
ME 322
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<names>

Abstract:

The goal of this experiment was to determine the logarithmic decrement and the natural frequency of a traditional bow. Two cases were considered: The case where an arrow was fired and the case where no arrow was fired (also known as a "dry fire"). A high speed camera recording at 240 frames per second was used to record the bow firing. Bow limb position data as a function of time was extracted from the video file using an image analysis program (ImageJ) and Scilab. The logarithmic decrement was calculated using Excel while a Scilab script was used to plot a Fourier power spectrum to determine the natural frequencies.

Experimental Setup:

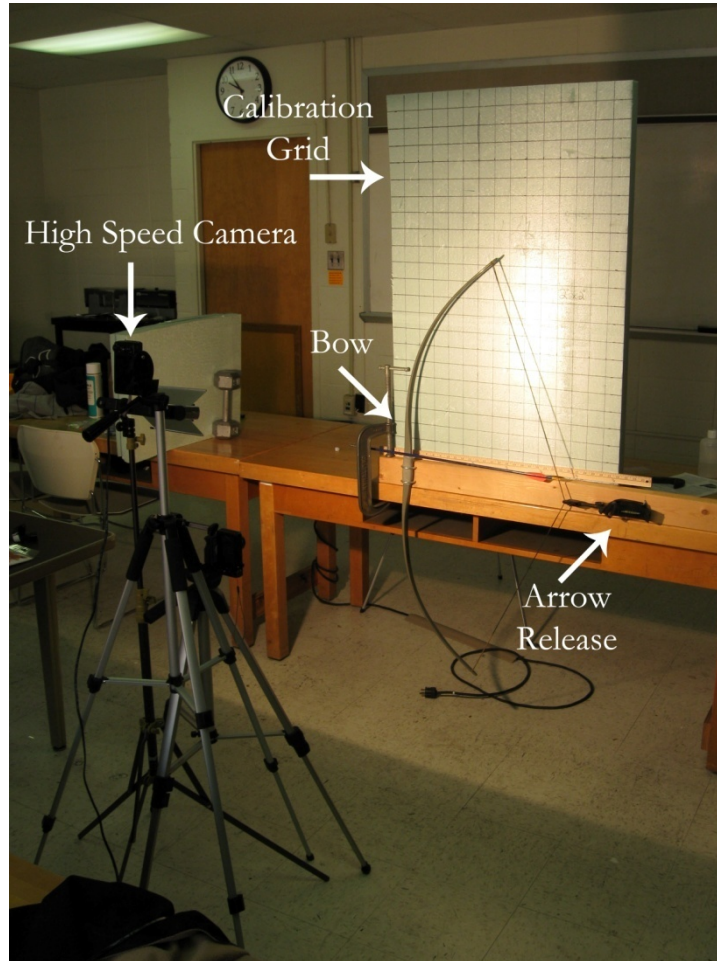


Figure 1: Experimental Setup

Testing equipment was set up as indicated in Figure 1. The test bow was a fiberglass bow with a 25 pound, 30 inch draw. A bow holder was constructed to hold the bow perpendicular to the floor. This holder was clamped to the bench for stability. A TruFire arrow release was used to hold the bow at a consistent draw length of 14.25 inches. This draw length is about half of the full draw of the bow. A Casio Exilim series camera recording at 240 frames per second was used to capture a video of the bow when fired. Two inch gridlines on a foam background were used for calibration of the image. The experiment was conducted for the bow firing a standard target arrow and for a dry fire.

Method of Analysis:

Two programs were used to analyze the data for this experiment. The first one was ImageJ, a free image analysis software while the second program was Scilab, an open source program comparable to Matlab. Before the analysis began, the high speed video was converted to a sequence of TIFF images like the one in Figure 2 below.

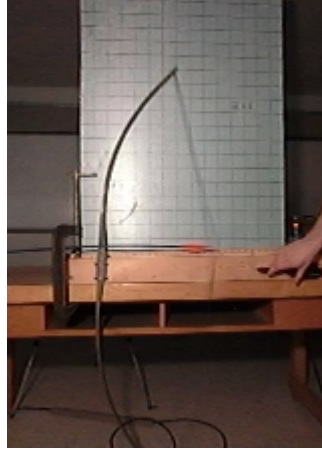


Figure 2: Original Image

The series of TIFF images was opened as a stack in ImageJ. The images were cropped to only show the upper half of the bow then were scaled up to increase their resolution. After the scaling, the two inch grid lines were used to calibrate the pixel distances to actual inch distances. An example of the cropped, scaled image is in Figure 3 below.



