



Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
Cambridge, MA 02139

Systems Problem

Out: Wednesday, October 19, 2005

Due: Wednesday, October 26, 2005

Name: _____

Time Spent: _____

Systems Problems and Labs #7

The Truss

Overview

In this laboratory exercise, you will:

- (a) Test a three-dimensional truss under transverse loading;
- (b) Measure its load-deflection characteristics and the strain in its internal bars/members;
- (c) Use the strain to determine the loads in the internal bars/members;
- (d) Compare the loads to values from analysis of a two-dimensional model of the truss;
- (e) Write a short laboratory report documenting your findings.

The concept of strain has not yet been introduced in material and structures lectures. However, a simplified explanation of strain, for a bar that is being pulled on at both ends with a constant load, is that it is the change in the length of the bar (Δl) divided by the initial length of the bar (l). As you might expect, strain is an important thing to predict in an aerospace structure so you should keep the deflection results and the strain results for possible use later in the course when these concepts are introduced in lecture.

In performing the laboratory, you will be introduced to a number of types of instrumentation and associated concepts. These are strain gages and the measurement of strain; deflection meters; loads cells; load-displacement relations; and the use of experimental/empirical calibration to obtain indirect measurements of one parameter via the direct measurement of another parameter (in this case member loads via member strains).

A very important part of this exercise is that you will get to compare the performance of an actual truss to the performance predicted by an analytical model of the truss, and therefore examine the validity of some of the assumptions made in forming the model.

Background

As was discussed in lecture, trusses are used for a number of different structures. They are structurally very efficient (i.e. they can carry high loads for a given mass of structure), and so they are widely used for space structures, and were used for early airframes. In the context of Unified Engineering trusses are also useful to us in introducing you to structural analysis, as they are relatively simple structures to analyze. However, it is important to realize, that for trusses, and for any other structure that we design or analyze, the analysis is performed on an idealization of the actual, physical structure. In conducting any structural analysis it is crucial at some point to assess whether the modeling assumptions required to perform the analysis are justified. This laboratory exercise will give you a chance to explore the assumptions we have made in order to analyze trusses.

Truss Model:

In this laboratory exercise you will test the performance of a truss with dimensions as shown in Figure 1 by placing loads of different masses in the middle of the truss. This Howe truss configuration is two identical two-dimensional trusses, connected by intervening members. This particular truss consists of four bays of the same length. The height of each bay is equal to its length. The intervening members have the same length as the length of each bay.

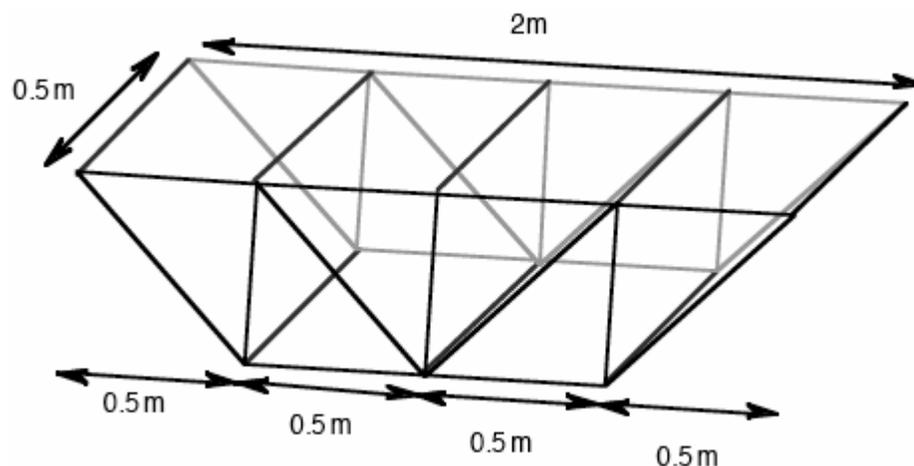


Figure 1. Illustration of truss configuration used in the lab.

You will then compare your results to results from an analytical model. The analysis and the

predicted performance will be provided to you after you have taken your measurements. However, it is important that you know that the model was developed under the following assumptions:

- (a) The truss members and joints have no mass;
- (b) The load is evenly distributed between each of the two two-dimensional trusses so each two-dimensional truss may be modeled independently with a point mass load equal to half the total payload mass;
- (c) The load is concentrated at the joint in the middle of the truss.
- (d) The normal assumptions associated with "idealized planar (two-dimensional) trusses" are valid:
 1. All bars are straight
 2. Bar joints are frictionless pins
 3. Bars are massless and perfectly rigid for loading analysis
 4. All loads and reactions are applied at the joints
 5. Loads in members are colinear
 6. Thus, bars carry only axial forces

The resulting analytical model configuration is shown in Figure 2.

