

The Print/Build system

and its utilization in space as a game changer

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Abstract

The main obstacles to space development are still, despite many decades went by since the beginning of the space age, the same, high costs of space accessibility, lack of adequate thrusters for heavy interplanetary payloads and dimension limitations due to reduce rocket geometry.

While the first two items are subject to space technology development since we are still relying in chemical fuel based systems the latter can be faced with alternative technologies not necessarily space related.

A real breakthrough can be considered using 3d printing or additive manufacturing (AM), which is a process of making a three-dimensional solid object where successive layers of material are laid down in virtually any shape from a digital model.

3D printing is thus distinct from traditional machining techniques, which rely on the removal of material by methods such as cutting or drilling (subtractive processes). By properly utilizing its capabilities we can revolutionize the payloads and by doing so allowing many missions in need of heavy and large payloads to be implemented.

For instance, the habitat needed for a deep-space destination could be manufactured and assembled in space into the inflatable structure that would be sent empty with the exception of the 3D printer and sufficient amount of printable plastic material needed for the building components.

In off-earth surfaces, the crew could deploy inflatable Habs to be equipped with lightweight 3D printed components and utilizing the same process. Such system will drastically reduce the entire load to a fraction of a conventional one.

In this paper we want to describe the potential of 3d printing in space development both in space itself as well as in other bodies such as the moon, mars or the asteroids.

Keywords: *Mars Development, Construction Systems, 3D Printing.*

Scope of work

The scope of work will allow to define the best utilization for 3d printing in space s follows:

- Utilization in space mission, such as building a hab in an inflatable structure in this case a construction system with modular components that can be manufactured in space with a 3d printer.

The system will consist in wall, slabs, and equipped modules to assemble a proper habitat to be utilized by a manned crew in an inflatable structure.

While the Hab my look as the most common subject, other products can be manufactured in flight such as the rover vehicle, tanks, other equipment component.

- Utilization in surface bodies.

At arrival in other bodies the 3d printing equipment can be utilized for major structures and equipment manufacturing, starting with a construction system not limited by size as in space but with unlimited possibilities of utilization and expansion in the surface as well as underground facilities. Furthermore the possibility to utilize local material, such as regolith or others will add several capabilities to the system.

- Housing system and equipment manufacturing.

The main scope is to develop a construction system suitable for 3d printer capabilities that can optimize the functionality of the houses as well as the manufacturing systems.

- Mission architecture utilizing 3d printing concepts.

In order to utilize the benefits of the system a proposed manned mars mission, that could be implemented immediately utilizing available off the shelf technology is being described and evaluated.

The above scope will allow to explore the system capabilities and immediate benefits to space missions.

Goals

The main goals are related to the following:

For the system itself:

- Demonstrate the technology capabilities.
- Developing a construction and equipment manufacturing capability.

For general scope:

- Improve mission capabilities with available technology.
- Define proper and beneficial utilization.

Proposal must be based on an incremental plan whose development in accordance to a progressive schedule and milestone results will lead to the desired goals:

- Set-up an entirely reusable transportation system while sending first manned mission.

The print-build system

This system is a proposed construction system composed of all needed building components for the space based one, following shapes and dimension dictated by the limited space at disposal. [See Fig. 1]

It consists in polyethylene-terephthalate (PET) derived plastic material that would form the needed components such as:

Walls

External-walls of 18 cm. thick, containing different materials for insulation or radiation protection purposes. Such container block-panels, will be easily connected between them and form the needed shape. [See Fig. 2]

They are shaped to be connected easily and be filled by different materials. For particular functions such as toilet, kitchen, bedroom or other functions specialized modules will be designed.

Water tanks and other equipment can be integrated in the walls as needed. [See Fig. 3]

To obtain higher resistance ribbed surfaces are being utilized that as an additional bonus, allow the passage of all piping and ducts, both electrical and sanitary. Internal walls follow the same concept but are only 8cm thick. Doors and windows, where needed, are included in the modules. [See Figs. 4-5]

Corner components

To join the wall panels and the slabs of various types specialized corner components are part of the system. They follow the circular shape defined by the wall panels. Three main types are considered the upper, the intermediate and the lower depending in their utilization in the system.

