Name: ____

Date of lab: ______________________ Section number: M E 345._______

Lab 2

Precalculations – Individual Portion
Basic Statistics Lab: Calculation of Basic Statistics

Precalculations Score (for instructor or TA use only):	_____ / 20

1. Using the standard resistor color code (available on the M E 345 website, References), determine the resistance and tolerance of a resistor with the following four color bands: red, blue, yellow, and gold.

2. The tolerance on resistors is ± 2σ by convention, i.e., approximately 95% confidence level. With 95% confidence, what is the range of resistance that you would expect to measure experimentally for resistors of the color banding of Question 1? Estimate the standard deviation.

3. A company manufactures resistors with R = 4.7 ohms and a tolerance of around ± 0.23 ohms. What color bands should they paint on these resistors?

4. Some resistors have 5 bands instead of 4. Do the five-band resistors have a *more* accurate or *less* accurate value than the four-band resistors? Justify your answer, i.e., discuss.

Lab 2

Cover Page for

Lab Report – Group Portion

Basic Statistics Lab: Calculation of Basic Statistics

Name 1: ______________________________________ Section M E 345._______

Name 2: ______________________________________ Section M E 345._______

Name 3: ______________________________________ Section M E 345._______

[Name 4: ______________________________________ Section M E 345._______]

Date: ____________________

Group Lab Report Score (For instructor or TA use only):

Lab experiment and results, plots, tables, etc.	______ / 50
Discussion	______ / 20
Neatness & grammar	______ / 10
TOTAL	**______ / 80**

Comments (For instructor or TA use only):

NOTE: The instructor or TA reserves the right to deduct points for any of the following:

- Arriving late to lab or leaving before your lab group is finished.
- Not participating in the work of your lab group (freeloading).
- Causing distractions, arguing, or not paying attention during lab.
- Other (at the discretion of the instructor or TA).

Basic Statistics Lab: Calculation of Basic Statistics

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Latest revision: 06 September 2011

Introduction and Background (*Note*: To save paper, you do *not* need to print this section for your lab report.)
The engineering profession is dependent on both *accurate* and *precise* representation of experimental data. Unfortunately, due to inherent uncertainties involved in making measurements, the *exact* value is often not obtainable. Consider, for example, measurement of the thickness of a piece of metal. Metal can be purchased in standard "stock" sizes, such as ¼-inch steel stock – a sheet of steel, nominally 0.2500… inches thick. However, if the thickness of a specimen is measured carefully at several locations with a precise instrument, such as a micrometer, you will find that the actual thickness is not perfectly uniform, and is not exactly ¼-inch thick, due to the manufacturing process. Similarly, a resistor that is color coded to an indicated resistance value will not have *precisely* that resistance when measured with a digital multimeter (DMM). If several resistors of the same nominal value are tested, there will be some variation (scatter or random differences) in the value of measured resistance, even if the resistors come from the same lot. The science of statistics enables us to quantify such variations, and the associated errors, by introducing parameters such as mean, standard deviation, etc. Definitions of these parameters are provided in the lecture material.

In this lab, ***basic statistical analysis***, sometimes called ***multiple point uncertainty analysis*** will be performed on samples measured in the lab.

Objectives

1. Become familiar with experimental measurements of thickness and resistance.
2. Learn how to use the vernier scale on a micrometer
3. Develop an appreciation for errors and uncertainties in experimental measurements.
4. Practice applying statistical techniques to quantify these errors and uncertainties.
5. Practice creating and interpreting histograms and probability density functions.
6. Determine whether a larger sample size produces better statistics.

Equipment

- aluminum metal stock –nominally ½ × 1 in, cut to 8 inches length (a different piece for each lab group, but all of them were cut from the same original piece of stock metal)
- micrometers:
  - sliding type with dual units (inches and cm) and vernier scale
  - ratchet type with vernier scale (some of them have a digital "odometer" type of readout too)
- container of 50 to 100 2-kΩ resistors
- digital multimeter (DMM), with appropriate cables as needed
- two cell phones (use your own personal cell phones); you do not actually answer the calls, so it won't cost you any minutes
- stopwatch

Procedure

Resistance measurements

1. All the resistors in your container should have the *same* color bands (same indicated resistance and tolerance). Record the color bands on your set of resistors.

2. Using the color bands, calculate and record the *indicated* resistance and tolerance (show your calculations here). This resistance is referred to as the *nominal* resistance; actual resistance will be measured with the digital multimeter (DMM).

Nominal resistance, *R* = ___________ Ω; Tolerance = ____________ %

3. Measure and record into an Excel spreadsheet the resistance in ohms (Ω) of *at least 20* resistors in your container, using the DMM. Make sure you choose the DMM range that provides the ***maximum possible resolution***. You should be able to measure to 5 significant digits of precision.
4. Calculate the ***sample mean***, ***sample median***, ***sample mode*** (if it exists), and ***sample standard deviation***.

Sample mean = ___________ Ω

Sample median = ___________ Ω

Sample mode = ___________ Ω

Sample standard deviation = ___________ Ω

5. Write the resistance in ***standard engineering form***, assuming 95% confidence.

R = ___________ +/- ___________ Ω

6. Calculate the difference between the sample mean and the nominal value. (This is a kind of bias error.)

Sample mean – nominal value = ___________ Ω

Thickness measurements

Note: Each lab station has two micrometers, a sliding type and a ratchet type. Practice with both. All of them have a vernier scale, with resolution of up to 0.0001 in. (e.g., 0.2653 inches) when using the vernier scale. Some of them also have a digital "odometer" type readout – ignore that part, and use the vernier scale instead. *Do not over-tighten the micrometers – they are fragile, and easily broken! Use the* ***outside*** *ratchet to tighten.*

1. Measure and record the nominal thickness of the piece of stock metal (in inches). In other words, round off to the nearest 1/8 inch. (e.g., 1/8, 1/4, 3/8, 1/2 ... inches, which are the standard stock sizes).