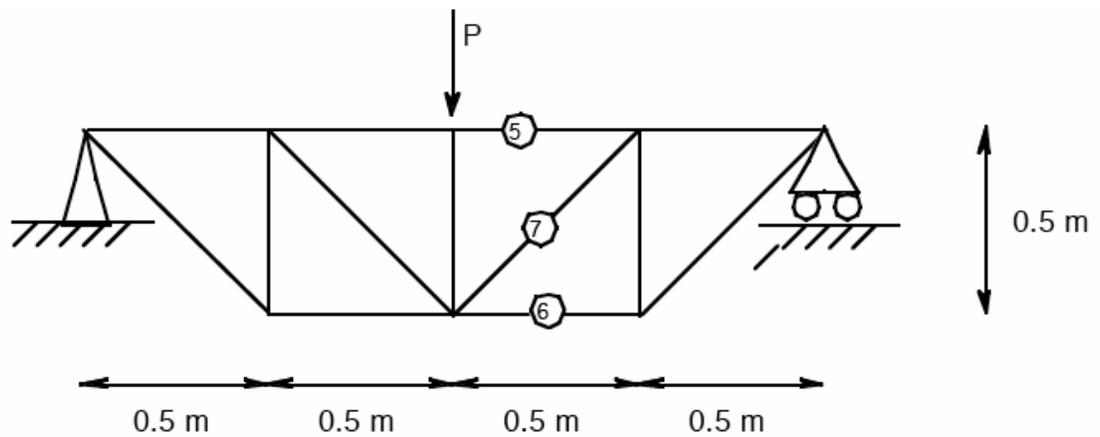


Figure 2. Illustration of two-dimensional model used in the analysis.

Experimental Apparatus and Setup

There will be two trusses setup in the hangar. One has steel bars and the other has aluminum bars. You will only get to test one truss (Sorry; Not enough time). Each set of apparatus will be as shown in figure 3. The truss is supported on a pair of unistrut supports with a horizontal separation of 2 meters.