Slabs

Also floor slabs are designed to support their loads with a functional ribbed system to reinforce them without adding weight slabs can be used for floors and ceilings with specific design. They are connected to corner components and central slab to distribute their loads.

For the utilization in surface bodies the system needs more flexibility not depending on previous dimensional limitations. For that reason different components will be designed as can be seen in the images. Building types can have many possibilities ranging from smaller circular units. Similar to the space based ones to bigger circular that will allow multifunctional activities, even a garden in the center area. Shapes can also be obtained with a straight shaped system, allowing to bigger areas with a system based also on center posts. In surface to beat radiation problems the container-components will be filled with local regolith to make a more conventional barrier. Other possibilities include the possibility to utilize the walls or central posts as water tanks, performing dual functions by the system.

Other 3d printing possibilities

During the travel or in the body surface many other products can be manufactured through the system.

Some of them that we want to exemplify are the rover vehicle. Such vehicle, especially if pressurized, requires large payload dimensions and heavy components, if we could assemble it utilizing 3d printing technology we can save substantial loads.

The Mars Plus mission

In the wake of the Inspiration Mars design competition whose scope was to send a manned mission to flyby Mars and back to Earth by the year 2018, and demonstrating that with due financing such mission could be possible, by applying 3d printing technology it would even be possible to purpose more ambitious mission that could consist in full manned landing.

As an application with several benefits with the adoption of the new technology, we have developed a mission profile for an immediate and very affordable first manned mission to mars. We want to briefly outline the following pages such possibility.

The components

We can list and analyze the components as follows: [See Figs. 6-7]

1- The inflatable Hab module (HAB)

Let's analyze in detail the proposed Hab which represent an original approach to the problem. This module consists of an inflatable 5m long, 6.50 m diameter (when inflated) system. Inside a 3d printing machine with a minimum of 400Kgs of PET like plastic material and needed glue element.

Such module, once inflated in space and utilizing 3d printing technology and the print build construction system, will allow the manufacture and the assembly of the entire HAB module as follows.

The two hab levels will consist of:

Upper level

- Two personal space modules.
- A toilet half module connected to a fitness half module.
- A kitchen dining module.
- A living room module.
- A command module with storage areas.

Lower level

- A water treatment and recycling equipment module.
- Three food production hydroponics agriculture modules.
- A storage module.
- An equipment module.

Once inflated the crew would enter the HAB, and start manufacturing the building components in a prearranged sequence so they could be used immediately in an assembling plan. [See Fig. 18]

To assemble the habitat by utilizing all stored components as shown. The floors and walls would be composed of ribbed panels 12 cm thick, finished by a tile system to allow easy removal for utilities inspection.

Some wall modules will contain water tanks and other specific equipment and furniture for its functioning.

The goal is to reduce its weight compared to existing technology. By utilizing pet based components such weight could be reduced at least by 90 % significantly. The design goal is a total weight of 1500Kgs for the entire HAB. This module will be designed with components (walls, furniture, and equipment) to be printed and part of the building system, further reducing the total load.

Such concept would allow to modify its interior layout for different utilizations by the crew.

The Hydroponic option

Three sectors of the lower level are dedicated to Hydroponic agriculture for a total of 144 linear meters. Such equipment will utilize recycled water, in a closed circuit system, and will yield several type of food saving hundreds of Kg from the food payload.

The 3D printing option

A revolutionary approach that can be considered an option may represent a valid alternative, applicable to all solutions, technologically available, despite its total innovative character, is the possibility to send a 3D printing machine, together with the raw materials for the construction of the HAB, in order to reduce drastically the payload weight to something slightly above 1 ton. [See Figs. 8-18]

In space, the PET type material, with due highly resistant structural shapes, extremely light and thin, can manufacture the needed building components to complete the HAB, its structure, its building components, (walls, floors, ceilings) its furniture. The work will be performed by the crew that will stay in the access capsule, during the HAB construction, which will require no more than 5 days.

The system will be composed by:

- A 3d printing machine of needed dimensions (weight no more than 100 Kg)
- Raw PET, plastic with bonding material (max 400 Kg)

It will be stored inside the deflated Hab for a total payload slightly over 1 ton. Being ultralight and filled by air, since its rigidity will be guaranteed by its ribbed shape, such solution may change the rules of the game allowing the construction of large dimensional building modules for the components that conventionally would not fit in a standard size payload stack.

