Lunar Bamboo Greenhouse

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Can bamboo be used to remove carbon dioxide from the air, supply oxygen and be a structural material on the moon?

What would the greenhouse look like when built for the moon?

Lunar Base and Carbon dioxide Removal

- The long-term goal for a lunar base is to develop mining and manufacturing capabilities. Making things that can be used on the moon and things that could be sent to space from the moon. Many people are hoping to mine water ice from the dark segments of the moon and be able to use it for oxygen, and for fuel for spacecraft that could be launched from the moon.
- One possibility is to mine materials from the lunar regolith. There are many metals and even oxygen that is in the regolith chemically. These can be difficult things to remove because of the amount of energy required to separate them from the regolith.
- Another possibility is to use some of the materials that we take with us to the moon in ways that are helpful for the lunar base. People on the moon require a continuous supply of oxygen that is either brought from Earth or produced on the moon. They exhale carbon dioxide, a poison, which has to be removed from the air. CO_2 has been removed from spacecraft in several different ways using various materials, including lithium hydroxide, zeolite, amine, metal oxide and a few others. All of these separate out the carbon dioxide from the air, but also remove a significant amount of water vapor from the air. We don't like to lose the water.
- Most methods release carbon dioxide out into the vacuum of space and thereby lose the oxygen that is contained within the carbon dioxide (along with some water). NASA has also used a Sabatier system that would mix the carbon dioxide with hydrogen and use a catalytic reaction to produce water and methane.

$$CO_2 + 4H_2 = CH_4 + 2H_2O$$

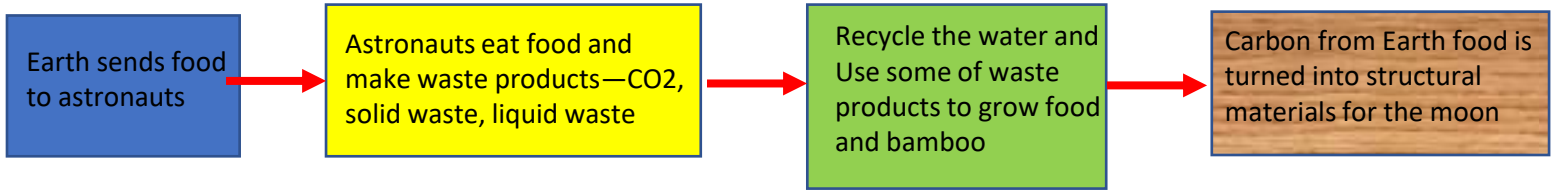
- The water would be kept on the space station and reused. The methane would be released out into space. In the future, we might use this Sabatier system to produce methane as a fuel.

Science fiction movie from the 70's

Why Bamboo?

- These are all complex systems that have to be repaired and have significant replacement parts. Another possibility for removing carbon dioxide is to use plants. Most plants in small numbers do not produce enough oxygen, nor remove enough carbon dioxide to be used in a small spacecraft and would require a very large volume. There are, however, several species of plants that photosynthesize large amounts of carbon dioxide and release oxygen back into the atmosphere. Bamboo has been studied extensively and is considered the most efficient at removing carbon dioxide from the air and turning it into plant fibers. Some bamboo can grow up to 2 feet or more in a day, implying that they are removing a large amount of carbon dioxide from the atmosphere. Growing two or 3 feet per day would obviously be a problem on a small spacecraft. However, if you have a large growing space on the moon, it may be possible to grow bamboo not just for carbon dioxide removal, but also to utilize the plant stocks as a structural material.

- Growing bamboo has a number of benefits. CO_2 removal, most bamboo shoots are edible, act as a structural material for construction on the moon but also the act of growing it is a mental health activity for the astronauts—a little bit of Earth on the moon. This Bamboo garden is not intended remove all of the CO_2 but is intended to act as a back up to the mechanical and chemical systems.



