Designing, Setting up, and Documenting High Quality Engineering Tests and Experiments

Well-designed engineering experiments and tests are critical to ensuring that high quality, usable engineering data is collected. In addition, experimentation and its documentation must be thorough and detailed so to as allow for both repeatability of an experiment, and reproducibility of its results. This is important in both research, and in industry.

Faculty should weight each section based on the importance they place upon it per their classroom objectives.

1. Background/Introduction: This is your reasoning into why you need to perform the experiments. Sample questions that you are trying to answer: • Why would we care about the problem & results? • What problem are you trying to solve? • What practical, scientific, theoretical, or artistic gap will your experiments fill?	/
2. Goal(s): Based on your research into the subject (background/introduction), what is the intended outcome of your efforts? Sample thoughts: • Impact if work is successful • Scope / context in the bigger picture if experiments shed insight	/
3. Criteria for Success/Failure: How will you determine the quality of results? Sample thoughts: • Specifically, what constitutes success or failure of your experiments? What numerical values of what measured parameters mean “success” (or “pass”), and what mean “failure” (or “not pass”)?	/
4. Results Needed: What results must be obtained in order to verify your goal(s)?	/
5. Measurements Needed: What measurements must you take in order to verify your goal(s) and achieve the results mentioned? What must be the accuracy of the measurements, in order to be sure; or what is/are the computed result(s) and accuracy that is/are needed?	/
6. Instruments Needed & Accuracy: • When hardware was utilized, the specific hardware employed is provided. Add here the types and models of equipment; but also the max/min measurement capabilities and the accuracy of the equipment. Give units as needed. Make sure that all equipment is listed. For example, a step might be to measure the length of something, but the test-writer forgot to add that testing needs a ruler, calipers, micrometer and specifications. • When software or analytical models are employed, reference(s) to this software/model are indicated. What inputs are needed and to what accuracy? What capabilities must the software have? What outputs must it calculate and give the accuracy of output/computations (based on input accuracy and the algorithm)? Indicate the ranges of inputs/outputs (and units). What equations must be handled (e.g., Navier-Stokes, anisotropic 3-D stress/strain)?	/

7. Experimental Setup & Connections: The test apparatus developed/used is explained in detail. Show a clear diagram of hookup of equipment. For coding, show software interfaces (I/O), and an overall logic diagram or algorithm. How inputs are taken and how outputs are provided. Label all equipment/software components clearly (by name and give each a number) and refer to these in the step-by-step procedure when the operator is told to interface with a specific component of the setup.	/
8. Step-by-Step Procedure: • If a component was fabricated (liquid, powder, etc.), the specific methodology employed was described including time, temperature, pressure, etc. • The specific conditions of the experiment are indicated o These should be in order (numbered, so that they can be referenced to return to a step or repeat a series of steps). Specify when to record data and where (provide table or software output - - when/how to save and in what format). Specify when to run codes. • Provide parameter ranges to test/run. • Specify when to use specific pieces of equipment (e.g., "measure the weight with the ???? scale", not just "measure the weight" without specifying how) and what results to record/capture. • For Tables, specify that these are computer generated or recorded 'by hand'. Give the tables at the end of the Test Procedure - - show specific parameters recorded with units. If computer produced, still need to give output parameters and units. • Provide a place in the Test Procedure for the operator to write his/her name and the date(s) performed. • Make sure that any 'conditions' are recorded. For mechanical/electrical tests, those conditions may be temperature, barometer, humidity, etc. For computer programs, there may be several 'standard' inputs that need to be given in order for a person trying to reproduce the results to know what standard parameters were used. • Refer to figures (e.g., experimental setup/connections) often and clearly explain steps using the components of the setup. • Indicate to operator when "notes" should be written, what those notes cover, and where/how to write the notes.	/
9. Number of Tests Run/Repetition: How do you ensure that the data you get is of high quality? Should be data repetition. One single data point will not typically be helpful. Should then be average results and standard deviations of those results. Tell the operator when to perform repeated runs and specifically which steps to repeat. Tell the operator how to determine if addition repeated runs are needed; i.e., based on what specific numerical results (or ranges of results) are more runs needed?	/
10. Statistical Analysis: When presenting experimental data in a table, the measurement accuracy is included. When providing experimental data in a figure, the experimental error is indicated.	/
11. Data Analysis & Results: Have you thoroughly explained the data you found and does it make sense (why or why not)? What conclusions/inferences can you draw from the outcomes, or is the data inconclusive requiring further testing? These may be clear to you (as the designer of the test), but may need further explanation to someone who is intelligent but not as close to this work as you are. Be as detailed here as you are in the step-by-step: do not assume too much knowledge/understanding of/by the operator/analyzer of the data.	/

