EXPLORING THE CONCH AND ITS ABILITY TO SURVIVE EXTREME CONDITIONS

Harnessing Nature to Enhance Survival

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HARNESSING NATURE TO ENHANCE SURVIVAL

Challenge 1: Sustainable Energy Conversion for Habitation on Mars

For any location to be habitable to humans, energy is necessary and essential. It is required for heating, lighting, refrigeration, cooking and other essential basic functions of society but it is also required for machinery and electronics, transportation, communications and computing. The most basic energy producer is the Sun which provides a huge amount of energy to Earth to sustain living organisms.

In space, on Mars specifically, the energy requirements per person will be greater than on Earth due to the need for Environment Control and Life Support Systems (ECLSS) (Mars Settlement, 2013). One crucial factor affecting the survival

Figure 1: Utilizing wind as a sustainable energy source

Mars has immense wind storms despite its thin atmosphere. These “Wind Trees” have tiny blades are housed within the leaf units of each tree. The blades turn inwards, letting the leaves turn in the wind (regardless of wind direction). They respond to wind as low as 2 meters per second and are silent. This is beneficial because sound is wasted energy and can be disruptive in urban environments. These structures could be used in places where people frequent, unlike traditional wind turbines which are very noisy and obtrusive (Byrne, 2014).

(Image from Byrne, James (2014), Figure 1)
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rate of living organisms is access to water. The only known water on Mars is at its poles in the form of massive ice deposits with an estimated volume of $1.2\text{-}1.7 \times 10^6$ km$^3$ and buried ice (Cockell, C. S., 2014). To extract buried ice and to melt it and the ice at the poles to have water for survival would take enormous amounts of energy.

In 2010, energy on Earth was attained from (in decreasing order) oil, coal, natural gas, biomass, nuclear fission, hydroelectric and other renewables. 80% of energy used on Earth is sourced from fossil fuels and less than 1% is obtained from other renewables such as solar, wind, wave, tidal, geothermal and ocean thermal sources (Mars Settlement, 2013). Most of these conventional energy sources are unavailable or undevelopable on Mars. What has potential for development is nuclear fission, solar, wind or aerothermal. With increasing carbon dioxide levels in Earth’s atmosphere, prompting climate change, more investments are being made into non-fossil fuel related energy sources making the development of these technologies more economically viable.

While solar power is a potential option for an energy source, Mars has high velocity dust storms that can block out the sun for months. Energy could be harnessed from the wind of these storms to provide energy for the requirements of sustainable life. Wind turbines (Bluck, 2001) have the potential to be the gateway into this solution as well as ‘hairy’ suits to harness the wind on Mars.

The development of sustainable energy conversion is an essential solution to make normally inhabitable environments habitable for humans in space.

Figure 2: Solar energy as a sustainable energy source

An example of sustainable energy conversion for barren environments are these “FERN”s (Future, Energy, Renewable, Nature). They are semi-transparent solar panels that are designed to follow the movement of the Sun. The stalk is of a flexible material that imitates the stalk of a plant (Onishi, 2010). They are designed for the deserts in Dubai. They provide shelter from the Sun during the day while collecting energy for electricity generation.

(Images from Onishi, Takuya (2010) Figures 5 and 1, respectively)
Challenge 2: Habitable Structures in Extreme Environments

The Martian environment is completely uninhabitable by humans as known today. Substantial alterations would have to be made for life to continue to survive once it has arrived. When comparing environmental condition on Mars to those on Earth it is seen that there are many differences that would be a factor in the survival rate of humans on Mars. Mars’ average atmospheric pressure is 7.5 millibars while Earth’s is 1,013 millibars (Smith, 2016) meaning Mars’ is only 0.75% the pressure of Earth’s. This influences human’s in the way we perceive sound, breathe, as well as the states the fluids within our bodies are in. At low pressures the boiling temperatures of certain substances decrease meaning they can convert from liquid to gas at lower temperatures than on Earth.