Requirements

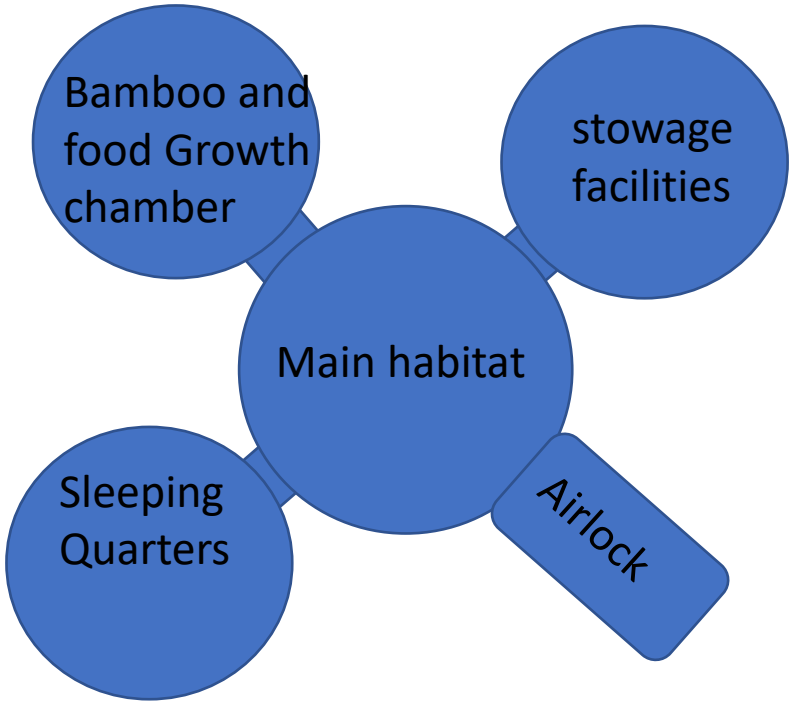
- Make a scaled model that will fit in a 2’x 2’ space on a table to demonstrate how bamboo and other food items could be grown in a 20’ diameter, lunar inflatable module that allows for people to tend and harvest the materials from the greenhouse. It should include:
  - Grow beds
  - Lighting
  - Plumbing—in and out
  - Mixture of air from other modules
  - Walkways and work areas
- Choose a bamboo species that could be valuable for growing on the moon –CO_2 removal and structural value.
  - Demonstrate that you can grow bamboo in lunar regolith or as hydroponics and habitat conditions
  - Show that the bamboo (roots and shoots) can be contained without damaging the inflatable habitat

Determine the types of bamboo that would be the most beneficial and
Grow them in simulated lunar regolith to demonstrate that they can be grown
Using artificial lighting and a growth

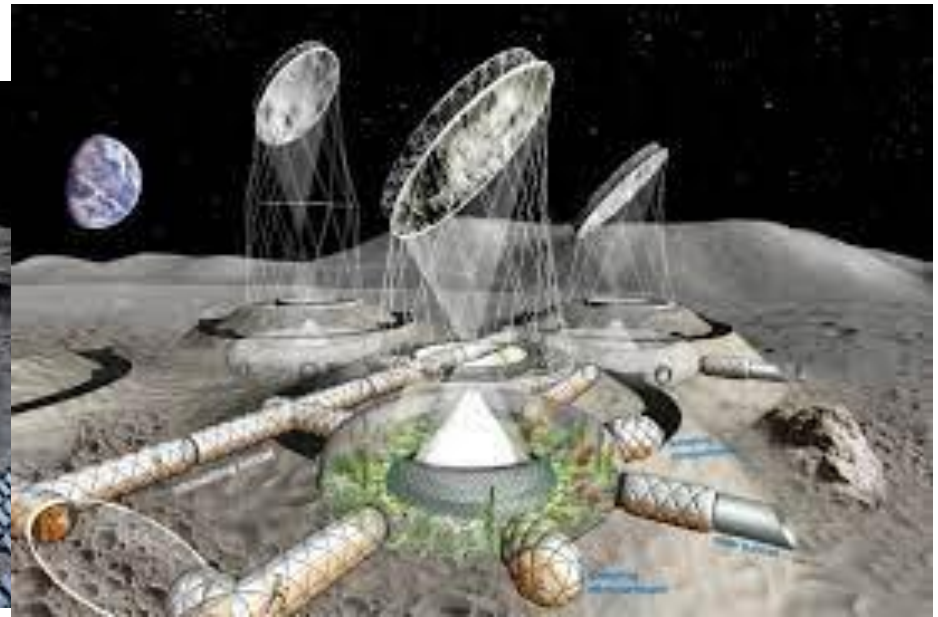
Lunar Greenhouse

What should a Lunar Greenhouse look like?

