California State Polytechnic University Pomona

Aerospace Engineering Department's

ARO 3570L Lab Manual

[Revision: 24F]

for the

Aerospace Structures Laboratory

Picture from Lab Report of Acuna, Duong, & Montes-Lucano (2017)

By

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ARO3570L Lab Manual, Rev. 24F

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1-1 Introduction

Purpose & Usage

This is the lab manual for CPP's Aerospace Structures Laboratory for ARO3570L. This manual should be used by all faculty and students involved with ARO3570L, and should be augmented & updated by each and every faculty member assigned to teach ARO3570L. Updates should be provided to Todd Coburn for inclusion in the latest release of this manual.

The *safety procedures* in this lab manual, and any corresponding documentation for tools, equipment or experimental methods implemented, are also intended for anyone and everyone using the laboratory, including students and faculty involved in club, project, build or research activities. Anyone using the laboratory is expected to read and review the safety section carefully, and to sign the safety form of page 1-2-4, and to provide a copy of this signed form to Dr Coburn *prior* to performing any design, build, fabrication or test activity in the 13-1114 laboratory.

The goal of this Lab Manual is as follows:

- To define & document the operating procedures of the test and fabrication equipment in the lab.
- To define experiments & fabrication activities that can be performed on the equipment in the lab.
- To document safety practices, procedures & expectations for the laboratory.
- To drive student learning in support of CPP's "Learn by Doing" philosophy and charter.

reinforce the analytical principles of Structural Mechanics though hands-on projects. This is intended to include both experiments and build projects.

Safety

After reading this subsection, and *before using any equipment or tools in the laboratory*, locate and read the laboratory safety guidelines included in Appendix A of this manual. Once you have read, understood, and agreed to all rules discussed there, be sure to sign the Lab Safety Commitment shown on page A-4 of this manual and submit to Dr Coburn.

Anyone who does not have a safety form on file with Dr Coburn will not be granted access to the laboratory, or will have their access revoked if their signed form is dated more than a year prior.

Anyone unwilling or unable to commit to the Lab Safety Rules of Appendix A will be unable to use the Aerospace Structures Laboratory.

Manual Updates

This lab manual is under continuous improvement. Be alert for updates from your instructor and have the latest copy on hand.

Responsibilities

In addition to the safety procedures & expectations of Section 1-2, anyone entering the laboratory is expected to maintain and enhance the organization, cleanliness, and efficient operation of the laboratory by managing the placement and removal of their own items and waste, by returning tools they use or ones they see lying about, and by monitoring & enhancing the cleanliness of the laboratory, tools and equipment. *Anyone unwilling to accept responsibility for enhancing the cleanliness & organization of the lab, even to the extent of cleaning messes they did not create, will not be allowed individual access to this laboratory.*

Floor Plan

The current floor layout of the Structures Lab is shown in Figure 1-1-1 below. Test equipment and areas of usage are indicated as well. The lab is currently being reengineered and the floor plan will be changing as needed.

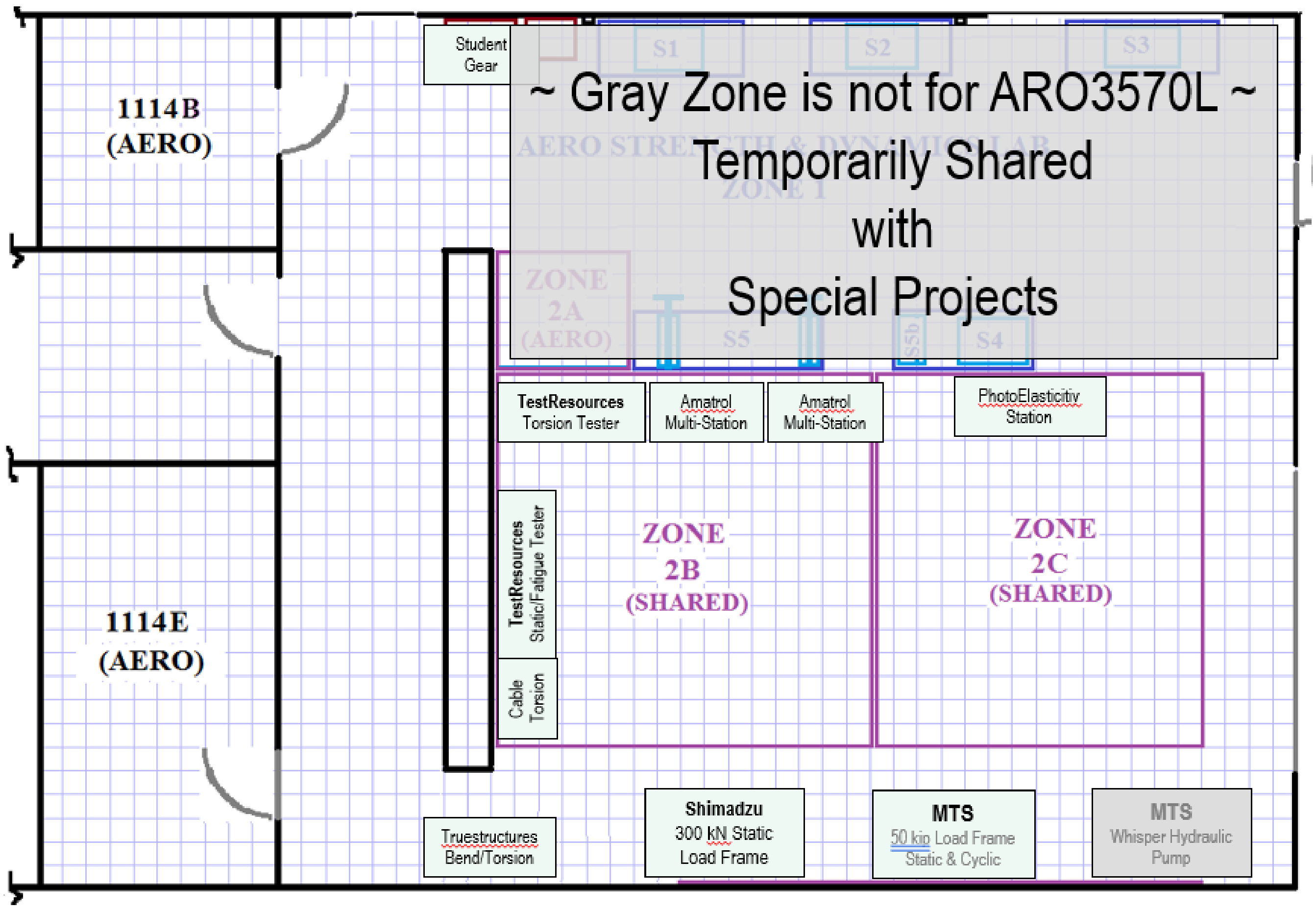


Fig. 1-1-1: Aerospace Structures Laboratory (Bldg 13-1114)

The Structures Lab was designed with a strongback wall and a strong floor, and with a configurable steel framing structure, to enable the attachment & loading of structures for large scale structural testing. This is the only laboratory that has this large-scale test capability at CPP, and this is a competitive advantage of the Aerospace Department and of the College of Engineering.

Figure 1-1-1 shows three test zones (2A, 2B, 2C) that are marked to enable multiple large-scale tests to be active at once. These areas can be used by students performing build activities when large scale tests are not underway. Students using these areas must remove their structures from the laboratory or to a delegated storage cubby in the lab with the permission of Dr Coburn. Any personal items or projects left anywhere in the laboratory (including in the storage cubbies) should be labeled with the contact information (including phone number) of the responsible student, the name of the faculty member overseeing the project, and with the year & semester of the activity. Any unmarked items will be permanently discarded and eliminated from the laboratory.

Test Equipment Usage

The test equipment and tools in the Aerospace Structures Lab are intended for student use to reinforce the engineering principles presented in the Aerospace sequence of courses.

However, no test systems in the laboratory may be used by students except as follows:

- When enrolled in ARO3570L and used under the guidance of the instructor.
- After obtaining written permission from the lab director (Dr. Todd Coburn) after being properly trained in the needed item's safe use.

The test equipment and tools in the Aerospace Structures Lab are intended for student use to reinforce engineering principles presented in the Aerospace sequence of courses.

Cleanup After Each Lab

After each lab session, each student lab team is expected to put everything away and to throroughly clean their workstation. Details as follows:

- Test Machines & Accessories: *After testing is complete, return all test equipment and accessories back to their prescribed locations. This should be precisely where they found the tool or accessory. Check with instructor if there is any uncertainty about where a tool or piece of equipment goes.*
- Tools & Support Equipment: *Any and all tools used should be returned to their prescribed locations. Tools painted with orange spray paint belong in the large red student-use toolbox. Others may go elsewhere. Check with instructor if there is any uncertainty about where a tool or piece of equipment goes.*
- Cleanup of Work Station: *The final step in each and every lab is to thoroughly clean the workstation. Find the cleaning cart, use the blue paper shop towels and the 409 to clean any dirt, dust or grime from all equipment & tabletops. Gently wipe down any computer equipment without using 409 on the monitor screen. Use the WD-40 & the red shop rags to wipe and lightly oil each metallic or moving piece of machinery or equipment.*

Any student teams doing a slipshod job will lose class points.

Student Tools

There is a red toolbox located across from the door to 13-1114E. It is for student and laboratory usage in the Structures Lab. All tools in it should be marked with orange spray paint, and any tools with orange paint on them should be returned to this toolbox. After using any tools, wipe them down with the red shop rags and a little WD-40 before returning to the toolbox.

Lab Manual Format

Each section of the lab manual documents a certain piece of test equipment. For example, Section 2 documents the Shimadzu AGS-X 300 kN Test System. The first subsection of each major section documents characteristics & capabilities of the machine that should be understood for most experiments. It also discusses safety procedures for the machine, and documents procedures for changing the machine into different configurations for different types of tests. For example, Section 2-0 discusses these things for the Shimadzu. Section 3-0 documents these things for the TestResources 810LE, etc. Each subsequent subsection (2-1, 2-2, etc) documents an experiment that can be performed on that particular piece of equipment.

Before starting an experiment, students should first read the first subsection (X-0) for a piece of equipment, and then should follow the proscribed procedure for the experiment assigned.

2-0 Shimadzu AGS-X 300kN Test System

The Shimadzu AGS-X 300kN (67 kip) Test System can be configured to perform tension, compression, and bending tests. It was provided to the department through a 2017 Air Force Grant.

Capability

- Static Vertical Load Capability
  - Max Load: 67 kips Static
  - Tension, Compression, or Bending
  - Stroke:

Fig. 2-0-1

Power Requirements

- Software: TrapeziumX (Version 1.4.5)
- Voltage: 200-230 3 Phase VAC ±10%

Configurations & Grips

- Tension Testing
  - Max Open Space for Tension: 25”
  - Max Tension Sample Length: 29”
  - 300kN Non-Shift Wedge Grips
    - Weight=33 kg (72.7 lb)
    - Flat Grip Faces: t=0 to 8.5 mm (0.3346”), w=50 mm (1.9685”), L=75 mm (2.952”)
    - V-Groove Grip Faces: 4 to 9 mm (0.457” to 0.354”), 250 kN & 300 kN
  - Epsilon Extensometer
    - 2” Gage Length w/ 25% (0.5” usable motion
- Compression
  - 250kN Compression Plates
    - Diameter: diameter=150 mm (5.9055”)
- Bending
  - 3-Point Bend Fixture:
    - 100 kN Capacity (Careful! The load frame can break this).
    - Span of 20-500 mm (0.787”-19.68”)
    - Weight: 30 kg (66.1 lb)
  - 23.5” Width Available in Load Frame

2-0-1 Basic Shimadzu Operating Procedures

This subsection defines the basic fundamental operating procedures for the Shimadzu. These procedures are universal and will be needed for any experiment using the Shimadzu. *Read this section carefully before starting any experiment with the Shimadzu, but do not perform any of the steps herein until directed by the lab procedure for the experiment assigned*. Pay special attention to the Emergency Sto procedures and to the section defining how to jog the loadhead.

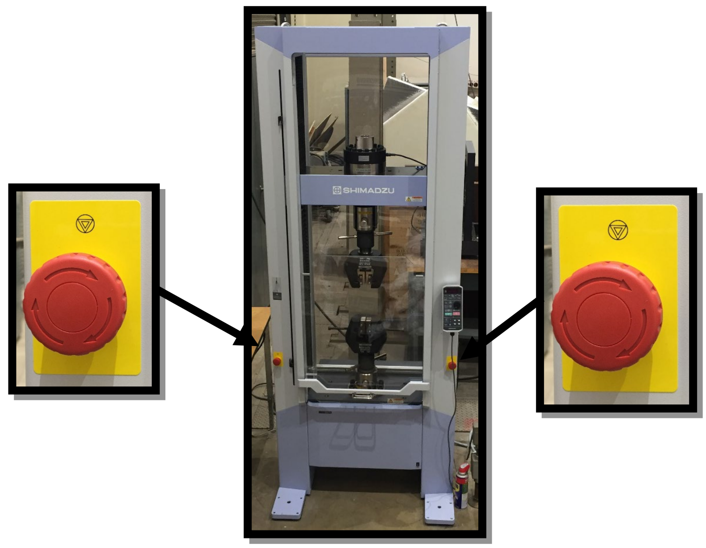
2-0-1-1 Before Starting the Machine (Emergency Procedures)

Before starting the machine, locate the two emergency stop (E-Stop) buttons located on the front of the machine, as shown at right.

Assign one student to constantly monitor the E-Stop button whenever the machine is being used.

Press the E-Stop button any time the machine appears to behave in an unsafe manner, or if anything looks suspicious, or if there appears any danger of injury to people or parts.

Once the E-stop button is pressed, it can be released by twisting the switch in a clockwise direction, as indicated by the direction arrows on the switch itself.



Emergency Stop Buttons

Safety Shield Usage

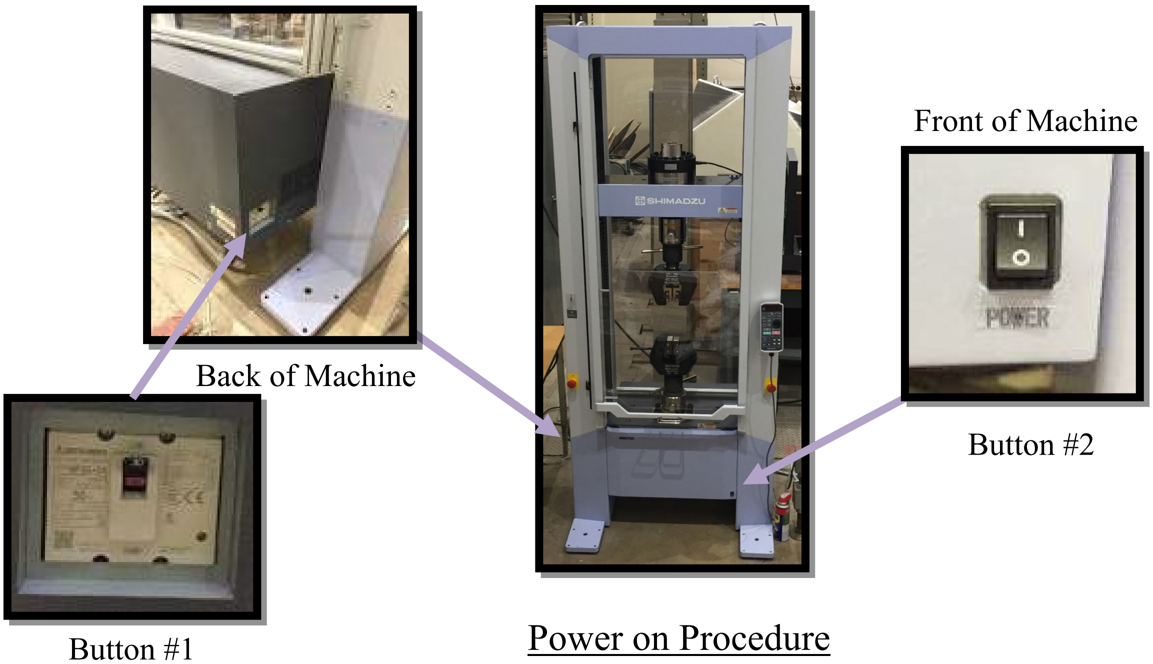
The Shimadzu has Safety Shields for the front and back of the machine. The aft shield is fixed in place. The front shield can be raised and lowered by squeezing the handle and applying light force in the direction desired.

The front Safety Shield can be raised to enable operations inside the test fixture before and after testing, but must be completely lowered before testing. If the Safety Shield is not all the way down, attempting to test will activate an alarm. If the alarm goes off, check to be sure the Safety Shield is completely lowered.

2-0-1-2 Starting the Machine

Once the Emergency Stop Buttons are understood (as described above), the Shimadzu Machine can be started.

The Shimadzu machine has two power buttons which need to be in the ON position in order for the machine to operate. The first is located on the front of the machine, and the second is located on the back of the machine, as shown below.



Power on Procedure

Once both buttons are in the 'ON' position, allow the machine to warm up for at least 15 min before any use of the machine.

2-0-1-3 Opening the Trapezium Test Software

Turn on the computer.

Log on to the computer using the following:

- USER: ARO357
- Password: ARO357.

Open the TrapeziumX software by double clicking the <TrapeziumX> icon located on the desktop (shown at right).

Log in to the Trapezium software using the following:

- USER: ARO357
- Password: ARO357.

This will bring up the TrapeziumX home screen, which looks like the figure below.

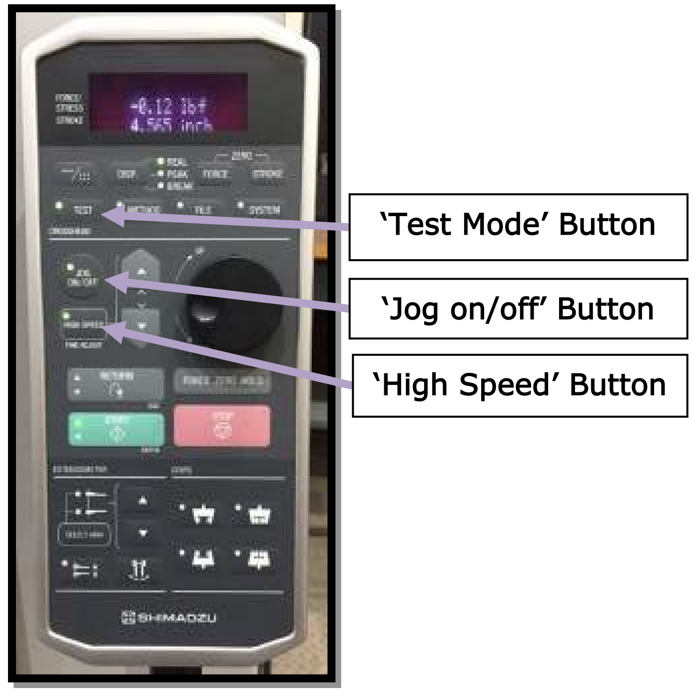
Stop at this point. If you are running an ARO3570L experiment, the procedure will identify which test file to use. If you are performing independent work on a project, you may need to create a test method unique to your needs. Consult the lab director (Dr Coburn) before attempting this.

2-0-1-4 Jogging (Moving) the Load Heads

Regardless of which test is being run, the load heads can be moved, or “jogged” using the handheld control panel shown at right.

Warning:

Care must be taken so the load heads are never moved until they contact each other, whether tension grips, compression platens, bend fixture, or some other apparatus is installed. Jogging the machine should be used to bring the load heads into proximity of the samples, so they can be loaded correctly and efficiently. Actual loading of parts and materials should only occur while the test software is used to monitor load, deflection, stresses and the like. Loading with the jogging feature, or using the jogging feature to create contact between the load heads or other structures of the test frame, can damage the test machine & equipment.



Control Panel

The jogging feature can be used with the preset jog speeds, or the jog speed can be changed in the <Settings> section of the Trapezium software.

To jog the testing heads do the following:

- Place the control panel in test mode by pressing the ‘Test’ button.
- Press the ‘Jog on/off’ button
- Press the ‘High Speed’ buttons
- Press the <^> or <**v**> buttons to move the loadhead up or down.
- When the load heads are near the desired position, the dial control knob can be used to make finer adjustments to the motion. This is best done with an index finger, which can be used to rotate the knob with a much finer resolution of control.
- Practice jogging the load head up and down, and using the high speed arrows as well as the dial controller, with plenty of free space between the load heads prior to attempting to approach a sample using the controller.

Note: A green light will indicate if the button has been pressed correctly. The image above shows the control panel with all three lights lit.

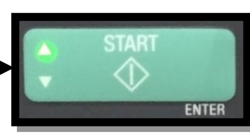
2-0-1-5 Calibration

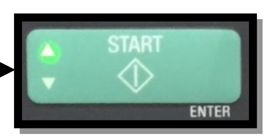
Once a sample has been prepared for testing, the system will need to calibrate itself prior to initiating the test. This is done using the hand-held control panel on the right vertical leg of the machine as follows:

1. Calibrate the test frame system using the hand-held control panel by clicking <System>.
2. Scroll down to "Calibration" using up and down arrows if needed.
3. Press <Start> once until "Force - Execution" is shown.
4. Press <Start> a second time and make sure selection arrow us aligned with "Execution".
5. Press <Start> a third time to start. (See Figures below).

Press 'Start' button to proceed

Press 'System' button to bring up calibration menu





With 'Force' Selected, Press start button twice

2-0-2 Changing Test Configuration & Accessories

The following subsections define the procedures for switching the configuration of the machine. Do not attempt to do this without the instructor's permission.

Before performing any experiments with the Shimadzu, scan this section to understand what information is presented here. When performing procedures for an experiment that requires a change of configuration, first check with the professor for permission to proceed, then carefully follow the instructions herein to switch the configuration. After completion of the experiment, check with the professor to see if the configuration should be switched back, or left as is.

2-0-2-1 Removal of Shimadzu Compression Plates

The following procedure documents how to remove the compression plates.

1. Secure permission of instructor or Dr Coburn before attempting this procedure.
2. Raise Shield.
3. Fetch the 2.5 mm Allen Wrench from Drawer 195 of Cabinet A3.
4. Support the compression platen from the bottom (Fig. 2-0-3), then loosen tension screw that secures the plate to the upper nut, and catch the upper compression plate when it falls free (Fig. 2-0-4).
5. Return the Allen screw in its threaded hole & tighten until snug.
6. Place upper compression platen on upper left shelf of Cabinet A-3.
7. Lift lower compression plate from base of load frame, and place on shelf upper left shelf of Cabinet A-3 (Fig. 2-0-2 & 2-0-5).
8. Grab spanner wrench from drawer 195 of Cabinet A3.
9. Use spanner wrench to loosen the nut that secures the upper compression plate to the upper cup, using your hand to support the nut so it doesn't fall free (Fig. 2-0-6).
10. Place the upper compression nut & cup in drawer 195 of Cabinet A3.

Fig. 2-0-2

Fig. 2-0-3

Fig. 2-0-4

Fig. 2-0-5

Fig. 2-0-6

2-0-2-2 Installation of Shimadzu Compression Plates

The following procedure documents how to set up the Shimadzu Machine for Compression Testing.

1. Secure permission of instructor or Dr Coburn before attempting this procedure.
2. Raise Shield.
3. Fetch the upper (Fig. 2-0-7) & lower (Fig. 2-0-8) compression plates from the upper left shelf of Cabinet A-3. The upper Plate has a retention groove on the post, the lower does not.
4. Insert the post of the lower compression plate into the hole at the center of the Test Frame as shown in Figure 2-0-9.
5. Fetch the Upper-Compression-Holding-Fixture-Screw shown in Fig. 2-0-10, the spanner wrench, and the 2.5 mm Allen Wrench from drawer 195 of Cabinet A-3.
6. Screw the Upper-Compression-Holding-Fixture-Screw into the upper Holding Cup as shown in Figure 2-0-10, then tighten it until snug with the spanner wrench.
7. As one student lifts the upper compression plate into the upper retention screw, have another student use the 2.5 mm Allen Wrench to tighten the retention-allen-screw that secures the plate to the upper nut until it is snug, as shown in Fig. 2-0-11.
8. Return the Allen & spanner wrenches to drawer 195 of Cabinet A3.
9. The machine is now ready for compression testing.

Fig. 2-0-7

Fig. 2-0-8

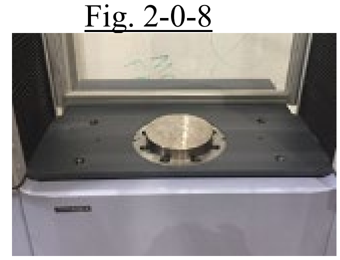


Fig. 2-0-9

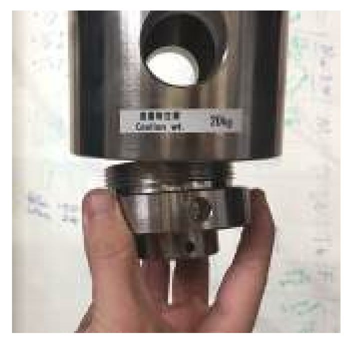


Fig. 2-0-10

Fig. 2-0-11

2-0-2-2 Attachment of Shimadzu Lower Post Attachment Boss (for Tension Test)

The following procedure documents how to attach the lower post attachment boss.

1. Secure permission of instructor or Dr Coburn before attempting this procedure.
2. Raise Shield.
3. Fetch the Lower Attachment Boss from the upper shelf of Cabinet A3 (Fig. 2-0-12) & 8 Allen-head bolts from drawer 122 (Fig. 2-0-13).
4. Place Lower Attachment Boss on machine (Fig. 2-0-14), and clock the holes so one of the holes is facing straight forward.
5. Finger tighten the 8 bolts, then fetch the ½” ratchet and 17 mm allen socket (Fig. 2-0-16) from drawer 195 (Fig. 2-0-15).
6. Once bolts are finger-tight, tighten with socket to snug+.

Fig. 2-0-12

Fig. 2-0-13

Fig. 2-0-14

Fig. 2-0-15

Fig. 2-0-16

2-0-2-3 Attachment of Shimadzu Tension Grips

The following procedure documents how to attach the Shimadzu Tension Grips.

1. Secure permission of instructor or Dr Coburn before attempting this procedure.
2. Verify that there is 20" or more of free space between the upper and lower post. If not, you will need to follow the procedures in the corresponding subsections below to start the Shimadzu Load frame and to jog the machine to provide the space required
3. Retrieve upper tension jaws from right side lower shelf cabinet A-3 (Fig. 2-0-17).
4. Retrieve tension pin and retention wire from drawer 122 of Cabinet A-3 (Fig. 2-0-18).
5. Have instructor or strong member of team lift upper jaw into the upper tension cup of test fixture (Fig. 2-0-19) while another student inserts the pin to hold it in place. Note: you may need to jiggle grips to get pin through hole.

Fig. 2-0-17

Fig. 2-0-18

Fig. 2-0-19

Fig. 2-0-20

6. Then attach the retaining spring (Fig. 2-0-20).
7. Repeat the procedure for the lower grips (Fig. 2-0-21).
8. Fetch the spanner wrench from the drawers of Cabinet A3 & use it to tighten the upper & lower spanner nuts (Fig. 2-0-22).
9. Note: Tension jaws should be installed with labels facing forward.

Fig. 2-0-21

Fig. 2-0-22

2-0-2-4 Extensometer Preparation

If the extensometer will be used in an experiment, it will need connected & configured prior to opening the test software or turning on the load frame as described below. If not, skip this section.

1. Get the extensometer from Drawer 122R of Cabinet A3. (See Fig. 2-0-23)
   - ***CAREFUL!!*** *Handle extensometer with care at all times.*
2. Carefully connect extensometer to the ESA (See Fig. 2-0-24):
   - There are two cables in the extensometer box: Plug in the short ASGX cable to the Channel 1 connector on the front of the ESA Box as shown in Figure 2-0-24.
   - Plug the longer cable with the circular connector to the ASGX cable.
3. Turn on ESA Box using the switch located on the front of the box.
4. Calibrate ESA Box (Fig. 2-0-24):
   - Press the <Mode> Button to switch to Cal/Set Mode.
   - With S-1 showing on the ESA screen, press <Enter> for "Individual," then press <Enter> for <Yes> to calibrate the extensometer with the ESA box.
   - Calibration is finished when the ESA screen returns to "Main Menu" screen.
5. Once the ESA Box has been calibrated, set the extensometer in a safe place and continue start-up procedures as detailed in the lab procedure section.
6. If anything looks fishy later in the experiment, this calibration step can be repeated after unloading the sample.

Fig. 2-0-23

Fig. 2-0-24: ESA Box

Holding & Attaching the Extensometer

The extensometer is connected as described above during the setup phase of the experiment. Later it will need to be attached to the specimen. The best way to handle and open the extensometer is using the Spiderman hold, which is identified in Figure 2-0-25. This grip can be used to hold the extensometer. Apply the Spider-Squeeze to open the jaws for attachment to sample. Slowly release the squeeze to allow the wire jaws to gently bite the sample so any relative motion can be measured by the extensometer. If the jaws do not fit the sample, there should be small rubber bands that can be used in lieu of the wire jaws shown below.

Photos from April 2018 Report of Gomez[2], Ramirez & Kussler

Fig. 2-0-25: Spiderman Hold for Holding & Attaching the Extensometer

2-0-2-5 Installing the 3-Point Bend Fixture

The following procedure documents how to prepare the Shimadzu Machine for 3-Point Bend Testing.

Fig. 2-0-26

1. Secure permission of instructor before attempting this procedure.
2. Retrieve the 3-Point Bend Fixture from the upper left shelf cabinet A-3 (Fig. 2-0-26).
3. Retrieve centering pin for the 3-Point Bend Fixture from the upper tray of drawer 195 if cabinet A-3 (Fig. 2-0-27). Be careful not to lose the centering pin during transportation.
4. Place the centering pin in the central hole of the Shimadzu load frame (See Fig. 2-0-28).

Fig. 2-0-27

Fig. 2-0-28

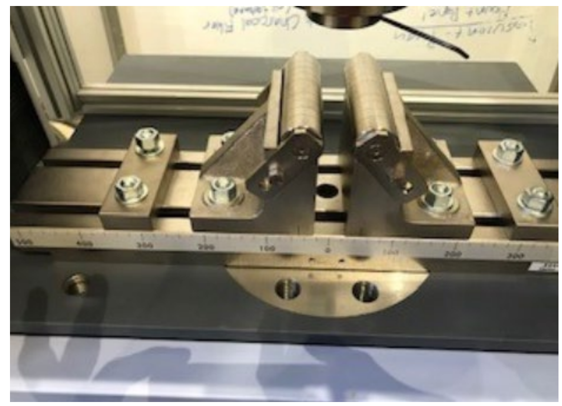


Fig. 2-0-29

5. Carefully set the 3-Point Bend Fixture in place over the centering pin (Fig. 2-0-29). Be careful not to pinch fingers as the fixture drops into place.
6. Retrieve the upper loading Tee from drawer 195 of Cabinet A-3 (Fig. 2-0-30).
7. Insert the Upper Loading Tee in the upper receptacle of the Load frame, and secure in position using the 2.5 mm Allen wrench and screw.
8. Your fixture should now look like Figure 2-0-31.

Fig. 2-0-30

Fig. 2-0-31

2-0-2-6 De-Installing the 3-Point Bend Fixture

The following procedure documents how to return the Shimadzu 3-Point Bend Fixture to its storage location.

1. Secure permission of instructor or Dr Coburn before attempting this procedure.
2. Carefully lift the 3-Point Bend Fixture off the centering pin of the Shimadzu lower frame, and set it gently and neatly on the foam on the upper left shelf of cabinet A-3 (Fig. 2-0-26).
3. Carefully pull the centering pin from the Shimadzu lower frame and place it in the upper tray of drawer 195 if cabinet A-3 (Fig. 2-0-27).
4. Use the 2.5 mm Allen wrench to loosen (without removing) the retaining allen screw holding the Upper Loading tee in place.
5. Return the upper loading Tee to drawer 195 of Cabinet A-3 (Fig. 2-0-30).

2-1 Experiment 2-1: Tension Test using Shimadzu

Purpose

In this experiment, student teams will use the Shimadzu 300 kN (67 kip) Static Test Machine to investigate tension response of a sample.

References:

- E.F. Bruhn, Analysis & Design of Flight Vehicle Structures, Section C8.

General Comments

This experiment is very important. It will be difficult to recall all aspects of the test later. Make sketches or take photos during all stages of testing for your report. Think about each step as you go, read each step aloud, and discuss with team members what you are doing, and any questions, insights, or concerns you have as you go. Jot down notes as appropriate.

Test Fixture Setup

1. Follow the following procedure to prepare the test equipment and run the test. Any errors, changes, or deviations from the procedure provided should be documented and communicated with the instructor for potential update to this manual. These deviations should also be documented in your lab report.
2. *Without turning anything on*, locate the Shimadzu 300kN Electrodynamic Test Machine in Lab. It should look roughly like Figure 2-1-1a.
3. *Without turning anything on*, locate the Manual Control Panel (See. Fig. 2-1-1b).
4. *Before proceeding further*, verify that the Tension grips are installed already (See Fig. 2-1-2). If not, with the instructor's permission, install by following the procedures of Sections 2-0-2-2 & 2-0-2-3.
5. *Read Section 2-0 of this manual*, which documents key procedures for starting and operating this machine.
6. Connect & prepare the extensometer as documented in Section 2-0-2-4. Do not attach to sample yet.
7. Turn on the Load Frame by following the procedures of Sections 2-0-1-1 & 2-0-1-2.
8. Start the computer & open the test software by following the procedure of Section 2-0-1-3.

Fig. 2-1-1a

Fig. 2-1-1b

9. Review Section 2-0-1-1 on usage & release of the Emergency Stop buttons. Assign one of your team members to monitor the stop buttons for the remainder of the test activity.
   - *The E-Stop buttons should be used any time a concern arises regarding safety of the students or equipment, or if testing proceeds in an unexpected manner.*
10. Calibrate the load frame software by following Section 2-0-1-5. This step can be repeated if anything is done to the setup that might have compromised the calibration.

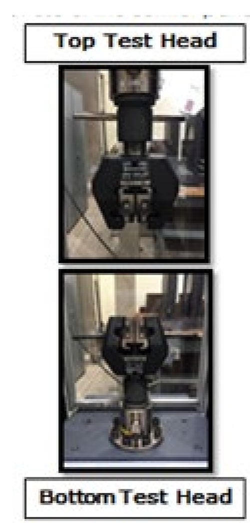


Fig. 2-1-2

Test Method Selection

1. In the TrapeziumX Software, Click on <Select Method and Test>
2. Select <ARO357_Al_Tens_w_Ext_Template_TC.xmas>

Sample Preparation

1. Get Test Specimens from instructor.
2. Measure sample completely. Sketch sample and note dimensions carefully.
3. The primary measurements are the width and thickness of the minimum section, and the gage length, but measure the sample completely, sketch it and identify all dimensions, including an approximate radius at the transition from the grips to the minimum section.
4. The gage length for entry in the software though is not from the sample dimensions, but from the extensometer dimensions. For our extensometer, the gage length is 2.0”. Use this number in the software.
5. Record all values for report and for entry into software later.
6. Go to Specimen Sizes on the left hand TrapeziumX menu as shown in Figure 2-1-4.
7. Input sample dimensions measured earlier as shown in Figure 2-1-5.

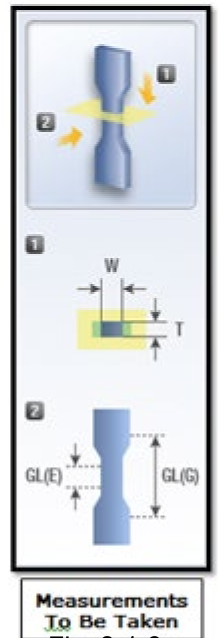


Fig. 2-1-3

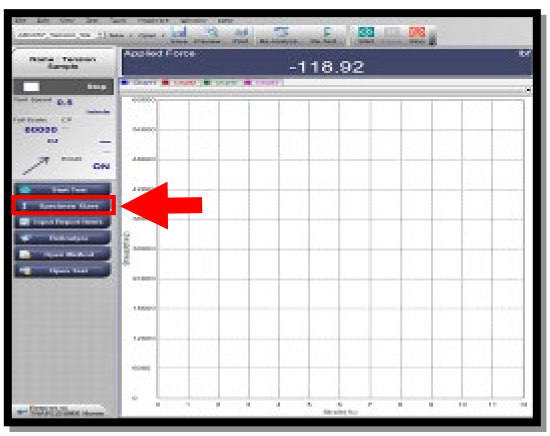


Fig. 2-1-4

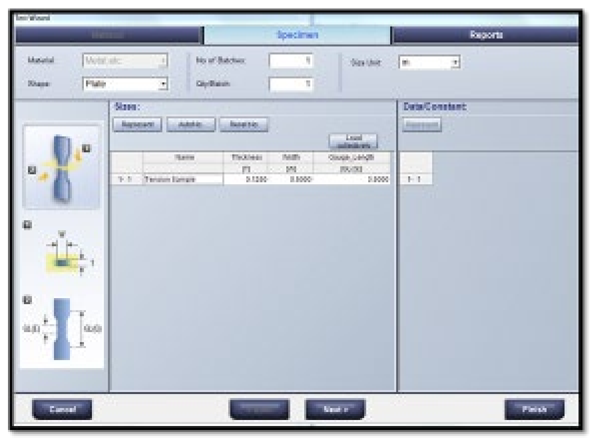


Fig. 2-1-5

8. Click <Next> then <Report>.

Report Preparation

1. Press the ‘Reports’ tab to bring up the reports page.
2. Enter group name/number into ‘Operator’ field.
3. Enter ‘Comments’ if necessary. Press ‘Finish’ to proceed

Fig. 2-1-6

Test Procedure

Fig. 2-1-7

Fig. 2-1-8

Fig. 2-1-9

1. Carefully follow Text Fixture Setup Procedure above.
2. Review the "Jogging" subsection of Section 2-0 to refresh your understanding of how test fixture crossbars are "jogged" up and down.
3. Assign one student to hold & monitor the emergency stop button at all times for remainder of test.
4. Assign another student who will operate the software & control the test while monitoring the software start and stop buttons.
5. Use the Shimadzu manual control panel to jog the loadhead to provide ample room for the sample between the tension grips.
6. Align the test specimen with the scribe line on the top grip (Fig. 2-1-7). Use the markings on the bottom of the upper grips and on the top of the lower grips to ensure the sample is centered and aligned. (*Note: Although it is best to align the top and bottom edges of a tension sample with the scribelines, it is also necessary to have about 2.5" of clear space between the grips to provide sufficient room to later attach the extensometer. If your sample is short, you may need to cheat the sample further from the scribelines than otherwise desired.)*
7. Tighten the top crank clockwise until the sample is fully clamped.
8. Jog the tension grips to align the bottom of the sample with the marking lines on the bottom grip. Use the knob on the control panel to adjust the grips more precisely. *Do not tighten the lower grips yet!* You will first zero force and stroke as identified below.
9. Sample may move during this adjustment, make sure that sample is still aligned and perpendicular after crank has been tightened.
10. Zero the ESA by pressing the "Zero" button on the front of the ESA box.
11. Zero the stroke, force, and extensometer deflection using the manual control panel (buttons) or in the TrapeziumX software (by clicking in measurement window and selecting zero).
12. Tighten the bottom crank on the lower tension loadhead counterclockwise until the sample is fully clamped in position. Note that this will introduce a force into the sample that will show in both the TrapeziumX test software & on the manual control panel.
13. Review Figure 2-0-20 & the preceding text on how to handle and attach the extensometer, then use the Spiderman Squeeze described to attach the extensometer to the sample.
14. Attach the extensometer to the test sample (Fig. 2-1-8 & Fig. 2-1-9). Allow a gap on the top and bottom of the extensometer and make sure extensometer will not touch the load frame during loading.
15. Remove the pin on the extensometer and let it hang so it will not catch on the test fixture during loading (Fig. 2-1-9).
16. Zero the extensometer on the software by right clicking on the "Extensometer" box in the TrapeziumX Test Software and clicking "zero."
17. Make sure to turn off the <jog on> on the manual control panel before running test.

18. Lower Plexiglass Safety Shield.
19. Make sure all team members are ready to start the test. Make sure the student in charge of monitoring the emergency buttons is ready to procedure.
20. To start the test, click on the <Start> button in the TrapeziumX Test Software as shown in Figure 2-1-10.
21. At the software will prompt of Figure 2-1-11, verify the position of the limit switches and of the emergency stop buttons, then press <Start Test> to proceed if all looks well.
22. Watch carefully. The stress-strain data ought to begin to appear on the screen as the test proceeds.
23. When the sample breaks, have one student use the handheld control panel <Jog> feature to raise the test fixture a foot or so above sample. Click <Jog>, <High speed> and last <^>.
24. Raise the Plexiglass Safety Shield & remove extensometer and then the specimen for examination.
25. Save data by selecting 'File'/Export/All' and specifying the saving location & file name as shown in Figure 2-1-12.
26. Examine files and copy to thumb-drive for post-processing.
27. Verify all data in possession, then delete your test files from computer & empty desktop recycle bin.
28. Repeat procedure if another specimen remains for testing.
29. When everything is done, close the software window.

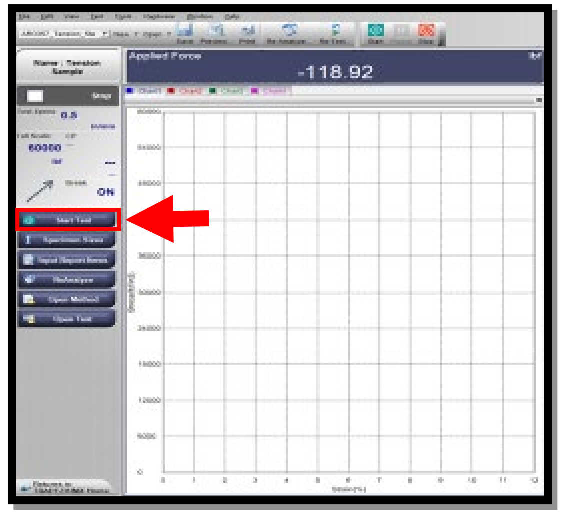


Fig. 2-1-10

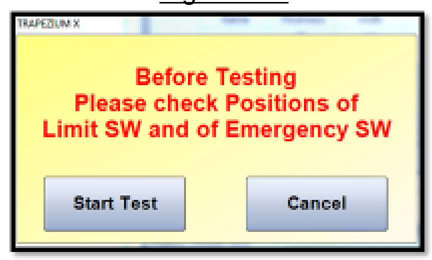


Fig. 2-1-11

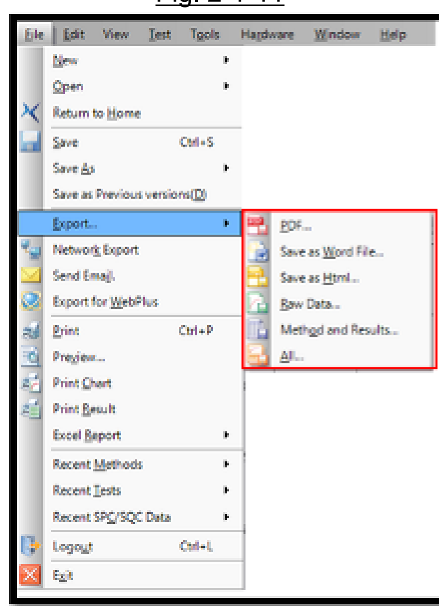


Fig. 2-1-12

Test Teardown:

1. Remove Sample.
2. Verify you have all data files on your thumb drive or personal computer.
3. Delete all personal test files from computer & empty desktop recycle bin.
4. Shut down the computer.
5. Turn off Test Machine by flipping front & rear switch.
6. *Carefully remove and return all test fixturing to Cabinet A3 in same location as found.* Any misplaced test equipment will result in loss of points for your lab team.
7. As you put away each piece of equipment, use the red shop rags with a little WD-40 to wipe down any metal surfaces of the test accessories or reusable samples that you used during the test.
8. Once all equipment is put away, clean your workstation using 409 or similar cleaner with the blue shop towels, then use the red shop rags with a little WD-40 to wipe down metal surfaces of the test equipment so the metal is clean, lightly oiled, and protected.
9. Check work area is clean and free of debris.

10. Check with instructor before leaving lab.

Analysis & Report

1. Prepare a lab report of your test per Appendix B guidelines, except as follows:
   - Procedure can simply state "Followed Experiment 1 Test procedure from Lab Manual".
   - If you add any steps to the procedure, these should be identified by saying "except added XXb, XXc or deleted YY" to indicate added sub-steps to step XX or deleted Step YY.
   - Apparatus section can be dropped from report.
   - Place the raw test data, including load-deflection values and stress strain values reported by the software in Appendix A. This can be in Word, Excel, or tabular format, and does not need prettied up. Also place any load-deflection, stress-strain, or other curves from the test software here. Any graphs or plots or segments of data that are useful for your discussion can be repeated in the body of your report to enhance clarity, or can be referenced to your appendix if this is sufficiently clear.
   - Place your hand calculations in Appendix B.
   - Provide clear dimensioned sketches or drawings of your samples in Appendix C. A dimensioned hand sketch is fine.
   - Place any supporting data in Appendix D+, if needed.
2. Include plot of load versus extensometer deflection. Comment on your curve in your Discussion
3. Include curve of stress (at minimum section) versus strain.
4. Determine Ultimate Tension Strength (Ftu), Tension Yield Strength (Fty), maximum strain (□), elongation (e), and modulus of elasticity (E) of the sample. Explain how determined and include sketches or annotations on chart, if needed.
5. Examine the broken end of each sample segment. Measure it as best you can. Comment on whether it looks like a brittle or ductile fracture. Research as needed to guide or support your conclusion.
6. Compare the results for any samples of different material. Which is stronger, more ductile, has more elongation? Comment on what this means or implies.
7. Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
8. Comment on anything else you notice, or that you feel should be addressed in the discussion.

2-2 Experiment 2-2: Cylinder Buckling using Shimadzu

Purpose

In this experiment, student teams will use the Shimadzu 300 kN (67 kip) Static Test Machine to investigate buckling of cylinders. An empty soda will be used to simulate cylindrical structure behavior.

References

1. Coburn, Aerospace Strength Handbook, Volume II, Section 15.
2. E.F. Bruhn, Analysis & Design of Flight Vehicle Structures, Section C8.

General Comments

This experiment is very important. It will be difficult to recall all aspects of the test later. Make sketches or take photos during all stages of testing for your report. Think about each step as you go, read each step aloud, and discuss with team members what you are doing, and any questions, insights, or concerns you have as you go. Jot down notes as appropriate.

