

ASEN 2003 LAB 2: BOUNCING BALL EXPERIMENT

- Assigned: Wednesday, February 1, 2017
- Group Report Due: **Wednesday, February 15 2017, beginning of lab**

OBJECTIVES

- Gain physical understanding of direct central impact problems and coefficient of restitution.
- Derive expressions for coefficient of restitution.
- Perform experiments to explore variations of measured results.
- Assess experimental results.

GROUPS

Groups will be decided by the TAs. Derivations are requested as part of this lab. *There is no requirement to type these, but you can.* The person in your group with the best handwriting can write them up and they should be put in an appendix. If you prefer to typeset them, that is fine.

PROBLEM STATEMENT

When a ball that is not spinning is dropped vertically on a horizontal surface we model the dynamics as a direct central impact of a particle. If the ball is released from rest at an initial height h_0 , the height of subsequent bounces and the total time the ball bounces may be used to estimate the coefficient of restitution of the ball and floor. In this lab assignment, your tasks are to derive the expressions for e as a function of ball heights, time between bounces, and time to stop bouncing, measure these values several times for different balls, compute and compare your derived estimates of e , and assess these results based upon experimental error.

THEORY

A ball is released from rest at a height, h_0 , above a horizontal surface. The height of the mass center of the ball after n subsequent bounces is termed h_n . The time required for a single bounce is t_n , and for the ball to stop bouncing is t_S (See Figure 1 below).

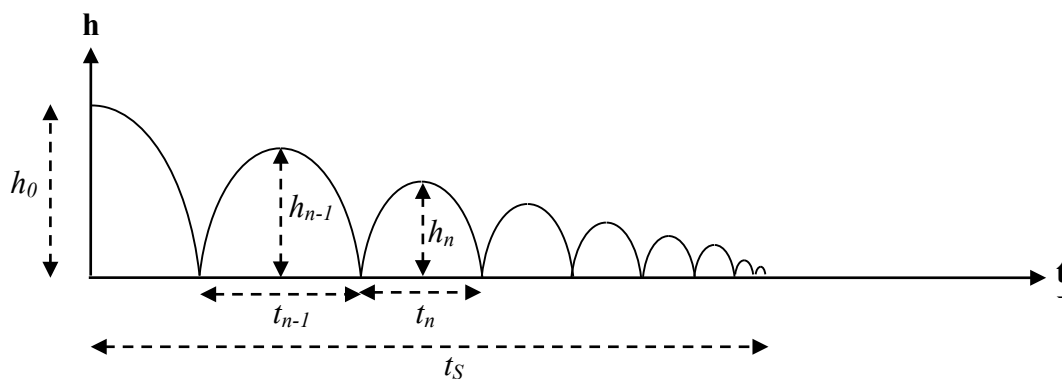


Figure 1. Ball height versus time for a sequence of bounces.

Starting with the principles of energy and momentum for direct central impacts, the coefficient of restitution can be estimated from three different methods. Derive the expressions given below for the coefficient of restitution for each method. For each method also calculate the sensitivity of the estimate to measurement error. We will be using propagation of errors, if you want to go back and read your notes from ASEN 2012. The sensitivity maps the errors in the measured quantities (i.e. the height or time) to errors in the final estimate of the coefficient of restitution.

Method 1: Height of Bounce

Estimate of e_{height} from height of bounces:

$$e = \left(\frac{h_n}{h_{n-1}} \right)^{\frac{1}{2}} = \left(\frac{h_n}{h_0} \right)^{\frac{1}{2n}} \quad [1]$$

Method 2: Time of Bounce

Estimate of e_{bounce} from time of 2 adjacent bounces

$$e = \left(\frac{t_n}{t_{n-1}} \right) \quad [2]$$

Method 3: Time to Stop

Estimate of e_{stop} from time to stop bouncing:

$$e = \frac{t_s - \sqrt{\frac{2h_0}{g}}}{t_s + \sqrt{\frac{2h_0}{g}}} \quad [3]$$

PROCEDURE & RESULTS

Using your cell phone camera and/or the equipment provided by the ITLL, design experiments to calculate the coefficient of restitution from each of the three methods presented above using one of the supplied ping-pong balls. Perform at least ten trials of each experiment. Note, the term *experiment* refers to the application of one of the methods described above to the ball. Thus, you will perform 3 total experiments with at least ten trials per experiment.

