Angular Kinetics - Part 4

Welcome back to more kinetics. In this section, we will look at levers and how they can be used for amplifying or diminishing forces. So there's a famous quote by Archimedes which you might have come across during your school days that, give me a lever long enough and a fulcrum on which to place it and I shall move the world. Now of course that goes without saying that we'll need somewhere to stand on, but the idea is that I can move very large objects all by myself if I have a lot of what is called leverage. You might have heard the term leverage in a lot of social contexts as well. Here we are only talking about the origins of leverage which is pure physics.

So let us take a look at the elements of lever, what constitutes this lever. So there is a rigid rod or a plank which can pivot or rotate on a fulcrum. This is called the pivot point here. This is called the pivot point.

Then you have the load acting on this lever. So if I was moving the world or a huge mountain, this is the load acting from that huge mountain over here and then there is the motor force which is my effort that I have applied on this end of the lever. Now the idea is that if I apply enough force here, I will be able to move this mass. So let's say I am capable of generating only 100 newtons of force and this is some 10,000 newtons of force that is acting here. So can I use a lever to solve this problem? Can I use a lever to lift this object? And these are the kinds of situations where a lever has been very helpful.

Now the other thing about, so in terms of the other terminology used is the perpendicular distance between the point of pivot and the direction of force application is called the motive arm. And this is called the resistance arm which is the perpendicular distance between the point of pivot, the pivot point, and the perpendicular direction of the force application. These terms will be important for us to consider whether to calculate whether this lever is going to help me or hurt me. So let's see. Okay, here is a thought experiment.

You go to a seesaw in the park and you have the seesaw here and you are sitting on one end here and your friend is sitting on the other end here. Now assuming this is a very good seesaw manufactured precisely and this body is horizontal, the seesaw is horizontal and you and your friend weigh the exact same weight, the lever, this is a lever, this should stay in a fixed orientation. This is what intuition, some of you might have already intuited and you might already know the reason behind it. The reason is there is a force acting on this end which is the weight of your friend and your weight on this end. Both of those are equal and you both are sitting at the same distance.

So, x_2, x_1, so what is, if I was to write the moment balance about this point here, that would be

$$-F_1x_1 + F_2x_2 = I\alpha$$

$$F_1 = F_2$$

$$x_1 = x_2$$

this right-hand, left-hand side becomes 0 total. Their summation becomes 0, so

$$\alpha = 0$$

So if you were at rest in the beginning and you were not rotating this, then this would stay perfectly still.

And that is the principle behind levers. Now if this, your friend was, let us say slightly heavier and you still want to maintain this balance without any additional force from your friend, then you can ask the friend to move closer and reduce this distance x_1 such that f_1 x_1 is equal to f_2 x_2 to maintain balance. So you, despite being lighter in weight, are able to lift or at least maintain and match your friend's weight. So this is the intuition behind levers. Let us now look at some interesting things about levers.

So mechanical advantage. How do I know that I am going to be able to move a particular object? This all of that depends on mechanical advantage. So the limiting condition is when I am in static equilibrium, I am able to maintain this orientation of the lever. And let us say this is hanging in the air about the fulcrum and there is a weight acting on this side, but there is a counterweight acting here that is the motive force, that is the effort, and that is able to keep this in equilibrium position, in some position like this. It does not, the equilibrium does not mean it has to be horizontal.

Equilibrium is just this force is sort of balanced out and the lever is in static equilibrium right now. For that limiting condition, we have done this calculation. So you have your motive arm and you have your resistance arm. So if there was a 100 Newton force acting on this end, I would want for this to remain in equilibrium, I would want a counter force from this lever to act on that body. So if the world was here, there is a force acting from the lever in this direction.

Is that force amplified or not? That is what mechanical advantage can tell me.

$$MA = \frac{motive\ arm\ (ma)}{resistive\ arm\ (ra)}$$

It looks like this does not include the force at all. It is just pure geometry. Let us try and understand this.

So there is a moment when this is in equilibrium. There is a moment acting about this point, which is the

$$MF * ma = RF * ra$$

Now from this relationship, you get

$$\frac{RF}{MF} = \frac{ma}{ra}$$

So what would you want? You would, if this is a large amount of force and this is a small amount of force, you would want to be able to move this or keep it in equilibrium. Ideally, you would want this to be larger than this, which means the motive arm is larger than the resistive arm.

You might want MA to be greater than 1 or at least equal to for lifting heavy loads. So this is the mechanical advantage of the arm of the lever. Then there is a fixed ratio of mass that you can or forces that you can deal with. So if I can only produce say 100 Newtons of force and my mechanical advantage is 2, let's say this is a motive arm is twice the length of resistive arm. My mechanical advantage is 2, then at max by placing the load on this at the resistance arm distance, I will be able to lift a weight of 100 times 2 that is 200 kgs only.

