EA467 Thermal Lab Fall 2006

The spacecraft thermal environment is very dynamic. Temperatures of spacecraft external surfaces can vary widely between those exposed to the sun and those exposed to the deep space background. Large temperature changes also can occur over short periods of time as spacecraft enter and leave eclipse. Spacecraft engineers must design the spacecraft Thermal Control System (TCS) to manage these large temperature swings such that payload and bus systems remain within allowable operational temperatures. Spacecraft batteries, sensitive communications and cryogenically cooled sensors must be kept within narrow temperature ranges while spacecraft are exposed to the following:

Energy Inputs:

- Solar Radiation
- Earth Albedo (reflected solar radiation)
- Earth Infrared (IR)
- Heat dissipation from spacecraft payload and bus systems

Energy Outputs:

- Spacecraft IR emission
- Emission at surfaces of radiators can be enhanced by heat pipes, conductive doublers and phase change materials.

Purpose: This laboratory will use our LABsats and other props to demonstrate all heat transfer mechanisms; conduction, convection and radiation by simulating spacecraft panels and radiators as well as pumped fluid loops. The focus is removing heat from electronics dissipating energy in the spacecraft. The electronics power dissipation will be simulated using strip heaters adhered to different surfaces. Strip heaters of this type are also used in thermal testing of spacecraft to simulate thermal inputs. The spacecraft panels will be simulated using 1/16 inch aluminum plates and the pumped fluid loop will be simulated using electronic heat sinks.

Part A. Heating in One Atmosphere:

There are two 2 inch by 2 inch pieces of 1/16 inch thick Aluminum embedded in a thermal insulator with one exposed free surface on the side of a LAPsat as shown in Figure 1. Resistive heater strips mounted to the underside of the plates will heat the plates initially. Temperatures will be measured by telemetry from a thermister mounted directly to the underside of the Aluminum. Upon reaching a nearly steady-state condition, a heat lamp will be turned on to further heat up the plates.

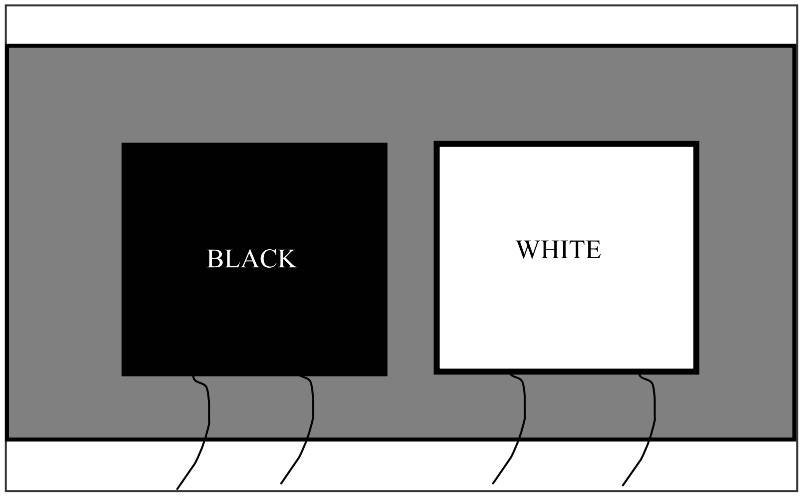

Figure 1. Aluminum plates mounted in insulation

Procedure: Select three volunteers to operate the lab apparatus. One will turn on/off heaters and lamps, one will keep time and read temperatures from the rotary dial thermocouple reader/thermometer and the third will record the data. Note the numbers on the dial and adjacent to the AL plates.

1. Record initial temperatures of all plates and room temperature.
2. Turn on the power supplies connected to the strip heaters simultaneously and immediately begin recording temperatures.
3. In the first five minutes you will need to record temperatures every 15 seconds.
4. You may reduce the measurement periodicity after the plates have completed the fastest part of the transient. Start with 30 seconds and then reduce to a measurement every minute.
5. Continue recording data until the temperatures reach steady state.

Note: Turn off the heaters and cool down the plates to room temperature.

<u>Part B. Heat Transfer in a vacuum:</u>

Repeat Part A except in a vacuum. Upon reaching a steady temperature, you will turn on a heat lamp.

1. Place samples in a vacuum as shown in Figure 2. This eliminates the effects of convection and since there is little conduction to their mounting system, the only heat transfer is via radiation.
2. Lower the bell jar and activate the vacuum pump. Operate the pump until the vacuum is less than 1000 microns and record temperatures as done in steps *1 through 5 of Part A*
3. Leaving the *power supplies on*, *turn on the lamp* and repeat step 3, 4 and 5 above in Part A.

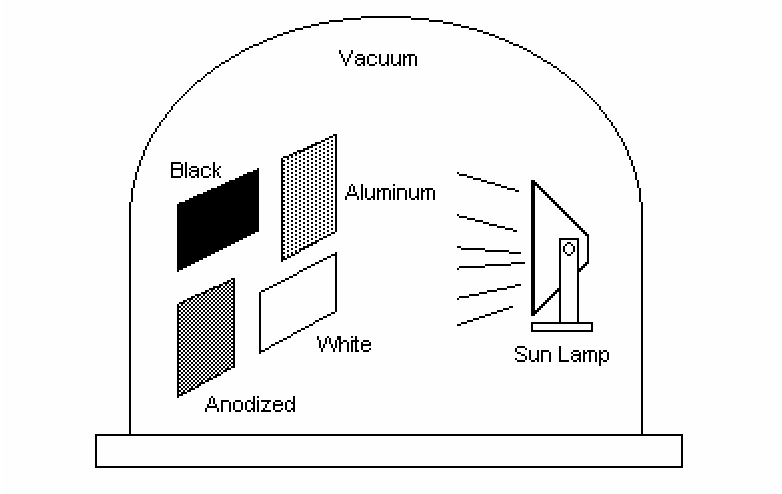

Figure 2. Radiative Heating in Vacuum

Part A and B Post Laboratory Questions:

1. The heaters used for this experiment are listed below. Use the power supply settings to comment on the actual input thermal power to the experiment plates. The power supplies are connected in series and the heaters are connected in parallel. Does this heater power correlate to the stated wiring plan? How does this relate to the heater strip specifications listed in Table 1 below?