The atmospheric components on Earth are 77% Nitrogen, 21% Oxygen, 1% Argon and 0.038% Carbon Dioxide (CO2) (Smith, 2016). Mars’ atmospheric components are 95.32% Carbon Dioxide, 2.7% Nitrogen, 1.6% Argon, 0.13% Oxygen, 0.03% Water Vapor and 0.01% Nitric Oxide (Smith, 2016). The most obvious issue with the proportions of molecules on Mars is the difference in percent of oxygen. Mars has significantly less oxygen than Earth especially considering the reduced atmospheric pressure which means there is less matter in the atmosphere. Another less obvious issue is the amount of CO2. At Earth’s proportion of 0.038% CO2 we see a severe threat to life on Earth with increases in global temperatures, destruction of ecosystems and loss of species. There have been no methods to combat this CO2 production or ways to store it. Mars has 95% CO2 which could

Figure 3: Habitable Structures in Extreme Environments

A challenge is structurally sound and material/energy sufficient buildings for habitation. Particularly on Mars some major issues for these structures are: temperature regulation, oxygen supply, and structural integrity to withstand severe storms.

This image is taken from Star Wars’ Mos Espa as a very primitive dwelling. As primitive as it may be, the domed structure is proved as one of the strongest shapes. It can therefore withstand major wind storms, like those on Mars.

(Image from headbugz, 2012, Figure 1).
cause an issue in sustaining life. It has also been modeled that Mars has been impacted by significant acid rains which may have been produced when iron from surrounding rocks was picked up by groundwater and underwent a chemical reaction to produce hydrogen atoms, increasing the acidity of the water it was evaporated with (Thompson, 2010).

The average distance of Earth from the Sun is 150 million kilometers while Mars is, on average, 288 million kilometers away from the Sun (Thompson, 2010). Mars will receive less sunlight and this causes lower surface temperatures. Earth’s average surface temperature is 14 degrees Celsius while Mars’ average surface temperature is -63 degrees Celsius (Thompson, 2010). Where people live must be energy efficient and insulating to protect its inhabitants. These extreme conditions on Mars make it a challenging place for long-term relocation.
Challenge 3: Navigation in Space

Initial navigation methods on Earth included using recognizable land formations as location markers (as they do not change significantly with time), compasses (utilizing the Earth’s magnetic field), and celestial body identification (using stars and constellations to pinpoint locations). In the 20th century, radio and sonar was developed and used as a navigation method when used with beacons. The gyroscopic compass involves holding its position relative to the rotation of the Earth. Once shipboard electricity was introduced, the gyroscopic compass could point to true north. This was important because a traditional metal compass was less reliable on steel vessels. Today, Global Position System’s (GPS’s) are used by utilizing the Doppler effect of radio signals sent from two or more satellites (Penobscot Marine Museum, 2012). When contemplating navigation and Mars, there are two major issues: Navigation through space (from Earth to Mars) and navigation on Mars (not becoming disorientated when traversing the planet).

Unlike Earth, space does not have predictable magnetic field lines, nor discernable topographical features that may be used to reference location. When thinking about utilizing a reference point, the fact that everything is moving relative to each other must be taken into consideration. The Earth is rotating around the Sun, the Sun around a galaxy, satellites around their object of orbit and final destinations are always moving.

The size of each object is vastly small relative to the distances separating them. When taking this into account along with the fact that they are also moving, calculating accurate path trajectories becomes very difficult. On Earth, the gravitational field of the Earth and the Sun are the main gravitational forces experienced. However, in space the gravitational fields of various other bodies (other planets, stars, asteroids etc.) must be considered as well. They each will affect the object travelling through space (like the Sun dictates the orbital path of the Earth).

![Image of a contour map illustrating detailed information including water depths, rocks and shoal locations, structures (abandoned lighthouse), buoys, the area that dries out at low tide (intertidal zone), made in 1993 by the NOAA Coast and Geodetic Survey (Penobscot Marine Museum, 2012).](Image from Penobscot Marine Museum, NOAA Chart 13309 (1993), Figure 1)

**Figure 5: Navigation in Space**

This image shows a contour map that illustrates detailed information including water depths, rocks and shoal locations, structures (abandoned lighthouse), buoys, the area that dries out at low tide (intertidal zone), made in 1993 by the NOAA Coast and Geodetic Survey (Penobscot Marine Museum, 2012). The spacing between the lines shows how quickly the gradient of the surface changes.

