Mechanical Engineering

Laboratory Handbook

School of Engineering
University of Portland

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SECTION I – MECHANICAL ENGINEERING LABORATORY CURRICULUM

A. Introduction

Experimentation and testing are at the root of modern engineering practice. While computer modeling allows significant analysis and design to be completed prior to hardware testing, the need for proper testing and experimentation is as great as it has ever been. Laboratory work is vital for improving and developing products and processes, validating designs and for gaining fundamental understanding of how materials, parts, components or systems will behave under a variety of conditions. As such it is essential that mechanical engineering students be able to work productively in this setting.

B. Purpose of this document

The Mechanical Engineering curriculum at the University of Portland requires students to take a variety of lecture and laboratory courses. Due to the nature of the way the curriculum is structured, at times students have the impression that there is little interrelation between the various courses they take. This is far from true. While students take laboratory courses in different mechanical engineering specialties (materials, fluids, thermodynamics, etc.), there is much in common between all laboratory and lecture courses. The purpose of this booklet is to provide a reference for students that is applicable in all engineering laboratories.

While all aspects of this booklet are relevant and important in any laboratory, certain aspects will be emphasized and taught more formally in specific course. In future courses, it will be assumed you are knowledgeable of the things you learn in the first labs.

This booklet does not attempt to cover any subject to any great depth, so the reader is referred to various sources where a greater knowledge may be acquired. This booklet is mandatory for all laboratory courses in Mechanical Engineering at the University of Portland. It is provided free of charge in EGR270, but will ***not*** be handed out to students in other courses. Therefore, students are responsible for keeping their own copy.

C. Purpose of laboratory work

The purpose of laboratory work is to study how something will actually behave. It is a supplement for analysis – ***both*** analysis and laboratory work are critical aspects of engineering design. Laboratory work may reveal faulty assumptions not identified during analysis. It may identify strengths or weaknesses overlooked in the analysis. Only through experiments and testing can the true behavior or performance of materials, components and systems be revealed.

The scale of the laboratory work may be large or small:
-small scale testing of materials or components
-scaled up system or component testing
-full scale testing (controlled conditions)
-field testing – actual use

D. Laboratory use in the School of Engineering

The University of Portland, School of Engineering laboratories exist for the use of its student's and faculty. Unlike large research institutions, undergraduates have ready access to all of the School's laboratories. Students typically use the laboratories either directly for a course or to acquire data for a project independently. In any case, students must understand that access to the laboratories is a privilege and not a right. This privilege is granted or revoked by the engineering faculty.

As part of professionalism, students must demonstrate proper respect for the School's laboratories, tools, and equipment. Common sense dictates:

- ❖ Do not borrow something without first asking permission. This includes laboratories themselves, tools and equipment. Before removing something from a laboratory, instructor permission must first be received and you must sign for the item (there is a sign out sheet in each laboratory). If there is no sign out sheet, contact the instructor.
- ❖ Do not use equipment, tools, or chemicals that you are unfamiliar with – this can lead to damage or injury.
- ❖ If you use the laboratories, make sure they are clean when you are finished. Return all used items to their proper place. Leave them in the same condition, or better, than you found them in.
- ❖ If you break or lose something, inform the appropriate faculty or staff.
- ❖ **NEVER work alone**! Even if you are not working with dangerous equipment, never work in the labs by yourselves! Strange accidents can happen. Medical emergencies can happen. If you are caught working alone you may lose the privilege of using any lab.
- ❖ When completed using the labs for projects, all materials not belonging to the School must be removed.

E. Student participation in laboratory courses

In the professional world, laboratory work does not just happen by itself. Testing is often relatively expensive and significant planning and preparation is required to make it economically justified. After the testing is complete, communication of the results is essential (oral and written). It is no different in an educational environment. In order to learn from the laboratory, students must be active participants doing all pre-lab and post-lab work. Students must learn not only how to conduct laboratory work, they must also learn how to plan it and they must learn to communicate the results in various formats (memoranda, letters, reports, oral presentations, etc.).

Prior to conducting a laboratory exercise, students should understand the purpose of the laboratory, the procedures and equipment to be used, the instrumentation and measurements required, and they should understand any analysis they will need to perform. A data sheet for recording results must be prepared *prior* to the laboratory. Each instructor may have different requirements for laboratory classes. For more detailed information regarding laboratory planning see Section IV – Tests and Experiments in this handout.