12. Revision of Testing Procedure: …may need to go back to #1 and see what revisions you need to make. State clearly what criteria must be met to need (or not need) repeated testing of the test procedure as currently written. Also state clearly (e.g., numerical values or inability to determine values) when the test procedure must be re-written. Examples are that the expected output accuracy is not sufficient; thus, new/better equipment is required or a different piece of software (with increase capabilities) is needed.	/
13. Conclusions: Write specific conclusions. Do not write "tests performed as expected" or "this was a good test"; but write that specific output parameters fell [or did not fall] into the acceptable ranges - - give the values (with errors) of the outputs and the values of the acceptable ranges. Be as numerical and quantitative as possible.	/

Yes, this is *a lot of work*. However, the goal of any good report, paper, thesis, or dissertation is that someone can repeat your efforts and achieve the same results. Therefore, enough information must be given so that a following student *can repeat your efforts* and that everyone can understand the accuracy of your work.

"In the last year, problems in reproducing academic research have drawn a lot of public attention, particularly in the context of translating research into medical advances. Recent studies indicate that up to 70% of research from academic labs cannot be reproduced, representing an enormous waste of money and effort," said Dr. Elizabeth Iorns (8/14/12 - http://blog.scienceexchange.com/2012/08/the-reproducibility-initiative/).

"An ambitious effort to replicate 100 research findings in psychology ended last week — and the data look worrying. Results posted online on 24 April, which have not yet been peer-reviewed, suggest that key findings from only 39 of the published studies could be reproduced." (4/30/15 - http://www.nature.com/news/first-results-from-psychology-s-largest-reproducibility-test-1.17433)

"Over the past decade, before pursuing a particular line of research, scientists (including C.G.B.) in the hematology and oncology department at the biotechnology firm Amgen in Thousand Oaks, California, tried to confirm published findings related to that work. Fifty-three papers were deemed 'landmark' studies. It was acknowledged from the outset that some of the data might not hold up, because papers were deliberately selected that described something completely new, such as fresh approaches to targeting cancers or alternative clinical uses for existing therapeutics. Nevertheless, scientific findings were confirmed in only 6 (11%) cases. Even knowing the limitations of preclinical research, this was a shocking result." (3/28/12 - http://www.nature.com/nature/journal/v483/n7391/full/483531a.html)

UNDERGRADUATE EXAMPLE

ME 455 Exercise 6: Measuring the Time Constant of a Type-K Thermocouple

1. Background/Introduction:

In many engineering situations, knowing the temperature is a critical parameter in determining how efficiently a system or device is operating. As a result, engineering students must become familiar with understanding how thermocouples work. This includes the theory of thermocouples, how they respond in an exponential manner, the influence of their time constant on acquiring temperature data, and the use of software algorithms to analyze the data.

2. Goals:

The primary purpose of this lab is to investigate the thermal lag associated with a typical thermocouple (aka determine the time constant). A secondary goal is to explore the benefits of digital filtering of real data.

3. Criteria for Success/Failure:

To demonstrate that the students have accomplished the primary purpose of the lab, they must determine the thermal lag numerically using an appropriately designed experiment. This includes measuring the lag at an appropriate frequency to highlight how quickly the thermocouple responds to a change in the measured environment. To document that the students achieved the secondary goal requires employing a digital filter and illustrating that it does not adversely influence the data acquired.

4. Results Needed:

- Thermal lag should range from 0.01 second to 0.1 second.
- Filtering should show that, for ???? filtering, the data is smoothed without changing the average of the results (no more than 1% change); and that over-filtering yields erroneous data that is off by 25-200%.