- For this stage of the Lunar base, the habitat will be composed of 4 inflatable modules and one rigid, aluminum airlock. Where one of the modules is for the growth chamber for growing food and bamboo.
- Each of the modules for lunar habitat is an inflated dome so the roof and walls will be curved. To protect the astronauts and the plants from the cosmic and solar radiation, the dome will be covered with regolith (lunar dirt).
- It will be very important that you design a system that will prevent plants from growing into, and possibly damaging, the roof walls and floor of the habitat. Is it possible to have a structure adjacent to each plant that will curve the stalk above a certain height?
- The chamber must be designed to allow people access for maintenance of the plants and the chamber itself.
- The chamber needs to be designed to make cultivation of mature plants easy to do.
- Your prototype should be a scaled model with all the structural requirements represented. You should also have detailed renderings of the full-size growth chamber, including a list of recommended materials (power, lights, water system, etc.)
- You should conduct research on the type of bamboo you recommend by growing a plant and monitoring growth variables. Consider using an old aquarium or some other analog for your growth chamber. Maybe even a something that allows viewing of the growth of the root system.



All these domes will have to be covered in dirt to minimize the radiation exposure to the plants and people as well as helping to regulate the internal temperature through the 28 day/night cycle.



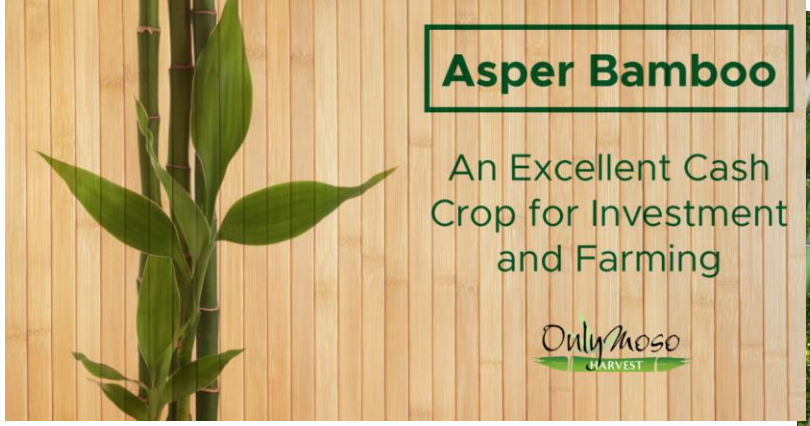
Bamboo on the Moon

Things to think about

- What kind of bamboo would remove the most carbon dioxide and also be most valuable as a construction material.
- All of the regolith on the moon is crushed or pulverized basaltic rock—kind of like a what you might find from a volcano--like Hawaii.
  - What kind of soil remediation for the regolith would be most beneficial for the type of bamboo you choose?
  - What species of bamboo would be most effective to grow in lunar regolith?
- What temperature can it grow in. Expect that the modules will be kept at around 71 degrees F and around 40% humidity.
- Suggest 3 different kinds of bamboo
- 2 different diameters of construction material
  - 1 kind that is good for food, maybe also good for construction
- Can you trim bamboo to make it grow to a larger diameter?
- Could bamboo be trained to grow in different shapes, besides poles and cylinders?
- The growing chamber will be an inflatable structure with regolith covering the outside to cut down on radiation.
  - This means the lighting will be artificial. What colors of light will be most beneficial for growing the bamboo?
  - We don’t want the bamboo growing and poking the inflatable module where they are growing. What method could be done to ensure the safety of the living space?

Scaled model for how it will be done on the moon

- Design a scaled growth chamber with a 20-foot diameter footprint.
- Your scaled model should not exceed 24- inch diameter so it will fit on half of a table for display. Build one half of dome so interior is visible – similar to a child's doll house
- Your presentation will also include detailed drawings of electrical and plumbing as well as testing data with bamboo grown in the lunar regolith.
- The chamber must be separated from the main living areas but provide for exchange of gasses (oxygen and carbon dioxide) with the rest of the lunar habitat.
- The chamber must contain
  - a lighting system that optimizes plant growth.
  - an efficient watering system, that can reclaim any water not taken up by the plants. Think humidity and condensation of the chamber walls.
  - Describe all soil nutrients necessary for plant health.



