IAC-12-E5.3.7

ADVANCED RECONFIGURABLE BUILDING SYSTEM (ARBS) FOR SPACECRAFT INTERIORS, EQUIPMENT SUPPORT, AND HUMAN ACCOMMODATIONS

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The requirement to mount or install a significant amount of support, computer, and science equipment in today's spacecraft has resulted in interior configurations that are limiting and non-adaptable. During short duration missions in smaller spacecraft this has been less of a problem but with the potential for longer duration future missions outside Earth orbit, to the Moon and Mars for example, this issue could become more problematic.

During the design of the International Space Station (ISS) the requirement for a standardized system to mount equipment resulted in the International Standard Payload Rack (ISPR) system. The development of the ISPR was an effort to aid in integration and interchangeability of payload hardware. This rack system has worked relatively well as a first generation solution but further evolution is needed.

This paper will discuss the design concept for a standardized system of high-performance reconfigurable building components or elements that could be utilized on spacecraft for interior build-out, equipment mounting and support, as well as human accommodation.

Adaptability is one of the primary benefits of this system. The ability to reconfigure interior spaces and equipment racks as needs evolve or change can be very beneficial. It is impossible to pre-determine all the needs a complex mission in an extreme environment may have. By utilizing a system that can be changed, users could reconfigure the components to accommodate emergencies, unforeseen needs, or varying human occupancy requirements.

I. HISTORICAL SPACECRAFT INTERIOR DESIGN PRECEDENCE

It is important to understand the historical precedence of spacecraft design and more specifically how spacecraft interior volumes have been designed and configured for mission requirements and human accommodations over the years.

Salyut & Skylab (1971-1986)

The first space station, Salyut 1, was launched into space by the former Soviet Union on April 19, 1971. The spacecraft was completely outfitted and built on Earth and then launched into Earth orbit. The crew was then subsequently launched and later rendezvoused with the station.

The United States' Skylab space station, launched on May 14, 1973, featured a similar design approach in that the spacecraft was pre-configured on Earth and then launched into orbit for occupancy. Once aboard crews had to live in the pre-configured spacecraft with little flexibility to change their interior environments (Figure 1).

Mir (1986-1998)

The Soviet Unions' Mir space station project was a successful program and developed many of the methodologies used for long duration human space flight. It was also the first space station to use a modular building concept. The station utilized the concept of launching a core module first followed by additional modules with specific uses added later. This approach allowed for greater flexibility and reduced the lifting capacity needed for launch vehicles.

This modular design approach to building the overall spacecraft did not, however, apply to the space stations interior design. Each module's interior was pre-configured on Earth and then launched into orbit. Cosmonauts on long duration Mir missions

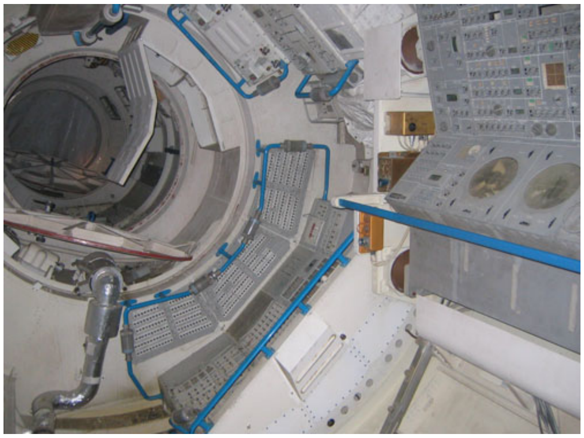

Figure 1: Mockup of Skylab's fixed interior.

had to often 'improvise' a solution to their needs living in space, be it human-factor related or mission related.

ISS (1998 – Present)

The International Space Station (ISS) continued to advance space station design. This huge station again used the modular approach to its overall assembly and construction. This approach has proved not only successful essential in the realization of international cooperation in space.

During the design of the ISS's first core module, the Destiny Lab, the need for a standardized system to mount interior equipment became more obvious. This need resulted in the design and development of the International Standard Payload Rack (ISPR) system.

This rack system uses a common set of interfaces allowing for an installation in any one of the ISS's 37 designated ISPR bays. The ISPR is a custom made framework built of carbon fiber and comes pre-configured to one specific dimension. The ISPR dimensions are about 2 m (79.3 in) high, 1.05 m (41.3 in) wide, and 85.9 cm (33.8 in) deep (Figure 2).