To draw this would have taken large amounts of time to physically review the features of the area to get accurate distances and depths.
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Utilizing methods like topographical features, celestial body identification, and GPS may be effective way of navigating on Mars, however they require trial and error as well as “set up time” for satellites to be positioned and topographical features to be mapped before they can be used. A method that could be used upon arrival on Mars is crucial to initializing the habitualization of the area.

Figure 6: Navigation in Space

The Aerospace Robotics Laboratory (ARL) at Stanford University has developed a GPS pseudolite-based local-area navigation system for Mars rovers. They use bi-directional ranging GPS transceivers scattered over a local area which allows the rover to be located with respect to the local array (Stanford University, 2010).

A pseudolite (“pseudo-satellite”) is a ground based radio transmitter that transmits a signal of a satellite navigation system. They act as a navigation satellite but operate from the ground. This technology expands existing navigation technology (satellites) to difficult environments, like indoors or areas where coverage of a satellite navigation system is poor (Stanford University, 2010).

(Image from Stanford University, 2010, Figure 1).
CONCH

FUNCTION
Withstands strong compressional forces

ORGANISM
Queen conch
Strombus gigas

BIOLOGIC STRATEGY
Conches, such as the Queen conch, are models of structural strength due to the way their shells form. Conch shells have a cross-lamellar structure consisting of lath-like aragonite crystals and an organic matrix. The lath-like aragonite crystals form plywood-like structures composed of three macro-layers. Each macro layer is composed of first-order lamellae which form second-order lamella, which then form third-order lamellae (Kamat, S., et al. 2000). The organization of these crystals allows for the shell to have a hardness of 10-100 times that of its individual constituents (aragonite, organic layer) (Lin Y. M., et al. 2006). One lamella rotates is lamellar plane about an angle of 70-90 degrees with respect to that of its neighbouring layer (Kamat, S., et al. 2000).

Damage zones develop around indentations which reflect the mechanical response of the crossed-lamellar microstructure. The crack deflection, crack bridging, crack branching and the fiber pullout are the main toughening mechanisms of the shell (Lin Y. M., et al. 2006).

MECHANISM
The organization of lath-like aragonite crystals in layers of lamellae rotated 70-90 degrees with respect to their neighbouring layers reduces brittleness, creating a strong, flexible structure.

Figure 7
SEM IMAGES OF THE FRACTURE SURFACE OF A SPECIMEN. A) FIRST AND SECOND ORDER LAMELLA INDICATED BY BLACK AND WHITE ARROWHEADS, RESPECTIVELY. B) THIRD ORDER LAMELLA (after Hou, D. F. et al., 2004, Fig. 4)
DESIGN PRINCIPLE
A material of first, second and third order lamellae that are organized in layers with orientations offset by 90 degrees that can withstand compressional forces, is insulating and corrosion-resistant.

![Figure 8: Structure of material with rotating layers of lath-like constituents](image)

APPLICATION IDEAS
Build habitable structures that are heat-resistant (insulative), corrosion-resistant, and load-bearing from this material

KEY LIFE’S PRINCIPLES
Protects organism within shell from predators and extreme environmental conditions

Protects organism from strong external compressional forces

REFERENCES


HONEYBEE

FUNCTION
Detect magnetic fields and uses them in navigation

ORGANISM
Western honeybee
Apis mellifera

BIOLOGIC STRATEGY
Honey bees, such as the Western honeybee, are models of a system for positioning and orientation due to the presence of superparamagnetic magnetite found in iron granules formed in their abdominal (Shuker, K., 2001). These are used in the mechanism of magnetoreception.

The relative direction of flight of the honeybee to the external magnetic field affects the modules in their abdominal. Allowing them to orient themselves (Hsu, C-Y, et al., 2007). The magnetic fields of flowers also orient themselves relative to that of the Earth’s allowing honeybees to locate flowers for pollination (Hsu, C-Y, et al., 2007).

