MASSACHUSETTS MARITIME ACADEMY

EN-3112L
Strength of Materials Lab

Contents

COURSE: EN3112L Strength of Materials Lab   **INSTRUCTOR:** LCDR G. M. Stephens
SEMESTER: Fall 2018   213A Harrington
ROOM: Br108   gstephens@maritime.edu
                                                                                                 (508) 830-5000 Ext 2042

OFFICE HOURS: Monday, and Wednesday 3rd period, Tuesday 3rd -4th period, Thursday 5th period or by appointment

COURSE DESCRIPTION: This laboratory reinforces the basic concepts of normal stress, shear stress, torsion, beam bending, beam deflection, and beam design as taught in the Strength of Materials course. Additional topics include: Izod and Charpy impact testing, compressive strength, and material hardness. Formal engineering reports are required with emphasis on writing and spreadsheet skills.

PREREQUISITE: Current enrollment in, or previous completion of, EN3112 Strength of Materials. **Note**: if you withdraw from the Strength of Materials class, you must withdraw from the lab. You may withdraw from the lab without withdrawing from the class.

TEXT: None

COURSE OBJECTVES: At the completion of this course, the student should be able to:

- o Conduct basic engineering experiments
- o Apply strength of materials concepts to physical systems
- o Analyze data and formulate engineering conclusions
- o Write professional technical documents
- o Organize and Display data in a logical and professional manner
- o Recognize the differences between theoretical and actual engineering systems
- o Work as a team to solve technical problems

CLASS SCHEDULE: This course meets once a week for 110 minutes in a laboratory setting.

GRADING: Lab Assignments/Quizzes – 75 %
                     Design Report - 20 %
                     Design Presentation - 5 %

NOTES REGARDING GRADING:
1. ALL written assignments are REQUIRED for successful completion of this class
2. Attendance and participation in the Design Presentation IS REQUIRED to pass the class

SUBMISSON POLICY:
1. All memoranda and/or lab reports are graded on an INDIVIDUAL basis and must be ORIGINAL work. If you are found to have used another student's work to complete your assignment, you are in violation of this requirement whether or not it amounts to an honor violation and are subject to removal from the course. DO NOT COPY SOMEONE ELSE'S WORK IN WHOLE OR IN PART.

2. Specific written assignments (MEMORANDA, LAB Report, and the DESIGN REPORT) must be uploaded and submitted to TURNITIN as noted on the attached assignment schedule before they are considered complete and ready for grading. Class ID and Passwords for TURNITIN are noted below.

Section	Class Name	Class ID	Password
21	Strength of Materials Lab Section 21	18901971	GStephens21
25	Strength of Materials Lab Section 25	18902204	GStephens25
43	Strength of Materials Lab Section 43	18902218	GStephens43

3. All written assignments will require a "peer review" prior to submission. Details of this process will be outlined/demonstrated before the first written assignment. Depending on the level of review, I may require you to use the Writing Resource Center (WRC) in the Information Commons prior to submission. If you are required to use the WRC, please be sure to attach the blue sheet to your final printed copy.

4. If your assignment is one day late, you will lose 10% on your grade. If your assignment is two days late, you will lose 30% on the grade. If your assignment is three days late, you will lose 60% on the grade. **Assignments 4 or more days late will be considered as a non-submission and will not be accepted**. If you fail to submit two assignments within the appropriate window, you will receive an F for the course and are no longer be eligible to remain in the lab. *Remember, if you have not filed your electronic copy on TurnItIn (if required), your submission is INCOMPLETE.*

DATA PROTECTION: If you save data on the computer, you **MUST** save it to the dropbox. The C drive is wiped with every reboot. This means there will be **NO AUTOSAVE** data if the computer crashes and the data was not saved to the dropbox.

Data from the Tinius Olsen machines are outputted as .csv files. You must save them as .xlsx or Excel workbook files to preserve any work you do on the file. Save the data file as an .xlxs as soon as you start working on the file.

ATTENDANCE: There will be NO makeup labs for unexcused absences. You must notify me in ADVANCE of your class period, with an approved reason for your absence, in order to be excused.

CELL PHONES: Cell phones and other similar electronic devices are to be silenced and stored out of sight. CALCULATORS ON CELL PHONES ARE NOT ALLOWED

SAFETY POLICY: You will need eye protection for many experiments conducted in this lab. Any additional safety precautions will be outlined prior to conducting each individual lab.

CONTRIBUTION TO THE PROFESSIONAL COMPONENT: Strength of Materials Lab, a required course for Marine Engineering, Facilities Engineering and Energy Systems Engineering, requires that students use the fundamental knowledge from other courses in the program, such as: mathematics, physics, and statics. This course contributes 1 semester hour to the engineering topic requirement.

RELATIONSHIP OF COURSE OBJECTIVES TO PROGRAM EDUCATIONAL OBJECTIVES:
Strength of Materials Lab supports the following Program Educational Objectives: all of the Intellectual Learning characteristics listed in MMA course catalog.

ABET CRITERION 3 OUTCOMES (2018-19):

Outcome	
1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	†
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	N
3. an ability to communicate effectively with a range of audiences	†
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	N
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	†
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	†
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies	†

† Outcome achieved
N – Outcome is not applicable

STUDENT ACCOMMODATIONS: *MMA is committed to providing reasonable accommodations to students with documented disabilities. Students who believe they may need accommodations for this class are required to contact Prof. Fran Tishkevich, Director of Disability Compliance, within the first two weeks of class at ext. 2208 or by e-mail at ftishkevich@maritime.edu*

Letter Grade Cut-Offs:

$93 \leq X \leq 100$	A	$77 \leq X \leq 79$	C+
$90 \leq X \leq 92$	A-	$73 \leq X \leq 76$	C
$87 \leq X \leq 89$	B+	$70 \leq X \leq 72$	C-
$83 \leq X \leq 86$	B	$67 \leq X \leq 69$	D+
$80 \leq X \leq 82$	B-	$63 \leq X \leq 66$	D
		$X < 63$	F

There will be no D- grades given. You must have an average ≥ 63 in order to pass this class

Massachusetts Maritime Academy ♦ Department of Engineering
EN-3112L Strength of Materials Lab ♦ Assignment #1

Objectives:

1. To learn the basics of Microsoft Excel for problem solving and plotting data.

Experimental Procedure:

1. Attend class tutorial on Excel
2. Searching the internet and on your own, learn the following functions.
   a. Logical functions: IF
   b. Math and Trigonometry Functions: COS, DEGREES, RADIANS, SIN, SUM
   c. Statistical functions: AVERAGE, COUNT, MAX, MIN
3. Additional help can be found on the Microsoft.com website and on youtube.
4. Prepare the assignment per the Homework section below.

Graphing Notes: Throughout this course please use the following methodology

1. Unless otherwise noted on an assignment, use an X-Y scatter graph.
   a. Use smooth lines (no markers) for theoretical values
   b. Use smooth line (no markers) if you have more than 10 data points
   c. Use markers only to denote experimental data if you have ≤ 10 data points.
   d. Use a trend line to show expected output if no theoretical data is plotted.
2. Do not use straight lines to graph data points
3. Chart, Graph, and Figure names are shown BELOW the graph. Use an ID and title (e.g. Figure 1 Height as a function of time for bouncing ball)
4. Be sure to include axis titles and units (along the axis)
5. Use a legend if you have more than one series of data. Be sure to identify the series and points of interest

Homework:

1. In Excel, solve the following equation from $2 \leq x \leq 10$, using increments of 0.04 :
$$y = -\frac{3}{x^2} + \pi^{-3x} + \sin(x)$$

Where y represents height as measured in inches and x represents time as measured in seconds

2. Graph the data from the equation in item 1. Be sure to include a graph title located BELOW the graph and axis labels.
3. Use the MAX and MIN function to determine the maximum and minimum points. Indicate these points using GREEN arrows and text boxes to include the value of x and y at each point (x,y). Round your values to 3 decimal places
4. Add a RED trend line to show the best fit polynomial (you decide what order gives the best fit, where $R^2 \approx 1$)
5. Determine the first root of the equation and indicate the coordinates of the point, (x,y), on the graph using a BLACK diamond
6. Display the equation of the trend line and the correlation coefficient (R^2) on the chart.
7. Email me the Excel workbook using the format: section_last name (i.e., 25_Smith) in the subject line.

