No 9 CENTRE OF GRAVITY

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1. Today, I am going to talk about the centre of gravity. Most people have some vague sense of what it might be but would be hard pushed to define it precisely.

2. It is, in fact, a very useful concept, particularly when we are thinking about balance. What keeps us in balance and what makes us fall over are issues of considerable relevance in our AT work.

3. Let's talk about gravity first. We won't go into Einstein and we won't talk about how things are when we are millions of miles away in space ship. We'll just concentrate on how gravity works for us on the surface of the earth.

4. Basically, we know that gravity acts to pull things towards the centre of the earth. So if I hang a weight on the end of a piece of string, we know it is being drawn towards the centre of the earth. This means that the line from my finger, the string, is pointing towards the centre of the earth.

5. This, in fact, is what we call the vertical. A line is vertical when it lies along a radius from the centre of the earth.

6. When a carpenter or someone doing wall-papering wants to get a vertical line they do exactly this and hang a heavy weight at the end of a piece of string and line up the paper against it.

7. This is called a plumb-line. For those of you who like your word derivations, it is called that because the weight used by builders and decorators was usually made of lead, for which the Latin word is plumbum.

8. So now let's think about the centre of gravity. This is the technical definition I looked up in a textbook called A Manual of Physics: *The centre of gravity is that point at which the whole weight of an object may be thought to act.*

9. We don't want to get too metaphysical about this. If we take something apart, or dissect a person, we won't find a little identifiable thing called the centre of gravity.

10. The point is that, for certain purposes, things behave as though their whole weight were acting through a particular point. This point is defined as their centre of gravity – engineers tend to refer to the centre of gravity as the CG.

11. But now let's look again at our weight. Since the centre of gravity is the point through which the whole weight of the object

can be thought to act, we can see that the suspension point, the centre of gravity of the object and the centre of the earth must all be in the same vertical straight line.

12. This gives us our first scientific rule. When we allow an object to hang freely, the CG is directly below the suspension point.

13. So now let us look at a more irregular object such as this piece of cardboard. Where is its centre of gravity? We can guess it is somewhere in the middle but how can we be more precise?

14. Let’s apply our rule. Suppose we hang the object from a hook like this, the CG will be vertically below it. We can use our weight at the end of a string to find the vertical – just like carpenters or wall-paperers do. So we know the CG must be somewhere on this line.

15. Now let’s hang it from another point and do the same thing. We know it must be on that line. Since it is also on the other line, the only place it can be is where the two lines intersect.

16. We can check this by hanging it from another point and we see the vertical line also goes through the CG. So here is the CG.

17. Another interesting thing about the CG, which we can find by experiment, is that it is also the point around upon which the object balances. So another way of finding the CG is to find its balance point.

18. Now let’s do something else. If I increase the weight of the object by adding some extra weight at the CG, nothing happens. But if I add it over here, not only is the weight of the object increased, the position of the CG is also shifted.

19. So here is another scientific rule. Shifting the distribution of weight within the body alters the position of the CG.

20. I said that knowledge of the position of the CG is useful in questions of balance. So now let’s look at this.

21. Here is a simple rectangular object with a CG here. If we tilt it a little bit, it comes back to its original position, but if we tilt it beyond a certain point, it topples over.

22. From experimenting, and you can also work it out mathematically, it turns out that the critical thing as far as returning or toppling over is whether the vertical line from the CG passes inside or outside the base of the object.

23. So here we have yet another scientific rule. When an object is tilted, it will return to its original position as long as the vertical line

from the CG remains within the base. Once this vertical line falls outside the base, the object topples over.

24. When the object is squarely on its base with the vertical from the CG well within the base, so that it is hard to push over, we say it is in a state of stable equilibrium. When it is balanced on one corner, with the vertical from the CG just on the edge of the base, so that it is very easy to knock over, we say it is in a state of unstable equilibrium.

