The First Step:
Sustainable Orbital Biological Additive Manufacturing

Bryan Kuklinski, George Tyson, Bryan Athan
✞ Orbital Construction Pioneers, Inc
Colorado City, Texas
bkpilot@protonmail.com

Abstract

Historically, all spaceflight missions, including resupply, have been 100% supported with resources from Earth. As humanity ventures further out, dependency on Earth resources becomes significantly more difficult. The ability to produce and utilize (in-situ) resources decreases dependency on Earth resources, is more cost / time effective, and unlike previous ventures, allows mission tailored operations / structures to be developed on site.

Orbital Construction Pioneers, Inc. (OCP), a Texas Corporation built on the foundation of Christ with investors from multiple States, is developing an orbital fabrication process for exceptionally large space structures.

The “First Step” orbital manufacturing system is based on additive manufactured biological modules, integrated into orbital structures, providing the base for a large-scale manufacturing process. Biological additive manufactured modules would create a sustainable and expandable symbiotic environment, improving quality of life and capacity for the human inhabitants. This system could create structures that produce artificial gravity, provide adequate protection from radiation and debris, facilitating permanent habitation and long duration mission space travel.

Utilizing a basic skeleton structure consisting of pressurized areas and trussing as a starting point, farm, and other purposed modules, i.e., laboratory, recreation, propulsion, could be added to the framework as they are produced. Inside each farm module is a hydroponic / aquaponic farm, with an environment tailored for optimum production of raw materials (mature plants). The entire plant, upon harvest, can be processed, (in another attached module), into human safe base materials for an additive manufacturing process; the plant would produce / become both the filler and the binder. The plant also provides oxygen and other resources in a symbiotic relationship with the crew.

Why is this the “First Step”? Unlike any other plans that have been developed to date; this has continuous manufacturing capability. Having the capability to produce large

structures, on demand, means the operation becomes more self-reliant over time, with the additional capability for growth of the facility and operation.

Introduction

As mankind expands into the solar system, certain needs must be met such as energy, food, water, breathable air, and shelter. The primary issue will be the health of the people and their ability to maintain their physical capabilities, so that they can efficiently complete complex and physically demanding tasks in a harsh environment.

As man ventures further out, the ability to resupply locally becomes more necessary. The ability to produce and utilize (in-situ) resources decreases dependency on Earth resources, is more cost / time effective, and unlike previous ventures, allows mission tailored operations / structures to be developed on site [1].

Microgravity

The current problem with long-term habitation of space is that microgravity causes irreversible degradation to the body. Multiple studies have shown that long-term exposure to microgravity causes the body to deteriorate at the cellular level. [2] So far, all the mediations developed by NASA have only slowed the deterioration, resulting in irreparable harm that could end a career. [3] Providing a simulated gravity environment in orbit is the only solution to prevent the disabling of personnel.

A simulated gravity environment can be created by rotating a ring-shaped structure. The strength of gravity is dependent on the diameter and RPM of the ring. Smaller diameter requires a higher RPM for the equivalent level of gravity; the issue becomes tolerance. Studies have shown that people can be trained to tolerate 7 to 10 RPMs and still function however; personnel could be in this environment for years. One RPM can be easily tolerated by 99% of the population without ill effects; it would also provide the best environment long-term. [4] This equates to a diameter of approximately 320 meters at one RPM for 1/6 Earth's gravity (equal to lunar gravity).

Traditional Construction

Traditional construction techniques used in building structures in space, e.g., the International Space Station (ISS), involves the fabrication of modules on the ground and then lifting them, one at a time, into orbit. Once in orbit, they can be attached to each other forming the final structure. The size, shape, and mass of each module is constrained by the lift vehicle.

The ISS is arguably the largest structure created by humans in space. It took more than 40 flights from Earth and over 10 years with an estimated cost of greater than $150 billion to complete. [5]

As humanity expands farther into space, supplying all needs from Earth becomes ever more expensive and time-consuming with complex logistics. While reaching Earth orbit is expensive, it has become routine. As of 2023 there have been 568 rockets launched by private companies. [5] One launch provider, SpaceX, has already launched over 1,000 tons to orbit. [6] However, there have only been 37 missions to the Moon and 16 to Mars since 2000. For sustainability of habitation in space, we must find ways to build larger structures quicker and at a far lower cost.

Current construction methodology requires all materials for construction to be lifted from Earth resulting in huge transport costs. The cost of lifting stuff (mass) to space is directly proportional to the depth of the gravity well (the strength of the gravity). It takes more energy, and a stronger vehicle, to lift 1 kg of mass from Earth to orbit than it takes from Mars to orbit.

Using this technique for a structure that is 320 m in diameter would make it exorbitantly expensive and time-consuming. The usefulness of the structure would be limited to one mission, leaving it as a proverbial “one trick pony.” It would also resemble a string of cans in a circle.

