Mycelium Materials for Habitation

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Subject Matter Expert:

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TX06: Human Health, Life Support, and Habitation Systems

TX12: Materials, Structures, Mechanical Systems, and Manufacturing

Abstract

Mycelium is the filament structure that fungi use to grow, similar in function to the roots of a plant. It feeds on a substrate composed of agricultural waste and can grow to fill the shape of various molds. As it grows, the agricultural waste is decomposed and bonded with the mycelium to form a living mesh. After three to five days, the mycelium can then be processed to stop growth while retaining the shape of the mold. The resulting material is lightweight yet strong, with excellent mechanical properties. The mycelium materials are insulators, waterproof, fire retardant, and do not produce toxic gasses. The material could also be radiotrophic if melanin-rich mycelium is used in production. Because of these several useful properties, the simple manufacturing process, and sustainability, mycelium materials are currently commercially produced as sustainable alternatives to plywood and packaging material. Our objective is to study mycelium materials for in situ habitation construction material for manned planetary missions. The proposed work focuses on structural analysis of mycelium structures with an experiment testing mycelium material as radiation shielding. This fits under Taxonomy 06: Human Health, Life Support, and Habitation Systems, and Taxonomy 12: Materials, Structures, Mechanical Systems, and Manufacturing.

Technical Merit and Work Plan

As constant scientific advancements push humanity closer towards manned exploration of space, NASA needs a cost-efficient yet effective solution to human habitation and radiation protection. The Apollo missions used the lunar module as a habitat and the aluminum skin of the spacecraft provided a minimal amount of radiation shielding. Each mission risked solar flares that would rapidly cause acute radiation sickness. Despite the risk, all Apollo astronauts received a minimal amount of radiation. However, larger crews and longer missions require larger habitations and significantly increases the risks of radiation exposure. Building such large habitations on Earth would require large amounts of energy, time, and cost to launch into space. In situ manufacturing would greatly reduce the costs of building larger habitations. Our proposed work would be to study mycelium materials as both habitation construction and insulation material in addition to radiation shielding.

What is mycelium? Mycelium is the filament structure that fungi use to grow, similar in function to the roots of a plant. It is the most active stage of the life cycle of a fungus; as the mycelium grows in the provided substrate, the material is decomposed, and the fungi is fed the absorbed nutrients. The mycelium then grows single cell width fibers that binds the surrounding material together akin to a living polymer. The colonized substrate can then be split in two and would continue to grow separately. Providing more substrate would allow a continuous supply of mycelium to grow. If placed in a mold, the mycelium continues growing until the substrate is saturated completely. After three to five days, the mycelium can be processed through different processes to kill the organism and stop growth.

The resulting mycelium material is extremely versatile. It can be molded into custom shapes and is waterproof, fire retardant, and an insulator. During this early development, mycelium requires oxygen exchange but not sunlight. Reishi mushroom mycelium has been proven as a prime candidate for it’s tenacity, extremely tight bonding, and appetite for widely available hemp hurd substrate. It is a voracious grower and has been used by entrepreneurial companies like Ecovative Designs to produce packaging material and wood substitute for furniture. In a matter of days a colony can be molded into any custom shape and produce hydrophobic, flame resistant, thermally insulating material. The post process involves ending the organisms life cycle by heat treating and desiccating it. When composted, this material will break down completely within a week.

The ideal fungi strain would be fast-growing, tight binding, and slow to fruit (produce mushrooms). After fruiting, the next step in the mycological life cycle is reproduction by sporulation, which is vital to avoid.

Mushroom spores are a major inhalation hazard for humans on Earth, let alone in space and long-term exposure leads to lung inflammation and acute lung disease. In a microgravity environment, this would prove to be a catastrophic level of foreign object debris (FOD). Fortunately, this phase is easily avoidable via regulated temperature, moisture, and observation given that fruiting and sporulation only make up about the last 5% of the fungi's life cycle (see fig. 1.). Even if fruit is produced, it can be harvested before sporulation occurs.