Test Fixture Setup

1. Follow the following procedure to prepare the test equipment and run the test. Any errors, changes, or deviations from the procedure provided should be documented and communicated with the instructor for potential update to this manual. These deviations should also be documented in your lab report.
2. *Without turning anything on*, locate the Shimadzu 300kN Electrodynamic Test Machine in Lab. It should look roughly like Figure 2-2-1.
3. *Without turning anything on*, locate the Manual Control Panel (See. Fig. 2-2-2).
4. *Before proceeding further*, verify that the compression plates are installed already (See Fig. 2-2-1). If not, with permission of instructor, follow the reverse of the procedure of Section 2-0-2-1 to install the compression plates.
5. *Read Section 2-0 of this manual*, which documents key procedures for starting and operating this machine.
6. Turn on the Load Frame by following the procedures of Sections 2-0-1-1 & 2-0-1-2.
7. Start the computer & open the test software by following the procedure of Section 2-0-1-3.
8. Review Section 2-0-1-1 on usage & release of the Emergency Stop buttons. Assign one of your team members to monitor the stop buttons for the remainder of the test activity.
   - *The E-Stop buttons should be used any time a concern arises regarding safety of the students or equipment, or if testing proceeds in an unexpected manner.*
9. Calibrate the load frame software by following Section 2-0-1-5. This step can be repeated if anything is done to the setup that might have compromised the calibration.

Fig. 2-2-1

Fig. 2-2-2

Test Method Selection

1. In the TrapeziumX Software, click on <Select Method and Test>.
2. Select <ARO_357_Compression_SodaCan_TC.xmas>.
3. Click <Finish>.

Sample Preparation

1. Secure three identical (except paint) 16 oz soda cans for testing.
2. Measure OD & length.
3. Cut one open using tin snips & measure thickness.
4. Sketch sample and record all values on sketch for report and for entry into software.
5. Go to Specimen Sizes on the left hand side of the TrapeziumX software & input sample dimensions.
6. Click Finish.

Test Procedure

1. Carefully follow Text Fixture Setup Procedure above.
2. Review the "Jogging" subsection of Section 2-0 to refresh your understanding of how test fixture crossbars are "jogged" up and down.
3. Assign one student to hold & monitor the emergency stop button at all times for remainder of test.
4. Assign another student who will operate the software & control the test while monitoring the software start and stop buttons.
5. Use the Shimadzu manual control panel to jog the loadhead to provide ample room for the sample between the compression plates.
6. Inspect upper compression plate. There is an Allen-head set screw retaining it to the upper test post. Get the 2.5 mm Allen wrench from Drawer 195 of cabinet A3 and verify that retaining Allen-head bolt is snug.
7. Jog loadhead to provide about 1 foot of free space between compression platens.
8. Place the test specimen at the center of the lower compression plate.
9. Jog loadhead downward until within about ½" of top of sample.
10. Lower Plexiglass Safety Shield.
11. Calibrate the system using the hand-held control panel (Shown on page 2-0-5 of Lab Manual) by clicking <System>, then scrolling down to "calibration", and pressing <Start> twice.
12. Wait till the calibration completes in about 1 minute, then click <Test> before proceeding.
13. Zero force and stroke by pressing those buttons on the hand-held control panel.
14. Make sure all other team members are ready to start the test.
15. To start the test, click on the <Start> button at the top middle screen of the test software. Clickl yes when prompt. Watch carefully as machine jogs toward sample until pre-defined preload force is reached.
16. When the preloading is completed, verify all looks okay, then press <Start> again to reinitiate loading.
17. Monitor loading and press <Stop> or <Emergency Stop> if anything looks fishy.
18. When the test stops, have one student use the handheld control panel <Jog> feature to raise the test fixture a foot or so above sample (Click <Jog>, <High speed> and last <^>.
19. Raise the Plexiglass Safety Shield & remove the specimen for examination.
20. Save data by selecting 'File'/Export/All' and specifying the saving location & file name.
21. Examine files and copy to thumb-drive for post-processing.
22. Verify all data in possession, then delete your test files from computer & empty desktop recycle bin.
23. Repeat procedure if another specimen remains for testing.

24. When everything is done, close the software window.

Test Teardown:

1. Remove Samples.
2. Verify you have all data files on your thumb drive or personal computer.
3. Delete all personal test files from computer & empty desktop recycle bin.
4. Shut down the computer.
5. Turn off Test Machine by flipping front & rear switch.
6. *Carefully remove and return all test fixturing to Cabinet A3 in same location as found.* Any misplaced test equipment will result in loss of points for your lab team.
7. As you put away each piece of equipment, use the red shop rags with a little WD-40 to wipe down any metal surfaces of the test accessories or reusable samples that you used during the test.
8. Once all equipment is put away, clean your workstation using 409 or similar cleaner with the blue shop towels, then use the red shop rags with a little WD-40 to wipe down metal surfaces of the test equipment so the metal is clean, lightly oiled, and protected.
9. Check work area is clean and free of debris.
10. Check with instructor before leaving lab.

Analysis & Report

- Prepare a lab report of your test per Appendix B guidelines, except as follows:
  - Data Section can be dropped from report if you prefer to include data in tables and graphs in the Discussion Section and you comment as you go on the data.
  - Place the Excel graphs & data generated by the test software in Appendix A. Repeat any pertinent graphs or table in your discussion as you comment on it.
  - Place hand calculations in Appendix B.
- Include plot of load versus deflection (stroke). Comment on your curve in your Discussion section.
- Determine experimental buckling load from load-deflection plot.
- Assume the length of the smooth part of the can is the effective length of the cylinder, and use the analytical methods of Reference [1] or [2] to predict the buckling load of the samples. Think about whether the ends of the cylinder behave as if they are simply supported or fixed, and reflect your decision in your analysis.
- Compute the Euler buckling allowable of the can using the same effective length assumption as before.
- Compare your predictions for Euler buckling and for Cylindrical buckling to your experimental result. Determine the error for both. Think about your two predictions, whether they should match your experimental results or not, and discuss your findings and conclusions.
- Comment on anything else you notice, or that you feel should be addressed in the discussion.

2-3 Experiment 2-3: 3-Point Bending using Shimadzu

Purpose

In this experiment, student teams will use the Shimadzu 300 kN (67 kip) Static Test Machine to investigate 3 Point Bending behavior of materials.

References

- Coburn, Aerospace Strength Handbook, Volume II.
- E.F. Bruhn, Analysis & Design of Flight Vehicle Structures.

Test Fixture Setup

1. Follow the following procedure to prepare the test equipment and run the test. Any errors, changes, or deviations from the procedure provided should be documented and communicated with the instructor for potential update to this manual. These deviations should also be documented in your lab report.
2. *Without turning anything on*, locate the Shimadzu 300kN Electrodynamic Test Machine in Lab. It should look roughly like Figure 2-3-TBD.
3. *Without turning anything on*, locate the Manual Control Panel (See. Fig. 2-2-2).
4. *With your professor's permission,* de-install any fixture remaining in the Shimadzu Load Frame following the appropriate procedure in Section 2-0.
5. *With your professor's permission,* install the 3-Point Bend Fixture in the Shimadzu Load Frame by following the procedure of Section 2-0-2-5.
6. *Read Section 2-0 of this manual*, which documents key procedures for starting and operating this machine.
7. Turn on the Load Frame by following the procedures of Sections 2-0-1-1 & 2-0-1-2.
8. Start the computer & open the test software by following the procedure of Section 2-0-1-3.
9. Review Section 2-0-1-1 on usage & release of the Emergency Stop buttons. Assign one of your team members to monitor the stop buttons for the remainder of the test activity.
   - *The E-Stop buttons should be used any time a concern arises regarding safety of the students or equipment, or if testing proceeds in an unexpected manner.*
10. Calibrate the load frame software by following Section 2-0-1-5. This step can be repeated if anything is done to the setup that might have compromised the calibration.

Fig. 2-3-1

Test Method Selection

1. In the TrapeziumX Software, click on <Select Method and Test>.
2. Select <ARO_3570L 3-Point Bend to 1 kip.xmas>.
3. Click <Finish>.

Sample Preparation

1. Get a test sample from your professor.
2. Measure the sample completely.
3. Cut one open using tin snips & measure thickness.
4. Sketch sample and record all values on sketch for report and for entry into software.
5. Go to Specimen Sizes on the left hand side of the TrapeziumX software & input sample dimensions.
6. Click Finish.

Test Procedure

1. Carefully follow Text Fixture Setup Procedure above.
2. Review the "Jogging" subsection of Section 2-0 to refresh your understanding of how test fixture crossbars are "jogged" up and down.
3. Assign one student to hold & monitor the emergency stop button at all times for remainder of test.
4. Assign another student who will operate the software & control the test while monitoring the software start and stop buttons.
5. Use the Shimadzu manual control panel to jog the loadhead to provide ample room for the sample between the compression plates.
6. Inspect setup to ensure all is in place.
7. Calibrate the system using the hand-held control panel (Shown on page 2-0-5 of Lab Manual) by clicking <System>, then scrolling down to "calibration", and pressing <Start> twice.
8. Wait till the calibration completes in about 1 minute, then click <Test> before proceeding.
9. Jog loadhead to provide room to place your sample.
10. Center your test specimen in the loading fixture.
11. Jog loadhead downward until within about 0.1" of the top of your sample.
12. Lower Plexiglass Safety Shield.
13. Zero force and stroke by pressing those buttons on the hand-held control panel.
14. Make sure all other team members are ready to start the test.
15. To start the test, click on the <Start> button at the top middle screen of the test software. Click yes when prompt.
16. Watch carefully as machine moves toward sample and begins to load the sample, while hovering your mouse over the pause or stop button.
17. Do not allow the sample to deform such that the hardware is jeopardized. Stop the test if there is any doubt.
18. When the preloading is completed, verify all looks okay, then press <Start> again to reinitiate loading.
19. Monitor loading and press <Stop> or <Emergency Stop> if anything looks fishy.
20. When the test stops, have one student use the handheld control panel <Jog> feature to raise the test fixture a foot or so above sample (Click <Jog>, <High speed> and last <^>.
21. Raise the Plexiglass Safety Shield & remove the specimen for examination.
22. Save data by selecting 'File'/Export/All' and specifying the saving location & file name.
23. Examine files and copy to thumb-drive for post-processing.

24. Verify all data in possession, then delete your test files from computer & empty desktop recycle bin.
25. Repeat procedure if another specimen remains for testing.
26. When everything is done, close the software window.

Test Teardown:

1. Remove Samples.
2. Verify you have all data files on your thumb drive or personal computer.
3. Delete all personal test files from computer & empty desktop recycle bin.
4. Return the 3-Point Bend Fixture and Accessories to their storage location by following the procedure of Section 2-0-2-6.
5. Shut down the computer.
6. Turn off Test Machine by flipping front & rear switch.
7. *Carefully remove and return all test fixturing to Cabinet A3 in same location as found.* Any misplaced test equipment will result in loss of points for your lab team.
8. As you put away each piece of equipment, use the red shop rags with a little WD-40 to wipe down any metal surfaces of the test accessories or reusable samples that you used during the test.
9. Once all equipment is put away, clean your workstation using 409 or similar cleaner with the blue shop towels, then use the red shop rags with a little WD-40 to wipe down metal surfaces of the test equipment so the metal is clean, lightly oiled, and protected.
10. Check work area is clean and free of debris.
11. Check with instructor before leaving lab.

Analysis & Report

- Prepare a lab report of your test using the template provided.
- Include plot of load versus deflection (stroke). Comment on your curve in your Discussion section.
- Calculate the stress applied to the sample.
- Calculate the maximum deflection you would expect based on your force measurement using typical published E values for your sample. Compare this value to your experimental one and discuss correlation or lack of it.
- Use the load deflection curve to estimate E of the material. Comment on what you find.
- Comment on anything else you notice, or that you feel should be addressed in the discussion.

2-4 Experiment 2-4: Adhesive Strength from 3-Point Bending

Purpose

In this experiment, student teams will use the Shimadzu 300 kN (67 kip) Static Test Machine to investigate the shear strength of an adhesive using a 3-Point Bend Test Setup.

References

- Coburn, Aerospace Strength Handbook, Volume II, Section 7.1.
- E.F. Bruhn, Analysis & Design of Flight Vehicle Structures.

Test Fixture Setup

1. Follow the following procedure to prepare the test equipment and run the test. Any errors, changes, or deviations from the procedure provided should be documented and communicated with the instructor for potential update to this manual. These deviations should also be documented in your lab report.
2. *Without turning anything on*, locate the Shimadzu 300kN Electrodynamic Test Machine in Lab. It should look roughly like Figure 2-3-TBD.
3. *Without turning anything on*, locate the Manual Control Panel (See. Fig. 2-2-2).
4. *With your professor's permission,* de-install any fixture remaining in the Shimadzu Load Frame following the appropriate procedure in Section 2-0.
5. *With your professor's permission,* install the 3-Point Bend Fixture in the Shimadzu Load Frame by following the procedure of Section 2-0-2-5.
6. *Read Section 2-0 of this manual*, which documents key procedures for starting and operating this machine.
7. Turn on the Load Frame by following the procedures of Sections 2-0-1-1 & 2-0-1-2.
8. Start the computer & open the test software by following the procedure of Section 2-0-1-3.
9. Review Section 2-0-1-1 on usage & release of the Emergency Stop buttons. Assign one of your team members to monitor the stop buttons for the remainder of the test activity.
   - *The E-Stop buttons should be used any time a concern arises regarding safety of the students or equipment, or if testing proceeds in an unexpected manner.*
10. Calibrate the load frame software by following Section 2-0-1-5. This step can be repeated if anything is done to the setup that might have compromised the calibration.

Fig. 2-3-1

Test Method Selection

1. In the TrapeziumX Software, click on <Select Method and Test>.
2. Select <ARO_3570L 3-Point Bend to 1 kip.xmas>.
3. Click <Finish>.

Sample Preparation

1. Get a test sample from your professor.
2. Measure the sample completely.
3. Carefully measure the dimensions of the bonded area.
4. Sketch sample and record all values on sketch for report and for entry into software.
5. Go to Specimen Sizes on the left hand side of the TrapeziumX software & input the gross sample dimensions (This is the total cross-sectional area of sample).
6. Click Finish.

Test Procedure

1. Carefully follow Text Fixture Setup Procedure above.
2. Review the “Jogging” subsection of Section 2-0 to refresh your understanding of how test fixture crossbars are “jogged” up and down.
3. Assign one student to hold & monitor the emergency stop button at all times for remainder of test.
4. Assign another student who will operate the software & control the test while monitoring the software start and stop buttons.
5. Use the Shimadzu manual control panel to jog the loadhead to provide ample room for the sample between the compression plates.
6. Inspect setup to ensure all is in place.
7. Calibrate the system using the hand-held control panel (Shown on page 2-0-5 of Lab Manual) by clicking <System>, then scrolling down to “calibration”, and pressing <Start> twice.
8. Wait till the calibration completes in about 1 minute, then click <Test> before proceeding.
9. Jog loadhead to provide room to place your sample.
10. Center your test specimen in the loading fixture.
11. Jog loadhead downward until within about 0.1” of the top of your sample.
12. Lower Plexiglass Safety Shield.
13. Zero force and stroke by pressing those buttons on the hand-held control panel.
14. Make sure all other team members are ready to start the test.
15. To start the test, click on the <Start> button at the top middle screen of the test software. Click yes when prompt.
16. Watch carefully as machine moves toward sample and begins to load the sample, while hovering your mouse over the pause or stop button.
17. Do not allow the sample to deform such that the hardware is jeopardized. Stop the test if there is any doubt.
18. When the preloading is completed, verify all looks okay, then press <Start> again to reinitiate loading.
19. Monitor loading and press <Stop> or <Emergency Stop> if anything looks fishy.
20. When the test stops, have one student use the handheld control panel <Jog> feature to raise the test fixture a foot or so above sample (Click <Jog>, <High speed> and last <^>.
21. Raise the Plexiglass Safety Shield & remove the specimen for examination.
22. Save data by selecting ‘File’/Export/All’ and specifying the saving location & file name.
23. Examine files and copy to thumb-drive for post-processing.

24. Verify all data in possession, then delete your test files from computer & empty desktop recycle bin.
25. Repeat procedure if another specimen remains for testing.
26. When everything is done, close the software window.

Test Teardown:

12. Remove Samples.
13. Verify you have all data files on your thumb drive or personal computer.
14. Delete all personal test files from computer & empty desktop recycle bin.
15. Return the 3-Point Bend Fixture and Accessories to their storage location by following the procedure of Section 2-0-2-6.
16. Shut down the computer.
17. Turn off Test Machine by flipping front & rear switch.
18. *Carefully remove and return all test fixturing to Cabinet A3 in same location as found.* Any misplaced test equipment will result in loss of points for your lab team.
19. As you put away each piece of equipment, use the red shop rags with a little WD-40 to wipe down any metal surfaces of the test accessories or reusable samples that you used during the test.
20. Once all equipment is put away, clean your workstation using 409 or similar cleaner with the blue shop towels, then use the red shop rags with a little WD-40 to wipe down metal surfaces of the test equipment so the metal is clean, lightly oiled, and protected.
21. Check work area is clean and free of debris.
22. Check with instructor before leaving lab.

Analysis & Report

- Prepare a lab report of your test using the template provided.
- Include plot of load versus deflection (stroke). Comment on your curve in your Discussion section.
- Calculate the maximum normal bending stress on the sample $f_b = Mc/I$ and the maximum shear stress $\tau = VQ/It$ of the bond.
- Compare the calculations maximum bending stress to expected allowables for your basic material using values from MMPDS-09, Bruhn, or The Aerospace Strength Handbook Volume II or III. Comment on your findings.
- Report the maximum shear stress of the adhesive, and compare it to the expected allowables for the basic material using values from MMPDS-09, Bruhn, or The Aerospace Strength Handbook Volume II or III. Comment on your findings.
- Comment on anything else you notice, or that you feel should be addressed in the discussion.

2-5 Experiment 2-5: Sandwich Insert in Tension

Coming Soon

This experiment will be added soon.

2-6 Experiment 2-6: Sandwich Insert in Shear

Coming Soon

This experiment will be added soon.

3-0 TestResources 810 LE Test System

Capability

Fig. 3-0-1

- Static Vertical Load Capability for Axial & Bending Tests
  - Max Load: 7150 lb Static
  - Tension or Compression
  - Max Stroke: 6”
- Fatigue Testing
  - Max Load: 5000 lb Cyclic
  - Max Speed: 4 in/s
  - Max Frequency: 15 Hz
  - Stroke: ±3 in

Power Requirements

- Power Requirements
  - Voltage: 200-240 3 Phase
  - Max Continuous Current: 18.3 A
  - Frequency 50/60 Hz
  - Connector: NEMA L15-30

Configurations & Grips

- Tension Testing
  - Max Sample Length: 14”
  - Max Grip Length: 7.6 cm (3.0”)
  - Max Grip Width: 4.6 cm max (1.81”)
  - Flat Grip Set #1 Thickness Range: 0 to 8 mm (0.315”)
  - Flat Grip Set #2 Thickness Range: 8 mm (0.315”) to 16 mm (0.63”)
    - Round Wedge Grip Set #1: Diameter Range: 2 mm (0.079”) to 9 mm (0.354”)
- Bending:
  - 3 & 4 Point Bending Test Fixture
  - Max Span: 480 cm (18.9”)
  - Max Width: 10 cm (3.94”)
- Compression
  - Spherical Rotation Platen: 1.16”, or 1.25”?
  - Tension or Compression
- Mechanical Jack Lift Extras
  - Axial Extensometer: 2” Gage w/ 50% Travel
  - Deflectometer for Compression: 0.5” travel
  - Fatigue Grips, Compression Platens, V Wedges
  - 4 Point Bend Fixture
  - Controller & Software

3-0-1 Basic TestResources 810LE Operating Procedures

This subsection defines the basic fundamental operating procedures for the TestResources 810LE Test System. These procedures are universal and will be needed for any experiment using this machine. *Read this section carefully before starting any experiment with this machine, but do not perform any of the steps herein until directed by the lab procedure for the experiment assigned*. Pay special attention to the Emergency Stop procedures and to the section defining how to jog the loadhead.

3-0-1-1 Before Starting the Machine (Emergency Procedures)

Before starting the machine, locate the emergency stop (E-Stop) button located on the controller or on the desktop, as shown at right.

Assign one student to constantly monitor the E-Stop button whenever the machine is being used.

Press the E-Stop button any time the machine appears to behave in an unsafe manner, or if anything looks suspicious, or if there appears any danger of injury to people or parts.

Once the E-stop button is pressed, it can be released by twisting the switch in a clockwise direction, as indicated by the direction arrows on the switch itself.

Fig. 3-0-2 (was10

a clockwise direction, as indicated by the direction arrows on the switch itself.

3-0-1-2 Starting the Machine & Opening the MTL32 Test Software

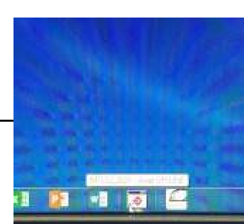
1. Turn on computer.
2. Turn on controller by first rotating the front red knob clockwise from 0 to 1 (Fig. 3-0-3a), and then by flipping the rear switch found in the upper back corner of the controller just above the power cord connection as shown in Fig. 3-0-3b (circled in red). Note: The controller is on a gray rolling cart that can be gently pulled out to improve access when needed, as shown in Figure 3-0-3c. Be certain to gently push it back until the face of the controller is slightly behind the face of the cabinet to safeguard the knobs on the machine from inadvertent damage.
3. Verify that the two green light up (Fig. 3-0-3c).

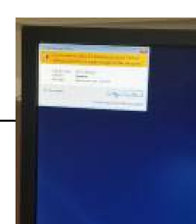
Fig. 3-0-3a

Fig. 3-0-3b

Fig. 3-0-3c

4. Locate emergency stop switch & assign one student to hold & monitor the emergency stop at all times for remainder of test (Fig. 3-0-2).
5. To run any test you will need to run both the MTL32 and the Monotonic Software. First the MTL software must be started and active, as described below.
6. Open MTL32_2020 software by clicking on the icon in the lower taskbar of computer (second icon from the





right per Fig. 3-0-4a), then click on the "yes" button when prompted (Fig. 3-0-4b).

7. Once this finishes booting up, a screen like that shown in Figure 3-0-4c should appear.

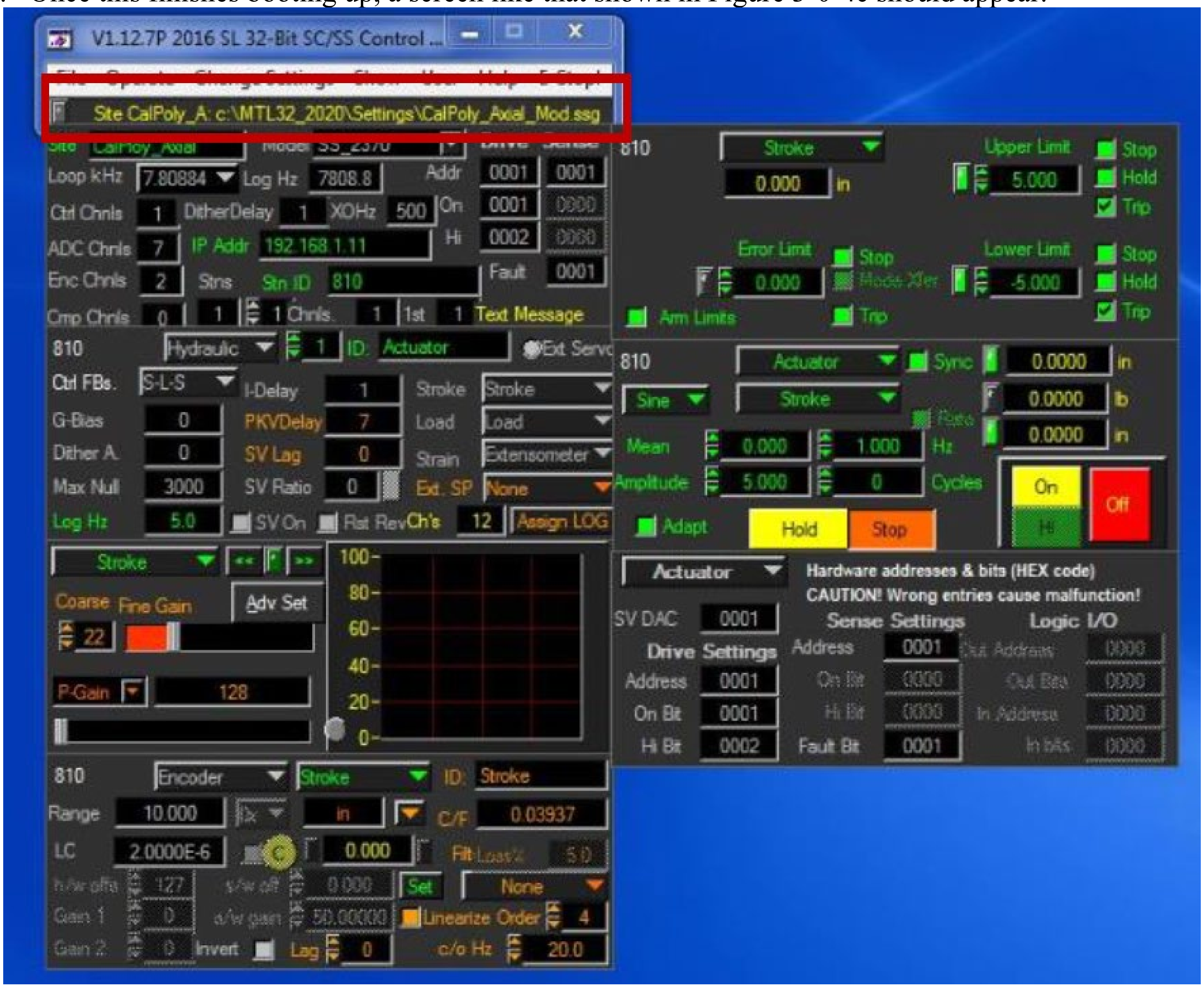


Fig. 3-0-4c: MTL32_2020 Software Window

8. Note the site ID in the upper left corner. When later (not yet) running the Monotonic Software, you will need to ensure that "CalPoly_A" is listed in the appropriate box (below the <Proceed> button, as indicated in step 14 below.
9. Also note the three pull-down menus near the middle of the screen. These must be correctly specified, as follows: (a) Stroke must always be set to stroke, (b) Load must always be set to Load, and (c) Strain must be set to **either** *extensometer* or *deflectometer*, depending on which instrument is used (extensometer for tension testing & deflectometer for bending or other tests using the deflectometer).
10. Be careful not to tamper with any other value in the fields.

11. Once these items are verified, go to its Task Bar and click <Show>, then select <Nothing> (Fig. 3-0-4d).

Fig. 3-0-4d

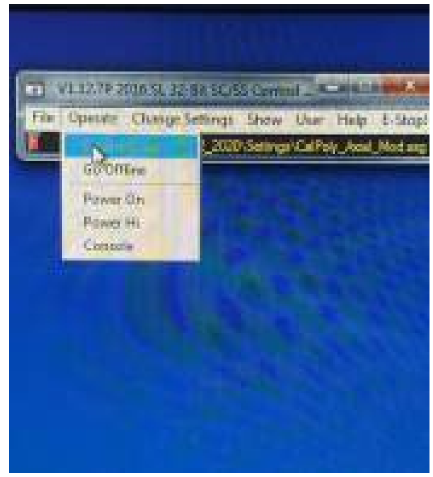


Fig. 3-04e

12. Next on the MTL32_2020 software Task Bar click <Operate> (Fig. 3-0-4e).
13. Then click <Go Online>, and wait until red box disappears.
14. You are now ready to open the Monotonic Software. Each experiment will describe in detail how the Monotonic Software is opened and operated. However, not that when it is opened, after selecting the appropriate test file and before proceeding from the greeting page, be sure that the Site ID in the text box below the <Proceed> button says CalPoly_A such that it matches the data set in the MTL32 software as described in step 8 above and shown in Figure 3-0-4f.

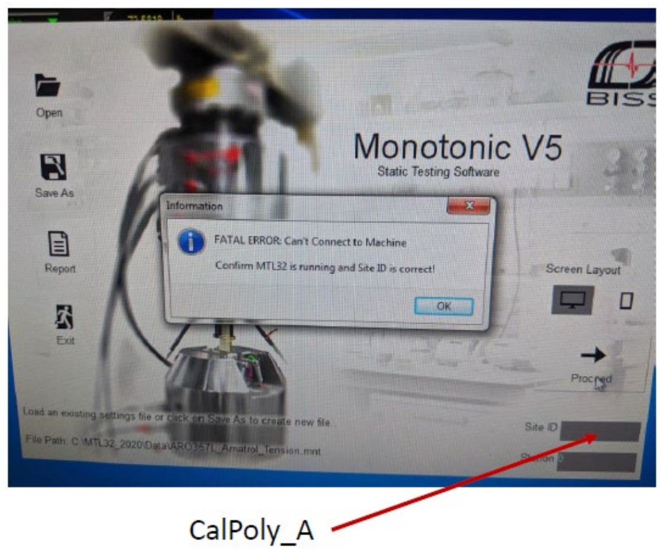


Fig. 3-0-4f

3-0-1-3 Jogging (Moving) the Load Heads

Moving the load heads, also known as "Jogging the machine", is done in the <Jog> Tab of the Monotonic Test Software. Read the experiment for details of how this is done.

3-0-2 Changing Test Configuration & Accessories

If the TestResources Test System is not configured for your test, see the instructor before attempting to change the configuration. Details for changing the test fixtures & accessories will be added to a later revision of this document.

3-0-2-1 Preparing Machine for Tension Testing:

Fig. 3-0-5

Fig. 3-0-6

The following procedure documents how to set up the TestResources 810LE for tension testing.

1. Locate the TestResources 810LE Electrodynamics Test Machine. It should look roughly like Figure 3-0-1.
2. The tension grips require a lot of space, and the load head will likely need to be positioned up at the highest extent of the machine. If the load head is not up within an inch or so of the top of the hand cranks screw's travel, it will need to be moved as documented in steps 3 through 5 below.
3. Loosen the four Allen bolts on the front of the machine (circled in Figure 3-0-5) using the ½" ratchet wrench and the ½"Allan Wrench attachment (found in middle upper drawer of Cabinet A2). If adaptor for Socket Wrench is not available, use the ½" drive ratchet found in the big red tool box. The tool should be marked in orange. Return the drive ratchet back to the big red tool box after it is done being used.
4. Use the hand crank (Figure 3-0-7) to move the upper load head until you have the required distance between the posts. Rotating the crank clockwise lowers the upper head and rotating it counterclockwise raises the upper head.
5. Obtain two cylindrical tension caps from Cabinet A2, Drawer 43, two ½" retention pins from Drawer 115, and two 15-mm pins from Drawer 43. See Figures 3-0-8 and 3-0-9.
6. Rotate the upper and lower posts so that the holes are 90 degrees from the front view.

Fig. 3-0-7: Hand Crank

Fig. 3-0-8: Tension Cups

Fig. 3-0-9: Retention Pins

7. The tension cups should already be mounted to the jaws with the ½" retention pins; if not, follow steps 8-10.
8. Jaw fixtures can be found in the bottom right hand door on Cabinet A2. CAUTION!! Jaws are heavy.

9. Verify that 15-mm retention pin fits into both tension caps and jaw fixtures. It may be necessary to adjust the hex collar and hex nut to fit retention pin (Figure 3-0-10).
10. Place lower jaws into lower tension cap. Insert a 15-mm tension pin.
11. Using the spanner wrench found in Drawer 115 of Cabinet A2 (Fig. 3-3-TBD), tighten the two spanner nuts found underneath the bottom tension cap. The bottom most spanner nut should be tightened to the bottom, square, black base. The top most spanner nut should be adjusted to touch the bottom of the tension cap, then tightened in this position. A gap between the two spanner nuts should be present (Fig. 3-0-XX).
12. Carefully lift upper jaws and upper tension cup to the upper post and repeat step 10.
13. Once jaws are locked into place with retention pin, re-tighten the hex collar and hex nut and attach the handles (Figure 3-0-10 & 11). The finished setup should look similar to Figure 3-0-12.
14. IMPORTANT: Tighten the four Allen bolts on the front of the machine with the socket wrench until snug.
15. Once setup is complete, double check that the four Allen bolts on the face of the upper crossbar are tight.


Fig. 3-0-10: Hex Collar


Fig. 3-0-11: Hex Collar


Fig. 3-0-12: Final Setup

3-0-2-2 Preparing Machine for Bending Testing:

The following procedure documents how to set up the TestResources 810LE for 3 Point & 4 Point Bend testing.

1. Locate the TestResources 810LE Electrodynamic Test Machine in Lab. It should look roughly like Figure 3-0-12a.

Fig. 3-0-12a: TR 810LE Machine


Fig. 3-0-12b: Measuring Free Space


Fig. 3-0-12c: Post Hole Position

2. Verify that there is about 16" between the upper surface of the Upper Test Post (UTP) & the Lower Test Post (LTP) as shown in Figure 3-0-12b. If not, follow the sub-procedure a thru d below.
    a. If not, get the 3/8" Ratchet Wrench, the 3/8" to ½" Adaptor, & the ½" Allen Drive (Fig. 3-0-12d) from drawer 115 of Cabinet A2.
    b. Loosen (do not remove) the four Allen bolts on the face of the machine (shown circled in red in Figure 3-0-12a).
    c. Use the hand crank to raise or lower the load head until about 16" of free space exists.
    d. Tighten the four Allen Bolts until snug (Do not overtighten).
3. In order to fit the bend fixture in the load frame, you will need to be able to rotate the UTP & LTP to approximately a 45° angle with the face of the machine. In order to do this, the two spanner nuts on each post will need to be loose, but close to the top & bottom to provide room for the bend fixture collar-attachment See Fig. 3-0-12c). The Spanner Wrench is located in the upper tray of drawer 115 of Cabinet A2. Get it and move the two top & bottom spanner nuts as needed.

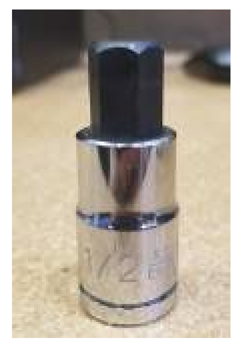


Fig. 3-0-12d: ½" Allen

Lower Bend Fixture (LBF) Setup:

4. Locate the retention pins from the upper tray of the leftmost upper drawer of Cabinet A2. Select the two longest retention pins (Fig. 3-0-13) and set them in work area.

Fig. 3-0-13: Retention Pins

Fig. 3-0-14: Beam Fixtures

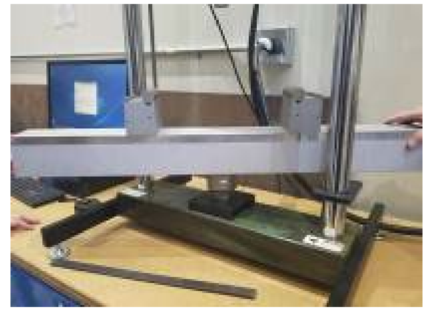


Fig. 3-0-15: Lower Beam Fixture

5. Locate Lower Bend Fixture (LBF) in bottom shelf of cabinet A2 [Left side of Fig. 3-0-14). It is the big one.
6. Identify two students to move fixture & one to guide and insert retention pins.
7. Involve two students to carefully remove LBF from cabinet without scratching cabinet, fixture, or floor.
8. Carefully lower the LBF diagonally onto Lower Test Post (LTP) of text fixture, being careful to keep LBF level as you lower it onto LTP (final position shown in Figure 3-0-15).
9. Have the third student insert the longest Retention Pin (RP) to secure the LBF to the LTP as two students slightly adjust elevation & clocking to align holes.
10. Lift fixture to pull it tight against RP & have third student hand-tighten the upper spanner nut, then lightly tighten it further using spanner wrench.

Upper Bend Fixture (UBF) Setup:

11. Locate the Upper Bend Fixture (UBF) on bottom shelf of cabinet A2 (Right side of Fig. 3-0-14).
12. Involve two students to carefully remove UBF from cabinet without scratching cabinet, fixture, or floor.
13. Carefully lift UBF to mount it diagonally onto upper post (UTP) of text fixture directly above & parallel to LTF (Fig. 3-0-16a), being careful to keep UBF level as you raise it onto UTP.

Fig. 3-0-16a: Upper Beam

Fig. 3-0-16b: Inserting Pin

Fig. 3-0-16c: Tightening spanner

14. Have third student insert the Retention Pin (RP) to secure UBF to UTP [Fig. 3-0-16b] as two students slightly adjust elevation to align holes.

15. Have the third student hand-tighten spanner nut (Fig. 3-0-16c), then lightly tighten it further using spanner wrench from the upper tray of drawer 115 of Cabinet A2.
16. Once the upper and lower bend fixtures are securely in place, tighten the spanner nuts as follows:
17. On the UTP, lightly tighten the upper spanner nut against the load cell and the lower spanner nut down against the collar of the UBF. The lower spanner nut should be loosely adjacent to the upper one (also shown in Fig. 3-0-16c).
18. On the LTP, lightly tighten the lower spanner nut down against the bottom plate of the test frame and the upper spanner nut upwards against the collar of the LBF.

3-0-2-3 Extensometer Preparation (if needed/desired)

If the extensometer will be used in an experiment, it will need connected & configured prior to opening the test software or turning on the load frame as described below. If not, skip this section.

1. Get the extensometer from the upper right drawer of Cabinet A2.
   - ***CAREFUL!!*** *Handle extensometer with care at all times*.
2. Connect to <Strain1> port on back of controller (not back of computer!). (See Fig. 3-0-TBD).
3. Set up carefully. Get instructor help if needed.
4. **Warning!** Whenever the extensometer is used, the MTL32 software must indicate an Extensometer is present on the Strain Channel, as described in Steps 7 & 9 of Section 3-0-1-2.

Holding & Attaching the Extensometer

The extensometer is connected as described above during the setup phase of the experiment. Later it will need to be attached to the specimen. The best way to handle and open the extensometer is using the Spiderman hold, which is identified in Figure 3-0-17. This grip can be used to hold the extensometer. Apply the Spider-Squeeze to open the jaws for attachment to sample. Slowly release the squeeze to allow the wire jaws to gently bite the sample so any relative motion can be measured by the extensometer. If the jaws do not fit the sample, there should be small rubber bands that can be used in lieu of the wire jaws shown below.

Photos from April 2018 Report of Gomez^2, Ramirez & Kussler

Fig. 3-0-17: Spiderman Hold for Holding & Attaching the Extensometer

3-0-2-4 Deflectometer Preparation (if needed/desired)

If the deflectometer will be used in an experiment, it will need connected & configured as described below. If not, skip this section.

5. The Deflectometer is fragile. Handle it with care.
6. Fetch the Deflectometer & Support Stand from the upper right drawer of Cabinet A2 & place it on the table (Fig. 3-0-18a & 3-0-18b).

Fig. 3-0-18a: Deflectometer & Stand


Fig. 3-0-18b: Deflectometer

7. Connect the Deflectometer connector to the <Strain2> port on the back of the controller (not back of computer!). (See Fig. 3-0-19a & 3-0-19b).

Fig. 3-0-19a

Fig. 3-0-19b

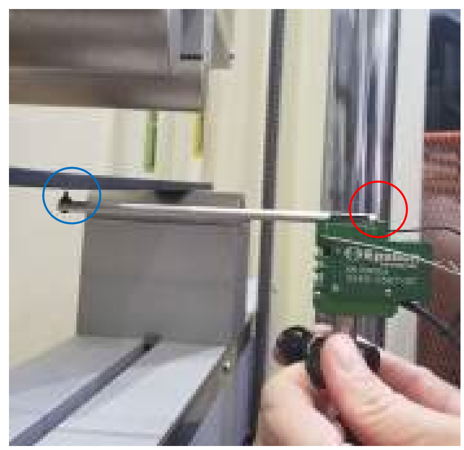
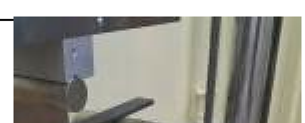


Fig. 3-0-20

8. Once the deflectometer is connected, set it aside until the fixture and sample are ready for its placement, as defined in the detailed experiment procedure being followed.
9. **Warning!** Whenever the deflectometer is used, the MTL32 software must indicate an Extensometer is present on the Strain Channel, as described in Steps 7 & 9 of Section 3-0-1-2.

10. Mount the Support Stand & Deflectometer in the position needed. The process below discusses positioning for a bend test. A similar procedure can be used to position it for other deflection measurements.



a. Before mounting, verify that the Deflectometer arm is pressed all the way back against the green backing plate as shown in Figure 3-0-20 (red circled area). Adjust if needed.
b. Have one student hold the Support Stand, while another holds the Deflectometer, & work together to determine the best location & orientation of gage & support such that the needle of the Deflectometer will be aligned directly under the center of the beam (Fig. 3-0-21).
c. The knob on the support stand loosens or tightens all rotating joints, and these can be manipulated as alignment is made.
d. When the Deflectometer & Support Stand are roughly aligned, rotate knob on the Support Stand CCW to activate holding magnet (Fig. 3-0-22).
e. Fine-tune alignment with one student adjusting the Deflectometer & Stand while others assist visually. Align Deflectometer so the arm is horizontal and so the tip is below the precise center of the beam with its tip within ¼" to ½" of the sample (but not touching it) as shown in Figure 3-0-20 (blue circled area).
f. Place finger immediately above Deflectometer arm (Fig. 3-0-23a), then slowly remove retaining pin on right side of Deflectometer (Fig. 3-0-23a) & allow Deflectometer arm to rotate gently upward until it contacts the bottom of sample (Fig. 3-0-23b).

Fig. 3-0-22: Stand

Fig. 3-0-23a

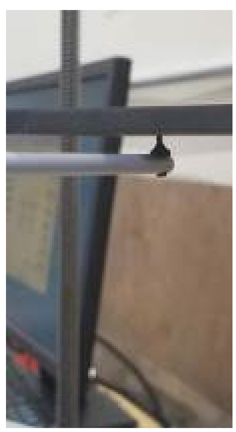


Fig. 3-0-23b

Fig. 3-0-24

Fig. 3-0-25

g. Verify that the deflectometer is secure, the pin is pulled, that the tip lightly touches the bottom of the beam at the precise location desired (center for this experiment), and that there is sufficient deflectometer travel available to allow deflection expected (Fig. 3-0-24).
h. Verify that upper and lower beam fixtures are still aligned, that sample is centered on fixture, and that Deflectometer contacts beam at the precise center of the beam (Fig. 3-0-25). Adjust if necessary.

3-1 Experiment 3-1: Tension Test using TestResources 810 LE

Purpose

In this experiment, student teams will use the TestResources 810 LE Test System to investigate tension response of a sample.

Test Fixture Setup

Switching from Bend Test Setup to Tension Test Setup:

1. Locate the TestResources 810LE Electrodynamics Test Machine. It should look roughly like Figure 3-1-1.
2. Set up the machine for tension testing by following the steps detailed in <Preparing Machine for Tension Testing> in Section 3-0.
3. The machine should look like that roughly like Figure 3-1-2 when it is set up correctly.
4. Once setup is complete, double check that the four Allen bolts on the face of the upper crossbar are tight (circled in red in Fig. 3-1-1).

Fig. 3-1- 1: Test Machine


Fig. 3-1-2: Tension Setup

Test Procedure

1. Thread the grip adjusting handles (from drawer 561 of Cabinet A-2) into the upper hex nut.
2. Use calipers to measure the gauge length, width, and thickness. Make a note of materials used.
3. Follow procedure for Starting the Machine & Opening the MTL32 Test Software from Section 3-0-1-2.
4. Open the Monotonic Test Software by clicking on the icon in the lower taskbar of computer (it should be the rightmost icon as shown in Fig. 3-2-3a), then click on the “yes” button when prompted (Fig. 3-2-3b).
5. When the Test Window Opens click <Open> as shown in Figure 3-2-3c.

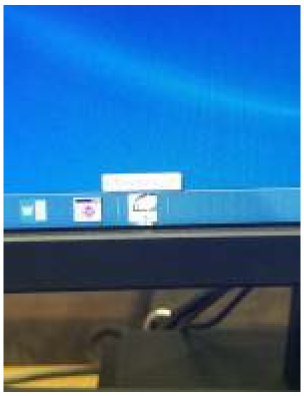


Fig. 3-1-3a

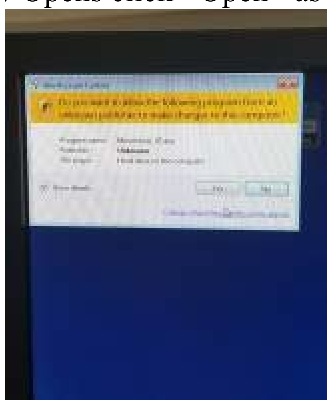


Fig. 3-2-3b

Fig. 3-2-3c

Fig. 3-2-3d

6. Select the <Amatrol Tension?> Tension Test Setup, then hit <Proceed>.
7. Make sure data is saved in the correct place. <Settings> <System Settings> Under “Data File Path,” choose “User Defined Directory.” <Select Directory> then go to “Desktop” and choose “Last Experiment Folder.”
8. Go to jog and set to 10 in/min.
9. Under “Limits” tab, change “High Limit” to 5” and change “Low Limit” to -5”.
10. Under settings, check that extensometer mounted button is selected and is set to 50% active range, 0 stress, and 0 strain, and that the auto continue test box is NOT selected.
11. Make sure “Stress” and “Strain” boxes are not checked next to “ksi.”
12. Go to <Settings>, “Test Settings.” Under “Step Mode,” select a step size of “1, ” select the edit function then select “Option 1” and change the end value to 4”.
13. Go to <Settings>, <System Settings> change DAQ Channel settings: under “Stroke Channel” change drop down box to “Stroke”, “Load Channel” drop down box should have “Load” selected and in the “Strain Channel” drop down box have “Extensometer” selected.
14. Go to <Settings>→ <Others> and make sure “Pre-Load Settings” box is unchecked. Verify that the following predefined parameters are selected: peak stress, 0.2% offset yield strength, modulus, stress-strain data, and strain % at max load. The slope region should have a range of 5” to 30”.
15. Before starting test, if “Fault” shows on program, press the Emergency Stop button. Ensure the Emergency button is completely depressed, then turn the button to release and reset. “ON” should appear on the software.
16. Go to MTL32 software and click <User>, <Administrator>. Click <Show> then <Show All Panels>. In the second panel down look for strain option, and in the drop-down selections, choose “Extensometer.” (Fig. 18-XX). Click <Show> and then <Nothing>.
17. Go to the <Specimen> tab and change the dimensions to match those measured from the test piece. The gauge length should be 2” if using the 2” extensometer.
18. Insert test piece into upper jaw. Pay careful attention to align and center the piece. Tighten jaws using grip adjusting handle.

19. Zero load.
20. Go to <Jog>, (if button reads "Lo" already, then continue jogging) click <On>, then<Hi>, then click the down stroke button to slowly lower test piece between the lower jaws.
21. You will need about 2.75" or more (3" is better) of space in between jaws to add the extensometer. Zero Load Again before lowering jaws down.
22. Use the grip adjusting handle to tighten lower jaws, being careful not to twist sample.
23. Install extensometer according the procedures described in Section 3-0-2-3.
24. Pull pin out of the extensometer.
25. Zero extensometer.
26. Click <Start> on the right-hand side of the software to begin testing.
27. Click <Yes> on the popup window.
28. After failure, click <Stop>.
29. Before exiting software, make sure to click "Report" tab and click "Excel Report" and "Export to CSV File," located on the bottom right hand side of the software screen to save data. Click "Return."
30. Delete data off computer and empty recycling bin before logging off of the computer.