Figure 3: Cropped Scaled Image

The scaled images were then converted to 8 bit grayscale images. A threshold command was used to convert the grayscale images into a binary image. This essentially removed the background and made tracking possible. An example of a binary image is in Figure 4 below.



Figure 4: Binary Bow

The position of the bow limb was tracked across the horizontal lines indicated in Figure 5.

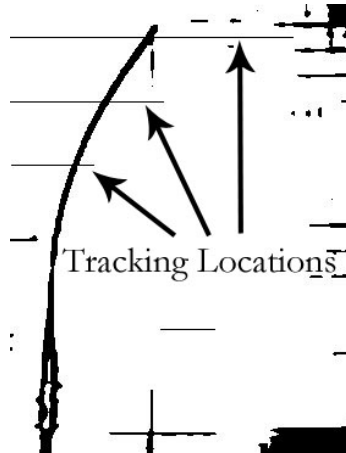


Figure 5: Tracking Locations

This was accomplished using a "Plot Profile" command. This command plotted the gray values of the image along the line. Because the image was properly calibrated to the known scale, this profile plot tracked the distance in inches the bow limb was along the line. Macro code found online (Appendix A) was used to plot the profile for each image in the image sequence. The result of this plot was a large array (approximately 250x1200) saved as a .csv file. This same procedure was repeated on the dry fired bow images.

Conditioning of the ImageJ data was accomplished by writing a script in Scilab (Appendix B). The net result of the script was the creation of a data file that recorded the position of the bow limb along the tracking lines as a function of time as well as a plot of this data. A characteristic plot is in Figure 6 below. The script was run for each tracking location on the bow with arrow and the dry fired bow.

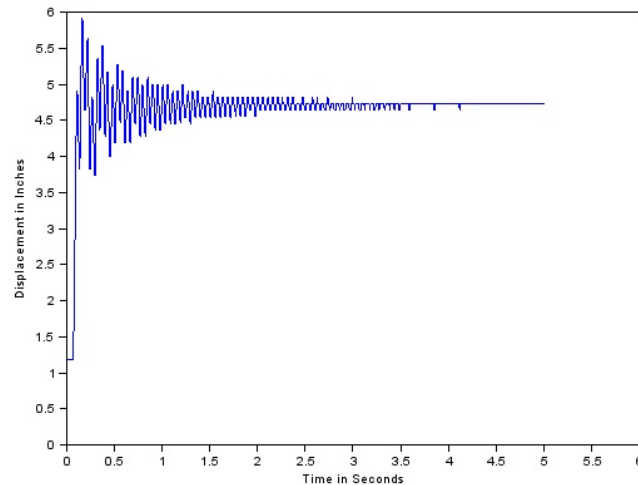


Figure 6: Scilab Plot

Microsoft Excel was used for subsequent analysis in determining the logarithmic decrement and the damping ratio of the bow.

Experimental Data:

Figures 8-10 below are plots of the bow limb position as a function of time. Figure 7 below indicates where the measurements were taken relative to the upright bow.

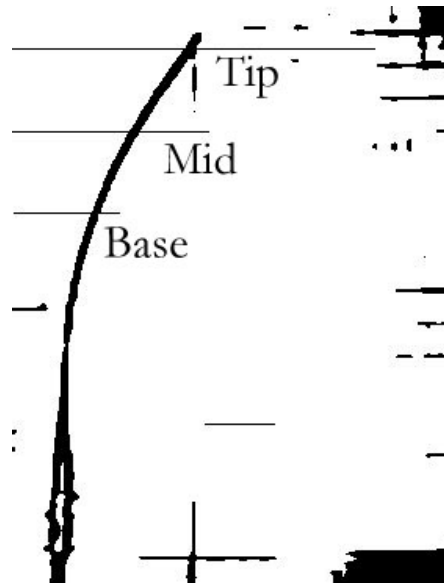


Figure 7: Measurement Locations for Bow Firing an Arrow.