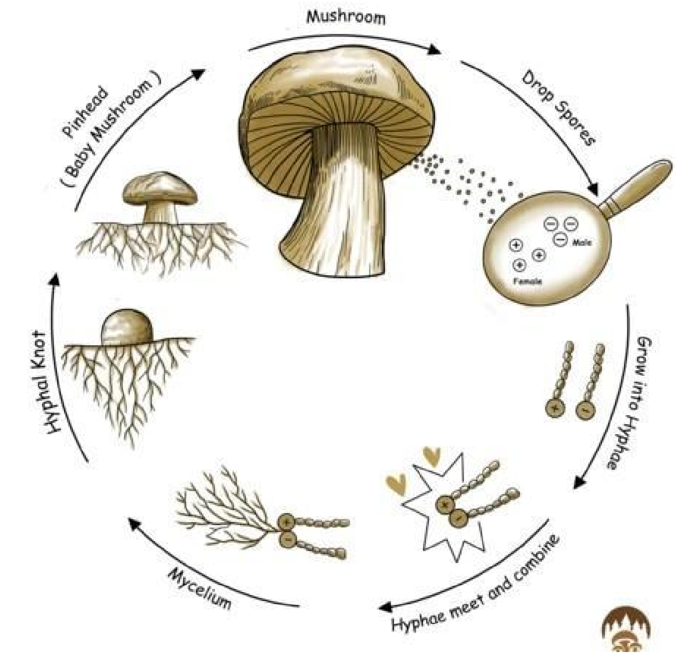

Fig. 1. The mushroom life cycle [27].

Fungi rapidly mutate to thrive in much more hostile and microgravity environments than on Earth. The Russian Mir station (20 February 1986 – 23 April 1996) famously had a number of microorganisms that had hitched a ride to space on (or in) the crew. These organisms evolved to digest metals and glass, and produced a distinct aroma visitors remarked on.

Radiotrophic fungi have also been studied as potential organic radiation shields that could be cultivated on Mars. While alive, the fungi 'photosynthesise' using melanin and radioactive energy. "One side of the petri dish was coated with the fungus; the other side had no fungus and served as a control. A detector was affixed to the back of the petri dish to measure radiation coming through. The detector was monitored for 30 days. The researchers found that the side of the petri dish that was covered with fungus reduced radiation levels coming through the dish by approximately 2% compared to the control side. That alone is inadequate as a safety shield, but the experiment serves as an indicator of what might be possible. On its
own, the fungus is known to grow, which means a rocket carrying humans could carry just a small amount with them. Once on Mars, the fungus could be cultivated on a shield structure" (Testing Chernobyl fungi as a radiation shield for astronauts by Bob Yirka , Phys.org).

Because these organisms are experts at adaptation and easily cultivated, they would be an amazing regenerative resource. A mix of substrates sourcing high-carbon, nutrient rich agricultural waste can be dehydrated, compacted and sent to space. In this state, it would take up little storage space and last indefinitely. Rehydrating and inoculating the material with a chosen mycelium culture would set cultivation and production of said material in motion. After inoculation, the mycelium will need additional nutrients in the form of a simple carbohydrate such as wheat flour within about 10 weeks.

While the substrate requires a fairly large amount of water per pound to hydrate (3 cups per 1 pound) and properly support the mycelium, all that water can be reclaimed during the post-processing of the material and recycled for drinking or other uses.

This technology has the potential to provide a truly renewable resource that can be cultivated entirely off of Earth. It would enable astronauts to build shelters in otherwise uninhabitable areas, and reduce the effects of cosmic radiation. As an added bonus, because this material is entirely biodegradable, using it to amend regolith would support larger scale agriculture with wider biodiversity.
By enabling humans to build outposts and habitat complexes, we would establish a real presence on the moon as opposed to ‘camping out’ in a lunar module. Besides establishing colonies on the moon and beyond, this green technology is completely applicable on Earth. Replacing common-use materials like concrete and lumber with mycelium materials would be a cost-effective and carbon negative solution.

Unlike lumber, which is very commonly treated with arsenic, formaldehyde or other dangerous compounds, mycelium-based material is entirely biodegradable, and would be an excellent regolith amendment as our need for agriculture expands. On Earth, it takes about five days to decompose once composted, compared to 500 years it would take the same volume of styrofoam.

In terms of both transporting and using the material, mycelium is significantly cheaper, lighter, and longer-lasting material compared to commonly used construction materials such as lumber.When paired with a substrate such as compacted hemp hurds (between three and eight times less dense as wood), it would be possible to grow thousands of square feet of mycelium material per pound, as opposed to the usable square footage of lumber-based structures.

Mycelium material could also be processed in many different ways, most commonly by desiccating the object in an oven, killing the organism and removing the moisture. Another method is applying heat and pressure to form it into a dense, wood-like board. But in an extreme environment like the moon or Mars, why not just expose the water-laden pieces to space? The water would freeze, but our team thinks that's worth looking into. The current protocol on the ISS for a solar event is for the crew to huddle in the middle of the module, piling up all the supplies - especially water - around them and hoping that it’s enough of a barrier to protect them from the worst of the storm. If a mycelium based construction material with high porosity was still full of water, would that increase its ability to shield human inhabitants from the harsh radiation of space and significant heat on certain astral bodies?

As more universities and entrepreneurs delve into this new technology, our team proposes NASA investigate the next steps; How resistant can this material be against cosmic radiation how can we integrate this with common insulating materials for enhanced performance at lower cost, and how can we set up astronauts and explorers to farm their future homes?

