ME 310 FALL 2012

Instrumentation and Theory of Experiments

LECTURE: A1: M-W 12 - 2 PM, PHO 211

LAB: Rm 113, 110 Cummington St.
6 sections: A5 (Tues 6-10pm), A2 (Thurs 6-10pm), A3 (F 9am – 1pm), A4 (F 1-5pm), A6 (W 6-10pm), depending on assigned section

TEXT: Beckwith, Marangoni, and Lienhard, *Mechanical Measurements,* custom version (based on the 6th edition, 2007), Pearson Prentice Hall. ISBN: 0-558-53345-0.
(optional) Taylor, *An Introduction to Error Analysis*, 2nd edition, Univ. Sci. Bks., 1997.
Handouts, on Blackboard site

LAB NOTEBOOKS: National Brand #43-591 or Roaring Spring #77591, or equivalent, at least 1 needed

PROFESSOR: Caleb Farny farny@bu.edu
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GRADING:

5%	Class and Lab performance
20%	Design Project
10%	Homework Sets
25%	Labs and Lab Reports
20%	Exam 1
20%	Exam 2

There will be 2 midterm exams, roughly 5 homework sets, 6 labs, and 1 design project.

CLASS: Class will be lively, informative, and PART OF YOUR ASSIGNED GRADED WORK. Don't expect to merely sit and be lectured to, you will participate. Come to class and be prepared to use the knowledge you already have as upperclass students, and to think on your feet.

HOMEWORK: Homework assignments are given out (roughly) every other week in class. They are due at the BEGINNING of class on the due date listed. LATE HOMEWORK WILL NOT BE ACCEPTED unless circumstances merit the exception.

EXAMS: The midterm exams will be given in lecture and will cover a specific section of the course material. They will be thorough and challenging. "Make-up" exams will rarely be given. In the case of prior knowledge of a time conflict you must arrange to take the test before you are away. A "make-up" exam will be different from the exam given in the class, and will possibly be oral. The first exam will be given on October 15th, and the second exam will be on December 3rd. There is no final exam.

DESIGN PROJECT: You will design and implement a complete transduction system to measure the frequency-dependent displacement of a damped mass on a spring. This will occupy roughly the final 5 weeks of laboratory meetings. Note that it is a design as well as lab project, and as such there will be significant work done OUTSIDE and BEFORE lab.

DROP DATES: Pay attention to the University's schedule of drop dates. You cannot drop this course after the last "W" date because of an impending low grade – you will receive your current grade if you drop after the official W date. "Incomplete" grades are reserved for the most extreme of circumstances, and are a NEGOTIATED CONTRACT between the student and myself.

PREREQUISITES: EK 301, ME303 and EK307.

COLLABORATION:

A. Homework: Do it individually. However, you are encouraged to consult with classmates on general concepts.

B. Lab reports: Also to be done individually. Pre-labs should be done individually. For some experiments, there will only be one copy of your raw data/results, which you must copy later for inclusion in your own reports. Your lab report should be a stand-alone document, and therefore you may not 'reference' any section in one of your lab partners' reports. However, you must consult with your lab partners even after the lab period to discuss findings and results.

C. Design project: This is a group collaborative project, and I expect to see some division of labor here, and there will only be 1 report per group, so each group member will receive the same grade. Despite the division of labor, since this is a class, each member of the group must understand the other member's contributions.

MATLAB ACCESS:

I **highly** recommend the use of Matlab for analysis and plotting for ME310. You can access it online through the BU ENG Grid. Check out the instructions at: http://collaborate.bu.edu/engit/MatlabRemoteAccess

LAB AND LAB REPORT POLICIES AND PROCEDURES:

0. **Groups**

   Organize yourselves into groups of no more than 4 students each. There will be no more than 4 groups per each lab period. Remember that lab reports are done individually.

