The Physics of Karate

Lab Ticket

- Read this lab write-up.
- Read the Condensed manual for the High Speed Camera. Located under the links section of this course's web page.
- Write an outline of the procedure you will follow during your two-week investigation.

There are two main parts to this experiment: measuring the amount of kinetic energy you can put into your hand and measuring the amount of energy necessary to break a piece of pine board. After completion of the lab you should be able to determine whether you can break a pine board without injury to your hand. You are in no way required to break a board but are welcome to try it after confirming that you theoretically can.

Equipment Provided:
1) High-speed video camera.
1) Two saw horses.
1) Load-Bearing board.
1) Dial indicator.

I. Introduction to the Physics of Karate

Karate is an ancient martial art that is believed to have begun on the island of Okinawa. After invasion by the Japanese the islanders were forced to yield all of their weapons. Consequently the islanders began training in empty-hand combat and developed techniques for effective fighting without weapons. Modern scientific investigations of these ancient techniques consistently find that they have been amazingly well designed. Many of the techniques taught as conventional wisdom translate into precise physical optimizations of human movement.

In the following you will investigate how a few of these techniques can be used to break boards. The first section of the lab investigates the energy that you can deliver in various punches. The second section is dedicated to finding out how strong pine boards are. These sections can be approached in either order, so if there is a group already working on the first section go ahead and work on the second one.

II. Energy in Your Hands

There is a stark contrast between eastern martial arts like karate and western styles of fighting like boxing. Martial arts experts use very quick extremely controlled strikes to injure their opponent and at the same time maintain their balance in case of counterstrikes. In contrast western boxers use less controlled punches with long follow through, designed to knock their opponents over. This difference in approach is important to keep in mind as you investigate karate strikes.

The first part of this experiment is dedicated to finding out how much energy you can deliver in a forward punch. A typical forward punch in karate is described below:

> Let us consider a forward punch in which the attacker does not move his feet. The fist starts at the waist with the closed palm upward, and as the fist is hurled forward, it turns over until the closed palm is downward when the arm is fully extended. [1]

Practice this movement a couple of times. You may find it useful to pull your other fist back as you punch. This rotates your hips and can add speed to the punch. However, be aware of your balance, this technique is useless if you don't maintain balance.

1) Take a high-speed video of both you and your partner performing this punch. While it may be tempting to use an extremely fast frame rate keep in mind that you have to analyze this video and a whole bunch of frames that you don't digitize is just extra baggage that will slow you down. A reasonable frame rate is 500 frames per second. It is also a good idea to take the video from the same side as the person is punching, that way you will be able to see their fist in all of the frames. (As always be sure to have something in the frame that you can use to scale the movie.)

1) Digitize your movies using the techniques described in the condensed manual for the high-speed camera. In VideoPoint, set the frame rate to 500 fps by clicking **Select Frame Rate** from the **Movie** menu.

1) What is the maximum speed that your hand reaches? How much energy is your hand carrying at this point? The following table can help you to estimate the mass of your hand (It is difficult to estimate a precise mass of your hand because it is attached to your forearm. It would be reasonable to include some of the mass of your forearm in the calculation of energy. However, keep in mind that for the purpose of calculating whether you can break a board it is safer to underestimate the energy that you can deliver with your hand. Thus don't include the mass of your full forearm):

MALE SUBJECTS = [M] FEMALE SUBJECTS = [F]

HEAD	6.940% [M]	6.68% [F]
TRUNK	43.456% [M]	42.57% [F]
UPPER ARM	2.707% [M]	2.55% [F]
FOREARM	1.625% [M]	1.38% [F]
HAND	0.614% [M]	0.56% [F]
THIGH	14.165% [M]	14.78% [F]
CALF	4.330% [M]	4.81% [F]
FOOT	1.370% [M]	1.29% [F]

Table 1. The table above presents the mass of various parts of the human body for both males and females given as percentages of total body mass. This data is from the findings of Zatsiorsky, *et. al*.