Table 1 is used to compare mycelium (which will be modelled as MycoComposite029) to various other materials such as aerogel, polyester film, aluminum, styrofoam, and plywood. These comparisons help us understand where mycelium outperforms the usual materials we use for building, and where it can be improved.

Table 1:

	General Application Reasoning	**Mycelium (MycoComposite029)**	**Aerogel**	**Polyester film (in MLI)**[13]	**Aluminum (in MLI)**	**Styrofoam**	**Plywood**
Density	Implied built	110 kg/m3	[23]	1390 kg/m3	[12]	[5]	[20]

	added mass		100 - 500 kg/m3		2700 kg/m3	50 kg/m3	520 - 760 kg/m3
Tension/Tensile Strength	Implied structural integrity and warranty	0.020 - 0.028 MPa	0.081 MPa	[9] 28000 - 34000 psi (193 - 234 MPa)	[6] 75 MPa	[15] 18 - 50.9 MPa	[21] 27.6 - 34.5 MPa
Compression	Implied required space storage and durability	0.070 - 0.150 MPa	500 kPa - 4.2 MPa	2.3 psi (0.016 MPa)	[6] 30 - 280 MPa	30 - 100 psi (0.207 - 0.689 MPa)	31.0 - 41.4 MPa
Noise Reducing Coefficient (1 meaning all sound is absorbed)	Hearing protection (most applicable to spacecraft travel)	0.6	[11] 0.67	N/A	N/A	[9] 0.2	[1] 0.10 - 0.15
R-Value (higher value = more effective insulation)	Heat resistance thru a certain thickness of the material	3.5 deg*F*ft2*h/BTU	10.3 per inch	[7] 1.5	[22] 1.80 per 0.5 in	[25] 5.0 per in	[1] 0.10 - 0.15
Fire Rating	Resistance rating, A being the lowest flame spread	Fireproof Rating A	[26] Fireproof Rating A1	[11] Combustible	[14] Non-combus tible	[2] Untreated EPS foam burns at 650-700 deg*F	[4] A, B, or C
Modulus of Elasticity [Young's Modulus]	Material flexibility in terms of elasticity (ratio stress:strain of linear region of material)	9.00E-4 - 1.700E-3 GPa	106E-7 GPa	[16] 3.79 GPa	[17] 0.048 - 342 GPa	[15] 1.65 - 3.4 GPa	N/A
Flexural Strength (greater value = greater force necessary to break)	Material flexibility breaking point (bending)	0.100 - 0.200 MPa	[24] Less than 10^-2 MPa	N/A	[17] 172 - 330 MPa	[15] 29.4 - 107 MPa	N/A
Flexural Modulus (higher meaning harder to bend)	Tensile and compressive strain	7.200E-3 - 1.300E-2 GPa	[3] 5,000 psi (0.034 GPa)	490kpsi (3.378 GPa)	[6] 106 GPa	[15] 1.4 - 3.45 GPa	[21] 8.20 - 10.3 GPa

Styrofoam and plywood are two common materials mycelium can replace. MLI, or Multi-Layered Insulation is a material often used to insulate spacecrafts. Their main two materials are polyester film and aluminum. Aerogel has more recently been implemented as a highly effective insulation material, but it does not contain significant strength or flexibility due to its solid but jelly-like structure. Although mycelium by itself lacks much of the structural strength, it can be strengthened depending on the mold and substrate material. Due to its structure, mycelium has a 0.6 noise reducing coefficient that could be used to build quieter spaces in habitats or protect inhabitants from harmful audio levels. Additionally, the material must be generally safe to handle since it will be transported for the purpose of human habitation. High combustible materials need additional labor, care, and supplies to meet safety requirements. Thermal insulation and shear stress must also be determined and enhanced to ensure long shelf life in a harsh environment

Project Management Approach

Preliminary Schedule for the Mycelium Materials for Habitation Project

Our team proposes to start the project this upcoming year at the start of the new year of 2022. During this initial first stage, we hope to develop the material in a reusable building block form that gives the desired mechanical and chemical properties. The following figures are the Gantt charts for testing, structural analysis, and growth viability of mycelium material.

Testing

Fig. 2. A timeline for radiation testing of the mycelium material, the span of this should be about 2-3 months.

Structural Analysis

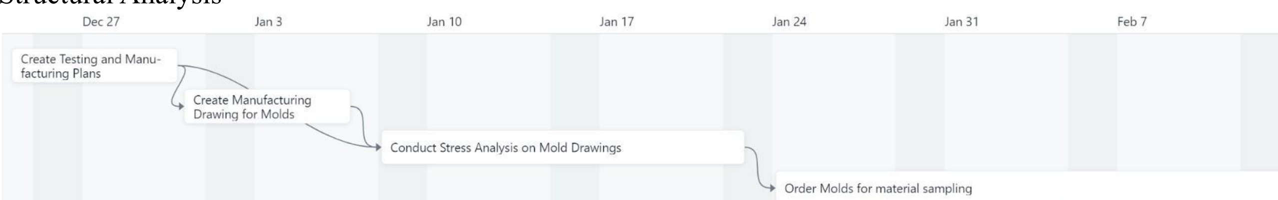

Fig. 3. We will also conduct structural analysis on the molds that we develop ourselves for the project and develop an infrastructure to help with the farming of the product. This will take about 3 months.