1. **Notebooks and Reports**

   a. Lab Notebook: Buy at least 1 square-ruled lab notebooks (with page numbers, preferably). They must be similar to National Brand #43-591 or Roaring Spring #77591. You will record all your in-lab data and observations for ALL LABS in this notebook, which is to be turned in at the end of the semester. Identify your notebook on the cover with your name, term and year, course number, and lab partner's names.

   b. Lab Report: Each student will generate a lab report for each experiment, the elements of which are spelled out in the sections below. These reports will be generated on a word processor with inclusion of graphs and plots (typically generated in a spreadsheet or other calculation program) and also with the inclusion of the photocopied pages of the lab notebook corresponding to the experiment.

   c. All entries (notebook especially) must be in permanent ink. Pencil is only used for drawings and graphs. Do not erase or 'white-out' mistakes. Instead, cross out with ONE mark and explain. Use only the right-hand side of pages.

   d. Format, content and neatness will be graded. Your writing or typing must be legible, intelligible, and concise but complete. As mentioned above, these reports are stand-alone documents. Do NOT assume that 'everyone knows that'.

   e. If you use information from a previous class or from some textbook (even our own) or even scarf pictures, plots, text, etc. from the lab manual handout, or (God forbid!) from the Web, you MUST document such with a citation.

   f. The pre-lab section of the report is due at the beginning of the lab. The TF will check, sign and date the prelab or you will receive no credit.

   g. The in-lab data section completed in the notebook must also be signed and dated by the TF, or no credit will be received.

2. **Due dates**

   Typically, lab reports are due at the beginning of the subsequent laboratory, which for most labs, means you have 1 week to complete the report. The one constant exception is Lab 5, which is due within 2 weeks. LATE LAB REPORTS WILL NOT BE ACCEPTED OR GRADED unless dire circumstances warrant the exception. You will be happy to learn that Lab 1 does not have a required lab report. This does **not** mean that you are free to skip this lab! The GTFs take attendance, and failure to show up for a lab session will result in an Incomplete for the course. See me as far in advance in possible if you have a scheduling issue and we'll arrange for you to make up the lab.

   In order to keep track of the reports, you are required to submit a printed copy of your report to your TF at the **beginning** of your lab session, AND a digital copy to the Blackboard drop box **before** your lab session.

3. **Error Analysis**

An estimate of your errors, their sources and impact on results is required in every lab report. Additionally, SPECIFIC LABS require a full formal uncertainty analysis. I have scheduled 1 free lab period following Lab 5 to ensure adequate time for preparation of the longer and more extensive lab report.

4. **Late or missed labs**

Only in the most extreme of circumstances will you be allowed to be late or miss a lab and schedule a makeup. These labs require a large amount of overhead in terms of equipment, prep, coordination and manpower, and it is not fair to anyone to reschedule without compelling cause.

5. **Lab Report Content**

I have many sample reports available in office for your perusal. On the following pages you will find a section by section breakdown of what is expected.

6. **Safety**

Safety is paramount. Never work alone. Tie up loose ends: this includes hair, clothing and jewelry. Keep workspaces free of clutter. NO FOOD OR DRINK IS ALLOWED IN THE LAB! REALLY!!!

ME 310 LAB REPORT CONTENT AND LAB NOTEBOOK USE

GENERAL INFORMATION

- Start each lab report section on a new page and use only the fronts of pages (or the right-hand-side of your lab notebook). Number your report and notebook pages (by hand in your notebook if you have to).
- Copies of the relevant pages of your lab notebook must be included in your lab report for each experiment when you turn it in post-lab.

PREPARATION BEFORE LAB (Prelab Report Section)

- Title page
- Objectives of lab
- Theory and preparation for analysis
- Appropriate tables of symbols and formulas
- Spot check preparation
- Listing of data needs
- Tentative equipment lists
- Procedure checklist

1. Title Page

This should include only the title of the experiment, the date the experiment was actually done, your name, and all other students who did the experiment with you, using your apparatus.

2. Objectives

Before each lab you must read and understand the lab write up. Then you must prepare your notebook for the lab. First, the objectives of the lab should be stated. This should be a **brief and concise** statement of what the scientific and/or engineering goals of the experiment are (e.g., investigate a phenomenon and/or demonstrate a theorem).