- Growing bamboo as food in Florida
- https://www.youtube.com/watch?v=l6HCB8l0Skc

- Bamboo in North Carolina
- https://www.youtube.com/watch?v=ht3Iyfl5LIM

- Growing bamboo in Tennesee
- https://www.youtube.com/watch?v=C5Ke83_QKtk

Hydroponics/Vertical Farming

- There are a variety of new types of indoor farming some of which are inspired by the drive to go to the moon and beyond. Some of them use some regolith others use less or none. The question we need to answer is if it can be done with bamboo. Many types of bamboo can be killed by having too much water and need to be in a sandy soil to allow for good percolation of water past the roots.
- Aquaponics that utilizes fish might sound like a good idea here on Earth but it would require a lot of water, fish food and maintenance that could be difficult on the moon. This means there would be a lot of challenges on the moon that I don't want you to have to demonstrate for this project. Therefore, NO FISH. Maybe on a later project.

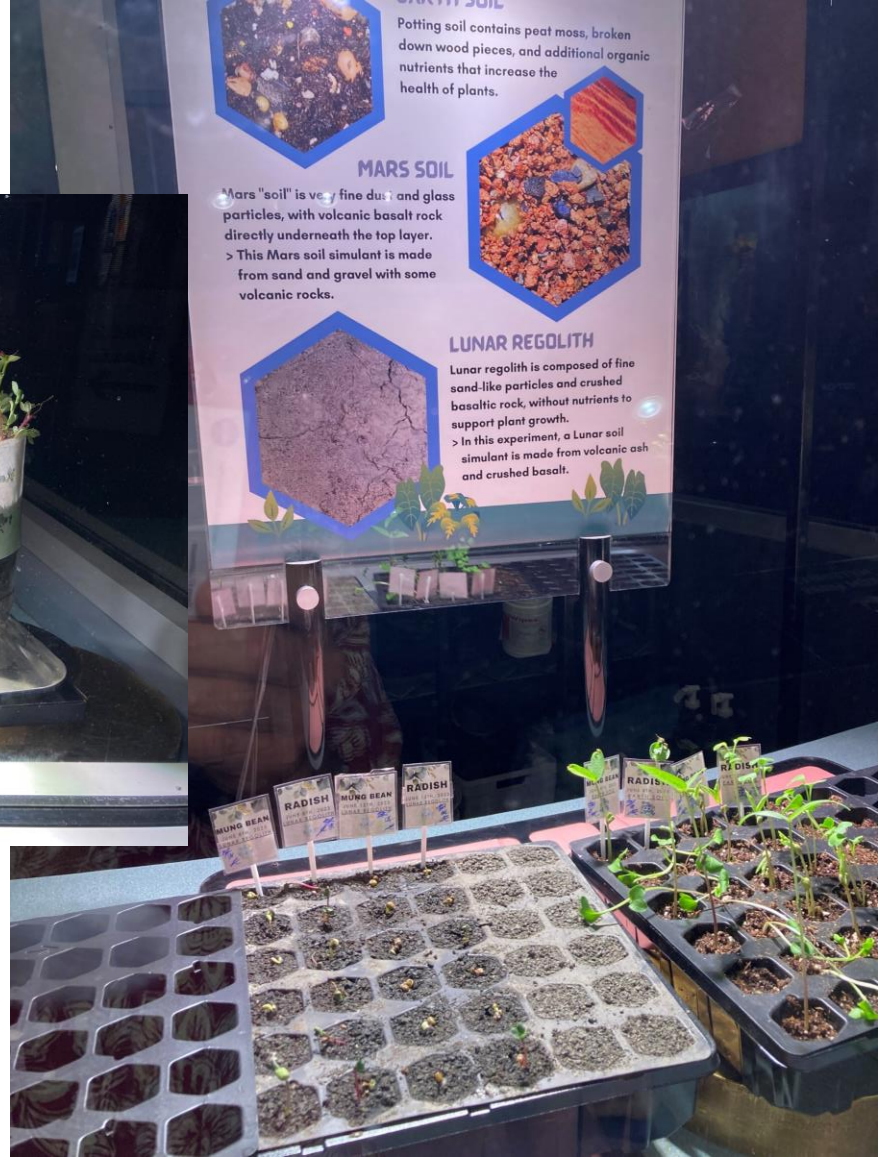
https://www.youtube.com/watch?v=suYcri3FzcI

Growing in Lunar regolith simulant.