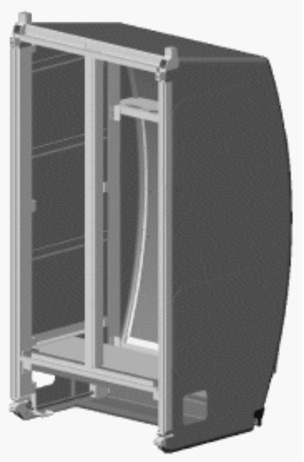

Figure 2: International Standard Payload Rack (ISPR).

The development of the ISPR was an effort to aid in integration and inter-changeability of payload hardware and represents the first modular approach to spacecraft interior configurations. While this first generation modular rack system has worked relatively well for rack equipment, as it was originally intended, it does not fully address human accommodation factors, nor is it a comprehensive modular interior design approach.

A New Approach

While an ISPR module can be installed into any ISPR bay, the on-orbit crews do not have the ability to deconstruct these racks themselves nor utilize them outside of a designated ISPR bay. Nor do they have the ability to construct or build other objects to improve their habitation, such as partitions, enclosed spaces, etc. On past ISS missions' on-orbit crews have even had to resort to using various packing materials designated as waste to solve architectural problems associated with living and working in space.

Clearly the lessons learned from the first space stations such as Salyut, Skylab, and Mir show that long duration human occupancy of space requires flexibility. Flexibility is also needed for evolving mission parameters, equipment failure, and even political and/or budgetary changes. The more complicated the mission, the more flexibility is needed.

In addition to the limitations surrounding the ISPR, there are many other important considerations when it comes to designing for space or other extreme environments. There are always space limitations on-board any spacecraft due to weight and size restrictions imposed by launch vehicles. For example, this limitation often requires the designation of one volume of space be used for multiple functions. The ability to reconfigure these spaces will be even more important on long duration space exploration missions, such as sending humans to the surface of Mars and returning them safely back to Earth. Recent mission planning suggests this type of mission may last approximately 900 days or 2.5 years. The ability to reconfigure equipment racks and even implement solutions to unforeseen space allocation problems is paramount in a mission of this duration.

II. MARS TRANSFER VEHICLE (MTV) CONCEPT DESIGN EXPLORATION

The realization of this need for a new approach to spacecraft interior design and configuration was developed during a design project at the University of Houston's Sasakawa International Center for Space Architecture (SISCA) in 2012.

An understanding of the details behind this space architecture project provides the context of how the reconfigurable building system concept came about and demonstrates how such a system could be utilized.

This project's goal was to explore architectural design solutions for a future mission to land Humans on Mars and return them safely back to Earth.

There are many proposed mission architecture approaches that could be adopted for a mission of this type, however the following mission parameters were assumed:

- All Payloads launched into orbit by future heavy-lift Space Launch System (SLS) vehicle(s).
- SLS shroud size diameter of 9 meters (29.5 ft.) by 20 meters (65.6 ft.) tall.
- The unmanned *Mars Lander Cargo* (MLC) launched and deployed to Mars surface first.
- *Mars Lander Manned* (MLM) and *Mars Transfer Vehicle* (MTV) subsequently launched into Low-Earth Orbit (LEO) for rendezvous.
- Human crewmembers subsequently transferred from Earth surface to orbiting MTV via Crew Exploration Vehicle (CEV).
- Conjoined MLM and MTV transit to Mars planet vicinity (200 days).
- Crew descends to Mars surface in MLM for surface mission (500 days).
- Crew ascends in MLM to Mars orbit to rendezvous with MTV and make return transit to Earth (200 days).
- MTV rendezvous with CEV for crew transfer and subsequent re-entry and landing on Earth.

This paper discusses the design of a Mars Transfer Vehicle (MTV) concept for the project from an architectural perspective, including human factors.

Initial MTV Concept Design and Evolution

The MTV project went through several design iterations. It started with the conventional approach of identifying both the essential spacecraft systems and the mission required systems and then organizing these systems into functional areas within the module. This included making accommodations for the consumables that would be required for such a long duration mission such as food and water.

Initial designs utilized a ‘standard’ rack approach with the habitable volumes being defined by the racks mounted parallel to one another along the perimeter. This approach seemed logical but it became apparent from an architectural point of view that this arrangement did not fully utilize the round shape created by the pre-defined MTV cylindrical module size of approximately 8 m in diameter by 18 m in length.

Subsequent designs began to explore various rack geometries and arrangements and how they affected the relationship with the habitable spaces that resulted. It became obvious that large pre-configured equipment racks such as the ISPR archetype had many limitations.

