

# Space Hardware Experiment Design

ASEN5519-002

## Midterm

Name: \_\_\_\_\_ Date: \_\_\_\_\_  
 Identifier \_\_\_\_\_

*Note: You may have to make assumptions (and properly state those) to solve the problems (that's life). Not all required information may be given. If in doubt, simplify with real life assumptions / good sound engineering practice / rules of thumb. This test is meant to be easy. Don't hesitate to ask questions (303) 492-5875 or email (hoehn@spot.colorado.edu) if you get stuck.*

### **1. Heat Transfer:**

Your experimental samples are transported aboard the Space Shuttle to the International Space Station (ISS) in a temperature-controlled incubator. The incubator uses power to heat or cool the incubator to maintain a setpoint of 18°C. The incubator is insulated using  $t=0.0126$  m thick foam ( $t = 1/2''$ ;  $k = 0.035 \text{ W m}^{-1}\text{K}^{-1}$  thermal conductivity). The total surface area of the incubator exposed to the ambient temperature of the Shuttle / ISS cabin is  $A = 1.00\text{m}^2$ . Due to air circulation and locker movement during transport between the Shuttle and the ISS, you can assume a convective heat transfer coefficient of  $5.0 \text{ Watt / (m}^2 \text{ K)}$  between the locker and the air.

The incubator consists of aluminum ( $m_{\text{al}}=10\text{kg}$ ,  $C_{p_{\text{al}}} = 912 \text{ J kg}^{-1}\text{K}^{-1}$ ) and is filled with aqueous samples ( $m_{\text{H}_2\text{O}}=10\text{kg}$ ,  $C_{p_{\text{H}_2\text{O}}} = 4183 \text{ J kg}^{-1}\text{K}^{-1}$ ). There is perfect (infinity) thermal conductivity between your samples and the incubator wall (i.e., the inner temperature of aluminum and aqueous samples = inner wall temperature of the insulation). Assume thermal conductivity through the insulation and convective heat transfer between cabin air and the surface of the insulation is the only heat transfer, and assume that the thermal heat transfer is through a flat plate of  $A=1.00\text{m}^2$ . (don't worry about the box, edges,...). There is infinite thermal conductivity in the aqueous solution and the inner aluminum walls (i.e., the internal temperature is uniform throughout).

During the transfer between the Shuttle and the ISS, your payload has no power. Therefore you cannot control temperature. You will lose your science if the temperature deviates more than 1°C from the setpoint of 18°C.

1. As a function of time ( $t$ ) and the ambient cabin temperature (30°C), calculate the temperature increase as a function of time of your samples, starting at the initial temperature of 18°C. How long will it take to warm the samples to 19°C ?

Here are some hints: (unless you want to calculate a second order differential equation), you need a spreadsheet or similar; you have to integrate / iterate over time (use  $\Delta t_i = 30$

sec intervals maybe) and you have to do it simple and fast (mission control is waiting for an answer how much time the astronauts may take to complete the move).

Remember:

$$T_{\text{ambient}} = \text{constant} = 30^{\circ}\text{C}$$

$$T_{\text{experiment}(t)} = T_i \text{ (changes with time as it warms up), } T_0 = 18^{\circ}\text{C}$$

$$Q_i = \frac{(T_{\text{experiment}(t)} - T_{\text{ambient}})}{\frac{1}{h_1 * A} + \frac{t}{k * A}} = \frac{(T_{\text{experiment}(t)} - T_{\text{ambient}})}{R_1 + R_2}$$

$$Q_i = (R_1 + R_2)^{-1} * (T_{\text{ambient}} - T_i)$$

$$[W=J/s = W / K * K]$$

$$\Delta H_i = Q_i * \Delta t_i \quad \Delta H_i = m * C_p * \Delta T_i \quad \text{Change of energy per time step}$$

$$[J = J/s * s]$$

$$m * C_p = (m_{\text{al}} * C_{p\text{al}} + m_{\text{H}_2\text{O}} * C_{p\text{H}_2\text{O}}) \quad \text{thermal mass in [J/K]}$$

$$\Delta T_i = \Delta H_i / (m * C_p) = Q_i * \Delta t_i / (m * C_p)$$

Hint:

at  $T_0=18^{\circ}\text{C}$  /  $T_{\text{ambient}} = 30^{\circ}\text{C}$ : should be around 50 minutes.

$T_0$	$T_{\text{ambient}}$	Time to reach $19^{\circ}\text{C}$ (sec / hh:mm:ss)
$18^{\circ}\text{C}$	$30^{\circ}\text{C}$	t =

If you had to do this again (transporting an experiment to the Space Station), and you want to be able to 'survive' longer periods without power at a desired temperature, what would you do (no power, longer duration at target temperature, simple, )

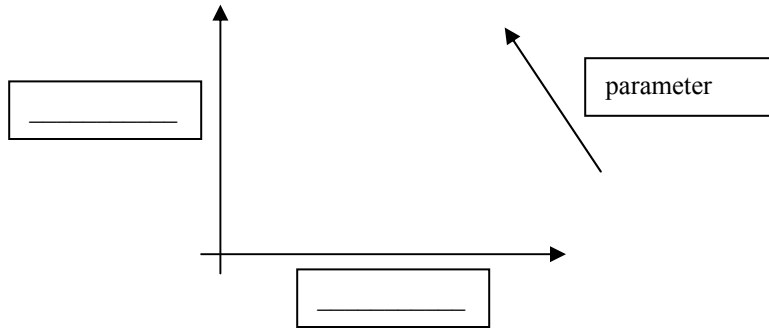
I would add / use \_\_\_\_\_

for passive temperature control (no power), in combination with better \_\_\_\_\_  
 \_\_\_\_\_ to extend the period. According to some class notes, some transport containers were able to maintain temperature for 1-2 weeks without power using these techniques.

