LTA 6

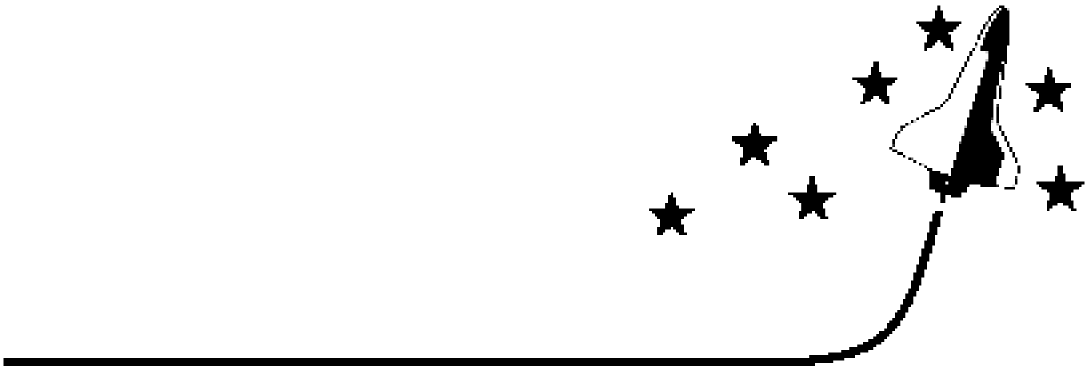
NASA - AMATYC - NSF
Project Coalition

Kennedy Space Center

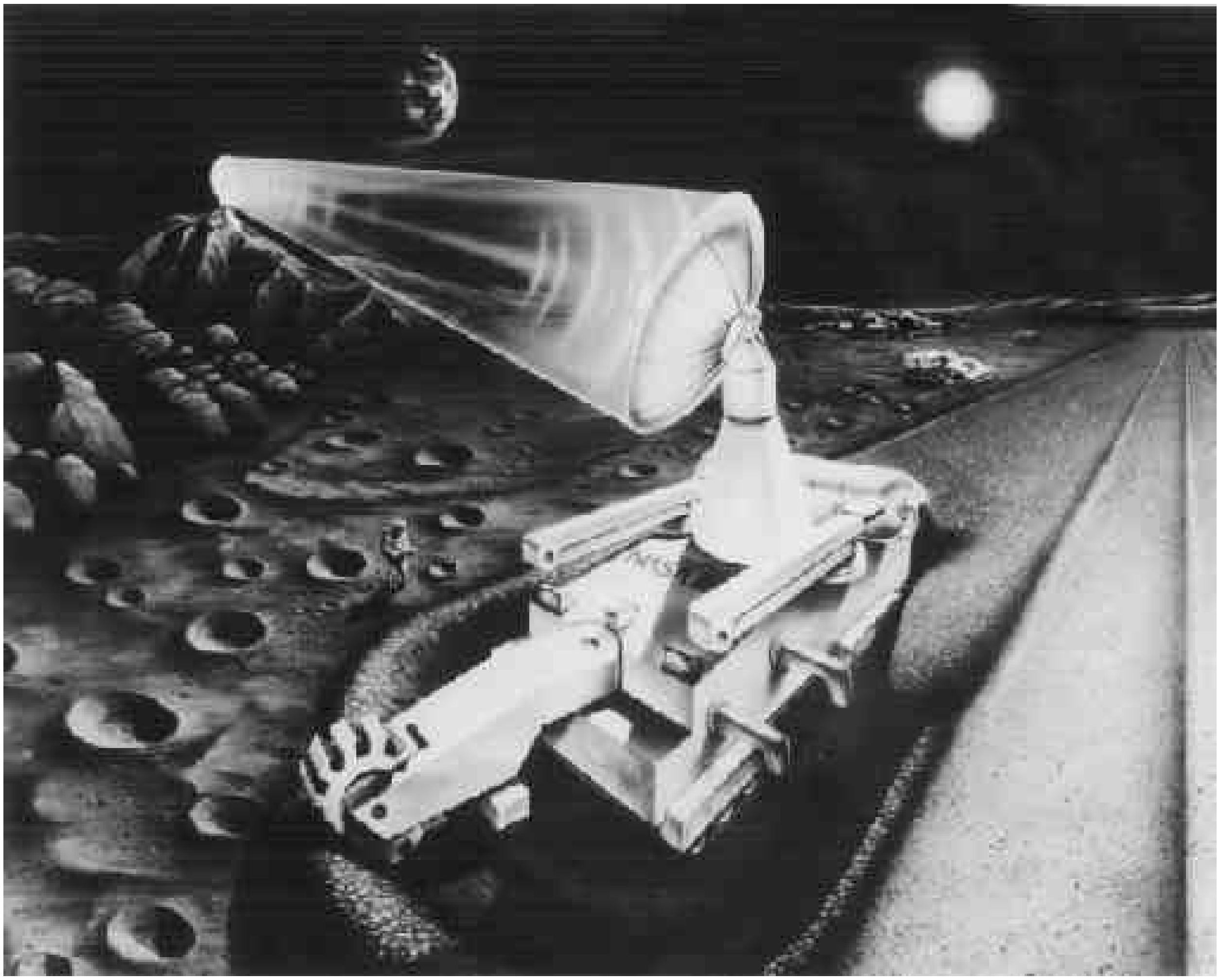
Surviving in a Lunar Base Station

Mathematics for Engineering Technology

Industrial and Management
Bioengineering
Agricultural



Capital Community-Technical College



University of Wisconsin-Madison design concept for a
Robotic Unit to extract gases from lunar soil.

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Agricultural Engineering Technology

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Eric Leung has been a mathematics faculty member at Harrisburg Area Community College since 1993. He was a Co-Principal Investigator of an NSF ILI project to develop a new reform interdisciplinary course that integrates the study of science and mathematics. Eric has received both institutional grants as well as an Alcoa Foundation grant to support his reform activities. He was awarded the 1998 NISOD Excellence Award for Teaching and Learning.

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Dennis Chamberland is a Bioenvironmental Engineer and is currently the Chief Design Engineer for the Challenger Station, which will form the command center for the first permanent seafloor station. He has a professional and personal interest in Advanced Life Support Systems and has designed several habitats for use in the oceans as an analog for space. One of these habitats, NASA's Scott Carpenter Space Analog Station, has already been tested for longterm underwater habitation.

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LTA 6

Surviving in a Lunar Base Station

Overview

To establish a lunar base station, careful planning and allocation of resources are needed for the safety and survival of the crew. The crew requires sufficient amounts of food, oxygen, and water. You are charged with the task of determining the resources needed for a lunar expedition. You must plan very carefully because insufficient resources may endanger the crew, and excessive inventory will make the cost prohibitive so that the mission will not be approved by Congress. Your mission, if you decide to accept it, is to allocate the resources that will result in a safe and successful expedition.