One well-known piece of advice that karate instructors give their students is to focus their punches into their target. Thus if you were striking another person in the chest you would aim to terminate the punch about a fists length inside of your opponent. Use the data you obtained in part 3) to evaluate this piece of advice. There is actually an extremely useful and general analysis technique that you can use in your evaluation of this advice, known as normalization. If you plot the velocity of your punch vs. the position of your punch, measured from where the punch began, you will have a good idea of where your punch attains its greatest speed and consequently its greatest energy. However, if you were to compare the position of this greatest speed to the position of your lab partners greatest speed they are most likely going to be different. This is not very surprising since you and your partner probably have very different builds and arm lengths. If you want to make a more general statement of where the maximum speed of a punch takes place, you would want to try and account for this dependence on different people.

2) For this part of the analysis, we will need to move the data to Excel. To do this, simply highlight the data from VideoPoint's table, copy it and past in Excel. Plot the speed of your punch vs. the position of your punch. Do the same for your partner. What are the positions when each of you reaches maximum speed? Are they substantially different? Now, plot the speed of your punch vs. the position of your punch divided by the total length of the punch? What is different about this plot? Explain. Create the same plot for your lab partner. Now, do the maximum speeds occur at the same normalized position (or at least are they closer to the same)? In these final two plots you have performed a normalization to total strike length.

The second strike you should evaluate is called the hammer fist strike. In the hammer fist strike you clench your fist and raise it above and behind your head. Then you quickly swing the fist down in front of you in a similar motion to a smithy striking an anvil with his hammer. Most people can attain much higher speeds with this strike then with the forward punch and it will probably be the one you use to break the board.

3) Make another high-speed video of yourself executing the hammer fist strike. Make one of your partner also. What is the maximum speed your fist reaches? How much energy does your hand have at this speed? (If you are interested you could develop a similar analysis of this strike as you did of the forward punch.)

III. The Work Needed to Break a Board

In addition to knowing how much energy you can wield with you hands you need to know how much work it takes to break a board. The two sawhorses, dial indicator and load-bearing board will help you to measure this work.

1) Setup the two sawhorses so that their inner edges are about 26 cm apart, leaving about 1cm of board overlapping on each side. Place one of the clear (*i.e. knot free*) pieces of pine on the saw horses so that the grain of the board runs parallel to the length of the sawhorses. Place a rod over the center of the pine board and use the clamp and stand setup to place the dial indicator on the rod. Calibrate the dial indicator so that it reads zero, since the board has not been deflected yet. Now weigh the load-bearing board and hang it from the rod. In your calculations, don't forget to include the contribution of the load-bearing board to the work needed to break the board.

2) Now, you can measure the work needed to break the board. Load five kilograms onto the load-bearing board. The pine board will bend under the weight and the dial indicator will measure this deflection. The pine board does not stop bending immediately so wait for about three minutes and then mark down the deflection. Ideally you would wait until the pine board had completely stopped bending but this can actually take quite some time. Repeat these steps until the board breaks.

3) Note that when you add 5 kgs to the load-bearing board the pine board is deflected an amount Δx equal to the final reading of the dial indicator minus the initial reading of the dial indicator. During this time the force acting on the board is constant and equal to the total weight on the load-bearing board. Use these facts to calculate the total work. Illustrate this calculation graphically.

IV. Can You Break the Board?

In this section you will use the maximum velocity you obtained in the hammer fist strike to evaluate whether you can break a board. Because the dynamics of your hands interaction with the board is quite complex you should begin with a simplified model. Think of the board as floating in outer space unsupported, this allows you to ignore the effects of the sawhorses. Now, consider the situation, depicted below, in which your hand with mass M comes in with velocity v_o just below the velocity necessary to break the board and collides inelastically with the board. In this situation the kinetic energy that your hand loses results in two effects, the first is to accelerate the board up to its final velocity (*i.e.* give the board kinetic energy) and the second is to deform the board. If the energy that goes into deforming the board is greater than the work that it takes to break the board then the board will rupture into pieces.

