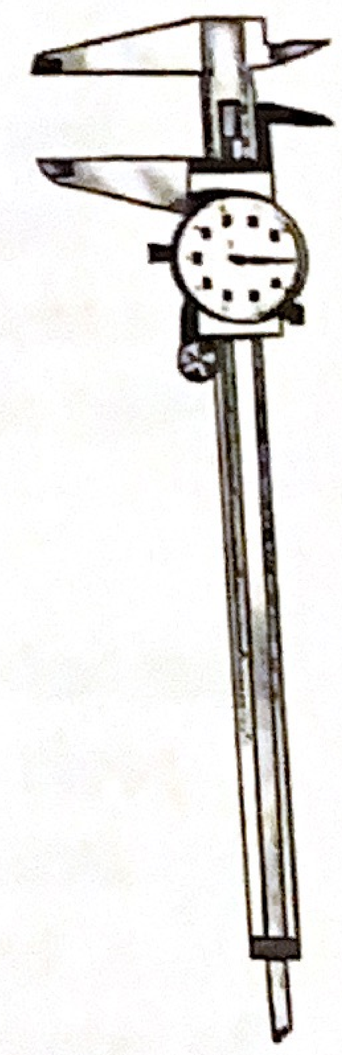
Measuring Your Block Work together as a team to measure the **width** of your aluminum block with a dial caliper; this dimension is nominally two inches. Approximate your readings to 20% of the smallest increment marked on the dial caliper.

Repeat the measurement six independent times and enter your nominal readings in the table below. Each person on your team should take at least one reading. Because the goal of this exercise is to estimate the repeatability of a dial caliper measurement, you should not record an uncertainty for these measurements.

i	W_i (in)
1	2.0384 in
2	2.0212 in
3	2.0182 in
4	2.0190 in
5	2.0168 in
6	2.0330 in



1. One benefit to repeating a measurement is that it allows you to detect measurement blunders. These are individual values that do not agree with the rest of the data due to a mistake, typically from reading the instrument incorrectly. Does your data set appear to include any measurement blunders? What caused them? Cross out any measurements that you are confident stemmed from blunders write an explanatory note in the margin.

No measurement blunders are apparent in our data

2. Look at your measurements in the table above, and guess their mean and standard deviation. After recording your guesses, do the actual calculations and write them down as well.

Guesses

Mean: 2.0250 in

Std Dev: 0.005 in

Calculated

Mean: 2.024 in

Std Dev: 0.008 in

3. Measuring instruments with analog (rather than digital) displays are often said to provide an uncertainty of 20% of the least count, where the least count is the smallest marked subdivision. How does the standard deviation of your sample compare with this standard estimate of uncertainty? If the two values are not similar, suggest an explanation for the difference.

Std Dev > Uncertainty

It could be because we're not familiar with how to use a caliper. We also kept changing who used it, so that is also a variable.

How to Record Measurements Because no measuring tool or method is perfect, scientists and engineers often record the **uncertainty** (also called **error**) that is associated with each of their nominal measurements. In this class you should express the uncertainty in your measurement by recording your estimate in the format , where indicates the nominal value and indicates the half-width of the region in which you believe the real measurement lies.

In other words, you should record your best estimate of the measurement as , recognizing that the actual dimension is almost certainly not equal to . The actual dimension is probably quite close to , and you indicate how close by the value you record for . If we assume that measurements have a normal (Gaussian, bell-shaped) distribution around the true dimension, as illustrated above, you should select so that you are about 68% confident that the measurement is within of the real value, so that is the standard deviation of the measurement's probability distribution.

You should include **units** on both the nominal measurement and the uncertainty to avoid confusion. For example, it might be convenient to give the nominal measurement in one unit and the uncertainty in another. **A measurement is useless if its units are not specified.**

For example, if you were to measure the thickness of your aluminum block with just your eyes, you might write down the following:

On the other hand, you would be able to record a more precise nominal value and a smaller uncertainty if you were using a **micrometer** (a measuring tool based on a calibrated screw). A good micrometer measurement of the block thickness might be the following:

Keep in mind that precision is just one way of evaluating a measuring tool. When choosing a tool, you also need to think about the accuracy, speed, cost, and availability of each option.

Note that significant figure conventions are sometimes used as an alternative for the method of recording measurements. We record uncertainty in this class because it is both clearer and more flexible.

Activity 1.2: Propagating Measurement Uncertainty

4. Use the dial caliper to measure the **thickness** of your aluminum block. Write this measurement below in form, using an uncertainty that you think is reasonable for the dial caliper. Then show all the steps needed to **convert** this measurement from inches to millimeters. Note that 1 inch equals exactly 2.54 centimeters. Box your answer.

Inches	×2.54 = cm	×10 = mm
0.8890	2.26	22.6 ± 0.00508
0.8868	2.25	22.5 ± 0.00508
0.8970	2.28	22.8 ± 0.00508

Uncertainty = 0.0002 × 25.4

from caliper

conversion in -> mm

Avg = 0.891 in

Avg = $\boxed{22.6 \text{ mm}}$

5. Use the dial caliper measurements you made above to compute the **cross-sectional area** (width x thickness) of your block in square inches, also calculating the uncertainty associated with this calculation. Box your answer.

$$A = wt = 2.024 \times 0.891 = 1.803 \text{ in}^2$$

$$\Delta y = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i}\right)^2 \Delta x_i^2}$$

$$= \sqrt{t^2(0.0002)^2 + w^2(0.0002)^2} = 0.0004423 \text{ in}^2$$

$$\Rightarrow \boxed{1.803 \text{ in}^2 \pm 0.0004423 \text{ in}^2}$$

Activity 2.2: Estimating Object Speed from a Movie

A video camera can record the position of an object over time, but we often want to know the object's speed as well. This activity gives you the opportunity to estimate object speed from a movie in one way and also think of a second way to make the same calculation.