Massachusetts Maritime Academy ♦ Department of Engineering
EN-3112L Strength of Materials Laboratory ♦ Izod/Charpy Impact Test

Name _____

Objectives:

To introduce basic impact theory to the class.

Theoretical Background:

Impact loading is a sudden dynamic, rather than static, application of load on a material. This can cause failures very differently than what has been looked at in class. Impact loading is of great concern to engineers because of things like crack propagation and the ductile to brittle transition temperature.

An Izod or Charpy impact test measures the amount of energy absorbed by the sample. For plastics, this tends to be more of a comparative tests than a definitive one.

Regardless of the test, Izod or Charpy, both experiments are based on converting potential energy into kinetic energy to strike the sample. Before the experiment, the anvil will have a potential energy determined by:

$$E_p = mgh \tag{1}$$

Where m is the mass of the anvil, g is the local acceleration due to gravity and h is the height of the anvil at rest. At any point in the experiment the kinetic energy is:

$$E_k = \frac{mv^2}{2} \tag{2}$$

Where v is the velocity of the anvil.

The Notch Impact Strength typically measured in $\frac{in-lb}{in^2}$ or $\frac{N-mm}{mm^2}$ can be found by:

$$Notch\ Impact\ Strength = \frac{Absorbed\ Energy}{Effective\ Cross\ Section\ Area} \tag{3}$$

Remember that in the English system that 32.2 lb$_m$ = 1 slug, and 1 lb$_f$ = 1 $\left[\frac{slug-ft}{s^2}\right]$ and

in the SI system 1 N = 1 $\frac{kg-m}{s^2}$

Experimental Procedure:

Using the Tinius Olsen IT504 Impact Tester with the Izod setup, break the plastic samples and record the energy absorbed by the sample on Table A. You will then repeat the experiment using the Charpy setup. You will be using the data from the entire class for your calculations, not just your own.

Prepared by: Dr. Robert Camp   Strength of Materials Lab   Page 1 of 3
Revised by: LCDR G. Stephens, P. E.   EN-3112L
Updated: 3 December 2018

Name _____

Analytical Procedure:

1. Determine the amount of Potential Energy in the system
2. Calculate the speed of the anvil when it strikes the sample
3. Using a column chart, plot the energy absorbed for each sample. In the Chart Tools>Layout ribbon, add the standard deviation error bars for each sample. You will do one chart for the Izod and one for the Charpy
4. Prepare a table showing the mean notch impact strength, mean energy absorbed and the standard deviation for each plastic type and each test type. Note: use formulas in Excel to calculate the necessary data and then report it in a table. You can use the Excel function [=stdev(range of boxes)] to calculate the standard deviation.

Assignment:

- Present the items described below in ONE EXCEL FILE and e-mail it to me as section_lastname (i.e., subject line should read: 88_Stephens).
- You submission should include the following:
    (1) One worksheet, that includes one table for raw data, one table for mean notch impact strength, mean energy absorbed, and the standard deviation for each type of plastic, and one column chart of the energy absorbed for each sample in the Izod Test. Be sure to name the tab at the bottom of the worksheet. Be sure all tables and Figures/Graphs are appropriately labeled (Tables at the top, Figures/Graphs at the bottom)
    (2) One worksheet for the Charpy Test, similar to that required for the Izod Test.
    (3) Once the two individual worksheets are created, insert a worksheet in front of the first one. On it, write a paragraph stating the potential energy of the system, the mass of the anvil, the speed of the anvil when it strikes the sample, and the material which absorbs the greatest energy and the least energy in each test.
- Be sure to include your name, section number and date on each page

Prepared by: Dr. Robert Camp
Revised by: LCDR G. Stephens, P. E.
Updated: 3 December 2018

Strength of Materials Lab
EN-3112L

Page 2 of 3

Appendix A. Raw Data
EN-3112L Strength of Materials Laboratory ♦ Izod/Charpy Impact

Table A. Izod Impact Energy			
	Energy Absorbed ( )		Energy Absorbed ( )
Effective area ( )		Effective area ( )	
1		1	
2		2	
3		3	
4		4	
5		5	

	Energy Absorbed ( )		Energy Absorbed ( )
Effective area ( )		Effective area ( )	
1		1	
2		2	
3		3	
4		4	
5		5	

Table B. Charpy Impact Energy			
	Energy Absorbed ( )		Energy Absorbed ( )
Effective area ( )		Effective area ( )	
1		1	
2		2	
3		3	
4		4	
5		5	

	Energy Absorbed ( )		Energy Absorbed ( )
Effective area ( )		Effective area ( )	
1		1	
2		2	
3		3	
4		4	
5		5	

Height of Anvil at rest (top) _____

Height of Anvil at strike (bottom) _____

Mass of Pendulum (calculated) _____

Massachusetts Maritime Academy ♦ Department of Engineering
EN-3112L Strength of Materials Laboratory ♦ Ultimate Shear Stress (SI)

Name _____

Objectives:

1. To determine the ultimate shear stress of a material
2. To compare the average experimental shear stress of a material with published data.

Theoretical Background:

Shear stress is found in a material that is subjected to a shearing load. The average shear stress in a material subject to a transverse load can be found using:

$$\tau_{ave} = \frac{P}{A} \tag{1}$$

Where P is the applied load and A is the cross sectional area of the sample over which the shear force occurs. If a material is subject to double shear then the shear force on each face is ½ of the overall force.

When the calculated or design shear stress exceeds the allowable shear stress, the material will begin to fail and ultimately fracture. The load where this happens is called the "Ultimate (or Failure) Load".

Experimental Procedure:

Using the *double shear fixture* and the Tinius Olsen Super L-60 machine, load one material sample until it breaks. Note: each group will break one sample of material.

Analytical Procedure:

1. Using the MAX function in Excel, determine the maximum load applied to the sample.
2. Using Equation (1), calculate the average experimental ultimate shearing *stress*. Remember, your sample experiences a shear force on two faces (double shear).
3. Compare the ultimate shearing stress (strength) to a published value. Be sure to note your source.
4. Plot the shear stress as a function of time on an X-Y scatter graph with smooth lines (no markers). Be sure to follow the guidelines in format documents.

Assignment:

- The format for this writing assignment will be a **MEMORANDUM.**
  - In your conclusion, discuss how the experimental data relates to the objectives of the lab. What other observations were made during the experiment. How do they relate to the mechanics of the material tested.
- Note: Use the Memorandum format writing sheet and Excel Graph handouts for reference
- Be sure to edit your memorandum and have it reviewed prior to submission.