Part A - Advanced Life Support Controlled Ecological Life Support System

NASA is considering the creation of a manned base station on the moon for research and exploration. This lunar base station will be inhabited for a considerable length of time. It is far too expensive to have all the supplies delivered from Earth. For example, the cost of sending one gallon of water to the moon is approximately $250,000. It therefore becomes necessary to continuously generate the oxygen, food, and water that are essential for the survival of the crew. Your goal is to plan a system that can support eight crew members who will live in the lunar base station.

The crew will construct a Biomass Production Chamber (BPC) in which plants grown for food also will produce water and oxygen. The Biomass Production Chamber contains trays of wheat, soybeans, lettuce, potatoes, and tomatoes. These food sources (called **biomass**) are grown in a hydroponic system with roots fed by a nutrient-rich liquid mixture (instead of soil).

The Biomass Production Chamber is a closed system similar to a terrarium in the sense that plant growth provides oxygen and water. As the plants grow, they emit water vapors which can be condensed through air circulation over cooled coils. The plants also produce oxygen and filter carbon dioxide from the air. A single closed chamber provides a life support system, with food, oxygen, and water all being produced simultaneously. (There is a requirement that energy must come from some external source, such as solar, nuclear, or chemical energy.)

In one NASA experiment, it was found that in order to provide enough food for one crew member, an area of 40 m^2 of biomass was needed. That is, biomass growing on 40 m^2 of area would produce enough food for one crew member. In a second experiment, five crew members needed 200 m^2 of biomass for their food. These results are summarized in the following table.