After performing the experiments and analyzing the data (see below), identify the method that provides the best results for each ball, refine your experiment, and collect additional data (at least 10 more trials) with that method only. Now using the best method, select a different ball, and conduct 10 trials (bring in your own or use one of the balls provided by the lab coordinators). Your lab report should include characteristics of the balls used in the trials (size, mass, etc).

For each experiment write up a clear and concise description of the experimental procedure you developed, including sketches as necessary. The description should be clear enough that other groups could perform your experiments from it. The description can take the form of numbered or bulleted list where each item clearly describes one step in the process. Describe how you came up with the experiment, justifying your choice of measuring devices and data collection methods. Also, describe important sources of error in your experiments.

ANALYSIS

All computation for this lab is to be done by hand or using MATLAB (No Excel or Mathematica). For each experiment, calculate the mean, median, standard deviation, and standard deviation of the mean for the data you collected. Describe and compare your results for the different experiments. How different are the results for different types of balls? How consistent are the results of different trials & methods for determining e for the same ball?

Error analysis is a significant component of any experimental study. What are the sources of experimental error in measuring the bounce heights and the stop time? For the experiments you designed, which have the greatest measurement error? Attempt to quantify the measurement error for each experiment. Error in the collected data creates error in the final estimate of the coefficient of restitution. Calculate the error you expect in the final estimate for the coefficient of restitution. Can you use this error analysis to suggest refinements to your experiment design?

Based on the experimental data and the error analysis, what is your final estimate of the coefficient of restitution? Include bounds on the accuracy of this estimate and justify its calculation.

Summary of data to be collected

- Ten trials for method 1 with ping pong ball.
- Ten trials for method 2 with ping pong ball.
- Ten trials for method 3 with ping pong ball.
- Pick one of the methods, improve it, and collect 10 more trials with ping pong ball. Also collect 10 trials with a new ball (your choice).

REPORT CONTENTS

Title Page - Lab# and Title, Course Number, Student Names, Date Submitted.

Abstract - Briefly summarize the rest of the report including the objectives of the lab, what was actually done, the most important qualitative and quantitative results, and your conclusions. The abstract should be less than 200 words.

Theory

- Re-state equations 1-3, with a figure to show what the variables mean (derivations in the appendix).
- State the sensitivity of Equations 1-3 to measurement errors (derivations in the appendix).

Procedures

- Provide qualitative descriptions of the experimental procedures, highlighting any innovative solutions.
- Provide a step by step description of each experiment.
- Explain how you designed each experiment.
- List the major sources of error in each experiment.

Results

- List results from the preliminary experiments, collecting data from at least 10 trials per experiment.
- Calculate statistics for results.
- List results for final experiment with your chosen method and calculate statistics.
- List results for your alternate ball experiments and calculate statistics.

Performance Analysis

- Compare and discuss results obtained for the different experiments.
- Perform error analysis and compare expected results to data.
- Present final estimates of coefficient of restitution for each ball analyzed.

Conclusions and Recommendations – Summarize your experience. What was learned from the process? Which experiment performed best? Worst? What recommendations would you make to someone else trying to measure the coefficient of restitution of an object?

References and Acknowledgements - List reference material used in a professional format. Describe assistance or contributions provided by classmates or others (not including group members who authored the report).

Appendix A – List the contributions of each member of the group.

Appendix B – Derivations.

Appendix C – Any additional procedure descriptions.

Appendix D, etc - Include any computer code you used to compute values or generate plots.

REPORT GRADING

	Title Page
5	Abstract
	Table of Contents
10	Theory
20	Procedures
10	Results
25	Analysis
5	Conclusions and Recommendations
5	References & Acknowledgments
5	Appendix B
15	<u>(Style and Clarity - includes title page, ToC, organization, grammar, spelling, plots, labels, tables, units)</u>

Coding Notes:

The coding needed for this lab is far less onerous than the roller coaster lab. The main requirements: name and purpose should be provided for each piece of code. Units and variable quantities should be defined at the top of all code (or within the code if that makes more sense).

Once the coefficient of restitution has been computed, the statistical analysis is –for the most part – the same, i.e. mean, standard deviation, standard deviation of the mean.

No random constants in your code. Sometimes there are constants that mean something to you, but they mean nothing to the rest of us. If the number of values in your file is 72, then say so. Define it as a variable instead of distributing 72 sporadically in your code.

Comment your code. I was given a copy of code written for this lab once and *literally* the only comment in the code is %Generate plots. This is not helpful.