Do not just copy the handout. In the conclusion section at the end of your lab you should return to the objectives to ascertain how well the objectives were realized. Since the conclusions depend on the results of the experiment, what is included in the results section will also depend on the objectives, so check what is asked for (or what will be obtained) in the results section before writing your objectives.

3. Theory

Next, a **brief** summary of pertinent theory or established empirical evidence related to the experiment should be given. The purpose of this is to clarify what data you are looking for in the experiment and how these data are to be reduced and analyzed to meet the lab's objectives. It is your responsibility to understand the theory well enough to know what measurements need to be made (e.g., if a Reynolds Number is required, then you need to measure temperature, which will allow you to look up the fluid's viscosity). Also, if the handout asks you to perform a derivation or dimensional analysis, it should be done in this section.

4. Formula Summary

This is a listing of the formulas you will need to find your results from your data and the theoretical values to which you will be comparing them. Also, list the meaning of all the symbols used in your formulas and their units.

5. Spot Check Preparation

It is almost always desirable to do an analysis of some data points in the lab while the experiment is running. This is called a spot check. A spot check permits you to see if the results make sense, or if the experiment is generating data that is obviously erroneous and either the experiment or your method of analysis needs correcting. As an example, in the Reynolds Apparatus experiment performed in ME303, you were looking for the Re that corresponds to the laminar to turbulent transition region. Were this lab done in ME310, you would outline in your prelab how to do this (such as viscosity tables and a calculator). Then, during your lab you could check that your results were consistent with the expected values for flow transition.

All ME310 labs include spot checks to help you identify bad data, bad analysis, bad lab technique or faulty equipment. **Sample calculations for spot checks should be prepared in your prelab**. These should include unit conversions and constants to reduce in-lab time. Then in the lab, you will only need to plug in your experimental values. Check during the previous lab what unit conversions will be needed in the next lab.

6. Data Needs

This section should include a list of data needs, including the range of variables the data will include. The purpose of this is to simplify in lab the construction of neat data tables that are easy and informative to read. It also allows you to determine a complete list of the data you'll need in lab, to reduce the chance you'll forget or miss a measurement.

Headings for table rows and columns should be devised as well as tentative unit assignments. In this section your tables should be "skeleton" or model tables containing no actual data. For example, if your data is to be voltage as a function of frequency, then you'll need to specify the min, max, and increment for the frequency. **If you have prepared only sample data tables for the prelab, keep in mind that the actual data tables, containing the actual data, must go in the data section (which follows the safety check) in your <u>lab notebook</u> and are to be constructed and filled with data only during the lab.**

7. Equipment List

Next should come a tentative list of equipment. It is a tentative list because there will be probably be some additions to the list to be made in the lab and for information on **equipment make, model number, and serial number**. Also, you will wish to record **stated accuracy** (with calibration data if available) and **instrument resolution** (smallest increment, or least count). Accuracy information can be found in the equipment manuals in the lab for the electronic instruments. You should construct this list in the form of a table (with plenty of blank spaces) and are permitted to fill it in with the unknown information during the lab.

8. Procedure Checklist

The last part of the prelab should be the procedure checklist. Here you will summarize how to set up and run the experiment in a list of brief statements that you then follow in lab. This is to help you to remember when to turn crucial valves so the lab doesn't flood out and when to take crucial data or perform spot checks so you don't have to repeat portions, or all, of an experiment. The labs can become somewhat confusing while in progress and it is not difficult to forget a procedure step, so a good procedure section is of some significance. This checklist can and often should be revised during the lab.

Obviously there is a fair amount of work involved in prelab preparation. It is a very significant part of doing an experiment and should not be raced through just prior to lab. The prelab comprises 30% of your lab grade.

LAB NOTEBOOK USE DURING LAB (Inlab Report Section)

- Complete equipment list
- Make and record a safety inspection
- Follow procedure checklist
- Take data
- Perform spot checks
- Note general observations
- Draw experimental setup

1. Complete Equipment List

Include the make, model, serial number and accuracy information where applicable. Put this information into the table in your prelab section, or record it directly in your lab notebook.