5. Measurements Needed:

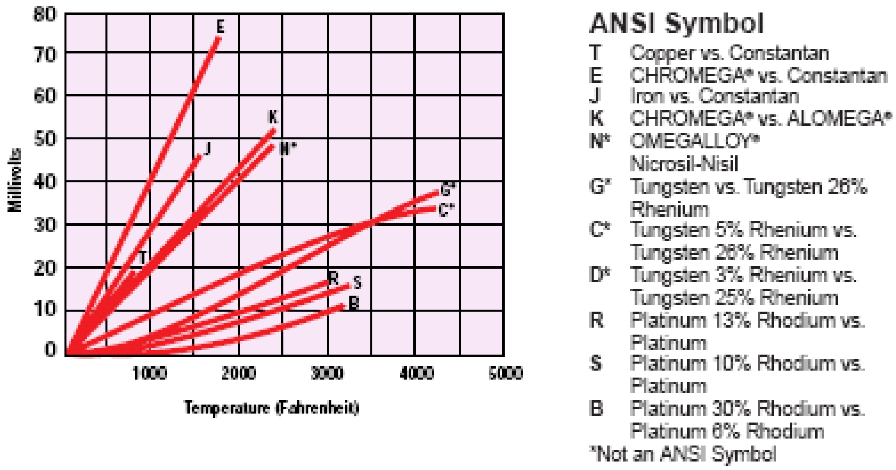

Figure 1. Various thermocouples' response (in voltage) as a function of temperature; of note, a Type-K thermocouple contains alumel (94% nickel, 3% manganese, 2% aluminum, 1% silicon) as the positive (+) electrode and chromel (90% nickel, 10% chromium) as the negative (-) electrode.

The measurements taken in this lab will enable the estimation of the time constant for a Type-K, exposed thermocouple. A few key characteristics of this measurement device are given in Figure 1. The measurements required in this laboratory are thus:

- Diameter (in) of the thermocouple junction
- Junction millivolts (mV) as a function of time
- Cold and hot bath temperatures (°F)

6. Instruments Needed and Accuracy:

1. One DMM; Fluke, model FLK115, 600 V, 0.01% FSO
2. One hotplate; Cadco model DR-1, 1500 W, 120 V, temp. range: 150 ^{o}F – 400 ^{o}F
3. One 300 ml Pyrex Beaker; 25 ml graduations
4. One 300 ml Plastic Beaker; 25 ml graduations
5. One OMEGA TAC 80B-K (Thermocouple to Analog Converter with internal reference junction (32 ^{o}F = 32 mV), 1 mV/^{o}F linearized output, and accuracy of ±7.2 ^{o}F (95%)
    a. w/Type-K thermocouple probe w/unshielded cable
    b. w/12 VDC / 120 VAC adapter
6. One banana-clip/male BNC adapter; Pomona Electronics, model 3957, 30 VAC, 60 VDC, 7" cable
7. One 75-ohm cable with two female BNC connectors; 500 VRMS, 1 m cable
8. One male BNC two-wire pigtail connector [black into Pinout 62 (AISENSE), Red into Pinout 68 (ACH0) on SCB-68 board (# 8) in Fig. 2]. Also, jump Pinout 62 with Pinout 27. L-Com, BC40, 15 cm cable
9. One NI SCB-68 data board and NI PCI-6013 DAQ board (E_{FSR} = ±10V, e_o = 0.5 x 0.305 mV = 0.153 mV, G = 1)
10. Frequency_Analysis.vi; Matlab; in-house vi
11. LabVIEW 2015

12. One micrometer (or caliper). Micrometer: Starrett, model T436.1XP-1, 0-1" range, 0.0001" vernier scale; Fowler Dial Calipers, model 52-0080704-0, 0-4" range, 0.001" graduations
13. One thermometer (Measurement range: ~0-10 ^{o}F to 220 ^{o}F). Cooper-Atkins, model 1051-03-1, 0-220 ^{o}F, +3 ^{o}F, 5 in length

7. Experimental Setup & Connections:

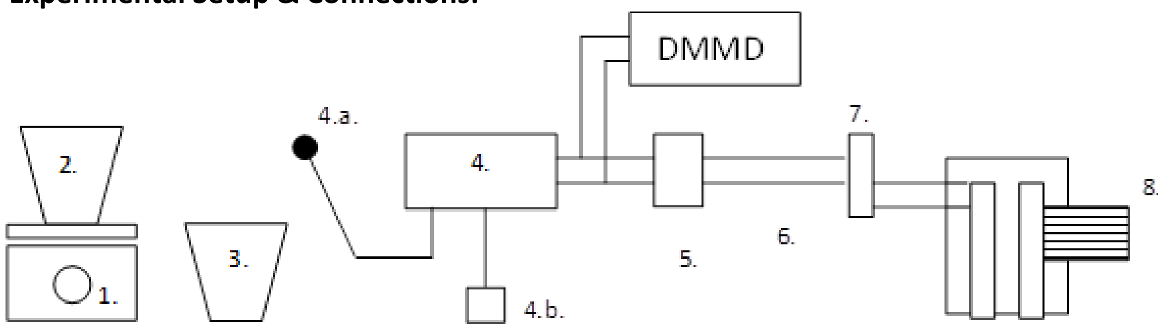

Figure 2. Connections (wiring) for experimental setup (refer to Equipment Required for Lab list for pieces of equipment corresponding to numerical labels in this figure)