The costs could be lowered if we could find the required materials in a lower gravity well, such as the Moon. In an Earthly analogy, if we built a structure on top of a mountain, we could lower our costs if we could find the materials (cement, wood, stone, etc.) we need ½ or even ¾ to the top as compared to transporting it from the mountain base. The amount of cost savings would be proportional to the amount of usable materials that can be sourced from the area close to the mountain summit.

Material Development

What if we could develop in-situ resources? The alternative to re-supply is using in situ resources. We must move technologically forward; utilize in-situ resources with newly developed construction techniques. Locally available materials could be processed into resources to meet many needs. However, processing requires building facilities and having sufficient energy and a suitable environment. This limits the processing options available.

OCP has been experimenting with additive manufacturing using thermosets mixed with various fillers. We are currently developing a material called Stellamer that is a bio-based thermoset, with zero volatile emissions, mixed with plant fiber for use in an additive manufacturing system. The bio-based system will allow us to grow our orbital in-situ construction material, providing building material continuously with greatly reduced need for Earth resources. This “First Step Manufacturing System” (FSMS) can be used to build the first large orbital structure that will be a healthy long-term orbital home with the built-in capability to build other large orbital structures. Our first FSMS build will be called ‘Station 520”.

There are approximately seven different types of additive manufacturing, but the type OCP utilizes is material extrusion known as FDM (Fused Deposition Modeling), or alternatively, FFF (Fused Filament Fabrication). The standard process works by directing a plastic filament from a supply spool, passing it through a heated chamber, and then out of a print nozzle. As the material exits the nozzle, it is deposited in the form of the current part cross-section on the build platform. Once a layer is complete, the print heads move up by one layer thickness. The process is repeated until the part is complete. The OCP process uses thermoset bio-materials in place of plastic filament. Additive manufacturing uses many different types of materials from photopolymers to metals. However, current systems do not use thermoset materials.

Thermosets

The advantages of using thermoset materials include:

- Thermoset materials enhance chemical resistance, heat resistance, and structural integrity. They can improve the material’s mechanical properties, and thermoset plastics are used for sealed products due to their resistance to deformation.
- Thermoset plastics are more resistant to high temperatures than thermoplastics. They have a highly flexible design. They offer thick to thin wall capabilities, they offer excellent aesthetic appearance, they come with high levels of dimensional stability & they are cost-effective.
- Thermosets do not display reversible change behavior during polymerization (curing). Thermoset polymers form links or chemical bonds between the adjacent chains; the result is a three-dimensional network that is much more rigid than the two-dimensional (linear) thermoplastic structure.
- Interlinked chains are not free to move when heat is applied, and the thermoset is set into a permanent rigid shape. The level of cross-linking can be varied and the materials with high cross-link densities are hard, rigid, and often brittle. The thermosets with low cross-link densities can be softened by heating to high

temperatures but they do not melt (like thermoplastics), and their original shape is maintained. [7]


Test article made from 100% bio-epoxy and hemp filler.

OCP has been doing extensive research into additive manufacturing using thermosets mixed with a filler for the construction of large space structures. From our research we have a patent pending 3D orbital printer design that can print objects up to 100 meters in diameter using in-situ resources. We have also tested several different types of epoxies and RTVs mixed with fillers that can be mined or manufactured on the Moon.

The FSMS concept uses 100% bio-derived thermosets and fillers providing the ability to grow, in orbit, the required in-situ materials which produce a renewable source of construction material.

Station 520

Purpose:
To construct the First Step manufacturing station using virtually 100% renewable, "on-station", produced plant-based thermoset mixed with plant fiber fillers in an additive manufacturing system.

Description of the First Step station:

The FSMS provides capability for large structure manufacturing and an environment that supports human and plant health. The FSMS is a rotating orbital, cylindrical manufacturing system with a diameter of 320 meters and a (floor) width of 15 meters (not including the gravity stabilization boom). Upon completion, it will have a livable pressurized space of approximately 774,000 cubic meters and, at the rim, provide gravity of approximately equal to the Moon (1/6 g). At the center of the structure will be an additive manufacturing printer capable of producing segments up to 50 meters in diameter by up to 6 meters thick.

The pressurized area will support:

- The hydroponics / aquaponics farms and processing equipment to provide the raw materials for the attached printer,
- drug manufacturing,

- thin film manufacturing,
- pharmaceutical development and manufacturing, and
- support for military personnel functions.

Goal:

- To establish the standard for the construction of large space structures. Such as orbital observatories, solar power platforms, refueling platforms, interplanetary vessels, or any other large structure.
- To construct the means to continuously build large structures using minimal Earth resources.
- To provide an environment where humans can live and work with minimal body degradation due to environmental factors such as microgravity and radiation.