2. Perform Safety Inspection

Before beginning the experiment, consider and note in your lab notebook the safety issues related to this experiment. Include both issues that were addressed and also those that were not addressed. For those issues that were not addressed, comment on how the safety of the experiment might be improved in the future. Note that this includes safety FOR the equipment, not just FROM it – you should be aware of the limitations of all equipment you use, and take appropriate steps to ensure no input or output loads exceed those limits.

3. Follow Procedure Checklist

Check off each step as you proceed through the checklist. You should pen in procedure changes if they become necessary. If there is extensive revision of the procedures necessary, you should record the revised procedures in the lab notebook.

4. Take Data

Record data in either in the tables which you've pasted into your lab notebook OR construct data tables based on the models you developed in your prelab and add these these tables in the lab notebook. Be sure to include appropriate units and other comments (e.g., which of several instruments you were using – e.g., which rotameter – or which scale you were using on your instrument). Be sure to record the **raw** data before you make **any** calculations, e.g., the height of each column of a differential manometer and not just the difference in heights (which would be the result of a calculation and result in the loss of some information – e.g., where on the scales you were working). All data must be recorded neatly and be **easily** legible to the graders (including the units of the data) or else loss of credit will result. The 5% credit given for this section is primarily given for format, presentation, and completeness. More credit will be lost if the data is faulty, leading to poor analysis and results.

5. Perform Spot Checks

Usually you will be told what spot checks to do, but for some labs you are expected to come up with some of your own. Regarding spot checks, it is not enough to simply do them. Comment on what information they supply, e.g. "demonstrates a linear relationship", or , "corresponds to a theoretical expectation", etc. Spot checks should be performed in the data section, near the relevant data. Since spot checks are so important this section is also worth 5%.

6. Note general observations

In addition to taking data, general observations that relate to the lab, such as problems and inconsistencies, should be recorded. However, problems that can be corrected by the students (e.g., poor flow meter calibration) should be corrected as well as noted.

7. Document experimental setup

Finally, in order to make sure you understand and remember how the experiment was set up, draw a block diagram of the measurement and instruments involved. Nothing fancy is necessary, but it should show the electrical connections between the instruments and the basic idea of how the instruments were positioned relative to the phenomena that they're measuring. Scan in or reproduce (manually or digitally) the block diagram as part of the lab report.

ANALYSIS AFTER LAB (Postlab Report Section)

- Analysis
- Uncertainty analysis
- Results
- Discussion and Conclusions

1. Analysis

The chief purpose of the analysis section is to show the calculations ("analysis") that you performed to transform the data into results. The analysis should appear in the lab report following photocopied pages from the lab notebook containing the information recorded during lab. It is very important that your analysis be clear to someone who did not do the lab. Therefore, you should annotate it well. Sample calculations for each different type of data point and calculation must be included. Be sure to specify which data point is being used in each sample calculation and to identify the source (including the page number in the lab notebook) of any typical data and reference data you use (e.g. viscosity values). Also, be certain to use and check units. Hint: sometimes it is easier to convert all data into SI units and then do your calculations.

Following the sample calculations, analysis of all of the data points should be summarized in tables, including intermediate as well as final results. The data points used in the sample calculations should also be included in these analysis tables as a check that the analysis behind the tables is working properly. All tables must have a name (e.g., Table 1) which you should use in your text (eg. "Table 1 lists the intermediate calculations performed for determining the relativistic correction to the mass"), clearly labeled columns and rows (variable names and units), and an explanatory caption. The name and caption are usually combined, for example, "Table 3a. List of relevant acoustic and thermal properties for tissue-mimicking gel. All values are experimentally determined as described in Section 2, except where citation indicates another source for the values". A Table title is sometimes useful, but optional.

