

The Effects of “Tilt” on Lab 2

After reading through the procedure for Lab 2, we should consider the physical consequences of the experiment with regards to what we were trying to measure. This specifically includes the properties and “dropping technique” of the Plexiglas “picket fence”.

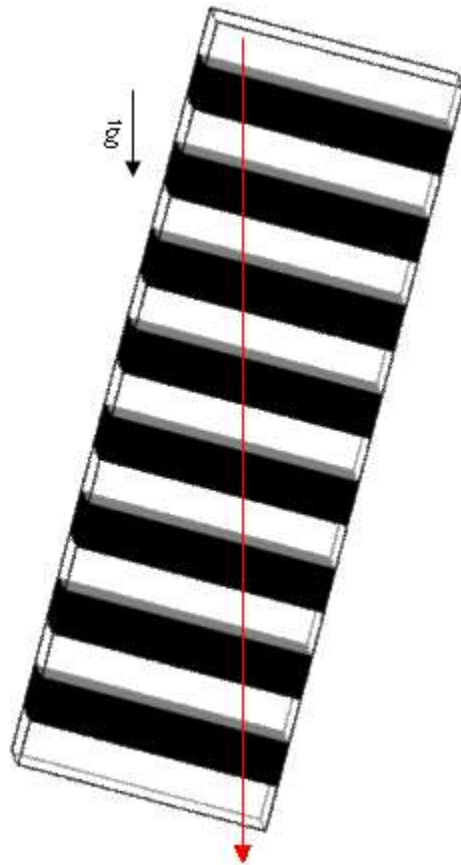
Experiment 2 will involve dropping the picket fence through a photogate into a box of paper padding. A representation of the picket fence is shown in the figure below.

Figure 1: Picket Fence used in Lab 2



Notice, that if you hold the picket fence “off center” at the top, you can see that a line connecting our contact point to the center of mass is always parallel to the acceleration due to gravity vector. The angle between the edge of the picket fence and the acceleration due to gravity vector is defined to be θ .

Figure 2: Picket Fence with “tilt” – Theta = -15°



The angle Theta is called “tilt” or “sideslip” and has a major impact on our data. (The figure above is of course greatly exaggerated, since realistically your hold point of the picket fence will not be as drastically off from the center point. However, the same effects are always present – unless the contact point is directly in line with the center of mass and the acceleration due to gravity vector.)

Tilt has the following effects on our data collection process:

- Creating simple harmonic motion.
- Pseudo-lengthening the effective width of the shaded bar areas.

Each of these effects is described in more detail below.

Creating simple harmonic motion

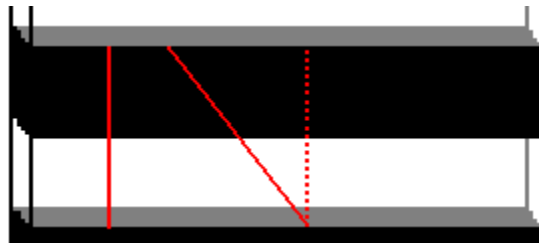
Once the picket fence with “tilt” is released, due to air resistance and the fact that gravity is not “constant” over relative distances, there will be an inherent “torque” on the system. This will cause the picket fence to want to rotate about its center of mass – in attempt to return the tilt to zero. Once the tilt is reduced to zero, the torque has then created an angular momentum and the rotation of the picket fence will “overshoot” the zero tilt, giving the picket fence another tilt with the sign reversed. [That is: in the image above,

the tilt is a negative 15 degrees. If there were no air resistance and no collision point below the picket fence, after enough time the tilt would be reversed to a positive 15 degrees. This swinging back and forth effect is called simple harmonic motion. It is equivalent to the motion of a block on a spring or a marble in a smooth bowl. Simple harmonic motion due to torque has the effect of changing the tilt of an object, which in turn changes the pseudo-length of the shaded bar areas. The smaller the initial tilt, the less effect simple harmonic motion will have.

Pseudo-lengthening the effective width of the bar regions

If we consider just a single clear/black band, there exists a minimum length measurement that can be obtained by using a ruler. If we apply a tilt to the ruler while making this measurement, we can see that the effective “length” of the bands changes (increases based on the amount of tilt applied to the ruler). [Tilting the ruler is analogous to dropping the picket fence with an inherent tilt.]

Figure 3: Relative lengths with tilt = 0° and tilt -15°

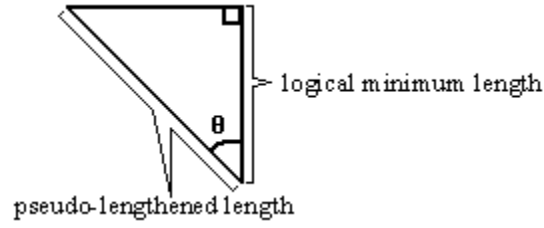


Of course, we would never measure the length of the bands using a tilted ruler, because we have always been taught that the length of something is the *logical minimum* distance from one point to another point. However, the computer’s Lab Pro software is not “smart” enough to know the amount of tilt on the picket fence – so in turn does not know if it is measuring the logical minimum distance. All the computer’s software knows is if the photogate is blocked or not.

It is fairly easy to mathematically show the amount by which the actual logical minimum length is pseudo-lengthened due to the tilt (we say *pseudo-lengthened* since there is not an actual lengthening occurring – just a “tricking” of the computer as explained above).