Name _____

Table A1. Sample Material _____	
Initial Specimen Length, L_i	
Initial Specimen Diameter, d_i	

Name _____

Objectives:

The purpose of this laboratory is to create a stress/strain diagram from the given stress and strain data and determine the following properties

1. Modulus of Elasticity [Young's Modulus] E
2. Ultimate Stress
3. Fracture [Breaking] Stress
4. Proportional Limit
5. 0.2% Offset Yield Stress
6. Percent Elongation
7. Percent Area Reduction

Theoretical Background:

Many useful material properties can be deduced using a stress/strain curve. Using force and displacement data, it is possible to create our own stress/strain curve for a material sample. The normal stress in a material when it has been loaded axially is found by equation 1.

$$\sigma = \frac{P}{A} \tag{1}$$

Where P is the applied load and A is the cross sectional area of the sample.

The strain is found by equation 2.

$$\varepsilon = \frac{\delta}{L} \tag{2}$$

Where δ is the amount of displacement and L is the original length.

The percent elongation that the specimen undergoes is found by equation 3.

$$\% \ elongation = \frac{L_f - L_i}{L_i} \ x \ 100 \tag{3}$$

Where L_i is the initial length and L_f is the final length of the specimen.

Finally, the percent area reduction of the specimen cross section is found using equation 4.

$$\% \ area \ reduction = \frac{A_i - A_f}{A_i} \ x \ 100 \tag{4}$$

Where A_i is the initial area and A_f is the final area of the specimen cross section.

Name _____

Experimental Procedure:

Using the Tinius Olsen Super L-120 machine, apply an increasing load on the material sample until it fractures.

Analytical Procedure:

1. Plot the stress/strain data using Excel. Use an x-y scatter plot with smooth lines (no markers.)
2. On your graph, **clearly identify the first 5 properties on the graph.** This means you will also have to plot the 0.2% offset curve.
3. From your stress/strain graph determine the value of each of the first 5 properties from the objectives section of the lab and display them in a table.
4. Using the attached raw data sheet, calculate properties 6 and 7.

Assignment:

- Present the items described below in ONE EXCEL FILE and e-mail it to me as section_lastname (i.e., 88_Stephens).
- You submission should include the following:
    o One worksheet for raw data obtained from the Tinius Olsen Super L120 Machine. (Last Tab)
    o One worksheet for the manipulated data used to create the stress vs. strain diagram and determine the properties shown on the graph. Be sure to use (show) equations to determine the properties. (Middle Tab)
    o One worksheet that includes the stress vs. strain diagram (graph) per the analytical procedures noted above and a table displaying items 1-7 listed in the objective. You must show the offset line along with the yield strength. (First Tab)
- Be sure to identify each of the tabs
- Be sure to identify each of your table and graph
- Be sure to include your name, section number and date on each page

Table A1. Sample Material _____	
Initial Specimen Length, L_i	
Initial Specimen Diameter, d_i	
Final Specimen Length, L_f	
Final Specimen Diameter, d_f	
Initial Area of Specimen, A_i	
Final Area of Specimen, A_f	

Masssachusetts Maritime Academy ♦ Department of Engineering
EN-3112L Strength of Materials Laboratory ♦ Torsion Laboratory

Objectives:

The purpose of this lab is to verify the relationship between shear stress and shear strain and to experimentally determine the Modulus of Rigidity (G) for a material.

Theoretical Background:

This lab is designed to investigate the relationship between the torque, length, and angle of twist of a circular shaft. The angle of twist, φ, in radians, is given by the equation:

$$\varphi = \frac{TL}{JG} \tag{1}$$

where T is the torque, L is the length of the shaft, G is the Modulus of Rigidity, and J is the polar moment of inertia of the cross section.

Knowing the torque on a circular shaft enables one to find the shear stress on the shaft using equation (2):

$$\tau = \frac{Tc}{J} \tag{2}$$

where T is the torque, c is the radius of the shaft, and J is the polar moment of inertia of the cross section. In the elastic region, the shear stress is related to shear strain by means of equation (3)

$$\tau = G\gamma \tag{3}$$

where τ is the shear stress, G is the modulus of rigidity of the material, and γ is the shear strain, measured in radians. Furthermore, the shear strain is a measure of twist along the shaft and varies with the length of the shaft. The maximum shear strain, γ, which occurs along the outside edge of the shaft (at the shaft radius) can be expressed as shown in equation (4)

$$\gamma = \frac{c\varphi}{L} \tag{4}$$

where c is the radius of the rod, φ is the angle of twist in radians, and L is the length of the shaft.

The polar moment of inertia for a circle is determined by the equation:

$$J_{circle} = \frac{\pi D^4}{32} \tag{4}$$

Experimental Procedure:

1. Mark a sample of aluminum or brass rod longitudinally (along the length of the rod). This will make the angle of twist on the rod visible.
2. Install the rod in the Tinius Olsen Lo-Torque torsion machine and record the length of the rod (between the two chucks.)
3. Using the Tinius Olsen Lo-Torque desktop torsion machine and the "Round Stock, Angle to Load" application, apply an increasing torque on the material sample until it fractures or as directed.

Analytical Procedure:

1. Plot the experimental shear stress verses shear strain. Remember to save the data in an Excel format within the Dropbox or on a flash drive.
2. Calculate the experimental G from the graph plotted above and compare it to a theoretical value from a published reference. Be sure to note the reference.
3. Show the experimental value of G on your graph.

Assignment:

- Present the items described below in ONE EXCEL FILE and e-mail it to me as section_lastname (i.e., 21_Stephens).
- You submission should include the following:
    - One worksheet for raw data obtained from the Tinius Olsen Torsion Machine (last)
    - One worksheet for the manipulated data used to plot the shear stress vs. shear strain for the sample (middle)
    - One worksheet that includes the shear stress vs. shear strain diagram (graph) per the analytical procedures above (first). Be sure to show the experimental value of G on the graph and the comparison and source on the same worksheet.
- Be sure to identify each of the worksheet tabs
- Be sure to identify each of your table and graph
- Be sure to include your name, section number and date on each page

Equipment Parameters and Sample Dimensions

Material _____

Rod Length, (inches) _____

Rod diameter, (inches) _____

Rate of Angle (deg/min) _____60°/min_____

Massachusetts Maritime Academy ♦ Department of Engineering
EN-3112L Strength of Materials Laboratory ♦ Poisson's Ratio Laboratory

Objectives:

1. Determine Poisson's ratio for aluminum
2. Compare the experimentally derived value to a known, published value
3. Determine the changes in dimensions of the beam sample

Theoretical Background:

Stress and strain are related by Hooke's Law:

$$\sigma = E\varepsilon \tag{1}$$

where σ is the normal stress, E is the modulus of elasticity, and ε is the normal strain. The modulus of elasticity for aluminum 6061 is 10.1 Mpsi or 70 GPa. The normal strain is found using equation (2).

$$\varepsilon = \frac{\delta}{L} \tag{2}$$

Where δ is the deformation (elongation or contraction) and L is the length of the material.