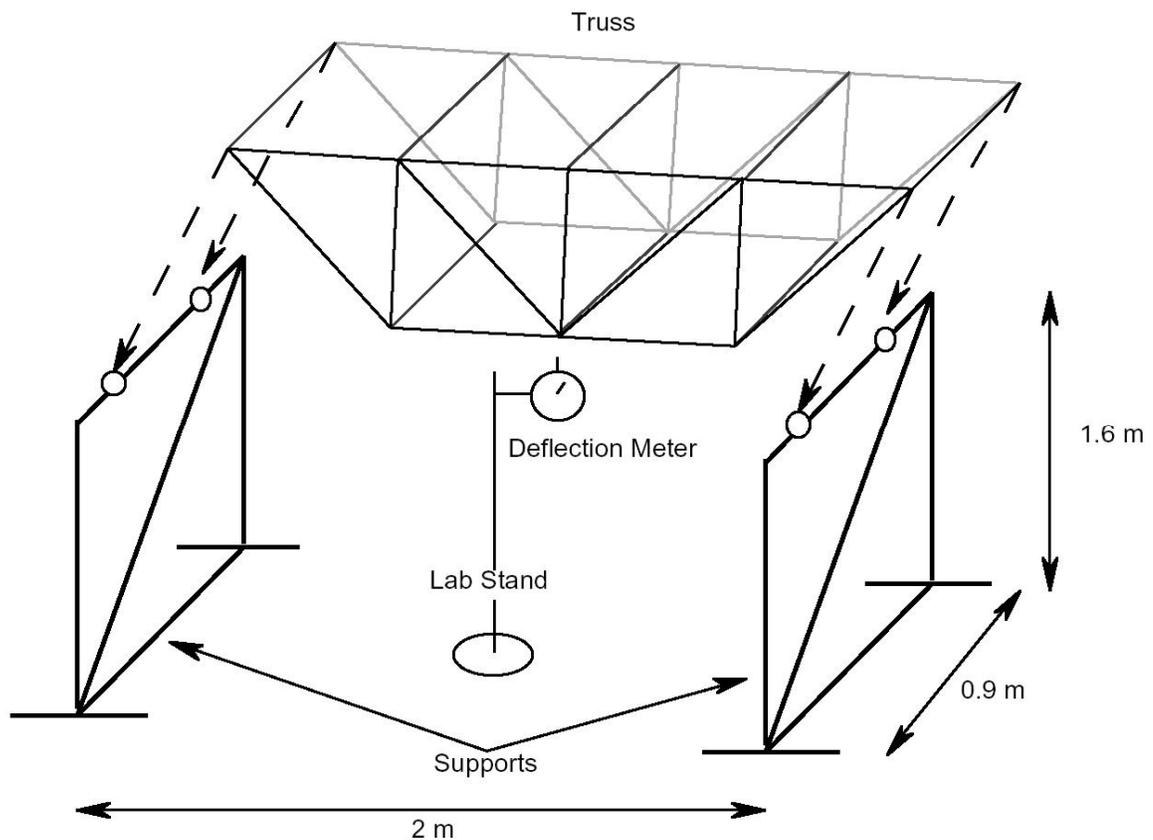


Figure 3. Illustration of experimental supports and truss configuration. Note that the dashed arrows indicate where the truss will actually rest on the supports.

Loading Setup

The truss is loaded using the jack and pulley set-up shown in Figure 4. This set-up is placed at the joints between the second and third bay so that the load is applied at the same point as shown in Figures 2.

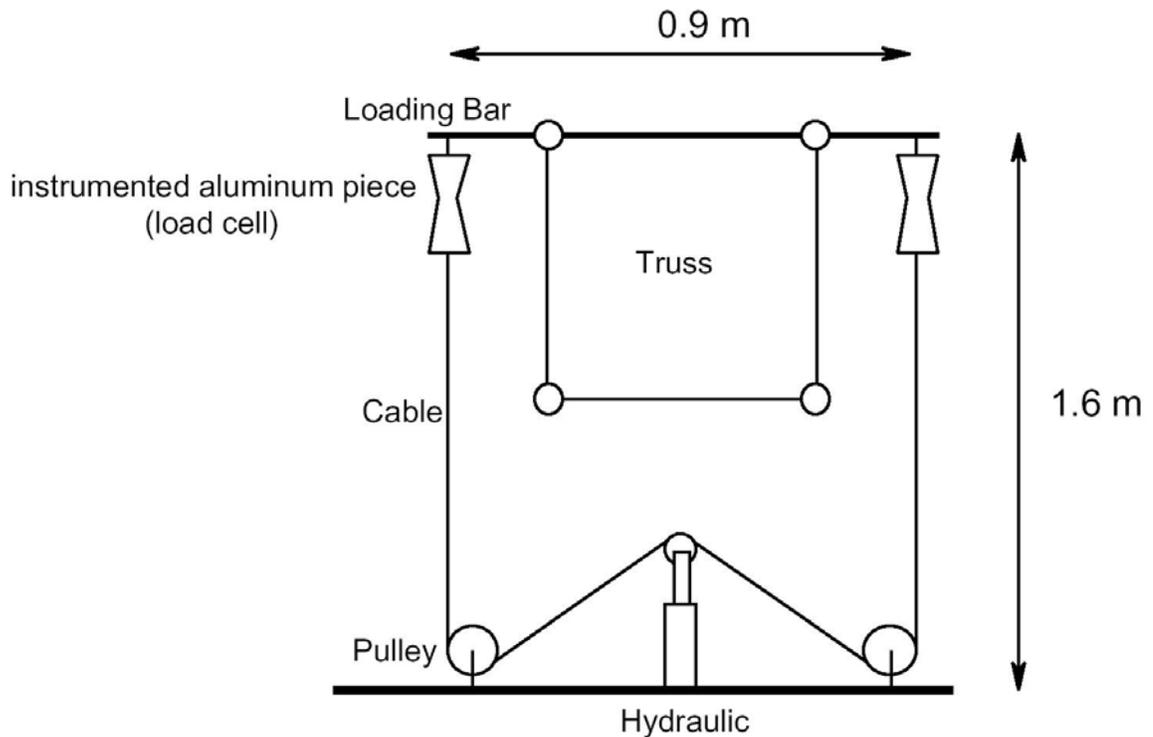


Figure 4. Cut-away side view, at loading point, of experimental loading configuration with jack and cable pulley set-up

Load Cells and Instrumented Bars

In this work we wish to measure the load applied to the overall structural configuration as well as load in specific members of the truss. This is done via an *indirect measurement and calibration technique*.

For the truss, the two load cells (labeled 8 and 9) are attached to the loading bar and to the loading cable and are thus in the line of load on each end. The load cells are instrumented with strain gauges and give a direct reading of the strain. Prior to the assembly of the test setup, calibration curves describing the load versus micro-strain were established by hanging known weights from the strain gauges and reading the output from them. The calibration curves will be handed out at the laboratory. It is important to note that calibration curves should generally not be used beyond the regime where the calibration took place. However, due to the linearity of the calibration curves shown in this case, some *extrapolation*, of the calibration curves is permitted if necessary.

