12.3 Dynamic Properties

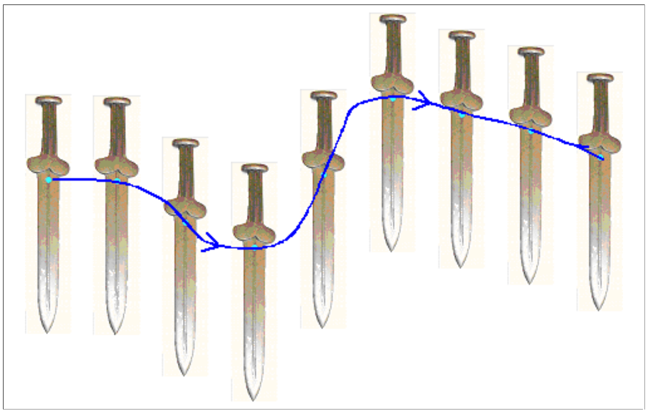
12.3.1 Moving a Stick

General Movement = Translation plus Rotation

I need to make a comment first before I delve into the topic "Dynamic Properties of a Sword". While static properties still are part of Materials Science, dynamic properties are not. How a sword bends, for example, depends on material properties like Young's modulus (and the geometry expressed in the area moment of inertia). How a sword moves depends *only* on its weight (distribution). In other words: Two swords made from completely different materials but with the same weight and geometry handle or move in exactly the same way.
Since the focus here is on Materials Science, I tried to keep this subchapter short.

- I failed. The topic is exceedingly complicated and it is almost impossible to describe the important parts without equations. I tried anyway but needed to use many words.

When your sword moves, its movements can be described as a combination of a pure translation and a pure rotation. Sounds a bit involved but the basics are very simple, just look at the pictures below:



Pure **translation of a sword. There is no rotation**
The center of mass is symbolized by a blue circle

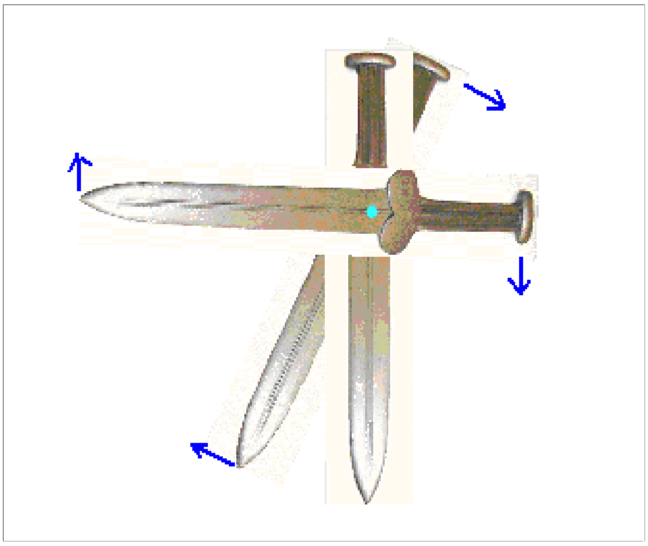
- The *center of mass* of the sword (blue point) moves along some line but the orientation of the sword in space does not change. You know what is meant by "center of mass"; otherwise don't worry. I will get to it quite soon.
  A translational movement contains all movements where the center of mass of something moves in any way. Up / down; left / right, to and fro, in a circle, whatever. A *pure* translational movement implies that the orientation of the object in space must not change. Nothing rotates.
- Here is a thought: All movements of a "point" are always translational. A point has no orientation in space and thus cannot rotate. A ball could rotate, but a ball is not an infinitesimally small point. Now you know why physics teachers and all and sundry love the "mass point" so much. You avoid having to cope with the difficult subjects of rotating things.

If the center of mass moves, some net forces must act act on the object. Newtons's first law couples forces and movement and allows to calculate what happens. When we consider the movements of a sword, it is useful to distinguish two kinds of forces:

1. Forces that act on the sword ***all the time***. Gravity, for example, is always there acts on any point on your sword. It wants to move your sword "down". Your hand around the grip is also always there and exerts force but *only on the grip* all the time.
2. ***Short term*** forces. The best example is the force acting on the edge when you hit something. It lasts only a short time.

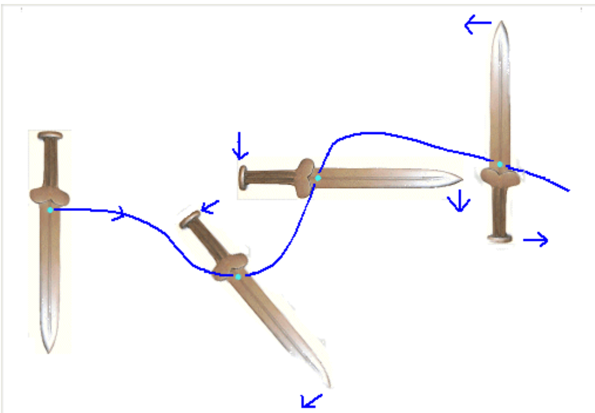
The pictures that follow contain many arrows symbolizing forces. They cannot not distinguish between permanent and short-term forces and you need to be aware of that.