If the weight is above 200 kgs, then I will not be able to, my force will not be able to overcome this. And if the mechanical advantage is equal to 1, in that case, the motive and the resistive forces are equal. So motive arm and resistive arms are equal. And in that case, all you're doing is changing the direction of the force that you're able to apply. So you were applying a force downwards at the other extreme end of this.

The force is now acting upwards on whatever object you wanted to apply force. So that brings us to classes of lever. Now if you notice here, there are three elements, motive force, resistance force, and fulcrum. So we will call F as fulcrum, resistive force as load, motive force as effort. So this is a handy sort of rhyme to remember.

FLE and levers 3 will each enter the center B. So in first class of levers, the motive force and resistive force are on the opposite end and the fulcrum is in the middle. And so this is class 1 of levers. In class 2 of levers, the load is in the center. The fulcrum is at one extreme and the effort applied is at the other extreme.

Same way, load, fulcrum, effort. And in class 3, you have the effort that is applied in the center. So FLE and you have load at one extreme and the fulcrum at the other extreme. So these are the fundamental three classes of lever. So you have seen these levers in action your entire life.

This is nothing new. I will just quickly cover some examples. So class 1 lever, applier. So the fulcrum is in the center. You put the load here, hopefully not my finger, and you apply the effort. And notice how this arm is much larger than this arm here.

This arm. So I would want to apply leverage as far away from the fulcrum as possible. So a small amount of force can apply a large amount of force at this end. Class 2 of levers. This is a hammer with a end to pry out nails. If you fix the nail here, like so, and you apply leverage on this end.

So let me try and do this. So I would apply leverage and this here, the point of contact becomes the fulcrum and I'm trying to apply this leverage upwards. So this is the effort and this pulls out the nail. So the nail will be driven upwards. Okay, last three of levers we'll see in some biomechanical principles as well. So why are we discussing levers of all things? It's because there are a lot of points in human body which acts, which act as levers.

So there's, and all three types of systems can be found here. Let us discuss each one of these. So let's take a look at first class of levers. So one example is where the point of attachment of the head, the skull to the vertebral column. The muscles at the back are what provide the effort.

The load is the weight of this body. So you have your brain acting here and then the fulcrum is the point of attachment. So it is in between the load and the effort. Now this is of course very versatile.

Can easily amplify the force. Any other examples that you can think of? One is triceps extension overhead. So you have a weight that you hold and here this is the lever and this is the motive force here. So you're trying to extend it. So that's one way you can use, you can expect a lever of first class in the human body. Okay, second class of levers can be observed in the foot when you are walking for example or running.

Okay. So you have your toe at the very end of the stance when your trailing leg is about to lift off or it is past the middle point of the body. You will notice that your toe, the foot, end of the foot acts as kind of a fulcrum or pivot point. Okay. The load is the weight of this segment. The force is acting here and the effort is the force provided by the muscles.

Okay. And because the effort is behind the load compared to the fulcrum, this qualifies as a lever of second class. So a wheelbarrow is another practical example of this where you are carrying the load. Right. And you can have the person carrying it. So you can carry huge amounts of load because you are applying the motor force here.

The load is acting here and this point acts as the fulcrum. Okay. If you do push up, in that case as well, when you're doing a pushup, right, this is the fulcrum.

And this is the force application. Right. So effort and this is the weight or the load. So overall as a whole system, the body acts as a lever of second class. In this case, this particular joint and the segments, limb segments involved in this form a lever of the second class. Okay. Now, of course, here there are multiple bone joints in between.

So the fundamental, we discussed earlier that the lever is rigid, may not entirely apply here but the principle holds. Okay. Same way you have third class of levers. So you're if you're doing a bicep curl.

So this is the fulcrum. You try to keep this as stationary as possible and then you put a heavy weight on the other end and you have your muscles attaching here on the forearm. Right. So I have to do a bicep curl like this. Right. And the idea is that because the force is amplified because the force is now amplified, you are applying, you're training your muscles for a lot of load.

Right. Most musculoskeletal arrangements, if you look at it carefully, are levers of third class. Right. And your muscle is where the motor force is coming from. So, that brings us to the conclusion of levers. Levers are used to increase, decrease, or simply redirect the applied effort you have applied.

Right. Mechanical advantage from levers quantifies the efficacy of the lever. So whether or not you can lift a certain load. The principle of FLE in levers three. So that is the three classes of levers.

And all three classes are observed in human body. Although a lot of musculoskeletal arrangements end up being levers of the third class, where the effort is being applied in the middle of the segment. Right. So that's it for levers. And we'll conclude this here. Thank you.