In this way, readings of the strain can be taken and the load on the bar determined from the calibration curve. This then gives the load on that side of the truss. This is the indirect measurement and calibration technique - *we do not directly measure forces, but infer them from the resultant strain*. It is important when using such a technique to occasionally check that the calibration is still valid. This will be done in each case for the load cells.

Three of the truss members (labeled 5,6, and 7 in Figure 2) have also been instrumented to allow you to read the strain that each member experiences when the truss is loaded. These instrumented members were also calibrated in the same way. Once again, strain will be directly measured and load in the members determined from the calibration curves, one for each instrumented member. In this case, since the truss is already assembled, calibration will not be able to be checked.

Strain Gages and Strain Measurement

Strain gages are basically long pieces of a conductor in the configuration shown in Figure 5. The conductor is on a carrier that allows application to the material of interest via an adhesive.

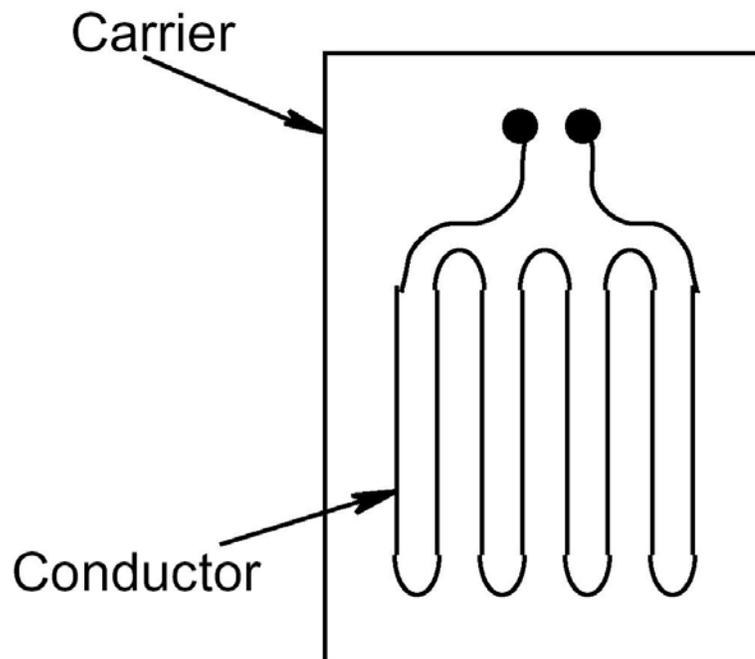


Figure 5. Illustration of strain gage

As the base material, to which the strain gage is bonded, changes length, the length of the strain gage changes. This changes the resistance of the strain gage material (as you learned in Physics). A calibration was done by the manufacturer to determine the relationship between the

change in the resistance of the strain gage and the measured strain. This is the basic concept of the strain gage. These changes in resistance are very small. A special circuit, known as the *Wheatstone bridge*, is utilized to measure the small change in voltage, which is then converted into a displayed micro-strain value.

Deflection Meter

The deflection meter/gage consists of a readout dial with a spring-loaded protrusion. This protruding piece is placed normal to a flat surface at the point where deflection is to be measured. The gauge is rigidly mounted so that deflection is measured relative to a known surface. The spring-loaded piece is preloaded (i.e. placed tightly against the surface so that it already registers a deflection) so that there is no dead space between it and the surface of interest. As the structure deflects, the protruding piece moves, causing the dial gauge to move. The change in this reading gives the deflection of the structure at that point.

Experimental Procedure

The lab takes place in the Hangar at the back of building 33.

The steel truss will be loaded from 0 to 1000 pounds (i.e. 500 lbs per load cell) in ten even increments of 100 pounds. The aluminum truss will be loaded from 0 to 500 pounds (250 lbs per load cell).

At each load level, six readings will be taken: readings of the strain in the two load cells and the three, instrumented members, and a reading of the deflection at the center of the truss. Measurements of micro-strain for each strain gage are obtained using a digital readout box. By setting a dial on the box, you can select which of the strain gages (or load cells) is being displayed on the box. Each strain gage is labeled so you can tell which gage corresponds to which channel on the digital readout box. The instrumented truss members correspond to channels 5, 6 and 7, as shown in Figure 2. The load cell gauges correspond to channels 8 and 9. When reading micro-strain values, be sure to wait until the readout has settled and is showing a relatively constant value. The deflection meter should be set up under the central joint as shown in Figure 3, and should be preloaded as described previously.

