COMPILATION: Unit 5 - friction vs surface area

Date: Thu, 20 Mar 2003
From: Rob Spencer <rspencer@KIVA.NET>
Subject: friction vs. surface area revisited

Mark Davids had his students perform an experiment (1997) in which friction force vs. surface area was studied. He indicated that the usual independent relationship was the result.

My students just finished this same experiment. Cardboard was carefully cut and attached to the bottom and one side of a piece of 2 x 4. Students were careful to make sure the "grain" was identical for all trials. Students then hooked a horizontal string to the block and ran it over a pulley to a mass hanger. They then collected position vs. time data for "flat" orientation (more surface area) and then "high" orientation. The hanger and mass were chosen large enough to ensure that only kinetic friction was being tested (meaning that the block accelerated in all trials...flat and high). Care was taken to ensure that the pulling string was still horizontal for both orientations (by switching to different position of multi-selection pulley).

The results: The four "high" trials produced an acceleration of approx. 1.95 m/s2 while the four "flat" trials produced an acceleration of approx. 2.02 m/s2. Thus the smaller surface area had slightly more friction because its net acceleration was smaller.

This was counter-intuitive to what my students expected. They expected the smaller surface area to produce less friction. I was expecting the null result. Given the lack of careful error analysis and the fact that the numbers are close enough together, I could see how the null result is possible within error...but every "flat" (more surface area) trial demonstrated more acceleration than every "high" (less surface area) trial out of 8 trials.

My students then argued that the same normal force was spread out over a smaller surface area producing more "pressing" together as an explanation for the surprising results.

Has anybody else seen similar results? Comments?

Date: Thursday, March 20, 2003
From: (unknown)

My students often get the same kind of "non-intuitive" results with the frictional force being slightly greater for the SMALLER surface area given the same normal force.

Here I feel it critical for the students to compare the PERCENT CHANGE in the frictional force to the PERCENT CHANGE in the surface area. They will soon come to see that these percent changes are quite different from each other, thus pooh-poohing cause and effect (i.e., the notion that the change in surface area CAUSES the change in frictional force we measure). This can then lead to an interesting whiteboard session on the actual source of the differences in frictional force (I suspect the great uncertainty in determining a REPEATABLE value for the frictional force due to surface interaction phenomena).

A RELEVANT DEMO I like to use:
I attach a toy battery-powered bulldozer to a piece of a 2 x 4 block. I place 4 1-kg masses on the block first with the largest surface in contact with my desk. The tractor can NOT move this block. Now remove one 1-kg mass at a time until the tractor CAN move the block across the desk (commonly 1 mass is left on the block). Now place the block with the narrow surface in contact with the desk and replace the 4 1-kg masses - this time on the top edge of the block. Ask your students to predict how many masses will be on the block when the tractor moves it now. MAKE A BIG DEAL OUT OF HOW MUCH LESS SURFACE AREA THERE IS IN CONTACT WITH THE DESK FOR THIS ORIENTATION OF THE BLOCK!). Then engage the tractor and remove the masses one at a time, as before.

Date: Fri, 21 Mar 2003
From: John Clement <clement@HAL-PC.ORG>

Actually there is nothing intuitive about frictional forces. It is purely an empirical observation, with some possible ways of understanding it. It may actually be experimentally true that a smaller surface really does produce a slightly larger frictional force. Or the result may depend on the type of surfaces that are in contact, or how clean the surfaces are. It is perfectly possible to have other surfaces work differently. The "intuitive" result is probably that the force increases proportionally to the surface area.

The actual theory of frictional forces is fairly complex, and is not suitable material for most HS classes. However, students need to understand that there might be a small effect due to surface area, but it can usually be ignored compared to the large effect of the normal force. In more advanced language, the surface area effect is probably a second order effect while the normal force is a first order effect. In other words they need to have a model where the surface area is not important, and only the normal force and coefficient of friction matter. This makes it possible to do fairly realistic problems. This is similar to the usual caveat "ignore air resistance and frictional forces". Notice that this is similar to the situation of dropping 2 balls from a height with one 2x as heavy as the other. If you take air resistance into account, the lighter one will usually hit slightly later. However Galileo pointed out to his critics that this was still dramatically different from the Aristotelian prediction of having the heavy ball fall 2x as fast.

I do a fairly dramatic interactive lecture demonstration with a plain 2 x 4 cut to about a 1-foot length. It has been sanded just to remove the surface dirt and make it less splintery. I do the demo on an ordinary flat Formica-top student desk. I first show the students the frictional force by pulling on it with a force probe. Then I have them predict the force if I pull it faster. I save the original graph, and they can clearly see that pulling about 2x the speed is about the same force. Then I have them predict the result if I turn the 2 x 4 on its side. Most predict a different frictional force. They are quite surprised to see that the graph is about the same. Finally I turn it on end so that the area is about 1/15 of what it was before. Again the graph is the same, and at this point the students are predicting it to be the same. Finally the students see the effect of adding more weights to the 2 x 4. I do this by stacking similarly cut 2 x 4's on top.

There are some important points in doing this. You have to learn to hold the force probe level, and it helps to have strategically placed eye hooks on the 2 x 4. I have noticed that sometimes the smaller area changes the frictional force slightly. This is fixed by cleaning the surfaces with white board cleaner. Perhaps you should try cleaning the student's surfaces. This interactive lecture demo is even more dramatic because it is done with ordinary materials which I got from a builder's scrap pile.

Incidentally the counter-intuitive nature of friction is easily seen by reading *Consumer Reports* tests on tires. They claim that as tires wear, the dry pavement friction increases by 5%, but the wet pavement friction decreases dramatically. The wet pavement is easily understood because the depth of the sipes in the tire decreases, which reduces the ability of the tire to prevent water from getting under the tread. However, why does the dry pavement friction increase??? You are not really changing the footprint by 5%.

The other interesting point is that students will claim that racing tires have more friction because of the greater area. Actually they have more friction because they are made of softer rubber which grips better. The greater area is necessary to distribute the force and reduce the force on any given square area. This prevents the soft rubber tire from disintegrating.

Date: Sat, 22 Mar 2003
From: WILLIAM JAMESON <wjameson@DEFOREST.K12.WI.US>

There was an excellent article on friction in *Physics Today* 3 or 4 years ago.

My recollection is that the surface area dependency shows up because of its effect on normal pressure (force/area), and results in the surface irregularities being pushed together. I have given up trying to do quantitative friction labs, since my AP physics students 3 years ago successfully showed that the coefficient of friction varies from place to place on our lab tables (by as much as 50%).

As for surface area effects, try this: take a block of wood, and a piece of cardboard, and a large number of identical pins. Push 3 pins through the cardboard to make a triangle. Place them point

down on the counter, and put the block of wood on top. Test the coefficient of friction. Then push (or have a student do this) about 100 pins through the cardboard, and repeat the experiment.
I tried it several years back, and was surprised by how small the change in friction was.