Due to these realizations, the concept of a building system that could be changed, modified, or reconfigured emerged. Research into other existing reconfigurable building systems was also completed, which helped to further evolve the concept.

Work on the initial MTV concept continued with a move toward trying to utilize a *reconfigurable* rack or building system. A preliminary reconfigurable system was defined and the idea of three main types of system parts or elements emerged; Structural Components, Connector Components, and add-on or Supplementary Components.

The Structural and Connector Components were joined and arranged to form the entire spacecraft interior structure (Figure 3).

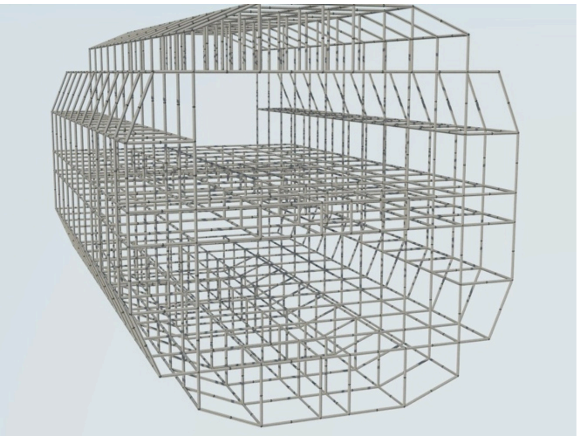

Figure 3: Initial MTV design components joined to form interior structure.

This framework would then be populated with Supplemental Components to complete the spacecraft interior build out and define the interior space.

These Supplemental Components would be things such as lightweight partition panels, storage lockers, computer equipment, personal restraint holds, and task lighting for example (Figure 4).

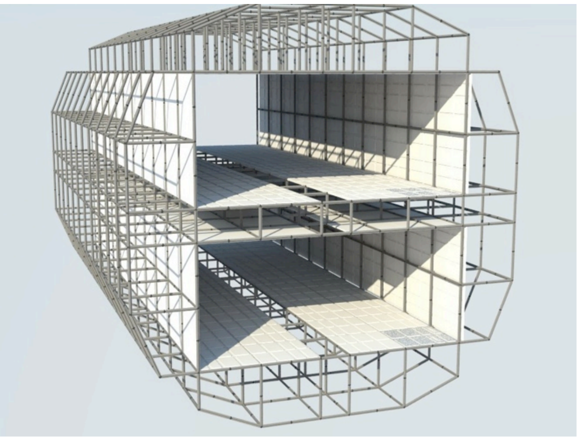

Figure 4: Partition panels added to framework.

The reconfigurable building system concept was now established and the initial design was completed (Figure 5). The next step was to further define the system in a revised final MTV concept.

Figure 5: Completed initial MTV concept interior.

Final MTV Concept Design and Revised Geometry

The final design of the MTV concept utilized this same evolving reconfigurable system approach as a new design framework but then explored different arrangements of the structure to improve the human experience of living and working in space.

This design exploration was now possible by using a system of reconfigurable elements. We are no longer constrained by the limitations and large dimensions of the pre-configured ISPR unit.

After thorough experimentation, the structural members of the system were ultimately reorganized to form habitable spaces that are hexagonal in cross-section (Figure 6). This geometry creates perfectly nested spaces within the cylindrical volume of the pre-defined MTV module size.

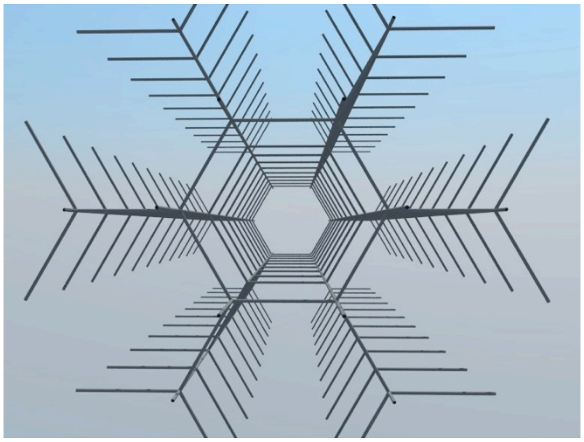

Figure 6: Final MTV design structural framework reconfigured into hexagonal arrangement.

Not surprisingly, this geometry also has a unique organic quality and is very similar to the cellular structures of organic matter when viewed under an electron microscope. The efficiency of nature is an excellent precedent to follow (Figure 7).