F. Safety

Obviously, safety is of paramount importance and must never be compromised. Safety is the responsibility of the School as well as the students. Students must be aware of potential hazards and must never work in an area without first receiving proper training. Students must NEVER work alone in any laboratory or workshop, and before working they must receive permission from a faculty member. Other than direct use in a laboratory course, both the student and faculty must sign the *Work Space Permission* form located in each laboratory.

F.1 Material Data Safety Sheet

Material Data Safety Sheets (MSDS's) contain descriptions of chemicals used in the workplace. Primarily, they contain information about potential hazards. At a minimum, the following information is provided:

- Name and description of the chemical, including composition, physical and chemical properties.
- Identification of potential hazards and toxicity description (such as corrosive, may cause burns, dangerous if swallowed, may cause cancer, etc.).
- First Aid measures – describes what to do if improper exposure has occurred.
- Accident response measures, including spill clean up and fire fighting.
- Handling and storage recommendations.

By federal law (Occupational Safety and Health Act, OSHA), employers are required to provide employees easy access to MSDS's for all chemicals found in the workplace. If you work with or around chemicals in school or on the job be sure to review the appropriate MSDS so that you understand potential hazards. Be sure to use all recommended personal protection devices and safety measures.

SECTION II – STANDARDS

A. Standardized testing

The word "standard" can be defined as "something established as a rule or basis of comparison in measuring or judging capacity" (*Webster's New World Dictionary*). Engineering standards allow for uniformity throughout the engineering community. Their use is so ubiquitous that they go almost unnoticed and are taken for granted. Everything from phone jacks, to raw materials, to test procedures, to bolts and nuts conform to engineering standards. It is no exaggeration to say that it would not be possible for our economy to exist with out the use of standardized parts and testing.

Standardized testing is a critical component of engineering. Not only does standardization prevent the "reinventing the wheel" syndrome (the test procedures are already developed) they assure validity of the results and assist with analysis and communication. A simple example is the tensile test used for determining basic mechanical properties of a material. ASTM International (formerly, American Society of Testing and Materials) has developed a standardized test for tensile testing (standard E8). It describes such things as valid geometry for test specimens (if they are too short and wide, uniform stress may not be present, and the results of $\sigma = F/A$ may not valid), strain rates, temperature, and so forth. When communicating the results of such a test, to describe the test procedures the author need only state "testing was conducted per ASTM E8."

B. Measurement standards

Unlike testing standards, which are primarily documents describing test specimens, conditions and procedures, measurement standards are physical entities and define what basic units of measure are. Measurement standards are an essential part of commerce and engineering. So much so that Article I, Section 8, of the U. S. Constitution grants power to congress "To coin money, regulate the value thereof, and of foreign coin, and **fix the Standard of Weights and Measures**". Without measurement standards, a pound of hamburger purchased from Safeway might actually weigh more than a pound of hamburger purchased from another store – what is a pound? How long is one foot? How cold is 10ºC? We need to define what we mean by the various units of measure, and standards do just that.

Measurement standards define the unit of measure. Table 1 is a list of the definitions of the ***primary*** standards. The standards *define* the variable. For example, the distance light travels in 1/299,792,458 seconds in a vacuum ***is by definition*** one meter. Inversely, the speed of light is now ***defined*** as 299,792,458 meters per second.

Table 1 – Definition of the seven physical variables comprising the primary standards.

Physical variable	Unit	Standard
Mass	Kg (lb_m)	platinum-iridium cylinder (France) (1 lb_m by definition equals 0.4535924 kg)
Time	second	9,192,631,770 periods of "oscillation" of cesium-131
Length	meter	distance light travels in 1/299,792,458 seconds
Temperature*	kelvin	complex, 1 kelvin unit is 1/273.16 thermodynamic triple point of water*
amount of a substance	mole	number of atoms in 0.012 kg of carbon-12
light intensity	candela	emission of $540X10^{12}$ Hz radiation at 1/683 watt per steradian
electric current	ampere	current to produce $2X10^{-7}$ N per meter between 2 wires, 1 m apart

*Temperature isn't so easy to define, but rather must be defined at discrete points:

Fixed point	Temperature (K)
Triple point of hydrogen	13.8033
Triple point of neon	24.5561
Triple point of oxygen	54.3584
Triple point of argon	83.8058
Triple point of mercury	234.3156
Triple point of water	273.16
Melting point of gallium	302.9146
Freezing point of lanthanum	429.7485
Freezing point of tin	505.078
Freezing point of zinc	692.677
Freezing point of aluminum	933.473
Freezing point of silver	1234.93
Freezing point of gold	1337.33
Freezing point of copper	1357.77

Triple point: the temperature at which solid, liquid and gas phases coexist.