**3. Little Things to Know**

Please answer as many questions as possible in very concise form (i.e. keywords, basic relationships, essentials). No essays / full sentences required ! Don't get scared - it's possible that you don't know everything and still be a damn good engineer !!

1. What is an independent and a dependent variable ? What is a parameter. Answer by labeling the axis of the graph below and add a view lines to show example relation between dependent, independent variable and parameter.



2. What gravity conditions exist in an orbiting spacecraft. Explain 'microgravity' vs. 'zero gravity' in 1-3 words.

Spacecraft = \_\_\_\_\_,

Microgravity ≠ Zero-G, because: \_\_\_\_\_

3. How can one simulate 'spaceflight gravity conditions' on Earth. For how long ?

\_\_\_\_\_ = \_\_\_\_\_ a few sec (typically)

\_\_\_\_\_ = \_\_\_\_\_ 10-20 sec

\_\_\_\_\_ = \_\_\_\_\_ up to 15 min

4. What are the essential (life-supporting) needs required for plant growth ?

\_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_

5. What are some rationales / justifications for growing plants in space (science, applied)?

1 \_\_\_\_\_, 2 \_\_\_\_\_,

3 \_\_\_\_\_, 4 \_\_\_\_\_

6. List some of the key technologies for plant growth in space that are more 'complicated' or different in the microgravity (physical) or spaceflight (policies, physical) environment when compared to growing plants in a research laboratory (not field study) ?

\_\_\_\_\_ , \_\_\_\_\_ , \_\_\_\_\_ , \_\_\_\_\_

7. List some of the key technologies for animal (example mouse or rat) research in space that are more 'complicated' or different in the microgravity (physical changes) or spaceflight (policies, physical) environment when compared to animal research in a university laboratory ?

8. What is relative humidity, moisture content, dew point ? Given a fixed amount of moisture (g H<sub>2</sub>O) in a fixed amount of air (g air), what affects relative humidity (i.e.  $rH = f(????)$ )?

RH [\_\_\_\_\_]: \_\_\_\_\_

Moisture [\_\_\_\_\_]: \_\_\_\_\_

Dew Point T [K, °C]: \_\_\_\_\_

9. Plant lighting: what's important (i.e., what measurements characterize the light environment perceived by plants?

\_\_\_\_\_ [nm], \_\_\_\_\_ [watt] , \_\_\_\_\_ [h/day]

10. Energy and Mass conservation: what goes in has to come out: how much heat does one have to reject from a human being consuming 2,500 kilo-calories (or roughly 10,000,000 Joules per day, assuming the human being is at thermal steady state (doesn't grow and doesn't warm up).

$Q = E / \Delta t =$  \_\_\_\_\_

10 b) Inverse: if a mouse gives of 4 Watt of heat, how many calories do you have to feed that mouse every day ?

10c) By what different means does that heat get rejected from the body (don't forget: Fido's panting – why ?)

1. \_\_\_\_\_ 2 \_\_\_\_\_ 3 \_\_\_\_\_ 4 \_\_\_\_\_

11. How much heat can a mass flow (water flow, air flow) transport, given the properties of the mass flow (flow rate, heat capacity, inlet / outlet temperature) ? What are the units for energy, heat, power ?

E = \_\_\_\_\_ [ \_\_\_\_\_ ]

Energy [ \_\_\_\_\_ ], heat [ \_\_\_\_\_ = \_\_\_\_\_ ], power [ \_\_\_\_\_ = \_\_\_\_\_ ]

12. A middeck locker aboard the Space Shuttle can have as much as 130 Watts of electric power. Why not more ? What limits the use of additional power ? What provisions would have to be made to provide more power to an experiment ?

**13. Plant Growth in Microgravity – Typical ‘State of the Art’ Spaceflight Plant Growth Chambers:**

The PGBA utilizes cabin air to replenish \_\_\_\_ (gas) to and to remove \_\_\_\_ (gas) from the plant growth chamber. Other payloads use pressurized \_\_\_\_ to provide a controlled environment for photosynthesis. The levels of \_\_\_\_ (gas) on Earth are around \_\_\_\_ ppm (standard Earth levels), while the crew cabin can be as high as \_\_\_\_ ppm,. Trace gases such as hydrocarbons (contaminants, offgassing), especially \_\_\_\_\_ (gas, a plant hormone), can have large effects on plant growth and have to be controlled. This can be accomplished using a \_\_\_\_\_.

At night, low light, or during germination, plants produce \_\_\_\_ (gas) and need \_\_\_\_ (gas) for their metabolism.

In order to not exceed toxic levels of this gas in the plant chamber, one can control / limit the level of this gas at night using \_\_\_\_\_.

Spaceflight plant growth chambers available to date only provide a growth area of about \_\_\_\_ x \_\_\_\_ x \_\_\_\_ inches / cm. To supply a human being with all food, oxygen, and CO2 scrubbing, an area of 25 – 100 m<sup>2</sup> is required.