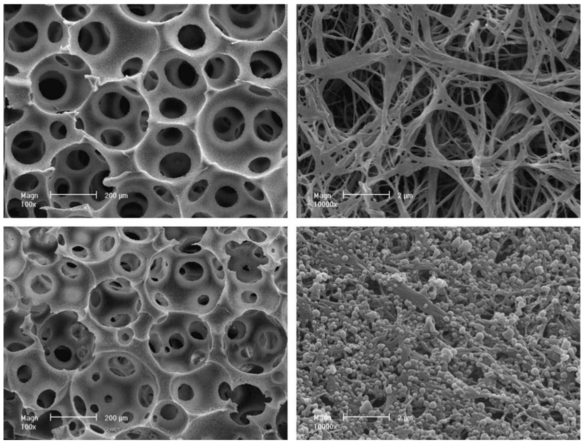

Figure 7: Organic matter when viewed at the cellular level.

This new framework became an efficient method of creating and defining habitable compartment spaces. The spaces were then organized into the required functional areas as previously completed in the initial MTV designs.

Equipment racks, privacy partitions, crew sleeping berths, water tanks, utility conduits, and storage lockers, etc. were added (Figures 8 and 9).

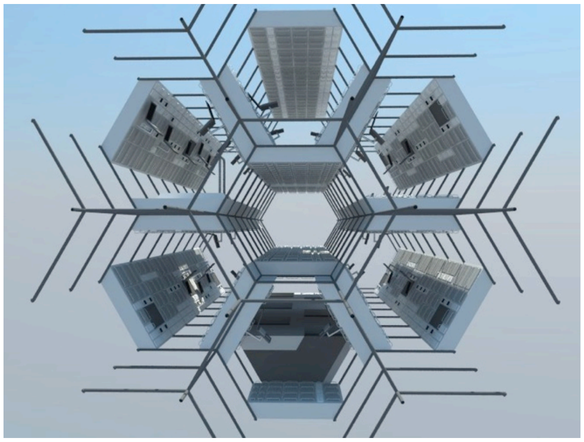

Figure 8: Equipment racks added to framework.

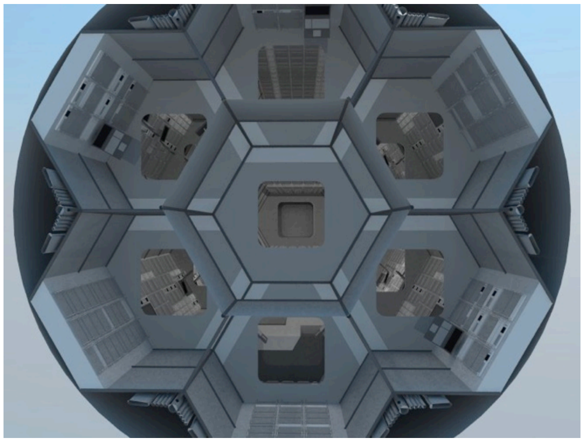

Figure 9: Completed final MTV concept design.

Another realization of this hexagonal geometry is that it alters the traditional assumption that a room should be a cube shaped space, which has walls, a floor, and a ceiling. In micro-gravity there is no need for a floor or a ceiling. There only needs to be boundaries. The space can now be utilized in the unique way crewmembers actually work in micro-gravity.

Instead of walls, a floor, or a ceiling, the spaces contain *work surfaces* that wrap around the perimeter of the volume and follow the hexagonal path of the structure (Figure 10). When equipment installation and storage locker depths are accounted for, the resultant space provides three work surfaces that meet at 120° angles, while the corridor ends become logical locations for partitions or compartment hatches. A typical interior space from the final MTV concept is shown below (Figure 10).

Figure 10: MTV compartment view with work surfaces wrapped around hexagonal framework.

III. RECONFIGURABLE BUILDING SYSTEM PRECEDENCES

There are numerous examples of reconfigurable building systems that have been created. Some have enjoyed more success than others. The following examples are presented.

In architecture, one well-known early example is the Dymaxion house designed by Buckminster Fuller in 1929. His goal was to produce an economical house of the future made from a standard kit of parts that could be quickly and easily assembled and/or disassemble for relocation (Figure 11).

A more recent example would be the R128 home designed by Werner Sobek in 2000. His design utilized a system of standardized bolt-together steel frame components that were pre-fabricated. Once on site, the entire frame was erected in just eleven days. Unlike other homes, this modular home is designed to be easily disassembled and recycled (Figure 12).