When a material is elongated in one direction by means of a tensile force, it is shortened in the other two directions. The strains in the longitudinal and lateral directions can be related by means of Poisson's ratio, which is a property of a given material:

$$\nu = \frac{-\ lateral\ strain}{longitudinal\ strain} \tag{3}$$

Where ν is Poisson's ratio for a given material. If a material undergoes loading along multiple axes, the generalized Hooke's Law can be used to find the strain in each direction (equations (4), (5), and (6).)

$$\varepsilon_x = \frac{\sigma_x}{E} - \nu\frac{\sigma_y}{E} - \nu\frac{\sigma_z}{E} \tag{4}$$

$$\varepsilon_y = -\nu\frac{\sigma_x}{E} + \frac{\sigma_y}{E} - \nu\frac{\sigma_z}{E} \tag{5}$$

$$\varepsilon_z = -\nu\frac{\sigma_x}{E} - \nu\frac{\sigma_y}{E} + \frac{\sigma_z}{E} \tag{6}$$

Experimental Procedure:

1. Get a ¼ inch thick aluminum beam with a longitudinal strain gauge on top and a transverse strain gauge on the bottom.

2. Set Channels 1 and 2 on the P-3 strain indicator to the "active" mode and in the "quarter bridge" configuration.

3. Connect the longitudinal strain gage to Channel 1 and the lateral strain gage to Channel 2 of the P-3 strain indicator using the one-quarter bridge connection as follows:
   a.   Red   = P+   (Positive Excitation)
   b.   White = S-   (Signal)
   c.   Black   =D120 (Dummy Resistor/Bridge Completion Module)

4. Set the gage factor (G. F.) for each channel according to the label on the back of the beam. This gage factor tells the P-3 indicator what type of strain gage is being read. Therefore be sure that Channel 1 is programmed with the GF for the strain gage attached to Channel 1 and Channel 2 is programmed with the GF for the strain gage attached to Channel 2.
5. Zero out the strain indicator using the "Balance" function.
6. Record the strain values for Channels 1 and 2 (gages 1 and 2, respectively) for loads varying from 100g to 900g.

Analytical Procedure:

1. Plot lateral strain vs longitudinal strain (y vs x) measured using the ¼ inch beam and determine Poisson's ratio statistically using Excel and Equation 3. Report this value on your graph. Use an X-Y scatter plot with markers only and include a linear trend line.
2. Create a table comparing your experimentally determined value with an accepted published value data. Be sure to reference the source of the comparative value.
3. Using equations (2) and (3), calculate the change in each dimension of the beam when the maximum load has been applied. Display the change of each dimension in a table.

Assignment:

- The format for this writing assignment will be a LAB Report which must be uploaded to www.turnitin.com prior to the due date & time. Your report should include the following elements: Cover Page, Abstract, Introduction, Procedure, Results, Discussion and Conclusions, References, and Appendices (see Blackboard for format documents).
    - o In the Introduction, as you explain the theoretical background, be sure to show the equations used. Use your own voice – do not copy from the assignment.
    - o In the Procedure section, incorporate a CAD drawing (preferably SolidWorks) of the system set up and/or equipment as you explain how the experiment was conducted,
    - o The items listed in the Analytical Procedure should be included in the results section of you report. DO NOT INCLUDE RAW DATA IN THIS SECTION. Be sure to introduce each graph, figure or table before you show it.
    - o In your Discussion and Conclusion section, remember to relate the results of your experiment to the stated objectives. Do not just state how well the experiment correlated to the expected results.

Appendix A. Raw Data

EN-3112L Strength of Materials Laboratory ♦ Poisson's Ratio and Bending Stress Laboratory

Table A1. Poisson's Ratio Data

Mass (g)	Longitudinal Strain με (10⁻⁶ in/in)	-Lateral Strain με (10⁻⁶ in/in)*

Beam Dimensions

Beam thickness, h (inches)   1/4

Beam length, L (inches)

Beam width, b (inches)

Appendix A. Raw Data
EN-3112L Strength of Materials Laboratory #5 ♦ Beam Deflection Laboratory

Objectives:

1. The purpose of this experiment is to measure the deflections of simply supported beams and to compare these values with theoretical calculations. In particular, the following relationships will be investigated:
   a. Deflection and load
   b. Deflection and thickness
2. Determine the effect of section modulus on the normal stress due to bending.

Theoretical Background:
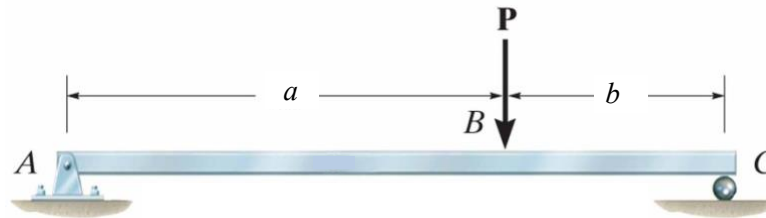
The theoretical equation for beam deflection, *y*, of a simply supported beam with a load applied at a known distance along its length is given by the equation:

$$y_B = -\frac{Pb(L^2 - b^2)^{\frac{3}{2}}}{9\sqrt{3}EIL} \qquad (1)$$

where *P* is the load, L is the length between the simple supports on the beam, *a* is the distance from the left support, *b* is the distance from the right support, *E* is the modulus of elasticity of the material, and *I* is the moment of inertia for the cross-section. For this loading condition, the maximum displacement is located at a distance x_m from the left edge of the beam, where x_m is found using equation (2).

$$x_m = \sqrt{\frac{(L^2 - b^2)}{3}} \qquad (2)$$

For a rectangular cross section, I_x is defined by:

$$I_x = \frac{1}{12}bh^3 \qquad (3)$$

For the modulus of elasticity, refer to Table 1.

Table 1. Material Properties		
Material	**E (GPa)**	**E (x10³ ksi)**
Aluminum	70	10.1
Brass	105	15
Steel	200	28

The maximum bending stress on a beam, σ, is given by:

$$\sigma = \frac{|M|}{S} \tag{4}$$

where M is the bending moment and S is the section modulus as defined in equation (5).

$$S = \frac{I}{c} \tag{5}$$

where c is the distance from the upper or lower surface of the beam to the neutral axis, and I is the moment of inertia as defined in equation (3)

Experimental Procedure:

Using the beam stand and the dial indicator, obtain data as described below. When measuring deflections, record the net change from the unloaded position. Overhang at the supports should be even and not excessive. Pay careful attention to the units displayed on the measuring devices. Make note of the accuracy of the gauges for use in your report conclusions.

1. Using a ¼ inch aluminum beam with supports a fixed length apart, measure the deflection for five different loads ranging from 100g and 1000g. Be sure to note the location of the load along the beam. Keep the location constant for all tests.
2. Set the beam supports a fixed length apart. Measure the deflection for five beams of different thickness keeping the magnitude of the load and its location constant for each test. Be sure to note the magnitude of the applied load and its location in your memo.

Analytical Procedure:

(From the first experiment)
1. Calculate and plot a graph of experimental and theoretical deflection vs. load. Plot the theoretical line as a smooth line only and the experimental data points as markers only.
2. Determine the location of the maximum deflection.

(From the second experiment)
3. Calculate and plot a graph of experimental and theoretical deflection vs. thickness. Plot the theoretical line as a smooth line only and the experimental data points as markers only.
4. Calculate and plot a graph of the maximum bending stress vs. section modulus. Plot the theoretical line as a smooth line only.

Appendix A. Raw Data
EN-3112L Strength of Materials Laboratory #5 ♦ Beam Deflection Laboratory

Assignment:

- The format for this writing assignment will be a **memorandum** which must be uploaded to www.turnitin.com prior to the due date and time. Your memorandum should include the following elements: Introduction, Results, Discussion and Conclusions, and Appendices (see Blackboard for format documents).
    - In the Introduction, state the purpose and a brief description of the experiment. Why was the lab created? Unlike the lab report, this should be a brief introduction. DO NOT SHOW EQUATIONS in this section (equations should be included in the appendix).
    - The Results section should include the items listed in the Analytical Procedure. In this case, you should have three graphs and a statement as to the location of the maximum deflection. DO NOT INCLUDE RAW DATA IN THIS SECTION. Be sure to introduce each graph, figure or table before you show it.
    - In your Discussion and Conclusion section, remember to <u>relate</u> the results of your experiment to the stated objectives. Do not just state how well the experiment correlated to the expected results.