A specific manufacturing schedule will be coordinated with the assembly sequence in order to allow early utilization of the assembled areas. Another advantage of this system is the possibility to manufacture non standard components, with any needed dimension.

The components will be divided in a modular system in ribbed blocks for each destination: Walls, joints, ceiling beams, ceiling blocks, structural posts, curved walls and any other as needed. By combining them through their built-in connecting system we can shape any major component in any dimension. As an additional benefit, specific walls can be filled with water and the walls utilized as water tanks.

2- The service module (SM)

The Service Module to be equipped with the following:

- Communications
- Propulsion
- Navigation
- Power generation
- Fuel tanks
- Engines
- SEP propulsion system
- CELSS systems

Such addition will add weight to the first payload, but all within the limits established by the designed scheme. Also in this case weight is the issue. An empty mass weight of 2500 Kg is the design goal.

3- A docking transfer node module

Such module for multiple transfers may be positioned in the most convenient way in accordance to the alternative, between the hab and the SM, or directly attached to either one. In some alternatives such module could be equipped for EVA activities.

The possible alternatives, in accordance with the basic concepts of the reference mission by eliminating some disadvantages and utilizing the standardized system as described previously are called Essential Mars due to their minimum requirements.

This solution will require a simpler launcher, due to a reduced payload in the basic alternative, and costs and will be based on more available technology as shown in the following pages.

The service module would be a commercial available one that will allow the additional equipment. These components, defined as vertical stack, will be launched by a single heavy payload capability unmanned launcher.

4- The crew command module.

In our case a modified, for reentry at high speed capability, Dragon V2 capsule that will transfer the crew from Earth to the vehicle, stay connected to the vertical stack till the end of the martian mission and finally detach and return to Earth with the crew.

This module will be sent with a separate launcher and will rendez-vous with the vertical stack transferring the crew. Such module will also support the crew during hab assembly activities.

5- The martian hab-lander.

This vehicle will be connected to the docking module. It is composed of a habitat lander and a shuttle in the upper part to carry the crew to the orbiting cruiser to go back to Earth.

This module will be launched as the last one in terrestrial orbit. At the interior, while built on earth will utilize the same light weight technology as the inflatable HAB. The HAB will be divided in three levels the upper being the crew area, the middle the common areas and the lower the labs and airlocks systems.

After the inflatable HAB completion the 3d printing equipment will be transferred to the martian-lander to be further utilized, during the trip to manufacture the rover and other needed equipment and on the planet to manufacture the local outpost buildings, together with inflatables also transported in the lander.

The launchers will be decided on the basis of the payload capability, possible from SpaceX or other commercial American available launcher.

Mission architecture

As specified the mission architecture will be based on three launches with rendezvous, but will allow the entire reutilization of the cycler vehicle for future missions, even in a profitable Earth-Moon cycling trajectory. [See Fig. 19]

- Mission1 - orbit the cruiser

The first mission will consist of launching the already assembled stack and connected service module, the docking node and the non inflated HAB module. Once in the terrestrial parking orbit the HAB will inflate for future utilization for the manufacturing and assembly of the building HAB components. Payload is estimated in 10 tons to martian destination and the recommended launcher is the Falcon Heavy.

- Mission 2 - consists of the launching and docking of the martian hab-lander.

Such vehicle will represent s payload of 10 tons and be launched by a Falcon Heavy launcher. Once in orbit this vehicle will rendezvous and dock with the previously orbited stack.

- Mission 3 - After the cruiser is fully connected and assembled in orbit the manned crew will follow with Dragon v2 capsule to rendezvous with the stack and man the mission. This mission will use a Falcon 9 launcher.

Once ready and assembled the cruiser will proceed to its martian destination by leaving its terrestrial parking orbit and following a Hohmann type of martian trajectory. Activate propulsion to be inserted in Mars trajectory and start charging the SEP.

During this phase the crew will manufacture and assemble the inflatable HAB. Such activity is estimated to take around a week.