Viability of Growth

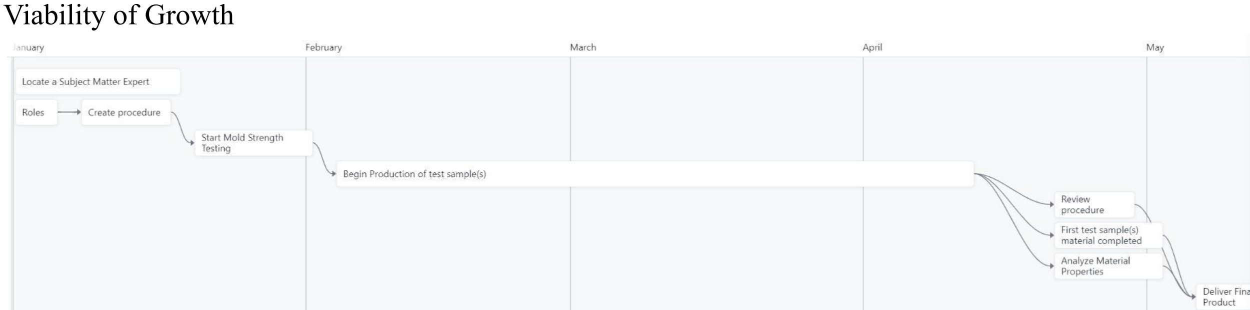

Fig. 4. Research and development will be conducted on the viability of growth of the product in space and we will also develop a proposed farming technique that we intend to test ourselves. This will take about 6 months.