(Source: Wheeler and Ganji, Introduction to Engineering Experimentation, Prentice Hall1996)

Measurement standards must have global availability (so they can be used where they are needed), they must be stable (so they don't change with time), and they must be traceable (so validity can be assured).

The standard for mass is a "fixed" object (artifact) kept in a vault at the International Bureau of Weights and Measures in France. This artifact is by definition 1 kilogram. In the United States, NIST maintains mass standards for kilogram and pound-mass. The other primary standards are “reproducible” in a properly equipped laboratory. Other physical variables are derived from these fundamental physical variables. For example, stress involves measuring length (to calculate area) and force. Force is based on mass and acceleration, and acceleration is based on time and length.

Standards are essential in calibrating measurement devices. The only way to know that the micrometer used in a laboratory to measure the diameter of a bar is “accurate” is to compare its measurement to a standard. Since it is not practical to have all micrometers calibrated based on the definition of a meter, secondary standards are used. Secondary standards are typically a physical artifact and are relatively easy to use for calibration. Gage blocks are the secondary standards for length. These are pieces of metal whose length is known precisely. Standards exist at various hierarchies:

Primary standards or reference standards – The standard (Table 1)
Inter-laboratory transfer standard - used within labs
Local standards - used by Calibration labs } Secondary standards
Working instrument - end user

Each level or hierarchy ***must*** be traceable to a higher level, up through to the primary standards. So the local standard used to calibrate micrometers must have been compared to either inter-laboratory transfer standards or directly to a primary standard. “Error” or uncertainty increases with each step away from the primary standards.

C. Calibration and certification

Calibration determines the uncertainty (error) of a measurement device by comparing its measurement with the appropriate measurement standard. Certification is the documentation of the calibration. In order for a measurement to be valid for engineering purposes the measurement device must be calibrated and certified. Certification almost always has a time limit. If the calibration has expired, even if nothing else has changed, then the measurement should not be considered to be reliable for engineering purposes.

Even if a piece of equipment is calibrated and certified, to assure accuracy is maintained it is common for operators to check the calibration prior to and after taking measurements. A common example includes using NIST traceable hardness calibration blocks before and after a series of hardness measurements (perhaps at the beginning and ending of each shift).

Measurement equipment used in school laboratories often is not calibrated or the calibration has expired. Calibration can be quite expensive (several thousand dollars to calibrate a tensile test machine’s load cell) so it is typically not justifiable for education purposes. Not having calibrated equipment does not mean the measurements are grossly in error, it just means you do not know the uncertainty of the measurement.

D. Organizations

Professional societies and other organizations play a very significant role in establishing and maintaining codes and standards. Anyone who has changed the oil in a car is familiar with SAE oil weights such as SAE 10-40. These are viscosity standards created by the Society of Automotive Engineers (SAE). Engineers should be familiar with the societies and organizations in their field and be sure to understand the relevant codes and standards (codes are standards that have been adopted by a government agency or business contract and are enforceable by law). The following are a few of the more prominent organizations related to measurement standards:

NIST – National Institute of Standards and Technology. NIST was formerly the National Bureau of Standards created by US Congress in 1901 (prior to this, standards were controlled by the US Treasury). NIST is not a professional society, rather it is the government agency mandated by the US Constitution responsible for assuring fairness in weights and measures. It is responsible for defining and providing measurement standards in the United States. All measurement standards in the US must be traceable to NIST. NIST Laboratories, located in both Gaithersburg, Maryland, and Boulder, Colorado, conduct research in a wide variety of physical and engineering sciences. The labs respond to industry needs for measurement methods, tools, data, and technology.

ISO - The ISO is a worldwide federation of national standards bodies organized to promote the development of standardization and related activities in the world with a view to facilitating the international exchange of goods and services, and to developing cooperation in the spheres of intellectual, scientific, technological and economic activity.

BIPM - International Bureau of Weights and Measures is the English name of the *Bureau international des poids et mesures* (BIPM). It is one of the three organizations established to maintain the International System of Units (SI) under the terms of the *Convention du Mètre* (Metre Convention). It is based at the Pavillon de Breteuil in Sevres, France. The task of the BIPM is to ensure world-wide uniformity of measurements and their traceability to the International System of Units (SI). The other organizations which maintain the SI system are:

- CGPM - The General Conference on Weights and Measures (CGPM, Conférence générale des poids et mesures).
- CIPM - The International Committee for Weights and Measures (CIPM, Comité international des poids et mesures).