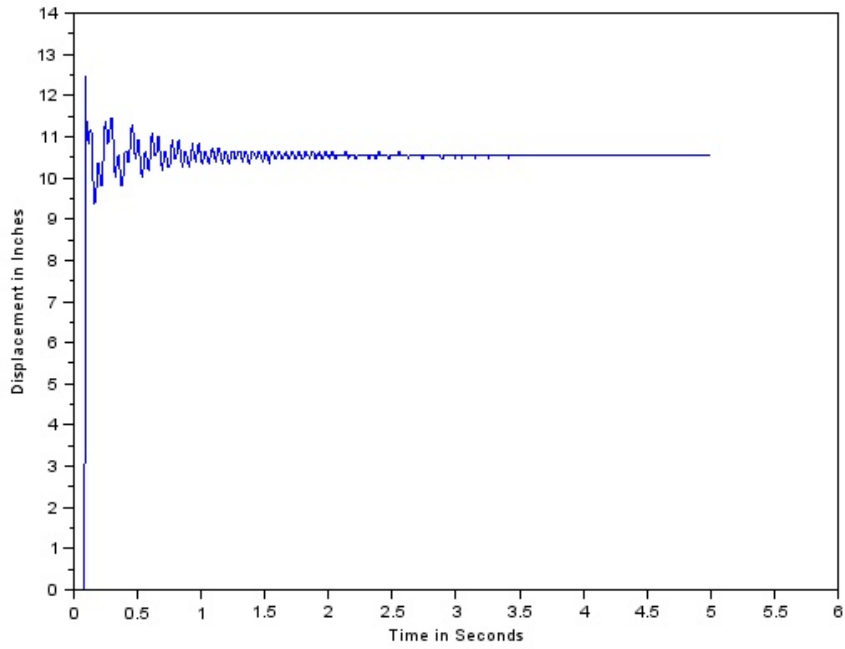


Figure 8: Bow Fired with Arrow: Tip

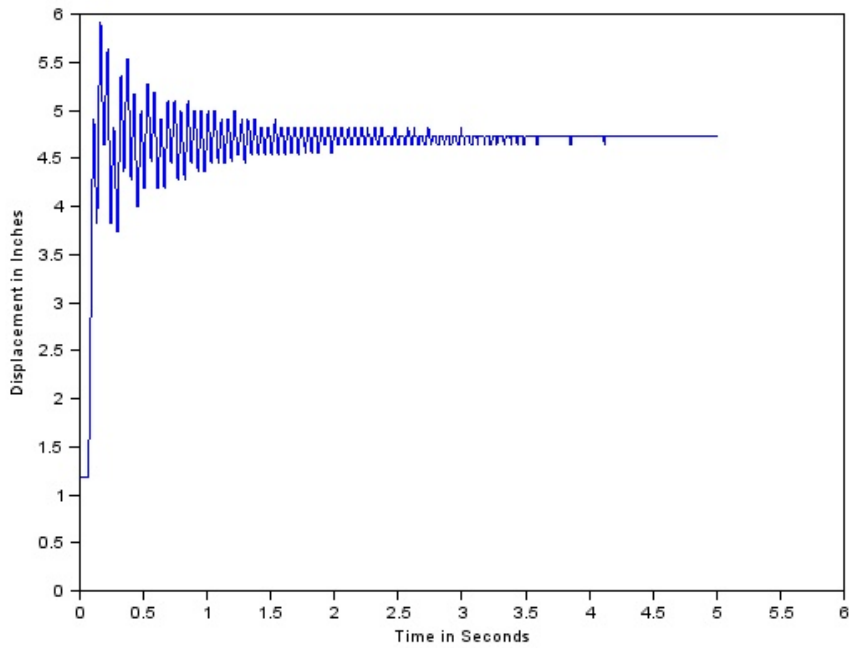


Figure 9: Bow Fired with Arrow: Mid

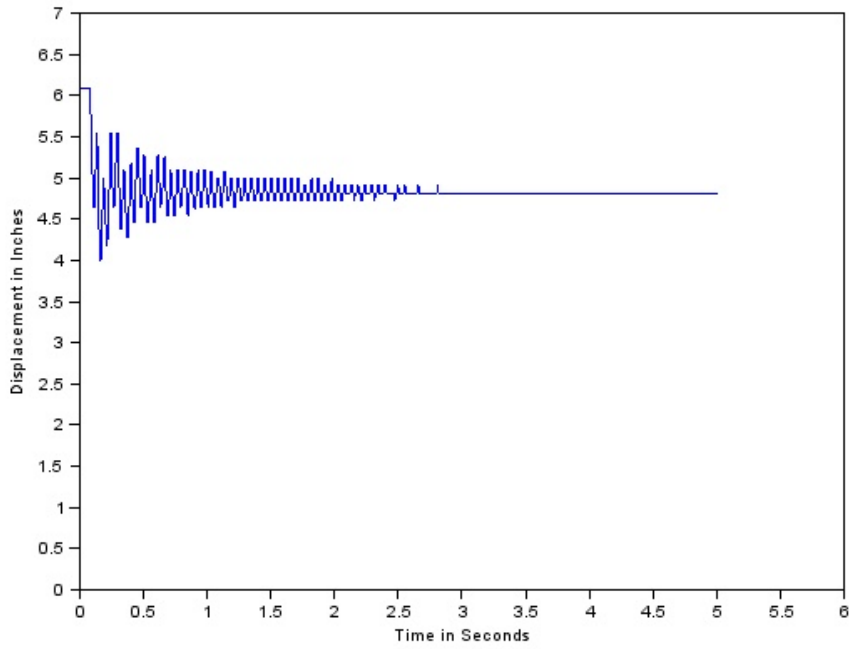


Figure 10: Bow Fired with Arrow: Base
 This was repeated for a bow fired without an arrow (a "dry fired bow").