Nominal thickness, *t* = _____________ in

2. Using the micrometer that gives the highest resolution (with vernier), measure and record (into Excel) the thickness (inches) at various positions on the stock metal. Take 30 or more thickness measurements, and *each* member should be given a chance to take measurements – a *minimum* of 10 per person. [One of the goals of this portion of the lab is to give each student some experience with using the micrometers.] Ask for assistance in reading the vernier scale if you are unfamiliar with vernier scales.
3. *If your micrometer has a zero error (non-zero reading when fully closed without the stock metal), subtract this bias error from each data point before proceeding*.
4. Add your names, section number, and computer name (e.g., "Measurement 02") to the spreadsheet. Give a copy of the Excel file to the TA via USB drive or e-mail. [Later on, we will combine your data with those of other lab groups so that you can analyze a larger sample – the ***population***.]
5. Create a nice-looking ***histogram*** from your thickness data. Use Sturgis' rule and/or the Rice rule as guides for how many bins to use. The actual number of bins depends on your choice of bin values. Specify your own bin values, as discussed in class, so that the histogram is nice-looking and neat.

Histogram of sample thickness data, our lab group only: see attached, Figure number ___________

Statistical analysis of the entire *population* of thickness data (*all samples from all lab groups in your section*)

1. Your instructor/TA will gather the thickness data from *all the lab groups in your section*, and he/she will collect *all the data from in your section into one Excel file* so that you can perform statistical analysis on the ***whole population*** (we call this the *population*, although it is really just a larger sample). Get this Excel file from your instructor or TA. If the file is not ready yet, move to the cell phone part.
2. Create a nice-looking ***histogram*** from the thickness data. Use Sturgis' rule and/or the Rice rule as guides for how many bins to use. The actual number of bins depends on your choice of bin values. Specify your own bin values, as discussed in class, so that the histogram is nice-looking and neat.

Histogram of population thickness data (all lab groups): see attached, Figure number ___________

3. Convert your histogram into a ***probability density function*** (PDF) *Hint*: Divide each value by *n*, the total number of measurements, and divide also by the bin width to generate $f(x)$. Plot $f(x)$ versus x_{mid}, the ***mid value*** of each *x*, with appropriate scales and labels on the axes. *Caution*: Excel's histogram plots are based on the *maximum x* value for each bin. However, for proper conversion to normalized form, the *middle* value of *x* in each bin must be used instead as discussed in class.

PDF of population thickness data [$f(x)$ vs. x]: see attached, Figure number ___________

4. Convert your PDF into a ***standard normalized PDF***, i.e. $f(z)$ vs. z instead of $f(x)$ vs. x. Be careful to properly convert both x and $f(x)$ using the transformations $\boxed{z = (x - \mu)/\sigma}$ and $\boxed{f(z) = \sigma \cdot f(x)}$, as discussed in class. Plot $f(z)$ vs. z on a scatter plot, using symbols only.
5. On the *same plot*, plot the standard Gaussian distribution function (using a curve only) for comparison.

PDF of thickness data [$f(z)$ vs. z] compared to Gaussian PDF: see attached, Figure number ___________

6. Record all the following data for the "population" of thickness data:

Population mean = ___________ in

Population median = ___________ in

Population mode = ___________ in

Population standard deviation = ___________ in

Thickness in engineering format = ___________ +/- ___________ in

Population mean – nominal value = ___________ in

Some fun with cell phones

1. In this section, we will take several measurements of how long it takes for a cell phone call to go through. Get two cell phones – one will be the caller and one will be the receiver.
2. Call the receiver phone from the caller phone. With a stopwatch, time how long it takes from the time you hit the SEND button until the first ring on the receiver phone. Record the time (seconds) as precisely as possible (typically to 1/100 of a second) in an Excel spreadsheet.
3. Repeat as many times as you want – no fewer than 20. Again, the more data you take the better should be your statistics.
4. Calculate the ***sample mean***, ***sample median***, ***sample mode*** (if it exists), and ***sample standard deviation***.

Sample mean = ___________ s

Sample median = ___________ s

Sample mode = ___________ s

Sample standard deviation = ___________ s

5. Draw a nice-looking histogram of the data.

Histogram of cell phone data: see attached, Figure number ___________

Discussion Questions

1. Statisticians often use standard deviation divided by mean ($S/\overline{x}$) as a nondimensional measure of the overall precision of a sample. Calculate $S/\overline{x}$ for your lab group's resistance and cell phone samples <u>on a percent basis</u>. Which set of measurements is more *precise*? Justify your answer and discuss.

2. List some of the reasons that one cell phone call may take longer to go through than another cell phone call, even when calling from the same phone to the same phone.

3. Based on the sample of resistors measured by your group, do *all* of the measured values of resistance lie within the tolerance band indicated on the resistors? Should they? Discuss.

4. Look at the histogram for your lab group's cell phone measurements. Does the distribution appear to be nearly Gaussian? If not, what aspect(s) of the histogram lead you to your conclusion? Discuss.

5. Finally, compare and discuss the histograms of the thickness measurements for *your group's data only* versus those of *your entire lab section* (which we are calling the *population*). Does a larger sample yield better statistics and better agreement with a standard bell curve shape? Should it? Discuss.