- Mission 4 - martian landing

At martian approach the vehicle will enter a martian orbit from where, after all successful controls of the martian lander and the selected landing site, the lander will land and starts surface operations leaving the cruiser in martian orbit.

- Mission 5 - surface activities

The lander will descend to the selected site with a manned crew and start all planned activities. [See Fig. 20]

The crew can unload the hab, including the already assembled rover vehicle components to finish the assembly with larger room and prepare the local hab with utilization of local resources building the first facilities on Mars to be followed by the manufacturing of equipment.

Once the planned mission will be finished the crew will board the martian shuttle on top of the HAB, that will remain on mars and rendezvous with the cruiser in martian orbit and begin their journey back to the earth. [See Fig. 21]

Conclusion

The first manned mission must be part of an integrated plan for Mars development and not a technological stunt as happened with Apollo.

Such mission must assure the creation of an affordable transportation system and basic infrastructures on Mars for further development in a step by step well defined plan.

Mars development, enabled by 3D printing technology from the first missions, must be part of a Master Plan, possibly sponsored by private enterprise through several business plans that will ensure profitable activities connected with the development of the red planet.

Such activities will allow an exponential growth to martian development, including the beginning of a local economy.

Figures

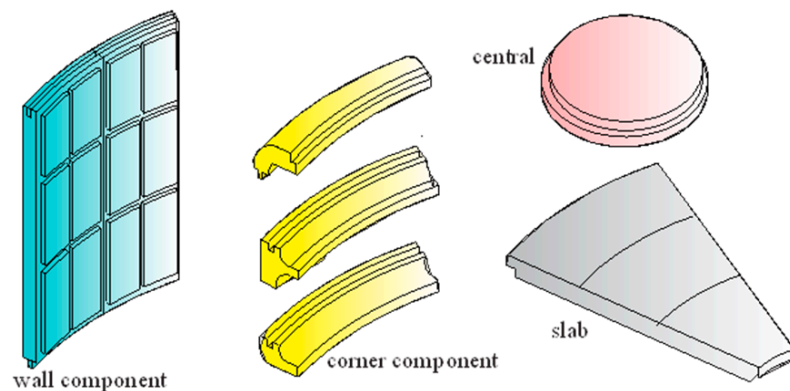


Fig. 1 : Print-build system components.

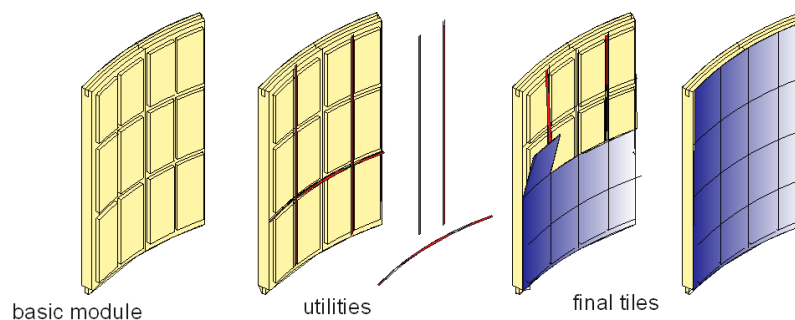


Fig. 2: Wall panel construction sequence.

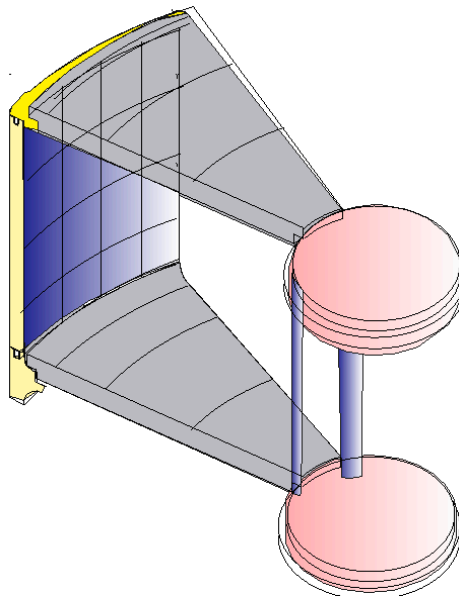


Fig. 3: Typical modular sector.