Budget

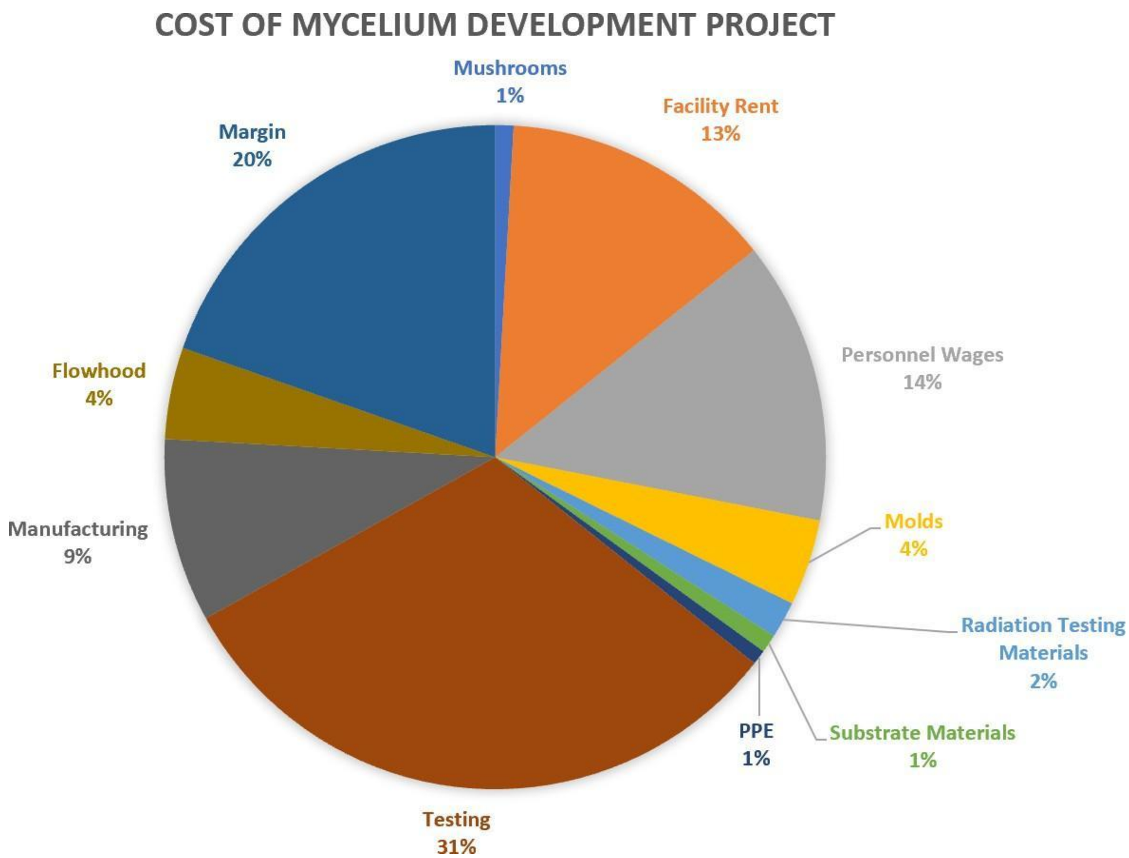

Fig. 5: Budget analysis of the project

The figure above represents the cost breakdown of this project where the largest allocations include personnel, manufacturing, testing, and facilities expenses. Generally, there should be a 20-30% margin reserved from the total project budget to fund unforeseen situations without severely totalling past the budget. In total, the cost of this development project is $10,000 including a 20% margin as that is the amount of grant this team hopes to receive.

Roles and Responsibilities

- NASA Program Executive - ensures that the project meets obligations, i.e. cost, schedule, and technical; facilitates transitions between phases.
    - Program Scientist - monitors science management and program execution and ensures the science of the mission remains viable and true to strategic objectives during development of the mission.
- Mission Manager - provides a team-based operational environment for day-to-day tasks.
    - Project Scientist - determines and executes research goals in relevant areas of expertise.
    - Mission Systems Engineer - understands all technical parts of the mission and how they come together.

- Principal Investigator - primary individual that has total responsibility for the project to succeed.
    - Project Manager - works with the PI to ensure that the project is meeting its goals and objectives with the resources proposed.
    - Executive Advisory Council - helps control costs, and resources.
    - Science Team - research, calculate, perform modelling on the scientific aspect of the mission.
    - Subject Matter Experts/Mentors - mentors or provides expert feedback on research and prototyping aims.
        - Structural Engineer - provides background knowledge and direction on structural integrity.
        - Material Scientist - provides background knowledge on material testing and creation.
        - Mycologist - provides background knowledge on topics concerning mushroom mycelium development.

Teaming and Workforce Development

Team Member	Major	Contribution
Alex Langenstein	Mechatronics	Mushroom farming experience, long-term conceptual farming techniques, research
Jessica Boen	Chemical Engineering	Thermal and radiation research and analysis, fluid dynamic modelling, designing P&IDs and SOPs
David Franco	Aerospace Engineering	Radiation experiment development and planning, structural and thermal analysis
Ashley Perez	Aerospace Engineering	Thermal, structural, and fluid dynamics analysis
Ricardo Guzman	Computer Science	Modeling, programming, calculations
Ariyan Kalami	Computer Engineering	Calculations, simulations for structural integrity tests, modeling, robotics
Alejandro Martin-Villa	Mechanical Engineering	Stress and fatigue testing, manufacturing techniques, concept design

Appendix (the following pages)

<u>Updated Quad Chart</u>

Mycelium Materials

PI: Alex Langenstein, Team # 13

Goal

- Investigate the use of mycelium as a material for use in building habitats off-Earth.
- Low-cost, high-yield, fire-resistant, dense material that can also be composted to provide radiation shielding, water storage, construction material, thermal insulation, and minimizing storage requirements such as mass, density, and weight.
- Currently, commercial production of mycelium 'particle board' takes about 4 days with Ecovatives' Mycelium Foundry, as opposed to particle board taking a matter of weeks, and containing numerous hazardous chemicals.
- Taxonomy 6-Human Health, Life Support, and Habitation Systems
- Taxonomy 12-Materials, Structures, Mechanical Systems, and Manufacturing

Team Overview

- During the NCAS program, I focused my efforts on this technology, and did copious amounts of research on it. I am also a hobbyist mycologist and grow several varieties of edible mushrooms (golden, grey,, blue, pink P. ostreatus, Laetiporus, H. erinaceus)
- Team members and their specialties would include as follows:
  - Jessica Boen - Chemical Engineering
    - Contribution: Thermal and radiation research and analysis, fluid dynamic modelling, designing P&IDs and SOPs
  - David Franco - Aerospace Engineering
    - Contribution: Radiation experiment development and planning, structural and thermal analysis
  - Ashley Perez - Aerospace Engineering
    - Contribution: Thermal, structural, and fluid dynamics analysis
  - Ricardo Guzman - Computer Science
    - Contribution: Modeling, programming, calculations
  - Ariyan Kalami - Computer Engineering
    - Contribution: Calculations, simulations for structural integrity tests, modeling, robotics
  - Alejandro Martin - Mechanical Engineering
    - Contribution: Stress and fatigue testing, manufacturing techniques, concept design

Metrics and Key Performance Parameters

- Stage One: Designing experiment(s)
  Stage Two: Research and development
  Stage Three: Conclusions and next steps
- In the ongoing search for solutions to habitat and radiation mitigation, this rapid-prototyping and endlessly customizable material would be highly beneficial to investigate with NASA's full gamut of research and resource infrastructure.
- Reishi mushroom mycelium has been proven as a prime candidate for it's tenacity, extremely tight bonding, and appetite for widely available hemp hurd substrate.
- Currently used for things such as packaging material or wood substitute in future
- Colony can be molded into any shape and produce hydrophobic, flame resistant, thermally insulating material.