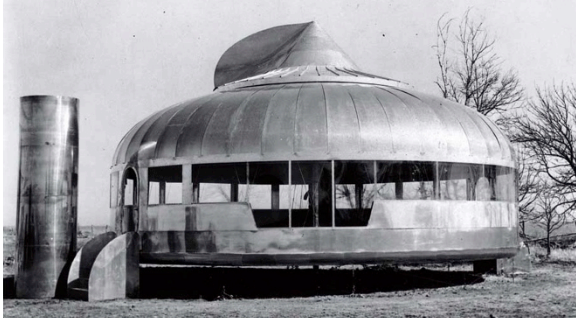

Figure 11: Dymaxion Home of 1929.

Figure 12: R128 used standardized bolt-together frame components.

Construction companies use a modular system of metal scaffolding components to wrap buildings so workers can complete their tasks. The scaffolding arrives on site broken down into its basic components, which are more easily transported. The components are then quickly assembled for use and can accommodate any shape building or structure. Once the work is complete, the components are disassembled and packed for transport to another jobsite. Modern metal scaffolding is a very efficient reconfigurable building system (Figure 13).

Figure 13: Typical construction metal scaffolding.

Another highly successful reconfigurable building system is LEGO building blocks. Although generally considered a toy, this product is really an advanced reconfigurable building system with a large inventory of standardized and modular construction elements made from ABS plastic.

These and other examples of modular and reconfigurable building systems demonstrate that the concept can be very successful when executed correctly.

IV. ADVANCED RECONFIGURABLE BUILDING SYSTEM (ARBS) DESCRIPTION

ARBS Concept Details

The system would employ a modular, reconfigurable structural building system for spacecraft interior build out, equipment support, and human accommodations. These components would be scalable and reconfigurable as needed. The system would consist of (but not limited to) three main types of components (Figure 14).

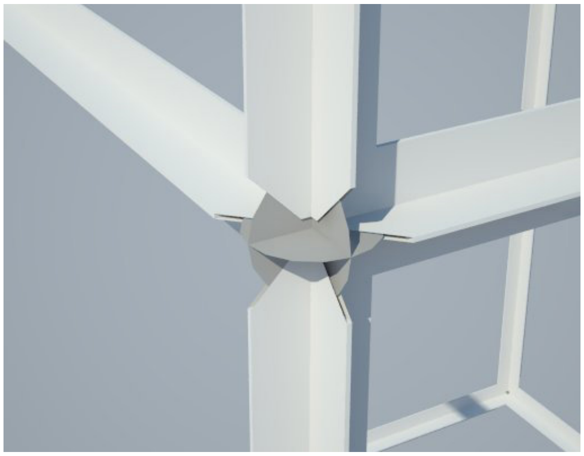

Figure 14: ARBS component connection example.

Structural Components (SC)

Linear Structural Components of various lengths: These members would provide the main structural strength of the system. These would be the equivalent of columns and beams in a gravity-based traditional structural system. However, due to varying gravitational forces in certain environments and mission envelopes, these components would need to be able to withstand both compression and tension.

These elements would also need to be sized in different lengths or be adjustable in length to accommodate a wider range of assembled configurations.

These components would also include a standardized system of spaced holes, tabs, or other means of attaching Supplemental Components as described below.

Connector Components (CC)

Connector Components to join or mate the structural components together: These connector components would need to accommodate all of the possible structural component variants and would obviously need to be structural strong as well.

There would be small number of different connector component types to allow attachment of the structural components in different angles or positions. Alternatively, the connector components might be adjustable to accommodate various attachment angles/positions. This is necessary to achieve greater flexibility in how a structure is configured.

Supplemental Components (SUPC)

Supplementary components that would allow additional utilization of the assembled structural framework: These specialized components would consist of items that add functionality to the assembled system of structural components mated with connector components.

Items within this category must also adhere to pre-determined modularity requirements of the system with regard to certain dimensions and/or means of attachment to facilitate use with the standardized structural components.

These include but are not limited to the following items:

- Crewmember personal restraint holds
- Sliding rails for stowage compartments
- Task or area lighting
- Laptop computer mounting arms
- Computer server rack mounts
- Soft lightweight fabric partitions for sound, odor, safety or privacy control
- Sleeping berths
- Personal hygiene equipment
- Experiment mounting racks
- Plant growing equipment racks
- Cable or utility conduit path control supports

In summary, the Structural Components and the Connector Components are used to form the structural framework and would consist of the fewest possible derivatives to keep the system efficient but modular. The Supplemental Components would be a broad category and would include all items used to fill in or build out the framework and make the spaces productive, useful, and habitable but always designed within the modular rules of the system.

