# A Simple Experiment to Enhance Student Learning in the Area of Fins

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## Abstract

At Penn State Erie - The Behrend College a project is underway to create a series of laboratory exercises to use in the Heat Transfer lab and the Fluid Power lab for Mechanical Engineering Technology (MET) curriculum. The intent of the exercises is to have simple to understand equipment so that the students can concentrate on the concepts rather than get distracted by the operation of the equipment. These exercises focus on key topics within the course. The exercise described in this paper relates to fin calculations, and the basic concepts affecting the results. This exercise is new, and has only been used one time to date.

This exercise does not simply employ a "cookbook" approach. A pre-exercise worksheet is used to have the students predict results based on an understanding of the theory. After the worksheets are complete the exercise is run and data is collected. A post-exercise worksheet is used by the students to help guide them in the analysis of the data, and to make comparisons with the applicable theory. This paper describes the worksheets, outlines the equipment and exercise and presents an evaluation of the student work for the first in class trial of the exercise. Suggestions for improvements are also discussed.

## Keywords

Fins, heatsink, experiment

## Introduction

Mechanical Technology students at Penn State Erie - The Behrend College tend to struggle with the basic concepts in fluid and thermal science courses. Instructors in these areas have teamed up to develop a group of classroom exercises designed to the students better understand some of these concepts[1]. One of the exercises focusses on fin concepts which is taught in an introductory course in heat transfer. Felder and others have noted that learning individual learning styles need to be recognized when developing educational materials[2,3,4]. The "hands-on" active learning exercises being developed by the authors should be beneficial to students with concrete learning styles. In fact, in general Crouch, et al[5] has shown that having students make a written commitment to their thoughts is a more effective teaching tool than just having them watch a demonstration. This exercise, along with the others under development, follow a simple pattern of a.) student predictions, b.) exercise execution, and c.) post-exercise student calculations and reflection.

These exercises have been modeled after a model for "workshop physics" by P. Laws, D. Sokoloff and R. Thornton[6]. This model provides a suggested general structure as follows:

- Use peer instruction and collaborative work
- Keep students actively involved by using activity-based materials
- Use a learning cycle beginning with predictions
- Emphasize conceptual understanding
- Let the physical world be the authority
- Make appropriate use of technology
- Begin with the specific and move to the general.

With all of this in mind, the intent of this exercise, and the others in the group, is to develop exercises that go beyond simple in-class demonstrations, and to have the students become actively involved in the process. This is one of the exercises that has been tried to date. The first implementation has revealed some strong points which will be kept, and some weak areas that need more development.

## Overview of the exercise

This section provides a brief description of the first trial of this exercise including the concept that is being focused on and the current state of development. The overall plan for development includes three general steps:

1. Clarifying the important concept represented by the exercise, and determining what needs to be presented to the students to help them to understand that concept.
2. Hardware design and manufacture.
3. Creation of the pre and post exercise worksheets.

The objective of this fin exercise is to investigate the heat transfer of a rectangular fin array in a forced convection environment. This includes the predicted axial temperature distribution of a single fin. The prediction is then compared to actual recorded values. Further, a comparison is made between the heat transfer rate at the base of the fin to the rate near the tip of the fin.

The general procedure for conducting the test is as follows:

1. Students are asked to make predictions about the results based on their understanding of conduction in fins.
2. The test is conducted as described below.
3. Students complete a post-exercise worksheet to analyze the results.

The pre-exercise worksheet asks the students to respond to three questions:

1. What will the temperature distribution look like along the fin axial direction?
2. What is the equation for temperature distribution of an adiabatic fin?
3. Describe what happens to the rate of heat transfer along the axial direction of the fin. Explain your thought using a sketch.

After completing the worksheet the test is conducted. The test device is shown in Figure 1. It is comprised of a finned heatsink with thermocouples mounted along the center fin. The thermocouples extend 0.75 inches into the fin to avoid edge effects. Two heating elements are fastened to the bottom of the heatsink, and the entire assembly sits on top of an insulation board.