Some prominent professional societies and organizations that are involved with developing standards for parts, processes, and materials include:

U.S. Military – has numerous standards (MIL-STD) for contractors doing defense business. The standard governing measurement and calibration is MIL-STD-45662A.

AGMA – American Gear Manufacturers Association. Since its founding in 1916 it has diversified and broadened its services to include both technical standards and business management practices for America and the world.

ASTM International (formerly, American Society of Testing and Materials) ASTM International is an international voluntary standards organization that develops and produces technical standards for materials, products, systems, and services. Today, ASTM International maintains more than 12,000 standards. The Annual Book of ASTM Standards consists of 77 volumes. Members represent manufacturers, users, governments, and academia from over 100 countries. ASTM Standards compliance is voluntary but in the United States, with the 1995 passage of the National Technology Transfer and Advancement Act, the U.S. government is required to use privately developed standards whenever possible. As a result, ASTM Standards have been incorporated into or are referred to by many federal regulations.

ASHRAE – American Society of Heating Refrigeration and Air conditioning Engineers. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE; pronounced 'ash'-'ray') is an international technical society for all individuals and organizations interested in heating, ventilation, air-conditioning, and refrigeration (HVAC&R). ASHRAE publishes a well recognized series of standards and guidelines relating to HVAC systems and issues. These standards are often referenced in building codes.

ASME International – The American Society of Mechanical Engineers (ASME) is a professional organization focused on mechanical engineering. The ASME was founded in 1880 by Alexander Lyman Holley, Henry Rossiter Worthington, John Edison Sweet and Matthias N. Forney in response to numerous steam boiler pressure vessel failures. The organization is known for setting codes and standards for mechanical devices.

ANSI – The American National Standards Institute or ANSI (pronounced "an-see") is a private nonprofit organization that oversees the development of voluntary consensus standards for products, services, processes, systems, and personnel in the United States. The organization also coordinates U.S. standards with international standards so that American products can be used worldwide.

AWS – American Welding Society. The mission of the American Welding Society is to advance the science, technology and application of welding and allied joining and cutting processes, including brazing, soldering and thermal spraying. It creates standards for welding materials and processes.

SAE – SAE International (SAE) is a professional organization for mobility engineering professionals in aerospace, automotive and the commercial vehicle industries. The Society is a standards development organization for the engineering of powered vehicles of all kinds, including cars, trucks, boats, and aircraft.

SECTION III – MEASUREMENT AND ANALYSIS

A. Types of errors (systematic and random)

Measurement error is the difference between the true value and the measured value:

error = measured value - true value

The "true" value is the value one would obtain with a perfect measurement. Since there is no such thing as a perfect measurement, the true value can never be known (with the exception of measuring the original artifact – for example the 1 kg mass in France). Since the true value can never be known, the error can never be known exactly – it can only be estimated using statistical analysis. Error or uncertainty is inherent in every measuring device; there is no such thing as a perfect measurement.

Errors are not only inherent in measuring devices, but due to extraneous circumstances, uncertainty (error) exists in experiments and tests themselves. These are referred to as experimental errors. In any experiment, two types of error can exist: systematic and random.

Systematic errors

- Systematic errors are caused by underlying factors (extraneous variables) which affect the results in a "consistent/reproducible" and sometime "knowable" way – they are not random. For example, measuring the length of a bar at various times of the day may result in errors due to temperature changes.
- A danger with systematic errors is that they can lead to **false conclusions**! It is important to not confuse correlation with causation. For example, let's say you wanted to know which of two different brands of electrical switches have longer life. You receive 10 samples of each brand for testing. You can only test one switch at a time and you choose to test all 10 of brand A's switches before testing brand B. The test shows brand A's lasted 50% longer on average. So you conclude brand A is better. Then someone points out to you that the ambient temperature during the testing of brand A was generally much cooler than when brand B was tested. Did brand A last longer because they were better or because it was cooler? Since lower temperature may have improved the life of the switch, it may have caused systematic error in this experiment. Based on this experiment you can not know why brand A lasted longer. This experiment was a *total* waste of time and resources! It was worthless. A better experiment would have involved randomizing the order the switches were tested. Even alternating between brand A and brand B (test A, then B, then A, then B…) could introduce systematic error. Randomizing the order of test conditions is the best way to avoid reaching false conclusions due to systematic errors.

- Systematic errors can be managed by properly designed experiments (randomize!). Remember, **correlation is not causation!**
- Some causes of systematic errors include:
  - Slow but consistent changes in temperatures
  - Different batches of material or samples
  - Different machines, operators, measurement tools, etc.
  - Unknown changes in procedures (an operator may not be familiar with a certain task in the procedure, but "improves" over time as the experiment progresses).