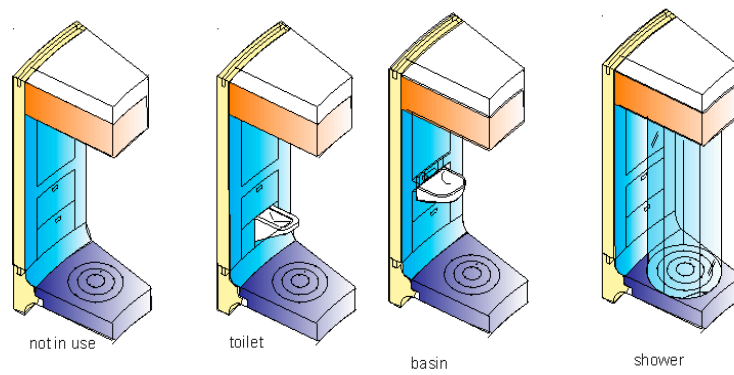


Fig. 4: Toilet specialized module

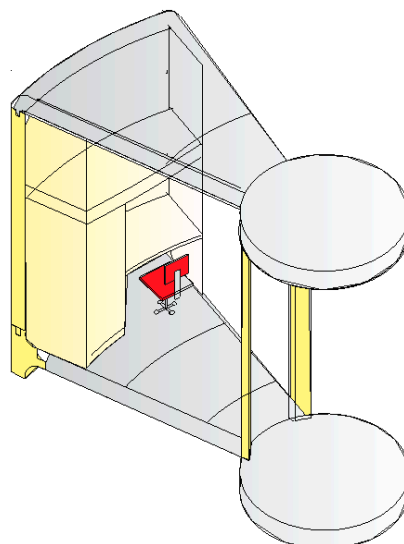


Fig. 5: Personal space.

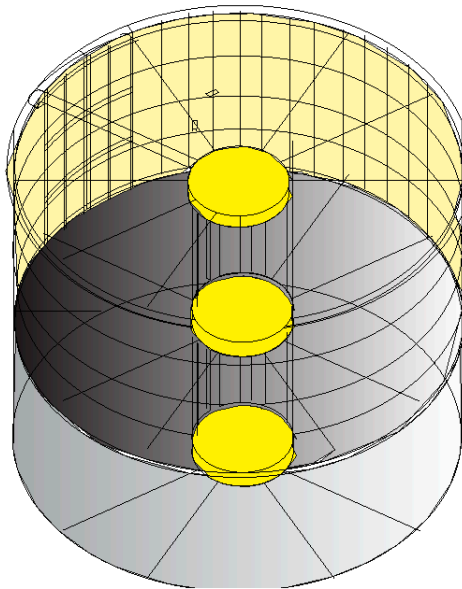


Fig. 6: HAB estructure completed.

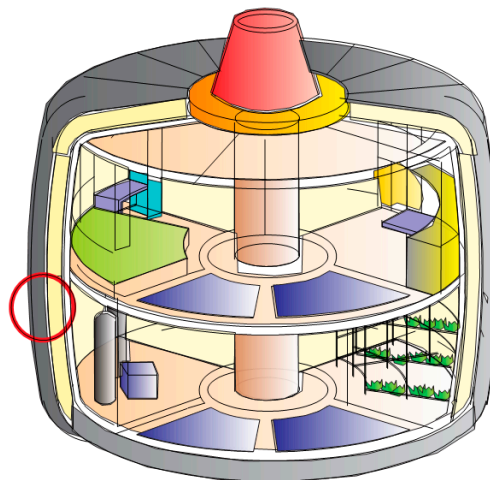


Fig. 7: Habitat.

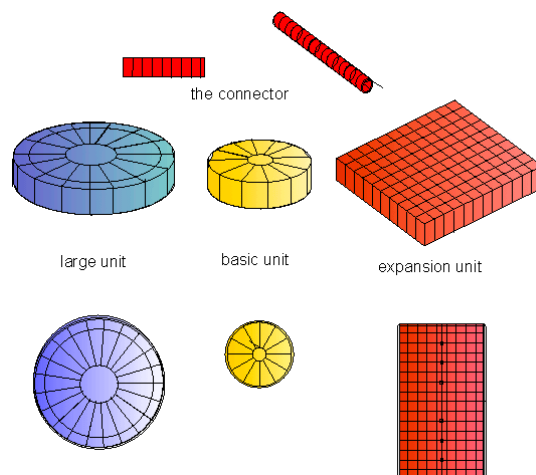


Fig. 8: Building components.

