Lab Experiment 4: Measurement of Temperature on a Heated Plate

Section 23L

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Adam VanBuskirk: Procedure, Theoretical Background, Discussion, Conclusion
Brandon Golino: Team Leader, Graphs/Tables, Uncertainty Analysis
Jacob Klofta: Equipment Diagram, Graphs/Tables, Uncertainty Analysis
Kyle Rodriguez: Equipment Operation, Design Objective

Experiment Performed: April 10, 2019
Report Submitted: April 24, 2019

Objectives:

- To investigate and measure transient conduction in an aluminum plate
- Develop a computer model of the plate temperature field and report to a contractor
- Recommend design changes that would protect an instrument attached to the plate

Summary:
In this lab, an aluminum plate is analyzed to investigate and measure the transient two-dimensional heat conduction. The plate was analyzed at different times and temperatures from each of its nodes were recorded.With all this information, we could recommend design changes to protect an instrument attached to the plate. For the answer to the design objective question, we took the conservative approach and used the most limiting set of data, which was the thermocouple data. This led us to recommend that the best location for the specimen to keep it within the temperature limits of 20 and 30 degrees celsius was the top right hand corner of the plate.

Theoretical Background:
The plate used in this experiment is coated with thermochromic liquid crystal (TLC), which are long organic chain molecules that are temperature sensitive. They change color depending on the temperature they are exposed to. This is done by changing molecular structure thus, the wavelength of the reflected light changes. (THC will turn red when cold and blue when hot.)
The plate in this experiment can be modeled as two-dimensional conduction, since the top and bottom surfaces are sufficiently insulated. After, this temperature is dependent on the x, y coordinates, and time. The time dependency can be solved at $T = T_o$ with the initial condition $T_o = T(x, y, 0)$ and the boundary conditions $T_1 = T(L, y, f)$, $q(0, y, t) = -k\frac{\delta T(0,y,t)}{\delta x} = q_1$, and $q(x, 0, t) = -k\frac{\delta T(x,0,t)}{\delta y} = q_2$. This these conditions, k is the thermal conductivity of aluminum plate, T_0 is known, and temperature T_1 and T_2 are assumed to be equal. Therefore, all the boundary conditions and the initial condition are completely determined.
The heat conduction law may be written as $\square^2 T = \frac{\delta^2 T}{\delta x^2} + \frac{\delta^2 T}{\delta y^2} = \frac{1}{\alpha}\frac{\delta T}{\delta t}$, where α is the thermal diffusivity of the plate. Solve for the transient conduction equations using a numerical technique.

Equipment:

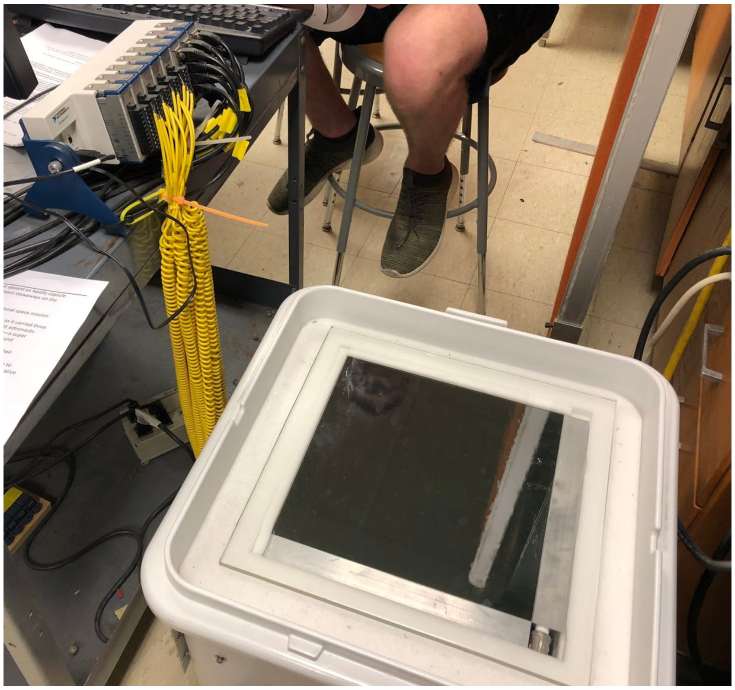

Figure 1: Aluminum, TLC-coated 12” x 12” x 2” test plate and monitoring station

Figure 2: Control box showing the constant voltage and amperage

The plate is surrounded on two sides by heaters providing constant heat flux, while the remaining sides are kept at a constant temperature, regulated by a cooled chiller. A thermochromic liquid crystal sheet attached on top shows the temperature distribution.