Analysis & Report

1. Prepare a lab report of your test per Appendix A guidelines, except as follows:
   - Place the raw test data, including load-deflection values and stress strain values reported by the software in Appendix A. This can be in Word, Excel, or tabular format, and does not need prettied up. Also place any load-deflection, stress-strain, or other curves from the test software here. Any graphs or plots or segments of data that are useful for your discussion can be repeated in the body of your report to enhance clarity, or can be referenced to your appendix if this is sufficiently clear.
   - Place your hand calculations in Appendix B.
   - Provide clear dimensioned sketches or drawings of your samples in Appendix C. A dimensioned hand sketch is fine.
   - Place any supporting data in Appendix D+, if needed.
2. Include plot of load versus extensometer deflection. Comment on your curve in your Discussion
3. Include curve of stress (at minimum section) versus strain.
4. Determine Ultimate Tension Strength (Ftu), Tension Yield Strength (Fty), maximum strain (□), elongation (e), and modulus of elasticity (E) of the sample. Explain how determined and include sketches or annotations on chart, if needed.
5. Examine the broken end of each sample segment. Measure it as best you can. Comment on whether it looks like a brittle or ductile fracture. Research as needed to guide or support your conclusion.
6. Compare the results for any samples of different material. Which is stronger, more ductile, has more elongation? Comment on what this means or implies.
7. Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
8. Comment on anything else you notice, or that you feel should be addressed in the discussion.

Test Teardown:

1. Be careful to Remove the extensometer, return its retaining pin, return it to its case, and to return that to the upper-right drawer of Cabinet A2.
2. Remove sample from fixture and measure, photograph, & study for report.
3. Copy your excel file to your thumb drive.
4. If desired, you may also copy the .mns file and the Monotonic software (lower left corner of desktop to your thumb drive. If you install the Monotonic Software on your computer, this will enable you to reprocess your data from the .mns file using the report option.
5. After securing your file on your thumbdrive & removing it from the USB port, delete your excel file and .mns file from the desktop of the lab's computer & then empty the desktop Recycle Bin.
6. Shut down the computer.
7. Turn off Controller using front knob & rear switch.
8. Place emergency stop on top of controller.
9. Once all equipment is put away, clean your workstation using 409 or similar cleaner with the blue shop towels, then use the red shop rags with a little WD-40 to wipe down metal surfaces of the test equipment so the metal is clean, lightly oiled, and protected.
10. Check work area is clean and free of debris.
11. Check with instructor before leaving lab.

3-2 Experiment 3-2: Bending Test using TestResources 810 LE

Purpose

In this experiment student teams will use the TestResources 810LE Electrodynamic Test Machine to investigate 4-Point bending of a sample.

References:

1. B&J Mechanics of Materials, Sections 4 & 9.
2. Aerospace Strength Handbook, Volume II, Appendix D, Case 9.

Fundamental Principles & Equations

This experiment involves a 4-Point Bend Test of a beam. The 4-Point Bend Test is a great test for evaluating the bending behavior & strength of a beam because it provides a constant moment in the center span of the beam and ensures that there is no shear in this span to disturb the bending strength or performance.

In this test, the actuator presses against a rigid plate, which applies half of the actuator force to each of the beam loading points, which are symmetrically spaced about the centerline, as shown in Fig. 3-2-1.

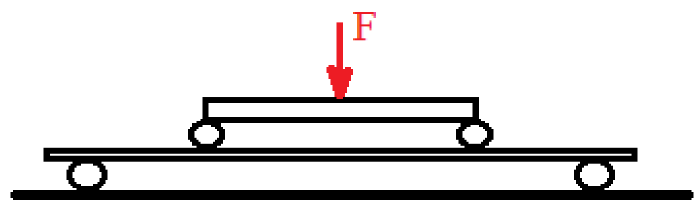


Fig. 3-2-1: 4-Point Bend

The test machine records the applied force and the corresponding stroke (movement) of the actuator. The deflectometer can be used to provide a more accurate indication of the deflection at the point it is applied.

The loading, shear and moment diagrams of the beam are shown in Figure 3-2-2.

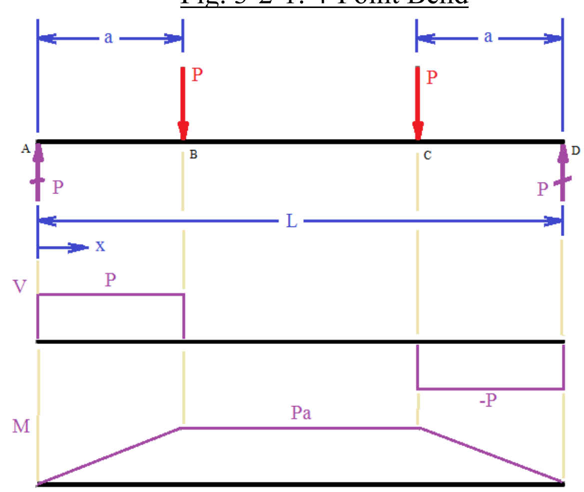


Fig. 3-2-2: Load, Shear & Moment Diagrams

The deflection of the beam at any point in the leftmost span AB is given by:

$$\Delta_{AB} = \frac{Px}{6EI}\left(x^2 + 3a^2 - 3La\right) \qquad 3\text{-}2\text{-}1$$

The deflection at any point in the middle span BC is given by:

$$\Delta_{BC} = \frac{Px}{6EI}\left(3x^2 + a^2 - 3Lx\right) \qquad 3\text{-}2\text{-}2$$

The maximum deflection occurs at the middle, and is given by:

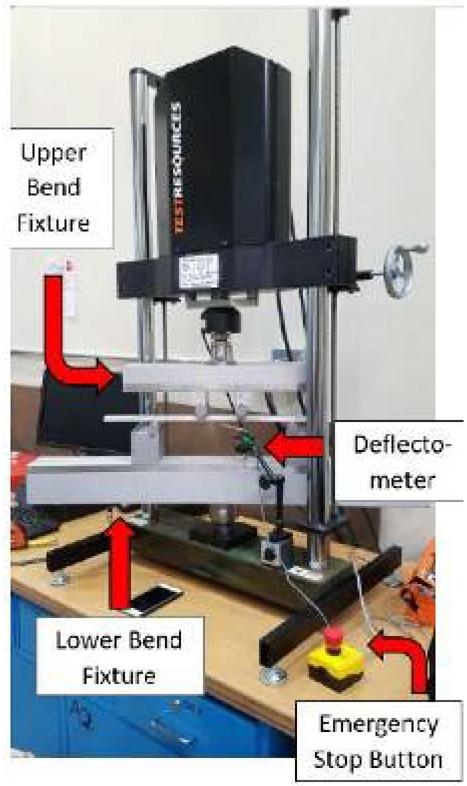
$$\Delta_{max} = \frac{Pa}{24EI}\left(4a^2 - 3L^2\right) \qquad 3\text{-}2\text{-}3$$

The maximum bending stress in the beam is constant through the middle span, and is given by:

$$f_{max} = \frac{Mc}{I} \qquad 3\text{-}2\text{-}4$$

Test Fixture Setup

1. Follow the following procedure to prepare the test equipment and run the test. Any errors, changes, or deviations from the procedure provided should be documented and communicated with the instructor for potential update to this manual. These deviations should also be documented in your lab report.
2. *Read Section 3-0 of this manual*, which documents key procedures for starting and operating this machine.
3. *Without turning anything on*, locate the TestResources 810LE Electrodynamics Test Machine. It should look roughly like Figure 3-0-1.
4. *Before proceeding further*, verify that the Bending Fixture is installed already. It should look roughly like Figure 3-2-1. If not, then set up the machine for bending testing by following the steps detailed in <Preparing Machine for Bending Testing> in Section 3-0-2-2.
5. Once setup is complete, double check that the four Allen bolts on the face of the upper crossbar are tight (Circled in red in Fig. 3-0-2).
6. Review Section 3-0-1-1 on usage & release of the Emergency Stop buttons. Assign one of your team members to monitor the stop buttons for the remainder of the test activity.
   - *The E-Stop buttons should be used any time a concern arises regarding safety of the students or equipment, or if testing proceeds in an unexpected manner.*
7. Follow the procedure of Section 3-0-2-4 to perform initial setup of the deflectometer. Set it aside in a safe place until ready for positioning.



Edwards, Murphy, Ton, & Younes, April 2018.

Fig. 3-2-1: Bend Fixture Setup

Sample Preparation

1. Test specimens should be located in the left lower shelves of cabinet A2. Pick one. It should be 16 or more inches long. See instructor to confirm your pick is acceptable.
2. Measure & record the sample length.
3. Measure & record the sample width & thickness at 5 points along the beam (Fig. 3-2-2). Calculate the average for use later in the test software to characterize your beam.
4. Check the straightness of the sample. Lie it on a flat table and measure any deviation from perfectly straight. Record for documentation in your report. (Later, when you position your sample, place the sample concave down so your test reduces any permanent bowing of the sample rather than aggravating it).

Fig. 3-2-2: Measuring Sample

Sample & Fixture Positioning

1. Note that the scale on the Upper Test Fixture (UTF) & Lower Test Fixture (LTF) is metric (Fig. 3-2-3). This experiment will be performed using US Customary units, so any usage of these scales will require conversion of units.

Fig. 3-2-3: Metric Scale

Fig. 3-2-4: Setting the Spans

Fig. 3-2-5: Moving the Rollers

2. Set the rollers on the LTF to provide a 14” span (Fig. 3-2-4 & 3-2-5).
   i. Notice that the blocks have a scribe mark that aligns with the center of the roller to ease measurement (Fig. 3-2-3).
   j. Use the 6 mm Allan wrench to loosen the Allan bolts so they can be moved, if necessary (Fig. 3-2-6). Be sure to tighten these after placement.
   k. Ensure that the roller supports are symmetric about the centerline.
3. Set the rollers on the UTF to provide a 4” span (Fig. 3-2-5).
   l. Note scribe marks on block for alignment (Fig. 3-2-3).
   m. Use the 6 mm Allan wrench to loosen the Allan bolts on the UBF & LBF so they can be moved, if necessary. Be sure to tighten these after placement.
   n. Ensure that the roller supports are symmetric about the centerline.

Fig. 3-2-6: Moving the Rollers

4. Verify your measurements by checking upper & lower roller spans with measuring tape.
5. Place your sample on top of the rollers of the LBF so that it centered longitudinally, and so that it is roughly in the middle of the fixture width-wise (Fig. 3-2-7). Verify that at least 2 inches of the sample extends past the roller on each end.
6. Test Fixture should look like Figure 3-2-7.

Fig. 3-2-7: Sample Setup

Deflectometer Setup Procedure:

1. Initial setup of the Deflectometer should have been done in Step 6 of the Test Fixture Setup subsection above. If not, follow the procedure of Section 3-0-2-4 now to perform the initial setup.
2. Next, mount the Support Stand & Deflectometer in the position needed as follows:
    a. Before mounting, verify that the Deflectometer arm is pressed all the way back against the green backing plate as shown in Figure 3-2-8 (red circled area). Adjust if needed.
    b. Have one student hold the Support Stand, while another holds the Deflectometer, & work together to determine the best location & orientation of gage & support such that the needle of the Deflectometer will be aligned directly under the center of the beam.
    c. The knob on the support stand loosens or tightens all rotating joints, and these can be manipulated as alignment is made.
    d. When the Deflectometer & Support Stand are roughly aligned, rotate knob on the Support Stand CCW to activate holding magnet (Fig. 3-2-9).
    e. Fine-tune alignment with one student adjusting the Deflectometer & Stand while others assist visually. Align Deflectometer so the arm is horizontal and so the tip is below the precise center of the beam with its tip within ¼" to ½" of the sample (but not touching it) as shown in Figure 3-2-8 (blue circled area).
    f. Place finger immediately above Deflectometer arm (Fig. 3-0-10a), then slowly remove retaining pin on right side of Deflectometer (Fig. 3-2-10a) & allow Deflectometer arm to rotate gently upward until it contacts the bottom of sample (Fig. 3-2-10b).

Fig. 3-2-8

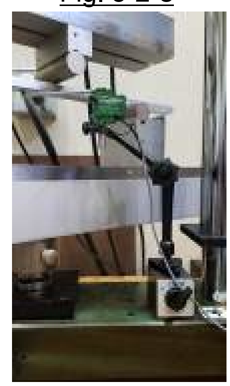


Fig. 3-2-9: Ready

Fig. 3-2-10a

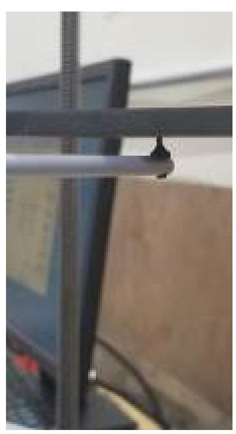


Fig. 3-2-10b

Fig. 3-2-11

Fig. 3-2-12

    g. Verify that the deflectometer is secure, the pin is pulled, that the tip lightly touches the bottom of the beam at the precise location desired, and that there is sufficient deflectometer travel available to allow deflection expected (Fig. 3-2-11).
    h. Verify that upper and lower beam fixtures are still aligned, that sample is centered on fixture, and that Deflectometer contacts beam at the precise center of the beam (Fig. 3-2-12). Adjust if necessary.

MTL32 & Monotonic Test Software Startup & Method Selection

31. Start the computer & open the MTL32 Test Software by following the procedure of Section 3-0-1-2.
32. Open the Monotonic Test Software by clicking on the icon in the lower taskbar of computer (it should be the rightmost icon as shown in Fig. 3-2-13a), then click on the "yes" button when prompted (Fig. 3-2-13b).
33. When the Test Window Opens click <Open> as shown in Figure 3-2-13c.

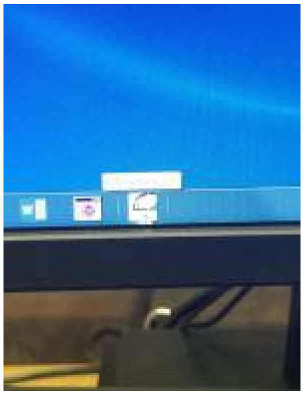


Fig. 3-2-13a

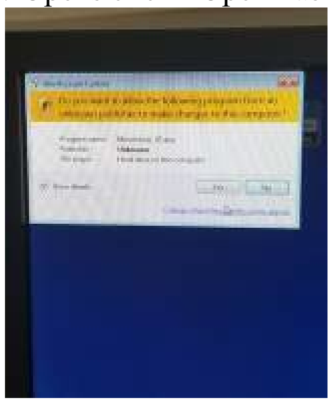


Fig. 3-2-13b


Fig. 3-2-13c


Fig. 3-2-13d

34. Click on the"ARO357_4P_Bend.mnt" file and then click <Open>.
35. Select <Proceed> as shown in Fig. 3-2-13d.
36. Verify that the "Test Type" says <Flexural - D6272 (4 Point Bend)> as shown in Fig. 3-2-14a.
37. Verify that the <Deflectometer Mounted> box is checked (Fig. 3-2-14a) and that the <Stop at 5% Flexural Strain> box is not checked.

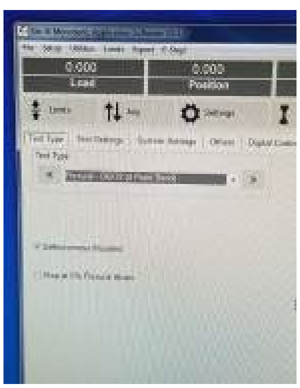


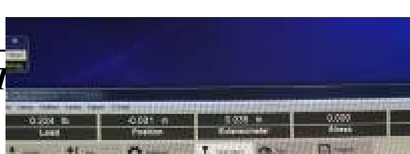
Fig. 3-2-14a

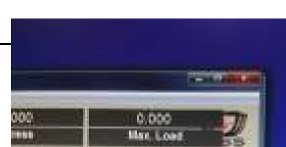

Fig. 3-2-14b


Fig. 3-2-14c


Fig. 3-2-14d

38. Select <Jog> from software menu (Fig. 3-2-14b).
39. Ensure that the <Switch Control Mode> is set to the <Stroke> option (Fig. 3-2-14c).
40. Use the slider bar to set the rate to about 10 inches/minute (Fig. 3-2-14d).
41. Select "Specimen" in software (Fig. 3-2-15).
42. Enter all specimen & span dimensions measured & prepared during earlier step (Fig. 3-28).
43. Ensure that Load Span Type is set to "1/2 Support Span" (This does not do anything for this test)
44. Ensure assigned student is holding the emergency stop button & is ready to press it if anything looks fishy (Fig. 3-0-2).
45. Select <Jog> (Fig 3-2-16a).





46. Click <On> in the upper right-hand corner of software (Fig. 3-2-16b), then click on <Hi> (Fig. 3-2-16c). This will toggle the display to offer <Lo>, which shows when you operate in <Hi> mode.

Fig. 3-2-17

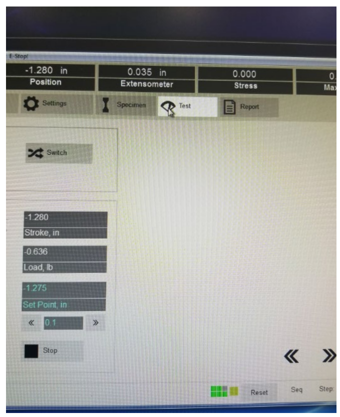


Fig. 3-2-18

Fig. 3-2-19a

Fig 3-2-19b

47. Watch the UBF carefully & lightly tap <↓> in the lower left-hand corner briefly 2 or 3 times to ensure that the loadhead is moving in a controlled manner (Fig. 3-2-17).
48. Press & hold <↓> until UBF is within about ¼ inch of the top of the sample (Fig. 3-2-17).
49. Select <Test>.
50. Press <Zero Extn.> near the bottom of the rightmost menu (Fig. 3-2-19a). This actually zeroes the Deflectometer).
51. When prompted "Do you want to offset readout of Deflectometer?", select <Yes> (Fig. 3-2-19b).
52. Click on <Zero Load>" near the bottom of the rightmost menu (Fig. 3-2-20a).

Fig. 3-2-20a

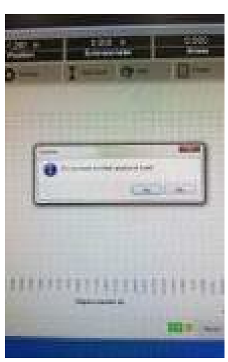


Fig. 3-2-20b

Fig. 3-2-20c

Fig. 3-2-21a

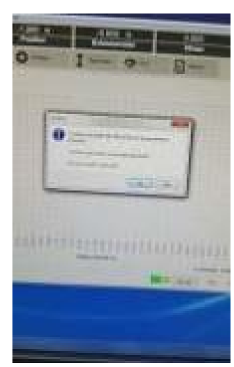


Fig. 3-2-21b

53. Click "Yes" when prompted "Do you want to offset readout of Load" (Fig. 3-2-20b).

54. Notice the load, stroke & extensometer readouts near the top of the test screen, and verify that the load is showing 0 (it'll oscillate about this value), & that the extensometer (actually measures whatever is connected to the Strain2 port) is showing precisely 0 (Fig. 3-2-20c).
55. Verify that the pin is (still) removed from Deflectometer (Fig. 3-2-10a).
56. With assigned student holding the emergency stop button, keep all body parts away from the machine & select <Preload> from near the middle of the rightmost menu (Fig. 3-2-21a).
57. Select <yes> when prompted (Fig. 3-2-21b).
58. When Pre-loading completes (Fig. 3-2-22), determine if both rollers have impacted the sample. If not, note that in your notes for later evaluation and continue test.


Fig. 3-2-22


Fig. 3-2-23a

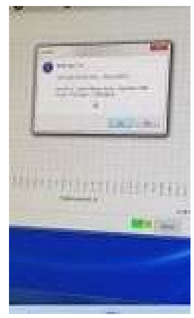


Fig. 3-2-23b

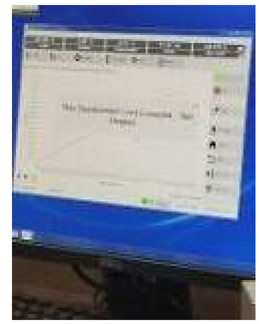


Fig. 3-2-23c

59. Before starting the test, please note that it is intended not to permanently deform the sample. Therefore, during testing, students will carefully monitor the load-deflection curve to ensure it is linear (it loads in a perfectly straight line). The students must stop the test as soon as any permanent deformation of the sample is noted (as evidenced by the load-deflection curve deviating from perfectly straight. As soon as the onset of permanent deformation is noted, the test should be stopped either by punching the stop button in the test software, or by hitting the emergency stop button. Alert the team of this intent before starting the test.
60. With assigned student holding emergency stop button, press <Start> (Fig. 3-2-23a).
61. Select <Yes> when prompted (Fig. 3-2-23b).
62. Test will commence until the stops that were programmed are reached or students stop the test as directed above. If the preset software stop is reached before nonlinear behavior starts, then the software will display "Max Displacement Limit Exceeded...Test Stopped" (Fig. 3-2-23c), and the stop will have to be reset before the loadhead can be jogged up and out of the way.
63. Click <Home> on rightmost menu to return UBF to preset home position (Fig. 3-2-24).
64. Click <Yes> at prompt even though you have not removed the sample (Fig. 3-2-25).
65. Record the Extensometer reading in the upper readout after beam is unloaded to enable assessment of potential plastic effects later.


Fig. 3-2-24

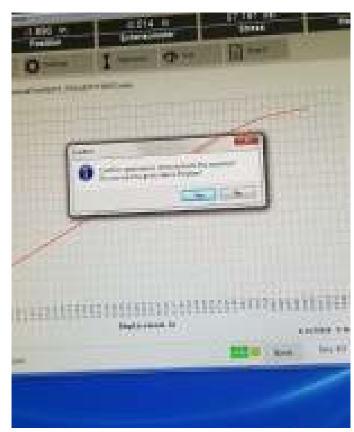


Fig. 3-2-25

Report Generation Procedure:

1. Click "Report" in rightmost menu (Circled in Fig. 3-2-26).
2. Click Excel Report in lower right corner (Fig. 3-2-27).
3. Wait, & when the "Plots" window opens, check the boxes: Load, Deflectometer, Stroke (Fig. 3-2-28).
4. Click <Plot>, then <OK> (Circled in Fig. 3-2-29).

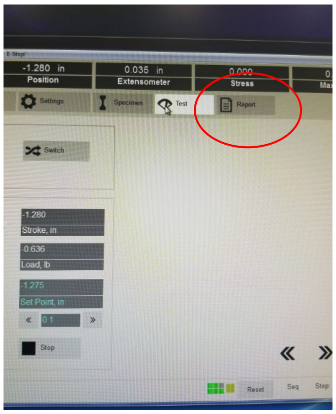


Fig. 3-2-26

Fig. 3-2-27

Fig. 3-2-28

Fig. 3-2-29

5. Close Plot window and select "Yes" to close window & generate Excel file (Fig. 3-30).
6. Record filename shown at the top of Excel file when Excel opens.
7. Briefly review excel data to make sure you have everything you need. Then close file.
8. Close Monotonic Post Processing Window (Fig. 3-2-31).
9. Close Monotonic test software and click <Yes> when prompted (Fig. 3-2-32).
10. Go to MTL software, select <File>, then <Shutdown & Quit>, then select <Yes> when prompted.

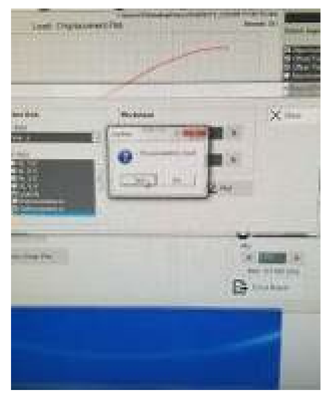


Fig. 3-2-30

Fig. 3-2-31

Fig. 3-2-32

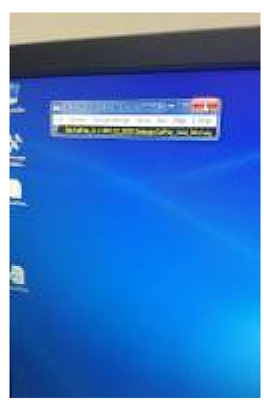


Fig. 3-2-33

Fig. 3-2-34

Test Teardown:

12. Use light finger pressure to bring Deflectometer back down to center position & insert retaining pin.
13. If no further tests are planned, remove Deflectometer & place it back in the box.
    a. Disconnect connector from Strain2 port on back of controller.
    b. Open box.
    c. Set Deflectometer flat on side with pin facing down into one of crate recesses so it does not bend while stored.
14. Remove sample from fixture and return it to cabinet.
15. Copy your excel file to your thumb drive.
16. If desired, you may also copy the .mns file and the Monotonic software (lower left corner of desktop to your thumb drive. If you install the Monotonic Software on your computer, this will enable you to reprocess your data from the .mns file using the report option.
17. After securing your file on your thumbdrive & removing it from the USB port, delete your excel file and .mns file from the desktop of the lab's computer & then empty the desktop Recycle Bin.
18. Shut down the computer.
19. Turn off Controller using front knob & rear switch.
20. Carefully remove and return UBF and LBF to the bottom shelf of the A2 Cabinet.
21. Lightly hand tighten upper & lower spanner nuts.
22. Place emergency stop on top of controller

Analysis & Report

1. Prepare a lab report of your test per Appendix B guidelines.
2. Show a clear dimensioned sketch of the sample, and of the bending setup.
3. Include plots of load versus deflection (using Deflectometer values) from the test. The software should be set to report the deflectometer values and to smoothly transition to stroke values once the deflectometer limit is passed.
4. Assume a typical modulus of elasticity for your sample (10 Msi for aluminum samples & 30 Msi for steel samples), and calculate the maximum stress, the maximum deflection, and the slope at the inflection points of the beam. Include these calculations in the discussion (or in Appendix B) and compare estimates to test results and comment on findings.
5. Since the test system provides measured force and deflection data, compare your prediction of deflection to the measured experimental value. Compute the percent difference, and comment on your findings.
6. Next, determine the apparent modulus of the beam by rearranging Equation 3-2-3 to solve for E and by inserting your measured deflection and force into this equation. Do this twice, as follows:
    a. First, use the maximum deflection and the applied load at that value to compute the apparent modulus E of the beam at maximum deflection.
    b. Next, do this again, but this time use a force and corresponding deflection value that is clearly in the elastic range (from the straight-line portion of the load deflection curve).
    c. Compare your two modulus predictions and comment on whether your loading entered the plastic range or not.
7. Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
8. Comment on anything else you notice, or that you feel should be addressed in the discussion.

3-3 Experiment 3-3: Euler Buckling of Columns

Purpose

In this experiment, student teams will use the TestResources 810 LE Test System to investigate the buckling response of a sample.

Apparatus

You will need the following parts: (a) the TestResources 810LE shown in Figure 3-3-1a, (b) one or more extensions as shown in Figure 3-3-1b (found in upper drawers of cabinet A-2), (c) the upper & lower collars & pins as shown in Figure 3-3-1c (note the collars & pins are machined to fit, find the correct mating pairs and do not force them), (d) the Pin-Constraint Nipples Shown in Figure 3-3-1d, (e) The Fixed-Constraint Nipples & Cups as shown in Figure 3-3-1e.

Fig. 3-3-1a: Test Machine

Fig. 3-3-1b: Extensions

Fig. 3-3-1c: Collars & Pins

Fig. 3-3-1d: Pin-Constraint Nipples

Fig. 3-3-1e: Fixed-Constraint Nipples & Cups

You will not need an extensometer nor deflectometer for this test.

Test Samples

There is an assortment of precut buckling samples in the back room. There is additional tube stock there also that can be cut to length if needed. This tube stock has a couple OD & ID options, as shown in Figure 3-3-3.

The fixed-support apparatus will not fit in the thicker stock unless pre-drilled. Either select samples with the proper ID to fit the nipples, or have students drill the ends of the sample to fit. Use a TBD drill to convert thicker samples.

The thinner stock should work without modification.

Each student team should test two lengths of samples, and should investigate buckling under simulated pinned-pinned, fixed-fixed, and pinned-fixed conditions.

Fig. 3-3-2: Samples

Test Fixture Setup

Setup as follows:

1. Locate the TestResources 810LE Electrodynamics Test Machine. It should look roughly like Figure 3-3-1a (above).
2. Locate the Lower Collar & Lower Buckling Adaptor Rod, and the Pins that fit the holes, and assemble as shown in Figure 3-3-2a. *Notice that the threaded adaptor rod has been machined to fit into the lower collar.*
3. Locate the Upper Collar & Upper Buckling Adaptor Rod, and the Pins that fit the holes, and assemble as shown in Figure 3-3-2b. *Notice that the threaded adaptor rod has been machined to fit into the upper collar.*
4. The completed assembly should look as shown in Figure 3-3-2c. *Be sure the pins are selected that fit snugly without forcing the pin thru the collar and adaptor.*

Fig. 3-3-2a: Lower Assembly

Fig. 3-3-2b: Upper Assembly

Fig. 3-3-2c: Buckling Assembly

5. Select adaptors as needed to fit the sample so that sufficient stroke of the load cell will test the sample without too much movement of the upper cross-member. A couple adaptors are available in the upper drawer of Cabinet A-2. Any of the other Amatrol adaptors will also fit.
6. In order to simulate a pinned condition with your test sample, select the pinned nipple and the single-threaded receptacle as shown in Figure 3-3-3. One end of the nipple fits down the end of the thin-walled tube samples. The other mates with the recessed portion of the threaded receptacle.


Fig. 3-3-3: Pinned Ends


Fig. 3-3-4a: Fixed Nipple


Fig. 3-3-4b: Fixed Setup

7. In order to run to simulate a fixed condition with your test sample, select the fixed nipple and the double-threaded receptacle as shown in Figure 3-3-4a & 3-3-4b. One end of the nipple fits down the end of the thin-walled tube samples, while the other threads into the double-threaded receptacle.
8. Students may follow steps 7 & 8 above to simulate a Pinned-Pinned, Fixed-Fixed, and Pinned-Fixed condition with their samples.
9. The loadcell on the TR 810LE Test System has 6” of travel. Therefore, the fixture will need to be prepared such that once the test specimen and adaptors are all in place, that the load cell has sufficient travel to reach and load the sample during testing. If needed, the four allen bolts on the upper cross-member can be loosened, the upper crossmember moved, and the bolts retightened.
10. Once setup is complete, double check that the four Allen bolts on the face of the upper crossbar are snug (circled in red in Fig. 3-3-1a).

Test Procedure

Caution! When simulating a fixed-fixed end condition, it may be easy to bend the nipples inserted into the sample, especially for shorter samples. Watch the sample closely. Stop the test before the fixed-end nipples become bent.

Buckling of a sample is evident when the load-deflection relationship diverges from a straight line.

During all buckling tests, the sample will be inserted into the fixture, the fixture will be adjusted as needed to enable sufficient stroke during testing, and the sample will be loaded with the test software while carefully watching the sample and the load deflection curve.

During each test, students must watch the load-deflection curve. When buckling occurs, the load-deflection curve will diverge from a (roughly) straight line. The test can be stopped at this point, and the buckling load recorded.

Meanwhile, especially during testing with a simulated fixed end, students will watch the ends carefully to ensure they do not bend the nipples that are inserted in the ends of the samples.

For all samples, the following procedure will be followed.

1. Place the sample in the fixture.
2. Switch end attachments as needed.
3. Adjust the upper crossbar if needed.
4. Load the sample in compression until buckling occurs or until the end fixtures look like they might be in danger of damage.
5. Stop the test and record the buckling allowable.

Choose a sample length, either long or medium, then test the following conditions:

a. Sample with a simulated pinned-pinned end condition.
b. Sample with a simulated pinned-fixed end condition.
c. Sample with a simulated fixed-fixed end condition.
d. Now choose a sample with about half the length, and test a simulated pinned-pinned end condition.

Note: Please to reuse samples if they remain straight after prior testing. Straightness can be checked by inspecting them while rolling them on a flat surface.

Test Teardown:

1. Be careful to all buckling hardware and to return it to the upper-middle drawer of Cabinet A2.
2. Remove sample from fixture and measure, photograph, & study for report.
3. Copy your excel file to your thumb drive.
4. If desired, you may also copy the .mns file and the Monotonic software (lower left corner of desktop to your thumb drive. If you install the Monotonic Software on your computer, this will enable you to reprocess your data from the .mns file using the report option.
5. After securing your file on your thumbdrive & removing it from the USB port, delete your excel file and .mns file from the desktop of the lab's computer & then empty the desktop Recycle Bin.
6. Shut down the computer.
7. Turn off Controller using front knob & rear switch.
8. Place emergency stop on top of controller.
9. Once all equipment is put away, clean your workstation using 409 or similar cleaner with the blue shop towels, then use the red shop rags with a little WD-40 to wipe down metal surfaces of the test equipment so the metal is clean, lightly oiled, and protected.
10. Check work area is clean and free of debris.
11. Check with instructor before leaving lab.

Analysis & Report

1. Provide a dimensioned sketch, drawing or photo of each test specimen.
2. Report any deviations from standard test procedure above.
3. Discuss test anomalies or difficulties.
4. Document any software or hardware issues and resolutions. Discuss these in report, and send separate E-Mail with these to your instructor *and* to Lab Director (tdcoburn@cpp.edu) for potential improvement to Lab Manual Instructions. Place "ARO3570L Lab Issue & Resolution" in Subject of E-Mail.
5. Provide load-deflection plots of all samples tested. Calculate the theoretical buckling allowable for each sample using methods from ARO3261. Provide a table comparing the theoretical computed allowables to the test values found. Compute and show percent error between values.
6. Discuss similarities or differences between your calculations and the test results.
7. Discuss similarities or differences between the samples with different end constraints.
8. Provide a conclusion of your perspective on the accuracy of the theoretical calculations and of the test results. Provide any insight you have to offer on improving the calculation and/or the test.

4-0 TestResources 160 Series Torsion Test System

The TestResources Torsional Tester was delivered in the Summer of 2017 and is being configured. Soon after it is operational we will begin using this equipment..

Fig. 4-0-1: TestResources 160S Torsion System

- Static & Cyclic Torsional Testing
  - Max Torque: 2655 in-lb Static, 1775 in-lb Fatigue
  - Fatigue, Static & Multi-Step Programming
  - Max Speed: 100 RPM
  - Digital Feedback for Angular osition Measurement & Control
  - 0.001 degree resolution
  - Data Acquisition to 3 kHz
  - Stroke: ±3 in
- Power Requirements
  - Voltage: 200-240 1 Phase
  - Max Continuous Current: 12 A
  - Frequency 50/60 Hz
  - Connector: NEMA L6-20

Changing Test Configuration

- If this test system is not configured for your test, see the instructor before attempting to change the configuration. Details for changing the test fixtures & accessories will be added to a later revision of this document.

Before Starting the Machine (Emergency Procedures)

Before starting the machine, locate the emergency stop (E-Stop) button located on the controller or on the desktop, as shown at right.

Assign one student to constantly monitor the E-Stop button whenever the machine is being used.

Press the E-Stop button any time the machine appears to behave in an unsafe manner, or if anything looks suspicious, or if there appears any danger of injury to people or parts.

Once the E-stop button is pressed, it can be released by twisting the switch in a clockwise direction, as indicated by the direction arrows on the switch itself.

Fig. 4-0-2

Starting the Machine & Opening the MTL32 Test Software

15. Turn on computer.
16. Turn on controller by first rotating the front red knob clockwise from 0 to 1 (Fig. 4-0-3a), and then by flipping the rear switch found in the upper back corner of the controller just above the power cord connection as shown in Fig. 4-0-3b (circled in red). Note: The controller is on a gray rolling cart that can be gently pulled out to improve access when needed, as shown in Figure 4-0-3c. Be certain to gently push it back until the face of the controller is slightly behind the face of the cabinet to safeguard the knobs on the machine from inadvertent damage.
17. Verify that the two green light up (Fig. 4-0-3c).

Fig. 4-0-3a

Fig. 4-0-3b

Fig. 4-0-3c

18. Locate emergency stop switch & assign one student to hold & monitor the emergency stop at all times for remainder of test (Fig. 4-0-2).
19. Open MTL32_2020 software by clicking on the icon in the lower taskbar of computer (Fig. 4-0-4a), then click on the “yes” button when prompted (Fig. 4-0-4b).
20. When the MTL32_2020 software opens, go to its Task Bar and click <Show>, then select <Nothing> (Fig. 4-0-4c).
21. Next on the MTL32_2020 software Task Bar click <Operate> (Fig. 4-0-5d). then <Go Online>, then wait until red box disappears.

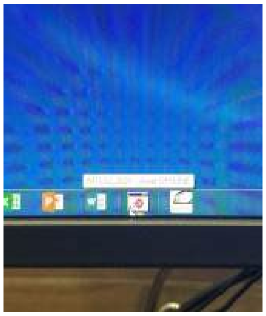


Fig. 4-0-4a

Fig. 4-0-4b

Fig. 4-0-4c

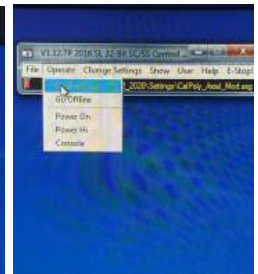


Fig. 4-0-4d

Software still appears non-operational. Stand by…

4-1 Experiment 4-1: Torsion Test using TestResources 160S Torsion

Purpose

TBD

References:

- B&J Mechanics of Materials, Sections TBD.
- Aerospace Strength Handbook, Volume I, TBD.

Test Setup Procedure

This experiment is very important. It will be difficult to recall all aspects of the test later. Make sketches or take photos during all stages of testing for your report. Think about each step as you go, read each step aloud, and discuss with team members what you are doing, and any questions, insights, or concerns you have as you go. Jot down notes as appropriate.

Test Fixture Setup

1. Locate the TestResources 160S Electrodynamic Torsional Test Machine in Lab. It should look roughly like Figure 4-1-1.

Test Procedure

1. TBD

•

5-0 MTS Hydraulic Static/Fatigue Test System

MTS 50 Kip Static/ Fatigue Test Machine

The MTS Hydraulic Test System can be configured to perform static & dynamic tension, compression, and bending tests. Refurbishment of this machine was provided to the department through a 2017 Air Force Grant.

Figure 5-0-0 shows the MTS Test Station and the MTS Load Frame equipped with the Hydraulic Grips, and the Hydraulic Grip Supply.

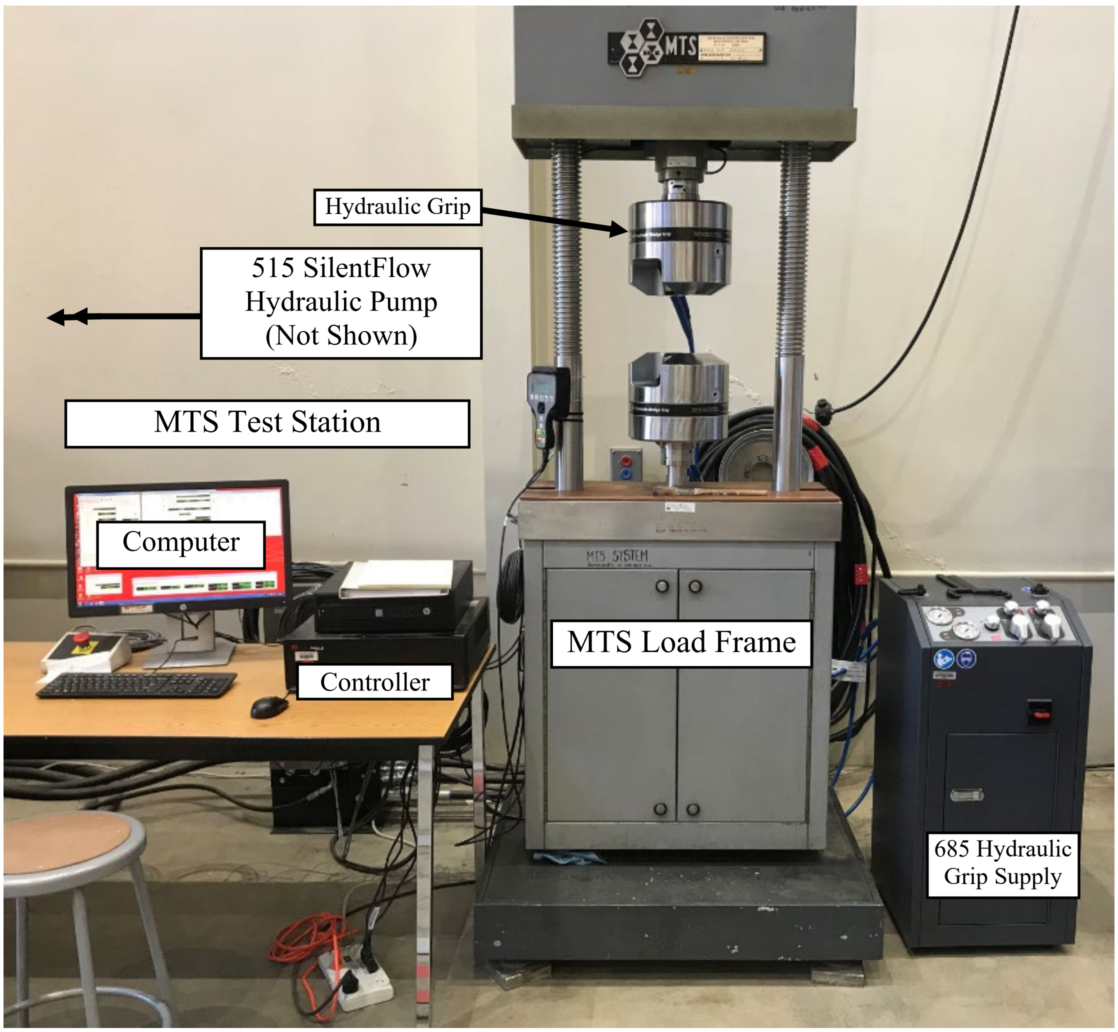


Figure 5-0-0 MTS Test Station

Capacity of the MTS Test System & other details are documented below.

Capability

- Vertical Load Capability
  - Max Load: 50 kips Static & Cyclic
  - Tension, Compression, or Bending
  - Stroke: 8” total (+/-4”). No cushion. Do not hit stops.
  - Accuracy: 1% of Reading
- MTS SilentFlow 515 Pump (515):
  - 20 gpm @ 3000 psi hydraulic system.
  - water coolest (must turn on prior to operation)
  - Jumper Plug: Allows pump to run independently.
  - Operating temperature: 105-110F Ideal, 115 MTS Recommended, 132F E-Stop
  - Filter: Watch Indicator for change.
  - Hydraulic Lines: red zip-ties on hydraulic feed lines, blue on return.
  - Overload must be reset using red button inside front panel of pump.
- Frame Actuator (Model 252.24g-01) w/ 10 gpm Servo Valve.
- Frame Threaded Rod: 1.5”-12 Thread
- Portable Actuator (Model 252.23g-01), 5 gpm
- Service Manifold
  - Enables pump to run without frame active.
  - 2 Channels (Frame & Actuator), more can be added
- Network & Controller Connection Settings:
  - Network IP Address: 148.150.203.190
  - Controller IP Address: 148.150.203.191
  - Documentation: In MTS 793 Software Folders
- Handset:
  - Either Handset or Computer is in control
  - To take control with the handset, press <Handset Button> then <Thumbwheel Button> on handset.
  - To recover control with software, check the <Exclusive Control> box in software.

Power Requirements

- Software: FlexTest 40
- Controller: 2 Channel, 2 Station Controller.
- Pump Voltage: 480 V, 3- Phase

Configurations & Grips

- Hydraulic Grip: Model 647.25
  - 75 kip Static Capacity
  - 50 kip Dynamic Capacity
  - Flat Grips
  - Diamond Grips:

Major Components

Fig. 5-0-1: MTS Load Frame

Fig. 5-0-2: MTS Hydraulic Pump

Fig. 5-0-3: MTS Feedwater Control

Fig. 5-0-4: MTS Handheld Controller

TBD

Fig. 5-0-5: MTS Service Manifold

Fig. 5-0-6: 685 Hydraulic Grip Supply

TBD

Fig. 5-0-7: Computer for MTS

Fig. 5-0-8: Controller for MTS (Lower Unit)

5-0-1-1 Before Starting the Machine (Emergency Procedures)

There are four ways to stop the machine. Locate all four before starting anything.

- One emergency stop button by the computer.
- One Emergency Stop Button on the Face of the Hydraulic Pump
- One red stop button on the hand-held controller
- One stop button in the test software (you can wait to verify this when you open the software).

Also, before starting the machine, note that when shutting down the pump and Service Manifold, be sure to change to low speed before shutting off.

Always start pump first, then manifold.

Any time the E-Stop button is pressed, you will need to do the following:

- Reset both E-Stop Buttons by rotating clockwise.
- Follow the latter "Starting the System" Steps.

5-0-1-2 Starting the System

Start the system as follows:

- Reset both E-Stop buttons (one on pump, one by computer).
- Turn on Controller using switch on back of it.
- Press <Power> button on front of computer.

Start Pump

- Turn on feedwater at shower near entry to lab. The feedwater is Off when the yellow handle is perpendicular to the hosing (See Fig) and is On when the yellow handle is inline with the hosing (see Fig).
- Rotate handle on front of pump from off to on.
  - Wait while the display comes on.
  - Select <English> by pressing American Flag.
  - System is always faulted when the machine comes on.
  - Press blue <status> button, then the blue <reset> button.
  - Rotate E-Stop button to release (check all). (should be pressed when turning off).
  - Setup should not need to be changed.
  - Select <MAIN>, then select <ENABLE MODULE #1>.
  - You can start the pump in one of two ways:
    - From the software, press <Remote Operation>. (We will usually do this).
    - From the Pump, press <RUN> on the face of the pump.

Feedwater Off

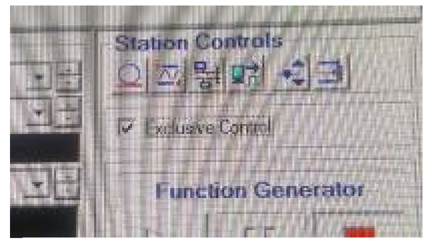
Feedwater On

5-0-1-3 Opening the MTS 793 (FlexTest) Test Software

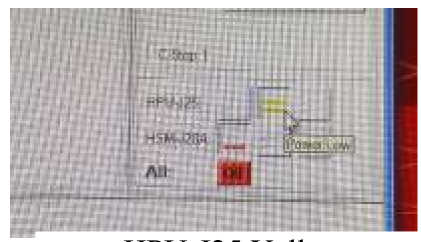
Turn on the computer.