8. Step-by-Step Procedure:

1. Fill the Pyrex beaker with water (about 2-inches high) and place it on the hotplate. Turn the hotplate to level 3-4; and monitor the water/hotplate while performing the next few steps. After several minutes, the water should be hot but not boiling. (Exercise caution in this lab as hot water [and the hotplate] can cause severe burns and damage equipment.)
2. Connect all of the components as shown in Fig. 2.
3. Measure the diameter of the thermocouple junction. Two "diameter" measurements will be required since the junction is not spherical. Record your values on the Raw Data Sheet then average them (no uncertainty analysis is necessary for this measurement).
4. As you did in Lab Exercise 2:
    a. Start LabVIEW 2015.
    b. Open the following LabVIEW VI: in My Documents, ME 455 Folder, LabView VIs sub-folder, open "Frequency_Analysis".
    c. Start the "Capture Waveform.vi". A screen similar to the one below will appear:

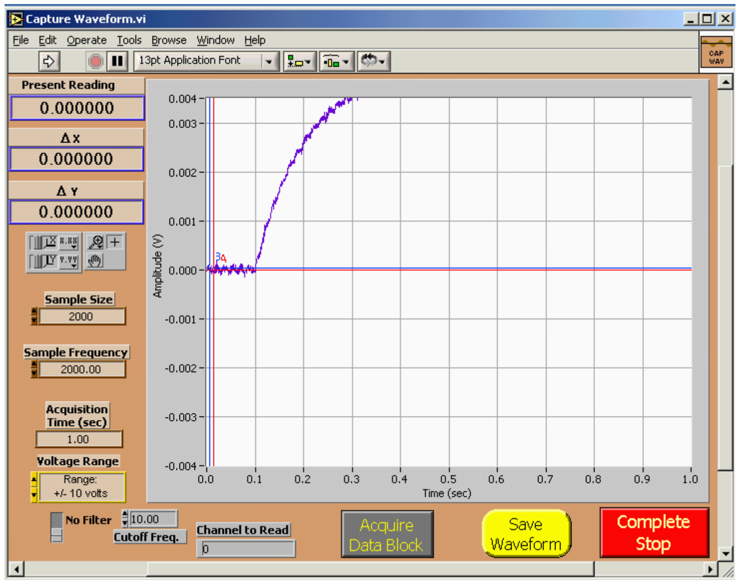

Figure 3. Opening screen for Capture Waveform.vi

d. Initial settings for this VI need to include: Voltage Range: ± 10V, Channel to Read: 0, and No Filter (should be default settings). Set the sample size (N) to 800. Set the Sample Frequency (f_s) to 400 Hz (nothing special about the chosen N or f_s). To clear the graph at any time, right-click on the graph and select Data Operations, then Clear Graph.

5. Add water to the plastic beaker - - about two-thirds full, add ice, stir the "mixture", and set the beaker aside.
6. Make sure the switch on the OMEGA TAC is in the ON position and that the temperature scale is switched to ^{o}F.
7. Press the 'Run' (right arrow) button on the front panel of the VI.
8. Stir the cold-water bath, insert the probe bath, and clip the probe to the plastic beaker's lip. You will note a value in the Present Reading display on the front panel. Once this value stabilizes to three significant figures record the mV reading in Table 1 on your raw data sheet [and record the temperature]. (Use the DMM to check the readings from LabView - - they should agree reasonably well. If not, there is a problem in the hookup; and you may need to check with a GTA.)
9. With the VI running, press the Acquire Data button and then quickly move the thermocouple probe to the hot water. (AGAIN – USE CAUTION WHEN MOVING THE PROBE).
10. When the VI finishes acquiring and displaying the data block, return the probe to the cold-water bath. Record the hot water bath data in Table 1 - - voltage and temperature.
11. You are now ready to measure the time constant. You will do this using the graph displayed in Fig. 4. Note the two pointers (cross-hair lines) on your VI (labeled 'A' and 'B'). Set pointer A just after the start of the rising edge of the waveform. Set pointer 'B' at a voltage where the curve has flattened (steady-state conditions appear to have developed). Note the behavior of the pointers as you move them around.