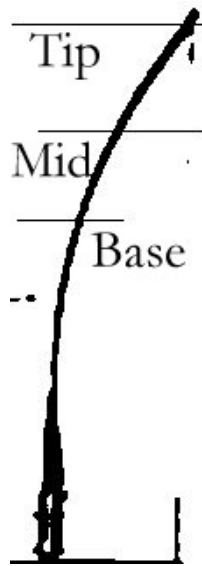


Figure 11: Measurement Locations for a Dry Fired Bow

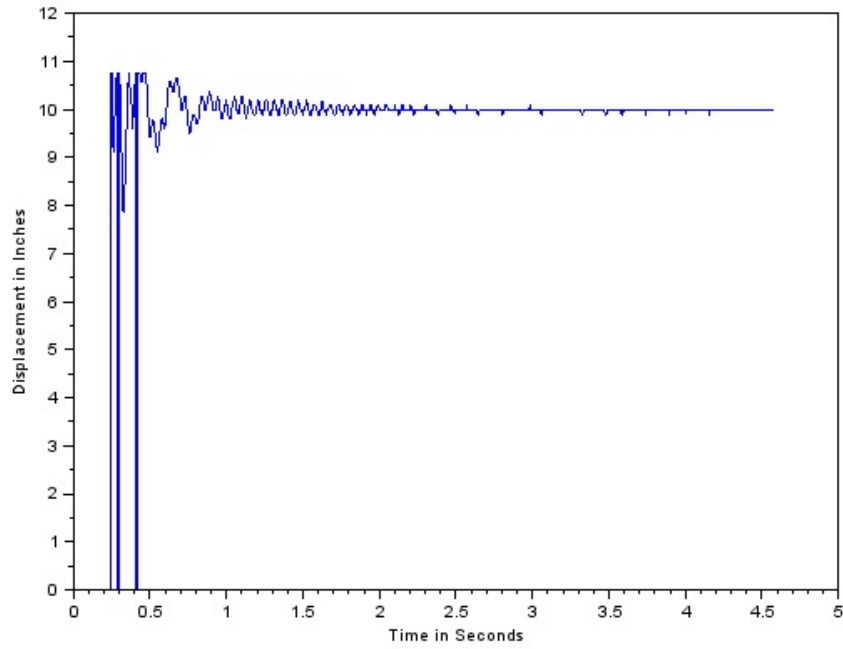


Figure 12: Dry Fired Bow: Tip

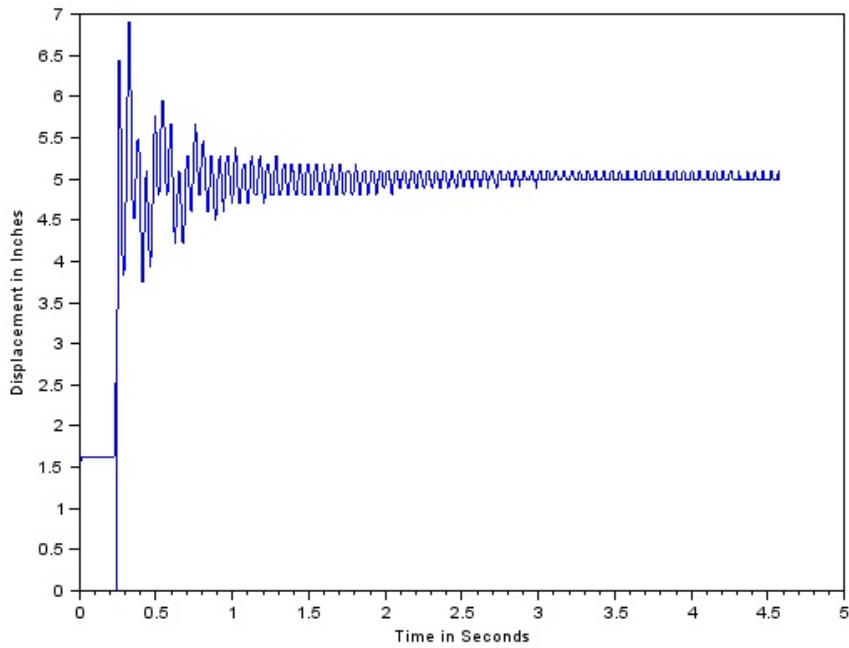


Figure 13: Dry Fired Bow: Mid

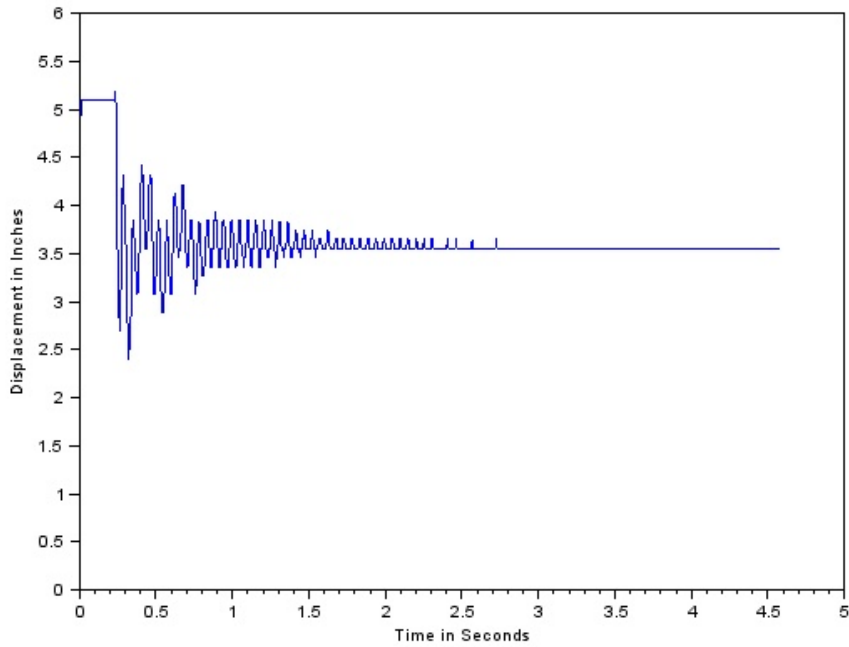


Figure 14: Dry Fired Bow: Base

Results and Analysis:

The zero displacement visible in Figures 8, 12, and 13 is due to issues in the data. The bow limbs did not have that great of a displacement. A comparison between Figures 9 and 12 demonstrate how the arrow fired bow damped out faster than the dry fired bow. This was due to the bow transferring energy to the arrow. In the dry fire case all energy was transferred to the bow limbs which caused greater amplitude oscillations. Bow manufacturers warn archers to never dry fire bows and these figures support this warning.

The data was exported to Microsoft Excel for some quantitative analysis. The logarithmic decrement was recorded for each case by noting the position and time of each positive peak, and adding a linear regression through these points. Generally, five to seven peaks were recorded in each case. Only the base data was analyzed for each firing case as it was thought to better represent the behavior of the bow. Only significant peaks were recorded to avoid confusing noise with legitimate data. The logarithmic decrement is summarized in Figure 15 below.