The drawing above is simple and it's easy to imagine all kinds of movements in this way, including movement in three dimensions. What's not so easy is to answer this question: How can you produce a pure translational movement like the one shown above? Obviously some forces are required. This is right but I will add right away that those forces must *only* act on the center of mass all the time for pure translational movements, i.e. if rotations are "forbidden".
Before I delve deeper into this, let's look at the case of *pure* rotation:



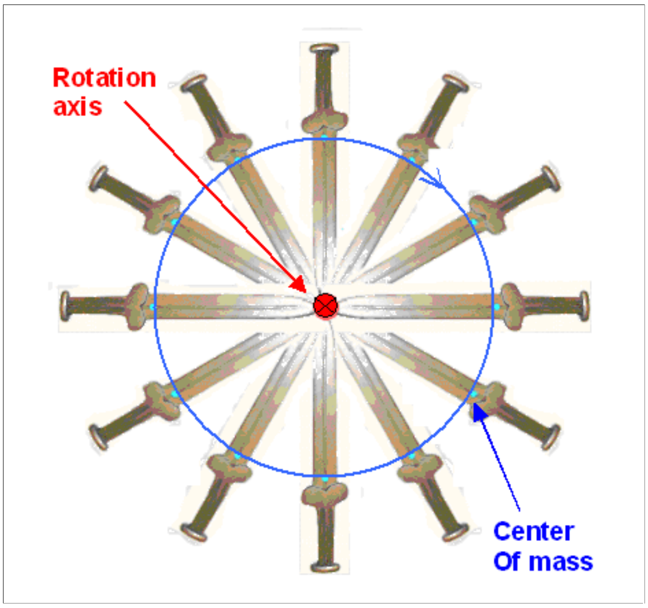
Pure rotation of a sword. There is no translation
The arrows symbolize the movement

- You will have no problem to grasp this "*pure rotation*" concept. Did you notice that the rotation axis runs through the center of mass? Probably yes. But do you know that for pure rotations this is a must? The rotation axis *must* run through the center of mass! Think about it. If it wouldn't do this the center of mass would move, and if the center of mass moves, we have a translation and thus no longer a *pure* rotation.
  - How can you produce a pure rotational movement like this? If you remember finer details from physics, you will tell me that some **moment of force** is required, also known as **torque**, *torsional moment* or *turning moment*.
    A moment of force is generally the product of the force causing a rotation times the distance of that force to the axis of rotation. That is a somewhat oversimplified and unscientific definition but it will be good enough for the time being.
    We have encountered torques before, but only in the science section about beam bending.
    For a *pure* rotation we actually need a *force couple* meaning *two* forces that are equal in magnitude and with opposing directions. They then cancel each other to a *net* force of zero with respect to translation. Otherwise the object would move and we wouldn't have a pure rotation anymore.
- I'll get back to this in gruesome detail but first let's look a the general case of movements: translation *and* rotation are somehow combined



Translational *and* rotational movement of a sword
Blue arrows show movements

  - We have the simple picture from above but now the sword translates *and* rotates. You would have to apply proper (and somewhat crazy) forces that also produce torques to cause such a movement, and calculating what it would take to cause such a movement is actually not all that easy.
- In many cases of movement it certainly looks as if the object simply rotates around some point that is *not* the center of mass. Think of your grandfather clock pendulum. It swings back and forth around a *pivot point* that is certainly not located in the center of mass, of the pendulum. Describing its movement as a rotation around its center of mass plus a translation of the centr of mass seems just not right. It appears to be overly complicated. I agree. It just wouldn't *look* right.
  So let's look at a case that is somewhat similar



Translational and rotational movement of a sword that can bedescribed as "rotation around a pivot point"

- This certainly looks like a simple rotational movement around a clear axis or pivot point. Let's call it "**pivot point rotation**". Having a name always makes things less scary.
  Simple it may look but it is nevertheless is *not* a *pure* rotation around an axis at the tip of the sword. The center of mass moves too (in a circle) and that is *translation* by definition. You have to supply a torque for the rotation but also some forces acting on the center of mass to cause its movement in a circle. You actually know that force. It's the (negative) centrifugal force (then called centripetal force) you experience when you swing your kid around. In the picture above the axis is experiencing that force.
  The earth experiences the gravitational force from the sun when it circles around the sun. You simply need a force that pulls the center of mass inwards towards the rotation axis to keep your kid (or the earth) form from flying off.
- To make the point once more in a different way: It is perfectly possible (and "legal") to describe the movement in the picture above as a *pivot point rotation* with a pivot point that does not coincide with the center of mass. In a more general point of view you can describe *any* movement as a rotation around some instantaneous or apparent rotation axis or pivot point that moves around in some way. It's a matter of preference *and* of being aware of the required changes in the math. Just don't mix up a *pure* rotation, always around the center of mass, with a rotation around some arbitrary axis.

Before I go on discussing sword movements, I need to give the center of mass a closer look. I'll do that in the next sub-chapter