ARBS Design Requirements

A standardized system of high-performance reconfigurable building components could be utilized on future spacecraft for interior build-out, equipment mounting and support, as well as human accommodation and would have numerous benefits.

An Advanced Reconfigurable Building System (ARBS) could also be adapted to other extreme environments such as arctic regions, desert regions, or underwater exploration and research. This is possible due to the favorable high-performance characteristics this system would possess for these types of environments as well.

There are design characteristics that would be important in developing a system of building components for use in both Space and other extreme environments. They include the following:

Modularity

The ARBS components must be modular in design, meaning that the components would be interchangeable with one another. This would enable the ability to quickly replace or change one element or even multiple elements if needed. The need to change element(s) would be to enhance, modify, repair, or redesign how the elements are being utilized in a given situation. In other words, a given interior configuration could be disassembled into its basic components and then re-assembled into an entirely new configuration using the very same components.

Another benefit of modularity is the ability to break down the system into its basic components for packing and storage. This enables the system to be deconstructed into a much smaller volume of space then when fully deployed. This has obvious benefits with regards to the typical high cost of transportation to any extreme or remote environment.

Standardization

By standardizing the components of the ARBS there would be many advantages as well. For example, by making larger qualities of similar components, the overall production costs could be lowered.

With a standard system that always uses the same components the overall training time would be reduced as well. Crews, engineers, and mission planners would become very familiar with the modularity of the system and would not need to spend time coming up with customized solutions.

Standardization helps to enable international cooperation as well. When counties, space agencies, and even private companies use the same set of interfaces to equip space modules, cooperative efforts can be simplified and thus encouraged.

ARBS Physical Requirements

While the ARBS would initially be designed and prototyped for spacecraft architecture, it could be applied in other extreme environments as well. Endeavors across other extreme environments would likely require very similar physical properties for a reconfigurable building system. The ARBS would be optimized to have the following physical attributes.

Lightweight

This system would need to be lightweight. This is a primary premise in the design and construction of Spacecraft. The cost per pound of launching on object into space can be very expensive. According to NASA, the average cost of launching the Space Shuttle in 2011 was approximately $450 million per mission. The Space Shuttle can carry a maximum payload of 53,600 lbs. into Low-Earth Orbit. This works out to a cost per pound of approximately $8,395. This cost means that every pound carried must be scrutinized and utilized in the best possible way. The ability to do more with less weight is critical.

High Strength

This system must be extremely strong to withstand forces during launch. The Space Shuttle experiences up to three g's or three times the force of normal gravity during launch. This building system would need to be able to withstand these launch forces.

Non-Corrosive

This building system would need to have low corrosive properties. Exposure to moisture, or other chemicals may be possible. This exposure can cause corrosion, which in turn would degrade an objects strength and/or lifespan. This characteristic is not desirable in any environment where the system must perform at a high level of reliability over a long duration. It may not always be possible to easily replace components that prematurely fail due to corrosion.

Resistance to extreme temperatures

The ARBS should be able to withstand large variations in temperatures without adverse affects. Spacecraft operate in the vacuum of space where temperatures can vary hundreds of degrees of Celsius. The actual temperature of space is near absolute zero (4º Kelvin or approximately -270º Celsius). This is in contrast to the heating that occurs to objects from the Sun's solar radiation. The result is an environment where one side of the spacecraft could be experiencing extreme cold and the other side is experiencing extreme heat.

Resistance to less severe but nonetheless extreme temperatures such as in arctic regions or desert regions would facilitate the potential for the system to be employed in these extreme Earth environments as well.

High Performance Material Options

There are some good options for materials that would meet all of the physical requirements of this system. One such material would be carbon fiber (CF) based composites. This could be in the form of carbon fiber reinforced polymers (CFRP) (Figure 15). CFRP's are widely used today in aviation, motorsports racing, sports equipment, sailing, and even large wind turbine blades.

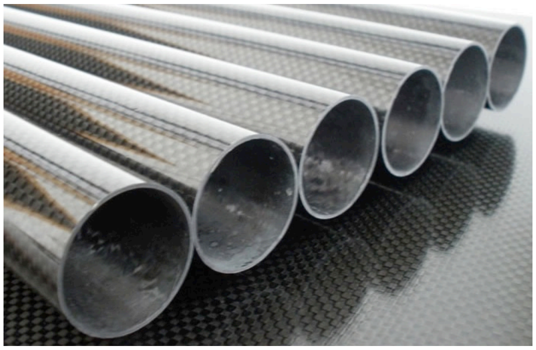

Figure 15: Typical Carbon Fiber Reinforced Polymer (CFRP) tubes.