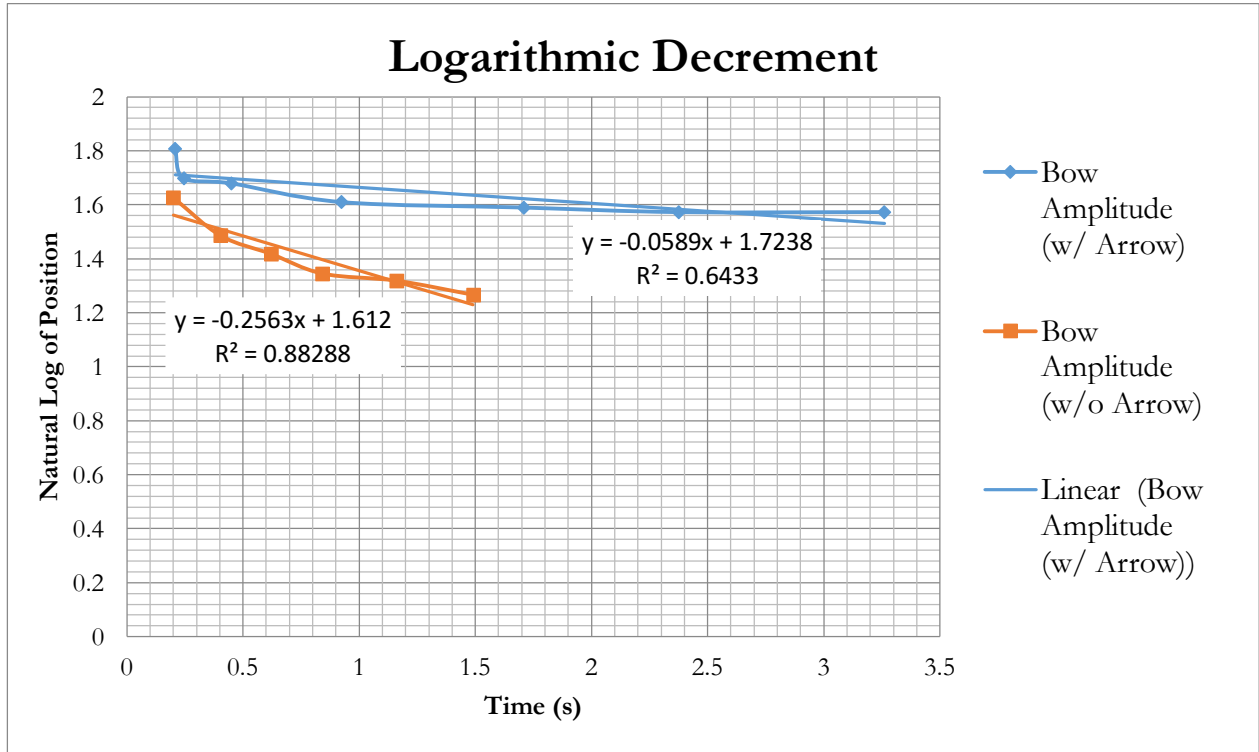


Figure 15: Logarithmic Decrement

The logarithmic decrement represents the $-\zeta\omega_n$ term in the differential equation. Assuming the natural frequency of the bow is constant (supported by Figures 16 and 17), the damping ratio was actually greater for the dry fired bow than the bow firing an arrow.

In addition to the logarithmic decrement, the natural frequencies of the bow was determined using a Fourier transform. A script (Appendix C) was used to create the plots for Figures 16 and 17. Once again, only the base data was analyzed because it seemed to provide the least noisy signal.

