Physics of the Real World Report: Heavy lifting with the hand truck

An Example PHYS 101 Report by Dean Livelybrooks

Introduction:

The hand truck is an example of a simple machine. It uses the principle of the lever to multiply forces. Thus, one can lift a heavy load with a smaller force than is required to lift the load using one's body. Once the load has been lifted off the ground, the hand truck uses wheels to expedite moving the load elsewhere. A well-designed hand truck includes a handle at the top that is bent relative to main axis of the machine— which allows the operator to comfortably apply a force in the horizontal direction without unbalancing the load.

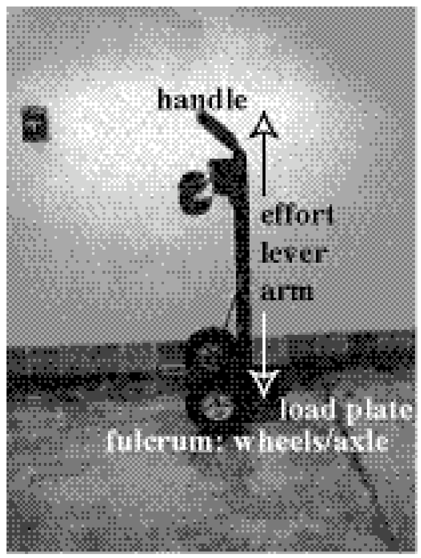

Figure 1: The hand truck

How it works:

How is the hand truck operated? We all know this, but it is useful to think of its operation in five steps:

1. Place the load plate (see Figure 1) under the load. Sometimes one has to tip back the load to allow clearance for the load plate to fit under it.
2. Stabilize the fulcrum (lower wheels and axle) by pushing down on the axle. This keeps the loaded hand truck from slipping forward when the load is being lifted (more on that later).
3. Pull back on the handle, applying a torque ("effort") about the fulcrum. In doing so, the load is lifted off the ground.
4. Apply a horizontal forward force on the now-balanced and loaded hand truck to move the load and truck in the forward direction. The force of friction placed on the loaded hand truck by the floor is easily overcome by the turning of the wheels.
5. When the destination is reached, the load is off-loaded by releasing the handle and allowing the unbalanced torque on the truck/lever (the force of gravity acting on the load close to the pivot) to rotate the truck to upright.

Analysis:

This report will focus on steps 3, 4 and 5. The principle physics rule that governs the actions of the truck and operator during these steps is the rotational equivalent to Newton's Second Law:

$$\Sigma\tau = I\,\alpha$$

where $\Sigma\tau$ is the sum of the torques acting about the center of rotation (the fulcrum), I is the moment of inertia of the loaded hand truck (again, with reference to the fulcrum), and α is the angular acceleration (how fast it changes rotational speed) of the hand truck about the fulcrum. During step 3, a force is applied on the handle, and perpendicular to the axis of the hand truck (see Figure 2, below). This force applied over the "effort lever arm" results in a torque on the hand truck causing it to want to rotate counterclockwise. Neglecting the mass of the hand truck, the only other torque exerted on it is caused by the force of gravity acting on the (now unsupported) load (the "load torque"). This force acts from its center of gravity, and the distance between the load's center of gravity and the fulcrum defines the "load lever arm." This torque wants the hand truck to rotate in the opposite sense (clockwise) than the "effort torque." To rotate and lift the load, the effort torque must temporarily overcome the load torque, so that the entire system rotates counter-clockwise.

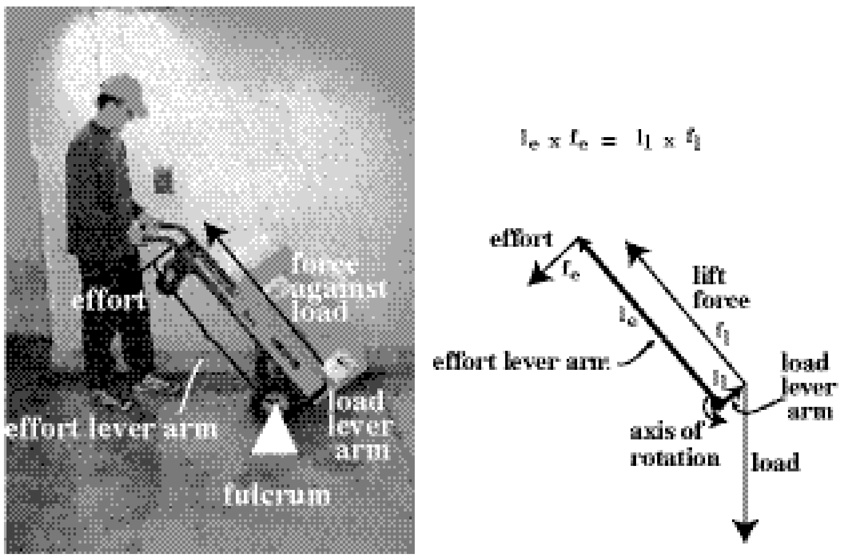

Figure 2: Using the hand truck to lift a load (step 3)

The hand truck is a first class lever, which multiplies forces. It multiplies forces during step 3 because the effort operates further away from the fulcrum than does the load. This is similar to the skinny kid lifting the big bully on the teeter-totter by sitting further away from the center. During step 4 the truck and load are pushed along when the operator applies a force to the right, along the line of the handles (this force is not shown to simplify the figure). Note that, in the proper operating position, the handles are parallel to the ground, so that all the pushing force is applied to move the load horizontally. Any other angle, and some of the pushing force would go towards unbalancing (rotating) the hand truck. The physics rules that governs motion of the loaded hand truck during step 2 are Newton's First and Second Laws:

$$\Sigma F = 0 = m\,a \text{ (First Law)} \qquad \Sigma F = m\,a \text{ (Second Law)}$$

When the loaded truck begins to move, the sum of the forces on it (pushing force and friction) is non-zero, and results in an acceleration of the load in the direction of the push (to the right, above). After the loaded truck reaches some velocity, the operator reduces the force of their push so that it is equal and opposite to the force of friction. Then the sum of the forces is zero, and the truck's motion doesn't change (constant velocity).

Experiments:

One could test the assumptions in step 3 by setting a known weight on the load plate (1000N) of the hand truck. Given the lengths of the effort and load lever arms, one can use the formula in Figure 2 to predict the effort force needed lift the weight (say effort and load lever arms are 2 and .2m, then the effort force should be 100N).