Food

Number of Crew Members	1	5
Growing Area of Biomass (m^2)	40	200

You perform similar experiments to determine how much biomass is required to supply oxygen and water to crews of different sizes. You carry out seven experiments for oxygen and seven for water to obtain the data pairs in the following tables. The tables show that the crew size in your experiments ranged from one to ten people, and that you did two experiments with a five-person crew. Can you suggest reasons why the two experiments with five-member crews needed different amounts of biomass?

Oxygen

Number of Crew Members	1	2	4	5	5	7	10
Growing Area of Biomass (m^2)	10	40	50	40	80	120	160

Water

Number of Crew Members	1	2	4	5	5	7	10
Growing Area of Biomass (m^2)	6	4	12	11	15	17.5	28

Given that the food growth also produces oxygen and water as by-products, the above tables show that 40 m^2 of growing biomass supply not only enough food for one crew member, but also that the same 40 m^2 of biomass supply enough oxygen for at least 2 crew members, as well as enough water for several crew members.

The following exercises will enable you to plan the Advanced Life Support - Controlled Ecological Life Support System. Remember, your objective is to generate enough food, oxygen, and water to support the crew. Also, remember that if you provide an excessive amount of resources, then the cost of the mission will be prohibitive.

1. a) Construct an *x*-*y* coordinate system, and plot the two data points corresponding to the two pairs of data in the table for food. Let the *x*-axis represent the number of crew members and let the *y*-axis represent the growing area of biomass.
   b) Draw the line connecting the two points. Use the graph to estimate the area of biomass required to feed a crew of eight.
   c) Find the algebraic equation that describes the line drawn in Exercise 1b. Express the result using the slope-intercept form of the equation of a straight line.
   d) Using the equation in Exercise 1c, determine the area of biomass needed to provide sufficient food for a crew of eight.

2. a) Plot the seven data points corresponding to the seven pairs of data in the table for oxygen.
   b) Sketch a straight line that appears to fit the points reasonably well.
   c) Using the straight line drawn in Exercise 2b, estimate the area of biomass required to provide sufficient oxygen for a crew of eight.

3. a) Using a graphing calculator or computer, enter the seven pairs of values from the table for water, and plot the data.
   b) Determine the equation of the regression line. (The regression line is the line that fits the data points best.)
   c) Using the equation from Exercise 3b, determine the area of biomass required to provide sufficient water for a crew of eight.

4) Based on the results from Exercises 1, 2, and 3, what area of biomass is required to provide sufficient food, oxygen, and water for a crew of eight? Explain how you arrived at this result.

5) Congratulations! NASA has just given you authorization to select a ninth crew member for the lunar base station. Use the equations of the lines you found in Exercises 1, 2, and 3 for the following.
    a) Determine the minimum additional growing area of biomass needed to produce food for this ninth crew member. This result, called **marginal change**, is the amount the output variable changes when the input variable changes by one unit. In this case, the marginal change is the amount that the food requirement changes when the crew size increases by one.
    b) Find the marginal change in biomass needed to produce oxygen for this ninth crew member.
    c) Find the marginal change in biomass needed to produce water for this ninth crew member.
    d) What is the relationship between the marginal change in food (found in 5a) and the slope of the straight line (for food and crew size) found in 1b?
    e) Find the marginal change in biomass needed to produce food, oxygen, and water for the ninth crew member.
    f) Determine the area of biomass required to provide sufficient food, oxygen, and water for a crew of nine. Write a brief memo to the NASA Project Director that gives your conclusion about the amount of biomass needed to sustain a crew of nine. Also, explain how you reached your conclusion.

Part B - Oxygen Leakage in the Biomass Production Chamber

So far, your calculations for the area of biomass needed to produce sufficient food, oxygen, and water have been based on the assumption of an airtight BPC. In reality, it is very difficult to construct a completely leak-free chamber. The leakage will not only reduce the supply of oxygen for use by the crew, but it will also have an impact on the production of food, oxygen, and water by the biomass. However, we shall simplify the situation by assuming that the loss of oxygen has no effect on the production of food and water.