MECHANISM
Natural forming iron modules composted of superparamagnetic magnetite orient themselves with respect to external magnetic fields.

Figure 9
MAGNETIC MAP HYPOTHESIS OF MAGNETORECEPTION FOR ORIENTATION AND POSITIONING DURING FORAGING AND HOMING
(after Hsu, Chin-Yuan et al., 2007, Fig. 7)
DESIGN PRINCIPLE
A device that utilizes superparamagnetic material to detect magnetic fields and can determine position and orientation with respect to the external magnetic field.

![Diagram of magnetic field orientations](image)

**Figure 10**
METHOD OF DEVICE TO DETECT EXTERNAL MAGNETIC FIELDS AND DETERMINE ORIENTATION AND POSITION

APPLICATION IDEAS
Determine location (position and orientation) relative to external magnetic fields in space or on Mars.

KEY LIFE’S PRINCIPLES
Detects food sources to be converted into energy for basic biological functions

Allows orientation and positioning to navigate and communicate with hive

REFERENCES

TERMITES

FUNCTION
Withstands strong compressional forces

ORGANISM
Mound-building termite
Macrotelmes jeanneli

BIOLOGIC STRATEGY
Termite mounds, such as those made by the African mound-building termite, are extensive systems of tunnels and conduits that are built above a subterranean nest. These tunnels are connected to the nest via shafts, that serve as a ventilation system for the underground nest. The mound has many storage chambers that require precise temperature control. The architecture of the mounds keeps the temperature almost constant (Heimbuch, 2012).

They are so well built that the mounds tend to outlast the colony of termites that built it (Gould and Gould, 2012). The basic building step involves making arches and domes, supporting a network of other arches and domes which provide most of the structural strength needed to support specialized chambers, ventilation shafts and insulating caves.

They are self regulating structures that maintain oxygen levels, temperature and humidity (Termites, 2007).

MECHANISM
The arches and domes within the mounds provide structural strength by resolving forces into compressive stresses and eliminating tensile stresses to support extensive networks of chambers, walkways and shafts.

Figure 11
CROSS SECTION OF TERMITE MOUND SHOWING TEMPERATURE CONTROLS AND Arch/Dome STRUCTURES
(after Termites, (2007), Fig. 4)
DESIGN PRINCIPLE

A structure that can withstand strong forces, regulate oxygen levels, temperature and humidity.

APPLICATION IDEAS

A habitable structure that will offer protection from the elements and keep its occupants comfortable.

KEY LIFE’S PRINCIPLES

Provides shelter from the elements and storage spaces (can withstand large external forces)

Regulates temperature and humidity of living environment

REFERENCES


**KNIFEFISH**

**FUNCTION**  
*Produce and detect electrical impulses*

**ORGANISM**  
*Black ghost knifefish*  
*Apteronotus albifrons*

**BIOLOGIC STRATEGY**  
The knifefish, like the Black ghost knifefish, is a model for use of electricity to navigate. It can both produce and sense electrical impulses. Electrogenesis occurs when a specialized electric organ in the tail of the fish generates electrical signals (Shuker, 2001). Electroreception occurs when sensory cells in the fish's skin detect the electrical charge. Their electric organs create an electric force field that surrounds the fish as it swims. It is modified by the relative conductivity of objects close to the fish. These electrical fluctuations are detected and interpreted by the fish through electroreceptors embedded in its body. This provides an electrical image that changes in real time. This is effective when navigating in low visibility environments or in the dark (MacIver et al. 2010).

Knifefish emit their own continuous electrical impulses. This allows the fish to determine the presence of nearby objects by sensing perturbations in timing and amplitude of its electric field. The electric fields generated by external sources are detected by ampullary organs. This is called passive electrolocation (MacIver, et al., 2010).

**MECHANISM**  
The detection and production of electrical fields allows for an electrical image of objects in near surroundings in low visibility areas.

*Figure 13  
KNIFEFISH ELECTRIC FIELD MECHANISM. IT DETECTS ANYTHING THAT COME WITHIN THE FIELD*  
(from University of South Dakota, accessed Dec, 2016).
DESIGN PRINCIPLE
A device that actively emits and electric field and detects perturbations within it to determine the presence of objects in its immediate surroundings.