Procedure:

First, record the initial plate temperature by cycling through the thermocouples; this provides the initial condition for your numerical simulation. Second, set the chiller temperature to 20°C and start the flow through the heat exchangers. This simulates cabin temperature with the T_1 and T_2 boundary conditions. Next, set the rheostats to provide a desired value of q_1 and q_2 in order to obtain maximum color play in the TLC sheet. Record the voltage and amperage. Last, record the temperatures form all the thermocouples every five minutes until steady state is reached.

Results:

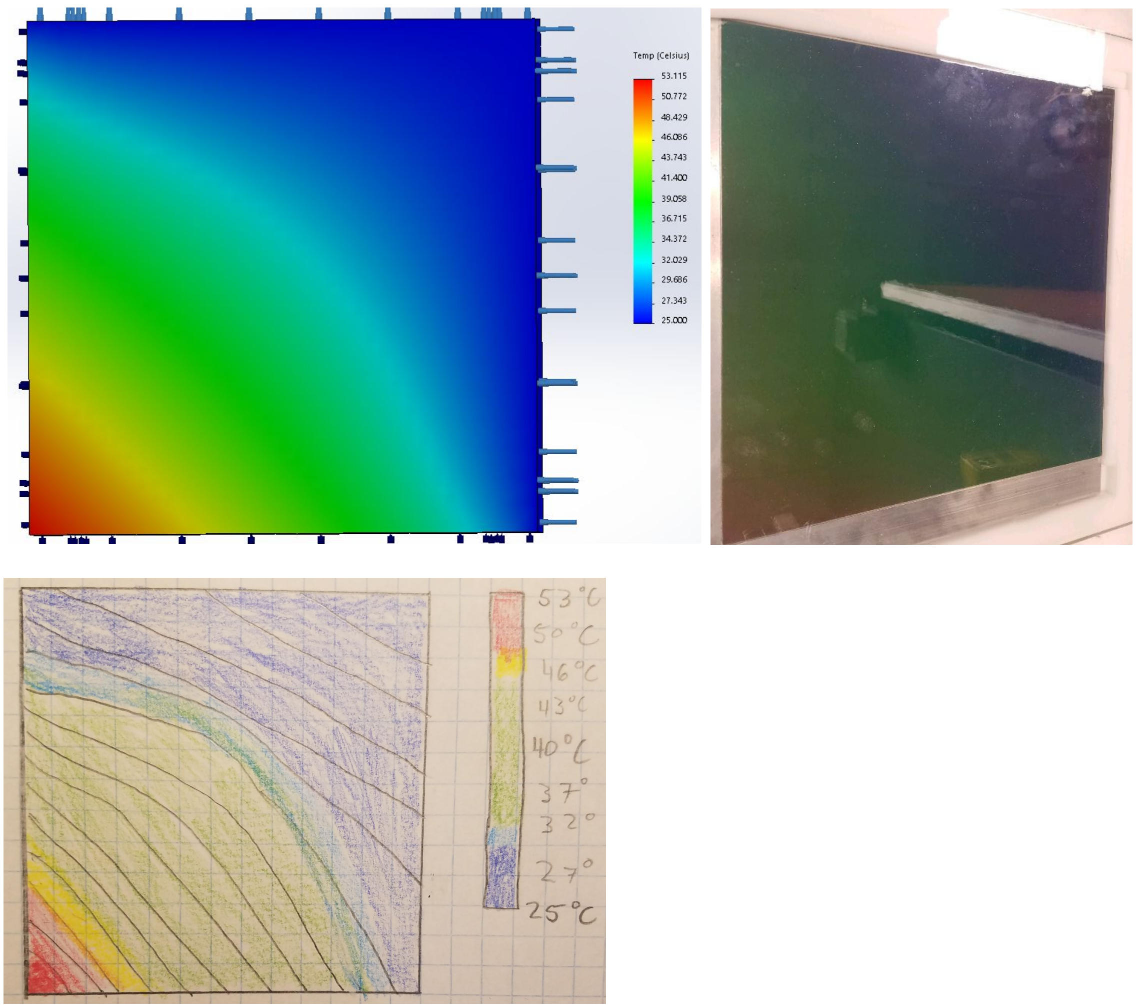

Figure 3: Solidworks thermal analysis compared to actual test plate at steady state temp and hand-drawn sketch of contours based on experimental data