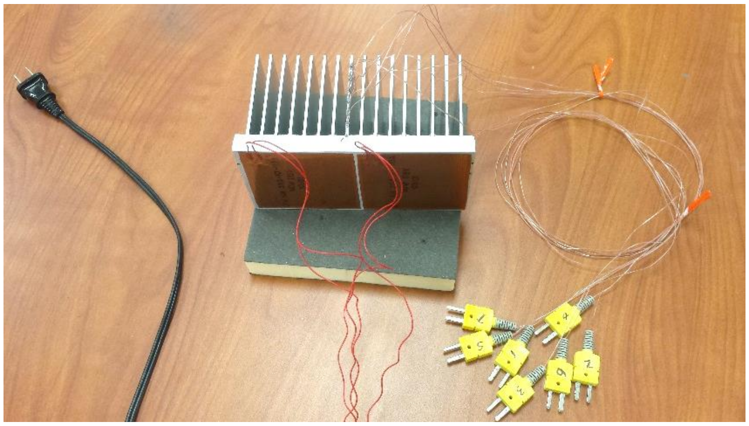

**Figure 1 – Test Apparatus**

The fin array is placed inside a small, homemade wind tunnel. Figure 2 shows a picture of the wind tunnel, and Figure 3 shows the heatsink inside the tunnel and instrumented. The electrical power to the heaters is turned on, and the power input is recorded from a wattmeter. The temperatures of each of the seven embedded thermocouples is recorded after the temperatures reach a steady-state. The test is run for two different air velocities in the wind tunnel.

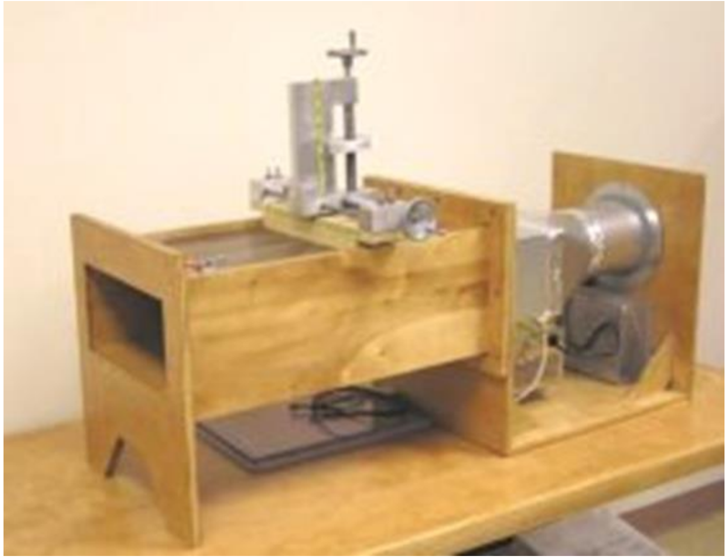

**Figure 2 – Small Wind Tunnel**

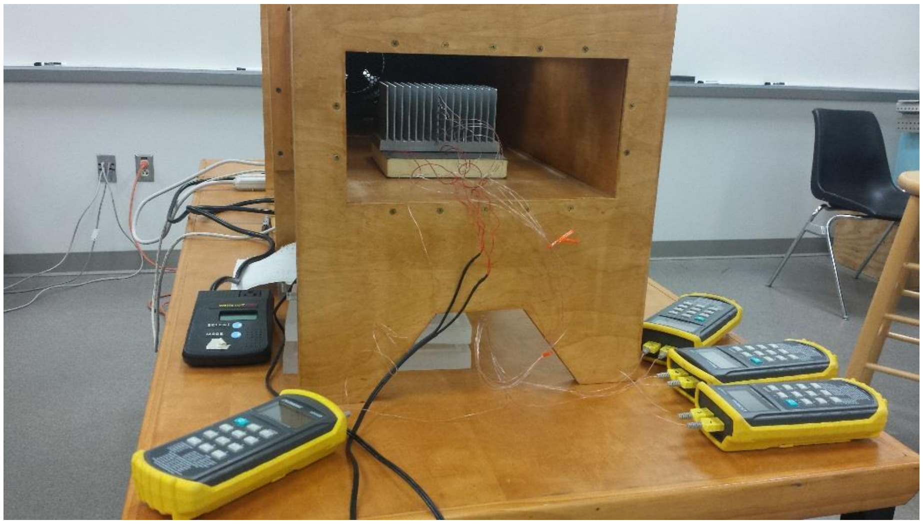

**Figure 3 – Fin Array in Wind Tunnel and Instrumented**

Once the test is completed the students are asked four questions which analyze the results:

1. Determine the average convective heat transfer coefficient on the fin surface.
2. What is the equation for temperature distribution of an adiabatic fin tip?
3. What is the heat flux at the base of one single fin? Use other methods to estimate the heat flux and discuss your results.
4. Compare the heat flux at the fin base to the section near the tip.

## First trial of the exercise

This exercise has been used one time to date during the Spring, 2016 semester. Twelve mechanical engineering technology students were involved. The students were allowed to work together in groups of two to three students. (Past experience has shown that when students work together, and are able to discuss their understanding of the material everyone benefits).

Each of the groups completed their own worksheets, but all of the groups shared the same test data. The apparatus functioned well, and it provided very good data for the students to analyze. Figure 4 shows a plot of the actual and theoretical temperature distribution along the fin. Having a device that produces good results is a very important component of a test designed to enhance student learning. If poor or inconsistent results are obtained it will only confuse the students rather than aid in their learning efforts. All five groups completed the exercise and presented their results in the form of a mini-report.