Apparatus Dimensions

Beam Length _____   Location of Load _____

Beam Width _____   (as measured from the left end)

Table A1. Effect of Load on Deflection

Mass (g)	Deflection y (mm or in)

Beam length, L (inches) _____   Location of Load _____

Applied Mass, (g) _____   (as measured from the left end)

Table A2. Effect of Beam Thickness on Deflection*

Thickness (in)	Deflection y (mm or in)
1/8	
3/16	
1/4	
5/16	
3/8	

Objectives:

The objective of the lab is to understand the relationship between stress and strain and to experimentally determine the stress concentration factor, K, in the vicinity of a hole, for a cantilever beam in bending.

Theoretical Background: Stress Concentration Factor, K

In the elastic region, the stress on a material can be calculated by experimentally measuring the strain on a material under load and using the known relationship expressed by Hooke's Law:

$$\sigma = E\varepsilon \tag{1}$$

where σ is the normal stress, E is the modulus of elasticity, and ε is the normal strain. Hooke's law can be verified for a cantilever beam in bending using equation [2].

$$\sigma = \frac{Mc}{I} = \frac{6\,PL}{bt^2} \tag{2}$$

Where P is the applied load on the cantilever beam, L is the length of the beam, b is the width of the beam, and t is the thickness of the beam.

The stress at a discontinuity (hole, fillet, etc) can be found using equation [3]

$$\sigma = K\frac{Mc}{I} = K\frac{6\,PL}{bt^2} \tag{3}$$

Where K is the stress concentration factor and all other variables are as previously defined.

However; for a cantilever beam with a discontinuity (hole or fillet, etc) the strain cannot directly be measured at a discontinuity (hole, fillet, groove, etc.). Therefore the strain must be extrapolated from measured data. For the case of a beam with a hole, the strain at a given location on a beam can be found using equation [4]:

$$\varepsilon_i = A + B\left(\frac{R}{X_i}\right)^2 + C\left(\frac{R}{X_i}\right)^4 \tag{4}$$

where R is the radius of the hole, X_i is the distance from the center of the hole to the strain gage$_i$ on the transverse centerline, and A, B, and C are coefficients to be determined from the measured strains at three points along the transverse centerline.

$$C = 5.86\,(\varepsilon_1 - \varepsilon_2) - 5.44\,(\varepsilon_2 - \varepsilon_3) \tag{5a}$$

$$B = 3.49\,(\varepsilon_1 - \varepsilon_2) - (1.20 \text{ x } C) \tag{5b}$$

$$A = \varepsilon_1 - (0.743 \text{ x } B) - (0.552 \text{ x } C) \tag{5c}$$

Since $\left(\frac{R}{X}\right) = 1$ at the edge of the hole, then equation [6] can be used to determine the strain at the hole.

$$\varepsilon_0 = A + B + C \; (peak\ strain\ at\ the\ discontinuity) \tag{6}$$

Finally, equation [7] can be used to determine the stress concentration factor, *K*.

$$K = \frac{\varepsilon_0}{\varepsilon_4} \tag{7}$$

Experimental Procedure:

1. Get a ¼ inch thick aluminum beam with a hole drilled through it. Notice the multiple strain gauges on top
2. Set Channels 1, 2, 3, and 4 on the P-3 strain indicator to the "active" mode and in the "quarter bridge" configuration.
3. Connect each strain gage to the channel number corresponding to the gage of the P-3 strain indicator using the one-quarter bridge connection as follows:
   a.   Red   = P+   (Positive Excitation)
   b.   White = S-   (Signal)
   c.   Black =D120 (Dummy Resistor/Bridge Completion Module)

4. Set the gage factor (G. F.) for each channel according to the label on the back of the beam. This gage factor tells the P-3 indicator what type of strain gage is being read.
5. Zero out the strain indicator using the "Balance" function.
6. Record the strain values for Channels 1-4 (gages 1-4, respectively) for a single load. Choose from 100g to 900g.
7. Calculate the coefficients A, B, and C using equation [5]
8. Calculate ε_0 using equation [6]

Analytical Procedure:

1. Plot the experimental strain versus the factor $\left(\frac{X}{R}\right)$ to visualize the strain (stress) distribution in the vicinity of the hole. Use markers for the three data points and add a 4th order polynomial trend line. Forecast "backward" the data to demonstrate what happens in the vicinity of the hole (where $\frac{X}{R} = 1$.)
2. Calculate the stress concentration factor, K, using equation [7].
3. Calculate the maximum stress in the vicinity of the hole (Equation [3].)

Assignment:

- Present the items described below in ONE EXCEL FILE and e-mail it to me as section_yourlastname (i.e., 21_Stephens).
- You submission should include the following:
  - Raw data including beam measurements on one tab (third tab)
  - Interim calculations for coefficients, ε_0, K_{hole} and σ_{MAX}, etc. (middle tab)
  - Plot of ε vs $\frac{x}{R}$ and text box reporting values of K_{hole} and σ_{MAX} (first tab)
- Be sure to identify each of the worksheet tabs
- Be sure to identify each of your table and graph
- Be sure to include your name, section number and date on top left corner of each page

Table A1. Stress Concentration Data

Mass (g)	Strain $\mu\varepsilon_1$ (μin/in or μm/m)	Strain $\mu\varepsilon_2$ (μin/in or μm/m)	Strain $\mu\varepsilon_3$ (μin/in or μm/m)	Strain $\mu\varepsilon_4$ (μin/in or μm/m)

Beam Dimensions

Beam thickness, h (inches, mm) _____

Beam length, L_1 (inches, mm) _____

Beam length, L_4 (inches, mm) _____

Beam width, b (inches, mm) _____

Diameter of Hole, d (inches, mm) _____

X_1 (in., mm) _____

X_2 (in., mm) _____

X_3 (in., mm) _____

Note: X_1, X_2, and X_3 are transverse distances from hole to specified strain gage

Objectives:

The objective of the lab is to understand the relationship between stress and strain and to experimentally determine the principal stresses for a cantilever beam in bending.

Theoretical Background: Principal Stresses

In general three strains measured along different axes at the same point can be used to determine the principal strains and corresponding principal stresses on an object. The three axes along which strains are to be measured can be arbitrarily oriented about the point of interest. An integral array of strain gages intended for simultaneous multiple strain measurements about a point is known as a "rosette". Figure 1 shows a rectangular three-gage strain rosette.
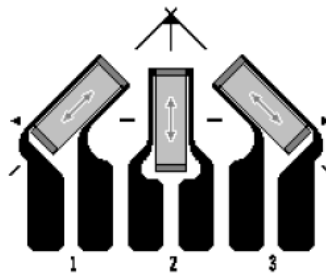

Figure 1: Labeling and orientation of gauges and axes for a rectangular rosette

The corresponding relationship for the rectangular rosette is given in Equation (1)

$$\varepsilon_{p,q} = \frac{\varepsilon_1 + \varepsilon_3}{2} \pm \frac{1}{\sqrt{2}}\sqrt{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2} \tag{1}$$

Where

$\varepsilon_{p,q}$: maximum and minimum principal strains, respectively, in/in (mm/mm).
$\varepsilon_1, \varepsilon_2, \varepsilon_3$: strains measured along corresponding axes of rosette elements, in/in (mm/mm)

Note: The algebraically maximum and minimum principal strains correspond to the plus and minus alternatives, respectively.

