EVOLVING ASTEROID STARSHIPS: A BIO-INSPIRED APPROACH FOR INTERSTELLAR SPACE SYSTEMS

Angelo Vermeulen\textsuperscript{1,2}, Mikhail Sirenko\textsuperscript{1}, Farshad Goldoust\textsuperscript{1}, Daniela Hallak\textsuperscript{1}, Brennan Lutkewitte\textsuperscript{3}, Alvaro Papic\textsuperscript{1}, Jason Kiem\textsuperscript{1,4}, Frances Brazier\textsuperscript{1}

\textsuperscript{1} Delft University of Technology, Delft, the Netherlands
\textsuperscript{2} SEAD (Space Ecologies Art and Design)
\textsuperscript{3} Technical University of Berlin, Berlin, Germany
\textsuperscript{4} SmartCrops BV, The Hague, the Netherlands
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TU DELFT E(A)S (EVOLVING ASTEROID STARSHIPS) PROJECT

![Image of asteroid with a ship inside]

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DETAILS

**Title:** TU Delft E(A)S (Evolving Asteroid Starships) project

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**Description:**
A group of students and researchers at Delft University of Technology are designing a starship capable of keeping generations of crew alive as they cross the gulf between stars - and they've turned to ESA for the starship's life support.

OYSTAR, the TU Delft Starship Team, is bringing together a wide variety of disciplines to perform advanced research and development.
CHALLENGES OF HUMAN INTERSTELLAR EXPLORATION

Radiation
Particles and dust
Regenerative life support
Not part of this study:
- propulsion & power supply
- social & cultural aspects
HUMAN INTERSTELLAR EXPLORATION IS A COMPLEX PROBLEM OPERATING UNDER DEEP UNCERTAINTY

Interconnectedness
Differing time scales
Dynamic behavior
Interminability
Deep uncertainty
To address interminability and deep uncertainty we have to design a complex adaptive system (CAS).

To create a complex system, emergence is needed.

Emergence can be operationalized through a combination of evolution and morphogenesis.
ASHBY’S LAW OF REQUISITE VARIETY

The larger the variety of actions available to a control system, the larger the variety of perturbations it is able to compensate.
GALL’S LAW

A complex system that works is invariably found to have evolved from a simple system that worked. A complex system designed from scratch never works and cannot be patched up to make it work. You have to start over with a working simple system.
JOIN THE TU DELFT STARSHIP TEAM

We’re a team of students and researchers with a shared passion for interstellar travel, looking for new team members from all faculties.
Interested in helping to develop starship concepts?
Curious how to integrate engineering, architecture and biology?

Welcome to our open work sessions
Mondays between 4 and 6 pm
TPM, Room B1.300

More information: Angelo Vermeulen, a.c.j.vermeulen@tudelft.nl
ASTEROID MINING

3D MANUFACTURING

Extruder Spinneret Creates Structural Elements of Desired Length

Material Source Spool

Stereo-optic Imager Performs Metrology

Robotic Arms Provide Mobility and Manipulation

SpiderFab, Tethers Unlimited & NASA, 2013
MODULE TYPES

1. Regenerative life support
2. Habitation
3. Radiation shielding
4. Collision shielding
5. Mining
6. Processing
7. Manufacturing
8. Ore storage
9. Refined materials storage
MORPHOGENETIC/EMERGENCE ENGINEERING
VON NEUMANN SELF-REPLICATION

- 3D manufacturing robot
- Manufacturing module
VON NEUMANN SELF-REPLICATION

- 3D manufacturing robot
- Manufacturing module
VON NEUMANN SELF-REPLICATION

- 3D manufacturing robot
- Manufacturing module
- Habitation module
- Ecosystem module
VON NEUMANN SELF-REPLICATION

3D manufacturing robot
Manufacturing module
Habitation module
Ecosystem module
VON NEUMANN SELF-REPLICATION

- 3D manufacturing robot
- Manufacturing module
- Habitation module
- Ecosystem module
DISCRETE EVENT SYSTEM SPECIFICATION