Random errors

- Random errors show no reproducible pattern – they are random.
- Random errors are sometimes referred to as "noise."
- Random errors are usually assumed to have normal distribution (bell shaped); therefore, averaging several readings can reduce random errors.

B. Basic statistical analysis

In EGR360-*Analaysis of Engineering Data*, students are taught basic statistical tools. The most basic of these include means, standard deviations, and linear regression. It is not the purpose of this document to provide in depth discussion of statistical tools, but students involved with designing, conducting, or analyzing an experiment or test should review basic statistical methods.

Due to its importance and lack of familiarity amongst many students, one particular statistical tool is worth a very brief review. Let's look at our switch example from above. Assuming it was properly randomized so systematic errors are not introduced, if brand A's last an average of 20% longer than brand B, is brand A truly better? Comparing the averages is NOT sufficient to answer that question! The best way to answer this sort of question is with the t-test. The t-test incorporates both the standard deviation of the data as well as the means to estimate a probability that one set of data is different than another set (A is better than B). Further explanation of the t-test is beyond the scope of this document, but it is assumed that students have the ability to refresh their memories.

SECTION IV – TESTS AND EXPERIMENTS

A. Tests verses experiments

Many people use "experiment" and "test" synonymously, but they can mean two very different things. They are similar to the extent they both typically involve collecting data in a laboratory setting. However, the two may be more clearly delineated as follows:

Testing

- Often evaluates performance of something (for example a test could determine the strength of a new material).
- Often has a "pass/fail" criteria (for example, it may answer the question does a product meet the strength requirements).
- Often is performed per an existing standard, method, or procedure.

Experiments

- Requires changing one or more variables to determine its effect on one or more dependent variables.
- Not associated with pass/fail, but rather evaluate "better/worse"
- Conducted to learn how things work or perform under differing conditions
- Conditions may be included where the outcome is known to be "bad"

Proper design of an experiment or test often requires balancing competing criteria, as does designing components. Cost, time, available equipment, control over variables, confidence in the outcome, etc. must all be considered. All experiments and tests require careful interpretation! Before relying on test results, you must understand how the data was created and was analyzed.

B. Variables

Variables are physical quantities that may or may not affect the results of an experiment or test. There are several types of variables associated with any test and experiment.

Controlled – these are variables whose level (magnitude, setting, value) are controlled. They may be held constant or intentionally varied. For example, temperature may be held constant (so that unintentional effects of temperature variation are not introduced) or it may be intentionally set to various levels (40°F and 60°F for example) in order to study the effect of temperature change.

Extraneous – variables that are not controlled and are considered to have no effect on the experiment or test are considered to be extraneous. For example, in an experiment conducted to determine the boiling point of a liquid, an extraneous variable might be how quickly the liquid is heated.

Dependent and Independent variables – the magnitude (value) of dependent variables are dependent upon other variables whereas the magnitudes of independent variables are not. For example, in an experiment to determine the effect of temperature change on the toughness of AISI 1045 steel, then temperature would be an independent variable and toughness would be a dependent variable.

Discrete – sometimes referred to as "attribute data". These are variables that cannot be quantified. For example, in an experiment to determine what manufacturing method results in a better part, a forging or a casting, then "manufacturing method" would be a discrete variable. Other examples include "operator" "machine" and "material batch".

Continuous – these are variables that are quantifiable. For example, an experiment might want to determine the effect of carbon content on the toughness of steel. "Carbon content" is a continuous variable since it can be varied continuously.

C. Test plans and experiment plans

References:

Wheeler and Ganji, *Introduction to Engineering Experimentation*, Prentice Hall, 1996.

J. P. Holman, *Experimental Methods for Engineers*, McGraw-Hill, 2001

No test or experiment should ever be conducted without a well thought out plan. The plan should include most or all of the following:

1) A clear description of the purpose (why is this being done).
2) Background information - explanation as to why the test or experiment is being conducted, what are similar test or experiments (including standardized tests) and any other information to "set the seen" for the experiment or test. Don't forget to cite references! See the School of Engineering's *Writing for Engineers* for description of backgrounds in general.
3) Description of all test variables (dependent, independent, and extraneous) and their levels (magnitudes, values).
4) Explanation of the experiment's design (what will be done to reduce systematic and random errors, what will be done to ensure valid results). The level of testing should be justified or explained (for example, is this a "low cost" experiment because spending more resources is not justified? Explain). Briefly discuss any standardized tests to be used.
5) Detailed description or list of required resources:
   a) Materials and test specimens (be sure to include extra materials and specimens for pre-test trials and mistakes that may occur during testing that may "ruin" the specimens).
   b) Personnel and expertise
   c) Instrumentation, transducers and measurement tools
   d) Equipment and fixtures
6) Estimated cost and schedule