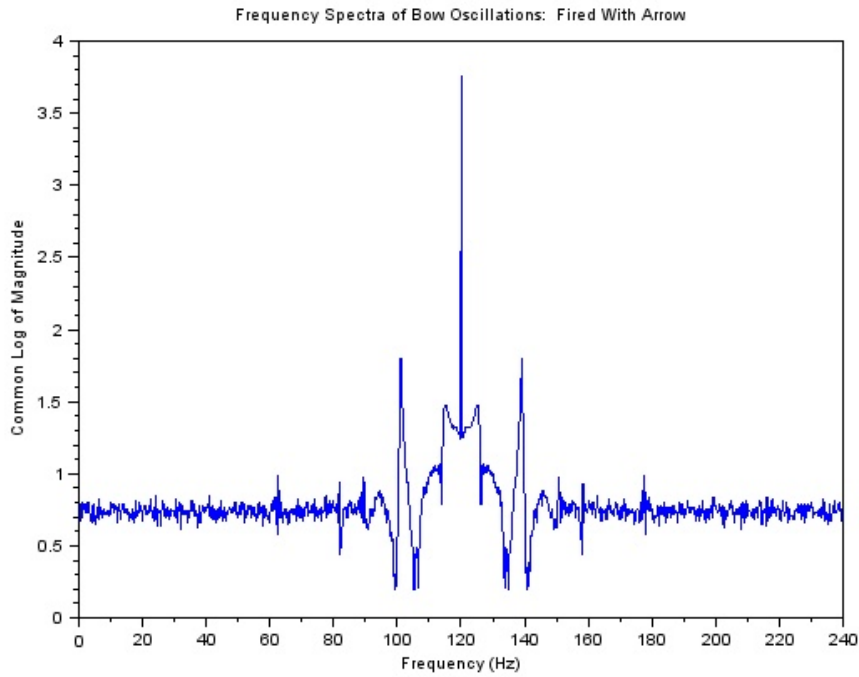


Figure 16: Frequency Spectra (Base) of Bow Fired with Arrow

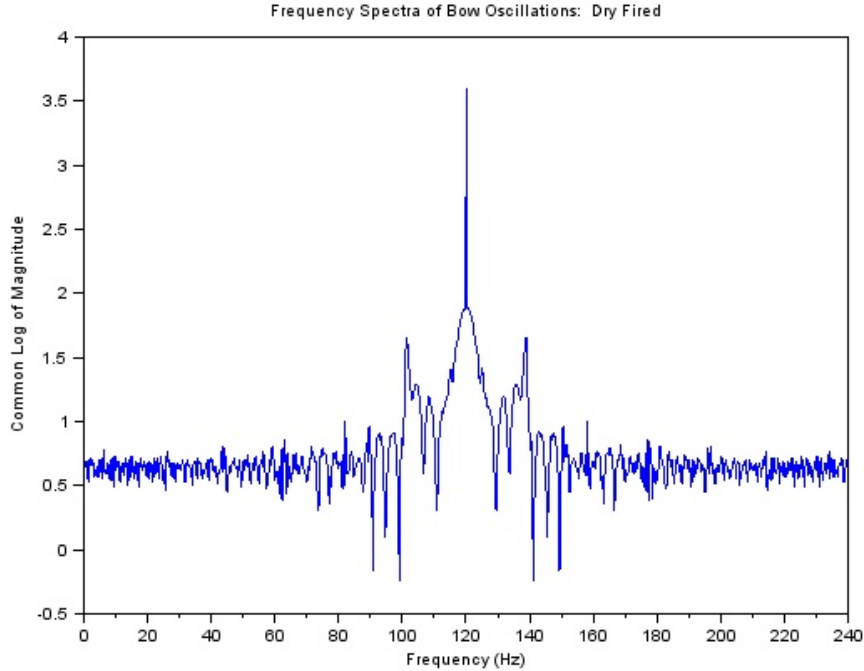


Figure 17: Frequency Spectra (Base) of Dry Fired Bow

This analysis indicates both the arrow fired and dry fired bow have peaks at 120 Hz, 100, Hz, and 140 Hz. The dry-fired bow has additional peaks between 100 Hz and 120 Hz and 120Hz

and 140 Hz. Unsurprisingly, the natural frequency of the bow did not depend on whether or not an arrow was fired.

Conclusion:

The analysis above indicates the bow behaves like an underdamped spring mass system. The degree to which the system is dampened depends on numerous factors including weight, size, material, and in this case, the firing of an arrow. When the bow is dry fired the dampening is surprisingly more than when an arrow is fired. The oscillation of the bow limbs was much greater for the dry fire than the arrow fire. This was because energy was transferred to the arrow rather than staying in the limbs of the bow.

[Note: Each appendix was on a separate page in the original document.]