The principal stress can be calculated by substituting the principal strains from Equation (1) into the biaxial expression for Hooke's law, Equation (2):

$$\sigma_p = \frac{E}{1 - v^2}(\varepsilon_p + v\varepsilon_q)$$
$$\sigma_q = \frac{E}{1 - v^2}(\varepsilon_q + v\varepsilon_p) \tag{2}$$

Where

$\sigma_{p,q}$: Maximum and minimum principal stresses, respectively, psi (Pa or N/m²)

ν : Poisson's ratio, $\nu = |\varepsilon_q|/|\varepsilon_p|$

E   : Modulus of elasticity (aluminum), psi (assume E=10.4×10⁶ psi or 71.7 GPa)

As a reminder, the general equation of a circle can be expressed using Equation (3), where *a* and *b* are the x and y-coordinates at the center of the circle.

$$(x - a)^2 + (y - b)^2 = R^2 \tag{3}$$

Experimental Procedure:

In this experiment, the principal strain and the principal stresses in a cantilever beam will be determined with a strain gage rosette.

1. Get a 1/8 inch thick aluminum beam with a rectangular rosette of strain gages.
2. Set Channels 1, 2, and 3 on the P-3 strain indicator to the "active" mode and in the "quarter bridge" configuration.
3. Connect strain gage 1 to Channel 1, strain gage 2 to Channel 2, and strain gage 3 to Channel 3 of the P-3 strain indicator using the one-quarter bridge connection as follows:
    a.   Red   = P+   (Positive Excitation)
    b.   White = S-   (Signal)
    c.   Black =D120 (Dummy Resistor/Bridge Completion Module)
4. Set the gage factor (G. F.) for <u>each channel</u> according to the label on the back of the beam. This gage factor tells the P-3 indicator what type of strain gage is being read. Therefore be sure that Channel 1 is programmed with the GF for the strain gage attached to Channel 1, etc.
5. Zero out the strain indicator using the "Balance" function.
6. Record the strain values for Channels 1, 2, and 3 (gages 1, 2, and 3, respectively) for a single load. You may choose any load from 100g to 900g.

Analytical Procedure:

1- Calculate the Principal Strains using Equation (1).
2- Calculate the Principal Stresses using Equation (2)
3- Construct the Mohr's circle (using Equation (3) in Excel) and clearly label the principal stresses
4- Determine the maximum shear stress from the Mohr's circle. Clearly label this point on the circle
5- Plot the state of stress at strain gage 3 on the rectangular rosette.
6- Determine the principal plane and indicate it's value on Mohr's circle

Massachusetts Maritime Academy ♦ Department of Engineering
EN-3112L Strength of Materials Laboratory ♦ Stress, Strain & Principal Stresses

Assignment:

- Present the items described below in ONE EXCEL FILE and e-mail it to me as section_yourlastname (i.e., 21_Stephens).
- You submission should include the following:
    - Raw data including beam measurements on one tab (third tab)
    - Interim calculations used to create Mohr's circle (middle tab)
    - Plot of Mohr's Circle showing the maximum and minimum normal stresses, the maximum shear stress, and the state of stress at strain gage 3. All points of interest should be clearly labeled. (first tab)
- Be sure to identify each of the worksheet tabs
- Be sure to identify each of your table and graph
- Be sure to include your name, section number and date on each page

Table A1. Strain Rosette Data

Mass (g)	Strain ε_1 (μin/in or μm/m)	Strain ε_2 (μin/in or μm/m)	Strain ε_3 (μin/in or μm/m)

Beam Dimensions

Beam thickness, h (inches, mm)   _____

Beam length, L (inches, mm)   _____

Beam width, b (inches, mm)   _____

Massachusetts Maritime Academy ◆ Department of Engineering
EN-3112L Strength of Materials Laboratory ◆ Elastic Curve

Objectives:

The objective of this lab is to explore the equation of the elastic curve for an overhanging beam with 2 concentrated loads.

Theoretical Background:

Deflections of prismatic beams can be predicted by use of the elastic curve. The elastic curve is a line that connects the centroids of every cross section along the length of the beam. Consider the following beam loading condition.
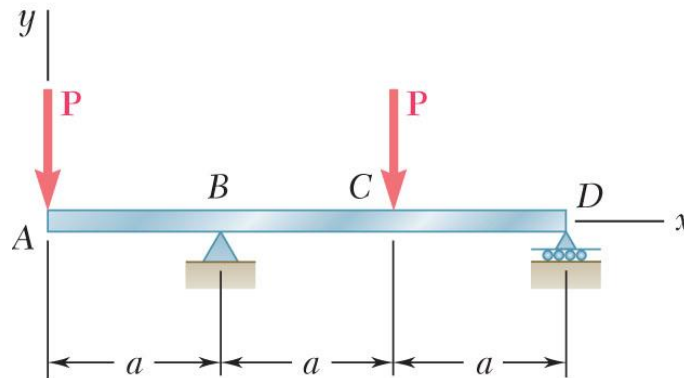

Figure 1. Beam Loading Condition

If we solve for the equation of the elastic curve, we will have three equations to map the curve.

From $0 < x_1 < a$, the equation is:

$$y_1 = -\left(\frac{P}{6EI}\right)x_1^3 + \left(\frac{11Pa^2}{12EI}\right)x_1 - \left(\frac{3Pa^3}{4EI}\right) \tag{1}$$

Where y_1 is the vertical displacement, E is the Modulus of Elasticity, I is the Moment of Inertia, and x_1 is the distance along the beam from end A.

From $a < x_2 < 2a$, the elastic curve equation is:

$$y_2 = -\left(\frac{P}{6EI}\right)x_2^3 + \left(\frac{1P}{3EI}\right)(x_2 - a)^3 + \left(\frac{11Pa^2}{12EI}\right)x_2 - \left(\frac{3Pa^3}{4EI}\right) \tag{2}$$

Where y_2 is the vertical displacement in this portion of the beam, E and I are the same as described above, and x_2 is the distance along the beam from end A.

And from $2a < x_3 < L$, the elastic curve equation is:

$$y_3 = -\left(\frac{P}{6EI}\right)x_3^3 + \left(\frac{1P}{3EI}\right)(x_3 - a)^3 - \left(\frac{1P}{6EI}\right)(x_3 - 2a)^3 + \left(\frac{11Pa^2}{12EI}\right)x_3 - \left(\frac{3Pa^3}{4EI}\right) \tag{2}$$

Where y_3 is the vertical displacement in this portion of the beam, E and I are the same as described above, and x_3 is the distance along the beam from end A.

The equation for the Moment of Inertia for a rectangle about its centroid is

$$\bar{I}_x = \frac{1}{12} b\, h^3 \qquad\qquad (3)$$

Where b is the width and h is the height of the rectangle (cross section of the beam)

Experimental Procedure:

Set up a simply supported beam, as shown in Figure 1. Set up 4-5 vertical gauges at any points along the beam to measure various deflections. Apply a load (P_1) at each location shown and measure the deflection at each of the gauges. These measurements are your "experimental" values.

Analytical Procedure:

1. Determine the value of "a" for your selected beam and calculate the theoretical elastic curve for each of your loading conditions using equations 1, 2, and 3. Remember, use equation 1 for $0 \leq x_1 \leq a$, equation 2 for $a \leq x_2 \leq 2a$, and equation 3 for $2a \leq x_3 \leq L$ (Do not include this data in your results section.)
2. Plot the theoretical elastic curve for your loading condition (plot the ENTIRE curve from 0 to L using a smooth line)
3. Plot the experimental (measured) values on the theoretical curve using markers only.
4. Determine the maximum positive vertical displacement for each load and clearly indicate these points on your curves.