National Aeronautics and Space Administration	Disclosure of Invention and New Technology (Including Software)	Form Approved O.M.B. NO. 2700-0009	DATE 07/01/2021
		CONTRACTOR CASE NO. 80NSSC19M0186	

This is an important legal document. Carefully complete and forward to the Patent Representative (NASA in-house innovation) or New Technology Representative (contractor/grantee innovation) at NASA. Use of this report form by contractor/grantee is optional; however, an alternative format must at a minimum contain the information required herein. NASA in-house disclosures should be read, understood and signed by a technically competent witness in the witness signature block at the end of this form. In completing each section, use whatever detail deemed appropriate for a "full and complete disclosure." Contractors/Grantees please refer to the New Technology or Patent Rights – Retention by the Contractor clauses. When necessary, attach additional documentation to provide a full, detailed description.

NASA CASE NO. (OFFICIAL USE ONLY)

1. DESCRIPTIVE TITLE

Growing Home: Mycelium Construction Material for Human Habitation

2. INNOVATOR(S) *(For each innovator provide: Name, Title, Work Address, Work Phone Number, and Work E-mail Address. If multiple innovators, number each to match Box 5.)*

Alex Langenstein, full-time student, 541-294-0673, alangenstein252@southseattle.edu

3. INNOVATOR'S EMPLOYER WHEN INNOVATION WAS MADE *(For each innovator provide: Name, Division and Address of Employer, Organizational Code/Mail Code, and Contract/Grant Number if applicable. If multiple innovators, number each to match Box 5.)*

none

4. PLACE OF PERFORMANCE *(Address(es) where innovation made)*

Alex Langenstein residence

5. EMPLOYER STATUS *(choose one for each innovator)*

Innovator #1   Innovator #2

SB

Innovator #3   Innovator #4

GE = Government
CU = College or University
NP = Non-Profit Organization
SB = Small Business Firm
LE = Large Entity

6. ORIGIN *(Check all that apply and provide all applicable numbers. If multiple Contracts/Grants, etc., list Contract/Grant Numbers in Box 3 with applicable employer information.)*

- ☐ NASA In-house Org. Mail Code — WBS
- ☐ Grant/Cooperative Agreement No. — WBS
- ☐ Prime Contract No. — WBS
  - Task No. — Report No.
  - Subcontractor; Subcontract Tier
  - WBS Joint Effort *(contractor, subcontractor and/or grantee contribution(s), and NASA in-house contribution)*
  - Multiple Effort *(multiple contractor, subcontractor and/or grantee contributions, no NASA in-house contribution)*
- ✔ Other (e.g., Space Act Agreement, MOA) No. L'SPACE — WBS

7. NASA CONTRACTING OFFICER'S TECHNICAL REPRESENTATIVE *(COTR)*

8. CONTRACTOR/GRANTEE NEW TECHNOLOGY REPRESENTATIVE *(POC)*

Alex Langenstein

☐
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☐

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9. BRIEF ABSTRACT *(A general description of the innovation which describes its capabilities, but does not reveal details that would enable duplication or imitation of the innovation.)*

Utilizing the natural hardiness and flexible properties of fungi mycelium, our team proposes using it as a material to construct habitats for humans in extreme environments off-Earth. This material could be used as an insulator in space stations, or to build shelters on the moon and Mars. Cultivating fungi and producing a range of different materials would enable a regenerative and completely biodegradable resource. After being used as a construction material, it can be composted and used to amend regolith.

SECTION I – DESCRIPTION OF THE PROBLEM OR OBJECTIVE THAT MOTIVATED THE INNOVATION'S DEVELOPMENT ***(Enter as appropriate: A. – General description of problem/objective; B. – Key or unique problem characteristics; C. – Prior art, i.e., prior techniques, methods, materials, or devices performing function of the innovation, or previous means for performing function of software; and D. – Disadvantages or limitation of prior art.)***

A. The current protocol for astronauts aboard the ISS in the event of a solar storm is to huddle together, and pile supplies (especially water) around themselves. Because cosmic radiation is so brutal, many materials we would normally use to shield us from radiation -like the lead apron at your dentists' visit- actually cause humans more harm than protection. Water has been shown to be a great way to deflect radiation, but it's also our most precious resource.