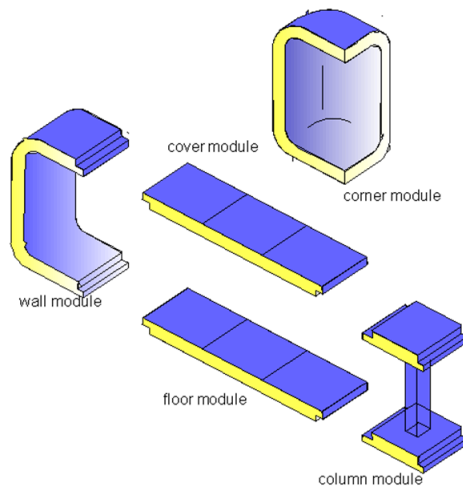


Fig. 9: Building components.

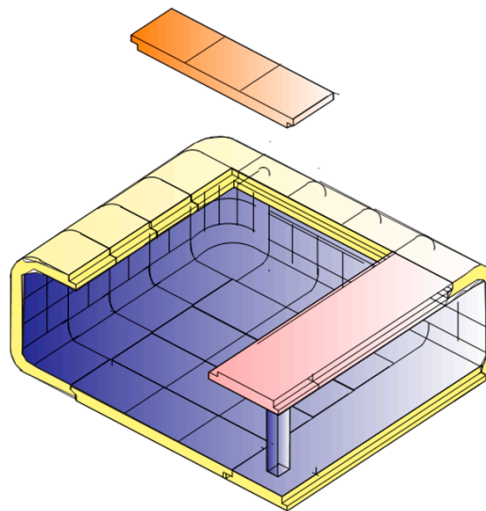


Fig. 10: Assembling sequence.

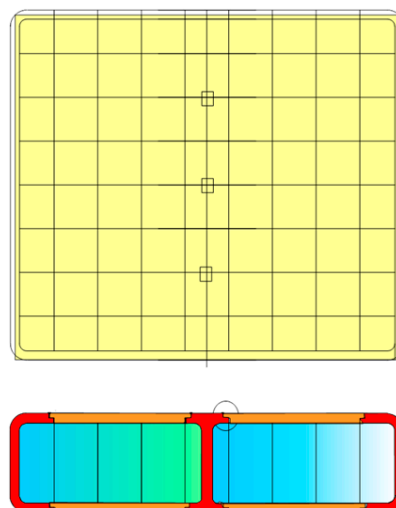


Fig. 11: Plant and section.

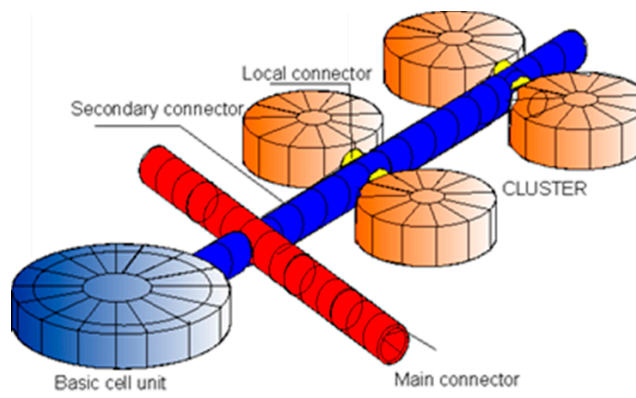


Fig. 12: Planning components.