1. Log on to the computer using the following:
   a) USER: Administrator
   b) Password: admin
2. Open the StationManager Software (See Fig) by double clicking the <Station Manager> icon located on the lower taskbar. Wait a few moments while it loads.
   a) Alternately, use the icon located on the desktop.
3. Click <Accept> to the License Agreement, if needed.
4. Select the Configuration file per experiment direction.
   - <Loadframe.cfg> if no extensometer is used
   - <Loadframe with Extensometer.cfg> if you are using an extensometer
5. Select the Parameter Sets per experiment direction.
   - <Tensile> if running a tension test.
   - <Fatigue> if running a fatigue test.
6. In the rightmost set of menus, press [Reset] next to the Interlock 1 checkbox.
7. In the [Station Controls] Area (See Fig), check the checkbox next to <Exclusive Control>.
8. In the {Station Controls] Area of the main window, the second indicator "Detectors" should usually be disabled.
9. If the pump is not yet running, turn on Pump, as follows:
   a) Make sure [REMOTE OPERATION] on Pump Front Panel is selected to give control to software.
   b) In the lower right of the main control window of the MTS Flextest Software Window, press the second icon to the right of HPU-J25 to set Pump to Low Power (See Fig).
   c) Wait until icon stops flashing yellow and shows solid yellow (See Fig).
   d) Click rightmost icon to set the power to high.
10. Turn on Service Manifold:
    a) Press the second icon to the right of HPU-J28A to set to Low Power.
    b) Wait until icon stops flashing yellow and shows solid yellow.
    c) Click rightmost icon to set the power to high (See Fig).
11. In the [Station Signals] Window (See Fig), find "Axial Force" & click the <Auto Offset> Icon (it looks like a belt clamp) to Zero the load. If using an extensometer, zero the axial strain as well.
12. Check Limits & set as needed (mostly not used).
13. The MTS 793 FlexTest Software should now be ready to support your test. Return to the Experiment Procedure for further instructions.

StationManager Software

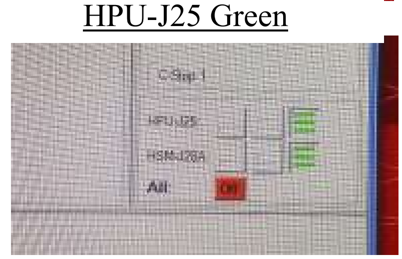


Station Controls Panel

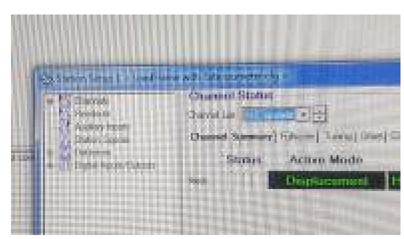


HPU-J25 Yellow

HPU-J25 Green



HPU-J28 Green



Station Signals

5-0-1-4 Jogging (Moving) the Load Heads

We will generally follow computer, controller, pump and software startup procedures before jogging the machine. Therefore, the entire system will typically be running before the loadhead is jogged into place for insertion of the test sample. When the system is running, we will use the handheld controller to jog the machine, as follows:

Select <Applications> <TestSuite> in the Flextest software to open the Testsuite Software.

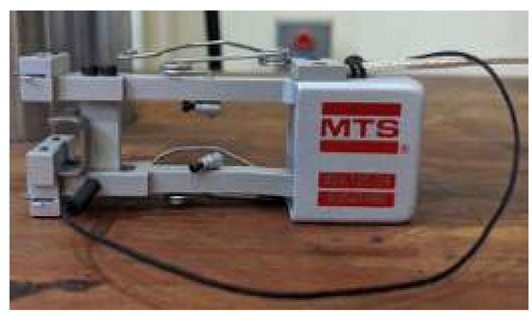
1. In the MTS FlexTest 40 Window, below [Station Controls], uncheck the "Exclusive Control" checkbox to allow the handheld controller to take control.
2. On the handheld controller, Press the upper right icon that looks like the handheld controller.
3. Press the dial control button below the thumbwheel itself to enable its use.
4. Use then use the thumbwheel to jog the loadhead. Be very careful to use the thumbwheel sparingly. It seems the actuator can lag, resulting in continued motion after the wheel stops turning. Keep hands away from machine and turn slowly and gently while carefully watching results.

MTS Handheld Controller

5-0-1-5 Mounting the Extensometer

If an extensometer is used, follow these steps…

1. Fetch the MTS Extensometer from the shelf of Cabinet A-7. Handle it with care.
2. Connect the connector to the plug behind the leftmost support of the load frame.
3. Attach when ready.



MTS Extensometer

5-0-1-5 Operating & Controlling the 647 Hydraulic Grip Supply

The hydraulic grips are operated and controlled with the 647 Hydraulic Grip Supply, which is a completely stand-alone unit located to the right of the MTS Load Frame, as shown in Figure 5-5-0 (above) and Figure 5-0-1-5a (below).

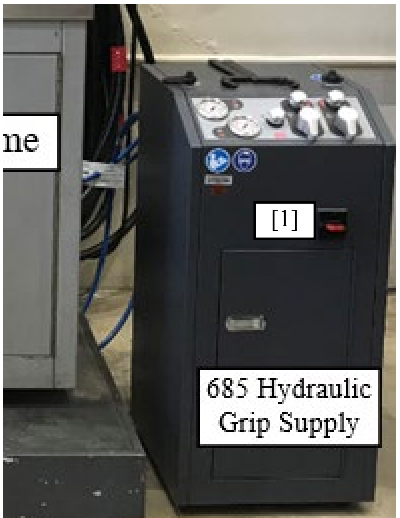


Fig. 5-0-1-5a: Hydraulic Grip

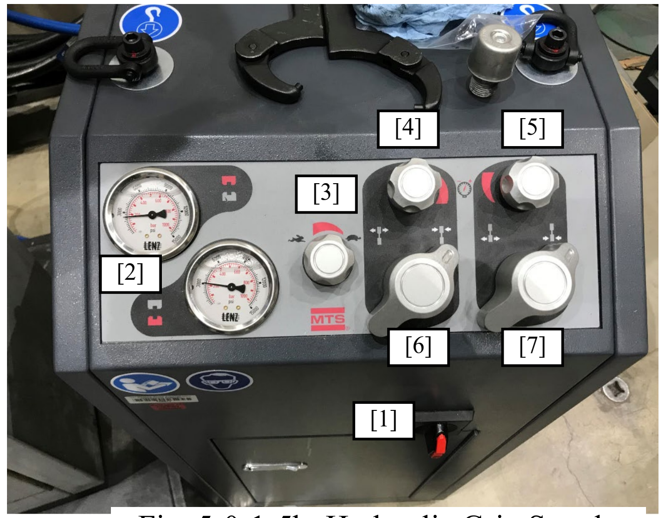


Fig. 5-0-1-5b: Hydraulic Grip Supply

Caution!

Use extreme care when operating the grips when students are near them or are inserting a sample. Communicate, and take extra care not to catch someone's finger or clothing.

Understanding the Hydraulic Grip Controls

The controls for the 647 Hydraulic Grip Supply are shown in Figure 5-1-0-5b. Controls for this unit are as follows:

1. The on switch [1] is located on the front of the unit (Fig. 5-0-1-5a&b).
2. The two dial gages [2] at left show the pressure of the upper (upper left gage) & lower grip (lower right gage). Pressure is controlled with the knobs [3], [4], [5] at right.
3. The center knob [3] controls how fast the grips clamp and unclamp. Rotating CW increases the clamping speed, CCW decreases it.
4. The 4 knobs at right control the grips.
5. Knob [4] controls how hard the upper grip holds the sample, and knob [6] controls opening and closing of the upper grip.
6. Knob [5] controls how hard the lower grip holds the sample, and knob [7] controls opening and closing of the lower grip.
7. Generally, students should use max pressure to hold aluminum, steel and titanium samples. Lesser pressure should be used for composite & plastic samples, or for samples that may be sensitive to crushing in the thickness direction.

Procedure for Gripping Samples

A procedure for operating the 647 Hydraulic Grip Controls is as follows:

1. Before placing sample, use the Hydraulic Load Frame to move the grips so that the distance between the nearest grip faces is slightly more than the sample length.
2. Place the sample in the upper grip, such that there is about ¼" between the end of the sample and the cheek of the grip, then align the sample centrally with the grip such that it is vertically straight.
3. While holding the sample in place, and using extreme caution not to get any fingers or other items caught in the grips, follow the following steps to grip the sample.

4. Rotate knob [3] to provide slow grip movement, and knob [4] to provide light gripping pressure.
5. With all lab partners focused on keeping fingers & extremities safe, have one lab partner operate knob [6] to clamp the sample into the upper grip.
6. Next, taking care to be sure the sample does not hit the lower grip as it rises, use the Hydraulic Load Frame to move the lower grip upwards until the end of the sample is about ¼” from the cheek of the grip.
7. Ensure knob [3] still provides slow grip movement, then rotate knob [5] to provide light gripping pressure.
8. With all lab partners focused on keeping fingers & extremities safe, have one lab partner operate knob [7] to clamp the sample into the lower grip.
9. Once the position looks good, be sure all hands are free of the clamping surfaces, rotate knobs [4] & [5] to increase the pressure so the grips hold the sample tightly.

Alternately, the above procedure can be used with the modification that the press is aligned so the sample fits lengthwise, and then both upper and lower grips are activated as described above.

Before Starting

Before testing, turn on the hydraulic grip controller and practice operating and controlling the grips.

5-1 Experiment 5-1: Tension Test using MTS System

Purpose

In this experiment student teams will use the MTS Hydraulic Test System to investigate Tension of a sample.

References:

1. B&J Mechanics of Materials.
2. Aerospace Strength Handbook, Volume II & III.

Fundamental Principles & Equations

TBD.

5-1-1 Running a Tension Test

Read the procedures and capabilities of Section 5-0 before running this experiment, then follow the procedure below carefully.

Preparing the System

2. Review the Emergency Stop procedures of Section 5-0-1-1.
3. Start the MTS System as directed in Section 5-0-1-2.
4. Start the MTS 793 FlexTest Software as directed in Section 5-0-1-3, being sure to select the following Configuration & Parameter files:
   - Configuration: Loadframe with Extensometer
   - Parameter: Tensile

Preparing & Positioning the Sample

5. Photograph and sketch your sample. Record all dimensions on your sketch for inclusion in your report. Calculate the area of the minimum section for insertion in the software momentarily.
6. Review Section 5-0-1-4 to review procedures for jogging the loadhead.
7. Review Section 5-0-1-5 to review procedures for placing the sample & using the hydraulic grips.
8. In the FlextTest Startup procedure, check the checkbox next to <Exclusive Control> in the [Station Controls] Area so the computer had control of the test fixture. In order to position the sample, we will uncheck this box momentarily.
9. *Verify that all team members are paying attention and that none of them are moving the loadhead while your fingers approach the machine*, and then position the sample in the tension grips, taking care of the following:
   - Try to insert the sample so the entire grip-portion of the sample is in the jaws of the grips, except for approximately ¼” of the sample widened length, which should extend past the MTS grips.
   - Strive to mount the sample near the center of the grips.
   - Strive to align the sample as straight vertically as possible.
   - Be sure there is sufficient room between the grips so that the extensometer can be mounted, if one is used.
10. Hook up extensometer if one is used (See Section 5-0-1-5).
11. Once the sample is positioned and securely in the fixture, recheck the checkbox next to <Exclusive Control> in the [Station Controls] Area so the computer had control of the test fixture. You are now ready to run the test.

Running the Test

12. In the Main MTS Flextest 40 Window, select <Applications> & <TestSuite> to start the TestSuite Software.
13. Click <Custom Templates>.
14. Select (by double clicking) the template needed.
    a) <TensileNoExtensometer> if running a tension test without an extensometer.
    b) <TensilewithExtensometer> if running a tension test with an extensometer.
15. <Click> the New Test Icon below "File Menu" in the Main MTS TestSuite Window.
16. In the Specimen Selection Window, Select <+> on the far upper right, then enter specimen name, then click <OK>.
17. In the [Setup Variables] Window, input the specimen/test variables:
    - Enter the specimen minimum area
    - Enter the grip separation distance (the distance between the nearest faces of the grips). This is used for a pseudo-strain calculation that is especially useful when the extensometer is not being used.
    - Verify that the loading rate is about 0.005 in/s.
18. Right-click on any of the "Meter Windows" (found near the bottom of the screen), and select <Reset all> to reset them to zero (This is actually only needed on second or subsequent test).
19. Click the green <Run the Test> button.
20. Watch the sample carefully.
    a) If the system limits trip, you will need to reset the system, as follows:
    b) Click the blue interlock reset button near the middle of the TestSuite Window.
    c) Under HPU/HSM icons, select the pulldown menu, and turn the HSM back on to high power.
21. Select Stop in the software when the sample breaks.
22. Remove sample.
23. Keep hands away from the machine, and click the Park Button which looks like a blue down arrow, and the machine will return its zero position.
24. Review Results in various results windows.
25. You will need to export the test data for your lab report.
    a) Click <Test Run>, then right-click <Export Data>, then save these to your thumbdrive. (This only saves raw data).
    b) Screen Print each of your graphs, and save these to your thumbdrive as well.
    c) You can also work with the software to develop a template that saves your test data as you wish it to look.
26. When you are done running all tests.
    a) Shut down the TestSuite software.
    b) Turn off the Service Manifold

5-1-2 Analysis & Report

1. Prepare a lab report of your test per Appendix A guidelines, except as follows:
   - Place the raw test data, including load-deflection values and stress strain values reported by the software in Appendix A. This can be in Word, Excel, or tabular format, and does not need prettied up. Also place any load-deflection, stress-strain, or other curves from the test software here. Any graphs or plots or segments of data that are useful for your discussion can be repeated in the body of your report to enhance clarity, or can be referenced to your appendix if this is sufficiently clear.
   - Place your hand calculations in Appendix B.
   - Provide clear dimensioned sketches or drawings of your samples in Appendix C. A dimensioned hand sketch is fine.
   - Place any supporting data in Appendix D+, if needed.
2. Include plot of load versus extensometer deflection. Comment on your curve in your Discussion
3. Include curve of stress (at minimum section) versus strain.
4. Determine Ultimate Tension Strength (Ftu), Tension Yield Strength (Fty), maximum strain (□), elongation (e), and modulus of elasticity (E) of the sample. Explain how determined and include sketches or annotations on chart, if needed.
5. Examine the broken end of each sample segment. Measure it as best you can. Comment on whether it looks like a brittle or ductile fracture. Research as needed to guide or support your conclusion.
6. Compare the results for any samples of different material. Which is stronger, more ductile, has more elongation? Comment on what this means or implies.
7. Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
8. Comment on anything else you notice, or that you feel should be addressed in the discussion.

5-1-3 Test Teardown

- Turn off Pump
- Turn off Service manifold
- Turn off feedwater.
- Once all equipment is put away, clean your workstation using 409 or similar cleaner with the blue shop towels, then use the red shop rags with a little WD-40 to wipe down metal surfaces of the test equipment so the metal is clean, lightly oiled, and protected.
- Check work area is clean and free of debris.
- Check with instructor before leaving lab.

5-2 Experiment 5-2: Fatigue Test using MTS System

Purpose

In this experiment student teams will use the MTS Hydraulic Test System to investigate fatigue of a sample loaded in a tension-tension cyclic loading.

References:

- B&J Mechanics of Materials.
- Aerospace Strength Handbook, Volume III.

Fundamental Principles & Equations

TBD.

5-2-1 Running a Fatigue Test

Read the procedures and capabilities of Section 5-0 before running this experiment, then follow the procedure below carefully.

Preparing the System

1. Review the Emergency Stop procedures of Section 5-0-1-1.
2. Start the MTS System as directed in Section 5-0-1-2.
3. Start the MTS 793 FlexTest Software as directed in Section 5-0-1-3.

Preparing & Positioning the Sample

4. Photograph and sketch your sample. Record all dimensions on your sketch for inclusion in your report. Calculate the area of the minimum section for insertion in the software momentarily.
5. Review Section 5-0-1-4 to review procedures for jogging the loadhead.
6. Review Section 5-0-1-5 to review procedures for placing the sample & using the hydraulic grips.
7. In the FlextTest Startup procedure, we checked the checkbox next to <Exclusive Control> in the [Station Controls] Area so the computer had control of the test fixture. In order to position the sample, we will uncheck this box momentarily.
8. Position the sample in the tension grips, being careful to get it as straight as possible, and to position so there is ample room for the extensometer, if one is used.
9. Hook up extensometer. (Add details).
10. Once the sample is positioned and securely in the fixture, recheck the checkbox next to <Exclusive Control> in the [Station Controls] Area so the computer had control of the test fixture. You are now ready to run the test.

Running the Test

11. In the Main MTS Flextest 40 Window, select <Applications> & <TestSuite> to start the TestSuite Software.
12. Click <Custom Templates>.
13. Select (by double clicking) the template needed.
    a) <FatigueNoExtensometer> if running a fatigue test without an extensometer.
14. <Click> the New Test Icon below "File Menu" in the Main MTS TestSuite Window.
15. In the Specimen Selection Window, Select <+> on the far upper right, then enter specimen name.
16. In the [Setup Variables] Window, input the specimen/test variables such as the specimen minimum area, the grip separation distance, etc.
17. Right-click on any of the "Meter Windows" (found near the bottom of the screen), and select <Reset all> to reset them to zero (This is actually only needed on second or subsequent test).

18. Click the green <Run the Test> button.
19. Watch the sample carefully.
    d) If the system limits trip, you will need to reset the system, as follows:
    e) Click the blue interlock reset button near the middle of the TestSuite Window.
    f) Under HPU/HSM icons, select the pulldown menu, and turn the HSM back on to high power.
20. Select Stop in the software when the sample breaks.
21. Remove sample.
22. Keep hands away from the machine, and click the Park Button which looks like a blue down arrow, and the machine will return its zero position.
23. Review Results in various results windows.
24. You will need to export the test data for your lab report.
    d) Click <Test Run>, then right-click <Export Data>, then save these to your thumbdrive. (This only saves raw data).
    e) Screen Print each of your graphs, and save these to your thumbdrive as well.
    f) You can also work with the software to develop a template that saves your test data as you wish it to look.
25. When you are done running all tests.
    c) Shut down the TestSuite software.
    d) Turn off the Service Manifold

5-2-2 Test Teardown

- Turn off Pump
- Turn off Service manifold
- Turn off feedwater.
- Etc.

5-2-3 Analysis & Report

1. Prepare a lab report of your test per Appendix A guidelines, except as follows:
   - Place the raw test data, including any graphs or plots or segments of data that are useful for your discussion, in Appendix A.
   - Place your hand calculations in Appendix B.
   - Provide clear dimensioned sketches or drawings of your samples in Appendix C. A dimensioned hand sketch is fine.
   - Place any supporting data in Appendix D+, if needed.
   - You may also repeat any data or plots in the body of your report to enhance clarity as needed.
2. Include a plot of stress versus number of cycles. You may need to convert time to cycles by multiplying time by your frequency (time x cycles/sec = cycles). Comment on your curve in your Discussion.
3. Include curve of stress (at minimum section) versus GrossStrain (based on minimum sample area & grip separation distance).
4. Perform any pertinent calculations from ARO329 that seem applicable, and comment on them.
5. Examine the broken end of each sample segment. Measure it as best you can. Comment on whether it looks like a brittle or ductile fracture. Research as needed to guide or support your conclusion.
6. Evaluate how many cycles your sample failed at, and where this failure occurs on the S-N curve, and how it relates to typical values of F_{tu} & S_e for the material.
7. Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
8. Comment on anything else you notice, or that you feel should be addressed in the discussion.

5-3 Exp. 5-3: Characterizing the Low Cycle Fatigue Curve

Limitations

This experiment is *only for student teams who have completed ARO329 or ARO3271*. Teams with any members who have not completed this class are ineligible to run this experiment.

Purpose

In this experiment student teams will use the MTS Hydraulic Test System to investigate the low cycle fatigue behavior of a sample loaded with a tension-tension cyclic loading.

To do this, multiple tests of the same sample will be run with decreasing max loading to determine the fatigue life for various load spectrums.

The data will be used to curve fit the S-N relationship to predict F_{tu}, f @ 1000 cycles (Recall f F_{tu}), and will predict f and report on the scatter of the data.

References:

- Aerospace Strength Handbook, Volume III.

Fundamental Principles & Equations

See Reference.

5-3-1 Running the Tests

In this experiment you will run the fatigue tests following the procedure of Experiment 5-2. Highlights of the additional steps you will take are summarized below.

Preparing the System

1. Prepare the system as outlined in Experiment 5-2.

Preparing & Positioning the Sample

2. Prepare, measure, sketch, document & position as outlined in Experiment 5-2.

Running the Test

3. You will perform 5-7 tests, depending on results. Run each test as outlined in Experiment 5-2 using the <fatigue test with extensometer> option, except for these tests you will set the parameters for the test to the following:
   a) Note: If any of the following samples fail beyond 1000 cycles, do not keep reducing the load on subsequent tests, but instead choose intermediate points between Ftu and your other max load values to more fully characterize the low cycle fatigue curve.
   b) Note: If you surpass 1000 cycles by your 4th sample, you can stop and not test the additional two samples.
   c) First sample: 1300-6000 lb at 1 Hz. Calculate F_{tu} based on this value.
   d) 2nd sample: 1300-0.95F_{tu} lb at 1 Hz.
   e) 3rd sample: 1300-0.90F_{tu} lb at 1 Hz.
   f) 4th sample: 1300-0.85F_{tu} lb at 1 Hz.
   g) 5th sample: 1300-0.80F_{tu} lb at 1 Hz. (only if 1000 cycles not reached yet).
   h) 6th sample: 1300-0.75F_{tu} lb at 1 Hz. (only if 1000 cycles not reached yet).
   i) 7th sample: 1300-0.70F_{tu} lb at 1 Hz. (only if 1000 cycles not reached yet).
4. Be sure to store your data after each test.

5-3-2 Test Teardown

- Shut down & tear down per Experiment 5-2.

5-3-3 Analysis & Report

1. Prepare a lab report of your test using the Lab Report Template provided.
2. Estimate F_{tu} from your first sample.
3. Plot your points on a log-log S-N curve.
4. Estimate f.
5. Discuss your results, including how it matches or redirects your thinking based on what you were taught in ARO329 or ARO3271.
6. Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
7. Comment on anything else you notice, or that you feel should be addressed in the discussion.

6-0 Photoelasticity Test Machine

Photoelasticity provides an excellent way to evaluate stress concentration factors in simple tension samples. Basic components of the Photoelasticity Test Machine are shown in Figure 6-0-1, and each is described below.

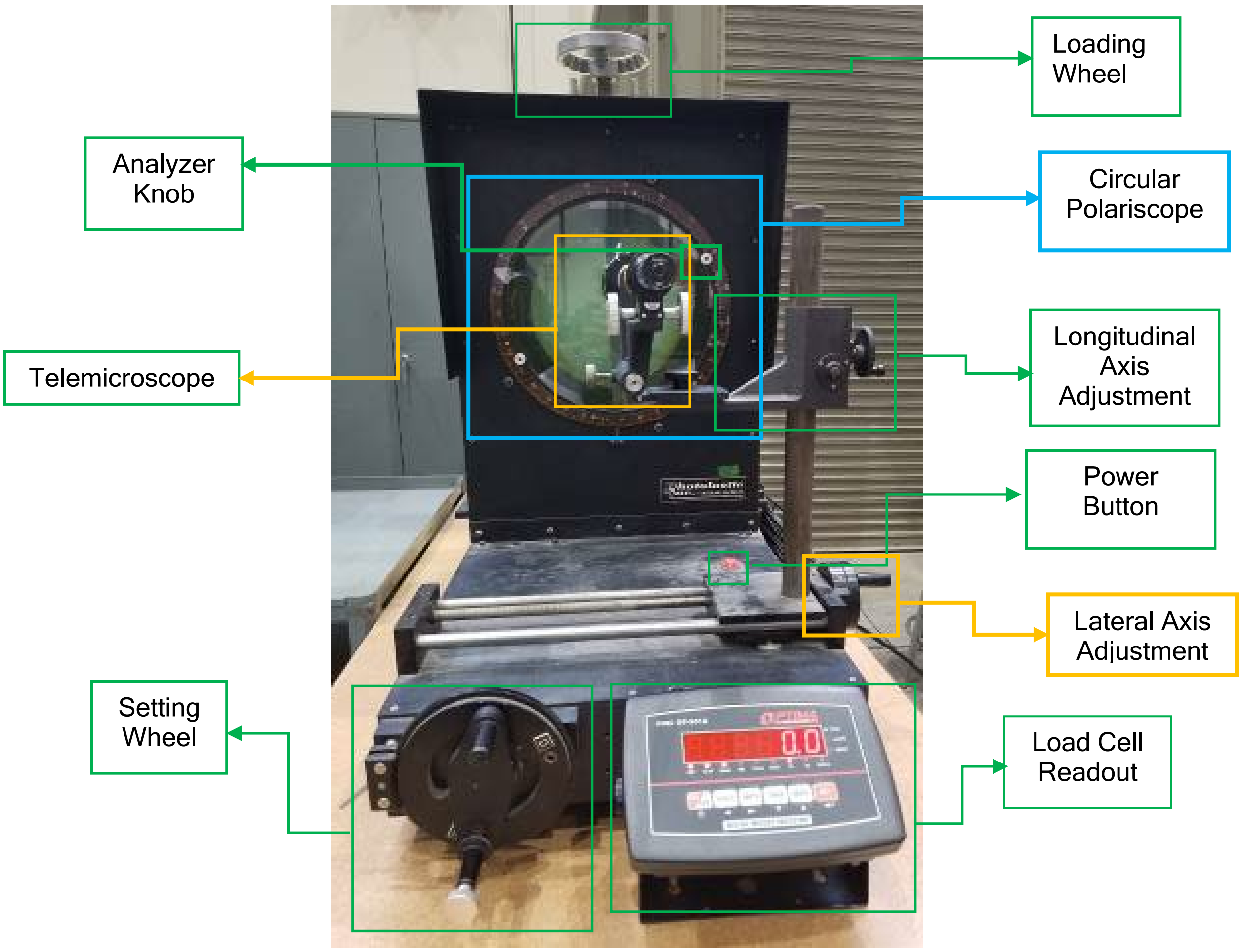


Figure 6-0-1: Polariscope Components

Circular Polariscope

The Circular Polariscope is a Model 031 Reflection Polariscope consisting of two ball-mounted polarizer/quarter-wave assemblies mounted to a common frame. This device is able to measure the following:

- The direction of the principal stresses or strains.
- The magnitude & sign of the tangential stress at free bourndaries, or at any point where a uniaxial stress state exists.
- The magnitude of the difference in strains at any point in a coated test sample.

Load Frame & Loading Wheel

The Load frame holds the sample and applies and reacts loads as the specimen is loaded by turning the loading wheel. The loading wheel is turned clockwise to apply tension to the sample, and counter-clockwise to unload the sample. The load frame is not designed to react more than 250 lbs.

Load Cell Readout

The Load cell readout shows the force applied to the sample.

Analyzer Knob

The Analyzer Knob is rotated to set the Polariscope to its dark or light field setting. With the power button on, rotated this knob until the light field is at its darkest setting to set the Polariscope to its dark field setting, and rotate it until the light field is as light as possible to set it to its light field setting.

Setting Wheel

The Setting Wheel is rotated to set the Polariscope so it reads the magnitude of stresses (Setting M) or their direction (Setting D). This will generally be using in the M position.

Telemicroscope

The Telemicroscope enables a closer look at the isochromatics of on the sample.

Longitudinal & Lateral Axis Adjustment

The longitudinal and lateral adjustment knobs enable the Telemicroscope to be secured in the position most advantageous for reading the peak stresses on the sample.

Isochromatics & Fringe Lines

A stressed photoelastic specimen will exhibit a colorful pattern. Every line of a given color represents a constant stress level. These colors, and the transitions between them, can be used to identify the stress in a sample if we know the photoelastic properties of the material.

Figure 6-0-X shows the color sequence observed in the Polariscope.

The bands of color initially progress from black to yellow to red to blue-green. The transition from red to blue-green is sharply marked, and this transition is what we call the 1st fringe, and corresponds to N=1.

After this, color transitions from blue-green to yellow to red to green, and the second fringe is found at the red-to-green transition, which is also sharply marked, and this corresponds with N=2.

After this, the color transitions from green to yellow to red to green again, and each red-to-green transition corresponds to the next fringe line, and the next N.

The stress along each isochromatic fringe represents the principal stress difference given by:

$$\sigma_1 - \sigma_2 = Nf/t \qquad \text{Eq. 6-0-1}$$

Where N is the fringe number from Table 6-0-X, f is the material photoelastic constant (f=50.34 for our samples), and t is the thickness of the test specimen.

Since the CPP Aerospace Photoelastic Load Frame applies pure tension to the samples, s2 is zero for all of our photoelastic tests, and Equation 6-0-1 becomes…

$$\sigma_1 = Nf/t \qquad \text{Eq. 6-0-2}$$

Isochromatics on a typical sample are shown in Figure 6-0-Y.

Color Observed	N
Black	0
Yellow	
Red	
1st Fringe	1
Blue-Green	
Yellow	
Red	
2nd Fringe	2
Green	
Yellow	
Red	
3rd Fringe	3
Green	
Yellow	
Red	
4th Fringe	4
Green	
Yellow	
…etc…	

Fig. 6-0-x: Photoelastic Fringe Lines

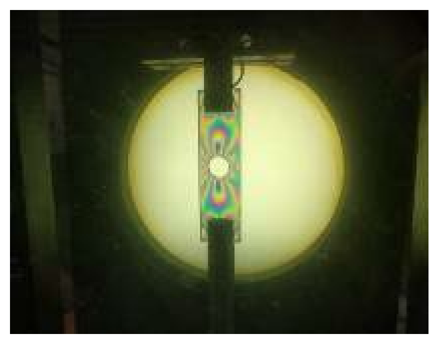


Fig. 6-0-Y: Isochromatics

6-1 Experiment 6-1: Photoelasticity

EXPERIMENT 8

Photoelasticity I

"Stress Concentration Factors"

The purpose of this experiment is to determine the Stress Concentration Factor K_t of an axially loaded flat bar using photoelastic methods.

Reading

Photoelasticity is an extremely versatile, simple, and powerful experimental method which can be used to determine magnitude, direction, distribution, and rate-of-change of the principal stresses in structural and machine elements.

A transparent photoelastic model of the part under study is examined in the polarized light field of a Polariscope with simulated operating loads applied.
Colored fringe patterns reveal a visible picture of the stress distribution over the whole area of the model (whole field method) and stress distribution which is accurately readable at any point for both direction and magnitude.

The **Polariscope** is an optical instrument that utilizes the properties of polarized light in its operation. For experimental stress-analysis work, two types are frequently employed:

1) the Plane Polariscope
2) the Circular Polariscope

The **Plane Polariscope** consists of two linear polarizers and a light source arranged as illustrated in Figure 1.
The **Circular Polariscope** employs circularly polarized light and it consists of two linear polarizers, two quarter-wave plates, and a light source arranged as illustrated in Figure 1.
The light (monochromatic or white) emitted from the light source travels in waves that vibrate along all possible directions in the x-y plane perpendicular to the direction of its propagation, the z-axis.

The **Linear Polarizer** is an optical element which absorbs the components of the light vector vibrating in the direction perpendicular to the axis of polarization. If two linear polarizers are aligned so that their axes of polarization (y-axis, Figure 2) are perpendicular to each other (crossed condition), then no light will emerge from the assembly.

The **Polarizer** is the linear polarizer nearest the light source. It converts the ordinary light into plane-polarized light (vibration is contained in one plane).

Isochromatic Fringes are continuous bands that follow in continuous sequence.

In the Plane Polariscope (not used here) and in the **dark field** of the Circular Polariscope (**used during the first step of this experiment**), the fringe order is related to increasing stress as follows:

Along the Black Field	N = 0
Along the First Isocromatic	N = 1
Along the Second Isocromatic	N = 2
Along the Third Isocromatic	N = 3
Alona the Fourth Isocromatic	N = 4

Note that the sequences red-green-green-red and green-red-red-green correspond to fringes of the same order.

In the **light field** of the Circular Polariscope (**used during the second step of this experiment**), all fringe lines are half order fringes & the fringe order is related to increasing stress as follows:

Along the Black Field	N = 0.5
Along the First Isocromatic	N = 1.5
Along the Second Isocromatic	N = 2.5
Along the Third Isocromatic	N = 3.5
Along the Fourth Isocromatic	N = 4.5

The advantage of employing both light- and dark-field arrangements is that twice as many data are obtained for the whole-field determination of principal stresses.

Along the length of each Isochromatic, the principal-stress difference ($\sigma_1 - \sigma_2$) is equal to a constant and given by

$$\sigma_1 - \sigma_2 = (Nf/t)$$

where N = fringe order observed at the point of measurement
f = material photoelastic constant
t = thickness of the specimen

The higher the fringe order, the higher the stress. The closer the fringes are together, the steeper the stress gradient, generally indicating a stress-concentration area.

Isoclinics are dark bands superimposed over the colored fringes. They indicate areas of same direction of principal stress. At every point on an isoclinic line, the directions of the principal stresses coincide with the directions of the axes of the crossed polarizer-analyzer.

Sharp and narrow isoclinics indicate rapid changes in the directions of σ_1 & σ_2, whereas broad black bands correspond to slowly varying directions.
Note that all Isoclinics will intersect at some points. These are isotropic points and $\sigma_1 - \sigma_2 = 0$
Also, at a free boundary, one of the principal stresses is parallel to the boundary.

Essential Apparatus:

- Circular Polariscope (Fig. 6-1-1)

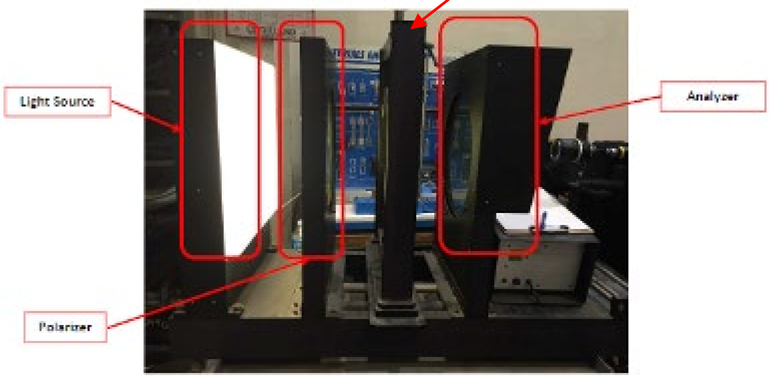


Fig. 6-1-1: Circular Polariscope

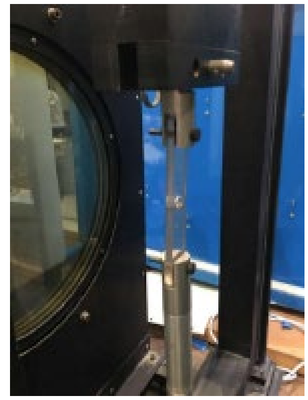


Fig. 6-1-2: Load Frame with Sample

- Load Frame & Load Cell (200 lb max).
- Telemicroscope (Fig. 6-1-3) [Found in Cabinet A4-156 LHS].
- Load Cell Readout (Fig. 6-1-4) [Found in Cabinet A4-156 RHS].
- Vernier Calipers [Found in Cabinet A1 Center Drawer].

Fig. 6-1--3: Telemicroscope

Fig. 6-1-4: Load Cell Readout

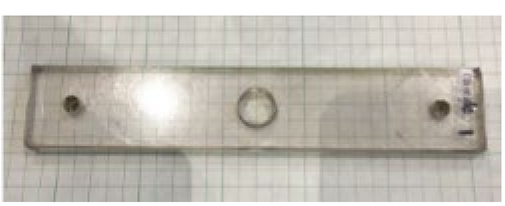


Fig. 6-1-5: Test Sample (Typical)

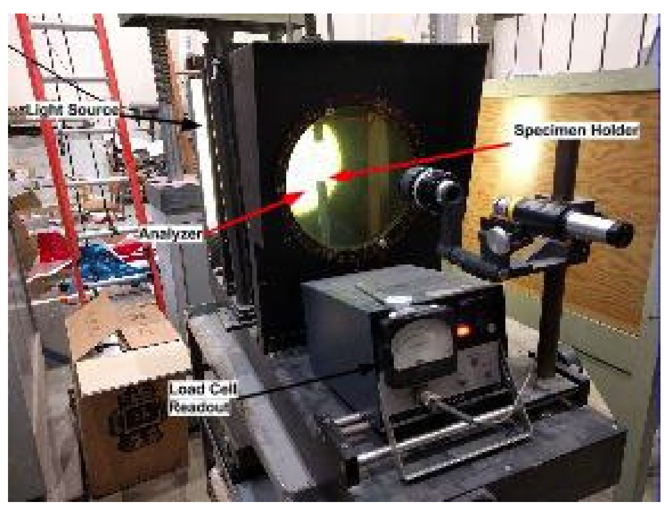


Fig. 6-1-6: Polariscope Setup

Test Specimens:

- Obtain Plastic Test Specimen Sample from the upper tray of the upper left drawer of Cabinet A4 (See Fig. 6-1-5). It should be marked "Use this Sample".
- Take care not to damage or overload sample, as it will be returned to stock and reused.
- **Photoelastic Constant f=50.34 lb/in** for plastic samples provided.

Procedure:

1. Measure the test sample(s) completely. Record data for report.
2. Before loading sample, examine the load wheel (shown circled in red in Fig. 6-1-7) on the top of the load frame. Note that when turned counterclockwise (when looking down) it spreads the supports to apply tension, and when turned clockwise it shortens the span between supports, which applies compression. Be careful to only load the sample as proscribed.
3. Mount sample in Polariscope load frame, secure with 3/16" pins (found in Telemicroscope case). Sample should fit loosely.
4. Obtain overhead power cable and secure near Polariscope electrical connector.
5. Obtain the Load Cell Readout from cabinet, place on cabinet and plug in to power.
6. Obtain the Telemicroscope (TM) from cabinet, mount to Polariscope fixture (Fig. 6-1-3 & 6-1-6), carefully attach lens, and adjust so it aims where sample will be place using the positioning knob shown in the lower right of Figure 6-1-8.
7. Position the Setting Wheel (circled in red in Fig. 6-1-9) to <M> to indicate "Measurement" rather than <D> which indicates "Direction".
8. Lock the Setting Wheel with the clamp on the wheel to hold it in place.
9. Plug in Polariscope & Load Cell.
10. Turn on the light source by pressing red switch.
11. Rotate the knob on the Analyzer (Shown boxed in red in Fig. 6-1-7) until the darkest field possible is showing. This is the dark field where the Circular Polariscope acts like a Plane Polariscope.
12. Adjust the Loading Wheel until the sample is near tension but completely unloaded.
13. Zero load cell before testing.
14. Gently turn the Loading Wheel CCW to initiate tension in the sample. The sample should change shades as stress develops in the sample. Watch areas of potential stress riser (such as the edges of the hole) carefully since this is where stress should develop first. The photoelastic sequence should appear first black, then yellow, then red-blue, and then green (or yellow-red-green). Gently turn the knob to move through this sequence at the critical spot one color at a time. First move past a color, then gently ease back until the prior color is on the brink of change to the next color, and record that as your N & force pair. Do not exceed 200 lb of force!
15. Continue this process from N=0 to 4 for the dark field.
16. Unload the sample gently, then repeat Step 11, but this time adjust the analyzer field as light as possible to investigate the light field isochromatics.
17. Repeat steps 12 thru 14 for the light field.

Fig. 6-1-7: Load Wheel & Analyzer Knob

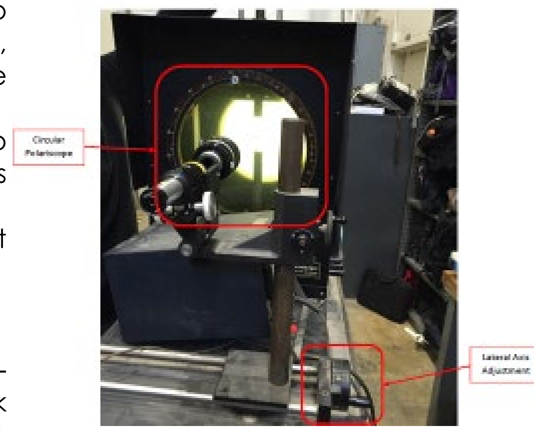


Fig. 6-1-8: TM Positioning Adjustment

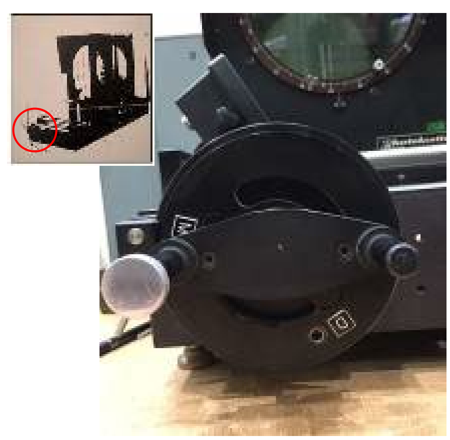


Fig. 6-1-9: Setting Wheel

Background

By definition stress equals force per unit area. Hence, the average stress in the material in the vicinity of the hole is

$$\sigma_{av} = P/[t(w-d)]$$

where
σ = stress
P = applied load
t = member thickness
w = member width
d = hole diameter

The maximum stress in the material is directly proportional to the magnitude of the average stress, i.e.

$$\sigma_{max} = K_t\sigma_{av} = K_tP/[t(w-d)] \qquad (1)$$

where K_t = stress concentration factor

and in terms of the photoelastic constants

$$\sigma_{max} = \sigma_1 = Nf/t \qquad (2)$$

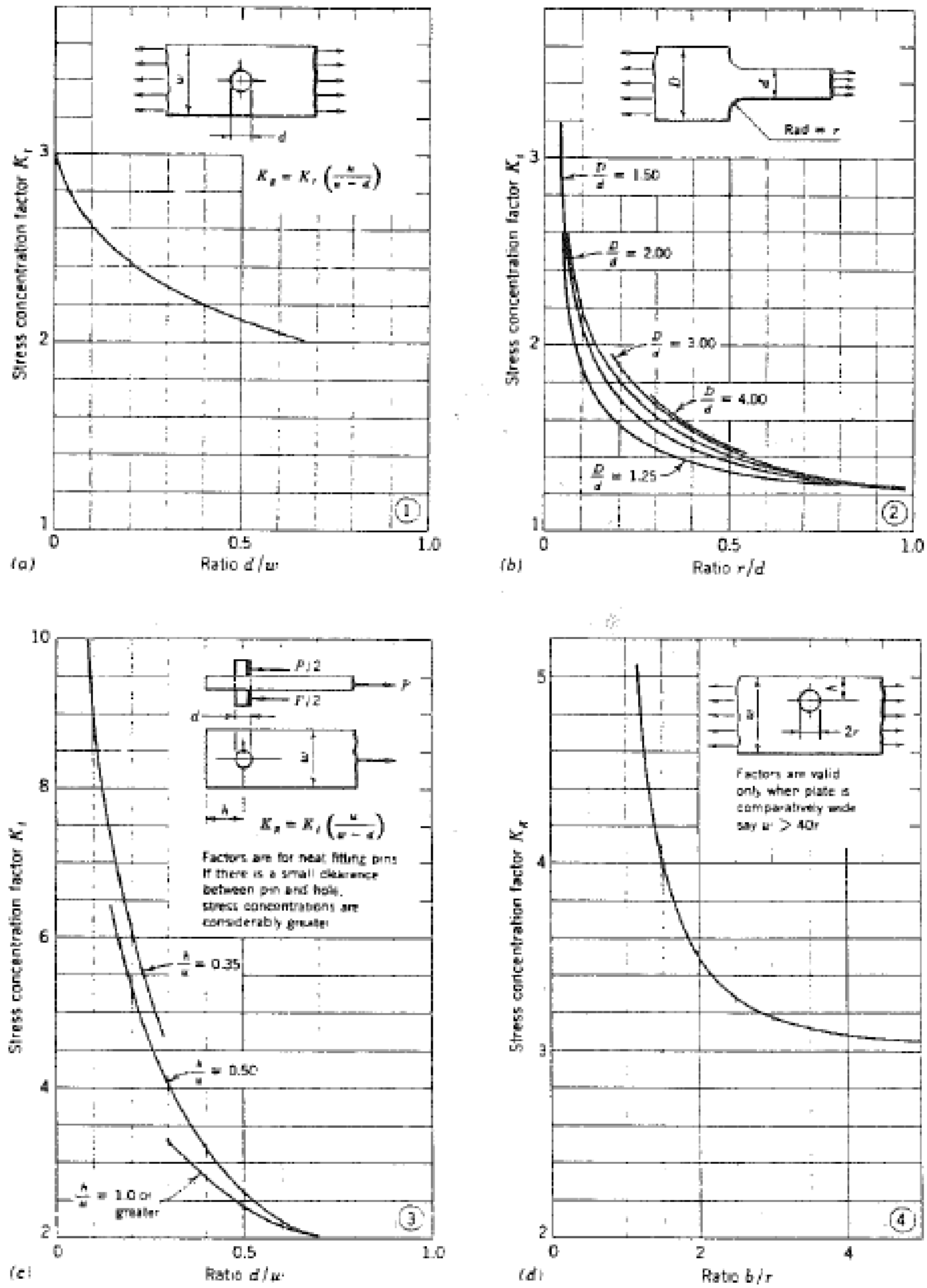
since $\sigma_2 = 0$ for axially loaded members.

Analysis

--- Using equations (1) and (2), develop an expression for the stress concentration factor K_t in terms of the applied load and the photoelastic constants.

--- Using the experimental data, plot **N** vs. **P** and draw the best straight line through the points.

--- Determine the experimental value of K_t and compare the result with the theoretical value obtained from Figure 4.



Stress concentration factors for axial loading of flat bars. FIG. 11-9

Figure 4

(Higdon, et al.,"Mechanics of Materials", Wiley & Sons, 1976)

6-1 Experiment 6-2: Stress Concentration using Photoelasticity

Purpose

In this experiment student teams will deepen their understanding of stress concentration by using the Photoelasticity machine to evaluate other samples.

References:

1. B&J Mechanics of Materials.

Fundamental Principles & Equations

TBD.

5-2-1 Running a Fatigue Test

Select 3 samples from drawer 138 of Cabinet A4 that have the same material as your sample from Experiment 6-1, but different geometry.

Follow the procedure of Experiment 6-1 with each sample to experimentally determine the stress concentration factor.

Estimate the stress concentration factor analytically and compare results.

7-0 TruestructuresTest System

More to come…

7-1 Experiment 7-1: TrueStructures Beam Test

Overview

This experiment uses the Turbine Technologies TrueStructures Strain Analysis System to Test an I-Beam (Exp. 7-1a), a circular section (Exp. 7-1b), or a box beam (Exp. 7-1c).

7-1-1 References

Students may find the following resources helpful in preparing for and completing this lab exercise.