Appendix A: ImageJ Plot Profile Macro Code

```
// StackProfileData
// This ImageJ macro gets the profile of all slices in a stack
// and writes the data to the Results table, one column per slice.
// Version 1.0, 24-Sep-2010 <name>
macro "Stack profile Data" {
if (!(selectionType==0 || selectionType==5 || selectionType==6))
exit("Line or Rectangle Selection Required");
setBatchMode(true);
run("Plot Profile");
Plot.getValues(x, y);
run("Clear Results");
for (i=0; i<x.length; i++)
setResult("x", i, x[i]);
close();
n = nSlices;
for (slice=1; slice<=n; slice++) {
showProgress(slice, n);
setSlice(slice);
profile = getProfile();
sliceLabel = toString(slice);
sliceData = split(getMetadata("Label"), "\n");
if (sliceData.length>0) {
line0 = sliceData[0];
if (lengthOf(sliceLabel) > 0)
sliceLabel = sliceLabel+ " (" + line0 + ")";
}
for (i=0; i<profile.length; i++)
setResult(sliceLabel, i, profile[i]);
}
setBatchMode(false);
updateResults;
}
```

Appendix B: Scilab Data Conditioning Script

```
//This script is designed to condition the data from ImageJ
clear
clc
clf
AnalyzeCount=0
tempmatrix=csvRead('Results.xls',ascii(9))//Read File
Rows=size(tempmatrix,1)//Rows
Columns=size(tempmatrix,2)//Columns
while AnalyzeCount<Columns-1
AnalyzeCount=AnalyzeCount+1
k=0
bowx=[0]
while k<Rows//Looks at the matrix rows
k=k+1
if tempmatrix(k,AnalyzeCount+1)>100 then bowx=tempmatrix(k,2)
end
end
if length(bowx)>0 then BowCoordinate(AnalyzeCount)=sum(bowx)/length(bowx)
else BowCoordinate(AnalyzeCount)=0
end
end
time=1:Columns-1;
plot(time./240,BowCoordinate)
xlabel('Time in Seconds')
ylabel('Displacement in Inches')
```

Appendix C: Fourier Transform Code

```
//Fourier Analysis Code
clear
clc
clf
y=[];
samplerate=240; //Sample Rate per Second
Data=csvRead('BowLocation.csv');
for i=1:size(Data,1)
y(i)=Data(i,2)
end
fouriertransform=fftshift(fft(y));
n=1:size(Data,1);
magnitude=log10(abs(fouriertransform))
frequency=n*(samplerate/size(Data,1))
plot(frequency,magnitude)
title('Frequency Spectra of Bow Oscillations')
ylabel('Common Log of Magnitude')
xlabel('Frequency (Hz)')
```

Comments:

This is a nice report overall, but there are some issues which are a bit problematic.

1. The Abstract is used as if it is also an Introduction section. An Abstract is not part of the report body. The report should be complete without the abstract. That's not the case here. If you start reading the report starting immediately after the abstract, you don't understand what it is all about. An abstract is a short summary of the whole paper that stands independently. It is normally formatted differently, often in a bold font. The abstract normally includes a brief qualitative summary of results. An introduction normally gives a much more detailed background and motivation for the laboratory exercise.
2. This characterization exercise is described as an "experiment", which isn't quite the case because there is no hypothesis that is being tested. The term "experiment" is sometimes used for an open ended exercise with no hypothesis when some unknown is to be determined, but this exercise is more properly a characterization.
3. Figure 1 should follow the callout rather than precede it.
4. No reference or source is given in the "Experimental Setup" section for the arrow and camera particulars, which might have been helpful. ("Procedure" probably would have been a better title for this section, since it addresses more than just the apparatus, but also how it was used.)
5. The labeling (axis labels, numbers) for Figure 6 are too small. Those for Figures 8-10 and 12-14 are marginal: larger would be better.
6. Figure 15 should not have a title at the top as well as the bottom, and should not be boxed. No units are given for position. The correlation expressions shown on the graph are never mentioned, and should be omitted unless explicitly discussed. No legend is given for "Linear Bow Amplitude w/o [without] arrow."
7. There is a good bit of blank space at the bottom of many pages. On the other hand, spaces between figure titles and the following text, and between the text and a following figure, are highly desirable. Some engineering of the layout might have allowed a more easily readable paper and perhaps squeezed the length down by a page. (For this manual the separate pages for the different appendices were consolidated to save a page.)
8. While this report uses color unnecessarily, the colors used are ones which should print OK in monochrome.