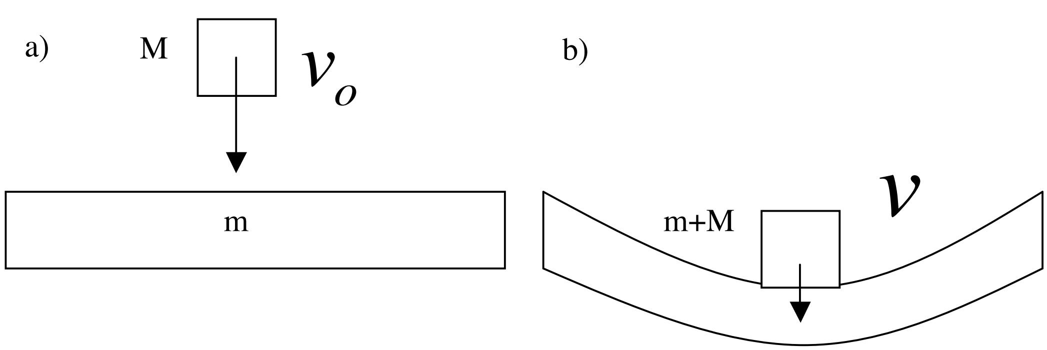

Figure 1. a) A mass M approaches a stationary board of mass m at velocity v_o.
b) The mass M inelastically collides with the board accelerating it to a velocity v and simultaneously deforming it.

1) Assume that the collision between the board and your hand is completely inelastic. Use conservation of momentum to find the speed v of your hand and the board after the collision in terms of v_o, M and m.

2) As has been emphasized in lecture, energy is always conserved but there are many forms that it can take on. Assuming that the only form of energy involved in this collision other than kinetic is the energy stored in the deformation of the board use the conservation of energy to determine how much energy went into the deformation of the board. [Answer: $E_{deform} = \frac{1}{2}\left(\frac{mM}{m+M}\right)v_o^2$]

3) Use the maximum velocity of your hammer fist strike that you found in II.5) to calculate how much energy you can put into the deformation of the board. Is this enough energy to break it? Note that the requirement for breaking the board is $E_{deform} \geq W_{break}$ (and not $KE_{hand} \geq W_{break}$) since only some of the energy of your hand goes to break the board.

Before breaking the board you have to evaluate whether you might be injured in this process. Research has shown that an impulse leading to a 900 N force for 0.006 seconds is enough to break a typical cheekbone.

4) If, as above, your hand makes an inelastic collision with the board resulting in a final velocity v, what is the momentum change of your hand?

5) Suppose you have a failure of nerve because you are afraid of hurting yourself so your hand slows down to a speed just below that which you need to break the board. Assume that in this case the board brings your hand to a complete stop. Calculate the momentum change of your hand.

6) Suppose that your hand is in contact with the board for about 6 ms (see [2]). Using the results of 4) and 5) what is the maximum force your hand can feel if you break the board? If you just barely fail to break the board?

7) If the injury you sustain is a function of the maximum force on your hand and if you know theoretically that you can break the board, what is the consequence of having a failure of nerve and slowing down your hand in mid-hit? Are you more likely to be injured or less likely to be injured? Why?

Now, that you have all of the relevant information you should show your calculations to the head lab instructor and he'll confirm that you can break a board. If you would like to try it, go ahead and setup the sawhorses again and put a piece of pine on them. Be sure to hit along the grain of the wood. Wood is ten times stronger against the grain and hitting it this way could result in serious injury.

V. Some Possible Extensions

Here are some further ideas that you could investigate experimentally: I) See references [1] and [2] for derivations of the deformation energy involved in these collisions. You could use the high-speed camera to take video of your partner smashing a board and determine to what degree the collision really was inelastic.

II) If you can find some dry semi-thin cinder block you could measure the work needed to break it and show that you would be unable to break it.

III) References [1] and [2] also have some more involved theoretical models that are very interesting.

[1] Walker, J. D. "Karate Strikes," AJP Vol. 43, 10, Oct. 1975
[2] Feld, M. S. *et. al*. "The Physics of Karate," *Scientific American*, pp. 150-158, April 1979.