25. So, with an object like this, as we tilt it, it moves from being in a condition of stable equilibrium to one of unstable equilibrium.

26. Let us now look at a simplified two-dimensional model of a human being – something with a fairly narrow base tapering upward like this. It is a bit like an Egyptian mummy.

27. I have already located the CG of this model and we can see it is about here. It is obvious that something like this is fairly unstable. If we give it a small tilt, it comes back but if we take it too far, it falls over. This shows that as rigid mummy-shaped objects we are very vulnerable to being knocked over.

28. But we have various ways of dealing with threats to our equilibrium. One of these is the arm. By manipulating the arm, altering the distribution of weight within the body, we are able to alter the position of the CG. And we can increase the effect by using two arms.

29. If we lean or are pushed to say the left side, so that our CG is displaced towards the left side of our base, we compensate by putting out an arm on the opposite side – to keep our CG within our base. The further we extend our arm, the greater the change in the position of the CG.

30. So much for flat two-dimensional objects. Three dimensional objects also have a centre of gravity but it’s inside them. So it’s more difficult to locate it.

31. One way of doing it, is hanging them up from different bits and boring holes in them to see where strings hang vertically through them. But this is a bit messy and painful if you are dealing with live human beings – though I suspect early anatomists were quite happy to use corpses.

32. There are also methods using mathematical calculations based on model human beings, about which we do not need to bother.

33. What we know is that the position of the human CG is sort of in the abdomen a bit below the navel. But there are obvious differences between the shapes of people so I imagine the relative

position of my CG would be a little different from that of a taller or slimmer person.

34. In the case of three-dimensional objects, the base is the portion in contact with the ground. The interesting thing about the base is that it does not have to be solid or continuous. In the case of a stool or a chair the base is defined by the line around the outside of the legs. In the case of people, it is a line drawn around the outside of the feet.

35. Staying in balance is obviously important for us as human beings – falling over tends to damage us. So we have various inbuilt sensing mechanisms by which the body warns us that we are creating conditions in which the vertical line from our centre of gravity is moving outside our base.

36. One of these is the system of pressure sensors in the soles of our feet which I mentioned in one of the earlier talks. As I lean forward, the sensors at the front of my foot detect the extra weight and tell the brain about it; as I lean back those at the back respond to the extra weight and tell the brain about it.

37. Our eyes provide us with an enormous amount of information about our position and orientation in our surroundings. But there are various ways in which they can be deceived – like in the crazy house in a funfair where things that we assume should be vertical are built at a tilt. We also find it a bit more difficult to keep our balance in the dark

38. We also have the vestibular system – in our inner ear which tells us about the movement and angle of the head. This is why we sometimes find our balance is affected when we have an inner ear infection.

39. One of the things we tend to do as we begin to sense ourselves going off balance, is to stiffen. This is because the first line of defence when we become aware that we are doing something wrong is to stop doing it.

40. But then we have a whole range of options for getting our CG comfortably back inside our base once we detect it is danger of going outside it so that we fall.

41. We saw how the arms can be used, but we have all the other bits of our bodies. Our head, hips, knees can be moved backward and forward and from side to side in order to adjust the position of our CG and keep it inside the area of the base. And we can also widen the area of the base by moving our feet further apart.

42. This is what happens in dancing, gymnastics and general free and relaxed movement.

43. It is also what happens when we going into a nicely balanced monkey, and are adjusting the various bits of the body, the hips back, the hands forward, allowing the head to be free on the top of the spine is all to do with keeping our CG comfortably within our base.

44. As usual, I emphasise that understanding the engineering does not tell us everything about what is going on. Nor does it give us a blueprint for where exactly each bit of us needs to be as we are giving and receiving AT lessons. This we can only learn by training and practice.

45. But I personally think an understanding of the basic mechanics of balance and the need to adjust the various bits of the body to keep the CG within the base is useful in understanding what is going on as we go about our business. It also helps to strengthen the rational underpinning of the AT.