Assignment:

- The format for this writing assignment will be a **memorandum.**
  - Items 2 through 4, listed in the Analytical Procedure, should be included in the results section of your report. In particular answer the following questions.
    - How well did the theoretical curve predict the experimental data?
  - In your conclusion, discuss how your results relate to the objective of the lab.

Appendix A. Raw Data
EN-3112L Strength of Materials Laboratory ♦ Elastic Curve

Table 1. Material Properties		
Material	**E (GPa)**	**E ($\times 10^6$ psi)**
Aluminum	70	10.1
Brass	105	15
Steel	200	28

Beam Length _____

Beam Width _____

Beam Thickness _____

Load _____**grams**

Table A2. Deflection Measurements		
Gauge	**Distance from End (x inches)**	**Vertical Displacement (x inches)**
1		
2		
3		
4		
5		

Massachusetts Maritime Academy ♦ Department of Engineering
EN-3112L Strength of Materials Laboratory ♦ Design Project

An aircraft manufacturer has issued a request for quote (RFQ) for the design and manufacture of a wing spar for a light sport aircraft. As part of the design team, you and your team have been asked to design the spar (beam) shape, material and dimension based on the given specifications. The specifications that are required are as follows:

1. The wing area will be 140 ft^2 and the wing span will be 28 ft. Assume a rectangular wing plan shape.
2. The wing spar will be connected at the fuselage centerline with rigid joins via complete welding.
3. The wing spar shall be limited to the following sectional shapes: round tube, square tube, or I-beam (S-flange or W-flange)
4. The cross-section height and width of the spar shall be limited to 6 inches maximum to fit within the wing profile.
5. For full aerodynamic performance in loops, the wing shall be designed to provide a maximum vertical lift force equivalent to an acceleration of 4.5 G (4.5 times the weight of the loaded aircraft)..
6. The maximum loaded aircraft weight shall be 1320 pounds.
7. The force of the lift on the wing, which has a rectangular shape, can be assumed as one resultant force at the center span and chord of each wing half, which can be further assumed to generate a bending load on the wing spar.
8. The deflection of the wing spar at the wing tip compared to the no-load condition shall be not more than L/30 inches due to the maximum lift force on the wing, where L represents the length from the wing tip to the centerline of the aircraft.
9. For full aerodynamic performance in rolls, the ailerons are designed to provide a maximum roll force of 120 pounds each.
10. The aileron area will be 2.5 ft^2 and the aileron span will be 5 ft. Assume a rectangular aileron plan shape.
11. The force on the aileron, which has a rectangular shape, can be assumed as one resultant force at the center span and chord of of the aileron, which can be further assumed to generate a torsion load on the wing spar.
12. The maximum angle of twist of the wing at the tip shall be less than $1.5°$.
13. Shall evaluate three different sectional area profiles for the wing spar.
14. Shall evaluate three different material types for the wing spar.
15. There shall be a factor of safety of at least 2 for the stress analysis of materials (bending, torsion, shear).
16. The wing spar that meets the requirements with the least weight shall be recommended, considering other factors such as corrosion and cost.
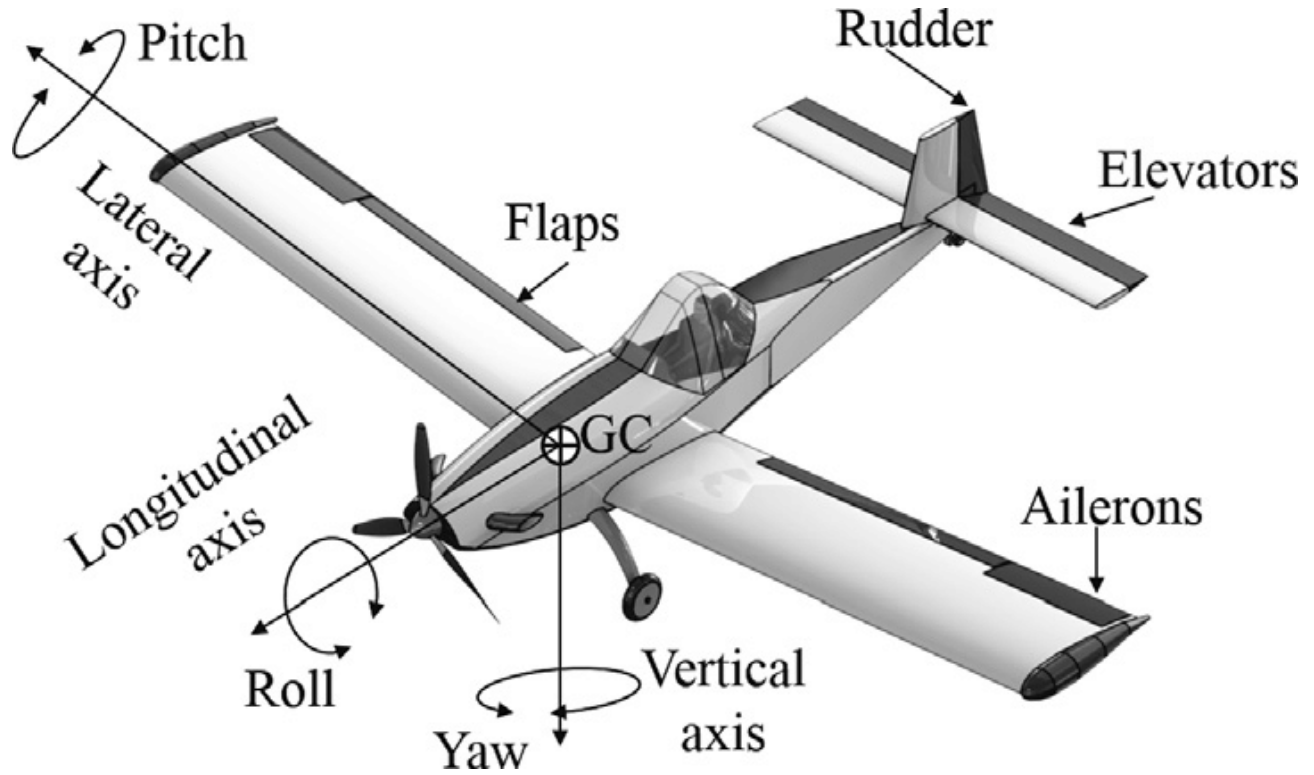
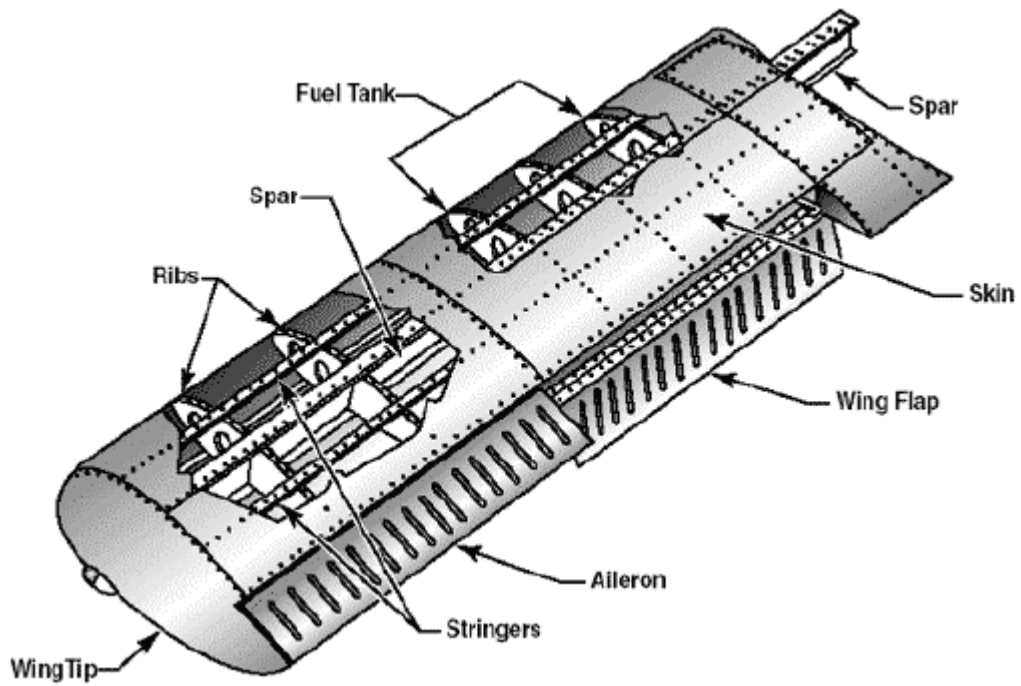Figure 1: Schematic of Aircraft components © *Hernan Cerón-M*