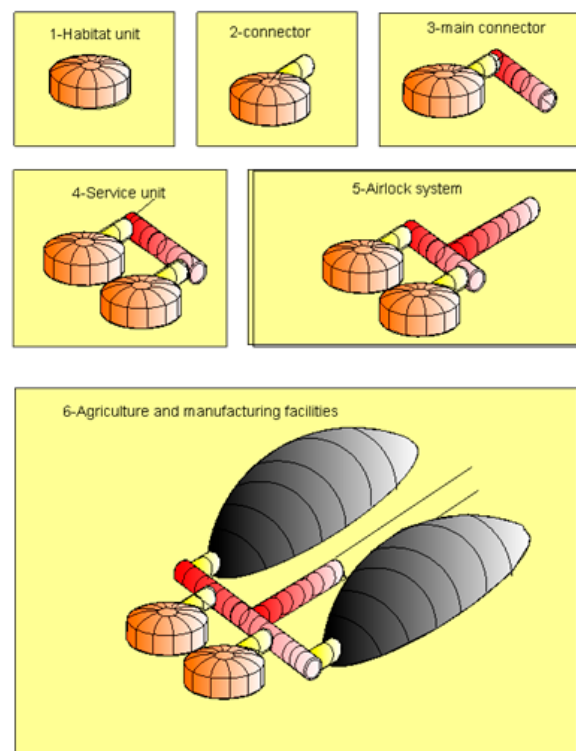


Fig. 13: Outpost construction sequence.

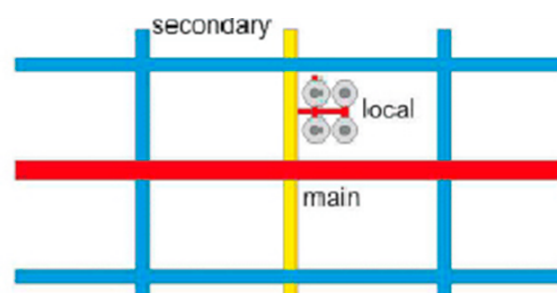


Fig. 14: Connector hierarchy.

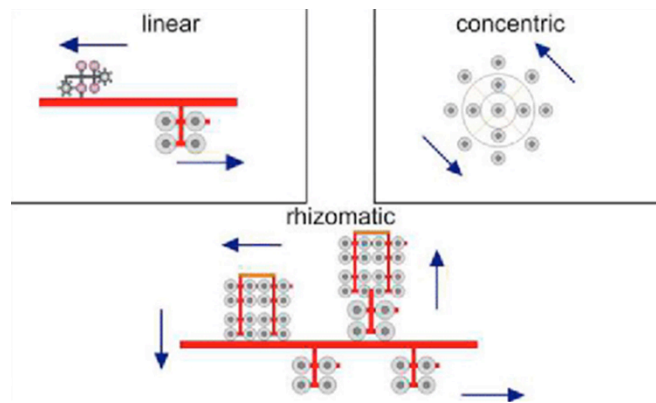


Fig. 15: Expansion alternatives.

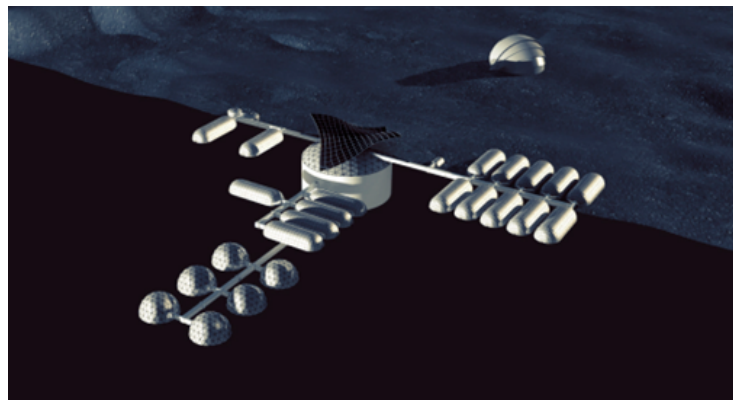


Fig. 16: Outpost rendering.

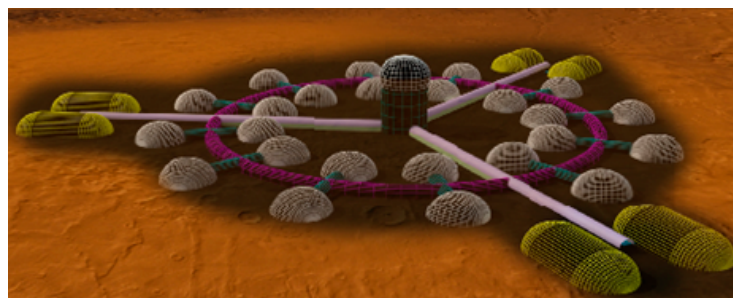


Fig. 17: Outpost rendering.