- https://www.me.psu.edu/cimbala/me345/Lectures/Strain_gages.pdf
- http://elektron.pol.lublin.pl/elekp/ap_notes/ni_an078_strain_gauge_meas.pdf
- http://www.turbinetechnologies.com/educational-lab-products/strain-analysis-lab/truestructuresstraincalculator

7-1-2 Test Setup

There are three tests that can be run with this experiment. These will be identified as 7-1A, 7-1B, & 7-1C, as follows:

A. Attach the I-Beam to the fixture.
B. Attach the Circular Section to the fixture.
C. Attach the Box Beam Section to the fixture.

See your instructor for which Lab to perform.

7-1-3 Test Procedure

Follow the procedure shown (*need to expand this section with more detail*).

1. Read Section 7-1-5 carefully, paying special attention to the parts that coincide with the fixture you are using from 7-1-2 above.
2. Perform the test as indicated in 7-1-5, being careful to record the voltages before and after loading.

7-1-4 Data Reduction Comments

Some useful equations are as follows: (*need to expand this section with more detail*).

The strain gagess used are basically 350 ohm resistors.

The excitation voltage (V_{EX}) is 15V or 15,000mV.

Note that the voltage readings (V_0) we will take are in mV.

The strain gage GF value is 2.09.

Use the simplified linear equation below to convert voltage into strains.

$$\varepsilon = \frac{4}{GF} \times \left(\frac{V_0}{V_{EX}}\right)$$

Or the more accurate non-linear equation

$$\frac{V_O}{V_{EX}} = -\frac{GF \bullet \varepsilon}{4}\left(\frac{1}{1 + GF \bullet \frac{\varepsilon}{2}}\right)$$

The strain due to the applied load (ignoring weight of the parts) will be obtained by subtracting the strain using the voltage reading before applying the load from the voltage reading after applying the load. Strains in the compression side are negative while strains in the tension side are positive.

You can verify your strains by using the true structures online calculator from reference 3.

For the rosettes, use the rosette equations first to obtain normal strains in the x and y direction (you may need to derive the equations for the given rosette orientation) as well as the shear strain. Then use biaxial equations (below) to compute stresses in the normal direction. The shear stress is just the shear strain times shear modulus.

7-1-5 Manufacturers Manual

Students may find the following information useful.

Turbine Technologies, LTD

TrueStructures™
Strain Analysis System

Operator's Manual
and
Sample Lab Procedures

TrueStructures™ Strain Analysis System shown with I-Beam, Torsion Tube and Airfoil Test Sections.

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Table of Contents

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Introduction to Strain Data Acquisition and Analysis

In this session (which will include Lesson #1: Introductory Measurement Exercise on Page 6), we will familiarize ourselves with the TrueStructures™ System. The knowledge gained will be the basis for all future analysis opportunities.

The System is comprised of the following components;

Rigid Frame

The frame of the system is a very rigid steel structure which will provide the proper strength to support the experimentation without deflection. It is designed to accommodate a number of basic structural members for analysis. NOTE: **See page 7 for caster adjustment photo if unit is on uneven floor.**

Test Structures

The TrueStructures™ System includes the following structures for analysis:
I-Beam: A very capable basic load supporting structure.
Tube: A very important configuration for structures and drive shafts.
Aircraft Airfoil: An advanced structure building on the basic I-Beam and Tube analysis.

TrueStructures™ Lab Test Sections/Components

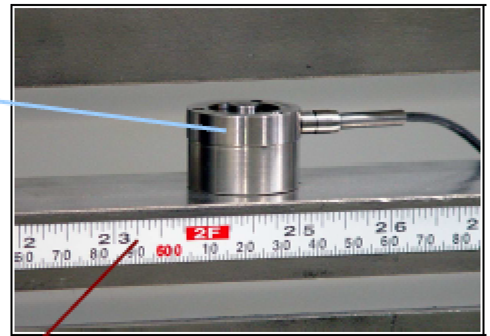
Note: The aircraft airfoil used in this lab is actually half of a horizontal stabilizer from a production aircraft. While the structure is essentially the same as an aircraft wing, the size allows the system to comfortably fit in the test frame and makes it more affordable.

Load Cell Point Load Applicator

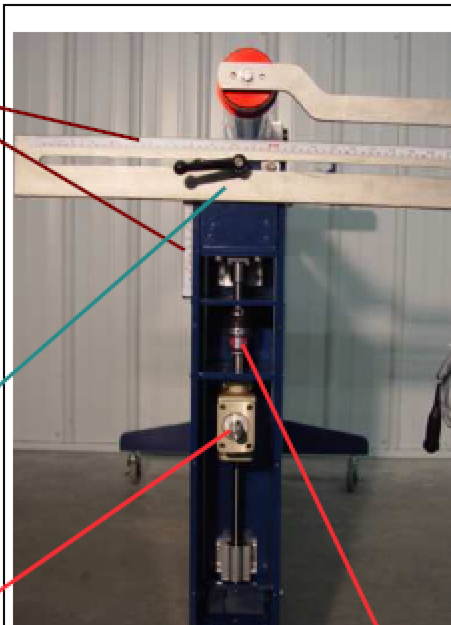
Utilizing a crank mechanism and adjustable position load cell, a force or load can be applied to the structure specimen.

- In regards to the wing structure, the force can be applied anywhere along the end of the wing from the front spar to behind the trailing edge of the wing. This force causes the normally cantilevered position of the wing at rest to take on bending or combination bending and torsional loads that might be encountered in flight, or upon landing.
- In regards to I-Beam and Tube test structures, the point load can be positioned at the centerline of each specimen.

Load Cell
Applies and measures force applied to test specimen. Signal sent to Strain Bridge Controller for display.

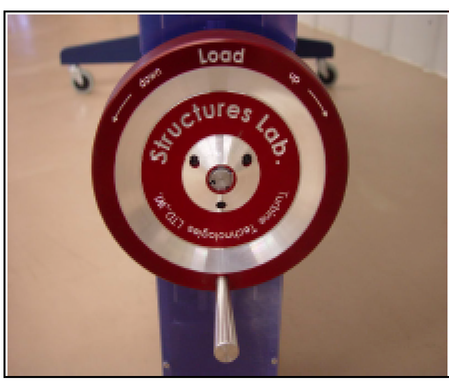


Position Scales
Graduated scales applied to the frame. Indicates position of Load Cell Point Load Applicator along x-axis and deflection of test specimen due to loading along y-axis.



Exposed Right Angle Drive System

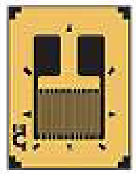
Adjustable Point Load Position Table
Enables load cell to be positioned at an infinite number of positions for variable loading scenarios. Utilizes friction clamp to lock table into desired position.



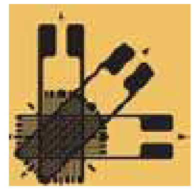
Angle Drive Crank Mechanism-Raises and lowers load cell platform for load application. Includes preset maximum load clutch to prevent system overload.

Strain Gages

Strategically-placed measurement devices used to provide strain data.



Uni-Axial Strain Gage

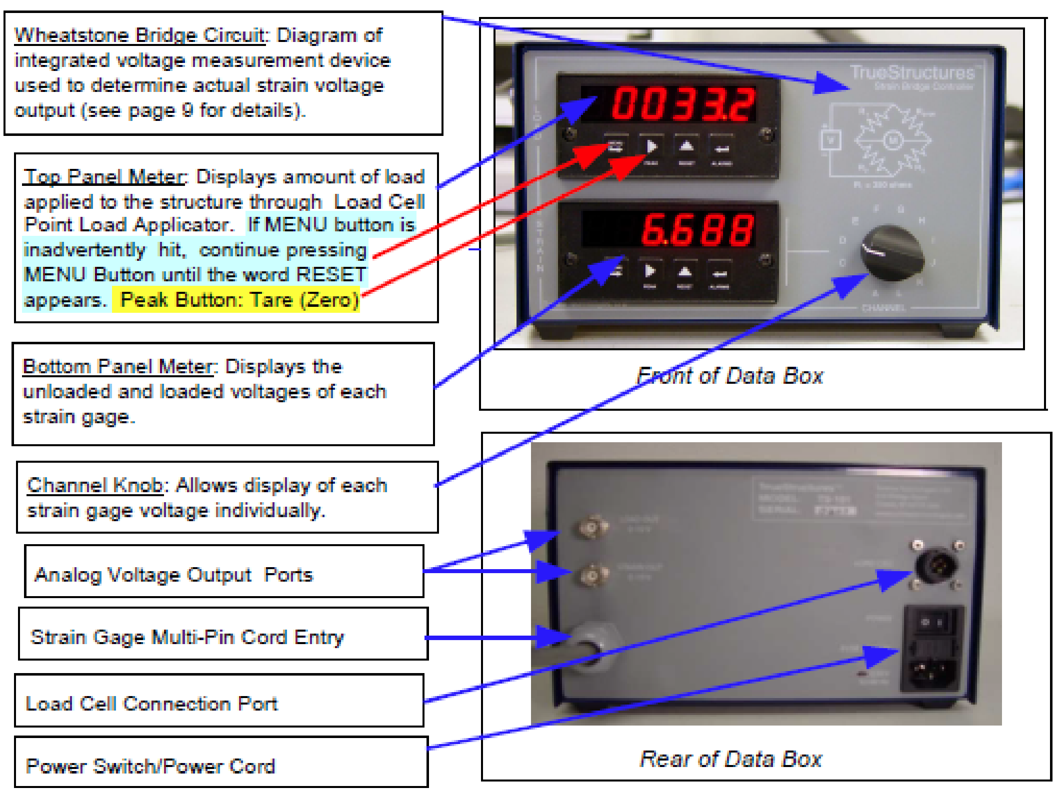


Tri-Axial Strain Gage Rosette

Strain gages are essentially grid shaped metallic wire, foil, or semiconductor materials that are bonded to the surface they are measuring by a carrier matrix and a thin insulating layer of adhesive. When the carrier matrix is strained, the strain is transmitted to the metallic grid through the adhesive, essentially deforming the grid and changing its electrical resistance. Variations in the electrical resistance of the grid are measured as an indication of strain. Each structural element contains two different types of strain gages: uni-axial and tri-axial rosette style (as pictured above). Each lesson will illustrate the structure being tested along with the location, type and identification letter of each individual strain gage.

Strain Bridge Controller ("Data Box")

This handy little box houses a number of functions that allow you to accomplish the task of measuring strain in your structure. Touring the face you will see:

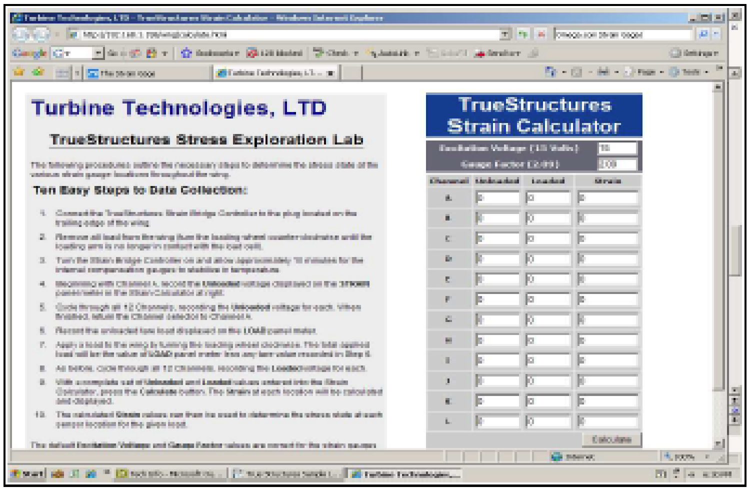


Front of Data Box

Rear of Data Box

Strain Calculator

Allows you to enter the unloaded and loaded voltage values from each strain gage. It automatically calculates the strain value for each channel. **Supplied on disk with manual.**

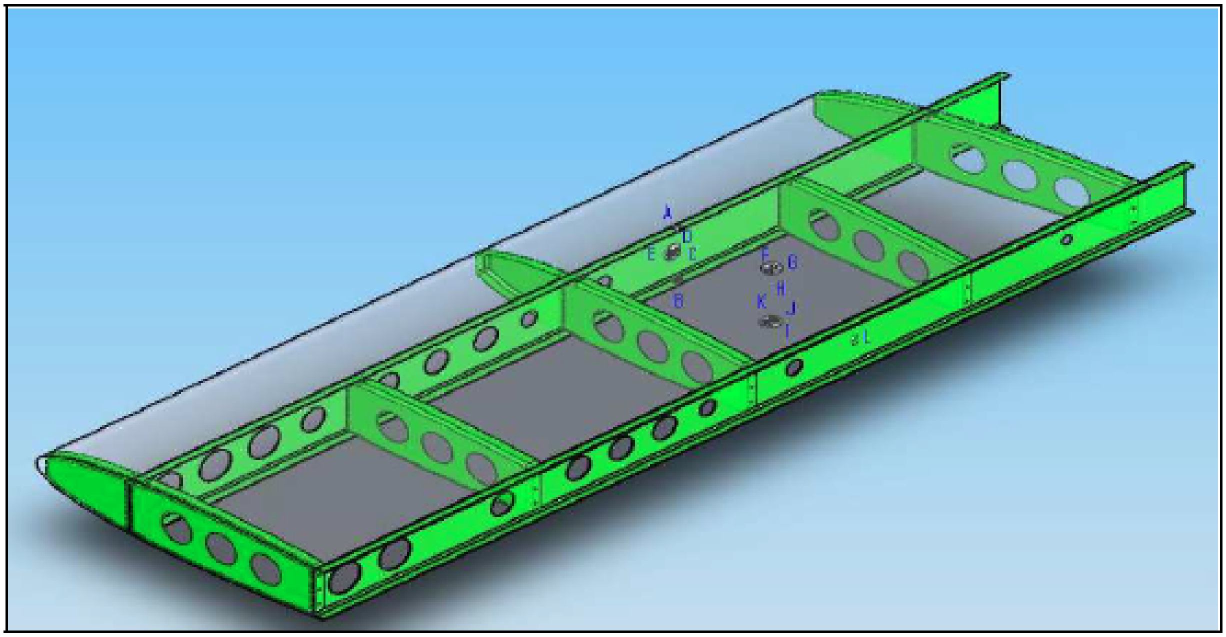


LESSON #1: Introductory Measurement Exercise

For this exercise, we will use the TrueStructures™ Airfoil (Wing) Section. If the wing is not installed, please install it as shown.

Position wing to align spar ends with fixture tangs.

Finger tighten knobs. Lift up on cantilever end of wing to remove any sag in system. Tighten knobs firmly while continuing to lift end of wing. Be sure load cell and and strain gage connections to strain bridge controller (data box).



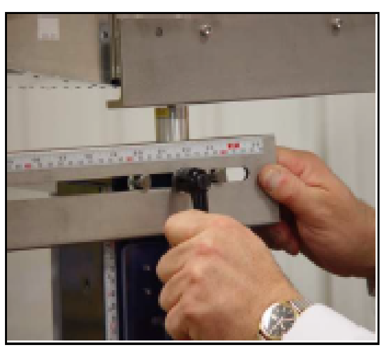
Aircraft Structure and Strain Gage Placements
(Please See Page 26 for location reference.)

Step 1. Turn on the Strain Bridge Controller and let it acclimate (This is Important). You want all internal resistors to stabilize. Allow 10 minutes for warm up.

Step 2. Bring up Strain Calculator on your computer.

NOTE: Because of the weight of the wing test section, there is play in the end of the wing after it is secured on the capture end. Before you start the test, lift up on the free end of the wing to remove any remaining "sag" and then crank up the load cell to the point of application so that it just touches the wing bottom. This will give you a more accurate starting point and deflection amount. Press PEAK button on Load Meter to "Tare" or Zero the meter.

Lift to remove any sag.



Loosen lock to position load cell.

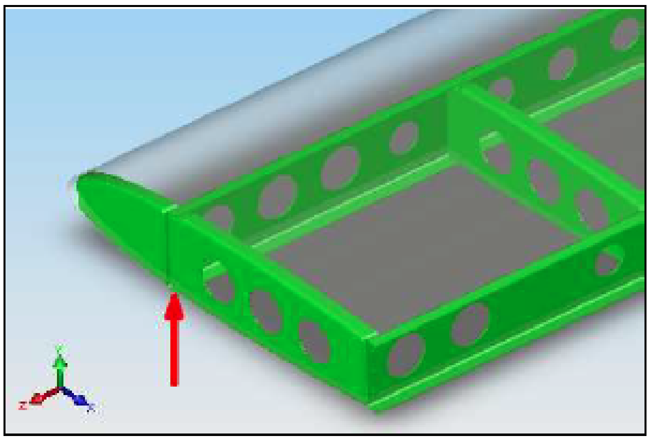
Caster Adjustment.

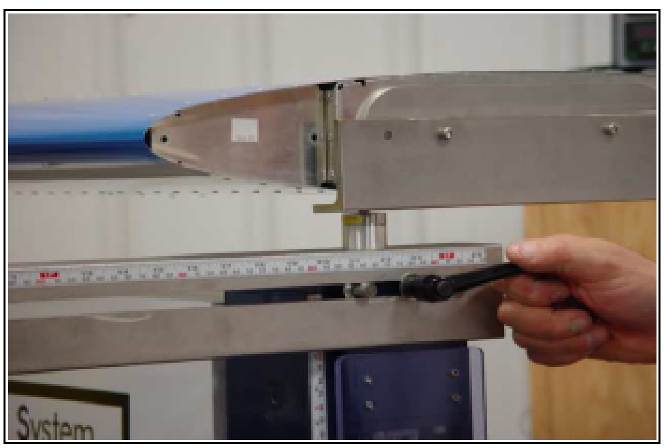
Step 3. After system has stabilized, record the at-rest voltage levels of each strain gage. This is accomplished by turning the channel knob to each strain gage channel (A-L), displaying the value of each channel in the lower panel meter. The location and corresponding letter of each strain gage is labeled in the illustration. Enter these channel values into the corresponding value windows in the Strain Calculator. ***NOTE: If wing sag causes interference with load table during the "at rest " cantilever check, please release load table lock knob and pull load table off.***

Step 4. Now, add a load to the system (replace load table if it was removed in the last step). This is accomplished by loosening the friction lock and sliding the Load Cell Point Load Applicator until it is positioned directly under the point of interest. In this exercise, position it in the middle of the front spar of the wing (see below).

Step 5. Tighten the friction lock.

Step 6. Make note of the value indicated on the load panel meter (top display of controller). Using crank handle, start cranking clockwise to add a load to the wing end-plate structure. For this exercise, add a net 50 pounds (compensating for any initial value on the display).





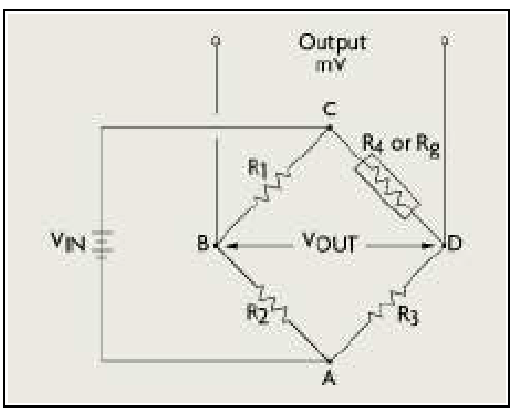
Front Spar Load Application Position

Taking readings from front wing spar loading.

Step 7. Allow the system to settle for a minute. Now record the loaded voltage levels of each strain gage by turning the channel knob to each strain gage channel (A-L) and entering the value of each channel displayed on the strain panel meter into the corresponding value window in the Strain Calculator.

Step 8. Once you have gathered all of the unloaded and loaded channel data, hit CALCULATE at the bottom of your Strain Calculator. All of the strain values for each channel (each strain gage) are calculated for you. Save this data.

Where did these numbers come from?
Let's start with the basics. We mentioned our **Wheatstone Bridge Circuit** earlier when describing the Strain Bridge Controller (Data Box).



Wheatstone Bridge Circuit

A known input voltage feeds four resistors in the system: If all four resistors have the same resistance, the output voltage (Vout) will match the input voltage (Vin) in a balanced circuit.

In our situation, 3 known resistors of 350 Ohms are fixed in the box while the fourth resistor to round out the bridge circuit is the particular strain gage the channel knob has currently selected. The shape of the strain gage (whether at rest or in a compressive or tensile loading condition) causes a certain resistance value, which changes the voltage output of the bridge circuit. As the gage is strained, its resistance changes, changing the output voltage of the circuit.

The change in resistance of the strain gage and resultant unbalanced voltage output of the bridge circuit is the basis for strain measurement data.

$$V_{out} = V_{in} \left[R3/(R3 + Rg) - R2/(R1+R2) \right]$$

Manufacturers of strain gages build in certain characteristics which allow steady, reliable readings from their strain gages. Gage Factor is one of those items. Essentially, the Gage Factor relates the ratio of the change in resistance with respect to initial resistance directly to the Strain Value. This is also known as strain sensitivity.

$$GF = \frac{\Delta Rg / Rg}{\varepsilon}$$

Where ΔRg = strained value of gage resistance

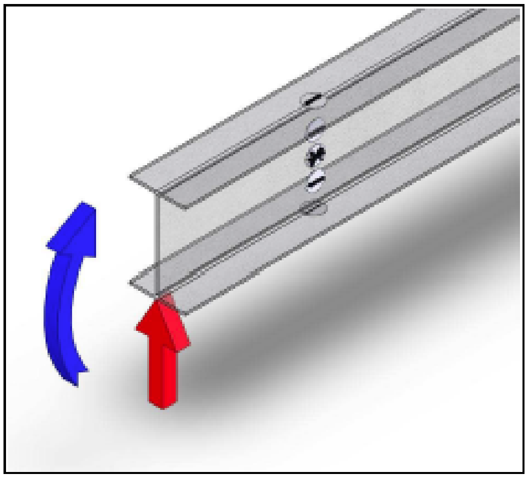
Rg = unstrained value of gage resistance

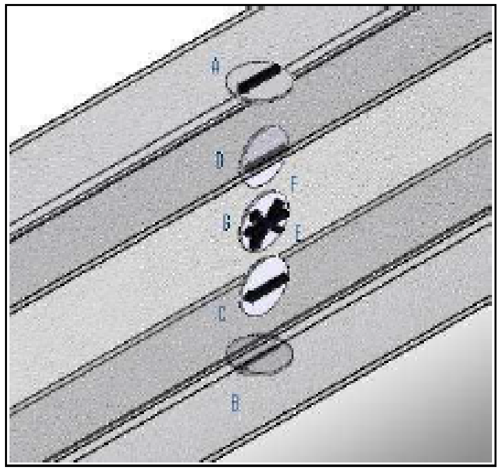
ε = Resulting Strain

The Gage Factor for your systems strain gages is shown on your Strain Calculator.
Now you have a feel for how to gather strain data and where the numbers come from. However, jumping into an analysis of an aircraft wing is sort of like jumping right into your PhD in engineering right out of high school. In the next couple of lab sessions, we'll analyze some basic structures to gain a fundamental understanding of the primary elements of strain on a structure. This will allow you to better understand the analysis of an aircraft wing.

LAB SESSION #2 The I-Beam in Bending

In this session, we will analyze a standard 6061-T6 Aluminum I-Beam using the TrueStructures™ System to place a pure bending load on it.

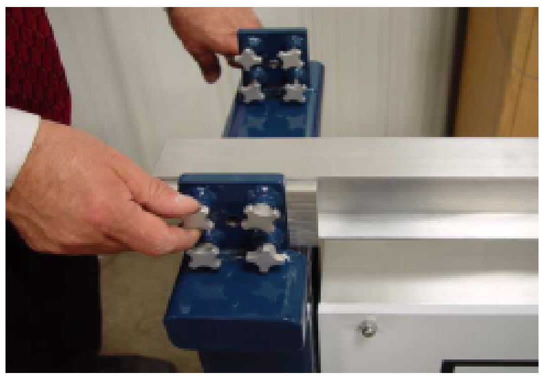




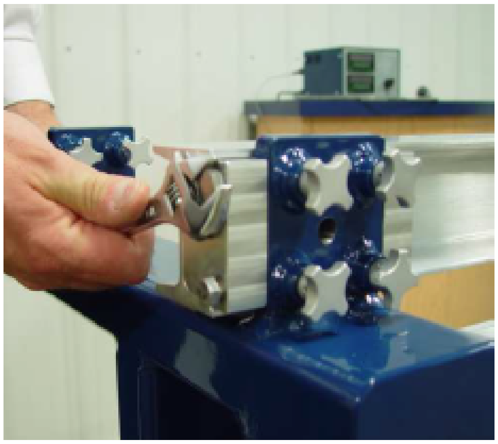
Loading and Strain Gage Placement/Identification

Setup Note: I-Beam should be mounted in the frame and strain gages electrically connected to the Data Box as shown below. If another element such as the Wing or Hollow Circular Shaft is currently in the frame, it should be carefully removed and stored.

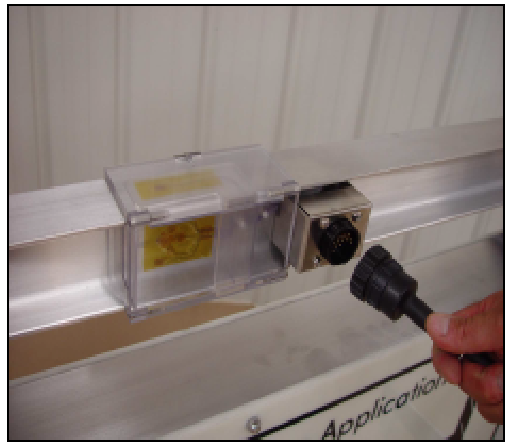
Position I-Beam Assembly Into Frame



Apply and finger tighten connection knobs. Pull up on cantilever end of beam to remove any sag and tighten knobs while pulling up on beam.

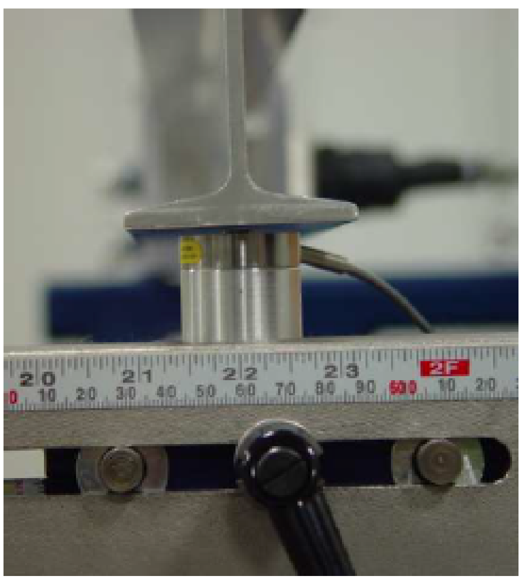


Tighten end bolts for sag-free connection.



Plug in Data Box Multi-Pin Connector

Turn the system on to allow acclimation (allow 10 minutes).



Position load cell under center of I-beam

Step 1. Position the load cell directly under the central vertical axis of the I-beam. Tighten friction clamp.

Step 2. Open up Strain Calculator on your computer. Record the unstrained values of each strain gage.

Step 3. Crank load cell up until it touches the bottom of the beam; note vertical position on deflection scale. Load reading display should read zero. Now crank in 50 lbs of load. Note new vertical position on scale (this is your tip deflection).

Step 4. Read and record the strain values of each strain gage into the Strain Calculator. Hit calculate to give you the strain values. Save your results.

Step 5. Measure the beam cross section and determine its Area Moment of Inertia. Why do we need to know this?

Step 6. Calculate the Section Modulus for the I-Beam (provide just a neutral axis calculation for this step to show your methodology). Why is this important?

Step 7. Determine the Modulus of Elasticity? Why is this important?

Step 8. Draw the Load, Shear and Bending Diagrams for this scenario.

Step 9. Calculate the theoretical normal stresses due to bending at each mid-span uni-axial strain gage location. Where do the highest normal stresses occur: web or flanges?

Step 10. Now, use your answers from Step 9 to calculate the theoretical normal strains at each uni-axial train gage location.

Step 11. Compare actual strain readings to theoretical calculations by plotting those values against the corresponding uni-axial strain gage positions on the I-Beam.

Step 12. Let's now consider our shear stresses due to bending. Calculate the theoretical shear stresses at each mid span uni-axial strain gage location and at the neutral axis of the beam (where is neutral axis and how is it determined?)

Step 13. Plot these values to show a shear distribution on the I-Beam. Where does a majority of the shear stress occur; web or flanges?

Advanced Analysis

Step 14. Using the readings from the rosette strain gages, determine the shear strain at the neutral axis. You will want to use the rosette equations developed for your particular rosette strain gage configuration (rectangular) and then utilize Mohr's Circe to plot the principle strains. How do your measured shear strains compare with the results of the theoretically calculated shear strains?

Extra Analysis

Step 15. Based on the loading, what is the shear flow of this beam cross-section? What is the consequence of shear flow in this particular application?

Lab Session #3 Hollow Shaft (Tube) Analysis

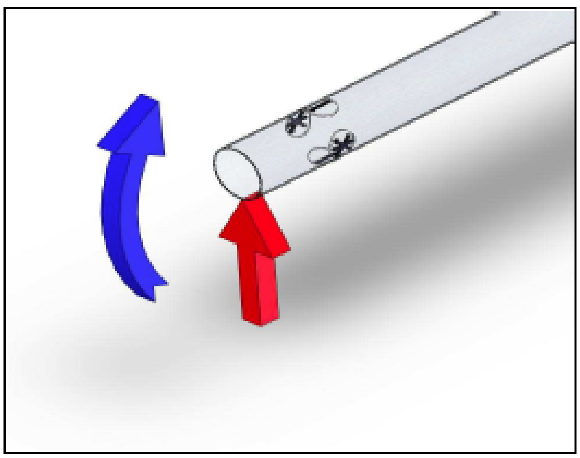
In this session, we will analyze a standard 6061-TL Aluminum tube using the TrueStructures™ System to place it in:

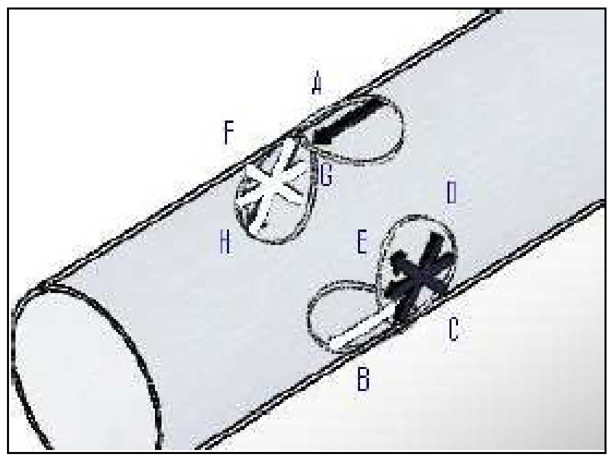
- pure bending
- pure torsion
- combination bending and torsion.

Hollow circular shafts (tubes) are used in static, rigid structures such as tubular bicycle frames and in dynamic, power transfer structures such as drive shafts. A good basic understanding of the load carrying capabilities of a tube will provide insight into more complicated structures such as an aircraft wing.

Exercise A: Pure Bending Analysis

Place the hollow shaft in pure bending.





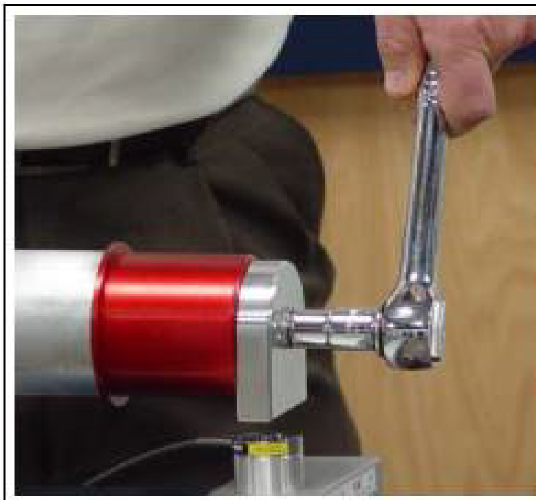
Loading and Strain Gage Placement/Identification

Setup Note: Hollow Shaft should be mounted in the frame and strain gages electrically connected to the data box as shown below. If another element such as the Wing or I-Beam is currently mounted in the frame, it should be carefully removed and stored. Please see the appropriate section of this manual for installation and removal instructions of any particular test section.

Position tube on frame as shown.

Secure block end with capture knobs while pulling up on cantilever end to remove sag.

Insert Cantilever Load Block on red end.



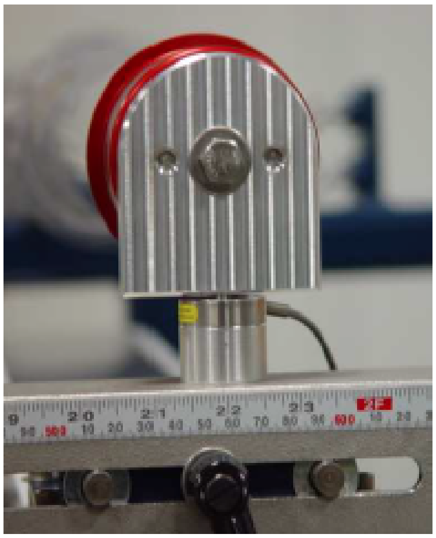
Tighten Load Block with socket wrench.

Turn the system on to allow acclimation (allow 10 minutes).

Step 1. Measure the hollow shaft cross section and determine its Area Moment of Inertia. Why do we need to know this?

Step 2. Determine the Modulus of Elasticity? Why is this important?

Step 3. Calculate the Section Modulus for the the Hollow Shaft. Why is this important?



Position load cell at tube centerline.

Step 4. Position the load cell directly under the central vertical axis of the Hollow Shaft.

Step 5. Open up Strain Calculator on your computer. Record the unstrained values of each strain gage.

Taking readings.

Step 6. Crank load cell up until it touches the bottom of the tube. Note vertical position on scale. Load reading display should read zero. Now crank in 50 lbs of load. Note new vertical position on scale (this is your tip deflection).

Step 7. Read and record the values of each strain gage into the strain calculator. Hit calculate to give you the strain values Save your data.

Step 8. Draw the Load, Shear and Bending Diagrams for this scenario.

Step 9. Calculate the theoretical normal and shear stresses due to bending at each mid-span strain gage location.

Step 10. Now, use your answers from Step 9 to calculate the theoretical normal and shear strains at each strain gage location.

Step 11. Compare actual strain readings to theoretical calculations by plotting those values against the corresponding strain gage positions on the tube.

Advanced Analysis

Step 12. Use Mohr's Circle Analysis to verify the above calculations and to plot the resulting bending and shear strains at each strain gage rosette mounted on the neutral axis of the tube. Verify the corresponding bending and shear stresses from this analysis and compare with the theoretical values calculated. These results will be important as comparison values for future loading of the tube in pure torsion and finally compound bending and torsion of the tube.

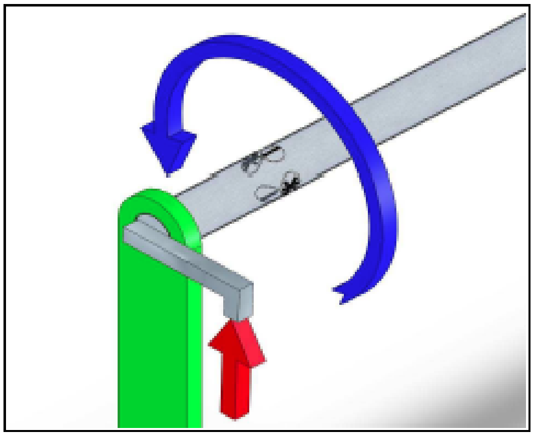
Extra Analysis

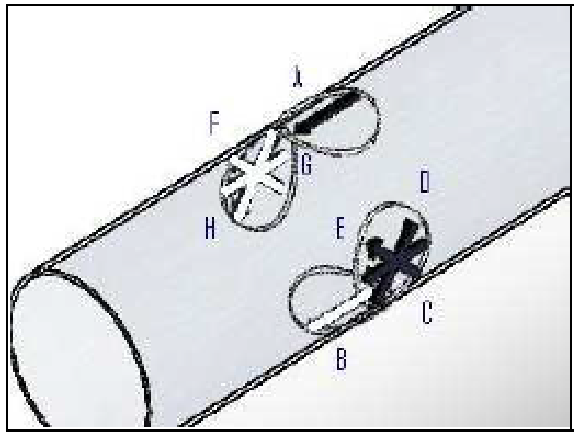
Step 13. Compare the resulting loading, stress, strain of the tube with that of the I-Beam for the applied load. What conclusions can be drawn from the analysis regarding suitability of a Tube verses I-Beam for a cantilever bending situation?

Step 14. Based on the loading, what is the shear flow of this tube cross-section? What is the consequence of shear flow in this particular application?

Exercise B: Pure Torsional Analysis

This exercise will apply pure torsional loading to a typical circular drive shaft which is restrained from bending on both ends. We are concerned with Shear Stress and Shear Strain in torsion with this type of shaft configuration.

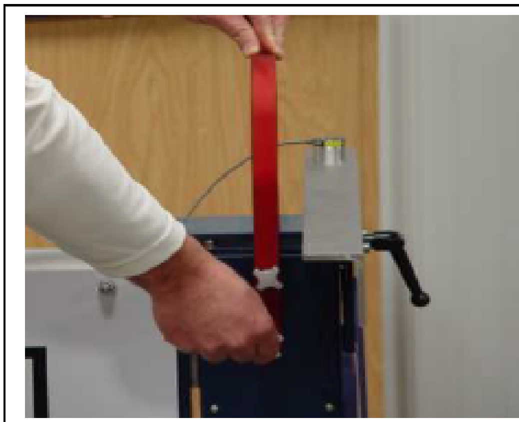




Loading and Strain Gage Placement/Identification

Setup Note: Hollow Shaft with Torsion Yoke End will be mounted in the frame and strain gages electrically connected to the Data Box. If the Wing or I-Beam is currently mounted in the frame, it should be carefully removed and stored. If you still have the tube mounted in the structure in the cantilever position with the load block on the end from the previous exercise, remove the load block, then remove the tube from the frame, reversing the process shown in the previous exercise (Exercise A). Then follow the new instructions below:

Position Yoke on Crank End (note correct face out as marked)



Align with frame holes and loosely secure with capture knobs (do not tighten yet).

NOTE: Turn the system on to allow acclimation if it has been off (allow 10 minutes).

Slide red end of tube into yoke. Push in fully.

Tighten block end knobs fully. Then tighten red yoke knobs securely.

Position guide pins and slide on Torque Arm

Tighten Torgue Arm Bolt securely with socket wrench.

Position Load Cell to desired moment arm dimension from tube centerline (Step 2).

Crank in load and take readings on each channel (Steps 3, 4, 5) .

Step 1. Measure the hollow shaft cross section and determine its Polar Moment of Inertia. What is Polar Moment of Inertia and why do we need to know this?

Step 2. Position load cell directly under the torsional loading arm axis of the Hollow Shaft as shown. Measure and record the moment arm from center of Hollow Shaft to load cell application point.

Step 3. Open up Strain Calculator on your computer. Record the unstrained values of each strain gage.

Step 4. Crank load cell up until it touches the bottom of the torsional loading arm; note vertical position on scale. Load reading display should read zero. Now crank in 50 lbs of load.

Step 5. Read and record the values of each strain gage into the strain calculator. Hit calculate to give you the strain values. Our main focus for this exercise will be the strain gage rosette.

Step 6. Sketch the loading diagrams for this scenario.

Step 7. Determine the Shear Modulus of Elasticity? Why is this important?

Step 8. Calculate the Maximum Torsional Shear Stress experienced by the shaft under this loading. Why is this important?

Step 9: Let's analyze the shear strain of our hollow shaft using Mohr's Circle as it applies to our rosette strain gage. The analysis is based on the clock-wise orientation of the rosette as positioned along the straight outer skin line. We use a rosette to compute the state of strain at that particular point. The resulting Mohr's Circle plot gives the value and orientation of the principle strains. The uni-axial strain gages react only to the shear stress in this configuration (as there is no bending). It will be important to compare the differences in the uni-axial strain gage readings with our next configuration (combination loading).

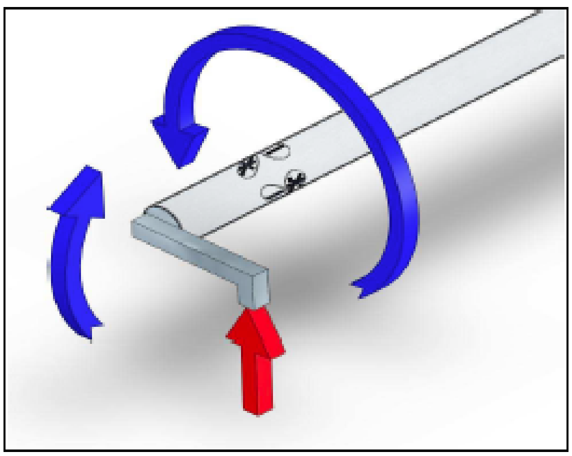
Additional Analysis

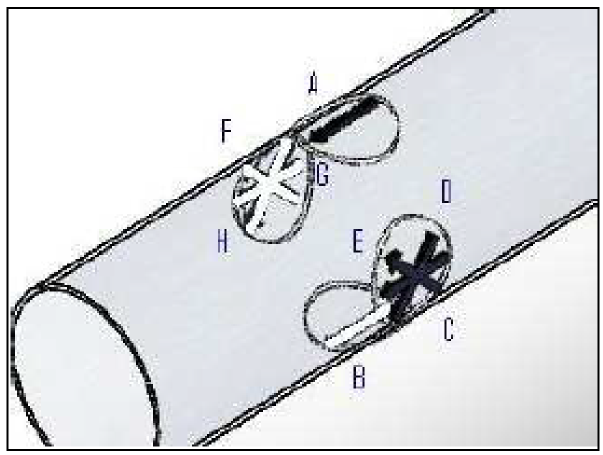
Step 10. Let's calculate the torsional deflection (twist) of the shaft between the strain gage location and applied torque position for the loading shown.

Step 11. Shear Stresses due to torsion on a closed element such as a hollow shaft or tube act around its cross-sectional perimeter. This is known as the Shear Flow for this configuration. Calculate the Shear Flow for the tube with current loading.

Exercise C: Combination Loading: Bending and Torsion

For this exercise, we will remove the torsional end Yoke from the pure torsion configuration to return the hollow circular shaft (tube) to a cantilever configuration. We will load the tube in torsion, as in Lesson B. However, as you will see, the tube will now absorb combination bending and torsion, a more demanding load configuration. This cantilever configuration will be compared with the previously restrained configuration to show the differences in these two scenarios.





Loading and Strain Gage Placement/Identification

Setup Note: Tube should be mounted in the frame and strain gages electrically connected to the data box according to the Operators Manual. If another element such as the Wing or I-Beam is currently mounted in the frame, it should be carefully removed and stored.

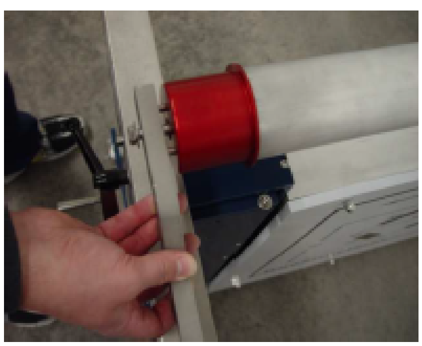
Important: Please be sure torsional end Yoke is removed from load end of tube before starting this analysis. Please follow these removal instructions:

Loosen Torque Arm with socket wrench and remove.

Loosen capture knobs on capture block end and slide tube out of yoke.

Loosen capture knobs, remove yoke.

Position tube in cantilever position, tighten hand knobs while pulling up on tube end..



Insert Torque Arm into Tube End.

Tighten Arm with Socket Wrench, then position Load Cell.

Turn the system on to allow acclimation if it has been off.

Step 1. Record the Polar and Area Moments of Inertia for the tube cross-section. Why do we need both of these?

Step 2. Position the load cell directly under the torsional loading arm axis of the Tube as shown. Measure the moment arm from center of Tube to load cell application point (use the same value as the previous exercise).

Step 3. Open up Strain Calculator on your computer. Record the unstrained values of each strain gage.

Step 4. Crank load cell up until it touches the bottom of the torsional loading arm; note vertical scale position Load reading display should read zero. Now crank in 50 lbs of load. ***Note:* *If there is some sag in the test section, pull up on red end of tube to remove the sag. While holding the tube in this spot, position the load cell so it just touches the bottom of the torque arm. Start your test from this position.***

Step 5. Read and record the values of each strain gage into the strain calculator. Hit calculate to give you the strain values. Unlike pure torsion, where our main focus was the strain gage rosettes, we will be very interested in all gages because of the added bending due to cantilever state of the hollow shaft

Step 7. Determine the Bending and Shear Modulus of Elasticity? Why do we need both?

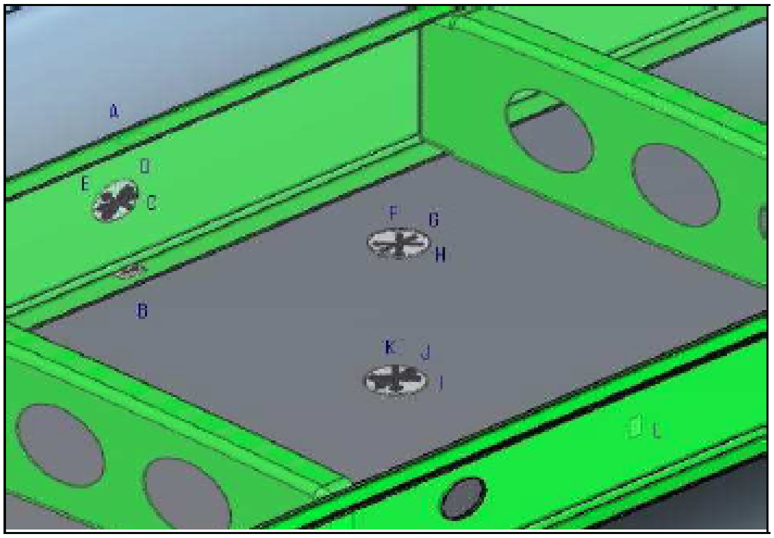
Step 8. Sketch the loading diagrams for this scenario.

Step 9. Calculate the maximum bending and shear stresses for this loading.

Step 10: Let's start by analyzing the new bending and shear stresses and strains of our tube using Mohr's Circle as it applies to our rosette strain gages. Compare your results with the restrained tube in Exercise B. Bending and shear stress now play a role due to the tube being unrestrained at the cantilevered end.

Step 11: Compare the readings of the axial (top and bottom) strain gages of this test verses to the pure torsional test. Based on just this data, what basic conclusion(s) can be drawn between a tube in pure torsion (restrained on both ends) verses a tube subjected to combination torsion and bending (cantilever configuration).