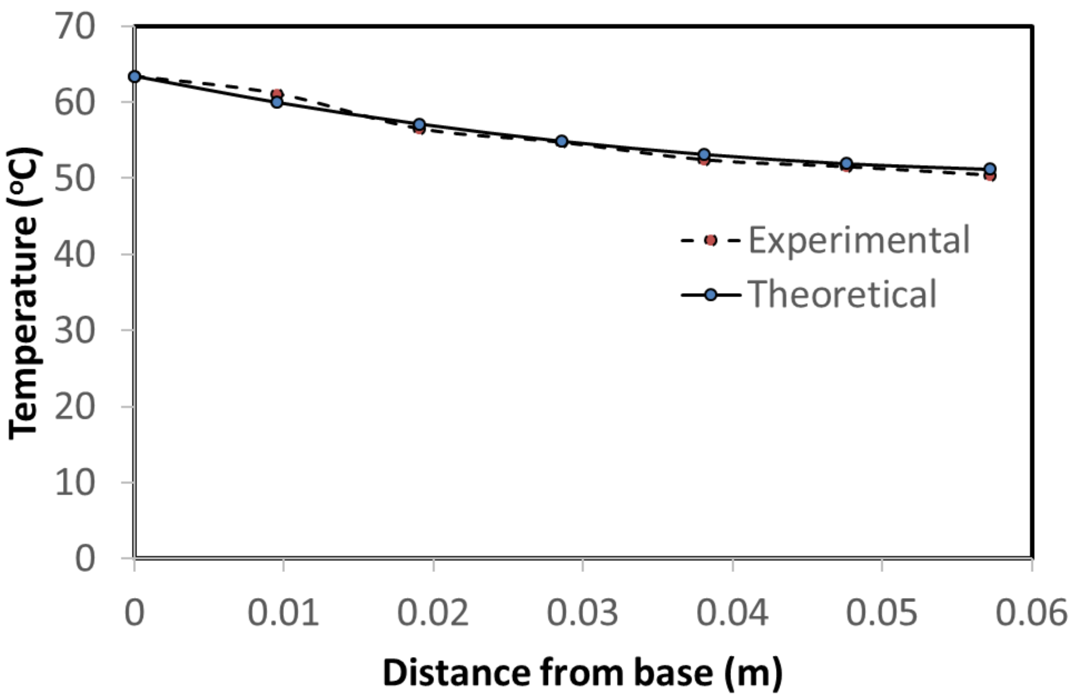


**Figure 4 – Plot of Actual vs. Theoretical Temperature Distribution**

## Assessment of student results

Two groups of three and three groups of two completed this exercise during the first trial. Each group handed in a mini report which included answers for the two worksheets and supporting documents showing their analysis of the results. The mini reports were graded out of 30. The grades are shown on Table 1.

| Group Number | Number of Students | Grade (out of 30) |
|---|---|---|
| 1 | 3 | 30 |
| 2 | 3 | 29 |
| 3 | 2 | 25 |
| 4 | 2 | 20 |
| 5 | 2 | 17 |

**Table 1 – Student Grades**

## Conclusions, recomendations

The first trial of this fin exercise described above was successfully conducted by twelve mechanical engineering technology students. The test clearly revealed some good features of the exercise as well as some areas that need to be addressed for improvement. The exercise was run in the thermal science lab, and not in a classroom as intended, so this discussion includes recommendations for adapting the exercise to a classroom environment. See the appendix for the current exercise write-up.

One of the major concerns was whether or not the apparatus would reliably function as designed. The results showed that everything functioned properly, and excellent temperature profile results were obtained. It provided a solid basis for the students making comparisons with theory. It appears that nothing needs to be improved on the test device itself. The wind tunnel is older and homemade. It has been tested repeatedly in the past to determine if the flow through the test section is uniform, and it shows excellent flow uniformity across the cross-section. In addition to the uniform flow characteristics it is also small enough to be easily moved to and used in a classroom environment. It appears to be a very good choice for this exercise.

The primary need for further development is to make the changes needed to convert this from an in-lab experience to a classroom experience. To accomplish that several areas must be addressed. First, the current lab format is too long for a 50-minute lecture period. This will require that the pre and post exercise worksheets be rewritten. This exercise appears to be a very nice one for use in the lab, so we will be considering the development of an in-class preliminary exercise which is followed up by the current in-lab exercise. This has been done in the past by the author with good success[7]. The classroom version will focus more on the concepts and less on the analysis of the data. The primary challenge is in the design of the worksheets.

Of lesser, but not insignificant concern is the ability to use the equipment in a classroom instead of in a lab. The heater wattage is under 200W which is very feasible in the classroom. The main issue remaining is accessibility for the wind tunnel. It is currently on a table with wheels, so even though getting it to a classroom should not be a problem, the table may not fit in many of the classrooms. It will probably have to be removed from the table and carried into the classroom. It is small enough that carrying it in should also be feasible, but it will have to be tried to know for sure.