Corresponding classes are defined in the following way.

```python
import numpy as np

class Spacecraft:
    """The overarching class for an evolving asteroid starship (EAS)"

    Attributes
    ----------
    structure : array
        A list of important spatial characteristics
    total_population : int
        Total population of a EAS
    n_modules : int
        Total number of modules of a spacecraft

    __init__(self, total_population=np.random.randint(50, 100), structures=[], n_modules=5):
        self.total_population = total_population # draw a sample from discrete random uniform from distribution
        self.structure = structure
        self.modules = []
        self.asteroid = Asteroid()
        for module in range(n_modules):
            module = Module()
            self.modules.append(module)

class Asteroid:
    """A class representing an asteroid object"

    Attributes
    ----------
    chemical_composition : array
        Chemical composition of a given asteroid

    __init__(self, chemical_composition=[0, 0, 0]):
        self.chemical_composition = chemical_composition

class Module:
```
```
UNPREDICTABLE CHALLENGES

COSMIC RADIATION
PARTICLES AND DUST
EVOLVABILITY

INTERSTELLAR MEDIUM

START

SENSING HORIZON

GROWTH

ANTICIPATED

SIMILAR

CHANGE

EVOLUTION
Simulation formalisms:
- ABM (agent-based modeling)
- DEVS (discrete event system specification)
- SD (system dynamics)
- EA (evolutionary algorithms)
AGENT-BASED MODELING

DEFINITION

• Works with agents and ticks
• Focus on interactions and emergent patterns
• High granularity and ontological correspondence
Bacterial Protein
Fecal Protein
Lipids
Polysaccharides
Food biomass
VFAs
HNO₃
NH₃
CO₂
H₂O
H₂
O₂

Compartment
Reservoir
Auxiliary process

MELiSSA MASS FLOWS

IVa  
IVb  
V

H₂ + O₂ → H₂O

H₂O₂
COMPARTMENT I

Fecal protein
\[3.2\text{CH}_{1.76}\text{O}_{0.239}\text{N}_{0.239} + 3.035\text{H}_2\text{O} = \text{C}_2\text{H}_4\text{O}_2 + 0.1\text{C}_4\text{H}_8\text{O}_2 + 2.3\text{H}_2 + 0.76\text{NH}_3 + 0.8\text{CO}_2\]

Bacterial protein
\[3.2\text{CH}_{1.4697}\text{O}_{0.34}\text{N}_{0.2807} + 2.712\text{H}_2\text{O} = \text{C}_2\text{H}_4\text{O}_2 + 0.1\text{C}_4\text{H}_8\text{O}_2 + 1.3162\text{H}_2 + 0.8982\text{NH}_3 + 0.8\text{CO}_2\]

Polysaccharides
\[3.199\text{CH}_{1.667}\text{O}_{0.833} + 1.134\text{H}_2\text{O} = \text{C}_2\text{H}_4\text{O}_2 + 0.1\text{C}_4\text{H}_8\text{O}_2 + 1.4\text{H}_2 + 0.8\text{CO}_2\]

Lipids
\[\text{C}_{16}\text{H}_{32}\text{O}_2 + 13.0278\text{H}_2\text{O} = 6.5278\text{C}_2\text{H}_4\text{O}_2 + 0.6528\text{C}_4\text{H}_8\text{O}_2 + 0.3333\text{CO}_2 + 13.3611\text{H}_2\]
COMPARTMENT I

Fecal protein
\[3.2\text{CH}_{1.76}\text{O}_{0.239}\text{N}_{0.239} + 3.035\text{H}_2\text{O} = \text{C}_2\text{H}_4\text{O}_2 + 0.1\text{C}_4\text{H}_8\text{O}_2 + 2.3\text{H}_2 + 0.76\text{NH}_3 + 0.8\text{CO}_2\]

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Polysaccharides
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<th>Compound</th>
<th>Consumed (g)</th>
<th>Produced (g)</th>
<th>Flow conservation</th>
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</table>
PLANT PLOT AGENT

ATTRIBUTES

- Ideal plant: 100 day growth cycle, 40g dry weight, 60kcal, 0.5 harvest index
- Plant plot agent: 180 plants, 1 plant plot provides enough nutrients for a crew of 6 for 1 day
- 100 day production line: 100 plant plots

BEHAVIOR

Input-output: stoichiometry
PLANT PLOT AGENT

STATES

• Growth follows a sigmoid curve
• Reaching 40g in 100 days (10% first and 10% last week)
• For each day there’s a specific biomass increase, and hence, the corresponding necessary input can be deduced according to the plant plot’s stoichiometry
REDUCED HARVEST
GROWTH (BIOMASS)

TIME (DAYS)

NO NUTRIENTS

REQUIRED NUTRIENTS

DELAYED HARVEST
GROWTH (BIOMASS)

NO NUTRIENTS

NO HARVEST

TIME (DAYS)
Simulation formalisms:
- ABM (agent-based modeling)
- DEVS (discrete event system specification)
- SD (system dynamics)
- EA (evolutionary algorithms)
CONCLUSIONS

- CAS approach to create a robust system
- Exploratory modeling, not predictive modeling
- Consequences: co-evolution, intractability