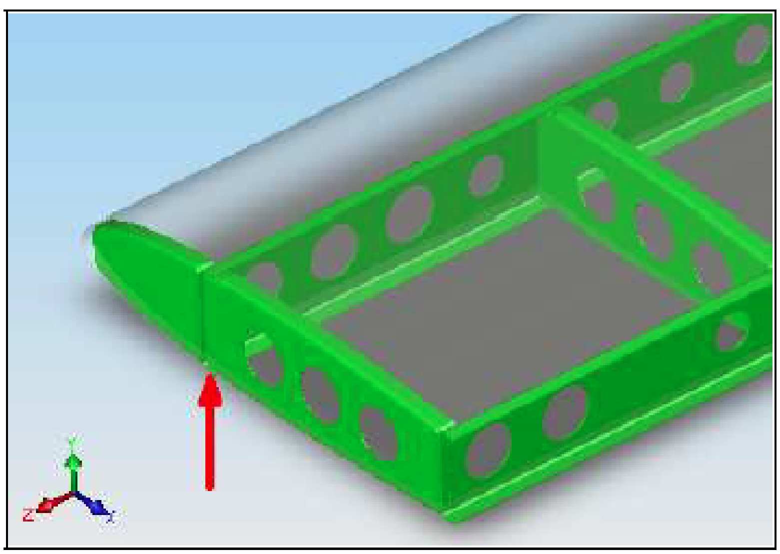
LAB SESSION #4: Wing Strain Analysis



Strain Gage Placement in Wing (**See Page 25 for reference location)**

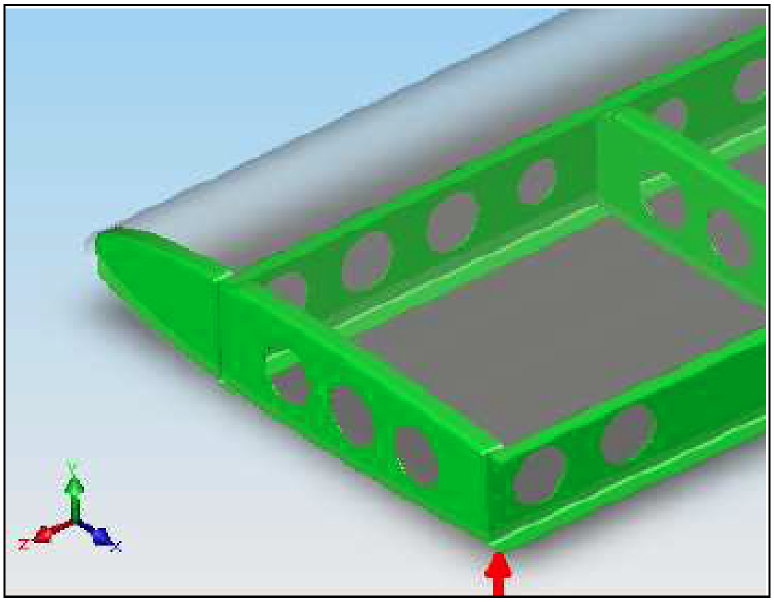
Now that we have some good experience with the TrueStructures™ System, it's time to tackle the wing structure. Using the knowledge gained analyzing the I-Beam and Tube, you can now see that the wing structure is an advanced combination of beams (spars and ribs) and tube (wing skin).

Step 1. Go back to **Lesson #1** and follow the steps outlined in the **Introductory Measurement Exercise**. The load will be 50 lb applied at the centerline of the wing's front spar. Record all the strain data from each channel and save it.



Front Spar Load Position

Step 2. Remove the load from the front spar and apply it to the rear spar centerline, following the same data recording steps.



Rear Spar Load Position

Step 3: Based on the two loading scenarios, compare how the spars and skin are stressed and strained. Use the previous I-Beam and Tube analysis exercises to simplify the basic elements that need to be examined in the wing. State your assumptions and methodology.

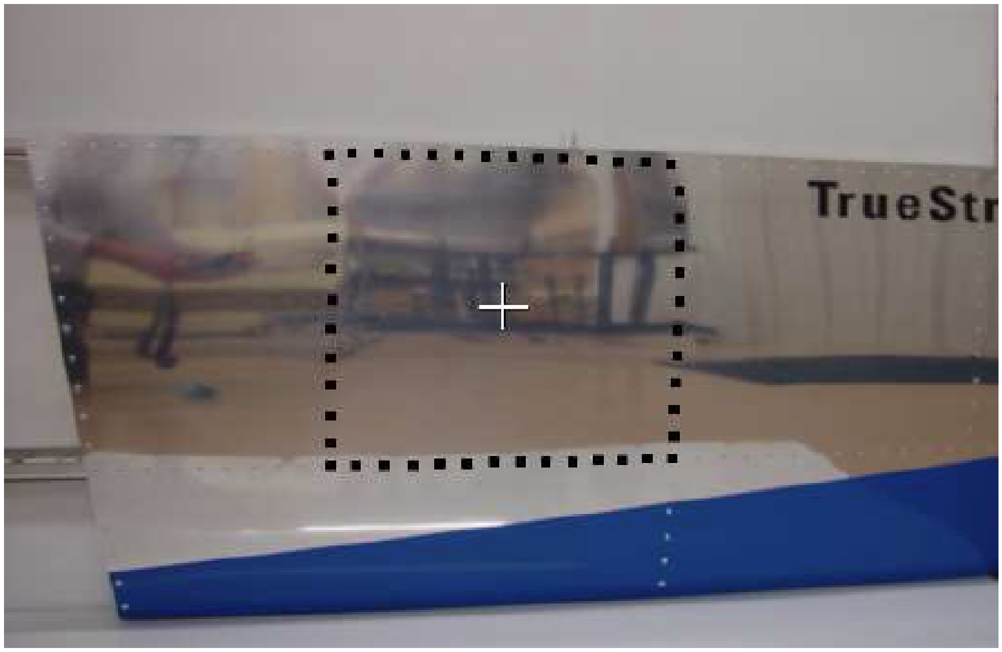
Step 4. For each strain rosette location, use Mohr's Circle to determine the states of stress and strain for each loading scenario (front spar, top and bottom wing skins). Focusing on the front spar rosette results, how do the stress and strain results compare with the corresponding calculations from Step 3?

Additional Analysis

Step 5. If our wing had a landing gear that transferred 50 lb of load upon touchdown the runway, which spar would be better suited to mount the gear to, from a load distribution point of view. Why?

Step 6. With the load positioned at the rear spar, calculate the shear stress and consequent shear flow at: Wing Tip and Strain Gage Placements.

Step 7. With the load positioned at the front spar, calculate the shear flow between spar and skin. What would be the minimum rivet spacing required to maintain this structure at this load with no factor of safety?



Strain Gages are located in the first full bay from spar roots as shown. The two Rosette Strain Gages are located in the center of the bay as indicated by the white hash mark in the photo. An axis indicator is labeled on the back spar for reference (see below)

Rear Spar has an indicated axis line for strain gages location. All strain gages are located on this axis.

8-0 Amatrol Test Multi-Station

Amatrol Multi-Stations

The Amatrol Multi-Stations use a small hydraulic cylinder to enable tension, compression, shear, and bending testing. These stations will be used by all students.

Experiment 8-1: Amatrol Tension Test

In this experiment student teams will test 3 tension samples to failure. This is intended to reinforce student understanding of force-deformation & stress-strain relations, modulus calculations, and test methods, measurements, and procedures for simple members in tension. It is also intended to illustrate the benefits of testing for material characterization, as well as the difficulties associated with obtaining accurate and meaningful test data.

Reading

Review your Mechanics of Materials Text.

Essential Apparatus

1. Amatrol's T9014 Materials Engineering Trainer (Figure 8-1-1)

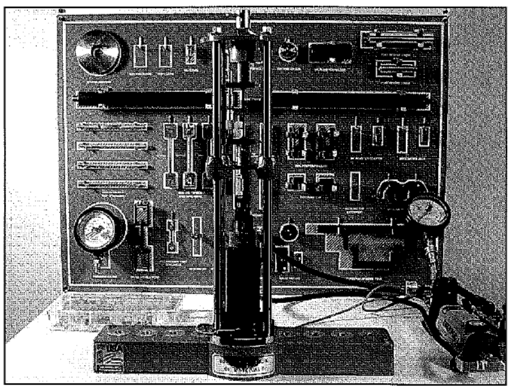


Fig. 8-1-1: Amatrol T9014 Setup

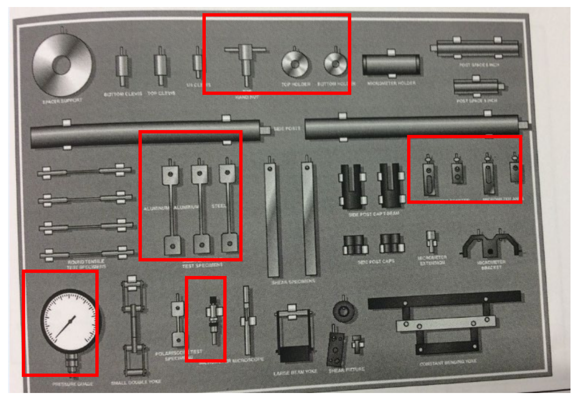


Fig. 8-1-2: Equipment Needed

2. Test components from T9014 Back Panel (Figure 8-1-2)
3. Steel & aluminum dogbone samples from T9014 Back Panel (Figure 8-1-2)
4. Calipers (From Toolbox)
5. Micrometer (From Toolbox)

Materials & Specimens

1. Steel Dogbone Sample
2. Aluminum Dogbone Sample

General Note

This experiment is very important. It will be difficult to recall all aspects of the test later. It will also be difficult to get accurate results. Take the following steps as you go to maximize your result.

- Make sketches or take photos during all stages of testing for your report.
- Duplicate as many actions & measurements as you can. Strive to have at least two students separately make each measurement, reading, or observation. Strive to have two separate students record the same data for the team as the test progresses. Compare readings & results at each convenient point, and discuss/rectify differences.
- You will record data during this test, and your raw data sheet must be a part of your report. Prepare your datasheet accordingly, and record all data neatly. Do not erase, but strikeout any errors and continue recording data.

- Procedure

1. Locate your Amatrol T9014 Station. It should look roughly as shown in Figure 8-1-1. If the spider assembly is not installed, install it now.
2. Locate the bottom clevis on the storage panel & install it as shown in Figure 8-1-3.

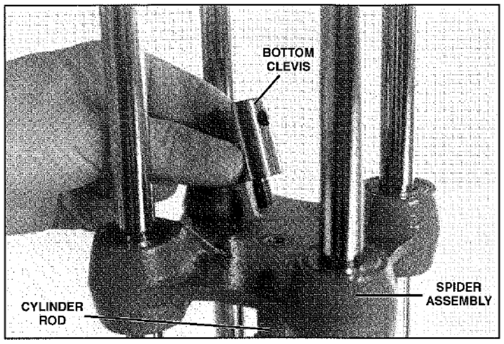


Fig. 8-1-3: Bottom Clevis Installation

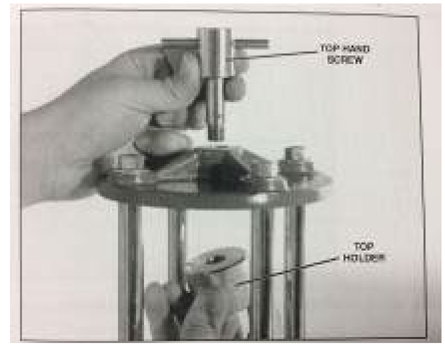


Fig. 8-1-4: Top Screw & Holder

3. Locate the top hand screw & holder on the storage panel & install them as shown in Figure 8-1-4.
4. Locate the **steel dogbone sample** on the storage panel, which should look similar to Figure 8-1-5.

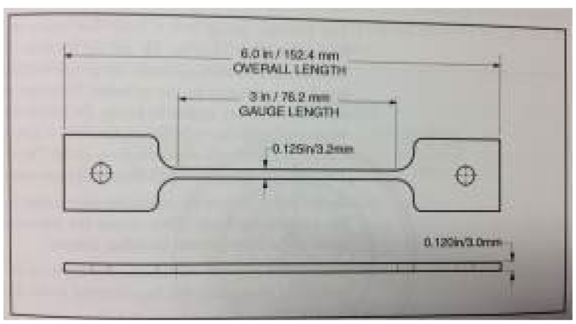


Fig. 8-1-5: Dogbone Sample

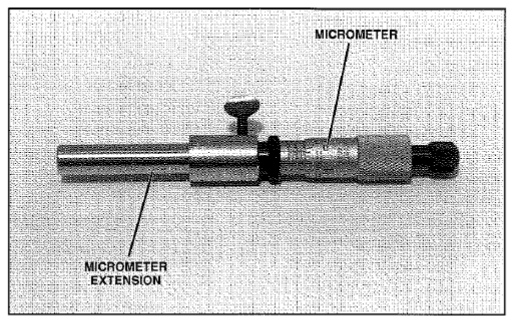


Fig. 8-1-6: Micrometer & Extension

5. Sketch & photograph your sample for your report. Then measure the sample completely with calipers & micrometer, striving for four decimal place accuracy for the cross sectional dimensions in the gage region.
6. Locate the micrometer & micrometer extension on the storage panel & assemble them as shown in Figure 8-1-6.
7. Adjust the micrometer until it reads zero.
8. Locate the rectangular micrometer adaptor on the storage panel & use it to attach the micrometer to the test specimen as shown in Figure 8-1-7.

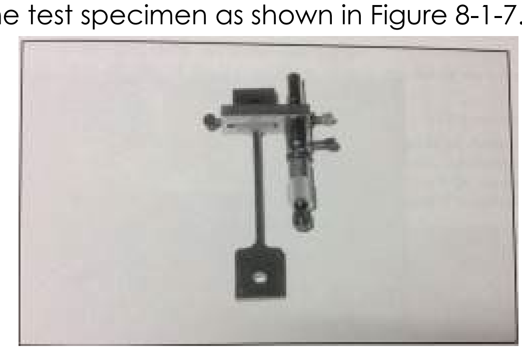


Fig. 8-1-7: Micrometer, Adaptor & Specimen

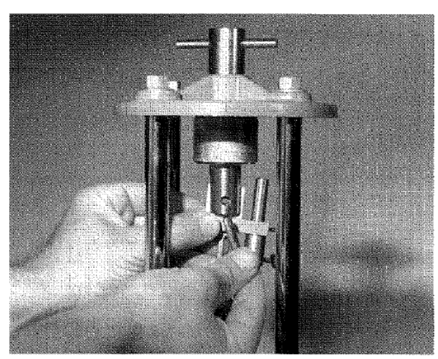


Fig. 8-1-8: Micrometer, Adaptor & Specimen

9. Attach the specimen, adaptor & micrometer to the upper test fixture using a dowel pin (not a compression sample) from the clear storage case as shown in Figure 8-1-8.

10. Once the sample is attached, loosen the thumbscrew & adjust the position of the micrometer adaptor so that it is flush & firmly pressed against the top clevis. This will maximize initial straightness of the micrometer & will result in more accurate measurements.
11. Locate the rectangular micrometer anvil on the storage panel & mount it to the bottom of the sample as shown in Figure 8-1-9.

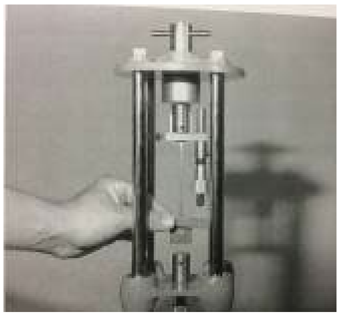


Fig. 8-1-9: Specimen Lower Attachment

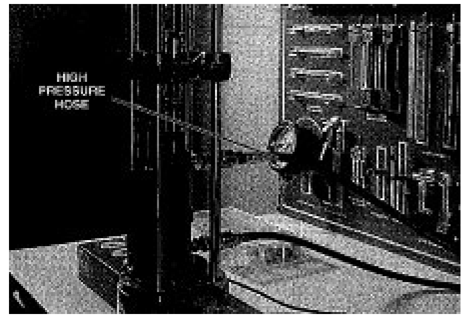


Fig. 8-1-10: Pressure Hose Connections

12. Locate the hydraulic pump, and attach its pressure lines to the test fixture, making sure that the high pressure line is attached to the upper connector on the test fixture, and the low pressure line onto the lower connector, as shown in Figure 8-1-10.

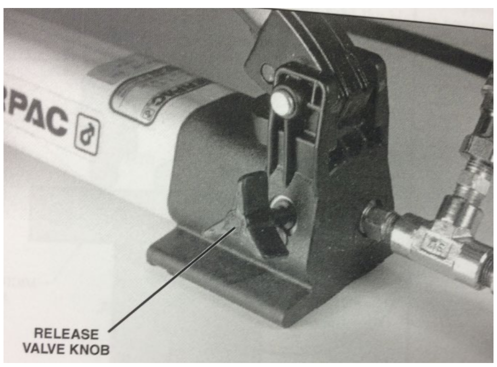


Fig. 8-1-11: Pressure Release Knob

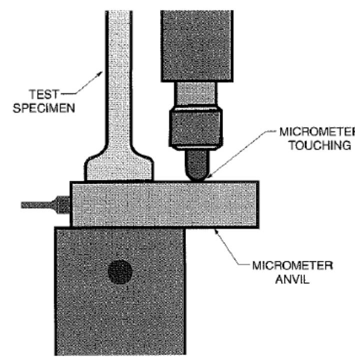


Fig. 8-1-12: Micrometer Adjustment

13. Find the release knob on the pump (see Fig. 8-1-11), & rotate it counterclockwise to release pressure from the system.
14. Once the pressure is released, carefully move the spider assembly by hand so that you can insert the clevis pin through the bottom hole of the sample as shown in Figure 8-1-9.
15. Adjust the position of the rectangular micrometer anvil so that it is flush and snug against the bottom clevis as done with the top clevis previously.
16. Loosen its thumbscrew on the micrometer adaptor, and slide the micrometer down until its measuring indicator is touching the micrometer anvil as shown in Figure 8-1-12, then carefully tighten in place.
17. Locate & mount the pressure indicator that shows a range from 0-10,000 psi (See Figure 8-1-13).
18. **Make sure all students on your team and nearby are wearing safety goggles**. [Anyone not wearing them, or testing without adequately warning nearby non-wearers will fail this experiment.]
19. Rotate the release valve on the pump clockwise until it is tight so that the pump can build pressure.
20. Make sure the knob on the pressure gage is resting on zero psi as shown in Figure 8-1-13.

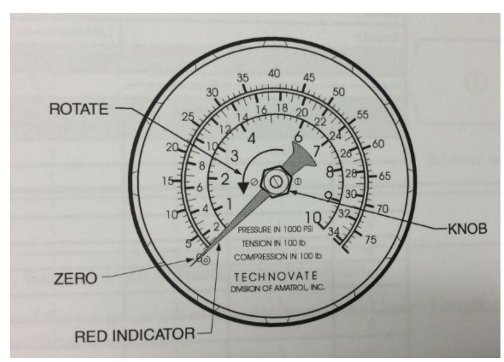


Fig. 8-1-13: Pressure Gage

21. Study the gage, and be sure you understand the increments for pressure and force so you can read it correctly.
22. Prepare your lab sheet to record pump pressure, force, and the micrometer reading. The table should be neat and data carefully recorded and this original sheet should be included in your later lab report, along with a "pretty" electronic version of the same.
23. Record the first set of readings for pressure, force and micrometer reading at zero pressure.
24. Slowly pump the handle on the hydraulic pump until the pressure is approximately 200 psi. Immediately read and record pressure and force, then read the micrometer and record its measurement.
25. Notice that the pressure may have decayed as the sample stretches, causing the black dial on the pressure gage to drop from the maximum value shown by the red needle. Rotate the red dial on the pressure gage down until it rides on the black arm of the gage, then continue testing.
26. Increment pressure another 200 psi or so, and make another set of measurements following steps 24 & 25.
27. Continue step 26 until failure of sample.
28. After failure, rotate the pressure release knob counterclockwise to release pressure. Then move the spider up until the sample is "connected" and make the best "final" measurement with the micrometer you can.
29. Remove the sample from the fixture. Examine it, and sketch and/or photograph it for your report.
30. **Repeat the entire procedure for the aluminum dogbone sample** obtained from the storage panel.
31. **Repeat the entire procedure for the third sample provided.**

Analysis & Report

- Prepare a lab report of your test per report guidelines.
- Develop a table for each sample that includes all measurements and computations, including the following:
  - Load increment
  - Pressure reading
  - Force reading
  - Calculated Force (a duplicate column of force that is calculated from the pressure, micrometer reading)
  - Total gage length (3" assumed initial plus your micrometer reading at each increment)
  - Stress (computed)
  - Strain (computed)
  - Modulus (computed)
- Plot load vs deflection & stress vs strain. Indicate the yield point and the maximum strength of the material on the curve. Comment on findings.
- Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
- Include your original data sheet in an appendix.
- **Save your failed samples. You will use these again in a later experiment**.

Experiment 8-2: Short Compression Test

In this experiment student teams will test 3 compression samples to failure. This is intended to reinforce student understanding of force-deformation & stress-strain relations, modulus calculations, and test methods, measurements, and procedures for simple members in compression. It is also intended to illustrate the benefits of testing for material characterization, as well as the difficulties associated with obtaining accurate and meaningful test data.

Reading

Review your Mechanics of Materials Text.

Essential Apparatus

1. Amatrol's T9014 Materials Engineering Trainer (Figure 8-2-1)

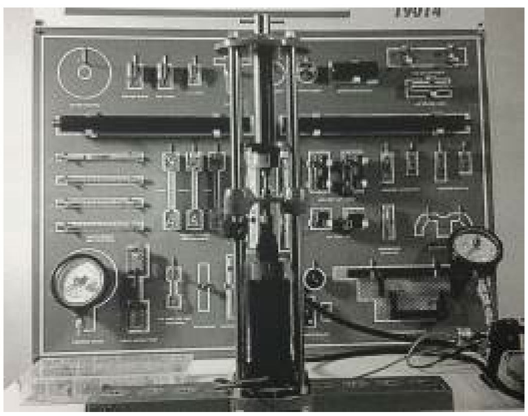


Fig. 8-2-1: Amatrol T9014 Setup

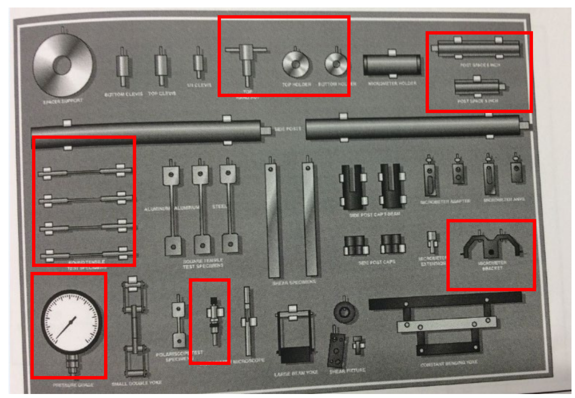


Fig. 8-2-2: Equipment Needed

2. Test components from T9014 Back Panel (Figure 8-2-2)
3. Steel & aluminum compression samples from T9014 Clear Parts Tray (Figure 8-2-1)
4. Calipers (From Toolbox)
5. Micrometer (From Toolbox)

Materials & Specimens

3. Steel compression Sample
4. Aluminum compression Sample

General Note

This experiment is very important. It will be difficult to recall all aspects of the test later. It will also be difficult to get accurate results. Take the following steps as you go to maximize your result.

- Make sketches or take photos during all stages of testing for your report.
- Duplicate as many actions & measurements as you can. Strive to have at least two students separately make each measurement, reading, or observation. Strive to have two separate students record the same data for the team as the test progresses. Compare readings & results at each convenient point, and discuss/rectify differences.
- You will record data during this test, and your raw data sheet must be a part of your report. Prepare your datasheet accordingly, and record all data neatly. Do not erase, but strikeout any errors and continue recording data.

- Procedure

32. Locate your Amatrol T9014 Station. It should look roughly as shown in Figure 10-1. If the spider assembly is not installed, install it now.
33. Locate the bottom compression adapter in the clear storage tray & screw it into the bottom cylinder rod as shown in Figure 8-2-3.

Fig. 8-2-3: Bottom Adapter Installation

Fig. 8-2-4: Top Adapter Installation

34. Locate the top compression adaptor in the storage tray & the top holder on the storage panel & install them as shown in Figure 8-2-4.
35. Locate and attach the 6" post spacer on the storage panel and attach it as shown in Figure 10-5.
36. Locate the top hand screw & circular compression brace on the storage panel & install them as shown in Figure 8-2-6.

Fig. 8-2-5:Post Spacer Attachment

Fig. 8-2-6: Top Hand Screw & Compression

37. Place the post spacer assembly thru the compression brace hole & install it as shown in Figure 8-2-7. Use a large washer from the storage tray if needed to hold the compression brace in place.

Fig. 8-2-7:Post Spacer Installation

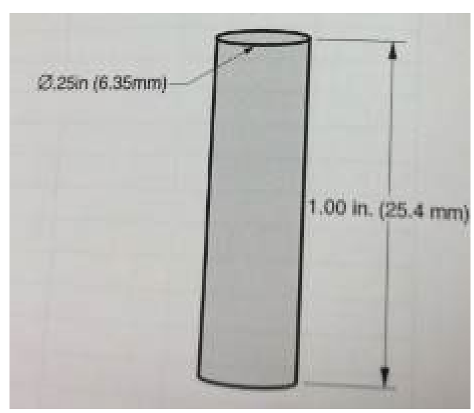


Fig. 8-2-8: Compression Sample

38. Locate a **6061-T6 aluminum compression sample** (not a dowel pin) in the clear storage tray. It should look similar to Figure 8-2-8.

39. Sketch & photograph your sample for your report. Then measure the sample completely with calipers & micrometer, striving for four decimal place accuracy for the cross sectional dimensions and length.
40. Locate the hydraulic hand pump, and attach its pressure lines to the test fixture, making sure that the high pressure line is attached to the lower connector on the test fixture, and the low pressure line onto the upper connector, as shown in Figure 8-2-9.

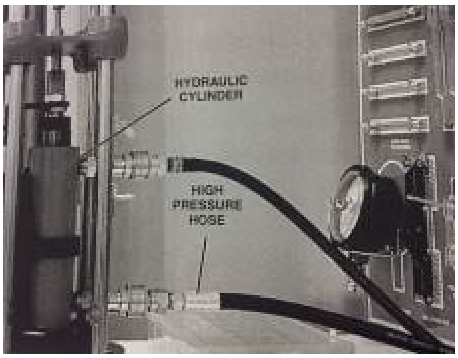


Fig. 8-2-9: Hydraulic Line Configuration

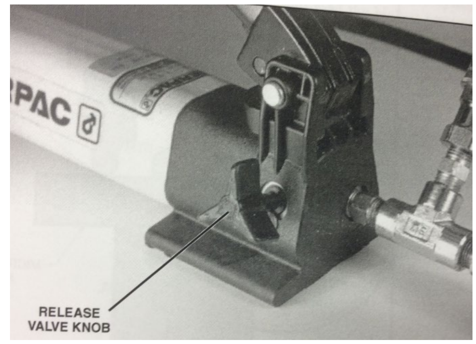


Fig. 8-2-10: Pressure Release Knob

41. Find the release knob on the pump (see Fig. 10-10), & rotate it counterclockwise to release pressure from the system.
42. Place the compression sample on the bottom compression adapter as shown in Figure 8-2-11.

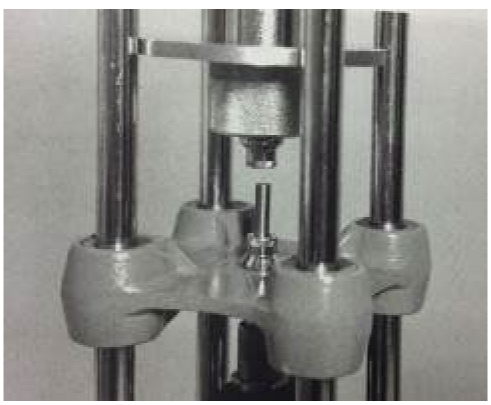


Fig. 8-2-11: Compression Sample Lower Placement

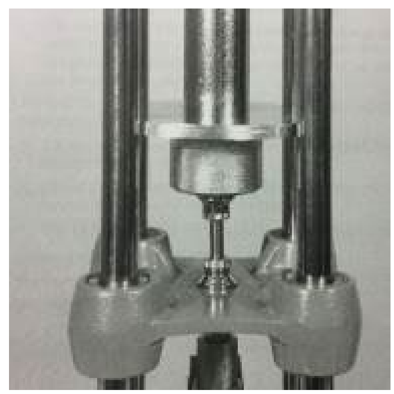


Fig. 8-2-12: Compression Sample Upper Placement

43. Since the pressure is released, carefully move the spider assembly upwards by hand & fit the compression sample into the upper compression adapter as shown in Figure 8-2-12.
44. Locate the micrometer and micrometer bracket on the storage panel, set the micrometer to about 0.2", and install the micrometer to the bracket as shown in Figure 8-2-13.

Fig. 8-2-13: Micrometer and Bracket Assembly

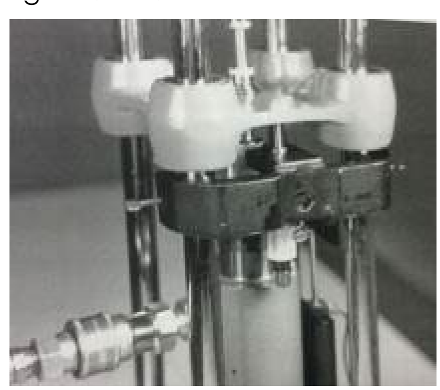


Fig. 8-2-14: Micrometer and Bracket Installation

45. Place the micrometer & bracket assembly below the spider assembly, taking care that the micrometer tip (the end that measures) is pointed up and touches the spider assembly so that the micrometer can be extended and read as the spider assembly moves away from the bracket during testing.
46. Check to make sure that the bracket is aligned and the micrometer is turned so that the scale on the micrometer can be easily read during testing, then tighten the thumbscrews to hold the bracket assembly in place.
47. Check again that the spider assembly is tight against the sample, and make any final adjustments to the micrometer so that it is touching the spider assembly. This will be the "zero-deflection" point for the test, and all deflection measurements will be made relative to this position.
48. Locate & mount the pressure indicator that shows a range from 0-10,000 psi (See Figure 8-2-13).

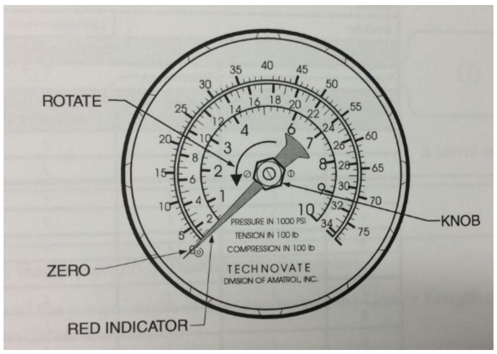


Fig. 8-2-13: Pressure Gage

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49. Note the scale on the gage. During the test you will be reading both pressure (innermost scale) and compression force (outermost scale). The middle scale is for tension force, and is of no use for this test.
50. **Make sure all students on your team and nearby are wearing safety goggles**. [Anyone not wearing them, or testing without adequately warning nearby non-wearers will fail this experiment.]
51. Rotate the release valve on the pump clockwise until it is tight so that the pump can build pressure.
52. Make sure the knob on the pressure gage is resting on zero psi as shown in Figure 8-2-13.
53. Study the gage, and be sure you understand the increments for pressure and force so you can read it correctly.
54. Prepare your lab sheet to record pump pressure, compression force, and the micrometer reading. The table should be neat and data carefully recorded and this original sheet should be included in your later lab report, along with a "pretty" electronic version of the same.
55. Record the first set of readings for pressure, force and micrometer reading at zero pressure.
56. Slowly pump the handle on the hydraulic pump until the pressure is approximately 200 psi. Immediately read and record pressure and force, then read the micrometer and record its measurement.
57. Notice that the pressure may have decayed as the sample compresses, causing the black dial on the pressure gage to drop from the maximum value shown by the red needle. Rotate the red dial on the pressure gage down until it rides on the black arm of the gage, then continue testing.
58. Increment pressure another 200 psi or so, and make another set of measurements following steps 25 & 26.
59. Continue step 27 until failure of sample.
60. After failure, rotate the pressure release knob counterclockwise to release pressure
61. Remove the sample from the fixture. Examine it, and sketch and/or photograph it for your report.
62. **Repeat the entire procedure for the 1018 Steel compression sample** obtained from the storage tray.
63. **Repeat the entire procedure for the third sample provided, making any adjustments to setup needed.**

Analysis & Report

- Prepare a lab report of your test per report guidelines.
- Develop a table for each sample that includes all measurements and computations, including the following:
    - Load increment
    - Pressure reading
    - Force reading
    - Calculated Force (a duplicate column of force that is calculated from the pressure, micrometer reading)
    - Total gage length (Sample initial length less the difference between the micrometer reading at each increment of load minus your initial micrometer reading)
    - Stress (computed)
    - Strain (computed)
    - Modulus (computed)
- Plot load vs deflection & stress vs strain. Indicate the yield point and the maximum strength of the material on the curve. Comment on findings.
- Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
- Include your original data sheet in an appendix.
- **Save your failed samples. You will use these again in a later experiment**.

Experiment 8-3: Amatrol Shear Test

In this experiment student teams will test 2 shear samples to failure. This is intended to reinforce student understanding of test methods, measurements, and procedures for members in shear. It is also intended to illustrate the benefits of testing for material characterization, as well as the difficulties associated with obtaining accurate and meaningful test data.

Reading

Review your Mechanics of Materials Text.

Essential Apparatus

6. Amatrol's T9014 Materials Engineering Trainer (Figure 8-3-1)

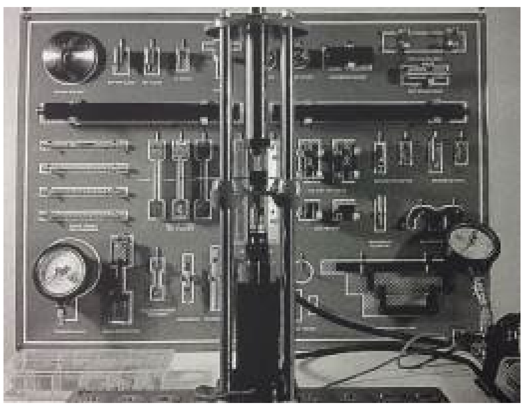


Fig. 8-3-1: Amatrol T9014 Setup

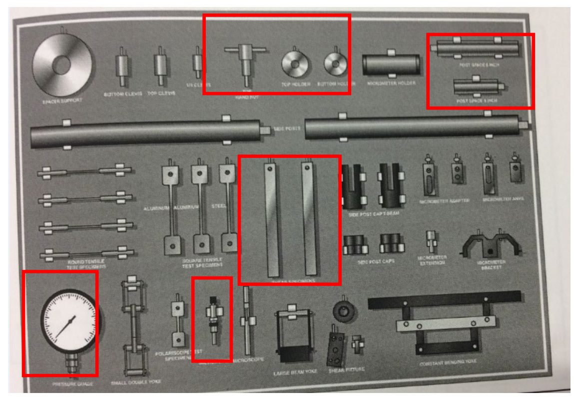


Fig. 8-3-2: Equipment Needed

7. Test components from T9014 Back Panel (Figure 8-3-2)
8. Steel & aluminum shear samples from T9014 Back Panel (Figure 8-3-2)
9. Calipers (From Toolbox)
10. Micrometer (From Toolbox)

Materials & Specimens

5. Steel shear Sample
6. Aluminum shear Sample

General Note

This experiment is very important. It will be difficult to recall all aspects of the test later. It will also be difficult to get accurate results. Take the following steps as you go to maximize your result.

- Make sketches or take photos during all stages of testing for your report.
- Duplicate as many actions & measurements as you can. Strive to have at least two students separately make each measurement, reading, or observation. Strive to have two separate students record the same data for the team as the test progresses. Compare readings & results at each convenient point, and discuss/rectify differences.
- You will record data during this test, and your raw data sheet must be a part of your report. Prepare your datasheet accordingly, and record all data neatly. Do not erase, but strikeout any errors and continue recording data.

- Procedure

64. Locate your Amatrol T9014 Station. It should look roughly as shown in Figure 8-3-1. If the spider assembly is not installed, install it now.
65. Locate the top hand screw & the 6” post spacer on the storage panel & install them as shown in Figure 8-3-3.

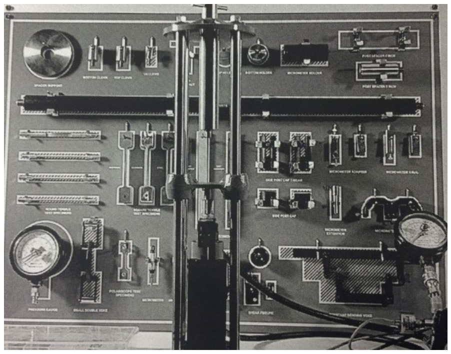


Fig. 8-3-3: Top Screw & Spacer Installation

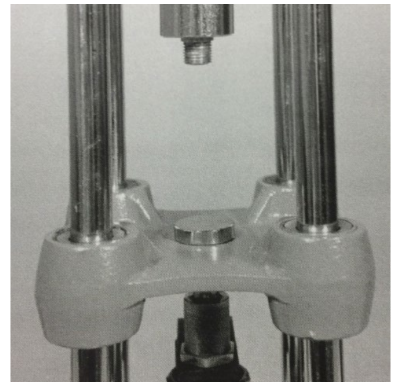


Fig. 8-3-4: Bottom Adaptor Installation

66. Locate the bottom adaptor on the storage panel & install it thru the spider assembly as shown in Figure 8-3-4.
67. Locate the round shear adapter & shear punch. They may be on the storage panel or in the clear storage tray. Install these as shown in Figure 8-3-5.

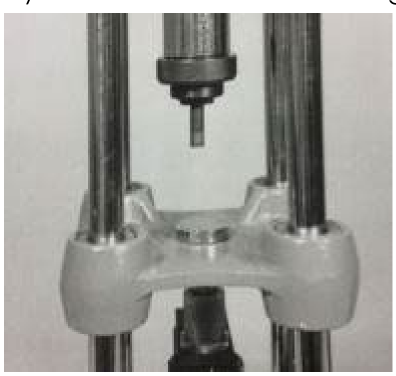


Fig. 8-3-5: Shear Adapter & Punch

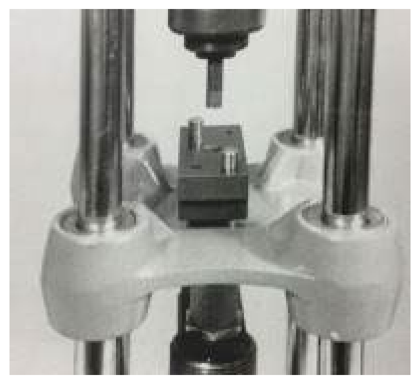


Fig. 8-3-6: Shear Die Placement

68. Locate the shear die, which consists of two square rectangular pieces with a central hole, and place it on the bottom adapter as shown in Figure 8-3-6.
69. Locate the **6061-T6 Aluminum shear sample that is 1/16” thick** on the storage panel, which are located as shown in Figure 8-3-7.

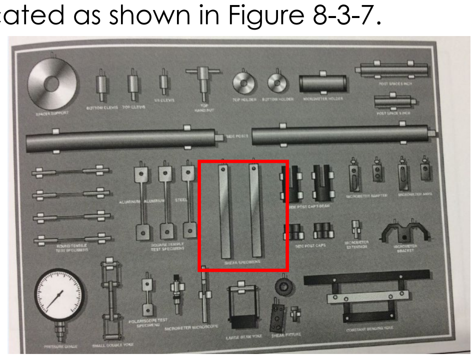


Fig. 8-3-7: Shear Specimens

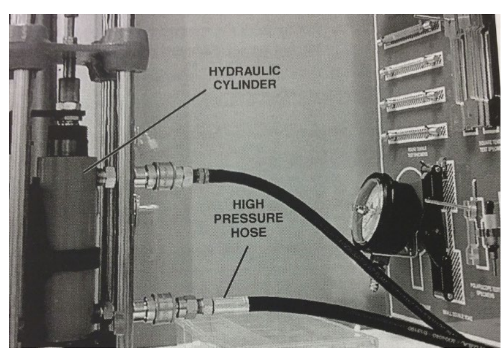


Fig. 8-3-8: Pressure Hose Connections

70. Locate the hydraulic pump, and attach its pressure lines to the test fixture, making sure that the high pressure line is attached to the lower connector on the test fixture, and the low pressure line onto the upper connector, as shown in Figure 8-3-8.

71. Find the release knob on the pump (see Fig. 8-3-9), & rotate it counterclockwise to release pressure from the system.

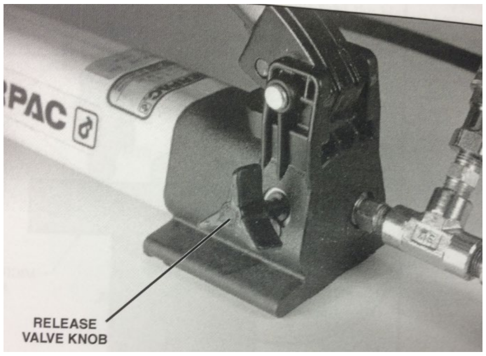


Fig. 8-3-9: Pressure Release Knob

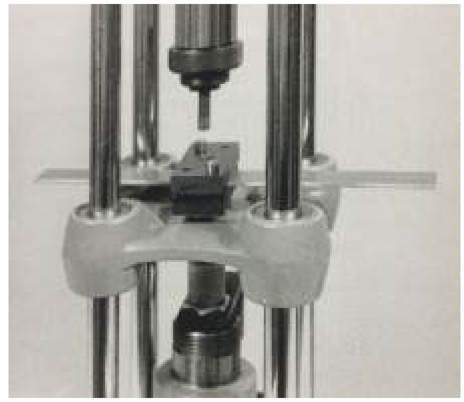


Fig. 8-3-10: Specimen Placement

72. Sketch & photograph your test specimen for your report. Then measure the sample completely with calipers & micrometer, striving for four decimal place accuracy for the cross sectional dimensions.
73. Place the shear specimen into the shear die and center the specimen and die in the shear fixture as shown in Figure 8-3-10.
74. Since the pressure is released, carefully move the spider assembly upwards by hand, and align the shear punch with the hole in the shear die without putting any pressure on the specimen so that your fixture looks similar to Figure 8-3-11.

Fig. 8-3-11: Shear Punch Alignment

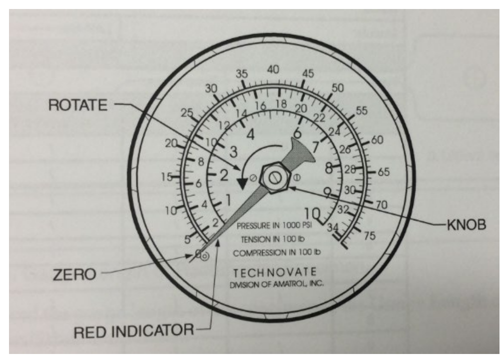


Fig. 8-3-12: Pressure Gage

75. Locate & mount the pressure indicator that shows a range from 0-10,000 psi (See Figure 8-3-12).
76. **Make sure all students on your team and nearby are wearing safety goggles**. [Anyone not wearing them, or testing without adequately warning nearby non-wearers will fail this experiment.]
77. Rotate the release valve on the pump clockwise until it is tight so that the pump can build pressure.
78. Make sure the knob on the pressure gage is resting on zero psi as shown in Figure 8-3-12.
79. Study the gage, and be sure you understand the increments for pressure and force so you can read it correctly. You will be using compression to shear the material, so be sure to read the outer compression scale when recording force.
80. Prepare your lab sheet to record pump pressure and force. The table should be neat and data carefully recorded and this original sheet should be included in your later lab report, along with a "pretty" electronic version of the same.
81. Record the first set of readings for pressure & force at zero pressure.
82. Slowly pump the handle on the hydraulic pump until the pressure is approximately 200 psi. Immediately read and record pressure and force, then read the micrometer and record its measurement.

83. Notice that the pressure may have decayed as the sample deforms during measurement, causing the black dial on the pressure gage to drop from the maximum value shown by the red needle. Rotate the red dial on the pressure gage down until it rides on the black arm of the gage, then continue testing.
84. Increment pressure another 200 psi or so, and make another set of measurements following steps 19 & 20.
85. Continue step 21 until failure of sample.
86. After failure, rotate the pressure release knob counterclockwise to release pressure.
87. Remove the sample from the fixture. Examine it, and sketch and/or photograph it for your report.
88. **Repeat the entire procedure for the 6061-T6 aluminum sample that is 1/32" thick** obtained from the storage panel.

Analysis & Report

- Prepare a lab report of your test per report guidelines.
- Develop a table for each sample that includes all measurements and computations, including the following:
    - Load increment
    - Pressure reading
    - Force reading
    - Calculated Force (a duplicate column of force that is calculated from the pressure, micrometer reading)
    - Shear stress (computed)
- Comment on results.
- Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
- Include your original data sheet in an appendix.
- **Return your failed samples to the storage panel for reuse by other students.**

Experiment 8-4: Amatrol Hardness Test

In this experiment student teams will test the hardness of various samples & estimate material and strength. This is intended to reinforce student understanding of material characterization tests and methods, as well as the difficulties associated with obtaining accurate and meaningful test data.

Reading

Review your Mechanics of Materials Text.

Essential Apparatus

11. Amatrol's T9014 Materials Engineering Trainer (Figure 8-4-1)

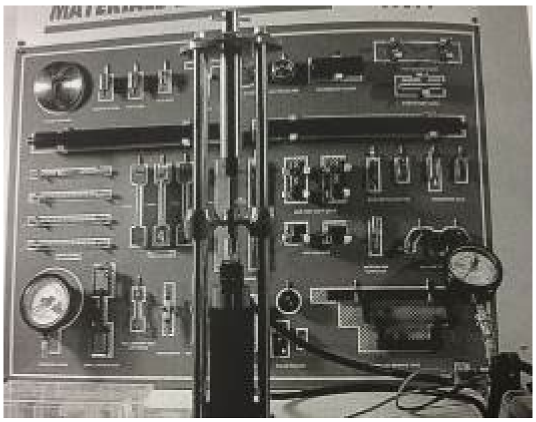


Fig. 8-4-1: Amatrol T9014 Setup

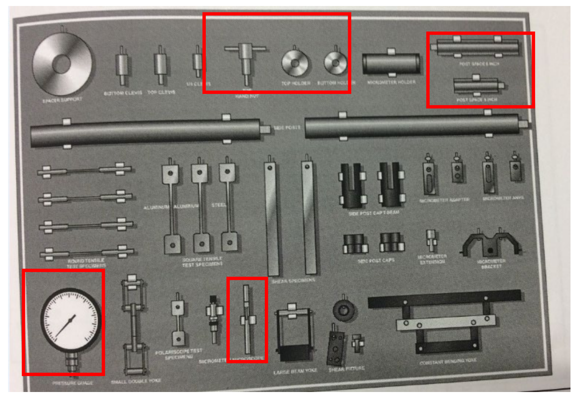


Fig. 8-4-2: Equipment Needed

12. Test components from T9014 Back Panel (Figure 8-4-2)
13. Calipers (From Toolbox)
14. Micrometer (From Toolbox)

Materials & Specimens

7. Two Hardness Sample of differing materials.
8. Your broken tension sample from Experiment #8-1.

General Note

This experiment is very important. It will be difficult to recall all aspects of the test later. It will also be difficult to get accurate results. Take the following steps as you go to maximize your result.