Assume that the Lunar Base Station houses a crew of eight, and there is a Biomass Production Chamber (BPC) which provides the required oxygen (Figure 1). The oxygen level of the atmosphere in the crew quarters is carefully controlled so that it stays close to 20.8%, the percentage desirable for human respiration. At the beginning of a research project, the chamber is producing just enough oxygen to satisfy the needs of a fully active crew. However, a leak in the chamber has occurred, and 10% of the oxygen is being lost every 90 days. In response to this leakage, the crew members reduce their activity to a bare minimum. By doing so, the crew members use about half as much oxygen as they use when they are fully active. Based on studies of human oxygen consumption, it is reasonable to assume that a fully active crew member will need 1 kg of oxygen per day.

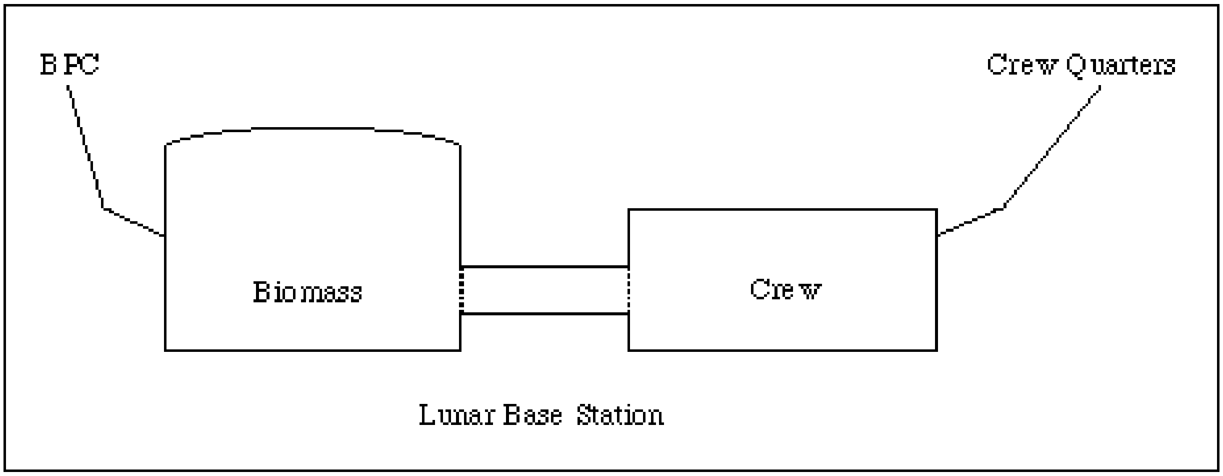

Figure 1

If each fully active crew member uses 1 kg of oxygen per day, a crew of eight will use 8 kg/day. Recall that the BPC produces just enough oxygen to sustain a fully functioning crew. This implies that if there is no leakage, the BPC can continuously maintain 8 kg of oxygen, but no more, for use by the crew. On the other hand, if a leak occurs, even though the biomass continues to produce 8 kg of oxygen per day, the amount of oxygen in the crew quarters continuously declines. That is, prior to the time when the leak began, the crew quarters contained 8 kg of oxygen and maintained this level, but from the time ($t = 0$) the leak began, the amount of oxygen available for use by the crew decreases continuously and exponentially. By reducing their physical activity to a minimum, the eight-member crew can remain in the Station until the oxygen level declines to 4 kg. In an effort to predict the amount of oxygen in the station at any particular time after the leak began, you decide to do a mathematical analysis of the situation.

1) Represent the functional relationship between amount of oxygen and the time since the leak began in three different ways - an equation, a graph, and a table.
   a) Equation: Find an equation that relates the amount of oxygen (y measured in kg) in the crew quarters to the time in days (t) since the leak began.
   b) Graph: Use a graphing calculator to represent the function by a graph on the interval from $t = 0$ to $t = 1000$ days.
   c) Table: Use a graphing calculator to represent the function by a table of t and y values where t changes in increments of 10 days.

2) Use the equation you developed in Exercise 1a to find how much oxygen is left after 2 weeks.

3) Use the graph you developed in Exercise 1b to find how much oxygen is left after 8 weeks.