Your ideas for bamboo should be tested in your own grow chamber with bamboo and then represented in a scaled model that depicts the building on the moon.

Some types of bamboo have roots and shoots that can be very invasive. How thick of plastics or other materials are needed to keep them from poking through? At $1.2 million per pound to send materials to the moon, we would like to send no more than is needed.

I was at the Houston Museum of Natural Science and they had an experiment going where they were growing different plants (radishes and purslane) in Lunar regolith. Lunar regolith is mostly crushed rocks so it doesn't have organic materials in it but does have lots of minerals. This would be similar to a basaltic rock (like in Hawaii) that has been crushed up into small particles. It may be helpful to look for bamboo that grows well in volcanic regolith.



Radishes, mung beans, purslane grown in Lunar Regolith simulant and Mars regolith simulant.

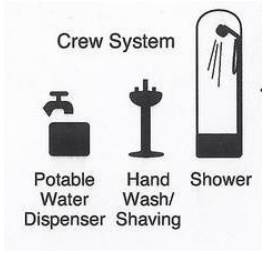
Lunar Regolith simulant

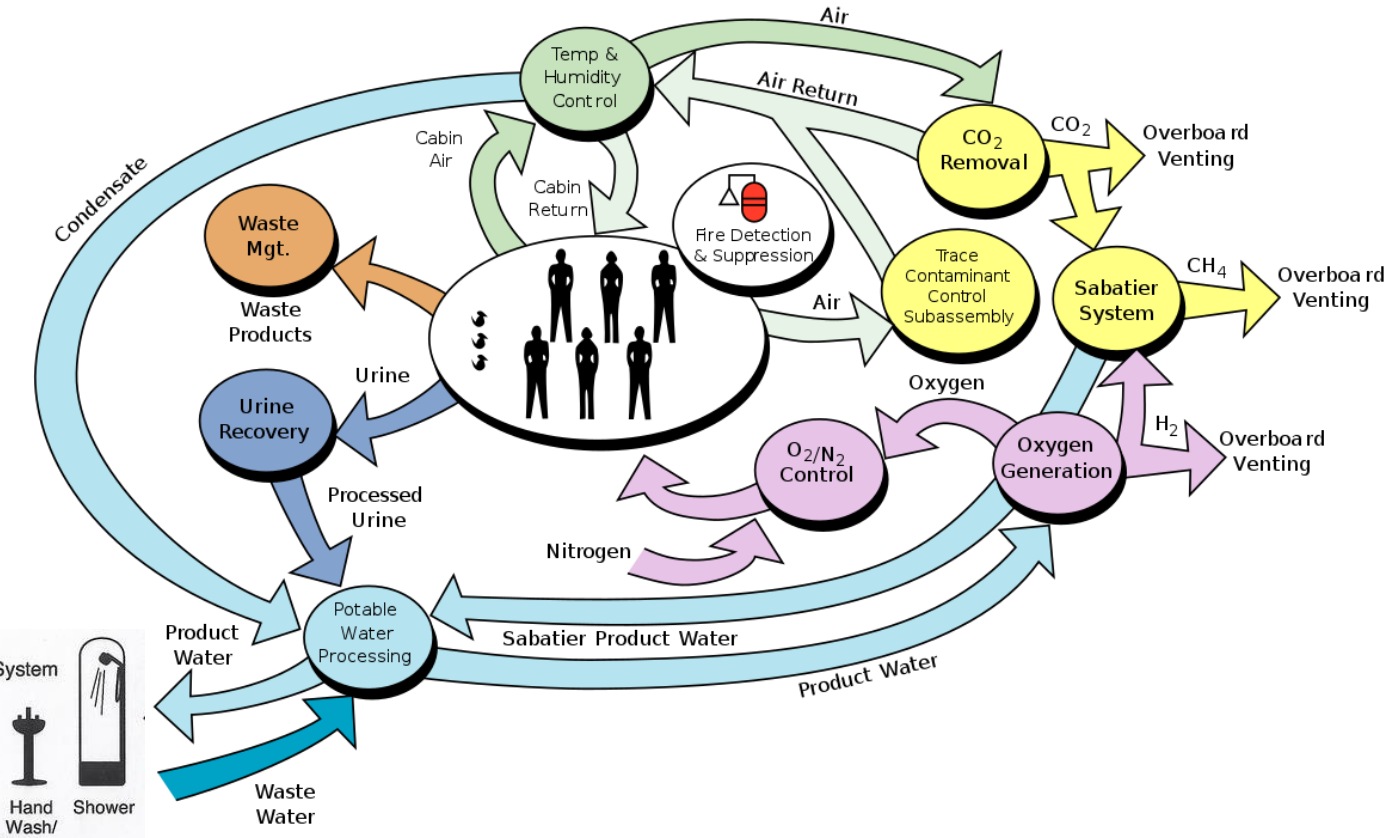
- Regolith—Lunar regolith is a very specific term and is composed of broken up basaltic rock. This would be similar to the lava rock in Hawaii but broken up into a mixture of fine powder and gravel from being hit by meteors. Because there isn't any flowing water or air on the moon, the particles are very sharp and jagged unlike sand on Earth.
- Soil—a mixture of organic material from decomposed plants and animals, clay, and rock particles that have been decomposed by both chemical and mechanical weathering.
- Dirt—a very generic term that often refers to cleanliness (or the lack of) and can include mud, organic materials, inorganic materials, …
- As you might guess, there is a very limited amount of Lunar regolith on the Earth and very little of it has been used for trying to grow plants.
- It is possible to buy Lunar Regolith simulant but it can be expensive. It can also be made fairly cheaply if you are willing to put some effort into it.
- If you are growing only a few bamboo plants, you may not need very much lunar regolith simulant.
- Get some lava rock or granite from the garden center. There may be some of the sand and dust from the rocks on the floor or in a bag.
- Because it is a fine powder, the lunar regolith will need to be kept moist so it sticks together and doesn't get kicked all over.