Calibration curves and other curves needed for the analysis of data should also be included in the Analysis Section, however, all results graphs belong in the Results Section only. All graphs must have name (e.g., Figure 1), which you should use in your text (eg. "Figure 1 plots the output gain as a function of frequency"), and an explanatory caption below the graph which describes the features and parameters of the graph. The name and caption are usually combined, for example, "Figure 5. Light emission as a function of duty cycle for 5 different pressures with symbols as indicated in the legend. Frequency = 1 MHz, DGC = 0.03"). A Figure title is sometimes useful, but optional. If there is more than one curve on a graph, clearly distinguish them by different symbols, line types, and/or colors in a legend included somewhere on the graph. The scales of the x- and y-axes must be clearly shown and labeled with variable names and units. Be sure to use the appropriate graph axis type in your graphing application: log-log, semi-log, etc. Graphs should be sized so that they take up most of a report page width.

Sample calculations may be done by hand or using a *symbolic* manipulator program (such as Mathematica or Maple), but the rest of analysis, as well as uncertainty analysis and graphs should be done with a computer (Matlab and Excel are available in the CAD lab). Hand-written sample calculations may be done in the lab notebook for convenience, then photocopied for the report. Alternatively, you may simply leave space in your report pages for the appropriate hand-written calculations.

2. Uncertainty Analysis

The uncertainty analysis should include your estimated elemental experimental uncertainty in each measurand (both bias and precision, identified as such, as well as total uncertainty), statistical analysis of data where appropriate, and uncertainty propagation for formulas and results using partial differential root sum square propagation formulae, and sample calculations. Also, discuss, combine and propagate the uncertainties introduced by your equipment.

Sample calculations must be shown for a single point for each type of measurand and a single example for each type of resultant. Following the sample calculations, uncertainty in all values and results must be calculated and displayed in tables. Due to its great importance, uncertainty analysis counts for 20% of your lab grade on the labs requiring uncertainty analysis.

3. Results

Results should be given in terms of tables and graphs whenever possible (refer to above paragraph on graphs for format). **Do not include intermediate calculations (those belong in the analysis section), only final results in the results tables**. Final results are those that are needed to meet the objectives of the experiment. Data points should have error or uncertainty ranges indicated, where appropriate, in both tables and graphs (on graphs it should be represented as error bars when possible). **If a graph will convey the same information as a table, then just use a graph.**

4. Discussion and Conclusions

In the discussion section you should evaluate your results and discuss the physical meaning of the numbers and graphs. If there are relevant theoretical or empirical results available, compare your results with them, and attempt to explain any discrepancies. Answer any and all questions asked in the procedure section of the lab handout. Mention experimental limitations and ways the lab might be improved. Were the lab's objectives met? Remember to include uncertainty in this discussion. Because it is important to think about and communicate experimental results as well as get them, this section comprises 15% of your lab grade.

ADDITIONAL GRADING

Presentation

The presentation quality of your lab report will, at a minimum, be graded for readability, completeness and placement of items in the proper section.

SUMMARY OF LAB REPORT ORDER AND CREDIT

For each experiment, the report should consist of:

	Section	**Max. Credit**
Prelab	Title page	2%
	Objective	3%
	Theory	4%
	Formula summary	1%
	Spot check preparation	5%
	Data needs	5%
	Equipment list	5%
	Procedure checklist and safety	5%
Inlab	Data	5%
	Spot checks, block diagram	5%
Postlab	Analysis	10%
	Uncertainty analysis	20%
	Results	10%
	Discussion	15%
All Sections	Presentation	5%

Some thoughts on lab report word processing…

You are free to use whatever word processor you prefer when you go about typing up your weekly lab reports. HOWEVER: Personal experience and lots of student feedback has shown that Microsoft Word can make your life very difficult when it comes to assembling long documents that contain both embedded figures and equations. It can be done, but you might have gained some bags under your eyes and lost a few hairs by the time you're finished. As a less stressful alternative, I recommend learning how to use LaTeX. It's an open source platform, so its name was clearly not generated by a marketing team, and it has a short learning curve, but it will be your best friend after the initial time investment. Also, it's (virtually) free, in that the package for the Mac platform (TeXShop) is free and the Windows platform (WinEdt) has a recommended payment reminder that can be ignored if you've got the patience.