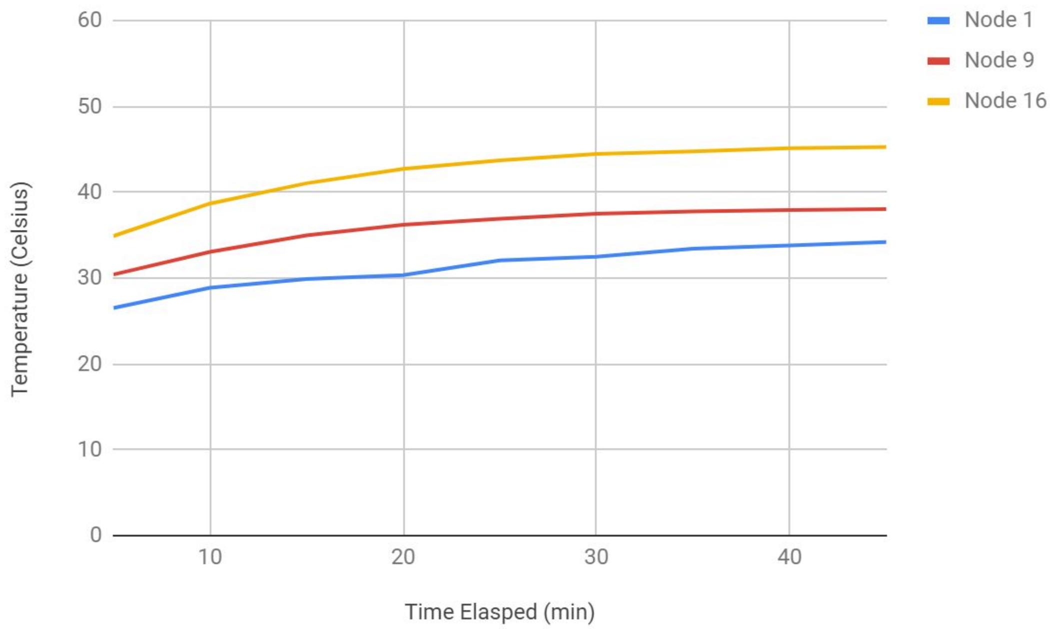

Figure 4: Comparative plot of the temperature vs. time for several thermocouples

Uncertainty Analysis:

Thermocouple	Experimental Temp (°C)	Calculated Temp (°C)	Error
1	34.196	30.017	17.489
2	37.428	28.331	82.755
3	38.384	27.070	128.007
4	27.943	25.787	4.648
5	41.017	35.747	27.741
6	37.616	32.682	21.680
7	34.624	29.846	22.829
8	32.105	26.830	26.884
9	45.259	41.544	13.801
10	41.752	27.239	210.627

11	38.174	32.528	31.877
12	34.045	28.110	35.224
13	49.277	48.038	1.535
14	45.781	41.978	14.463
15	42.096	35.861	38.875
16	38.041	30.608	55.249
		Sqrt(sum(errors))	27.087

Table1: Uncertainty Analysis for Steady-State Temp

Error was calculated using the root mean square method. An unusually high error is seen here, and some of the experiment data appears to be an issue. Some of the thermocouples were reading at temperatures that were not consistent with the visual results. For example, T3 is hotter than T2, which should not be possible in the given loading condition. We can note however that the maximum node temperature was consistent in both the experiment and the calculations.

Discussion & Conclusion:

In order to convert the TLC results to quantitative data, the thermocouple readings need to be compared to the colors of corresponding temperatures, then extrapolated to assign temperature values to accurately describe the color distribution. Doing this is not necessary first due to having the data from the thermocouples at various times. In addition, this process estimates, which adds error to the data.

The discrepancies between the sets of data are due to boundary conditions, light pollution on the TLC, and distortion in the photos. The error between the actual and desired heater output and the constant temperature produced by the chiller is a result of the circulating water heating up.

Shown in the SolidWorks model and the results, the temperature distribution flows from bottom left (hotter) to the top right (colder). Despite the model and the results having similar patterns, discrepancies are due to outside factors acting on the experimental model whereas the computer model is calculated using ideal conditions.

In order to create a more uniform, cooler surface, the plate should be covered with an insulating material and another plate should be added. This will increase thermal resistance, effectively lowering the temperatures across the added plate. This is done by increasing the resistance of the heat source before it reaches the sensitive plate.. Another way to make a more uniform, cooler surface includes, attaching another plate in a way where it is raised off the wall creating an air gap which allows air current through the cabin. This will convect heat away from the plate on the wall before it reaches the sensitive plate.

Design Objective Analysis:

1. Our results and analysis lead us to recommend to NASA that the best location to place the instrument package so that it protects the specimen is in the top right corner of the plate. This part of the plate was the largest area that stayed within the required boundaries. This was because of the proximity to the lower constant temperature boundary conditions and the distance from the heat flux boundary conditions of the plate. Placing the instrument plate here will result in the specimens staying in the container, alive, and protected.

Appendix A: Lab Roles

Lab Section 023L - A1 Experiment # 4 Date 4/10/19

Note: Roles must be agreed on before work starts. Every team member must be represented. It is a commitment. The roles should be rotated for each experiment. Each role in principle has a specific contribution (page or paragraph) to create for the report.