- What is important is you need to start with a regolith that has
  - High mineral content
  - Sandy to fine grain
  - **No organics—**it is valuable to bake your regolith at around 400 F for an hour to kill off any organics in it.

Humidity and temperature

- Many types of bamboo grow well in temperatures of around 80 to 90 degrees F but most people want to live in temperatures around 69 to 72.
- The main purpose of sending bamboo to the moon is to help remove CO2 from the atmosphere and provide some O2, that can only be done by circulating air between all the modules with the greenhouse. But that also means you are spreading humidity and temperature between modules as well. If the habitat is much cooler than the greenhouse, the water will condense in the habitat on the equipment and the plants will be sending their warmer air and moisture to the other modules. This means your attached greenhouse will be fighting with your habitat for both temperature and humidity. You will have to come up with some kind of compromise where your bamboo may not be growing at its optimum rate and/or your people may be dealing with a warmer temperature than they would prefer.





Water tank

Both the Habitat and the Bamboo Greenhouse will need water storage. The crew need to have water that can be cleaned and waiting for use for drinking, food rehydration and hygiene activities. The bamboo and other plants need water with the appropriate minerals added to help them grow. As water evaporates from the plants, soil, drying towels and clothing, steaming food, sweating people, … the condensing water will be cleaned and made available to both tanks of water.

The ECLSS system should have at least 100 gal of extra water to work with.

The bamboo and plants should also have around 100 gal of extra water to pull from.

Is it better to have one tank for each location or should there be multiple smaller tanks for separation and safety?

Several 50 gal tanks or two 100 gal tanks?

