I Used Physics to Calculate How Much Yoda Weighs

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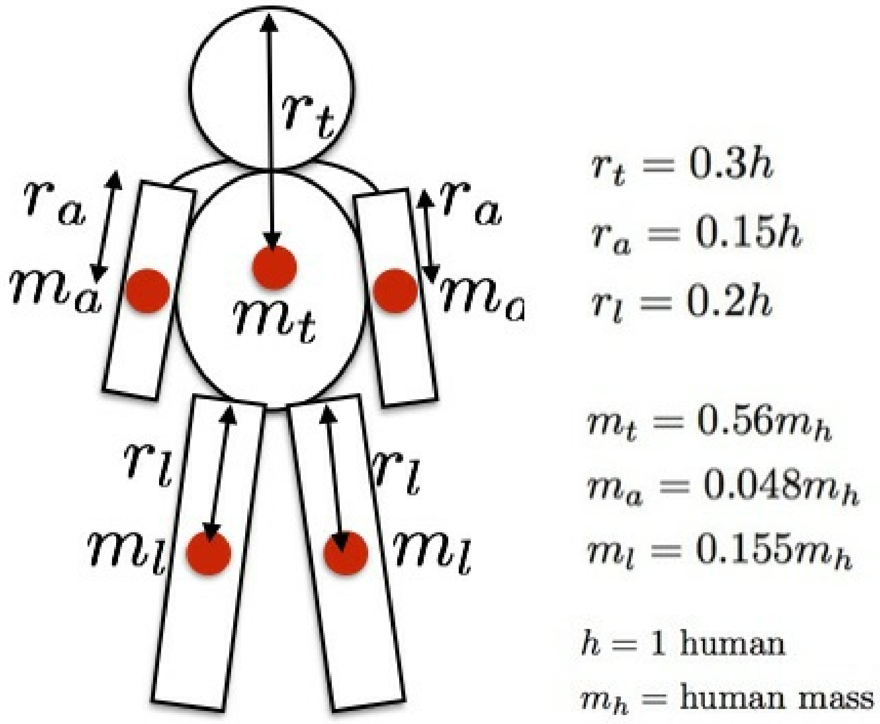
Lucasfilm

Everyone knows Luke Skywalker travels to Dagobah to learn the ways of The Force (like his father before him). He trains with Jedi master Yoda. Perhaps you recall the scene where Luke does a one-armed handstand while balancing Yoda on one foot. Yes, for a real person this is pretty much impossible—but not for a Jedi.

Ok, so here is the plan: I am going to use Luke's pose to estimate the mass of Yoda. This will be all about the center of mass. If the Luke-Yoda system is in equilibrium, then the center of mass for the entire system must be directly above Luke's one hand on the ground. (If you want a more detailed explanation of center of mass and balance, check this post where I use center of mass to estimate the mass of Darth Vader.) To do this, I will make the following assumptions:

- The planet Dagobah is just like Earth—the gravitational field on the surface of the planet doesn't really matter, but still I am going to assume this.
- Luke's mass and mass distribution is just like any normal human. I guess Luke is a human. Now that I think of it, he should be an alien, right?
- Luke has a height of 5 feet 9 inches and a weight of 150 pounds (1.75 m and 68 kg).
- There are only two external forces on the Luke-Yoda system: the gravitational force and the force of the ground pushing up. For this calculation, there is no The Force force.
- What is the mass distribution for a human? I am going to use some values from this very interesting survey of different measurements of the human body (pdf).

The paper I listed has multiple representations of the human body. Just to be clear, I am going to use the values based on Dempster. I am going to represent my human (or alien that looks like a human) as a five-point mass. Here are the locations and values of these masses:



Now we can look at the Luke-Yoda system. Here are those point masses (including Yoda). A helpful tip: Even though I am looking at an image, Tracker Video Analysis can be useful for measuring points.

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I don't really care about the vertical position of the total center of mass, but with this data I know the total x center of mass must be zero (since I put the origin at Luke's hand). The x coordinate of the center of mass of the whole Luke-Yoda system would be:

$$x_{cm} = \frac{m_l x_{rl} + m_l x_{ll} + m_t x_t + m_a x_{ra} + m_a x_{la} + m_y x_y}{2m_l + 2m_a + m_t + m_y}$$

Here I am using the notation of x_{rl} for the x-position of the right (r) leg (l). Hopefully that makes sense. Now I know all of these values except for the mass of Yoda. It's time for a wee bit of algebra (assuming x_{cm} = 0 meters) I can get:

$$m_y = \frac{-m_l x_{rl} - m_l x_{ll} - m_t x_t - m_a x_{ra} - m_a x_{la}}{x_y}$$

Using the x-position values from the video along with the mass values from my estimations, I get a Yoda-mass of -43.7 kg. Yes, that is a negative mass. But what does that mean? It means that in order for Luke to balance in that position, Yoda would have to pull UP on his leg rather than push down. One way to pull up would be to have a negative mass (which we don't see). The other way for Yoda to pull up on Luke would be with The Force.

No, Luke is not using the Force to hold Yoda up. In fact, even if Luke was doing a handstand without Yoda pulling up, his center of mass would be 12 cm to the right of his hand. He would tip over. Why is it that Yoda using The Force and not Luke? Luke doesn't know what he is doing. He couldn't even lift the X-wing (which happens right after this). He's just a student. Yoda was just helping Luke because he wanted him to feel a small sense of accomplishment after his failure in the cave.

Preemptive Comments

Clearly this post will require some feedback. As the unofficial inventor of preemptive comments, I must occasionally reply to your comments before you even comment.

- *I don't get it. Why are you even wasting your time on this. I don't even know why I read this dumb blog. The Empire Strikes Back has been around for 35 years and you are just now looking at Luke's handstand? Of course he couldn't do a handstand like that. News Flash—Yoda couldn't really lift an X-wing either and X-wings don't even exist. You are wasting your time.* No comment.
- *Why did you ignore the center of mass in the y-direction?* Oh! That's a real question. Really, this is all about torque. If Luke-Yoda is in equilibrium, the net force and the net torque must be zero. Putting the center of mass for Luke-Yoda over the hand would create zero torque (that's why I solved for the x-cm). However, it doesn't matter about the y-value of the center of mass as long as it is over the hand.
- *I think your assumptions for the locations and values of the points masses in the human body are wrong.* Yes, they may indeed be incorrect. But whatever they are, I'm still fairly certain that the stuff on the right side of Luke has a greater mass than the

stuff on the left side. Yoda would still have to pull up to make Luke balance.

- *What if Yoda floats like a balloon and is using his weird feet to pull up on Luke? That way he wouldn't have to use the force.* That's a very interesting idea. Of course if Dagobah has an atmosphere like Earth, the buoyancy force on a shape the size of Yoda would still be very small and not anywhere near the equivalent mass of 43.7 kg. This would be a great calculation for your blog.

One last thing. Real handstands are difficult, but one-handed handstands are doubly difficult. When you put two hands on the ground, it is fairly simple to adjust the force your two hands exert on the ground to create torque that brings you back into equilibrium. For front and back motion, you would have adjust your body's center of mass to stabilize your position. Now when you switch to one-handed handstand, you must adjust your center of mass in both the front-back and side-to-side directions for balance. This is tough. Oh, and you have to support your weight with just one arm.