7) Procedures and methods clearly described
8) Sketches of samples or specimens
9) Sketches of experimental setup
10) Analysis plan. Describe what analysis will be conducted and what methods will be used to analyze and interpret the data.
11) "Data sheet" (a.k.a. "check sheet" or "run sheet" – a table or similar document showing the conditions of the experiment with blanks values to be recorded during the experiment. It must include variable names and units). A hardcopy of the run sheet should be created even if all data is to be recorded electronically.

When designing an experiment, students are encouraged to avoid the "one variable at a time" approach. Such experiments rarely produce meaningful trustworthy results. Again, discussion of alternatives is outside the scope of this document, but students are encouraged to seek advice on experimental designs before investing significant resources on a worthless experiment. Statistical Design of Experiments (DOE) is a powerful tool to optimize limited resources.

Data Sheets

Laboratory data sheets are used to record critical information prior to and during laboratory work. They are created during the planning stages of an experiment (pre-lab work). They should be sufficiently detailed so as to record all critical information including hardware to be used and the data recorded. They should include the following where applicable:

- Name of the experiment
- The name of the participants.
- The name of the person recording the data.
- The date(s) that the laboratory was conducted.
- Description of test equipment and fixtures (including model and identification numbers).
- Description of measuring instruments and transducers (including model and identification numbers and calibration dates).
- To assist with data taking, a sketch of the laboratory setup including location of the transducers may be required.
- A table or list with blank places to record the data. It must be clear in this table what the test conditions are for each set of data. The blanks should appear in the order they are to be filled in. The data may include extraneous, dependent, and independent variables. If data is recorded electronically, a printout of the data should be attached to the data sheet at the completion of the laboratory.

D. **Example Plan (University of Portland)**

The following is an example of a simple experiment plan to determine the stress near a hole in a plate.

<u>Purpose</u>

The purpose of this experiment is to determine the axial stress near a hole in a flat plate of steel. The simple test specimen is based on an actual part being designed for a landing gear in a small aircraft and a correlation between the stress and applied force is desired to assist with designing the part.

Background:

Holes in parts are known to cause stress concentrations (localized increase in stress). For the sake of designing an aircraft part with such a stress concentration, it is desired to know if a linear relation exists between the applied axial load and stress near the hole.

Test Variables:

- Extraneous
  - Ambient temperature
  - Ambient humidity (will not be recorded)
  - Material variability of test specimen (not evaluated or measured)
  - Surface finish of the hole (will not be measured)
- Controlled variables
  - Magnitude of applied force
  - Load rate
  - Specimen geometry and material specification
  - Location and orientation of strain gages
- Dependent variables
  - Strain at three locations near the hole (see Figure 1)

Experiment Design

A simple relation between load and stress is desired to aid with design. A high degree of accuracy is not required for this experiment, and therefore only one specimen will be used. Uncertainty created by lot-to-lot variability of the material, strain gage orientation and positions, and other similar variables are assumed to be negligible. The run order of the applied force will be randomize to reduce systematic errors, and the experiment will be repeated once to assure the effects of plastic deformation potentially introduced by the experiment are evaluated.

Required Resources

Equipment and materials required for preparation

- One specimen (see Figure 1)
- Strain gage application materials and tools (wire, adhesive, solder, soldering iron)
- Three uniaxial single strain gages (Vishay, p/n 015LA).

Equipment and materials required for experiment

- Thermometer (for measuring ambient temperature)
- Digital Strain Indicator, Switch and Balance Unit
- SATEC load frame with specimen clamping fixtures
- Calipers

Personnel skills required:

- Applying strain gages

Measuring strain using strain gages
Using SATEC load frame and recording loads.
Machining skills to manufacture the test specimen

Estimated Cost and Schedule

Estimated costs are $1500 total

$200 specimen
$100 gages and consumables
$200 mounting the gages
$500 test frame time
$500 analysis and report writing

All required equipment is available in-house.