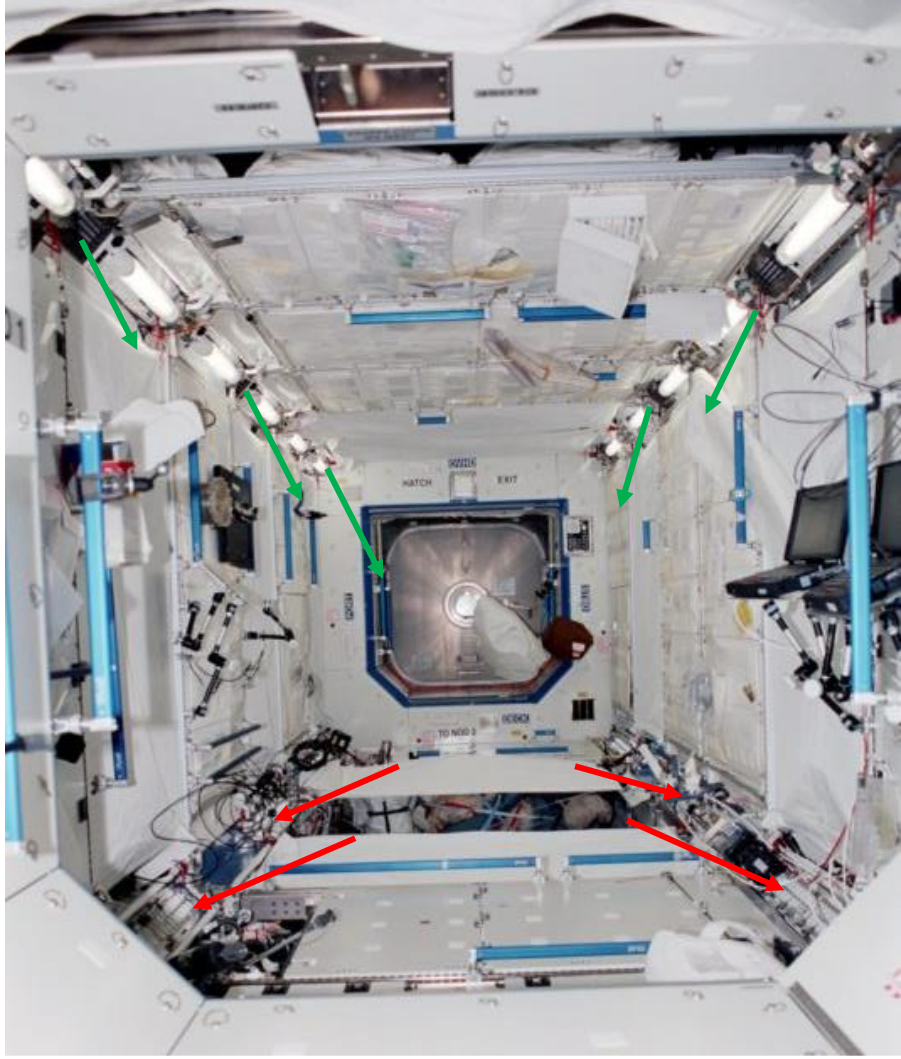
Mixing of air in Micro-G


S121E07401

Air is being pushed from the Space Shuttle that was docked to the Space Station through the hose and air is flowing back from the Station into the Shuttle through the hatch.


S129E009490

Once the hose from the Shuttle comes into the Space Station, the hoses pushing air from the shuttle pass through connections to the sides of the hatch with valves that can open and close so the hoses don't obstruct the ability to close the hatch.