- Make sketches or take photos during all stages of testing for your report.
- Duplicate as many actions & measurements as you can. Strive to have at least two students separately make each measurement, reading, or observation. Strive to have two separate students record the same data for the team as the test progresses. Compare readings & results at each convenient point, and discuss/rectify differences.
- You will record data during this test, and your raw data sheet must be a part of your report. Prepare your datasheet accordingly, and record all data neatly. Do not erase, but strikeout any errors and continue recording data.

Procedure

89. Locate your Amatrol T9014 Station. It should look roughly as shown in Figure 8-4-1. If the spider assembly is not installed, install it now.
90. Locate the top hand screw & the 6" post spacer on the storage panel & install them as shown in Figure 8-4-3.

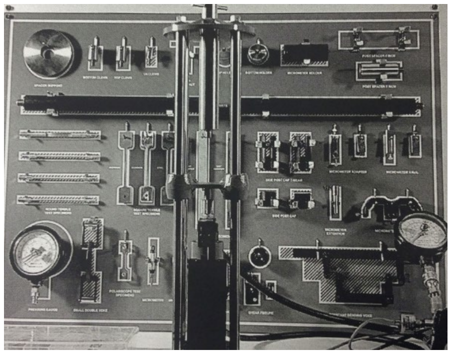


Fig. 8-4-3: Top Screw & Spacer Installation

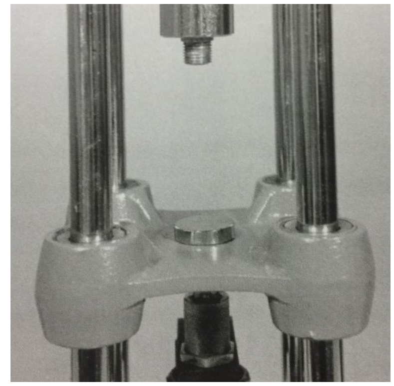


Fig. 8-4-4: Bottom Adaptor Installation

91. Locate the bottom adaptor on the storage panel & install it thru the spider assembly as shown in Figure 8-4-4.
92. Locate the hardness fixture assembly in the clear storage tray. This consists of a housing, hardness plate, & steel ball, as shown in Figure 8-4-5.

Fig. 12-5: Hardness Fixture Components

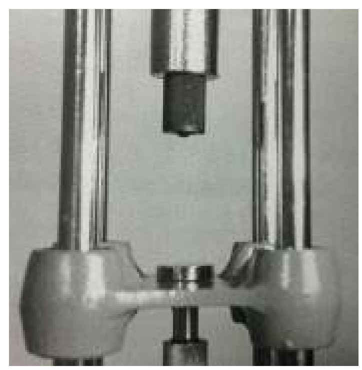


Fig. 8-4-6: Hardness Fixture Attachment

93. Install the hardness fixture as shown in Figure 8-4-6.
94. Locate the **cylindrical hardness samples** in the clear storage tray, which are shown in Figure 8-4-7.

Fig. 12-7: Hardness Specimens

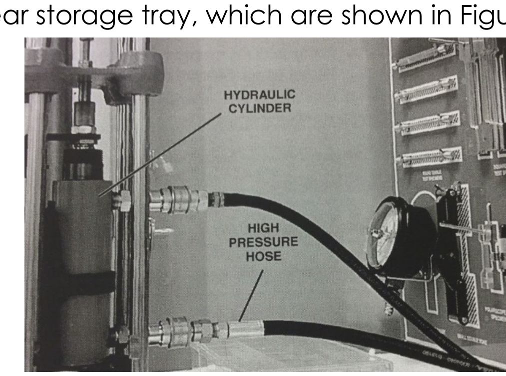


Fig. 8-4-8: Pressure Hose Connections

95. Locate the hydraulic pump, and attach its pressure lines to the test fixture, making sure that the high pressure line is attached to the lower connector on the test fixture, and the low pressure line onto the upper connector, as shown in Figure 8-4-8.

96. Find the release knob on the pump (see Fig. 8-4-9), & rotate it counterclockwise to release pressure from the system.

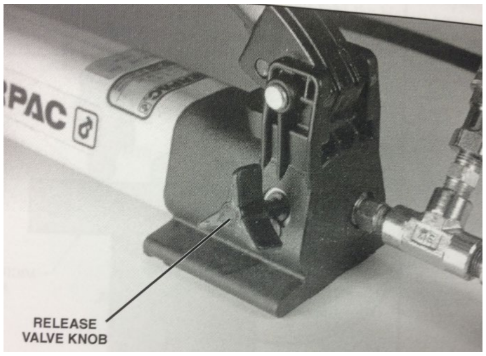


Fig. 8-4-9: Pressure Release Knob

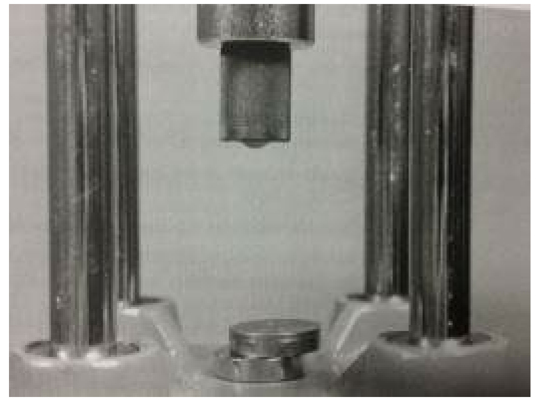


Fig. 8-4-10: Specimen Placement

97. Sketch & photograph your test specimen for your report. Then measure the sample completely with calipers & micrometer, striving for four decimal place accuracy for the cross sectional dimensions.
98. Place the first hardness specimen onto the bottom adaptor as shown in Figure 8-4-10.
99. Since the pressure is released, carefully move the spider assembly upwards by hand, and align the hardness sample with the hardness fixture until the sample is about ½" below the fixture, as shown in Figure 8-4-11.

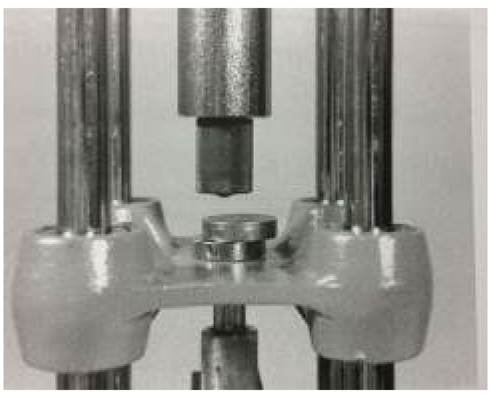


Fig. 8-4-11: Sample Alignment

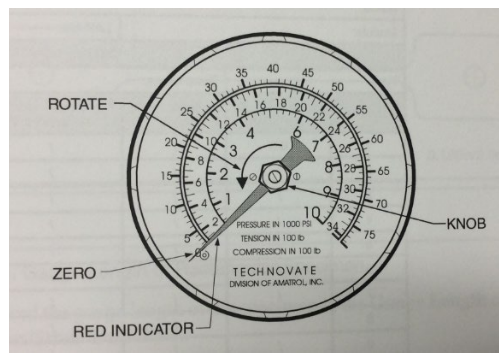


Fig. 8-4-12: Pressure Gage

100. Locate & mount the pressure indicator that shows a range from 0-10,000 psi (See Figure 8-4-12).
101. **Make sure all students on your team and nearby are wearing safety goggles**. [Anyone not wearing them, or testing without adequately warning nearby non-wearers will fail this experiment.]
102. Rotate the release valve on the pump clockwise until it is tight so that the pump can build pressure.
103. Make sure the knob on the pressure gage is resting on zero psi as shown in Figure 8-4-12.
104. Study the gage, and be sure you understand the increments for pressure and force so you can read it correctly. You will be using compression to test the material, so be sure to read the outer compression scale when recording force.
105. Examine your test specimen. If there are any prior indentations, mark them with a small x using a permanent marker so that you do not mistake your measurement with a prior one.
106. Prepare your lab sheet to record pump pressure and force. The table should be neat and data carefully recorded and this original sheet should be included in your later lab report, along with a "pretty" electronic version of the same.
107. There is no need to record the zero pressure values for this test.
108. Slowly pump the handle on the hydraulic pump until the ball of the hardness tester touches the sample, then continue pumping until the pressure reads 1400 psi, which corresponds with the force of a 500 kg mass typically used for these tests.

109. Rotate the pressure release knob counterclockwise to release pressure.

110. Remove the sample from the fixture. Examine it, and sketch and/or photograph it for your report.

111. Locate the microscope on the storage panel. Look into it, and notice its divisions are similar to that shown in Figure 8-4-13.

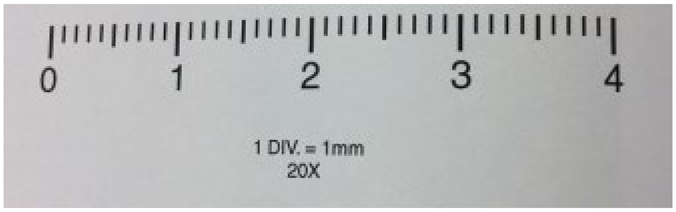


Fig. 8-4-13: Similar Microscope Scale

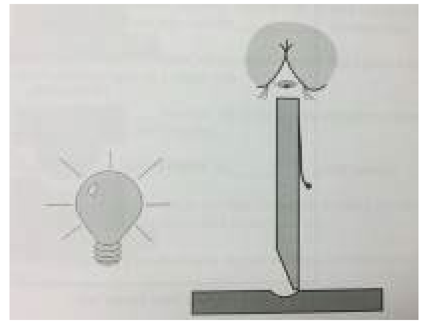


Fig. 8-4-14: Reading the Microscope

112. Use the microscope as shown in Figure 12-14 to read the diameter of the indentation.

113. Note that hard and soft metals respond differently to this test, as shown in Figure 8-4-15. Be sure to read the actual indentation, and not to mistake effects around the indentation to confuse your measurement.

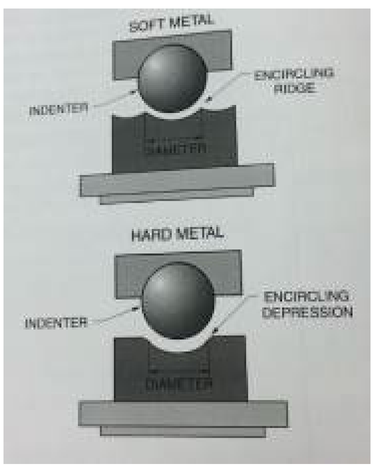


Fig. 8-415: Measurement Challenges

114. Record the pressure used to indent the sample, and the diameter of the indentation on your test data sheet.

115. **Repeat the entire procedure twice more on the same sample**.

116. **Repeat the entire procedure (3 measurements) on the second hardness sample** obtained from the storage tray.

117. **Repeat the entire procedure (3 measurements) on a piece of your failed tension sample** from Experiement 9.

Analysis & Report

- Prepare a lab report of your test per report guidelines.
- Develop a clear way of showing your measurements & results for each sample.
- Calculate the mean and standard deviation of your diameter measurements for each sample.
- Compare the average diameter of each sample with Figure 12-16 and determine the Brinell Hardness Number (BHN) of each sample.

IMPRESSION Diameter (mm)	BRINELL NUMBER		IMPRESSION Diameter (mm)	BRINELL NUMBER	
	500-kg Load	3000-kg Load		500-kg Load	3000-kg Load
2.00	158	945	3.10	64.6	388
2.05	150	899	3.15	62.5	375
2.10	143	856	3.20	60.5	363
2.15	136	817	3.25	58.6	352
2.20	130	780	3.30	56.8	341
2.25	124	745	3.35	55.1	331
2.30	119	712	3.40	53.4	321
2.35	114	682	3.45	51.8	311
2.40	109	653	3.50	50.3	302
2.45	104	627	3.55	48.9	293
2.50	100	601	3.60	47.5	285
2.55	96.3	578	3.65	46.1	277
2.60	92.6	555	3.70	44.9	269
2.65	89.0	534	3.75	43.6	262
2.70	85.7	514	3.80	42.4	255
2.75	82.6	495	3.85	41.3	248
2.80	79.6	477	3.90	40.2	241
2.85	76.8	461	3.95	39.1	236
2.90	74.1	444	4.00	38.1	229
2.95	71.5	429	4.05	37.1	223
3.00	69.1	415	4.10	36.2	217
3.05	66.8	401	4.15	35.3	212

Fig. 12-16: Indentation Diameter vs. Brinell Hardness Number

MATERIAL	ULTIMATE TENSILE STRENGTH ksi (mPa)	BHN
Aluminum		
2024-T4	68 (469)	120
6061-T6	45 (310)	95
Copper		
C11000	50 (345)	40
Steel		
1018	64 (441)	131
1045	91 (627)	187
Stainless Steel		
303	87 (600)	160
304	82 (565)	150

Fig. 12-17: Strength & Material vs. BHN

- Estimate the material of each sample by comparing your BHN calculation to Figure 12-17.
- Estimate the tensile strength of each material using the approximate relation F_{tu}=500(BHN).
- Compare your strength estimate with the values of Figure 12-17. Comment on your findings.
- Comment on results.
- Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
- Include your original data sheet in an appendix.
- **Return your failed samples to the storage panel for reuse by other students.**

Experiment 8-5: Stability of Columns Using Amatrol Multi-Station

In this experiment student teams will investigate the stability of columns using the Amatrol Multi-Station. This is intended to reinforce student understanding of compression and stability relations, test methods, measurements, and procedures for simple members in compression. It is also intended to illustrate the benefits of testing for material characterization, as well as the difficulties associated with obtaining accurate and meaningful test data.

References:

Review your Mechanics of Materials Text.

Test Fixture Setup

15. Locate the Amatrol's T9014 Materials Engineering Trainer (Figure 8-5-1). Select a machine that is already set up with the 4 long rods, rather than the short ones.

Fig. 8-5-1: Amatrol T9014 Setup

Fig. 8-5-2: Components

Fig. 8-5-3: Equipment Needed

16. Most of the small components needed for this test have been removed from the Multi-Station, and can be obtained from the upper right drawer of Cabinet A5 (Figure 8-5-2). These are shown in detail in Figure 8-5-3.
17. You will also need calipers and/or a micrometer for this experiment. These can be found in the upper middle drawer of Cabinet A1.
18. Attach the bottom adapter into the bottom of the assembly as shown in Figure 8-5-4.

Fig. 8-5-4: Lower Fixture Setup

Fig. 8-5-5: Upper Fixture

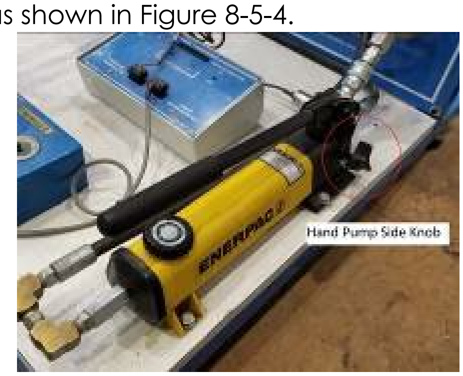


Fig. 8-5-6: Hand Pump

19. Attach the top spacers by first inserting the Hand Screw into the hole in the top and then attaching the appropriate size of spacer(s) as shown in Figure 8-5-5. The short sample should require both spacers while the long samples will only need the shorter spacer.

20. Attach the top adapter to the spacers. The top of the assembly should resemble that shown in Figure 8-5-5 for the short sample case. Insert the sample with the correct supports inserted into the space between the adapters and connect the supports to the adapters by applying load using the hand pump, pictured in Figure 8-5-0-5.
21. Locate the hand pump (Figure 7-6), & verify that the digital pressure gage is attached (shown at far right of Fig. 8-5-1).
22. Verify that the pressure lines are connected correctly to the test fixture, with the high-pressure line attached to the lower connector on the hydraulic cylinder, and the low-pressure line onto the upper connector, as shown in Figure 8-5-7. Correct setup can be verified by loosening the side knob (circled in red in Figure 8-5-6), so that the sample is under no load prior to data acquisition. Before inserting any samples, tighten this knob and work the hand pump a few times to verify that pressure moves the lower cylinder upward (for compression application). If so, the hoses are attached correctly for this experiment. If not, use the quick release fittings and switch the two hose attachments on the back of the hydraulic cylinder in the test fixture. After verifying this, loosen the hand knob again, press the cylinder back down to its lowest position, and retighten the hand knob.
23. The dial indicator will be used to measure axial deflection. The dial gage is stored in the upper right drawer of Cabinet A5. The final setup of this dial indicator deflection gage is shown in Figure 8-5-8.
24. We will use weights to elevate the gage to an appropriate position. Obtain these from the lower left cabinet-door of Cabinet A5.
25. Use the weights to elevate the dial-indicator deflection gage such that it measures axial deflection. The assembly should resemble Figure 8-5-8.
26. Note: when the pressure lines are set up to introduce compression to the sample, the pressure can be converted to force by the relation $P=pA_c$, where $A_c=0.785$ in^2, which represents the area of the compression cylinder of the hydraulic cylinder. For reference, when the pressure lines are reversed, the relation is $P=pA_t$, where $A_t=0.343$ in^2, which represents the area of the tension cylinder of the hydraulic cylinder.

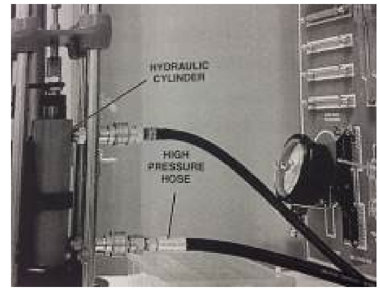


Fig. 8-5-7: Hydraulic Line

Fig. 8-5-8: Final Setup

Sample Preparation Procedure

7. Get Test specimens from instructor. These are stored in the back room of the lab. You should receive two or more lengths of samples.
8. Sketch & photograph your sample(s) for your report. Then measure the sample completely with calipers & micrometer, striving for four decimal place accuracy for the cross sectional dimensions and length.
9. Also, attempt to measure the straightness of the sample by placing it on a flat surface, rolling it back and forth, and using calipers or a scale to measure any lateral variance.
10. Record all dimensions on your sketch, or in a table, so the sample is completely defined and documented.

Test Procedure

118. Mount your first sample in the test fixture. It should look roughly like the one in Figure 8-5-8.

119. In this experiment you will try to determine the buckling allowable of each sample. You will develop a test estimate of the buckling allowable, and you will compare to a theoretical value. You will measure pressure and deflection, and plot these values as you go until the pressure-deflection curve appears to go nonlinear, which is the point at which buckling starts.

120. Long, slender samples can buckle at very low loads, therefore, measure deflection & pressure for longer samples in increments of about 50 psi, and measure these for shorter samples in increments of about 100 psi.

121. First test your longest sample with the fittings that simulate a ***pinned-pinned*** end condition. Mount the sample into the fixture with the corresponding end fittings, record pressure and deflection until the load-pressure curve goes nonlinear, and document your results.

122. Unload the sample & remove it from the fixture. Repeat step 3 of the Sample Preparation Procedure (above) to measure the non-straightness of the sample after testing. Do your best to straighten the sample by hand, and then re-measure. You will retest this sample and want an estimate of its straightness. Record your post-first-test straightness measurement and then continue.

123. Next test the **same sample** again in the exact same way. Once again record pressure and deflection until the load-pressure curve goes nonlinear, and document your results. Then unload and remove the sample. This will enable you to evaluate the repeatability of the test, the scatter (a little) and will give an idea of what effect any permanent deformation from the prior test has.

124. Unload the sample & remove it from the fixture. Repeat step 3 of the Sample Preparation Procedure (above) to measure the non-straightness of the sample after testing. Do your best to straighten the sample by hand, and then re-measure. If this sample is still fairly straight, you can re-use it for the next test. If not, get a new (identical) sample from your instructor. Record the straightness of this sample before continuing, and whether your next test involves a new sample or one from a prior test.

125. Next, test the same sample (or a different but identical sample based on your straightness findings) with the fittings that simulate a ***pinned-fixed*** end condition. Mount the sample into the fixture with the corresponding end fittings, record pressure and deflection until the load-pressure curve goes nonlinear, and document your results. Then unload the sample.

126. Unload the sample & remove it from the fixture. Repeat step 3 of the Sample Preparation Procedure (above) to measure the non-straightness of the sample after testing. Do your best to straighten the sample by hand, and then re-measure. You will retest this sample and want an estimate of its straightness. Record your post-first-test straightness measurement and then continue.

127. Repeat step 7 (above) to evaluate whether the sample is straight enough (or can be straightened enough) for use in the next test. Get a new sample from your instructor if necessary.

128. Next, test the same sample (or a different but identical sample) with the fittings that simulate a ***fixed-fixed*** end condition. Mount the sample into the fixture with the corresponding end fittings, record pressure and deflection until the load-pressure curve goes nonlinear, and document your results. Then unload the sample.

129. Repeat steps 5 & 6 (immediately above) to retest this sample with the same end conditions.

130. You now should have two tests on a certain length and cross-sectional area of sample with the end conditions pinned-pinned, pinned-fixed, and fixed-fixed. When you later process your data you will compare your test results with your theoretical estimates, and can comment on the repeatability of the test and on the effect of any non-straightness of the sample.

131. Next, test a different shorter sample with the fittings that again simulate a ***pinned-pinned*** end condition. Mount the sample into the fixture with the corresponding end fittings, record pressure and deflection until the load-pressure curve goes nonlinear, and document your results. Then unload the sample. This sample will only be tested once.

Test Teardown:

1. Remove Sample.
2. Verify you have all data.
3. Return all components for this experiment exactly where you got them.
4. Check work area is clean and free of debris.

Analysis & Report

- Prepare a lab report of your test per Appendix B guidelines, except as follows:
  - Data Section can be dropped from report if you prefer to include data in tables and graphs in the Discussion Section and you comment as you go on the data.
  - Place the Excel graphs & data generated by the test software in Appendix A. Repeat any pertinent graphs or table in your discussion as you comment on it.
  - Place hand calculations in Appendix B.
- Include your raw data of pressure versus deflection. Your raw measurements can be in an appendix, but a pretty table should also appear in the body of your report. This table should show not only your pressure and deflection readings, but also your calculated force, and the calculated stress in the sample. Any equations used should be identified in your report.
- Include a plot of stress versus deflection for each sample and test. This should ideally be all shown on the same plot, unless the scales are so different that one or more tests are not adequately defined due to the different scales.
- Review Sections 10.0 thru 10.3 of the Aerospace Strength Handbook, Volume II, Revision r1, by Todd Coburn, or your elementary Mechanics of Materials Text, and calculate the theoretical Euler Buckling load for each column. Compare your test results to your theoretical calculations. Show all equations used, and all intermediate calculations, and comment on how your theoretical calculations compare to the theoretical values.
- Comment in your report on accuracy (or lack of it) of measurements, calculations, etc., and on how one might improve the experiment.
- Comment on anything else you notice, or that you feel should be addressed in the discussion.

9-0 Heritage Experiments

More to come...

EXPERIMENT 1

Flexural Loading Applications I

"Maxwell's Theorem"

The purpose of this experiment is to demonstrate Maxwell's Theorem of Reciprocal Displacements.

Reading

Flexural Loading: Deflections due to bending (Reference any text on Mechanics of Solids or Strength of Materials).

Essential Apparatus

(1) Scott Materials Test Machine
(2) Pressure gage (2,000 psi capacity)
(3) Micrometer
(4) Vernier Caliper
(5) Measuring tape
(6) Dial-gage micrometers

Materials & Specimens

Rectangular cross-section prismatic bar made of mild steel. Other materials may be substituted.

Procedure

(1) -- Measure with the vernier caliper and record the cross-sectional dimensions of the bar to be tested.
Mark with a pencil the midsection of the bar and sections located at 2 in. on either side of it.

(2) -- Set up the beam in the Scott tester as shown in Figure 1 (symmetrical configuration of supports).
Use the single yoke assembly (part 0471-1) for the application of loads to the midspan of the beam.

(3) -- Install the micrometer in the apparatus, so that displacements at the midspan of the beam can be measured, and place the dial-gage micrometer underneath the beam as shown in Figure 1.

(4) -- Install the 2,000 psi capacity pressure gage. Engage the hand-pump by tightening the side knob and apply a small load to the specimen by operating the arm.

(5) -- Release the pressure by loosening the side knob on the hand-pump. Adjust the micrometer to read zero and record the initial reading of the dial-gage micrometer.

(6) -- Apply loads slowly and continuously. Take simultaneous pressure and deflection readings at 100 psi., initially, and for increment of every 60 psi., thereafter. Stop the loading after six readings have been taken or when the deflection is no longer proportional to the load.

(7) -- Retract the micrometer and release the pressure. Check the initial displacement readings at zero load. Repeat procedure step 6 at least twice and check for convergence of the readings.

(8) -- Without disturbing the dial-gage micrometer, set up the beam as shown in Figure 2 (asymmetrical configuration of supports) by shifting the posts in the apparatus 2 in. to the right.
Repeat procedure steps 6 and 7.

Background

The load **P** applied to the beam can be determined from the corrected gage pressure $\mathbf{P_g}$ and the cross-sectional area of the ram piston rod $\mathbf{A_p}$.

$$P = P_g \times A_p \qquad (1)$$

where $A_p = 0.223\ in^2$ (tensile mode only)

Analysis

--- Calculate the deformation at point **a**, δ_a, and point **b**, δ_b for the beam of Figure 1 and the deformation at point **a'**, δ_a' and point **b'**, δ_b' for the beam of Figure 2 for a load **P**= 1.

--- Compare the deformation per unit load at **a** and **b**, when the load is applied at **a**, to the deformation per unit load at **a'** and **b'**, when the load is applied at **b'**.
State Maxwell's Theorem of Reciprocal Displacements based on your observations.

--- Using the data from procedure step 6, generate plots of Deformation at point **a**, δ_a, and Deformation at point **b**, δ_b, vs. true pressure and evaluate the slopes of the resulting straight lines.
Adjust the results to reflect Deformation per unit Load.

These values represent the flexibilities f of the beam (i.e. f_a and f_b, respectively).

--- Using the data from procedure step 8, generate plots of Deformation at point a', δ_a' and Deformation at point b', δ_b' vs. true pressure and evaluate the slopes of the resulting straight lines.
Determine the flexibilities f_a' and f_b'

--- Compare the experimental values to theoretical ones and state your conclusions.

CALIFORNIA STATE POLYTECHNIC UNIVERSITY, POMONA
AEROSPACE ENGINEERING DEPARTMENT
AEROSPACE STRUCTURES LABORATORY

Experiment 1

Name________________________Date__________Section____Group No.____

Span__________in : Breadth__________in : Width__________in

--- Symmetrical Configuration ---

Pg_i (psi)	Pg_t (psi)	DEFORMATION (in) δ_a		δ_b	

--- Asymmetrical Configuration ---

Pg_i (psi)	Pg_t (psi)	DEFORMATION (in) $\delta_{a'}$		$\delta_{b'}$	

Experiment 1

Name______________________Date_________Section____Group No.____

--- Summary of Results ---

δ_a / P = ___________ $\delta_{a'} / P$ = ___________

δ_b / P = ___________ $\delta_{b'} / P$ = ___________

f_a = ___________ in/lb $f_{a'}$ = ___________ in/lb

f_b = ___________ in/lb $f_{b'}$ = ___________ in/lb

FIGURES

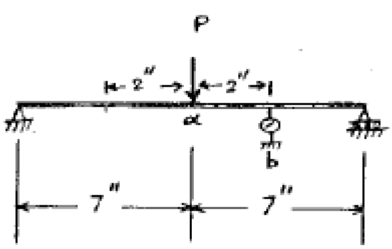


Figure 1

Symmetrical Configuration

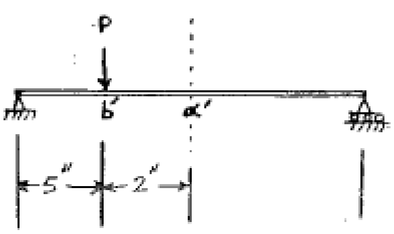


Figure 2

Asymmetrical Configuration

9-2 Experiment 9-2: Torsion of Non-Round Sections on Torsion Wheel

Purpose

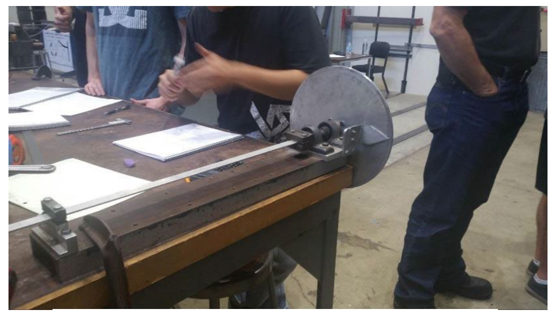
In this experiment, student teams will investigate the torsion of non-round sections & compare predictions of angle of twist with experimental values.

References

1. Coburn, Aerospace Strength Handbook, Volume II.
2. E.F. Bruhn, Analysis & Design of Flight Vehicle Structures.

Apparatus

1. Locate the Torsion Test Wheel (See Fig).
2. Get a set of weights and a weight hangar (See Fig) from the lower left shelf of Cabinet A5.


Torsion Test-Wheel

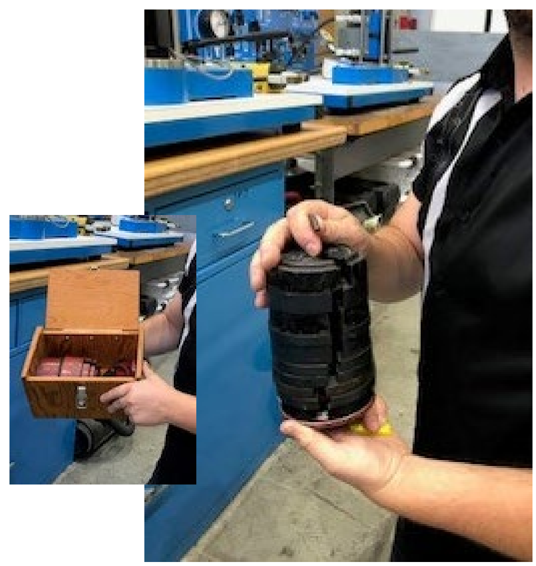
Samples

1. Choose two samples from the upper left shelf of Cabinet A-1, each 20” or more in length, and making sure one is aluminum and one is steel.
2. Sketch each sample, measure it completely, and record all values on the sketch for the report.

Test Procedure

Part A

1. Remove the tape that retains the wire on the disk (be sure to re-tape after completion of the experiment).
2. Taking care NOT to overtighten the bolts holding the sample in place, install the first sample in test fixture and position it for a 20” long test length.
3. Be careful to align the centroid of the section with the cavity in the center of the moving clamp using appropriate spacers to ensure that the longitudinal axis of the member coincides with the loading axis of the apparatus.
4. Measure and record the diameter of the loading disk of the test machine, and note the markings on the wheel indicate 1/2^{o}, 1^{o}, and 5^{o} increments.
5. In this experiment you will apply load in ½ lb or 1 lb increments (depending on the beefiness of your sample), and measure the angle of twist at each load.
6. Suspend each weight, read the angle of twist off the scale, record the data, and plot load versus angle of twist as you go.
7. Watch the load-twist plot to ensure the bar does not start deforming plastically. Stop loading if the load-twist curve is not completely linear.


Weights & Hanger

8. Incrementally add load in the specified increments to get 6-8 measurements, but stopping at any point where plastic deformation of the sample is evident from the plot.
9. After you stop loading, incrementally unload the sample in the same increments, and record the angle of twist, and plot the unloading curve on top of the loading curve.
10. Repeat steps 1-8 with the second sample.

Part B

1. Select whichever of your samples deflected the most, and use that sample for additional testing, as follows:
2. Fetch a 7/16" & ½" open end or box wrench from the Red Student Toolbox for loosening & tightening the bolts when adjusting the length of the shaft in the following steps. Be sure not to overtighten the bolts (These are easily stripped).
3. Reduce the span to 16", then test this sample with weights to record the angle of twist at approximately 25%, 50% & 75% of the maximum load tested in Part A.
4. Plot the values as before.
5. Repeat step 2 & 3 using reduced spans of 8" & 4".

Analysis

1. Include your tables of load versus angle of twist in your report. Calculate the applied moment for each of these and show the load, moment, twist values using appropriate significant figures.
2. Analytically determine the stress and angle of twist in your report, showing the equations and tabulating the values with the other data.
3. Include your load versus angle of twist plots in your report.
4. Add Moment versus angle of twist plots, plotting each set of data for a given length as separate lines on the same plot (this gives four curves per plot per sample).
5. Use the slope of the M-θ curve to determine the torsional spring constant $K_\theta = M/\theta$.
6. Use your moment-twist values to estimate the torsional constant J of each sample. Compare this to the analytical value computed using the methods of ARO326/ARO3261, etc.

EXPERIMENT 3

Axial Loading Applications I

"Thin-wall Cylindrical Pressure Vessel"

The purposes of this experiment are to determine the longitudinal and transverse strains occurring in thin-wall cylindrical shells subjected to uniform internal pressure and to demonstrate the application of the strain gage rosette in experimental stress analysis.

Reading

Thin-walled pressure vessels; Transformation of strain; Stress-strain relationships (Reference any text on Mechanics of Solids or Strength of Materials).

Essential Apparatus

(1) Cylindrical pressure vessel instrumented with a rectangular (0°-45°-90°) strain gage rosette
(2) Oil pump
(3) Switch box
(4) Electronic strain indicator (reads strain in micro in/in)

Materials & Specimens

The cylinder is made of 1015-Steel with a Poisson's ratio of 0.27 and Modulus of Elasticity of 29.6×10^6 psi.

Procedure

(1) -- Record the geometric dimensions of the cylinder and calibration data for the pressure gage. This information is contained in the pouch attached to the apparatus.

(2) -- Set the gage factor using the adjustment knob on the strain indicator to the value specified for the rosette. Note that the instrument displays the actual value times 10^3.

(3) -- Make a sketch of the rosette gages indicating their orientation relative to the cylinder's longitudinal axis and label them according to the way they are connected to the switch unit.

(4) -- Apply an initial pressure. Release the pressure and record the initial "reference" reading for each gage at zero load.

(5) -- Apply pressure gradually and continuously. Take simultaneous pressure and strain readings for increment of every 50 psi. Do not exceed 400 psi.

(6) -- Release the pressure. Check the reference strain readings at zero load. Repeat procedure step 5 twice to ascertain repeatability.

Analysis

--- Generate plots of indicated strain vs. true pressure for each strain gage and evaluate the magnitude of the slope of the resulting straight lines. These values represent strain per unit pressure in the direction of each gage. Transform these strains to principal strains per unit pressure. These values now represent the magnitude of the tangential and longitudinal strains per unit pressure.

--- Calculate the principal stresses per unit pressure employing Hooke's law.

--- Determine the theoretical values of the principal stresses per unit pressure employing thin-cylinder formulae. Compare to the experimental results and discuss any differences.

--- Why is it necessary to calculate the principal strains before the experimental results can be used to represent the material's strains?

--- Was the rosette perfectly lined up with the longitudinal axis of the cylinder? Substantiate your comment.

Experiment 3

Name__________________________Date__________Section____Group No.____

Pg_i (psi)	Pg_t (psi)	STRAIN GAGE OUTPUT ($x\ 10^{-6}$ in/in) Gage 1		Gage 2		Gage 3	

Slope Gage 1__________ /psi ϵ_1 =__________ /psi

Slope Gage 2__________ /psi ϵ_2 =__________ /psi

Slope Gage 3__________ /psi

σ_1 = __________ % error __________

σ_2 = __________ % error __________

EXPERIMENT 4

Combined Loading Applications I

"Cantilever Hollow-Section Shaft"

The purposes of this experiment are to determine the stresses produced by the combined effect of Torsional and Flexural loading, to compare experimental values with theoretical results, to demonstrate the principle of superposition, and to become familiar with the analysis of thin-walled sections.

Reading

Combined Static Loading - Torsion & Bending (Reference any text on Mechanics of Solids or Strength of Materials).

Essential Apparatus

(1) Thin, hollow, circular cross-section shaft instrumented with a rectangular strain gage rosette.
(2) Electronic strain indicator (reads strain in micro in/in)
(3) Switch box
(4) Laboratory Weights
(5) Vernier Caliper
(6) Measuring Tape

Materials & Specimens

Circular cross-section hollow tube made of aluminum.

Procedure

(1) -- Set the gage factor using the adjustment knob on the strain indicator to the value specified for the rosette. Note that the instrument displays the actual value times 10^3.

(2) -- Make a sketch of the rosette gages indicating their orientation relative to the tube's longitudinal axis and label them according to the way they are connected to the switch unit.

(3) -- Measure with the vernier caliper and record the thickness (t) and outer diameter (OD) of the tube.
Use the measuring tape to determine the distance (L) between

the center of the rosette and the centerline of the side holes at the free end of the tube.

(4) -- Using the tube as a cantilever, apply an initial load. Remove the load and record the initial "reference" reading for each gage at zero load.

(5) -- Load the cantilever in increments without exceeding 8 lb and unload in increments. Each time record the load and the corresponding strains. Check the reference strain readings at zero load.

(6) -- Restrain the end of the tube against vertical displacement. Insert the supplied lever in the openings at the free end of the tube and adjust it so that the moment arm is exactly 10".

(7) -- Record the initial strain readings. Hang weights from the tip of the lever in increments without exceeding 8 lb and unload in increments. Each time record the load and the corresponding strains. Check the reference strain readings at zero load.

(8) -- Repeat step 7 with the end of the tube unrestrained.

Background

A summary of the most important equations is incorporated.

Analysis

Part A

--- Using the data from procedure step 5, generate plots of measured strain vs. applied load and evaluate the magnitude of the slope of the resulting straight lines. These values represent strain per unit load in the direction of each gage. Transform these strains to principal strains per unit load. These values now represent the magnitude of the longitudinal and transverse strains per unit load.

--- Using the stress - strain relations for biaxial stress, determine the magnitude and direction of the principal stresses and compare the results with theoretical values.

Part B

--- Using the data from procedure step 7, generate plots of measured strain vs. applied load and evaluate the magnitude of the slope of the resulting straight lines. These values represent strain per unit load in the direction of each gage.

Calculate the principal (maximum) shearing strain per unit load.

--- Determine the magnitude and direction of the principal shearing stress and compare the result with the theoretical value.

--- Calculate the maximum shearing stress employing the shear flow equation and compare the result to the previous values. What is the difference between this method and the one previously used? What is the ratio of inner- to outer-diameter for the case studied?

Part C

--- Using the data from procedure step 8, generate plots of measured strain vs. applied load and evaluate the magnitude of the slope of the resulting straight lines. These values represent strain per unit load in the direction of each gage. Transform these strains to principal and maximum shearing strains per unit load.

--- Calculate the principal and maximum shearing stresses per unit load. Determine their direction and compare to the directions found in parts A & B.

Part D

--- Assume that the stresses in the tube are represented by the plane stress case where the normal stress in one direction is equal to the maximum principal stress from part A, the normal stress in the other direction (normal to the first) is equal to zero, and the in-plane shear stress is equal to the maximum shearing stress from part B.

--- Construct the appropriate block diagram to illustrate the stresses with respect to an orthogonal set of axes and calculate the principal and maximum shearing stresses for this case of plane stress.

--- Compare the results with the values from part C. Discuss and explain any similarities or differences.

SUMMARY OF EQUATIONS

FLEXURE FORMULAE: $\epsilon_x = [(M_y)z]/[EI_y]$

$\sigma_x = [(M_y)z]/[I_y]$

TORSION FORMULAE: $\gamma_s = [Tr]/[GJ]$

$\tau_s = [Tr]/J$

SHEAR FLOW FORMULA: $\tau_q = T/[2At]$

where
- A = Area of hollow section
- E = Modulus of Elasticity
- G = Modulus of Rigidity
- I_y = 2nd Moment of Area
- J = Polar Moment of Area
- M_y = Bending Moment
- r = Radial distance from N.A. to fiber of interest
- t = Thickness
- T = Torque
- z = Distance from N.A. to fiber of interest
- γ = Shearing Strain
- ϵ = Normal Strain
- σ = Normal Stress
- τ = Shearing Stress

Experiment 4

Name________________________Date__________Section____Group No.____

Outer Diam.__________in : Thickness__________in : Length__________in

--- Cantilever Beam ---

LOAD (lbs)	STRAIN GAGE OUTPUT ($\times 10^{-6}$ in/in) Gage 1		Gage 2		Gage 3	

--- Torsional Shaft ---

LOAD (lbs)	STRAIN GAGE OUTPUT ($\times 10^{-6}$ in/in) Gage 1		Gage 2		Gage 3	

Experiment 4

Name______________________Date__________Section____Group No.____

--- Combined Loading ---

LOAD (lbs)	STRAIN GAGE OUTPUT (x 10^{-6} in/in) Gage 1		Gage 2		Gage 3	

SLOPES	GAGE 1	GAGE 2	GAGE 3
Part A			
Part B			
Part C			

Experiment 4

Name______________________Date_________Section____Group No.____

--- Part A ---

ϵ_1 = __________ /lb ν = __________ σ_1 = __________ /in^2

ϵ_2 = __________ /lb   E = __________ psi σ_2 = __________ /in^2

G = __________ psi

--- Part B ---

γ_s = __________ /lb

τ_s = __________ /in^2 τ_q = __________ /in^2 (thin approx.)

--- Part C ---

ϵ_1 = __________ /lb σ_1 = __________ /in^2

ϵ_2 = __________ /lb σ_2 = __________ /in^2

γ_s = __________ /lb τ_s = __________ /in^2

--- Part D ---

σ_1 = __________ /in^2 % difference __________

σ_2 = __________ /in^2 % difference __________

τ_s = __________ /in^2 % difference __________

EXPERIMENT 5

Flexural Loading Applications II

"Flexural Rigidity & Shear Constant"

The purpose of this experiment is to determine the Flexural Rigidity and Shear Constant of a metal spar.

Reading

Flexural Loading: Deflections due to Bending and Shear stress; Shear & Moment Diagrams (Reference any text on Mechanics of Solids or Strength of Materials).

Essential Apparatus

normalize results

(1) Scott Materials Test Machine
(2) Pressure gage (2,000 psi capacity) 1401b→01b
(3) Micrometer
(4) Vernier Caliper
(5) Measuring tape
(6) Dial-gage micrometers

Materials & Specimens

Rectangular cross-section prismatic bar made of mild steel. Other materials may be substituted.

Procedure

(1) -- Measure with the vernier caliper and record the cross-sectional dimensions of the bar to be tested. Mark with a pencil the midsection of the bar and sections located at 3 in. on either side of it.

(2) -- Set up the bar in the Scott tester as a simply supported beam. The supports should be 18 in. apart. Use the double-arm yoke assembly (part 0482-1) with its rollers at 6 in. apart for loading the beam.

(3) -- Install the micrometer in the apparatus and place the dial-gage micrometers underneath the beam so that displacements at the midspan of the beam and points of application of the load can be measured.

--- Develop an expression for the displacement as a function of spanwise location **x** of a simply supported beam of length **L** subjected to a central load **P**.

--- Develop an expression for the maximum displacement of a simply supported beam of length **l** subjected to end-bending moments **M** of equal magnitude and opposite direction.
Let **M = (PL/6)**. What does the result represent?
(Hint: compare the magnitude of **M** to the values from the Bending Moment Diagrams)

--- Using the data from procedure step 6, generate plots of recorded displacement vs. true pressure and evaluate the slopes of the resulting straight lines. Adjust the results to reflect Displacement per unit Load. These values represent the flexibilities **f** of the beam.
The flexibilities obtained from the Dial-Gage micrometer readings should be identical due to symmetry. If they are not, compute an average. Subtract the result from the third flexibility. This value represents the maximum displacement per unit load due to bending only f_b. Substitute into the equation

$$f_b = (Ll^2)/(48EI)$$

to determine the Flexural Rigidity **EI** of the beam.
Derive the above equation from the developed expressions for displacement.
Calculate the moment of inertia of the cross-section of the beam and determine from the Flexural Rigidity the Modulus of Elasticity of the material. How does it compare to published values for steel?

--- Using the data from procedure step 8, generate plots of recorded displacement vs. true pressure and evaluate the slopes of the resulting straight lines.
Determine the flexibilities for this loading configuration and compute the average of the flexibilities obtained from the Dial-Gage micrometer readings f_a.
Using the Flexural Rigidity of the beam and the equation

$$f_c = (L^3)/(48EI)$$

determine the theoretical value of the maximum displacement per unit load f_c and subtract it from the flexibility obtained from the micrometer readings. The result represents the displacement per unit load due to shear only f_s at the midspan of the beam. Discuss why this is the case.
Derive the above equation from the developed expressions for displacement.

--- Using Equation (2) and the result for f_s, determine the Shear Constant of the beam.

--- Using the displacement expression developed for the centrally loaded beam and the Flexural Rigidity, calculate the displacement per unit load at the location of the Dial-Gage micrometer $\mathbf{f_{pb}}$ (contribution from Bending).
Using Equation (2) and the Shear Constant, calculate the displacement per unit load at the location of the Dial-Gage micrometer $\mathbf{f_{ps}}$ (contribution from Shear).
Calculate the total deformation per unit load at the location of the Dial-Gage micrometer $\mathbf{f_p}$ ($f_p = f_{pb}+f_{ps}$) and compare the result to $\mathbf{f_a}$.
What is the percent contribution of Shear to the tctal deformation? Discuss your conclusions.

Experiment 5

Name________________________Date__________Section____Group No.____

Span__________in : Breadth__________in : Width__________in

--- Double Arm Beam Yoke ---

Pg_i	Pg_t	DEFORMATION (in)					
(psi)	(psi)	micrometer		left dial-gage		right dial-gage	

--- Single Arm Beam Yoke ---

Pg_i	Pg_t	DEFORMATION (in)					
(psi)	(psi)	micrometer		left dial-gage		right dial-gage	

Experiment 5

Name________________________Date__________Section_____Group No._____

--- Double Arm Beam Yoke ---

Slope Left dial-gage________________ in/lb

Slope micrometer____________________ in/lb

Slope Right dial-gage_______________ in/lb

--- Single Arm Beam Yoke ---

Slope Left dial-gage________________ in/lb

Slope micrometer____________________ in/lb

Slope Right dial-gage_______________ in/lb

--- Summary of Results ---

f_b = ___________ in/lb   EI = ___________ lb in^2

f_a = ___________ in/lb f_c = ___________ in/lb

f_s = ___________ in/lb k_s = ___________ /lb

f_{pb} = __________ in/lb f_{ps} = __________ in/lb

f_p = ___________ in/lb   % shear cntrbtn __________

EXPERIMENT 6

Statically Indeterminate Structure I

"Indeterminate Beam"

The purpose of this experiment is to determine the support reactions in a statically indeterminate beam from measurements of deformation.