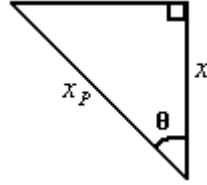
Consider a triangle with one edge being the logical minimum length and the hypotenuse being the pseudo-lengthened length. Compare this to figure 3.

Figure 4: Triangle Created from Logical Minimum Length and Pseudo-length Created from a Tilt of Theta



It is obvious from the above figure that the pseudo-length will *always* be larger than the logical minimum length. This is true regardless of the sign of theta. For sake of simplicity, let us call the logical minimum length x , and the pseudo-lengthened length x_p .

Figure 5: Triangle to Calculate the Extended Pseudo-length Created from a Tilt of Theta



From simple trigonometry, we can see the following:

$$\cos(\theta) = \frac{x}{x_p}$$

Solving this for x_p :

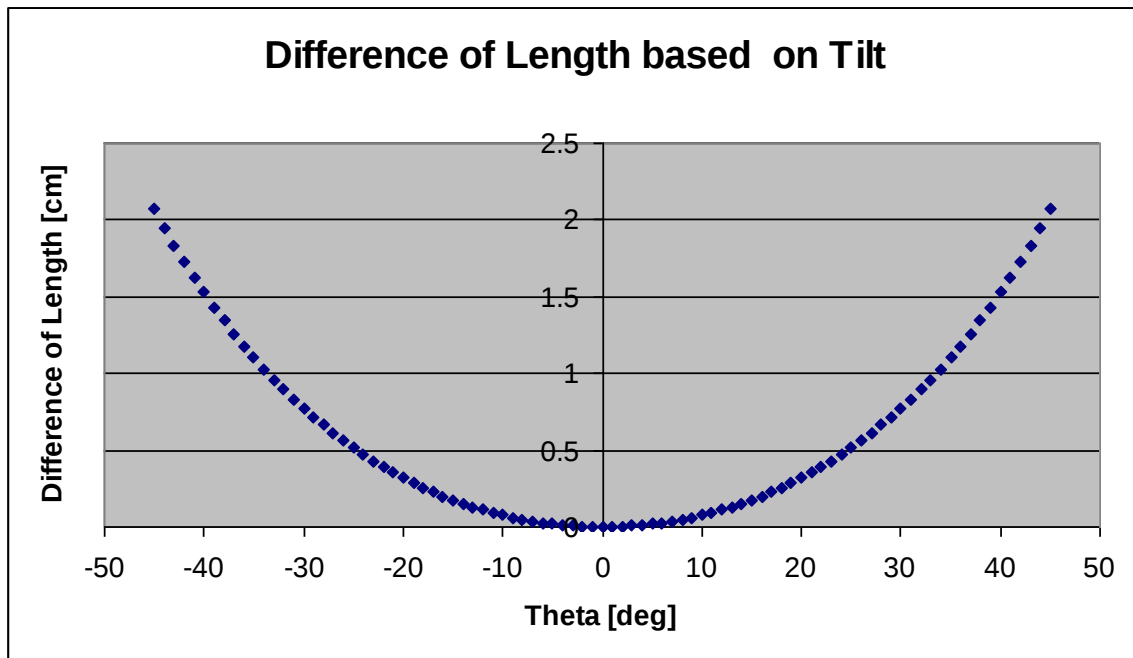
$$x_p = \frac{x}{\cos(\theta)}$$

Let us define the difference between the pseudo-lengthened length and the logical minimum length to be Δx . This value is how much longer the logical minimum length appears to the computer.

$$\Delta x = x_p - x = \frac{x}{\cos(\theta)} - x$$

$$\Delta x = x \left(\frac{1}{\cos(\theta)} - 1 \right)$$

If we create a plot of this graph, we can use it to determine the “level of acceptance” of tilt. This graph is shown below for the range of $-45^\circ \leq \theta \leq 45^\circ$.



It is easy to see that the relative difference of length is very nearly zero on the range of $-5^\circ \leq \theta \leq 5^\circ$. So as long as the tilt is kept within this range, the error associated with tilt can be kept to a minimum.

To improve the “quality” of our data, we attempted to minimize the tilt of the picket fence by holding the picket fence very nearly the center of the top. It is important to note that by performing the experiment three times, the averaging calculations performed later in the lab will slightly help to eliminate random error.

To completely eliminate tilt and its effects, we would have to perform a very thorough calculation of the center of mass for the picket fence and use clear marking to specify where exactly to hold the picket fence for it to be aligned exactly parallel to the acceleration due to gravity vector. (Of course this is way beyond the expectation of this lab.)

It is important to note that we performed the above analysis for only one dimension of our relative coordinate axis. There could be similar effect if we viewed the picket fence from the side or the top. That is to say, for a side view - if the top edge and bottom edge of the picket fence are not directly aligned with the acceleration due to gravity vector, there could be another torque acting on the system creating simple harmonic motion. This is called “angle of attack” The effects due to “roll” (where either the left side or right side of the picket fence are turned) have very nearly zero effect. The minimized effects of “roll” are due to the fact that there is no acceleration in the x-direction. Reconsider the kinematic equations in 3D and compare tilt, angle of attack and roll.