The experiment will take approximately 8 weeks from the start:

4 week – manufacturer specimen
1 week to mount strain gages
1 week for load frame (for schedule – actual testing time, 1 day)
2 weeks analysis and report writing

Pre-experiment Procedures

1) Obtain or manufacture test specimen
2) Apply strain gages to the specimen
3) Wire the strain gages

Experiment Procedures:

1) Measure the specimens width, thickness, hole diameter, and edge margin.
2) Load specimen in SATEC clamping fixtures making sure the axis of the specimen is aligned with the SATEC axis.
3) Attach the strain gage wires to the Digital Strain Indicator and Switch and Balance Unit.
4) Check the continuity of the strain gages to ensure they are functioning.
5) Prior to applying load, null the load cell and strain gages.
6) Apply five loads of various magnitudes according to the data sheet, unload before reloading.
7) Record the strain levels on each of the three gages.

Sketch of Test Specimen
All dimensions are inches (not to scale)
Material: AISI 4140 Q&T

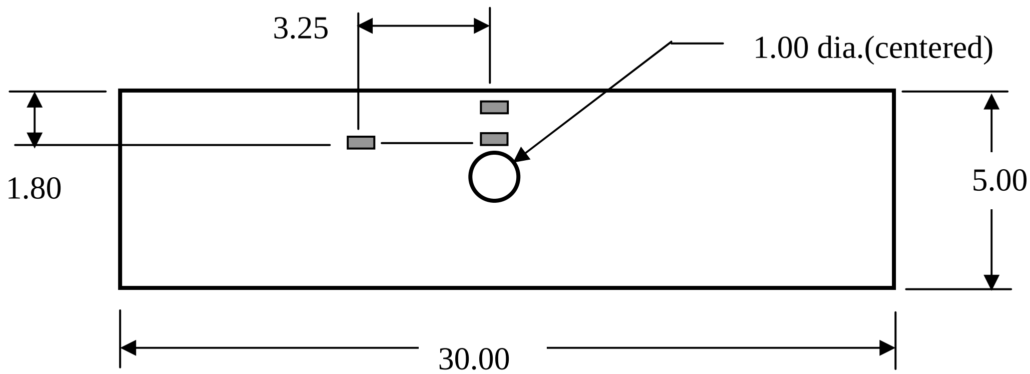


Figure 1 – test specimen sketch

Sketch of Experiment Setup
The specimen should be centered in the grips

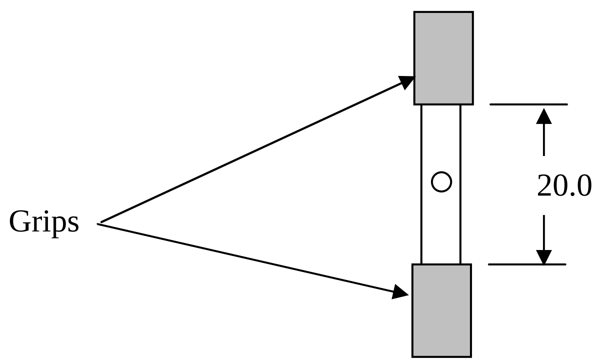


Figure 2 – sketch of specimen in grip fixtures

Analysis Plan

The stress values from the three gages will be plotted on an x-y scatter plot and the linear regression will be calculated to determine if a linear relation between force and strain is produced. Stress is calculated as:

$$\sigma = E*\varepsilon$$

Where σ is the axial stress, ε is the axial strain measured by the strain gages, and E is Young's modulus (30Mpsi for steel).

Data Sheet

Experiment title: strain near hole in plate due to axial load.

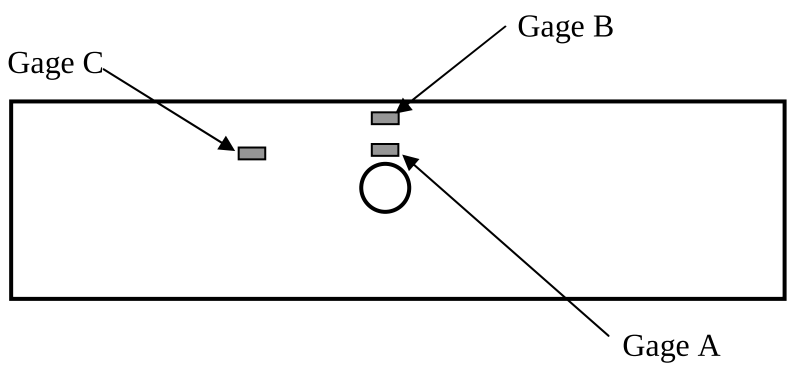
Experiment conducted by:______________________________

