Human Free-Body Diagram

Jeff Bigler Lynn English HS; Lynn, MA mrbigler@mrbigler.com

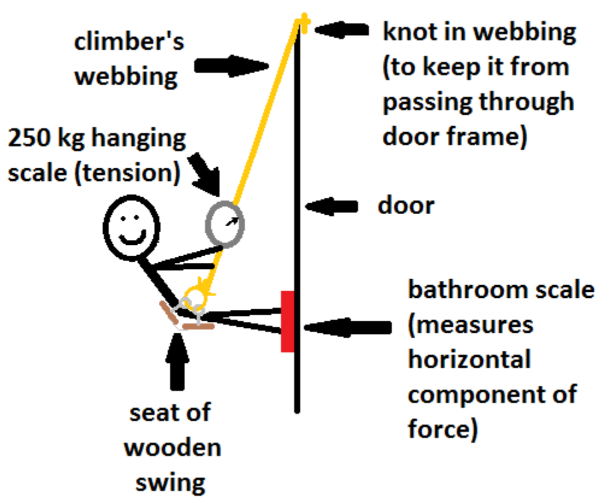
Motivation

Most physics students can learn to draw a correct free-body diagram for a climber attached to a rope at an angle:

With practice, students can successfully resolve the tension in the rope into its vertical and horizontal components, balanced by gravity and the normal force. However, many students never develop an intuitive feel for the process. This participatory demonstration places the student in the middle of the free-body diagram where he/she can directly observe and interact with the forces involved.

Set-Up

The set-up looks like the following:



Construction

The apparatus is constructed as follows:

Anchor Point: The apparatus is anchored to a closed door, which must be solid, have sturdy hinges, be in good repair, and be able to be latched with the webbing jammed into the frame.

Important Note: *the webbing will exert a substantial force on the door. The student should be on the side of the door* ***<u>without</u>*** *the hinges, to ensure that the force pulls the door into the door frame, not away from it.*

Webbing: A roughly 6' length of 1" tubular nylon webbing with a loop tied in one end and a large knot in the other. The door is closed such that the knot is outside the door and the rest of the webbing (which will be attached to the apparatus) is inside. (The knot keeps the webbing from passing through the door slit.)

Hanging Scale: a 250-kg hanging scale (about $25 from Amazon) with carabiners attached to the top and bottom. One carabiner is attached to the webbing (described above). The other end is attached to the seat (described below).

Seat: A wooden seat made from two 24" lengths of 2" × 6" pressure-treated lumber, held together with a corner bracket that was widened to approximately a 120° angle. A ½" hole was drilled onto each side of both the seat bottom and seat back, and an eye bolt was bolted through each hole. A roughly 10' piece of $^{7}/_{16}$" climbing rope was threaded through the two eye bolts on each side and knotted securely.

Bathroom Scale: a bathroom scale is placed between the student's feet and the wall to measure the horizontal component of the force.

The apparatus should be set up such that the seat is approximately the height of a laboratory stool.

The Demonstration

A student climbs into the apparatus in a sitting position, with feet pressing into the door. The student should be able to read the tension in the rope, as measured by the hanging scale.

The teacher places the bathroom scale on the wall for the student to "stand" on. The bathroom scale measures the horizontal component of the force.

The length of rope, height to the top of the door, and distance of the apparatus from the door can be measured using a tape measure or meter stick.

You will find that the tension in the rope is greater than the student's weight (as expected), and that the normal force is less than the student's weight (also as expected). However, exact calculations usually do not yield good results because the location of the student's center of mass varies, depending on the student's body position. (One student was delighted that we calculated her weight to be 115 pounds!)

Nevertheless, the demonstration is helpful for students to experience and see approximate values of the forces on a body in static equilibrium.