Lastly, the current use of digital thermometers to measure the temperatures is very cumbersome for projecting the information to a classroom full of students. A data acquisition system tied to the classroom computer could solve this problem. The logistics of using a system such as that will need to be worked out because the classroom computers are not set-up to handle devices that might be connected to them.

Overall, the issues that need to be solved before moving this exercise to the classroom as intended should not pose much of a barrier to making the transition.

## References:

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## Robert Edwards

Robert Edwards is a Lecturer in the Mechanical Engineering Technology department at Penn State Erie - The Behrend College. He has a BS from Rochester Institute of Technology and a MEng from Gannon University. His fields of interest are in the Fluid and Thermal sciences, specifically Thermodynamics and Heat Transfer. He has worked for many years on designing and implementing active learning experiments for use in both lab settings and classroom settings.

## Liyong Sun, PhD

Dr. Liyong Sun is an assistant professor of engineering at Penn State Erie - The Behrend College. He received his PhD in Mechanical Engineering in 2007 from the University of Minnesota.

## APPENDIX: Lab Write-up for In Lab Exercise

Fin Heat Transfer

DELICATE INSTRUMENT HANDLE WITH CARE

Reading: Before you begin this test, read an introductory chapter on fins (may be called "extended surfaces") in an undergraduate heat transfer text.

Objective:

You will investigate the heat transfer characteristics of a rectangular-fin array in a forced-convection environment. The primary goals of the investigation include:

1. To compare the performance of a single fin to theoretical predictions of the axial temperature distribution.

2. To compare the rate of heat transfer at the base of the fin to the one near the tip of the fin.

Experimental Facility:

Heat transfer from an array of extended surfaces will be studied in a forces convective environment provided by a suction type wind tunnel in the laboratory. There are two heating elements taped at the bottom of an array of fins. Each heater can dissipate up to 90 W. The electrical power consumed by the heater is measured using a wattmeter. The fin array is mounted on top of a roof insulation board. This insulation is assumed to direct all the heat transfer into the fin array.

The fin array is machined from 6061-T6 alloy aluminum having a thermal conductivity k of 167 W/m-K. The central fin in this array is instrumented with seven thermocouples positioned along the axis of the fin, and covering the distance from base to tip. The thermocouples are mounted 3/8 inch apart and 3/4 inch deep into the fin. The entire array is mounted in the wind tunnel to expose the fins to a nearly uniform approaching air flow. Air temperature is also measured.

Recommended Procedure:

1. To evaluate the fin performance over a range of conditions, tests should be conducted in the wind tunnel at two different velocities, one low and one high velocity.

2. Under steady state conditions, record the temperature distribution along the length of the fin.

3. Measure the geometry of the fin array and count the number of fins in the fin array.

Data process:

1. Calculate the average temperature of the fin using the 7 measured temperatures.
2. Calculate the rate of heat transfer of one fin to the air. Use the measured electrical power divided by the number of fins. Why can we do this without causing noticeable error?

3. Estimate the average convective heat transfer coefficient on the fin surface. Use the convective heat transfer equation.
4. Generate the theoretical temperature distribution of a single fin. Use the adiabatic fin tip boundary condition. Use the measured temperature of thermocouple 1 as the base temperature. Why use adiabatic fin tip boundary condition?
5. Compare experimental and theoretical temperature distributions and discuss discrepancies between the two.
6. Heat flux at the base of the fin can be calculated using the conduction equation. Temperatures at 1 and 2, the distance between them and thermal conductivity of the fin will be used in this calculation. Calculate heat flux near the tip of the fin. Use temperatures at 6 and 7. Compare these two heat flux and explain.

Report: Excel print out of experimental and theoretical temperature distributions for both low and high velocities. Post exercise sheet. Original data sheet.

Low velocity

| | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |

High velocity

| | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |

MET331W Heat Transfer Lab

Pre-exercise Worksheet

Fin Heat Transfer

1) What will the temperature distribution look like along the fin axial direction?

2) What is the equation of temperature distribution of adiabatic fin tip?

3) Describe what happens to the rate of heat transfer along the axial direction of the fin. Explain your thought using a sketch.

# MET331W Heat Transfer Lab

## Post-exercise Worksheet

## Fin Heat Transfer

Choose one case, low velocity or high velocity, answer the following questions:

1) Determine the average convective heat transfer coefficient on the fin surface.

2) What is the equation of temperature distribution of adiabatic fin tip? Now all the variables have fixed values.

3) What is heat flux at the base of one single fin? Use other ways to estimate the heat flux and discuss your results.

4) Compare the heat flux at the fin base and the part near the fin tip.