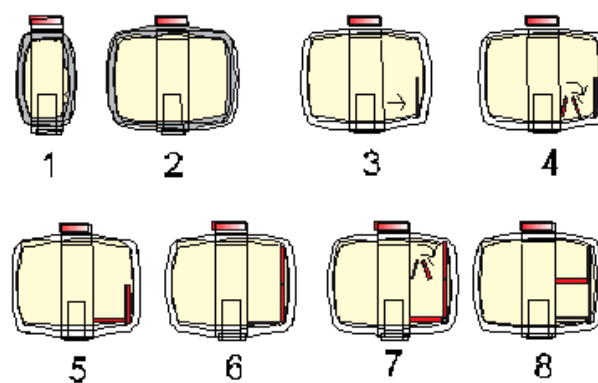


Fig. 18: HAB assembly sequence.

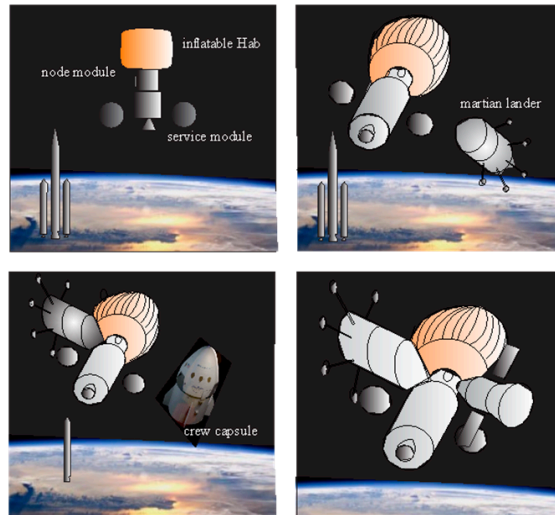


Fig. 19: Mission architecture.

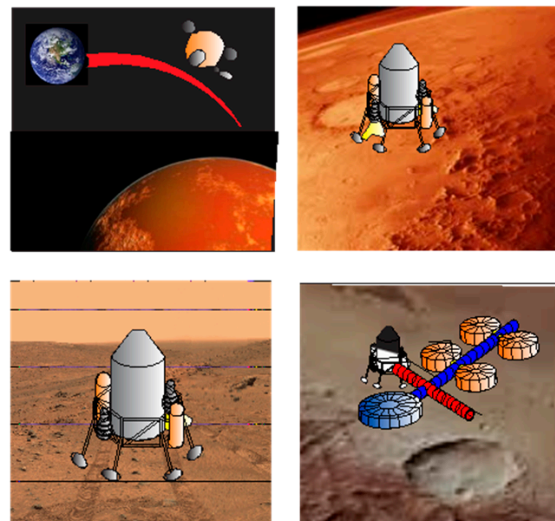


Fig. 20: Mars surface operations.

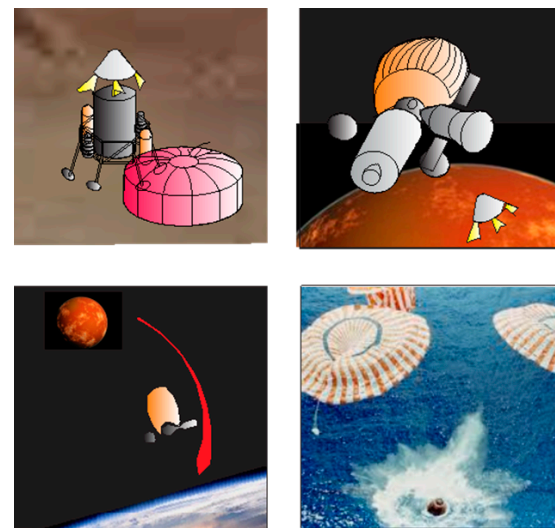


Fig. 21: Martian shuttle departure, journey and arrival to Earth.

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