Construction Steps

The First Step program is designed to build an orbital additive manufacturing system that can produce segments for very large structures (>300 meters) using a bio-material derived from plants grown and processed on site (in orbit). The goal is to be as self-reliant as possible through recycling and innovative bio-based engineering. We estimate that seven Starship sized vehicles would be required to start the construction (the initial seven vehicles would be incorporated into the structure); after which the construction would progress with minimal input from Earth resources.

The First Step program reduces dependance on Earth resources, provides the first step in the orbital manufacturing of large structures, and provides a suitable habitat for long-term habitation.

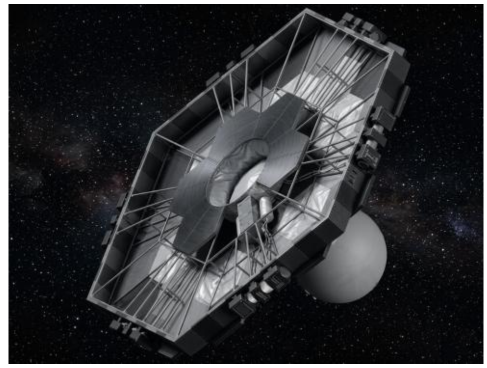
Defining First Step:

- First step in the orbital manufacturing of large structures.
- First step in permanent human habitation of space (as opposed to continuously manned).
- First step in man spreading across the Solar System.
- First step in reducing reliance on Earth resources.
- First Step in providing means and methods for the US to seize the technological and commercial lead in utilization of our solar system and its resources.
- First step in developing an advanced and robust space defense for the United States.

Program Purpose:
To construct the First Step manufacturing station using virtually 100% renewable, “on-station”, produced plant-based thermoset mixed with plant fiber fillers in an additive manufacturing system.

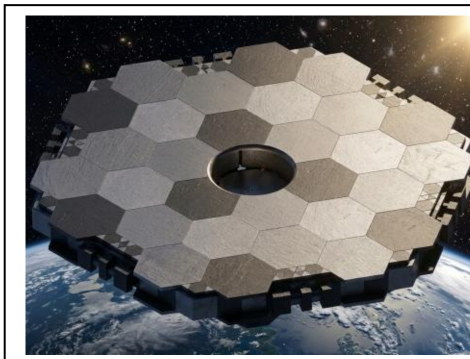
Construction Steps:

1. Launch seven (7) V3 sized Starship vehicles containing:
    a. enough scaffolding for the station skeleton,
    b. hydroponics / aquaponics materials,
    c. necessary items for the construction of the 3D printer located at the center,
    d. plant processing equipment,
    e. food, water, air, tools, and EVA suits used by the construction crew,
    f. repair station for EVA suit and equipment maintenance, and
    g. small startup crew's quarters / work area.



Station 520 under construction. The top is in process of being eclosed, exposing the internal scaffolding.

2. Using the scaffolding, build the station skeleton incorporating the seven vehicles. Relocate appropriate items (propulsion, electronics, pumps, etc.) from the vehicles to their permanent placement on the scaffolding.
3. Connect the tanks and cargo areas providing pressurized sections for the initial farms.
4. Begin 1/3 rotation; mount and activate hydroponic / aquaponic systems.
5. Assemble and activate the plant processing system as raw material becomes available, creating the material (thermoset epoxy and plant fibers) for use in the printer.
6. Using a mix of the station produced thermoset and plant material, print the outside skin and inside bulkheads.
7. As the outside of the station is skinned, enclose and pressurize sections for new hydroponic / aquaponic farms.
8. Once the construction of the station is complete, increase rotation to 1 rpm and welcome tenants.



Completed Station 520 from the top. The "cup" is the printer area.

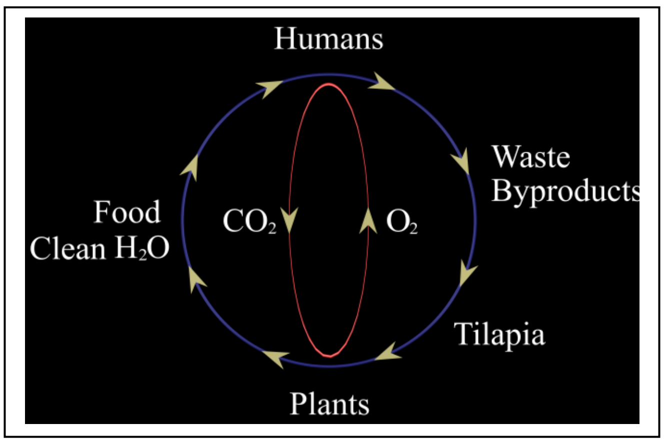
Printer

Integrated into the structure of the station, the printer will utilize materials grown and processed on the station. Printed items up to 50 meters across and 6 meters thick will be used to sheet the truss frame of the station. The printer is also capable of printing other shaped parts of varying size, such as I-beams, triangles, tubes, tanks, etc., creating various pressurized modules, increasing the size and volume of the station and other applications.