Be sure to wear safety glasses in this experiment, since a failure of the loading mechanism or the truss could be dangerous.

The specific steps in the experiment are as follows:

1. Record the zero readings of all instruments at zero load. Because the strain gauges follow a very linear calibration curve, we are interested in changes in the readings of the gages, not necessarily the absolute values. Thus, readings can be taken at zero load and these readings subtracted from readings at the other loads to determine the actual reading. Record the micro-strain readings from each gage and the deflection meter in Table 1 on the Lab Worksheet.
2. Prior to beginning any loading, the calibration of the two load cells (#8 and #9) needs to be checked. Hang a known weight (~ 30 lb) off of each load cell, one at a time, using the hook apparatus provided in lab. Record the micro-strain values for each gauge in Table 2. Check the micro-strain reading you obtain against the expected value for that strain gauge based on the calibration data. Note that because we are only hanging 30 lb off of the load cell, this is not really sufficient to check the entire calibration of the gauge, but it is enough to ensure that the gain or scale setting for the gauge readout has not changed since the calibration was performed.
3. Once the initial zero readings have been taken and the calibration check is finished, begin loading by jacking the load apparatus until the two load cells give a micro-strain reading corresponding to 50 pounds for each load cell (or a total sum of 100 pounds. Remember the assumption of even load distribution with regard to the analytical model. This assumption is also used in terms of load distribution between the two two-dimensional trusses in the experimental apparatus). Record the raw readings of the two load cells (#8 and #9), the three instrumented members (#5, #6, #7), and the deflection meter in Table 3. The zero readings you recorded earlier will be used later to correct these values.
4. Repeat this procedure by increasing the load on each load cell in 50 lb increments up to a total of 500 lb for the steel truss, or 250 lbs in 25 lb increments for the aluminum truss. Do not exceed 500 lb (250 lbs) on each load cell (1000 lb or 500 lb total load) - monitor the load cells while loading the truss. When complete, slowly remove the loading.
5. When the load is again zero, again take readings (record in Table 4). This allows you to check to see if the zero values you originally read/set are again achieved. If not, this gives you some idea as to errors that may have built up within the system.
6. Next, calculate the load applied to each gauge using the data you entered in table 3, correcting with the zero readings from Table 1. Use the calibration data to convert micro-strain into load. Record these load values in table 5.

This ends the in-lab part of the systems problem. You will then need to make a brief write-

up on the lab. The specific steps for this are:

1. Plot the *idea/load* in truss members #5, #6, and #7 vs. the applied load, P , from the analysis that is provided to you of the ideal two-dimensional truss. Plot the load in each member on a separate graph, with the applied load along the x-axis going up to the maximum load applied. Label your axes, including units and use sensible intervals on the axes. You may do this using a computer program, or on graph paper.
2. Next overlay plots of the experimentally-measured load for the three physical truss members (#5, #6, #7) as a function of the applied load on each of the ideal plots. Be careful to distinguish between the experimental data and the results of the model.
Remember that:
3. Plot the deflection of the truss vs. the applied load.
4. Comment on the analytical and experimental results, particularly paying attention to the ability of the analytical model to capture the behavior actually observed (for load only, not the total deflection of the structure). Try to explain any differences by considering possible sources of error in the measurements as well as inadequacies of the analytical model.
5. Write a short report using the material from 2 to 4. Include the attached data worksheet to your write up.

WORKSHEET

The Truss

Zero Readings

Table 1
Raw readings at zero load

Load Cell 8	Load Cell 9	Bar 3	Bar 4	Bar 5	Deflection Meter

Be sure to include proper units!

Load Cell Calibration Readings

Table 2
Calibration readings

Known Load	Load Cell 8	Load Cell 9

Be sure to include proper units!

Raw Test Results

Table 3
Raw experimental measurements

Interval	Load Cell 8	Load Cell 9	Bar 5	Bar 6	Bar 7	Deflection Meter
Units -->						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Put proper units at head of column

Final Zero Check

Table 4

Raw readings at zero load

Load Cell 8	Load Cell 9	Bar 5	Bar 6	Bar 7	Deflection Meter

Be sure to include proper units!

Converted Test Results

Use proper calibration curves attached at the end of this Worksheet

Table 5
Load measurements

Interval	Load Cell 8	Load Cell 9	Bar 5	Bar 6	Bar 7	Deflection Meter
Units -->						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
Rezero						

Put proper units at head of column