Reading

Statically Indeterminate Beams: The Superposition Method (Reference any text on Mechanics of Solids or Strength of Materials).

Essential Apparatus

Reference **EXPERIMENT 1.**

Materials & Specimens

Reference **EXPERIMENT 1.**

Procedure

Reference **EXPERIMENT 1.**

Background

Reference **EXPERIMENT 1.**

Analysis

Reference **EXPERIMENT 1.**

--- Form the ratio: $[f_a'/f_a]$

This value represents the magnitude of the reaction developed at the central support of the statically indeterminate beam shown in Figure 3 per unit value of applied load, i.e. **R/P**.

--- Derive the elastic curve equation for the free-body-diagram of Figure 2 using singularity functions.

Let the variables **L** and **a** represent the span of the beam and the location of the point of application of the load **P**, respectively.

--- Apply the Principle of Superposition to solve for the reaction **R** of the beam shown in Figure 3.
Calculate the ratio **R/P** and compare with the experimental value.

FIGURES

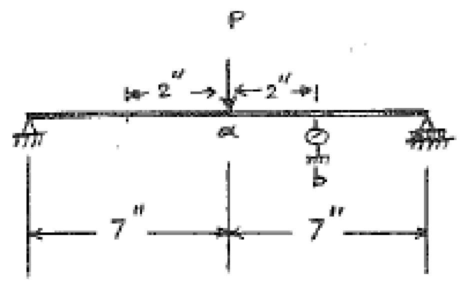


Figure 1

Symmetrical Configuration

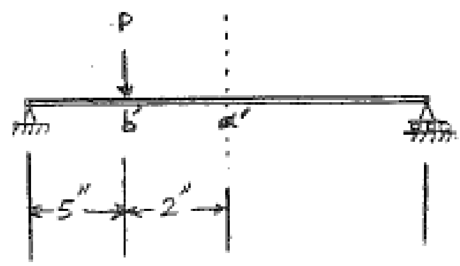


Figure 2

Asymmetrical Configuration

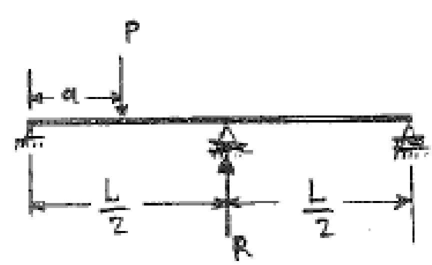


Figure 3

Statically Indeterminate Beam

10-0 Airwolf 3D Printer

Operating the Airwolf Axiom 20 3D Printer

This section describes procedures for 3D printing samples using the Airwolf Axionm-20 3D Printer.

Printer Specs:

- Filament size: 3.00 mm or 2.85 mm
- Filament materials: PLA, ABS, PolyCarbonate, Nylon, Flexible materials, exotics
- Build Volume (X,Y,Z): mm – (360,310,506) in. – (14.17, 12.2, 19.92)
- Extruders: 2
- Nozzle Diameters (mm): 0.35, 0.4, 0.5, 0.6, 0.8 (they are changed to inquire if not sure)
- Nozzle max Temp: 290 C
- Bed max temp: 110 C
- File Format: .gcode
- Printer Firmware: Marlin

Printer Assistance Contacts

- Beginning a Print: Axiom20Printing@gmail.com
- Access/General Questions: Dr. Todd Coburn
    - Tdcoburn@cpp.edu
- Technical - ARO Printing Manager: Jonathan Roberts
    - jdroberts@cpp.edu
- Technical – Raymond baker
    - rbbaker@cpp.edu

Preparing the Printer:

In order to verify safe use of the machine students may print on their own time **after** being trained.

To be trained, contact a technical contact above and schedule sometime in which you bring a 3D file you would like to print (in either .sldprt, .sldasm, or .stl) and the file is then "sliced" for you and the you are talked through how to run the machine. After that, you may have a file sliced at any time with proper approval to run the printer.


Figure 10-0-1 Power Switch Location

1. Power on the printer – switch is on the back, bottom, right as seen in Figure 10-0-1
2. Verify the correct material(s) is loaded into the machine, if not, refer to "Changing Filament" manual section
3. Verify the bed is prepared according to anticipated material (Table 1)
    a. The bed preparation is important for the part to "adhere" well to the print surface to ensure that temperature gradients are not successful in "warping" the part of the bed
    b. The longer the print, the more vital the bed surfacing
4. Preheat the printer to the correct temperatures (Table 1)
5. Insert micro-SD card
6. Select "Change SD card"
7. Select "Print from SD card"
8. Select the sliced file to be printed

Changing Filament

When changing materials/filaments in the printer, it is important to ensure that all of the previous material is "primed" out of the nozzle before printing; this is especially important when going to a material of lower melting temperature in which if the previous material remains, it will thicken in the nozzle and clog the extrusion of filament.

1. Go to "prepare" menu and choose a preheat setting of the higher temperature material between the previous and new materials that are being swapped.
2. Choose Preheat all
3. Once the nozzles are up to target temperature, go to "Prepare" and choose the nozzle which you are changing filament (left is extruder 1)
4. Choose remove filament
5. Remove the filament from the Teflon tube
6. Clip the end of the new filament at a 45 degree angle and run it through the Teflon tube
7. Hold the filament inside the extruder as seen in Figure 10-0-2 and navigate to Prepare>Extruder>Load filament
8. Hold the filament there with your hand until you feel the material continuously moving down the extruder
9. After the Extruder stops moving, navigate again to Prepare>Extruder>Prime and repeat this step until ALL of the previous filament is out of the nozzle
10. Clean the excess extruded filament

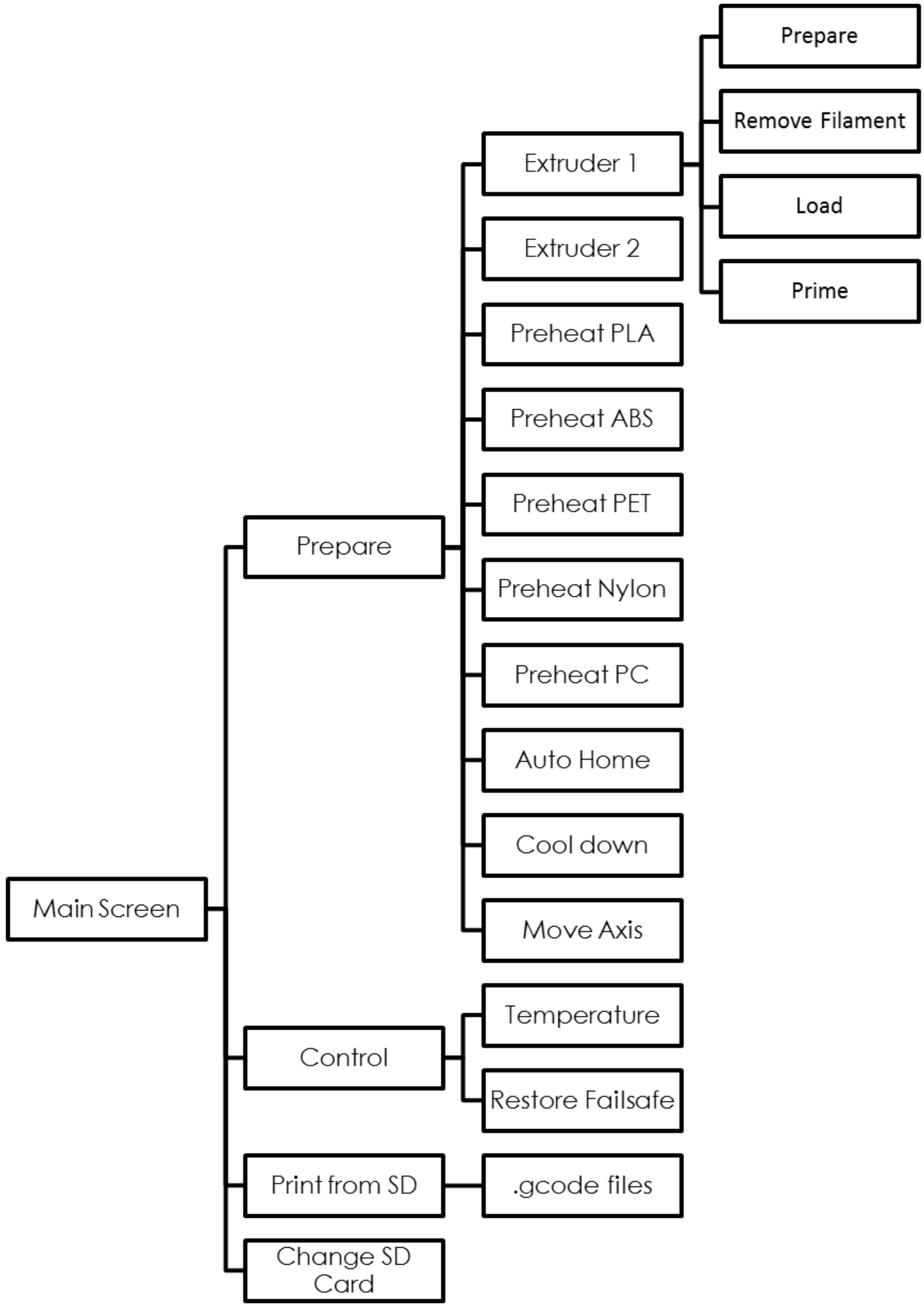
Figure 10-0-2: Changing Filament

3D Printer Reference Table

Material	Nozzle Temperature	Bed Temperature	Bed Surfacing	Hood?
PLA	220	65	Clean or Stick Glue	No
ABS	245	100	Stick Glue or WolfBite	Yes
Nylon	245	75	WolfBite	Yes
Polycarbonate	290	140	WolfBite	Yes
PETG	245	60	Stick Glue or Clean	No

Table 1 Material Reference

Printer Menu Navigation



11-0 Autoclave

What is an Autoclave?

An autoclave is used to apply temperature and pressure in a contained environment. While autoclaves are also useful for sterilization and other uses, the primary structural use is to cure composites at elevated temperature and pressure to provide better curing and compaction of the composite material, which results in improved properties at elevated temperature.

Where is the CPP Autoclave located?

The CPP Autoclave is located in Building 13-1307A.

What does the CPP Autoclave Look Like?

The CPP Autoclaveis shown in Figures 11-0-1 through 11-0-8.

Fig. 11-0-1: Autoclave - Front LHS

Fig. 11-0-2: Autoclave Front - RHS

Fig. 11-0-3: Autoclave - Front

Fig. 11-0-4: Autoclave - RH Rear

Fig. 11-0-5: Autoclave – Rear LHS

Fig. 11-0-6: Autoclave Rear - LHS

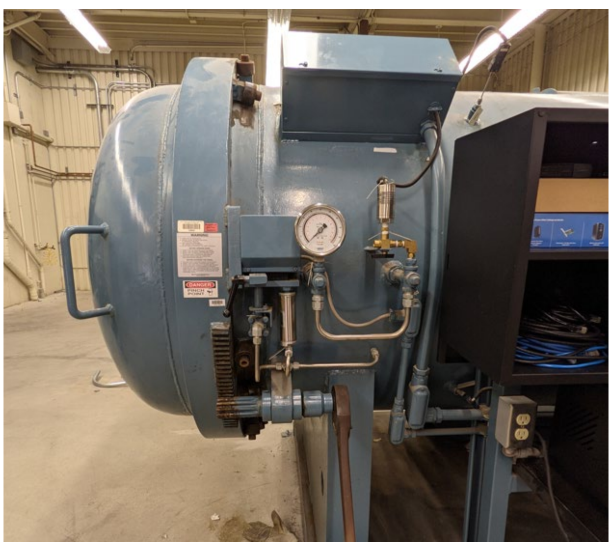


Fig. 11-0-7: Autoclave – LHS Front

Fig. 11-0-8: Autoclave – Control Computer

Procedures for Using the CPP Autoclave

Documented procedures for using the CPP Autoclave are being developed and will be available soon.

12-0-1 Composite Fabrication Activities

This subsection defines the some composite build and fabrication activities.

It is desired to add more fabrication activities to the lab. These will be announced as they are conceptualized.

12-1-1 Fabricating Composite Tension Samples from Prepreg

This subsection defines the basic procedure for fabricating a composite tension test sample from prepreg.

Material Acquisition

First get the materials you need.

1. Place plastic (Mylar) cover on table (protect table from all potential stains and messes).
2. Obtain two clean flat caul plates from instructor (shown in Fig.11-1-1) to perform lay-up on (preferably samples free of divots, bumps, impurities, sharp edges and points as these will show up in final product).

Fig. 11-1-1: Flat Metal Caul Plate

Fig. 11-1-2: Prepreg Roll

Fig. 11-1-3: Other Materials

3. Clean off the lay-up surface with 409 to remove all impurities so the sample is not contaminated.
4. Obtain carbon fiber (pre-impregnated) from the freezer in room 13-1229c, the West System 105 epoxy resin and 205 hardener and PVA release film (shown in Figures 11-1-2 and 11-1-3) from the yellow materials cabinet, because the quality of the epoxy on the prepreg fiber has degraded and is not sufficient to cure and solidify.
5. Get protective gear from instructor including: nitrile/latex gloves, respirator, & safety glasses (Fig. 11-1-4).
6. Put on protective gear.

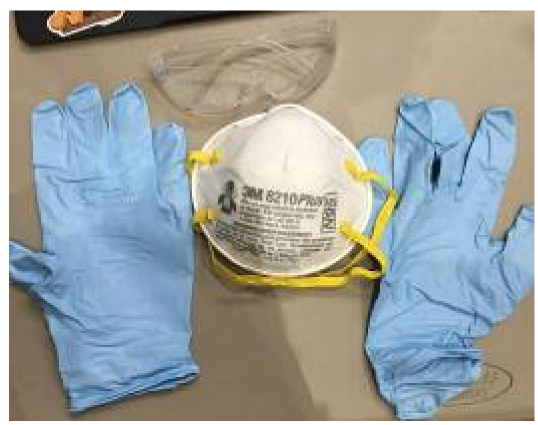


Fig. 11-1-4: Protective Gear

Preparing Resin

1. You will need to add the resin & hardener in proper proportions. Mix one pump of resin (Fig. 11-1-5) and one pump of hardener (Fig. 11-1-6) in a small paper cup.

Fig. 11-1-5: Adding Resin

Fig. 11-1-6: Adding Hardener

Fig. 11-1-7: Mixing

2. Mix with a popsicle stick or your gloved finger (Fig. 11-1-7).
3. When the resin & hardener have a consistent color & viscosity (Fig. 11-1-8) it is ready to be used.

Fig. 11-1-8: Ready for Use

Preparing Layup Area

1. Apply some WD40 on the lay-up plate surface and spread it evenly.
2. Place wax paper on top of WD40, taping the paper to the underside of the plate.
3. Apply PVA release film on top of wax paper (even coat).
4. Repeat steps 3 – 5 for the second metal plate.

Preparing Fabric & Making Panel

1. Inspect the fabric to make sure that it is free of impurities.
2. Cut out 5-10 square samples pieces, making sure each edge is about ¼ inches smaller than the edge of the plate. This is to ensure the quality of the lay-up is not affected by the boundaries of the plate during the curing process (Fig. 11-1-9).

Fig. 11-1-9: Cutting Fabric

3. Remove white film from carbon fiber and place sticky side down onto the PVA coated wax paper.
4. Prepreg typically does not need an additional bonding agent, but since most of our material is donated after it has exceeded the out-time recommendation of the manufacturer, it may be a little resin starved and its adhesive properties may be diminished. To counter this potential strength detriment, dribble a little epoxy on the surface of each ply as shown in Figure 11-1-10.
5. Spread an even layer of this epoxy on the prepreg without oversaturating the ply as shown in Figure 11-1-11 (Note: you can tell when the ply is saturated when there is a thin layer of epoxy on the surface of the ply).
6. Place another layer of prepreg on top of the previous layer, being careful to align the fiber at the exact desired orientation.
7. Once the ply is in the proper orientation, do your best to smooth-out any trapped air as shown in Figure 11-1-12.

8. Repeat steps 4 thru 7 until all plies have been placed.
9. Once all the sheets have been laid, place the second caul plate on top of the carbon fiber plies.

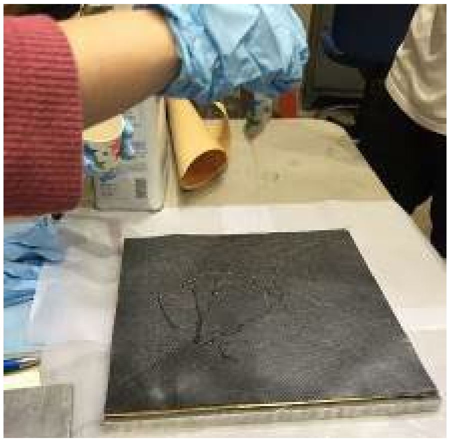


Fig. 11-1-10: Applying Epoxy

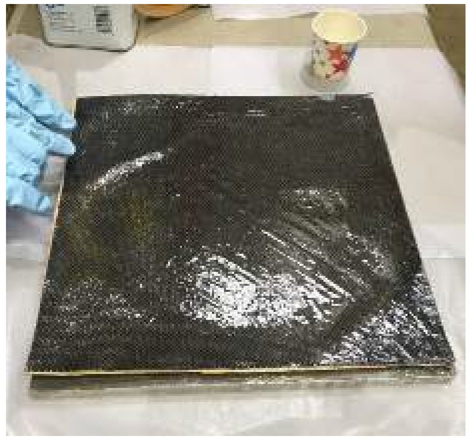


Fig. 11-1-11: Spreading Epoxy


Fig. 11-1-12: Removing Bubbles

10. Put downward pressure on the upper caul plate and push from inside out to make sure all layers adhere to each other and to remove excess epoxy.
11. Clamp the edges of the two plates so the plies are pressed firmly together without pressing so hard as to crush the fibers.
12. Place the sample in autoclave/oven for curing. For many Gr/Ep laminates, 3 to 6 hours at 350 F is desired. Do not leave the curing sample unattended at any time during curing. Do not cure in an area that does not have good ventilation. Do not cure in a place where food is prepared. Ideally, use the CPP Autoclave for curing.
13. Clean up work station and place remaining carbon fiber back into freezer. Put away resin, hardener, and PVA back into back into the yellow cabinet.

11-1-1-3 Cutting Test Samples from the Composite Panel

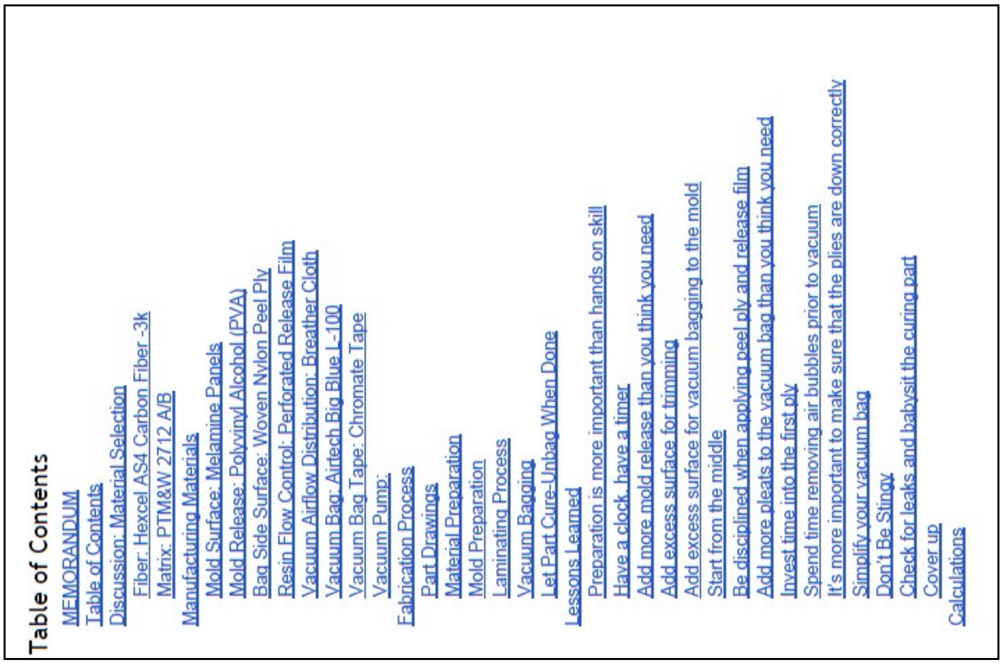
Once the panel is cured, we will cut samples from the panel. This will be described herein soon.

11-1-1-4 Testing the Composite Test Samples

Estimate the tension failure load for your sample. If the expected failure load is below 5000 lbs, follow the test procedure for experiment 3-1 to test your sample. If the expected failure load is above 5000 lbs, follow the test procedure for experiment 2-1 to test your sample.

12-2-1 Fabricating Composite Parts from Dry Cloth with Resin

This subsection defines how to fabricate a composite part from dry cloth with resin.



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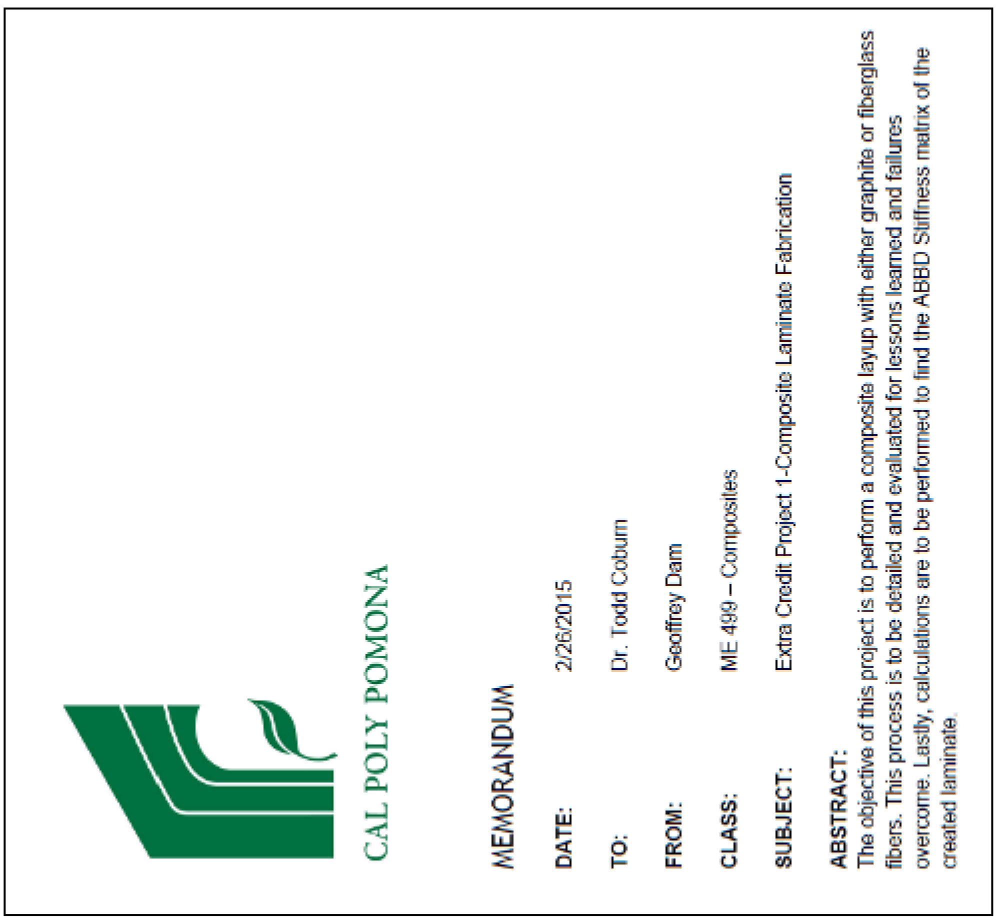


CAL POLY POMONA

MEMORANDUM

DATE: 2/26/2015

TO: Dr. Todd Coburn

FROM: Geoffrey Dam

CLASS: ME 499 – Composites

SUBJECT: Extra Credit Project 1-Composite Laminate Fabrication

ABSTRACT:
The objective of this project is to perform a composite layup with either graphite or fiberglass fibers. This process is to be detailed and evaluated for lessons learned and failures overcome. Lastly, calculations are to be performed to find the ABBD Stiffness matrix of the created laminate.

Discussion: Material Selection

Fiber: Hexcel AS4 Carbon Fiber -3k

The Hexcel AS4 Carbon fiber was chosen due to its low price, easy acquisition, and easily accessible material properties.

At most composites retail outlets, such as Aircraft Spruce, it can be purchased by the lineal yard (50" x 36"). It cost approximately $21 retail and $15 wholesale if one were to purchase a full roll of fabric.

Hexcel AS4 fibers are listed as high strength, high strain fibers. This means that in comparison to other grades of carbon fiber, they are tougher, thus more suitable to applications where prolonged material failure is desired. The material properties of the individual tow can be found online, published by Hexcel.

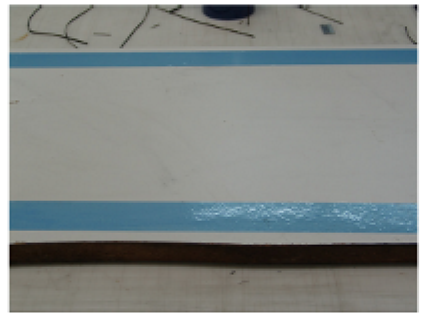
Matrix: PTM&W 2712 A/B

The PTM&W 2712A/B2 is another material who is both readily accessible by retail means and has well published material properties. It is an epoxy based matrix, designed for room temperature curing. The B2 hardener has a 1 hour pot life, allowing for long work times. In addition, it has a low viscosity of 320 cps, which is roughly the same as that of a thin latex paint. This makes it easy to work the resin through the material

PTM&W 2712 is a room temperature cure resin. It cures at 75 F, which was the temperture of the building during the layup.

Manufacturing Materials

Mold Surface: Melamine Panels



For a vacuum bag layup in which vacuum pressure will be used to compact a laminate as it cures, a sturdy mold or support material must be used. The ideal support material will exhibit little to no deflection under vacuum pressure.

Melamine is an organic base and is mixed with resin to provide a non-porous, relatively smooth surface on panels of wood particle board. This non-porous attribute is necessary for any material that will be in contact with the matrix material as it cures.

Mold Release: Polyvinyl Alcohol (PVA)

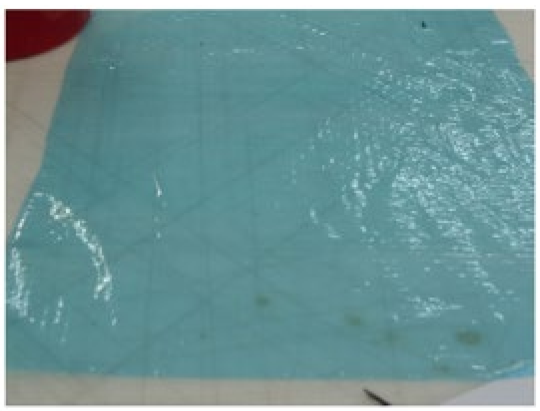
Polyvinyl alcohol, referred to by its initials PVA, is a plastic suspended in a quick drying alcohol based solvent. It's closely related to the white glue one can purchase at the craft store as the plastic material suspended is the same

PVA forms a thin barrier between the epoxy and the mold surface, preventing stickage. It is best reserved for molds with poor surfaces (400 grit or below) because it imparts an orange peel textured when sprayed

Bag Side Surface: Woven Nylon Peel Ply

The mold surface is dictated by woven nylon peel ply. This is a thin, sheer fabric woven of non-stick nylon. It is used as a release film to prevent the epoxy matrix from sticking onto the vacuum bag. It imparts a rough, tight-woven fabric like surface on the part.

Resin Flow Control: Perforated Release Film



Perforated release film serves to control the suction of resin from a curing laminate. For laminates, there is an ideal resin volume fraction which that must be maintained.

Vacuum Airflow Distribution: Breather Cloth

Breather cloth is a loosely tangles cloth made of polyester. It allow vacuum to flow through its body. By placing it after the release film, it allows even distribution of vacuum pressure on the curing laminate.

In addition. The breather serves to draw out excess resin from the laminate. The amount of resin drawn from the laminate is roughly logarithmically proportional to the thickness of breather applied on the surface of the laminate. As one increases the thickness of the breather, one will draw out more resin from the laminate, but only up to a point. However, increasing breather thickness also reduces the pressure compacting the laminate.

Vacuum Bag: Airtech Big Blue L-100

Vacuum Bag is the final step on the layup process. It seals the laminate from the outside environment and allows for compaction of the laminate to occur. Different vacuum bags offer different properties.

The primary property is temperature range. The maximum acceptable temperature for the vacuum bag should exceed that of which the matrix cures at.

The second property is bag stiffness. The stiffer the bag, the better it transmits the force of the vacuum onto the part. However, the less stiff the bag is, the better it conforms to complex part geometries.

Vacuum Bag Tape: Chromate Tape

Fabrication Process

Disclaimer: All manufacturing processes henceforth described are based on personal experience in composites manufacturing.

Part Drawings

Prepare a part drawing or note detailing the following:

- materials
- ply orientation
- ply thickness
- laminate thickness
- notes and other requirements

Material Preparation

1. Cut the fabric into shape, taking account the ply orientation. fabric should be larger than the final part

2. Measure the mass of epoxy and hardener needed, taking into account the ratio between resin and hardener. DO NOT MIX YET

3. Cut the appropriate amount of peel ply. Peel ply should be at least 2 inches larger about the perimeter than the fabric

4. Cut the appropriate amount of perforated release film. Peel ply should be at least 2 inches larger about the perimeter than the fabric

Mold Preparation

1. Apply vacuum bag tape onto the perimeter of the melamine. Cover the tape with masking tape to prevent resin from dripping on it and ruining the adhesion.

2. Apply PVA onto the surface. You can either spray it on with a large tip paint gun set t high pressure, and high paint feet, or rub it on quickly with a clean, lint free rag

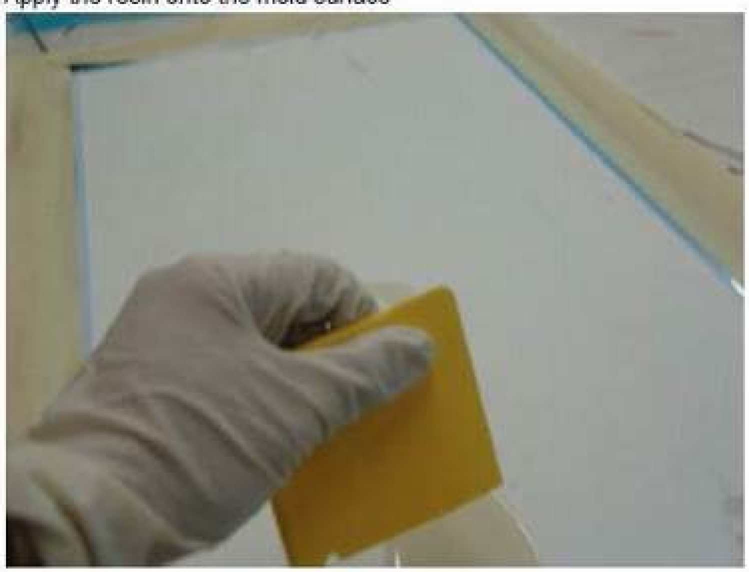
5. Cut the appropriate amount of breather cloth. Peel ply should be at least 1 inch larger about the perimeter than the fabric

6. Cut the appropriate amount of vacuum bag. The vacuum bag must conform to the mold surface. If necessary, form pleats with the bag, folding it upon itself, so that it may conform to the mold surface. The perimeter of the vacuum bag should be at least 4 inches larger than the perimeter of the fabric.

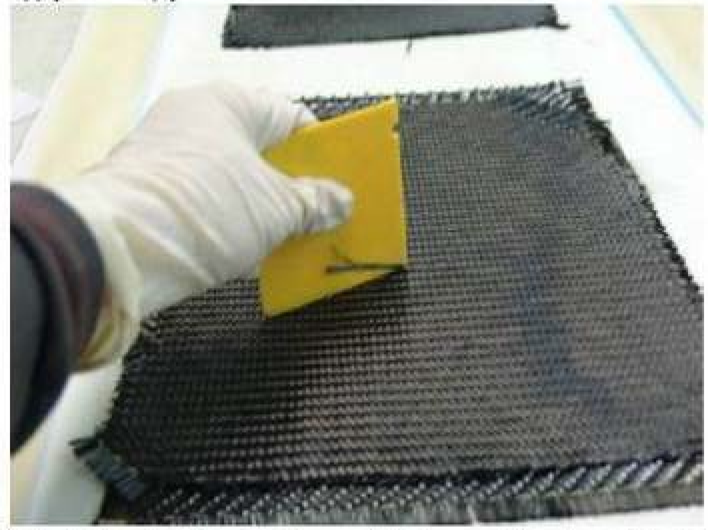
Laminating Process

1. Mix the resin and hardener until color and viscosity are consistent

2. Apply the resin onto the mold surface



3. Apply the first ply with the correct orientation.

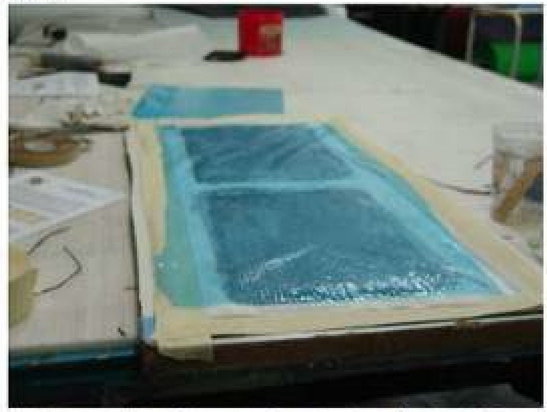


4. Saturate the ply with resin. You can tell when a ply is saturated by the liquid like sheen of the resin over the carbon
5. Press down on the ply with a clean paintbrush or epoxy roller to squeeze out air bubbles
6. Apply next ply
7. Repeat until all plies are laminated

Vacuum Bagging

1. Apply peel ply. Make sure peel ply exceeds all edges of laminate

2. Apply perforated release film. Make sure perforated release film exceeds all edges of laminate



3. Apply breather cloth. Make sure perforated release film does NOT exceed edges of perforated release film

4. Set nipple of vacuum pump. Cut slit into vacuum bag to allow nipple through. Seal the nipple

5. Seal the vacuum bag onto the vacuum bag tape earlier applied

6. Turn on the vacuum
7. Check for leaks. You'll hear a hissing sound. Seal the leaks with vacuum bag tape

Let Part Cure-Unbag When Done

Lessons Learned

THis is a summary of the lessons I've learned when working with composites. They will go from the most general of recommendations to niche tips with regards to wet hand layup

Preparation is more important than hands on skill

Because composite layups are limited by the work time of the resin, one needs to have every aspect of the layup prepared and accounted for. The less improvisation, the better.

Have a clock, have a timer

Layups are time sensitive. Have a clock or some reference based on when you first mix your resin. When working in teams on larger parts, have one person call out the time since mixing and keep track of milestones in the curing process.

Add more mold release than you think you need

One of the worst things that can happen is that your part gets stuck to the mold. When using mold release, whether a PVA, paste wax, semi-permanent release, or even hairspray (yes, that actually works), please use multiple coats to ensure full mold coverage. The thickness of the mold release isn't what is critical. It is ensuring coverage

Add excess surface for trimming

The edge of a composite part is highly frayed and disjointed. Regardless of how skilled you are and the layup process, there will be trimming of the part. Leave an inch or two at the end of part so that you can get a clean edge.

Add excess surface for vacuum bagging to the mold

As a corollary to what was said before, you want excess surface on the mold so you have both excess trim stock for the part, and surface to apply your vacuum bag tape. Other bagging methods, such as full envelope bagging (where you bag the entire mold and part) are feasible, but often are a waste of material.

Start from the middle

When laying up a part, apply the fibers in the middle of the part and work outward. This will allow the perimeter of the fibers, which are far more flexible, to conform to the shape of the mold. As opposed to machining, in which you have to equally focus on every detail, composites requires a more holistic mindset in which you emphasize the overall quality of the part first before working on more minute details.

Be disciplined when applying peel ply and release film

On a normal part, you would often never be seeing the dirt side that interfaces with the bag during cure. However, it is important to smoothly apply the release agents for three reasons

1. it controls the amount of resin and excess air being sucked away from the composite
2. if controls the thickness of the part
3. the bag side of the part might have to interface with another component

All three are critical for more technical composite work. While composites aren't often required to be precisely laid up, there will be situations where part thickness and resin content are critical to performance

Add more pleats to the vacuum bag than you think you need

The pleat allows the relatively rigid vacuum bag to wrinkle and conform to compound curvatures. It's important that vacuum pressure is applied over the entirety of the part, lest you get resin pools and voids.

Invest time into the first ply

THe first ply is important as it is the most visible and any errors will propagate throughout the rest of the layup. If there is an excess resin pool or an fold in the surface, the thickness will throw off the manufacturer as they try to work down the plies above.

Spend time removing air bubbles prior to vacuum

Use a roller or putty knife to press down on the wet laminate to for air out of the part after you lay down each ply. It will make the vacuum more effective and reduces the effort as you try to press each ply down flat.

It's more important to make sure that the plies are down correctly

Prioritize getting the plies on the mold correctly as opposed to obeying the clock and working quickly. A slow layup results in a part with slightly more resin. A bad ply can effectively ruin a part.

Simplify your vacuum bag

The simpler the vacuum bag, the easier it is to check for leaks. The last thing you want is to scurry about a large pleat, hunting for a tiny hiss.

Don't Be Stingy

Composites is very voluminous work. An extra roll of gum tape could be the difference between a sealed bag and a one that can't fully apply vacuum pressure

Check for leaks and babysit the curing part

When checking for leaks, do so periodically as the part is curing. The vacuum is a still a constant force, stretching the bag. Tear develop and you need to address them fast.

Cover up

When laying up and trimming a part, make sure that your skin is minimally exposed. Composite fibers are sharp and itchy. The last thing you want is for stray carbon dust to work its way into your pores.

As a corollary to this, when taking showers after composite work, use cold water to prevent your pores from opening. After a thorough rinsing, you can then switch to hot water.

13-0 Building Hardware

Purpose

TBD

Lab Safety Guidelines

Common Sense

Common sense is a necessity in any lab or production environment. Consistent application of good common sense can preclude a number of unforeseeable situations from developing in the lab. Alertness is also required. Be sure to get enough sleep before entering the lab and to keep your wits about you at all times.

Commit yourself to safe practices, and to monitoring your own actions and to remaining aware of the activities and actions of others in the lab at all times. Report any unsafe or careless activities to your instructor immediately. If the instructor ever becomes unavailable, report any such activities to the department administrator (909-869-2235) or to CPP's Emergency Services (909-869-6981) immediately.

Clothing

Proper clothing must be worn in the lab at all times. The following guidelines should be followed by all in the lab.

Safety Goggles must be worn in the lab at all times.

No loose or baggy clothing is allowed when running any power equipment or any test machines.

Shoes must be worn at all times. Shoes must completely cover the foot, and must not have pointy heels.

Hair below shoulder length must be tied or confined so that it does not hang where it can be pulled into machines or hardware, and where it cannot catch fire.

Emergency Exits

Be sure to note emergency exits, safety equipment including fire extinguishers, fire blankets, eye wash facilities, first aid kits, and the lab phone.

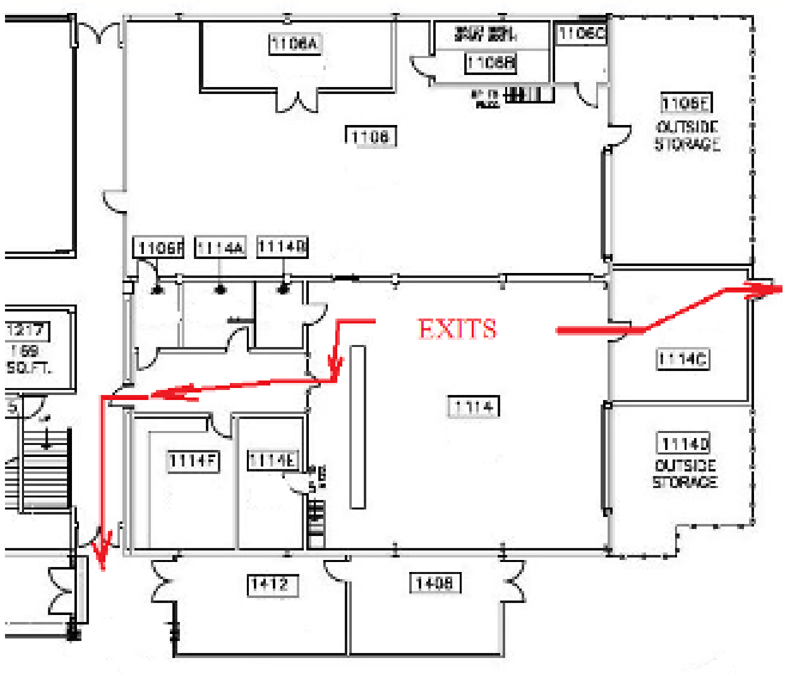


Figure A-1: Emergency Exits

In Case of Emergency

In case of emergency, be sure to take appropriate actions, such as the following:

- Shut down equipment.
- Notify instructor and alert others to emergency conditions.
- In event of fire where personal safety is not threatened, use fire extinguisher to extinguish flames.
- If personal safety is threatened, evacuate lab immediately and then notify campus security at 911.

Before Using Equipment

Prior to using any equipment, be sure to do the following:

- Read the lab manual.
- Study the lab manual and the equipment and be sure you understand its safe use before turning on any machine or attempting to use it.
- Make sure you understand the fastest and safest way to shut the machine off before turning it on.
- Carefully inspect each piece of machinery and equipment before usage to ensure every piece is in working order and is undamaged.
- Carefully check each sample to be sure it is not damaged or defective such that it can fail in an unexpected or dangerous manner.
- Check nearby machines, equipment, and people to ensure nothing will jeopardize the equipment during operation or nearby people during usage.
- Do not start the experiment if any hazardous conditions are apparent.

While Using Equipment

While using any equipment, be sure to do the following:

- Remain alert for developing safety hazards. These can be characterized by unusual noise, deflection, vibration, smoke, or change in temperature.
- Remain alert for unsuspecting people, animals, or insects entering the lab or approaching the experiment.
- Shut down the machine or equipment if any safety hazards begin to appear.
- Only use the equipment as described in the Lab Manual unless you obtain your instructor's consent.

After Using Equipment

While done using any equipment, be sure to do the following:

- Shut down all equipment.
- Return all machinery, equipment, accessories, tools, samples and measuring devices to their proper places.
- Clean all surfaces of any dirt, residue, oil, powder, particles, or fragments. Use towels, soap and water, or other appropriate means to leave the test area cleaner and in better shape than when you arrived.
- Have each member of your team verify that the area is clean and ready for use for the next student or class.

General Lab Rules Always in Effect

The following is always in effect in the lab:

- No equipment can by operated without two or more people present, both of which must have previously studied these lab rules and must have their signature on file with faculty that they adhere to these rules.
- No equipment can be operated without aerospace faculty knowledge of your specific time and purpose of use.
- Anyone in the lab is responsible for his or her own safety, and for the safety of others, and for the safety of the equipment.
- No eating, drinking, or smoking in the lab.
- No sitting or standing on workbenches at any time.
- No horseplay in the lab.

COMMITMENT TO SAFETY FORM

Prior to using the laboratory, all students must carefully read these safety guidelines and commit to following them at all times while in the lab, then sign the following and present it to their instructor or advisor.

Additional safety guidelines may also be required for certain activities. All students are responsible to ensure that their actions fall within the intent of this manual and of the Aerospace Department.

Bronco ID	Last Name	First Name	Signature	Date

Lab Report Format

In addition to providing students the opportunity to experimentally verify some of the principles in the structures sequence, and to develop a little hands-on building experience, ARO3570L is intended to develop the technical writing capabilities of each student, and their ability to develop quality, understandable technical reports. In order to give them a solid shove forward in this regard, a Lab Manual template was prepared that demonstrates some of the quality attributes necessary for a report of this nature. This template may be provided by the instructor, or can be dowenloaded directly from the following website (http://toddcoburn.com/CPP/Pubs.htm).

Alternately, this appendix defines report expectations for ARO3570L lab reports.

Lab reports should be comprehensive, neat, concise, well written, and should be of a professional quality. Grammar and punctuation should be correct.

Page numbering of the report can be sequential, or can follow a hybrid numbering scheme, such as 1-1, 1-2, 1-3, 2-1, etc.

Appropriate significant figures should be used.

The following sections should be present in the prescribed order, and should include the items listed as a minimum.

Title Page

The title page should be neat, professional, and clear. Ideally it will "grab" the reader, and should include the following:

- School name.
- Department Name
- Class Name, Number & Section
- Professor's Name
- Experiment Name & Number
- Listing of all lab team members.
- Date

The page number of the title page is "i", but is typically not shown.

Table of Contents

The table of contents should be neat, legible, clear and have a pleasant font size, format, & spacing. It should list the name and page number of every section of the report including any appendices. The page number of this page should be ii.

Introduction

The Introduction should be section 1 of the report, and should discuss the purpose and objectives of the experiment, and briefly summarize the results or findings.

Apparatus

The Apparatus should be section 2, and should identify any and all equipment and/or test devices used in the experiment. Ample use of sketches or photos should be used. Shortcomings or strengths of the equipment can be discussed briefly.

Procedure

The Procedure Section should be section 3, and should list all steps taken to perform the experiment. If the procedure is defined in this manual, then the Procedure section can simply state "The procedure for experiment XX in the xx MMMMM YYYY edition of the Aerospace Structures Lab Manual was followed in this experiment with no deviations".

If any deviations are made, the above statement can be used, with the caveat "except for the following:", where a step-by-step detail of which steps are added, removed, or modified.

Any corrections to the documented procedures from the Lab Manual, or useful additions or subtractions, should be written up and communicated with Dr Coburn for future Lab Manual Updates.

Data

The Data Section should be section 4, and should present all data and measurements of the experiment. Data in its original form should be included in Appendix A, and all this data should be presented neatly and efficiently in tables, words, graphs, or other clear format in this section.

It should be clear whether data presented is a measurement or a calculation. Any formulas used should be identified before use.

Discussion

The Results Section should be section 5, and should include all calculations, conclusions, or processing of the original measured data. Figures, photos, sketches, tables and graphs should be used extensively as needed, and discussion of results should be provided in a clear and cohesive manner.

Some kind of error analysis should be present, where student predictions are identified and compared against experimental results.

Conclusion

The Conclusion should be section 6, and should restate the purpose or objective and should concisely list any and all conclusions or findings.

References

References should be section 7, and should list any and all references used in performing the experiment or in preparing the report. Format should follow standard referencing rules.

Appendix A

Appendix A should include all datasheets or records in their original, unmodified form. There should be page numbers and other report format on these pages though. They can be attached and carefully hand-numbered, or scanned and dropped on the report-formatted pages.

Other Appendices

Other appendices can be included as needed to present photos, related work or papers, etc.