The printer will use station derived thermoset bio-binder and plant derived fillers. These will be hydroponically grown and processed on the station.

Sustainability

Once the station is operational / completed, the construction materials produced could be used for printing other structures, repairing or modifying the station, creation of other purposed modules, and/or creating other stations, bases and vessels. The station, besides supporting its own needs, is able to support other space operations. Excess resources would be available for trade.



The station is a self-contained eco-system with symbiotic relationships. Nothing is wasted on the station. An aquaponics operation provides fruit, vegetables, and fish for the crew. Human, fish, and plant waste are re-cycled. Waste is used to feed plants, the plant waste feeds the fish, fish waste feeds the plants. Mature fish and plants feed the crew. These processes also clean the water and produce other by-products; herbs, spices and other medicinal plants are also grown.

An additional symbiotic cycle exists between O2 given off by plants and CO2 exhaled by humans. Methane is produced from waste. Water, the most important resource, goes through a cycle, carrying nutrients to plants, fish and humans, while carrying waste away. Water can also be separated into hydrogen and oxygen.

The station is able to produce / provide secondary products. These products would include, but are not limited to:

- oxygen (O2),
- potable water,
- food, and
- methane.

A vessel docked at the station would have access to the station's resources for re-supply. Expended items / waste from the visiting ship could be exchanged. This exchange keeps the station self-reliant, independent from Earth re-supply.

Oxygen could be used for replenishing fuel cells, producing electric power, LOX for propulsion, and re-supply / refresh of the on-board atmosphere. CO_2 could be removed from the visiting vessel as well as other waste products.

Clean potable water supports life for both crew and fish.

Methane produced from decomposing materials would be collected and available for fuel, making this a refueling stop.

Besides growing plants for construction materials, other plants will be harvested for food for the crew. Fish (tilapia and others) would provide a good source of protein for the crew. Vegetables and herbs would also be available. Excess production can be sold and / or traded as the space economy develops.

This is the beginning of in space commerce. Station 520 becomes the gateway.

Economic Development

Space commerce is the cornerstone to a space economy. The ability to trade resources in space means sustainability, survivability, and creation of business models independent of Earth resources. The first step program is the first step to developing an orbital / space-based economy.

Space Economy

The main product of Station 520 will be construction material / modules for other structures. Our customers will include governments, corporations, and individuals. Anybody who wants to build a structure in orbit can contract with OCP for the construction of an orbital asset; from a rotating habitat to a solar power satellite. This service will provide an impetus to orbital habitation, and possibly the solar system. Our secondary products reduce the need for Earth resources, creating an environment for continuous trade.

Our secondary products are byproducts from the process of creating sections for other structures. They come from the aquaponics / hydroponics that are used to grow the plants that support the creation of Stellamer. Waste disposal, potable water, food, and methane are naturally produced by process. We anticipate that the production of these byproducts will exceed our needs, allowing for trade with other orbital inhabitants.

Trading / selling our byproducts to our orbital neighbors reduces their costs (less reliance on Earth resources) and provides resources we will need. Just like ships returning to port after a long voyage, a customer would dock with Station 520 and offload waste (to be broken down and used as fertilizer) and spent resources such as empty containers, gas canisters, and CO_2 scrubbers, while loading potable water, oxygen, and food for the crew, along with additional engine fuel in the form of methane. This is the first step to a truly space-based economy.

The creation and trading of products and services in orbit / space, without relying on Earth resources, reduces costs and creates an economy that is not Earth centric. Instead, Earth becomes one of the many nodes of the economy that is buying and selling goods and services.

The military will also contribute to the space-based economy. The development of Stellamer technology, as stated above, will have potential defense and military applications. The economy will benefit from the construction of military structures and the logistics that will develop in support of the military mission.

As commercial and military systems are brought online, a space economy will be established providing goods and services to be used outside of Earth. Eventually, as humanity spreads throughout the Solar System, Earth becomes one of many suppliers and consumers in the Solar System economy.

Conclusion

It is apparent that if humanity is to become a spacefaring race, then how we build space structures has to change. We must move forward to utilize in-situ resources with newly developed construction techniques. The OCP approach meets both requirements and provides the ability to construct extremely large structures. However, it is only one piece of an exceptionally large and complex puzzle. Just as building a large structure on Earth requires many different processes, companies, and resources, so will construction in space. Eventually a space-based economy will develop that is not Earth-centric but where Earth is a part of it.

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