	Name
Team Leader/ Coordinator	BG
Theoretical and Procedure write up	AV
Equipment operation (1 or more)	KR
Data recorder	Jon S
Equipment diagram (sketch or photo. Include instrumentation)	JK
Graphs, data tables for report (2 people)	JK/BG
Data & Uncertainty analysis for report (2 people)	JK / BG
Discussion and Conclusion	AV
Summary Letter	Jon S
Report typing and compilation	KR
Design Objective Analysis (2 people)	AV/KR

TA initial CL

Appendix B: Figures

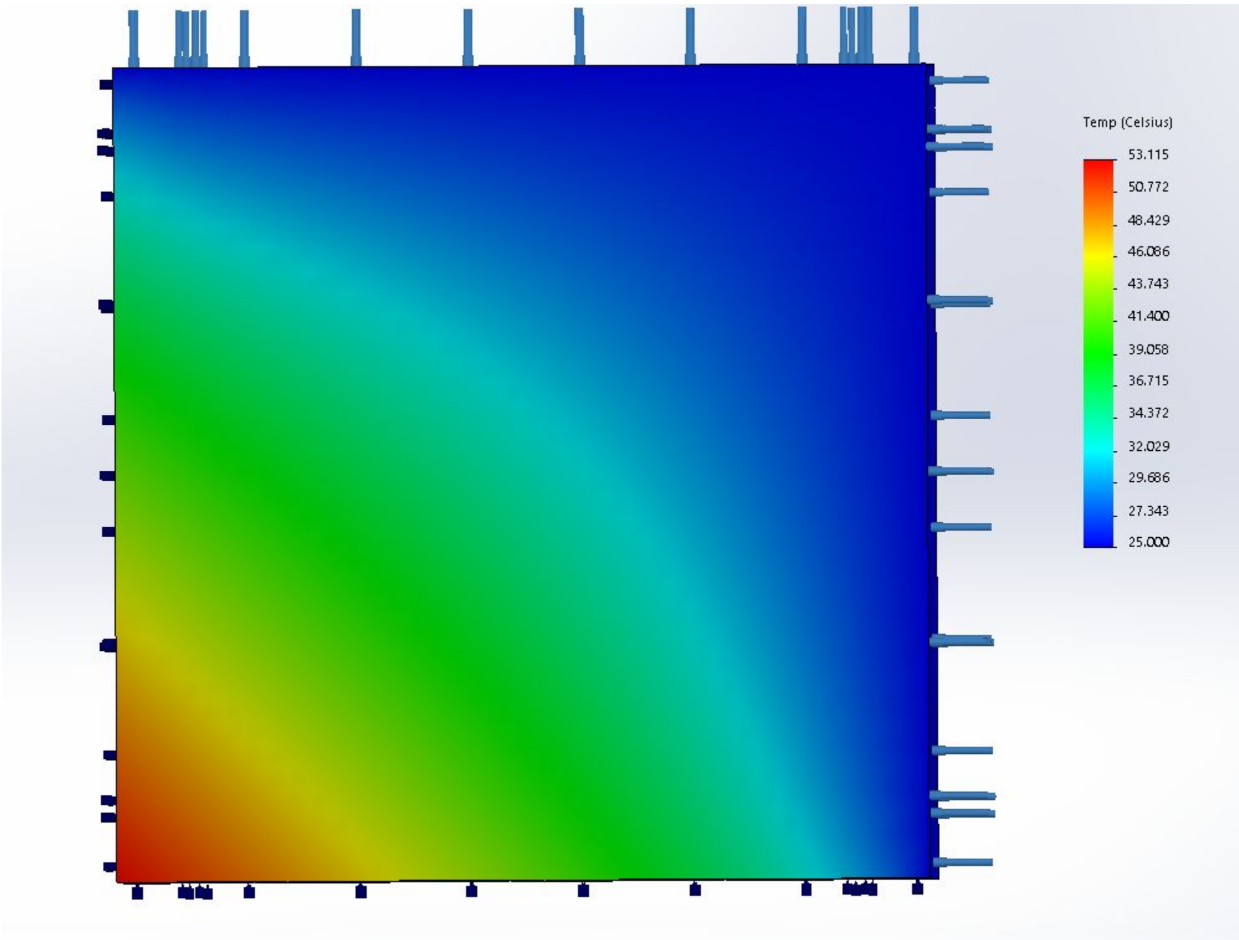

Figure 5: Solidworks thermal analysis done on a similarly dimensioned aluminum plate. Boundary temperatures were 25C, and the total heat was calculated to be 423W from the given readouts.