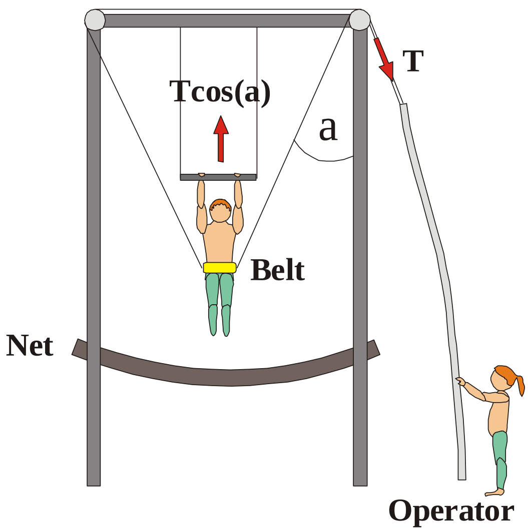
Investigation 9: The safety lines

Safety is extremely important on the trapeze. Even though the net is very stretchy, and you could fall from right at the very top of your swing and not hurt yourself if you land on your back, it is quite likely that (unless the fall is planned) you will fall awkwardly. Even a fall into the net will do considerable damage if you land on your head.

Experienced trapeze artists do not use safety lines. This is not because they do not fall, but rather that they are skilled at moving their body during a fall to land cleanly on their backs. How they do this is way beyond the scope of this investigation. Flying without lines gives a much greater sense of freedom of flight, but does not come without certain risks. New tricks should always be learnt in safety lines, so you can experiment and get 'the feel of' a trick without worrying about falling awkwardly.

How do they work?



The operation of the safety lines is best demonstrated with a diagram. Basically, an operator stands on the ground next to the trapeze. The lines are clipped to the belt at the board, and allow the flyer to swing with them, and even be caught (they travel along the trapeze with the flyer). The lines leave the flyer's belt on each side, are looped over two pulleys at the top of the trapeze, and recombine as one thicker rope, which the operator holds. During normal operation, the operator pulls the rope to take up excess slack. When the flyer falls, the operator pulls down hard on the rope to exert a force upwards on the flyer, slowing his descent. It should be stressed that there is no mechanical advantage in the lines, that is to say that any force exerted on one end of the lines will be transmitted to the other end.

Since there is never much slack in the rope, as soon as the flyer falls, the lines exert an upward force on him. Therefore if the operator pulls on the ropes with a force equal to the flyer's weight (taking into account the cos a), he will hang in mid-air. In other words, the flyer never builds up speed during the fall, requiring no larger impulse to stop him. There are three cases to consider; firstly when there are no safety lines, secondly when the flyer is lighter than the operator, and thirdly when the flyer is heavier than the operator.

Case 1: No safety lines

Let us assume that the flyer falls from the extreme height of his swing (about 5m).

a is approximately 0.3^c, so cos a = 0.95. Let us assume that in this case he weighs 70kg. Ignoring air resistance:

No upward force, so acceleration is due to gravity (g) and is $9.8ms^{-1}$

$$v^2 = u^2 + 2as$$

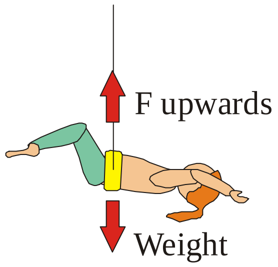
We will assume starting velocity (u) = 0 so $v^2 = 2as$

$$v^2 = 2 \times 9.8 \times 5 = 98$$

$$v = 9.9ms\text{-}1$$

Notice this was independent of the man's mass.

Case 2: Light flyer



Using same assumptions from case 1, except flyer has a mass of only 50kg (child) and the operator has a mass of 70kg.

In this case, the child can exert a maximum force on the safety lines of 500N.

$$T (\cos a) = 500N$$

$$T = 526N$$

Since the operator weighs 700N this will not be enough to lift his from the ground, so he can support the child (and even provide enough force to lift her up…should he want to) and let her down at any speed he wants to (ideally very slowly).

Case 3: Heavy flyer

Again, using the same assumptions as in case 1, with the flyer having a mass of 90kg, and the operator with a mass of 70kg.

$$F=ma$$ (taking downwards as positive)

$$90g - 70g(\cos a) = 90 \times a$$

(all operator's weight hanging on lines)

$$a = 2.56ms^{-2}$$

$$v^2 = u^2 + 2as$$

We will assume starting velocity (u) = 0 so $v^2 = 2as$

$$v^2 = 2 \times 2.56 \times 5 = 25.6$$

$$v = 5.1ms^{-1}$$

Although this is a reduction of about half, this still seems rather a large, especially given that people over 90kg will fall faster (up to max of $9.9ms^{-1}$). What must be remembered however, is that the net is extremely deformable, and will absorb most of the impact, greatly reducing the risk of injury. This works since it stretches, and exerts the force over a long period. Since the impulse needed to stop the descent is the same, and is given by I = Ft, you can either have a large force over a short time, or a smaller force over a long period. The net adopts the second option, reducing the force on the falling flyer to a minimum. Even if you would not want to fall to the ground at $5ms^{-1}$, this would be a very acceptable speed for falling into the net.

In reality of course, the pulley is not completely efficient and there is a good deal of friction. This means that the pulley itself resists the rope running through it and therefore resists the flyer's fall. Or in other words it 'helps' the safety line operator. In most cases, the operator is able to slow the decent of the flyer much more that in our perfect world calculations with much less force.

If we briefly look at the forces on the operator, we see that if the force upwards is greater than his weight, there will be an upwards acceleration. Normally rather than letting themselves be pulled into the air by the lines, most operators will let the rope run through their hands (applying friction with their hands). This slows the flyer less, but the operator remains on the ground and in control.