The teaching team used the motion-capture system to record a movie of a practice golf ball swinging back and forth on a string, so that it acts like a **pendulum**. To ensure good visibility, the ball is white, and the background is black. In future labs, you will be recording your own movies of a wide variety of motions.

Video

The video file is located on canvas under this assignment. Open it with QuickTime or VLC Player.

Watch the whole movie several times to become familiar with the type of motion that was captured. You can also stop the movie to examine individual frames as needed; the left and right arrow keys on the keyboard step the movie frame by frame.

This movie was recorded at a frame rate of 60 FPS. Because its digital electronics are very precise, you may assume that the camera's frame rate is exact.

Alternatively, you may find it easier to use MATLAB to analyze your video. You may find implay, VideoReader, image, and/or the Data Cursor tool useful. These can all be searched for online and/or on the MATLAB docs.

6. Use measurements of the ball's position in **two successive movie frames**, plus any other information you need, to estimate the ball's **maximum horizontal speed** in real physical space. Provide your answer in **meters per second**, and ignore uncertainty for the moment. Work with your teammates, show all of your steps, and box your answer.

	Pixels in F1	Pixels in F2
L	(302, 141)	(308, 139)
R	(332, 141)	(338, 139)
C	(317, 141)	(323, 139)

Distance traveled in px := d_{px}

$$\sqrt{(317-323)^2+(141-139)^2} = 6.325px$$

Ball diameter = 30px = 4cm = 0.04m

$$d_m = 6.325px \times \frac{0.04m}{30px} = 0.0084m$$

$$t = \frac{1}{60} = 0.0167s$$

$$\Rightarrow v = \frac{d_m}{t} = \frac{0.0084}{0.0167} = \boxed{0.506m/s}$$

7. Look over your calculation from the previous question and notice that your ball speed estimate was calculated from several uncertain measurements. Calculate the **uncertainty** associated with your above estimate of maximum ball speed, using the uncertainties associated with each measurement by following the rules presented above. Work with your teammates, show all of your steps, and box your answer.

30px = 0.04m

Uncertainty from Blur → $\text{blur} = 3\text{px} \times \frac{0.04\text{m}}{30\text{px}} = 0.004\text{m}$

$\boxed{\text{Uncertainty} = \pm 0.004\text{m}}$

8. Briefly explain a way that you could estimate maximum ball speed using measurements from just **one movie frame**. You do not need to do this calculation, but you should talk with your teammates to make sure you understand how it could be done. You do not need to worry about uncertainty for this question. Ask the teaching team for help if you get stuck.

$mgh = \frac{1}{2}mv^2$

PE @ highest point = KE @ lowest (fastest) point

- Use the frame where the ball is at its highest

Now that you've seen the basics, spend several minutes **playing around with MATLAB,** working together with your teammates. Try some of the above commands, and ask for help from the teaching team if you have questions. Try to get an error message, and then try to interpret it.

9. Which MATLAB function can compute the **standard deviation** of a vector? If you have time, use this function to check your standard deviation calculation from the start of this lab.

   std(A, w, vecdim)

Activity 3.2: Plotting "PENN" in MATLAB

For the final activity of this lab, you will use MATLAB to make a nice plot. Graphing data is a very common task in science and engineering, and it is useful to know how to do this quickly and well. Here is a quick summary of how to create plots in MATLAB.

The main MATLAB command for making plots is **plot**. As explained at the start of its help file, which you should read, calling plot(x,y) will plot vector y against vector x. The two vectors need to have the same number of elements. The first vector will be used along the horizontal axis, and the second along the vertical.

Issuing a plot command will open a **new figure window** if none exist yet, or it will plot in the active window if one or many figure windows are already open.

Here is a sample set of commands, enter them into your command window to see what they plot.

```
>> mx = [1 1 1.5 2 2];
>> my = [1 3 2 3 1];
>> plot(mx,my,'mo-')
>> axis([0 3 -1 5])
```

The **semicolon** (;) at the end of the variable creation lines suppresses MATLAB's output, so that it does not confirm each entry. This is useful for keeping your command window clean.

The short string 'mo-' passed as the third argument to the plot command specifies the **graphical appearance** of the plotted data. The above set of parameters creates a magenta-colored line with circles at each data point.

Typing the command plot(mx,my,'g*') graphs the same data with green star markers at the data points and no line connecting them, as shown at right. The help file for the plot command lists all of the possible formatting commands.

The axis command sets the **minimum and maximum values** that should be shown on the x- and y-axes. Use the help function to learn about its details.

As listed at the bottom of the plot command's help, the commands title, xlabel, and ylabel let you modify existing plots by adding a **title, x-axis label**, and **y-axis label**. Many more sophisticated