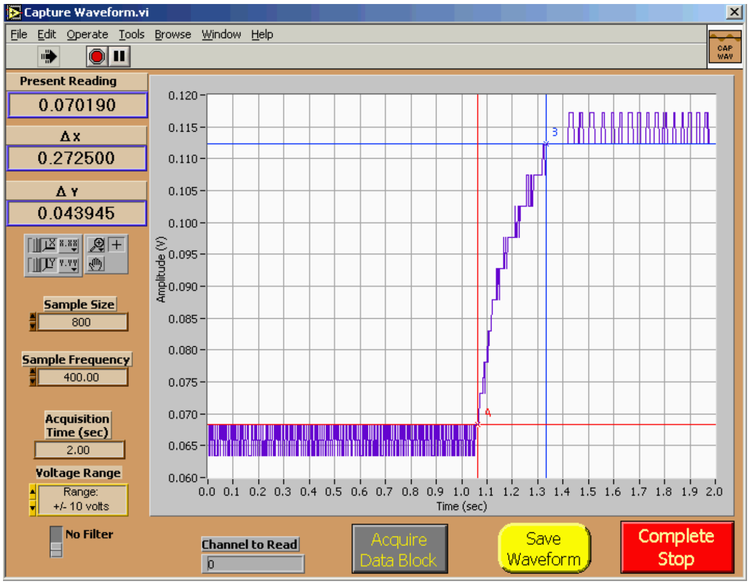

Figure 4. Example thermocouple response curve captured by LabVIEW

12. The VI will display the Δx and Δy values for each cursor. Use the cursors to find the total change for voltage (Δy). Record this value in Table 1.
13. Calculate the value of the voltage that corresponds to 63.2% of Δy. The time at which the temperature reaches this value is one time constant.
14. Determine the value of the time constant by leaving the pointer 'A' at the beginning of the change and setting pointer 'B' so that the new Δy value is equal to that calculated in Step #13. Record the difference in time between the 'A' and 'B' pointer locations (Δx) in Table 1.

9. Number of Test Runs/Repetition:

15. Repeat steps 7-13 so that you have 5 readings with the FILTER in the OFF position and 5 readings with the low pass FILTER in the ON position (cutoff frequency should be set at 10 Hz). Make sure that the cold-water bath voltage is close to when you started (be patient). The cold bath temperature will slowly rise during the course of your experimentation.
16. When all of the data has been taken, exit LabVIEW being sure to say '**DON'T SAVE SUB-VIs**' to the request to save changes. No data files are needed for the lab assignment.

10. Statistical Analysis:

Here we should document what type of statistical analysis is required for this laboratory

11. Data Analysis & Results (aka Deliverables):

The data analysis required by this laboratory includes turning in the worksheet on the next page [with the questions answered] for this exercise. Moreover, attach the completed Table 1 (on an accompanying page) and Fig. 5 (on page 12 of this handout): 'Metal Sheathed Thermocouple Probe Time Response Study in Water'.

11. Data Sheets

ME 455 Exercise 6 Worksheet Questions (Due Mar. 3, 5 or 9, 2009 in Lab Session)

Name: ___________________________________

Lab Session: ______________________________________

Date Turned In: ____

1. Why is there noise in the unfiltered signal?

2. Why is the cold-water bath voltage not 32 ^{o}F? Why is the reading of the cold-water bath reasonable? When should the bath voltage read 32 ^{o}F?

3. What benefits were observed in using the digital filter?

11. Data Sheets

ME 455 Exercise 6 Worksheet Questions (Due Mar. 3, 5 or 9, 2009 in Lab Session)

Name: ___________________________________

Lab Session: ______________________________________

Date Turned In: ____

4. Would applying the filter increase your confidence in estimating the true value of the time constant? Explain?

5. Using the measurements of your thermocouple junction, plot the average filtered time constant point on the following manufacturer's graph (Fig. 5) with standard deviation (S_x) noted (i.e., draw a range above and below the mean value to indicate the range of possible values within one sigma (68.3%)). ***Does it appear to agree with the manufacturer's data?*** (The y-axis is the time constant). ***Explain***.

11. Data Analysis & Results

ME455 Exercise 6 Raw Data Sheet

Name: ____ **Date:** __________________

Group# (members): ____

Thermocouple Junction Diameters

D_1 (in):________ D_2 (in):___________ D_{avg} (in):___________

Table 1. Experimental data.

Reading (repeated data taken)	Cold Bath Voltage (V)	Cold Bath Temperature (measured by thermometer) (°F)	Hot Bath Voltage (V)	Hot Bath Temperature (measured by thermometer) (°F)	Delta-Voltage - Δy - (V)	63.2% of Δy (V)	Corresponding Δx (s) at 63.2% of Δy; which is ?