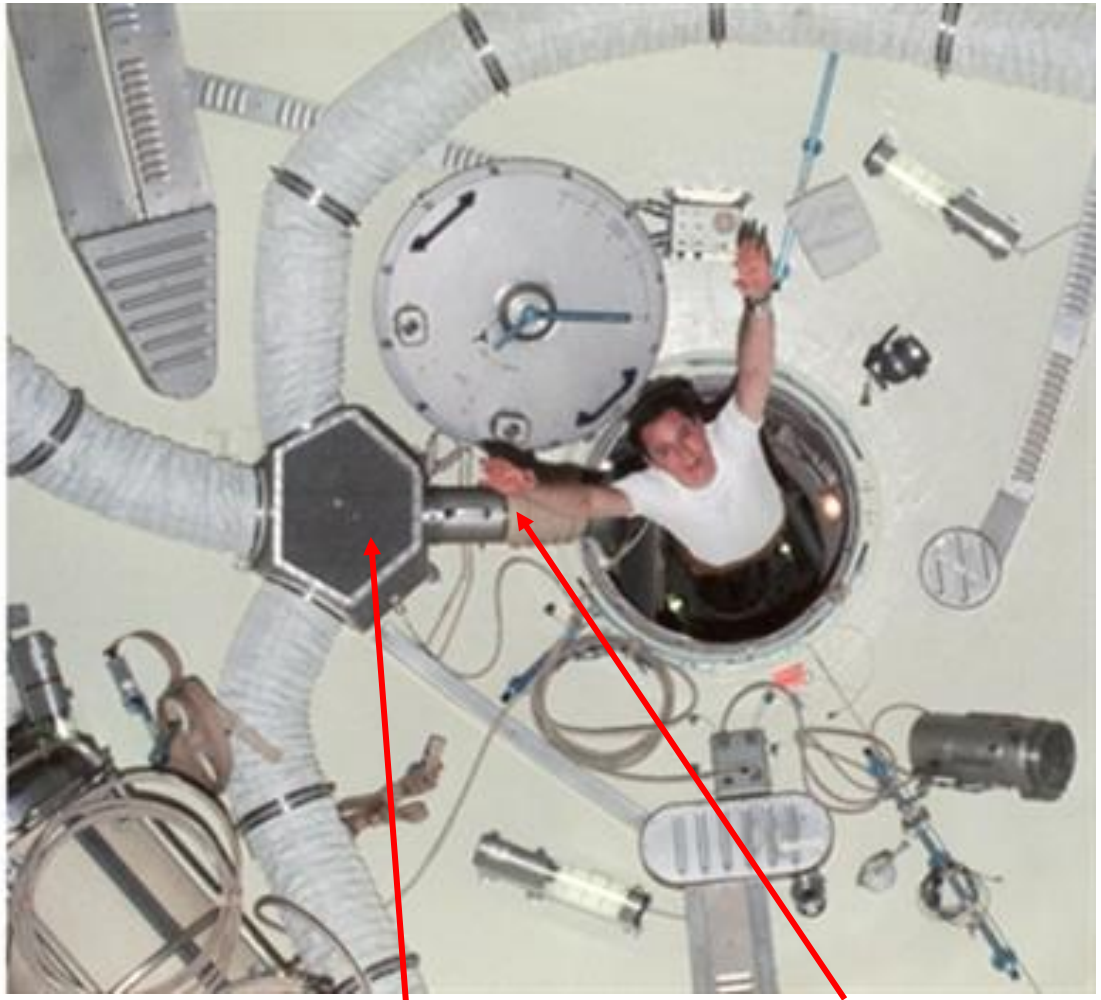


This is an early photo of the US Lab on the International Space Station. Notice the lights are on the overhead stand-offs. Air vents exhaust cool clean air from between the lights and inlet vents pull in air in the stand-offs at the deck with filters that collect the dust.

These are pictures from Skylab, NASA's space station in the early 1970s. Notice the gray ducting for helping circulate air through the space station.

When a Space Shuttle is not connected to the ISS, air is pushed through ducting from the Russian side of the Space Station to the other side of the Space Station from one module to the next. All of the air returns back to the Russian side through the hatches with lots of mixing in each module before it returns.

Without gravity there isn't any natural convection (hot air rises, cold air sinks) so it is very important to have forced mixing of the air. The moon has some gravity so there will be some convection which will help mix the air but it will still need to have good mixing and air flow.



The air ducts don't need to be as big as these but the larger the air duct, the easier it is to mix lots of air. Small fans turn faster and are louder. Big fans can turn slower and be quieter.

In-line fan

Air inlet with filter for capturing dust. This gets vacuumed every week

Ducting going through a hatch that pulls air from another section of the space station

Ideas to share.

1. Make sure you start your experimental evaluation of bamboo species as soon as possible. We want to see quantifiable data on the parameters you have measured -such as, optimal water requirements, nutrients, optimal light, hydroponics-vs-soil. How do we turn sterile lunar regolith into a viable growth medium?
2. Don't forget to focus on the big picture. Your task is to design a fully functional green house. When you get to the CDR you need architectural drawings and a model that include all the requirements of a greenhouse capable of successfully growing crops - electrical power grid, water reservoir & piping, lights, and a (modified) HVAC capable of circulating air from the other areas in the habitat - and control the humidity in the green house.
3. Finally, make your design modular. The purpose of the greenhouse is not to just grow bamboo, over time we need to rearrange the configuration to grow consumables. Design your system so that reconfiguring growing areas can meet these requirements. Think racks/shelves that can easily be modified to meet multiple needs.

4. Don't forget that this greenhouse is on the moon where the gravity is only 1/6th that of Earth. What modifications are needed to "direct" fast growing bamboo, and prevent it from impacting the dome? What pressure will water pumps need to effectively deliver water to the plants? Are there other modifications to consider?