CFRP is made by bundling thousands of carbon-based filament strands into a tow (similar to thread), which in turn are woven into a fabric. This fabric is then combined with a polymer, usually an epoxy, in a mold forming an extremely strong, rigid and lightweight material. This composite material can also be combined with other fibers besides carbon such as Kevlar or aluminum.

V. ADVANCED RECONFIGURABLE BUILDING SYSTEM (ARBS) BENEFITS AND APPLICATIONS

Adaptability is one of the primary benefits of the ARBS. The ability to reconfigure interior spaces and equipment racks as needs evolve or change can be very beneficial. It is impossible to pre-determine all the needs a complex mission in an extreme environment may have. By utilizing a system that can be changed, users could reconfigure the components to accommodate emergencies, unforeseen needs, or varying human occupancy requirements.

Benefits include:

- *Ability to Reconfigure:* The ability to reconfigure these components into whatever the users or environments demands is the key difference in this system and is it's most advantageous aspect.
- *Emotional and/or Psychological Factors:* There may be real human emotional and/or psychological needs to modify, or change ones own living space on long duration exploration missions. Psychological studies have shown that humans can benefit from the ability to modify their environment. The ARBS would enable this.
- *Better Space Utilization:* The ARBS would provide a means of converting spaces from one function or purpose into another, making them multi-use. For example, a functional area that is only needed occasionally might be collapsed or stored until needed then expanded or re-assembled quickly.
- *Adaptable to Changing Gravity Scenarios:* The ARBS could address changing gravity conditions such as the difference between launch loads and the micro gravity of en-route space travel. For example, an interior could be configured to better withstand high g-forces in a specific direction during launch and then reconfigured for micro gravity once in space by removing structural elements that are no longer needed, making the space more open of efficient.
- *Better accessibility for Repairs:* If an installed Supplemental Component or other spacecraft system becomes inoperative, it could be accessed for repair or replacement more easily due to the modular nature of the system. The Supplemental, Structural, or Connector Components could be easily disassembled or removed for access and then reassembled later.
- *Easily Transported:* These components can be disassembled and packaged into a much smaller footprint than current permanent alternatives such as large ISPR racks. Environments such as arctic regions, remote deserts, or ocean locales can be very difficult and expensive to get to. Having a deployable building system that is lightweight and which occupied the least amount of space when disassembled would greatly aid in transportation to these remote environments.
- *Lower Long-Term Costs:* Currently, the ISPR racks are custom made for a specific use. When new mission parameters or equipment is

required, the ISPR is removed and replaced with another expensive custom-built ISPR unit. This is inefficient, as each ISPR fabrication requires many man-hours, as well as the use of expensive materials. If these same man-hours and expensive materials were applied to building a *reconfigurable* and *reusable* component system, a long term cost savings would result. The manufacturing costs could also be lowered by making standardized elements in greater quantities and purchasing raw materials in quantity. Since there would be only a limited number of variations in the system's component inventory, the manufacturing process could be automated, which would further reduce costs.

Applications:

There are other extreme environments that the ARBS could be applied to. They include the following types:

Spaceflight

The ARBS would initially be designed for spacecraft interior build-out, equipment support, and human accommodation. Prototyping the system for a space environment first would better ensure use in other environments as space travel is generally considered to be the most demanding of extreme environments.

For example, the parameters for spaceflight include high g-loads during launch and then micro-gravity while in orbit. Space also includes freezing cold temperatures in the vacuum of space as well as extreme heat and radiation while in view of the Sun.

In addition to spaceflight, however, the system could be adapted to the following extreme environments:

Arctic Regions

Application in arctic regions could provide useful. Many of the constraints that apply to operating in Space also apply to operating in the harsh and freezing temperatures of the regions of Antarctica.

The Amundsen–Scott South Pole Station is an American scientific research station located on the high plateau of Antarctica at the southernmost place on the Earth (Figure 16).

Getting materials and supplies to this remote location is very expensive. In most cases they must be flown in by aircraft during a favorable time of year. Flights do not operate year-round due to the extremely harsh conditions of winter. This makes every inch of space and every pound on board the re-supply aircraft very valuable. This is an ideal application for a reconfigurable building system of lightweight, strong, temperature resistant, non-corrosive components.