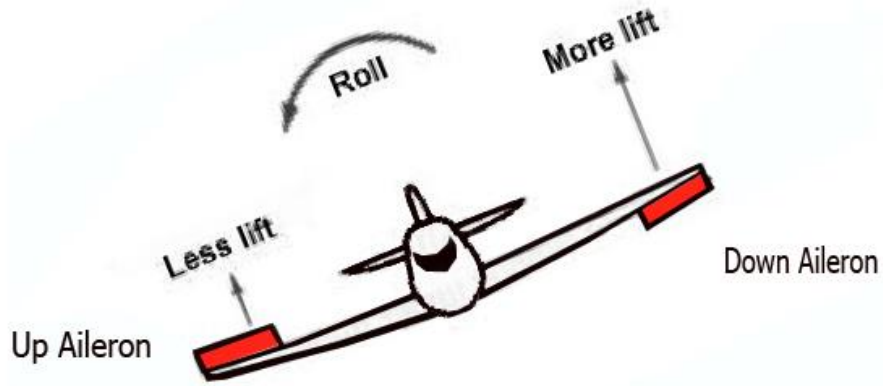Figure 2: Structural components of aircraft wing © *David C. Wynn*

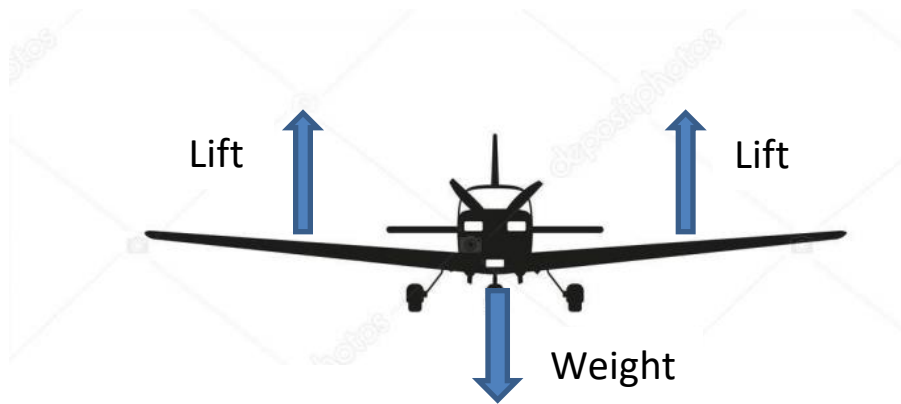Figure 3: Aileron operation © *Kasım 4, 2017, How To Control An Aircraft, Control Surfaces, Roll Axis,*

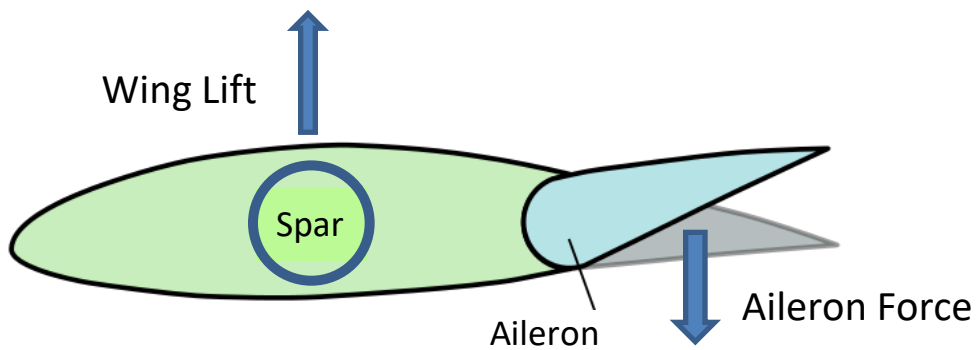Figure 4: Lift and Weight Balance © *Shain, Sep 21, 2017*

Figure 5: Lift and Aileron Force Locations © *Wikiwand*

In your report you must include:

a. Material comparison and supportive explanation for selected material for the spar (compare minimum of 3 materials).

b. Dimensions of the spar including the length and the profile of the cross sectional area.

c. Complete bending (including moment diagram), torsion, and deflection analysis

d. Cost estimate to manufacture the spar.

After your team has submitted its proposal, you will need to prepare a 10 minute Power Point presentation.

Design Team:

Your team may have no more than 3 and no less than 2 members. Each team will submit one complete report as described below. Each team member should receive the same grade. However, final grading is left to the discretion of the instructor and will be commensurate on the level of effort of the individual team member.

Design Procedure:

1. List all assumptions required for the design

2. You must source where you found the material properties (book, MatWeb, etc.)

3. Provide a complete design and weight estimate for the wing spar.

4. Include a complete bending stress, deflection and angle of twist analysis of the wing spar.

5. Include a calculation and declaration of the maximum deflection of your spar and compare it to the allowable given deflection.

6. Include a calculation and declaration of the maximum angle of twist of your spar and compare it to the allowable given angle of twist.

7. Include a calculation and declaration for the weight of the spar

7. In your appendix, <u>you must show that your team analyzed three profiles and three different materials</u>.

Report:

The laboratory report shall include the following sections.

o The <u>Cover Letter</u> section will be in business letter format referring to the original design specifications and summarizing the results of the design analysis and cost estimate

o The <u>Procedure</u> section will describe the design process including calculations and the process described above.

o   The <u>Design Summary</u> section will include dimensional AutoCAD (or SolidWorks) drawing of the final spar design (cross sectional drawing of the spar) along with all of the required elements specified above. The maximum deflection and angle of twist should also be included. Be sure to explain the reasoning for your choice of profile(s), material(s). Compare and contrast your different options. You will also provide a table with the following information for the material – USE THE UNITS SHOWN BELOW

·   G (psi)
·   E (psi)
·   CTE ($°F^{-1}$)
·   Ultimate Shear Strength (psi)
·   Ultimate Yield Strength (psi)
·   Density (lb_f/in^3)

o   The <u>weight</u> of the section will define the total weight of the spar. Material weight will be based on researched p or calculated weight per foot multiplied by the total length of the spar. Make sure you cite your sources.

Remember, everything in this report is to be <u>YOUR TEAM'S OWN WORK</u>. Use of any portion of another Team's/Students Design will be considered a violation of the course Academic Honesty policy and will be dealt with accordingly.