So what's LaTeX you ask? LaTeX is a document formatting software that relies on a user-programmable typeset language that makes embedding figures, figure numbers, equations, equation numbers, tables, table numbers, and section headings, etc, all much easier to update and position within your document. It performs all this and produces a slick-looking report that's sure to get you an A based just on its appearance! (if you were still in high school, that is…)

In a nutshell, the program consists of an editor window, where you write your text, provide links to your figure files, and program your equation symbols, and a window where it displays the typeset document in PDF format.

The only downside is that proofreading can be difficult, since the editor window is not formatted in a well-presented manner. I highly suggest carefully proofreading the PDF version, and then making notes where you'll want to make changes on the editor window side.

Mac download:
http://pages.uoregon.edu/koch/texshop/

Windows download:
http://faculty.smu.edu/barr/latex/

I've posted a lab report template on the Blackboard website.

ME310 Semester Schedule				
L	**Dates**	**Topics/Classroom Activities**	**HW**	**Labs**
1	9/5	Course, lab & report overview		
2	9/10	Measurement methodology		1: DSO, DMM, LabView overview
3	9/12	Measurement methodology; error analysis		
4	9/17	Uncertainty overview		2: Filters, Op Amps
5	9/19	Prec vs Bias Uncertainty		
6	9/24	Uncertainty, linear measurement systems	HW 1 due	3: Strain gauges
7	9/26	Measurement overview: Temperature sensing		
8	10/1	Measurement systems: response functions, sensitivity, linear regression	HW 2 due	4: Pipe Flow
9	10/3	A/D, sampling		
10	10/9	Regression, weighted fit; Instrumentation error	HW 3 due	5: Drag and Pressure (2 wks for report) 6: Temperature Calibration
11	10/10	KERN Temperature module		
12	10/15	Exam 1 review		
13	10/17	Exam 1		
14	10/22	Measurement overview: Filters		
15	10/24	1st order systems		
16	10/29	1st order systems, 2nd order systems		
17	10/31	2nd order systems continued	HW 4 due	
18	11/5	Project descriptions		Projects
19	11/7	Coupled systems		
20	11/12	Quality factor, experimental methods for time-dependent systems	HW 5 due	
21	11/14	In-class project work		
22	11/19	In-class project work		
23	11/26	In-class project work		
24	11/28	In-class project work		
25	12/3	Exam 2 review		
26	12/5	Exam 2		Report due
27	12/10	No class		
28	12/12	No class		

FALL 2012 ME 310 Lab Schedule

Note: there may not be 4 groups in each section depending on enrollment, but 4 is the max

Holidays	Section	A6	Tues 6-10			A7	Wed 6-10			A5	Thurs 2-6			A2	Thurs 6-10			A3	Fri 9-1			A4	Fri 1-5		
		Group #				Group #				Group #				Group #				Group #				Group #			
	Week of	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	10-Sep	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	17-Sep	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	24-Sep	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	3-Oct	4	6	5	f	4	6	5	f	4	6	5	f	4	6	5	f	4	6	5	f	4	6	5	f
Columbus Day	8-Oct	x	x	x	x	5	4	f	6	5	4	f	6	5	4	f	6	5	4	f	6	5	4	f	6
	15-Oct	5	4	f	6	f	5	6	4	f	5	6	4	f	5	6	4	f	5	6	4	f	5	6	4
	22-Oct	f	5	6	4	6	f	4	5	6	f	4	5	6	f	4	5	6	f	4	5	6	f	4	5
	29-Oct	6	f	4	5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	5-Nov	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	12-Nov	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Thanksgiving	19-Nov	7	7	7	7	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	26-Nov	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	3-Dec	7	7	7	7	Project Presentation				Project Presentation				Project Presentations				Project Presentations				Project Presentatior			
	10-Dec	Project Presentations				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Possible pts	Experiment number and title
	1 Intro to scope, MM/DMM, and DAQ NO report!
80	2 Filters and Op-Amps
80	3 Strain Gauges
80	4 Pipe Flow
180	5 Flow Over a Sphere (2 weeks for report)
100	6 Temperature Measurement and Calibration
100	7 DESIGN PROJECT: Mechanical 2nd Order System and Digital Data Acquisition
	f Free lab period for your group
	x MW Schedule/Holiday
	Labs 5-7 require formal error analysis