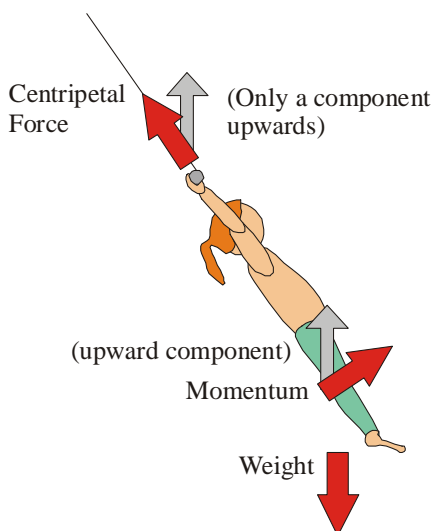
The role of momentum

Momentum is explained in Fullick as 'unstoppability'. Momentum is a quantity, given by the product of the mass and the velocity, which tells us how hard it is to get an object moving, and how difficult it is to stop.

Newton's Second Law states that:

Impulse = change in momentum

$$Ft = m(v-u)$$



The performer's legs have momentum during the swing (since they have both mass and speed). At the front end of the swing, the force due to gravity, acting over a time t , has reduced the momentum of the legs to zero at the front end. Just before the front end, they will still have some momentum. Since they are moving at an angle to the ground (approx. 0.74 radians), and since momentum is a vector quantity, the legs will have a component of momentum upwards.

When the performer is $7/8$ through his forward swing, what is his speed?

$$1/4 \times 1.5 \text{ gives height below starting point} = 0.375\text{m}$$

$$v = 2gh \text{ (from Investigation 1)}$$

$$\text{So } v = 2 \times 9.8 \times 0.375$$

$$v = 2.7\text{ms}^{-1}$$

$$\text{Momentum} = m \times v = 35\text{kg} \times 2.7\text{ms}^{-1} = 94.5\text{kgms}^{-1}$$

$$\text{Component upwards} = 94.5 \times \cos(0.74) = 69.8\text{kgms}^{-1}$$

At this point in the swing, the performer's legs have 69.8kgms^{-1} of momentum upwards, which means that he only has to put in enough force to oppose gravity (350N) and a component of the centripetal force, and his legs will naturally move upwards. The later he leaves it before the front end, the easier it will get, since the centripetal force will decrease as the speed decreases.

This should be compared to the force needed at the bottom of the swing. The performer has no upward momentum (only horizontal), so he needs to exert a force upwards, over a time t , to bring about a change in momentum, so his legs will move up. Unfortunately, this is not enough, since gravity will constantly be exerting a force downwards on him as well, trying to decrease any upward momentum, and he needs to exert a force to oppose this. He also has to work against the tendency of his legs to move outwards, so he needs an extra 222N to oppose this. It is therefore MUCH easier as he approaches the front end.

This is further evidence of the importance of timing on the trapeze. Movements can be made much easier by choosing the right time, and as a result, extraordinary strength and agility are certainly not necessary, since you can use the momentum in your swing to make up for any lack of strength.