B. Because mycelium has high porosity and water content, the thought is that it would be an excellent shielding material. If a sealed piece of material was cultivated in a human-friendly environment, then suddenly was exposed to the extremely cold environment of space or the lunar surface, it would kill the organism and freeze all of the water in said piece. Also, because there are radiotrophic (nuclear energy consuming) fungi that thrive in the depths of Chernobyl, our team considered the possibility of radiation mitigation by way of keeping the organism as a living material, combining woody, structurally robust mycelium with another species that feeds on radiation.

SECTION II – TECHNICALLY COMPLETE AND EASILY UNDERSTANDABLE DESCRIPTION OF INNOVATION DEVELOPED TO SOLVE THE PROBLEM OR MEET THE OBJECTIVE ***(Enter as appropriate; existing reports, if available, may form a part of the disclosure, and reference thereto can be made to complete this description: A. – Purpose and description of innovation/software; B. – Identification of component parts or steps, and explanation of mode of operation of innovation/software preferably referring to drawings, sketches, photographs, graphs, flow charts, and/or parts or ingredient lists illustrating the components; C. – Functional operation; D. – Alternate embodiments of the innovation/software; E. – Supportive theory; F. – Engineering specifications; G. – Peripheral equipment; and H. – Maintenance, reliability, safety factors.)***

A. Protect humans from harmful cosmic radiation with dense, fungi based materials

B. Reishi Mycelium, hemp hurd substrate, water, flour, mold form

B1. colonize the substrate with the specific strain of fungi by mixing the fungi culture with the substrate. After 24 hours, add water and flour, mix thoroughly, and press into form. After 3-5 days the substrate will turn white from the mycelium penetrating and binding the substrate together, solidifying it into a single piece. At this point the piece can be removed from the mold and desiccated to produce styrofoam-like material, or pressed and heated to form plywood-like board.

C. Placing the styrofoam-like board within the walls of a spacecraft would insulate from the extreme cold and heat of space. Using this material as bricks or unique molded pieces could construct modular shelters.

D. Alternatively, keeping the material alive and coupling it with a second species that digests radiation

E. Research from the following:

https://interestingengineering.com/future-construction-mushroom-building
s https://phys.org/news/2020-07-chernobyl-fungi-shield-astronauts.html
https://www.biorxiv.org/content/10.1101/2020.07.16.205534v5
http://2018.igem.org/Team:Stanford-Brown-RISD
http://2017.igem.org/Team:Stanford-Brown/Overview

G. Mycelium, substrate, forms for growing pieces, water, simple carbohydrate (wheat or rice flour), gloves, spray bottle, isopropyl alcohol

H. This material is low maintenance; It will continue to grow as long as it's given adequate substrate and water. After being packed into the mold, it will colonize the substrate completely. At that point it should be removed from the form. If it were allowed to keep growing, it would eventually fruit, then sporulate. Sporeulation must be avoided at all costs, as it would be a severe health hazard.

SECTION III – UNIQUE OR NOVEL FEATURES OF THE INNOVATION AND THE RESULTS OR BENEFITS OF ITS APPLICATION ***(Enter as appropriate: A. – Novel or unique features; B. – Advantages of innovation/software; C. – Development or new conceptual problems; D. – Test data and source of error; E. – Analysis of capabilities; and F. – For software, any re-use or re-engineering of existing code, use of shareware, or use of code owned by a non-federal entity.)***

A- Because this is a colony-based organism, it can be cloned from a tissue sample of a known strain with desirable qualities for dense, tight binding mycelium. The colony can also be continually propegated and is only limited by the amount of food and substrate made avaialable to it, making it an invaluable resource in space.

B- It is highly adaptable and will undoubtedly acclimate faster to life in space than humans. Encouraging it to metabolize radiation and form strong materials will be mutually beneficial for the fungi and humans alike

C- Sporulation would be extremely dangerous; The fungi must not be allowed to mature and reproduce freely.

SECTION IV – SPECULATION REGARDING POTENTIAL COMMERCIAL APPLICATIONS AND POINTS OF CONTACT (***Including names of companies producing or using similar products.)***

Ecovative Designs

10. ADDITIONAL DOCUMENTATION *(Include copies or list below any pertinent documentation which aids in the understanding or application of the innovation (e.g., articles, contractor reports, engineering specs, assembly/manufacturing drawings, parts or ingredients list, operating manuals, test data, assembly/manufacturing procedures, etc.).)*

TITLE	PAGE	DATE
http://2018.igem.org/Team:Stanford-Brown-RISD		
http://2017.igem.org/Team:Stanford-Brown/Overview		
https://www.biorxiv.org/content/10.1101/2020.07.16.205534v5		
ecovativedesign.com		
https://phys.org/news/2020-07-chernobyl-fungi-shield-astronauts.html		

11. DEGREE OF TECHNOLOGY SIGNIFICANCE (*Which best expresses the degree of technological significance of this innovation?)*