4) Use the table you developed in Exercise 1c to find how much oxygen is left after 90 weeks.

5) Use any of the functional representations you developed in Exercise 1 to find the amount of oxygen that is left after 4 weeks. How much oxygen is left after 1 year?

6) When should the crew return to Earth? (If all crew members remain inactive, then they need at least 50% of the original amount of oxygen that was present at $t = 0$.) The crew is scheduled to return to Earth in two years. Will the crew need to schedule an earlier departure?

If some of the crew departed the Lunar Base Station, the remaining crew members could stay there longer. For example, if one crew member left the station, how long could the remaining 7 crew members remain in the station? Seven crew members will use less oxygen than eight. In fact, if there were no leak, then seven fully active crew members would need only 7 kg of oxygen. In this case the BPC would initially be able to provide the crew with more oxygen than seven active crew members need. Now, if the seven member crew were to slow down to a minimum, they could stay in the station until the oxygen level was reduced to 3.5 kg. Thus, to find the number of days that a seven member crew could stay, use the function you developed in Exercise 1 to determine the time when exactly 3.5 kg of oxygen is in the station. Using this idea, you now turn to the problem of determining how much time crews of various sizes could remain in the station.

7. a) Depending on the number of crew members who leave the station, determine when the remaining crew should return to Earth. Answer this question by completing Table 1.
   b) Graph your results on the coordinate system in Figure 2. Record the number of remaining crew members on the x-axis and the number of days they can safely stay in the Station on the y-axis.

Table 1

Number of crew members who depart	Number of crew members who remain (x)	Number of days (y) that remaining crew can stay in the Station
1		
2		
3		
4		
5		
6		
7		

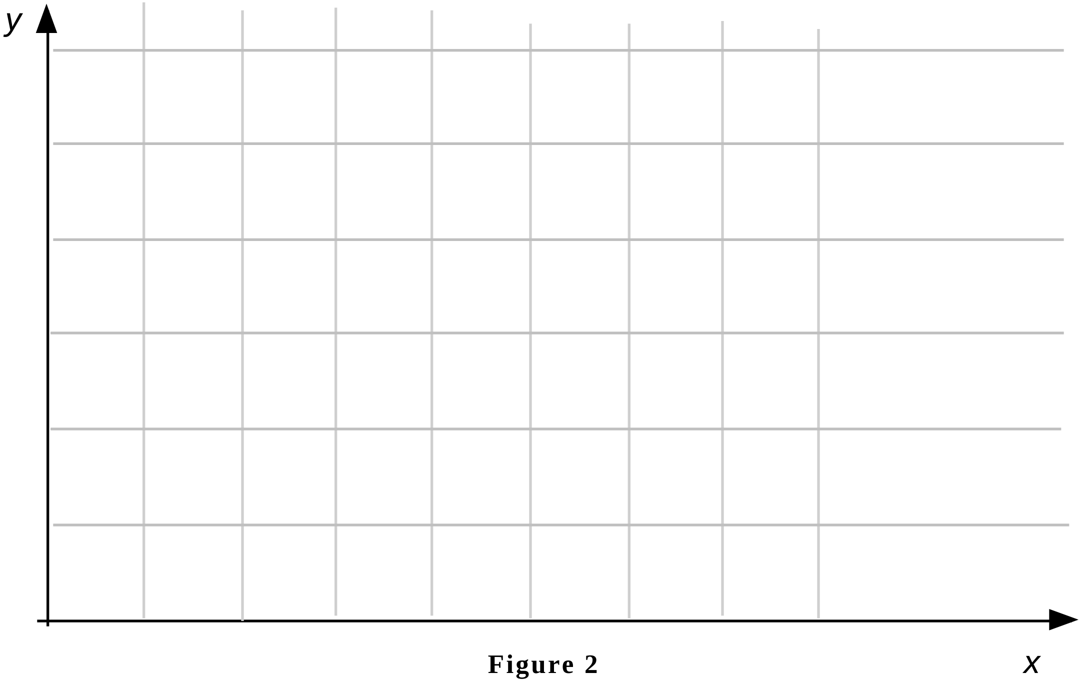

Figure 2

8) Identify a function that can be used to model the data in Exercise 7.