Table 1. Heater specifications from OMEGA Engineering

Without PSA Model No.	With PSA Model No.	Width, In.(cm)	Length, In.(cm)	Total Wattage for Watt Density		
				$2.5W/in^2$	$5W/in^2$	$10W/in^2$
SRFG-202/*	SRFG-202/*-P	2(5)	2(5)	10	20	40

Source: http://www.omega.com/pptst/SRFR_SRFG.html

2. Based on the plate and room temperatures calculate the free convection heat transfer coefficient using correlations provided pre-laboratory (note: It should be between 7-8 watt/m^2-K depending on the plate area).

Steady State Measurements (w/o lamp) – in one atmosphere and vaccum:

3. Starting with the 2 in. by 2 in. black plate and assuming an emissivity of 0.9 (or use Table 2 below), determine the heater power to obtain the surface temperature at steady state before turning on the lamp. Compare this value to the heater power determined in question 1 above. Can you think of any reason why these values differ? Is all the heat from heater going into the Al plate? How accurate is your convection estimate? How can you check the convection heat loss?

4. Using the results from 3, estimate the emissivity of the other plate (white). How does this compare to table 2?

Steady State Measurements (w/lamp) – in vacuum:

5. Examine the steady state temperatures for the 2 in by 2 in black plate using the lamp and heater combined. Assuming an absorptivity of 0.9 (or use Table 2 below) and using the area of the plate, determine the lamp flux in watts/m^2.

6. Using the estimate of lamp flux from question 6, determine the absorptivity values for the white plate. How do these correlate with the solar absorptivity values found in Table 2 below? What could cause the experimental values to be different?

Table 2. Surface Radiative Properties

Surface	**Asborptivity** α_{solar}	**Emissivity** ε_{IR}
Black Paint	0.975	0.874
White Paint (enamel)	0.252	0.853
Polished Aluminum	0.2	0.031
Aluminum (as received)	0.379	0.0346

Source: SMAD 3^{rd} Ed., Table 1-44, p-437

Transient Heating (heating w/o lamp): – in one atmosphere and vaccum:

7. Plot the transient data from the black and white plates. Comment on the results. Why does one heat faster than the other does?

8. Using the convection heat transfer coefficient from above, estimated emissivities and heater power, model the system by forming a 1^{st} order ODE initial value problem and solve it using a Matlab™ ODE solver.

9. Plot your solutions with the experimental curves. How does your solution compare to the experimental data? Does your model predict the calculated and experimental steady state temperature and the time required to reach steady state? Also:
   a. What is the time constant for the experimental data? Compare τ_t for the black and white plates.
   b. What percent of the predicted steady state value should be obtained to determine this time?
   c. How much would you expect the heat transfer coefficient change if you used variable properties?

Transient Heating (heating w/ lamp): – in vacuum:

10. Using the steady temperature for heating without the lamp (the temperature it reached before turning on the lamp) as your initial condition, repeat steps 7, 8 and 9 above.

Transient Cooling in One Atmosphere and Vacuum:

11. What was the vacuum pressure you recorded above? To what altitude does it correlate? Space conditions are simulated in vacuum chambers that can attain much lower pressure than our Bell Jar. How does this vacuum pressure compare? What is the significance of this information?

12. Use your ODE solution above with the initial condition(s) as the highest temperature reached in one atmosphere and vacuum. Determine the time required to reach steady state in one atmosphere and vacuum. What is the significance of this difference to spacecraft design and operations?

Laboratory Report: For your report you must do the following: Prepare a team laboratory report following the departmental guidelines for formal reports (2 person team).

- Use a standard report cover page.
- Include a Table of Contents.
- Describe the laboratory's purpose, apparatus, procedures, results and conclusions.
- Briefly describe the laboratory setup, including a block diagram.
- Answer the "Post-Lab" questions. Include all figures, data tables, and graphs and fully integrate these "Post-Lab" questions into your results section.
- Summarize your conclusions and discuss how well the theory supports the observations.
- Include a bibliography.
- Make specific comments concerning knowledge gained, the knowledge's suitability for naval officers, and the laboratory's value as a learning tool. Recommend any improvements to the laboratory.

References:

1. Larson, W. J. and Wertz, J. R. *Space Mission Analysis and Design*, 3rd Ed., Microcosm Inc., 1999.
2. Incopera, F. P., DeWitt, D. P., *Introduction to Heat Transfer*, John Wiley and Sons, 2nd Ed., 1990.
3. Holman, J. P., *Heat Transfer*, McGraw Hill, 8th Ed., 1997.
4. Agrawal, Brij N., *Design of Geosynchronous Spacecraft*, Prentice-Hall, Inc., 1986.