No 4 Levering and mechanical advantage

17 March 2008

1. Last week we looked at twisting and bending. One example is using a wrench to undo a nut. We saw that the twisting or turning tendency – called the turning moment – is mathematically represented by F x d. We can increase the twisting tendency by increasing the distance, or the force, or both.
2. Then we looked at using a push and a pull separated by a distance when undoing a bottle top, closing off the water supply or hauling up an anchor. I mentioned that a pair of forces like this, pushing and pulling and going round in circles, is known as a couple. The twisting tendency, or turning moment, exerted by a couple is also given by the formula F x d.
3. We also had a look at bending and how it involves stretching on one side and tightening and shortening on the other. When we think of ourselves, say, bending forward, we are shortening the front flexors and allowing the back muscles to extend.
4. So if we start off with ourselves pulled back and down and then shorten our flexors, we get ourselves badly compressed. We have what Alexander called a shortening in stature.
5. Today, I want to look at the principle of the lever. The word lever, incidentally, comes from the French *lever* to lift.
6. In its simplest form, a lever is basically a seesaw. There is straight bit and there is the support on which it is balanced – called the fulcrum.
7. If I am facing the problem of raising something really heavy from the ground and I am able to find a lever and a fulcrum I am in business. I stick my lever under the thing, I put my fulcrum in place, and I apply a force at the other end of the lever. And up it comes.
8. Here, I am using a small force at a distance from the fulcrum to lift a large force that is close to the fulcrum. Once again our F x d formula tells us what is happening. The more I increase the distance, the greater the weight I am able to lift. Archimedes said “*Give me a lever long enough and a fulcrum strong enough and single-handed I can move the world.”*
9. When we look around, we see we are applying the principle of the lever all the time. Gardeners use it, for example, when they rest the spade on their knee and bear down on the handle to lift

a heavy lump of soil. When we use a screwdriver to lever off the lid of a tin of paint we are using – the principle of the lever. People in a rowing boat, pull back to push the blade of the oar against the water.

10. A couple of technical terms for when we are looking at levers. The distance from the applied force to the fulcrum is known as the lever arm and the distance from the fulcrum to the weight being lifted is known as the resistance arm. We can designate them L_a and R_a.

11. The ability of the lever to allow us to use a small downward force to apply a larger upward force is sometimes referred to as the mechanical advantage of the lever – particularly in the more old-fashioned physics text books. In textbook terms, *"The mechanical advantage of a machine is the factor by which it multiplies any applied force"* – and, of course, a lever is a simple machine.

12. Alexander's description of monkey and other positions as a *"position of mechanical advantage"* has caused a certain amount of confusion because people have tried to link it into the ordinary engineering use of the term. We will discuss that at the end of this talk but for now we will stay with the conventional engineering.

13. Lets us take a simple lever like this in which I am using a force of 1 tonne to lift a force of ten tonnes. In this case we say the mechanical advantage of the system is 10. And if we measure the lever arm and the resistance arm, we find that the ratio L_a / R_a = 10. The lever arm is ten times longer than the resistance arm.

14. There is, of course, a price to be paid for this mechanical advantage. It is that the distance of movement of the levering force is considerably greater than the amount of movement of the resisting force. A lever enables us to use a small force moving through a certain distance to move a larger force through a shorter distance.

15. But just to make life interesting, we find that there are various kinds of levers

16. The type of lever we have been looking at, which is used to lift something in which the fulcrum is between the applied force and the object being moved is known as a first class lever.

17. There are all kinds of first class levers. The person using their knee as a fulcrum to lever up a heavy lump of soil when

digging; using a screw driver to lever off the lid of a can of paint; using an oar to propel a boat and so on.

18. We can also join two first class levers together so that each one acts as the fulcrum for the other - as we do in a scissors. If we look at a small pair of scissors, like a nail scissors, we have two miniature levers working together to cut our nails.

19. But if you go into a tailor's shop, you will see that there are really big scissors for cutting thick fabrics or leather. Then we have the shears, or garden clippers, which is used for cutting the hedge.

20. One of the things we notice about using a garden clippers is that there is usually a notch in the blades at the top of the blades. We can use this notch to hold a tough branch for cutting. Here we are giving ourselves a mechanical advantage by keeping the tough branch close in to the fulcrum and putting our hands as far out along the handles as possible.

21. By applying the force from our arms far out along the handles, we are obtaining a mechanical advantage and managing to apply a much greater force at the notch which cuts through the wood.

22. There are other possible arrangements. We can have a tower crane, which has a very heavy counterweight close to the fulcrum and uses it to balance a lighter weight at a greater distance. We could also have a pair of barbecue tongs which enables us to pick up something hot at a greater distance from the fulcrum than where we are applying the force with our hand.

23. In both these cases, we are using a large force close to the fulcrum to resist a smaller force further away – we are, if you like, obtaining a mechanical disadvantage.

24. Here is another kind of lever. It is called a **Second class lever.** In this case the fulcrum is at one end of the lever, the applied force is at this end and the weight is in between.

25. Exactly the same principles apply to the second class lever as they do in the case of the first class lever. The lever arm L_a arm is longer than the resistance arm R_a. We are using a smaller force to lift a bigger one and obtain a mechanical advantage.

26. If the levering force is say 4 and the resisting force is 1, we have a mechanical advantage of 4. If we look at the ratio of the two arms L_a / R_a we find that it is also 4.

27. One might wonder where one is likely to come across a strange device like this second class lever. One common example is a wheelbarrow. The fulcrum is the wheel. The levering force is provided by my hands at the end of the handles and the resisting force is the load I am carrying in the barrow.