☐ Modification to Existing Technology ✔ Substantial Advancement in the Art ☐ Major Breakthrough

12. STATE OF DEVELOPMENT

✔ Concept Only   Design   Prototype   Modification   Production Model   Used in Current Work

13. PATENT STATUS (Prior patent on/or related to this innovation.)

Application Filed   Application No.   Application Date

Patent Issued   Patent No.   Issue Date

14. INDICATE THE DATE OR THE APPROXIMATE TIME PERIOD WHICH THIS INNOVATION WAS DEVELOPED (*i.e., conceived, constructed, tested, etc.)*

April-June 2021

15. PREVIOUS OR CONTEMPLATED PUBLICATION OR PUBLIC DISCLOSURE INCLUDING DATES *(Provide as applicable: A. – Type of publication or disclosure, e.g., report, conference or seminar, oral presentation; B. – Disclosure by NASA or Contractor/Grantee; and C. – Title, volume no., page no., and date of publication.)*

16. QUESTIONS FOR SOFTWARE ONLY

(a) Using non-NASA employees to beta-test the program? ☐ YES ✔ NO   If Yes, done under a beta-test agreement? ☐ YES ☐ NO

(b) Modification of this program continued by civil servant and/or contractual agreement? ☐ YES ✔ NO

(c) Copyright registered? ☐ YES ✔ NO ☐ UNKNOWN   If Yes, then by whom?

(d) Has the latest version been distributed outside of NASA or contractor? ☐ YES ✔ NO ☐ UNKNOWN If Yes, date of first disclosure:

(e) Were prior versions distributed outside of NASA or Contractor? ☐ YES ✔ NO If Yes, supply NASA or contractor contract:

(f) Contains or based on code not owned by U.S. Government or its contractors? ☐ YES ☐ NO ☐ UNKNOWN If Yes, name of code and code's owner:

Has a license for use been obtained? ☐ YES ☐ NO ☐ UNKNOWN

17. DEVELOPMENT HISTORY			
STAGE OF DEVELOPMENT	DATE (MM/YYYY)	LOCATION	IDENTIFY SUPPORTING WITNESSES (NASA in-house only)
a. First disclosure to others	04/2021	online	
b. First sketch, drawing, logic chart or code			
c. First written description			
d. Completion of first model of full size device *(invention)* or beta version *(software)*			
e. First successful operational test *(invention)* or alpha version *(software)*			

f. Contribution of innovators *(if jointly developed, provide the contribution of each innovator)*

g. Indicate any past, present, or contemplated government use of the innovation

18. SIGNATURES OF INNOVATOR(S), WITNESS(ES), AND NASA APPROVAL			
TYPED NAME AND SIGNATURE *(Innovator #1)* Alex Langenstein	DATE 06/30/2021	TYPED NAME AND SIGNATURE *(Innovator #2)*	DATE
TYPED NAME AND SIGNATURE *(Innovator #3)*	DATE	TYPED NAME AND SIGNATURE *(Innovator #4)*	DATE
TYPED NAME AND SIGNATURE *(Witness #1)*	DATE	TYPED NAME AND SIGNATURE *(Witness #2)*	DATE
NASA APPROVED	TYPED NAME	SIGNATURE	DATE

Science Traceability Matrix

Column #	1	2	3	4	5	6	7	8
	Science Goals	Science Objectives	Scientific Measurement Requirements		Mycelium Performance Requirement		Projected Instrument Performance	Mission Requirements (Top Level)
			Observables	Physical parameters				
	Develop mycelium as an insulating/construction material for habitation shelters intended as outpost or habitation complexes	Develop a mycelium material withstandable for at least 6 months in space	Structural Integrity of Overall Material or Composite	Tensile, Compression Strength, Shear Stress	Structural Integrity	30-40 MPa	28 MPa	Needs compressible packaging and stress-withstanding properties
				Size mycelium can support with optimal structural integrity	Max Radiation Leakage	Max tolerable radiation for humans: 20 mSv	15 mSv	
		Develop a procedure of material growing and finishing process		Composition and Mass of Feed	Heat Resistance R-Value	5	5-10	Must be packable in transportation storage
				Composition and Density of Substrate	Fire Rating	Medium-risk combustibility	Grade A, low combustibility	
		Test and enhance particle and thermal radiation resistance of mycelium to within human safety limits	Environmental Compatibility	Operable Temperature, Pressure, Microgravity, and Humidity	Thermal operable range	80 deg F	50-80 deg F	Must be compatible with astro-environments including Mars and Earth's Moon
			Thermal Resistivity	R-Value	Tensile Strength	0.02-0.10 MPa	0.03 MPa	
			Human Health	Fire Rating and	Compression Strength	0.15-1.0 MPa	0.20 MPa	

				Hazards				
			Radiation Absorba n ce	Absorban ce Spectra				

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