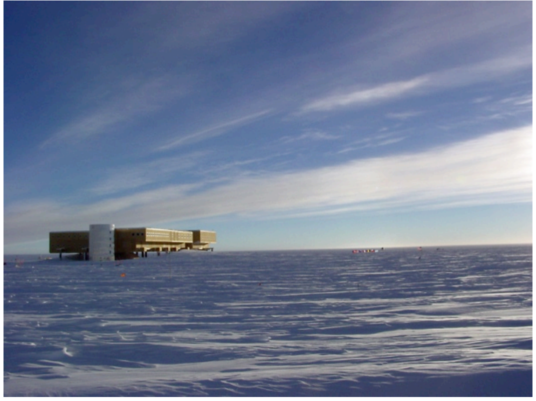

Figure 16: Amundsen-Scott Base, Antarctica.

The ARBS components could provide the structural framework to which exterior panels could be fastened making an enclosure for a habitat or shelter. The ARBS could be further used for interior build out, partitioning, and equipment installation due to its modular design.

In cases where the arctic weather becomes dangerous the ARBS components might also be used to construct small-scale emergency shelters very quickly.

Desert Regions

The ARBS could be applicable to desert regions as well. Desert environments require building materials that are not affected by the sun's extreme heating. This system could be used to quickly make large shade structures for survival or simply to protect men and equipment from the sun's damaging heat and UV rays. This would be ideal for desert researchers such as biologists or geologists.

NASA also uses desert environments to test equipment and train personnel. The harshness and remoteness of many desert locations provide a realistic simulation for conditions on the surface of Mars. During the 11th annual Desert RATS (Research and Technology Studies), NASA tested two variants of a new generation of surface rovers (Figure 17).

The ARBS could be used in these desert test scenarios to not only test future space habitats but in fact to support the actual research and support teams which setup and implement the tests. This would show how versatile this type of system would be. It would be ideal in any environment where a high-performance, high-strength, and lightweight building system is desirable.

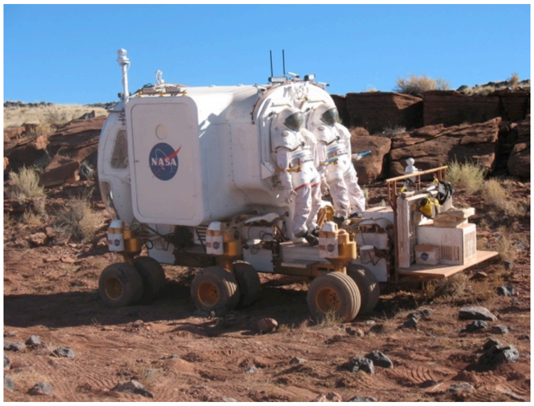

Figure 17: NASA's Desert Research and Technology Studies (RATS).

Water Submersible and/or Surface Platforms

The resistance to extreme pressures, temperatures, and low corrosive properties of the ARBS may be advantageous in water submersible applications.

NASA's Extreme Environment Mission Operations (NEEMO) project near Key Largo, FL is a test bed for studying human survival in an underwater laboratory in preparation for future space exploration (Figure 18).

Figure 18: NASA's Extreme Environment Mission Operations (NEEMO) underwater project.

The system would also have potential application for surface water programs such as oilrig platforms, or science research vessels.

Operating on or below the surface of seawater creates many challenges. Salt water is extremely corrosive. As one descends in depth, the weight of the water also creates extremely high pressures. There are almost as many challenges in building a habitat for humans in extremely deep water as to building one in space. The ARBS would be able to withstand these high pressures and highly corrosive saltwater environments.

In summary, this system could be utilized as structural framework and/or interior build out in almost any extreme environment due to its high-performance characteristics and favorable design qualities of modularity and re-configurability.

VI. CONCLUSION

This paper presents a new approach to spacecraft architecture using the concept of an *Advanced, Reconfigurable Building System*. This system could replace the current non-adaptable approach of rigid spacecraft interiors, pre-configured on Earth and then launched into Space, with improved reconfigurable interiors for better human accommodations and provide new mission flexibility and capability.

Future spacecraft design must be rooted in real world engineering and in the requirements for human spaceflight due to the unforgiving and dangerous nature of these endeavors. However, by using a design approach based on both engineering *and architecture* to solve the problems, valuable new insight and exciting designs would be realized.

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