APPLICATION IDEAS
A device to act as eyes at night or in low visibility conditions such as a windstorm

KEY LIFE’S PRINCIPLES
Navigation in the dark or low visibility areas
Defense mechanism to detect when an external object nears

REFERENCES


ORIENTAL HORNET

FUNCTION
Absorption of sunlight

ORGANISM
Oriental hornet
Vespa orientalis

BIOLOGIC STRATEGY
The oriental hornet is a model for sustainable energy conversion. They have an outer layer (cuticle) that absorbs sunlight. The bands of brown and yellow pigments harvest solar energy. Each banded section has multiple layers with the brown having about 30 and the yellow have about 15 (Plotkin et al. 2010). The brown layer is covered in grooves that act like pathways which help direct light inward for better absorption. The yellow layer is covered in oval-shaped bumps that increase surface area for absorption. Both sections exhibit antireflection and light-trapping properties which enhances the absorption of light in the cuticle (Plotkin, 2009).

The sunlight that the hornets capture is converted into electrical energy. There is a voltage between the inner and outer layers of the yellow stripe that increases in response to illumination (Plotkin, 2009). This energy is then used in physical activity and temperature regulation as well as metabolic functions.

MECHANISM
Ridge-like grooves direct sunlight to bumpy surfaces to collect sunlight to be converted into electrical energy to be used for digging or metabolic processes.

Figure 15
BROWN AND YELLOW CUTICLES OF THE ORIENTAL HORNET THAT SHOWS RIDGES (BROWN) DIRECTING SUNLIGHT TO LARGER SURFACE AREA (YELLOW) (from Plotkin et al., 2010, Figure 2-9).
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DESIGN PRINCIPLE
A material with a mixture of ridges to direct sunlight to be absorbed and bumps to increase surface area for sunlight to be absorbed to act as an efficient solar panel for collecting energy.

REFERENCES

APPLICATION IDEAS
Solar panel that is efficient in absorbing sunlight and converting it to electrical energy for temperature regulation or mechanical tasks.

KEY LIFE’S PRINCIPLES
Enzymatic activity decreases when the hornet is exposed to light, conserving energy
Provide energy for basic functions
Moderate internal temperatures

Figure 16
RIDGE-LIKE LAYER (TOP) TO DIRECT SUNLIGHT TO BUMPY YELLOW AREA (BOTTOM) WITH LARGER SURFACE AREA TO ABSORB MAXIMUM SUNLIGHT
(from Plotkin, M., et al. (2009) Figure 2)

REFERENCES
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Conch

Challenge

Grow a habitable environment

Strategy

Arrangement of macroscopic and microscopic structures to produce strong structures

Challenge

Must be insulating

Strategy

Material with low thermal conductivity (insulating)

Must withstand compressional and tensile forces

Strategy

Flexible material that can bend with pressures

Strong shape

Design

Exterior surface coating

Multi-layered

Elongate microstructures to provide strength in one direction

Layers alternate orientation

Building material that is arranged in plastic layers

Dome shaped structure to protect from external pressures

Arches/curved ceiling to provide internal structure
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Cracks penetrate every other first-order lamella, propagating between the favourably and unfavourably oriented lamellae (Non-catastrophic failure) (from Kamat et al., 2000, Figure 3)

Elongate aragonite crystals allowing flexibility and producing lamellar layers. Oriented longitudinally. (from Zhang et al., (2014), Figure 6)

Rounded shape of the organism allows for greater resistance to compressional stresses. The dome is one of the strongest structures.
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Unit cells consist of layers made up of elongate constituents that are arranged parallel to one another.

Each layer is oriented 90 degrees to the layers above and below it.

Building material is made up of multiple layers of a ‘unit’ 3-layer cell.

Each elongate constituent is made up of smaller, elongate particles that are parallel to one another.

Each of these is oriented 90 degrees with respect to the layers beside it.

Dome structure for maximum strength to withstand storms.

Surface coating to prevent corrosion.
REFERENCES


REFERENCES CONTINUED