28. Because the barrow provides me with a mechanical advantage greater than one, I am able to carry a heavier weight in the barrow than I can lift with my unaided hands.

29. If I want to make it easier for myself and reduce the pull on my arms, I can push the weight a bit forward in the barrow. This increases the mechanical advantage. One can see that knowing a little bit about second class levers is quite useful in a garden or on a building site.

30. It also shows us that one needs to be fairly cautious when shifting heavy weights around in a wheelbarrow. Just because it is easy to wheel it around does not mean that you will not injure your back if you try to lift it out of the barrow.

31. We can also join two second class levers together to make a nutcracker. In this case, the hinge is the fulcrum. We apply the force at the end of the handle and the greater force is applied at the nut.

32. In this case, you will see that there are two positions for the nut. The one further from the fulcrum applies a lower force when we squeeze on the end but allows us a bigger movement and so we can crack a bigger nut. The small notch closer to the fulcrum gives us a bigger force but a smaller range of movement.

33. I am sure lots of people will be fascinated when you are at a party and can explain to them that the nutcracker they are using is actually a pair of second class levers. And if they are trying unsuccessfully to crack a nut in the big notch, you will be able to explain to them that they can increase their mechanical advantage by moving their hand further out along the handle or by using the smaller notch – or both.

34. We can now look at yet another kind of lever which is quite similar to the second class lever and is called a **Third class lever**. The fulcrum is at the end but the applied or input force is here and the output force is further away from the fulcrum.

35. In this case, the lever arm is shorter than the resistance arm. We apply a large force at a short distance from the fulcrum to produce a smaller force further away. The mechanical

advantage is less than one. There is a mechanical disadvantage.

36. The most familiar example of a third class lever is when we used a linked pair of them as a pair of tongs. Although this type of lever does not offer us the mechanical advantage of being able to use a small force to move a big one, it does enable us to lift things we do not want to touch with our fingers. This is for handling prints in a darkroom. A bigger version is found in the tongs we use for shifting hot coals about in the fire.

37. What may come as a surprise is that this type of lever is most commonly found in the human body. One of the clearest examples is the way the biceps brachii and the brachialis muscles work on the forearm (p102 Stone and Stone).

38. The elbow joint is the fulcrum. The muscle tendons from the upper arm insert into the bones of the lower arm – the biceps brachii into the radius and the brachialis into the ulna. These insertion points are quite close to the joint. When I flex my arm to raise my hand, I am using quite a strong force here beside the joint to counter the small downward force of the weight of my hand. The arm is thus an example of mechanical disadvantage in terms of its working as a mechanism.

39. If you look at an anatomy book like Stone and Stone you will lots of other examples where muscles insert close to the joint but the weight of the body part, or the force that is exerted when the muscle contracts, is further away.

40. The human body at work can quite accurately be described as a beautifully, or badly, coordinated set of third class levers.

41. I think that is enough to be going on with on the engineering aspects of levers. But as a postscript, I would like to look in a little more detail at how Alexander uses the term *“position of mechanical advantage”*.

42. As far as I am aware, the first time he uses the phrase *the position of* mechanical *advantage* is on p17 of the Mouritz edition of MSI. He is referring to what he means by relaxation and how it differs from collapse. He says relaxation, properly understood, is *“…a condition which is most readily secured in practice by adopting what I have called in my other writings the position of mechanical advantage.”*

43. In a footnote to this, he refers readers forward to p118 for an explanation of what he means by it.

44. On page 118, he says

> *By my system of obtaining the position of "mechanical advantage," a perfect system of natural internal massage is rendered possible, such as never before has been obtained by orthodox methods, a system which is extraordinarily beneficial in breaking up toxic accumulation; thus avoiding evils that arise from autointoxication.*

45. He goes on to say that *"The position of mechanical advantage, which may or may not a normal position, is the position which gives the teacher the opportunity to bring about quickly with his own hands a co-ordinated condition in the subject."*

46. In a footnote on the same page, he gives what he calls a *"simple practical example of what is meant by obtaining the position of mechanical advantage."* He goes on to give a detailed description of leaning a pupil backward in a chair while holding a couple of books against the back of the chair until the pupil is leaning against the books.

47. He then says *"The position thus secured is one of a number which I employ and which for the want of a better name I refer to as a position of mechanical advantage."*

48. It is an odd phrase to use and it obviously bothered Alexander because he came back to it some years later when he was working on CCCI. He says on p 112 *"Readers of MSI will remember that when I used the phrase 'position of mechanical advantage', I pointed out that I did so because a better one was not forthcoming".*

49. He says this failure to find a better expression was despite the fact that "*I had called to my aid a number of scientific and literary friends.*"

50. He goes on to say that he felt the same about other phrases like "*head forward and up… and widen the back…but with a teacher present to demonstrate in person what he means by them, they serve their purpose."*

51. So when Alexander uses the expression position of mechanical advantage it is his own personal shorthand for a position of the pupil which *"gives the teacher the opportunity to bring about quickly with his own hands a co-ordinated condition in the subject."*

52. This is a long way from anything related to the physics or engineering concept of the mechanical advantage that we obtain from using a lever. But as Alexander says, this does not matter as long as we know what we mean and are able to explain it to our pupil in person.

53. But we need to recognise that it is a very different meaning from that conventionally attached to the expression mechanical advantage.

54. If you are giving an engineer or a physicist a lesson and feel an urge to explain monkey as a position of mechanical advantage, bear in mind that it will not make things clearer to them. In fact I would tend not to use with such people.