Data recorded by:_____________________________________

Date(s) conducted_____________________________________

Equipment:

Description	Model	Serial number	Calibration due date
Calipers			
Thermometer			
Strain gage meter			
SATEC load frame (with clamp grips)			



Test specimen and gage identification

Data:
Controlled variables:
Load rate is to be 100 N/sec +/- 10N/sec
Extraneous variables:
Ambient room temperature at start of test_____________˚C

Experiment run table:

Run	Load set point (kN)	Actual load (kN)	Actual load rate (N/sec)	Strain Gage A (microstrain)	Strain Gage B (microstrain)	Strain Gage C (microstrain)
1	5					
2	20					
3	15					
4	10					
5	25					
6	20					
7	15					
8	5					
9	25					
10	10					

Ambient room temperature at end of test________________˚C

E. Example Plan (Freightliner)

An example of a different test plan is shown below (courtesy of Freightliner). Note the judicial use of test standards used to describe the procedures. It does not include a data sheet nor does it contain all of the elements described above. It is provided here not as an example of an appropriate test plan at the University of Portland, but rather to show one example of a test plan used in industry.

Methods and Equipment

Testing will be conducted in accordance with the following documents:

Freightliner Engineering Procedures

Calibration and Maintenance of Test Equipment	09TE-S02
Test Engineering Process	09TE-S03
Load Dump Tester Operation	09TE-K15
Thermotron Model SM16C Temperature/Humidity Chamber Operation	09TE-K16
Operation of Electrostatic Discharge Simulator Testing	09TE-K17
Steady State Conditions Voltage Test Guidelines	09TE-K18
Inductive Switching Tester Operation	09TE-K22
Suspension Spring Cycle Testing	09TE-K23
EM Test MPG 200 Micro Pulse Generator	09TE-K26
EM Test LD 200 Load Dump Generator	09TE-K27
Salt Fog Exposure Test and Chamber Operation & Maintenance	09TE-K50

Freightliner Engineering Standards

49-00085 Rev. A. Performance Requirements-Electrical/Electronic Module, sections 3.1 through 3.4.

SAE Publications

SAE J1455 Joint SAE/TMC Recommended Environmental Practices For Electronic Equipment Design (Heavy-Duty Trucks)

ASTM Publications

ASTM B117 Standard Practice for Operating Salt Spray (Fog) Apparatus

The test equipment used is listed in table 1 below.

Table 1 - Test Equipment

Description	***Model***	***ID#***	***Cal Due Date***
Digital Multi Meter	Fluke 26 III	EIL-19-043	01/12/00
Digital Multi Meter	Fluke 79	EIL-19-010	01/12/00
Digital Multi Meter	Fluke 23	EIL-19-023	01/12/00
Power Supply	Sorensen DCR 20-250A	Asset 99173	N/A*
Power Supply	TCR 20S90-1	S/N 83M-4744	N/A*
Power Supply	H-P 6268B	S/N TE 628384	N/A*
Dynamic Load	Transistor Devices	EIL-14-016	05/26/00
Load Dump Tester	EM Test LD 200	Asset 923690	05/26/00
Inductive Switching Tester	EM Test MPG 200	Asset 923689	05/26/00
Load Dump Tester	Freightliner	N/A	N/A*
Inductive Switching Tester	Freightliner	N/A	N/A*
Electrostatic Discharge Tester	ETS 930C	EIL-24-014	5/27/99
Digital Oscilloscope (DSO)	Fluke 97	EIL-22-007	05/24/00
Digital Oscilloscope (DSO)	Fluke 97	EIL-22-008	05/24/00
Power Supply	EMI - SCR	158C	N/A*
Environmental Chamber	Thermotron SM16T	15-004	N/A*
Environmental Chamber	Cascade TEK TFO-1	0100499	N/A*
Thermocouple Amplifier	Fluke 80TK	EIL 34-011	05/19/00
Variable Load Tester	Sun VAT-33	N/A	N/A
Current Clamp	Fluke Y8100	EIL-20-001	5/26/00
Data Logger	Fluke 2635A	S/N 6838312	1/29/99
Controller	Compaq Portable III	S/N 4035HN4H008	N/A*
Data Acquisition Board	Kiethley DAS-8 Mini	N/A	N/A*

* These items are calibrated as part of the test procedure.

SECTION V - References

Beckwith, Marangoni, and Lienhard, *Mechanical Measurements*, 5th ed., Addison-Wesley Publishing, 1993.

Wheeler and Ganji, *Introduction to Engineering Experimentation*, Prentice Hall, 1996.