Without - Filter

1.							
2.							
3.							
4.							
5.							
x_{avg}							
S_x							

10. Statistical Analysis

With 10 Hz Lowpass Filter

7.							
8.							
9.							
10.							
x_{avg}							
S_x							

10. Statistical Analysis

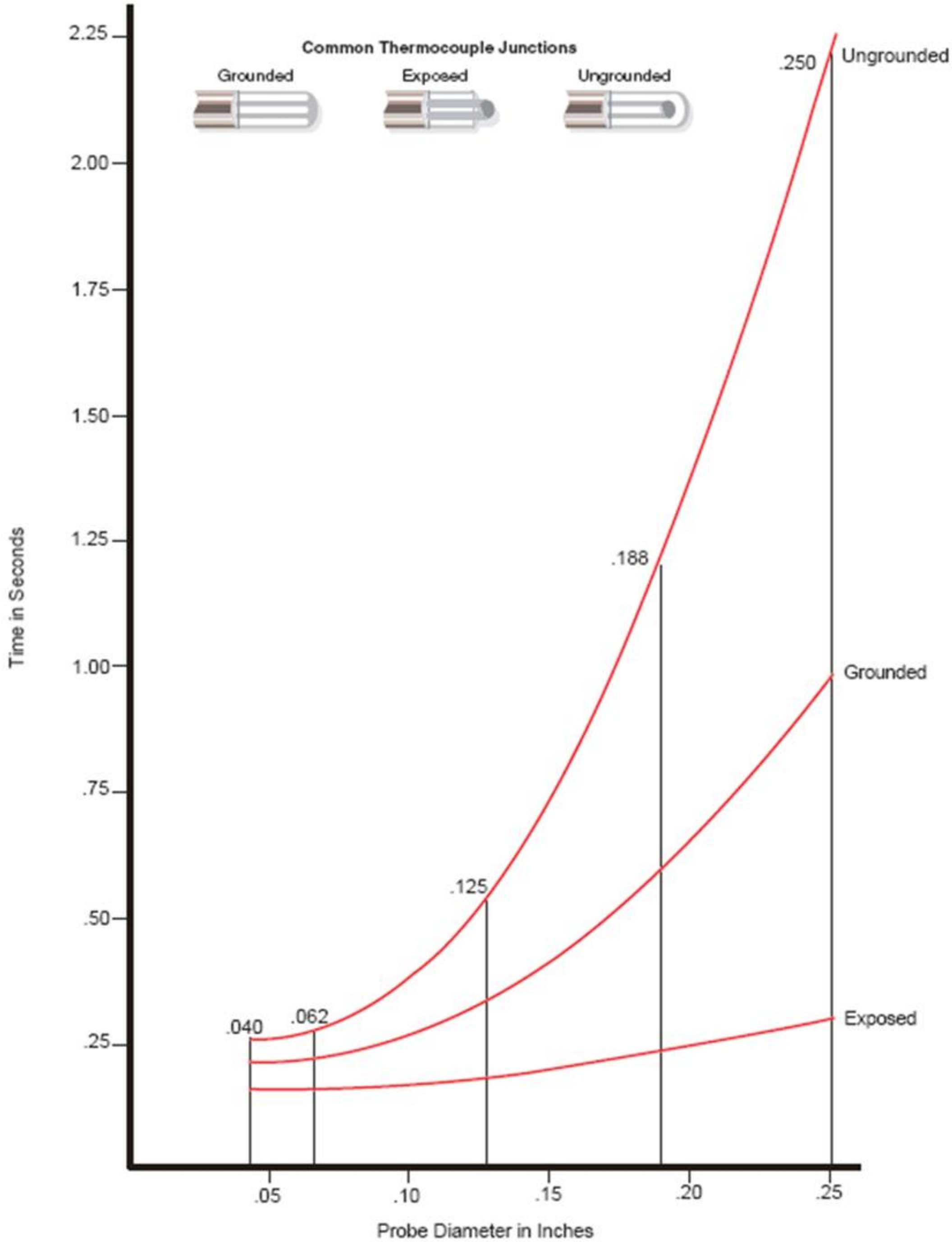

Figure 5. Metal Sheathed Thermocouple Probe Time Response Study in Water

12. Revision of Testing Procedure:

This is where we provide examples of what would be required in a revision.

13. Conclusions:

This is where we provide an example conclusion based on the findings.