

## **MARS PLUS**

### **A human round-trip to Mars in 2018-2020**

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#### **Abstract**

In the wake of Inspiration Mars (IM) competition and the actual possibility of sending a crewed spacecraft to a mars-flyby in 2018, relying on the premise of reusability, a recent breakthrough could allow us to expand such mission to include the first human landing and back with the same schedule.

The expansion of the original IM mission consists in the synergy and utilization of available flying hardware, 3d printing technology during the flight and in mars-surface, and in situ resources utilization.

The mars-landing hardware will be transported by the reusable cruiser and composed of three commercial type spacecrafts, two for cargo and one crewed, which will allow landing and after the missions goals are achieved, the crewed lander capsule will return to the cruiser in martian orbit and back to Earth.

The habitat (Hab) needed for the Earth-Mars round trip will be manufactured and assembled in space into the inflatable structure that will be sent empty with the exception of the 3D printer and sufficient amount of printable plastic material needed for the building components.

Such system will drastically reduce the entire load to a fraction of a conventional one. In mars surface, the crew will deploy inflatable Habs to be equipped with lightweight 3d printed components and utilize the same process for the rover that will be assembled on the planet. Also the empty martian lander will be reutilized as a 3d printed Hab facility.

The application on this mission of 3D printing technology will save great amount of weight to be launched from Earth as payload, and will set the standard for exploration class missions, demonstrating critical technologies required for sustainable off-earth settlements.

The proposed Mars Plus mission will be the initial milestone of martian development, becoming the basis of a new, renovated and ambitious space development plan. In this paper we want to present the entire mission architecture, its advantages, costs and benefits.

**Keywords:** *Mars Landing, Mars Development, 3D Printing.*

## **Introduction**

[Mars Plus 2.0 (MP) is an updated version of our Mars Plus entry for the International Inspiration Mars Student Design Contest, it incorporates new added ideas and the lessons learned gained from the review of other proposals plus bibliography] [1]

Present and new generations need to feel the thrill of ambitious space missions, like the one that grew up in the late 50s and 60s, when Mercury and Gemini first, and Apollo later, inspired an entire generation on a global scale.

Since then, several decades has passed with the absence of thrilling initiatives of space development such as a crewed mission to Mars or even a return to the Moon.

The feasibility of the known at the moment, and only governmentally funded “flag & footprints” missions has been demonstrated to be not achievable, in part by using an anachronic premise of design that is not considering the concept of reusability, and mainly due to a zero-sum game of politics that has inoculated an incredible inertia in most important space agencies.

Today with much more advanced technology than in those pioneering years, we can achieve more daring results, but the lack of an important motivation, and an absence of courage or braveness are not advancing the plans of expanding humanity in space.

But the dream is not dead and several private companies and ventures have taken positions as important players in the new paradigm of space technologies and space exploration.

The development of new launch technologies and unmanned and crewed spacecrafts that has been designed with the premise of reusability and for commercial purposes, such as the designed by SpaceX, is advancing forward a promise scenario of commercial development of space driven by private companies. [2]

Of course, we must give the credit where credit is due. Most of these advances in space technologies are being leveraged by NASA thanks to the implement of new model of contracts managed by the Commercial Crew & Cargo Program Office (C3PO).

MP integrates a further development of previous proposals that have been presented in the latest years. [3]

Recently, several private ventures, such as Inspiration Mars for a crewed martian flyby and Mars One for a one-way martian settlement are daring and motivating, however these proposals are suffering hard critics and a lack of support by space agencies. In this sense, we argue that one-way types of missions will only be publicly and politically accepted if human return missions have been successfully executed, validating key technologies and demonstrating in situ resources utilization capabilities. [4]

We understand that if someone wants to go on a one-way mission, that could be accepted, however we must previously set-up the infrastructure needed in order to give the possibility to someone who wants to return to Earth, and vice versa.

MP represents a technological breakthrough that could reopen the space race not for competition between space powers but as a response to the skeptics that always and only see a feasible crewed mission to Mars 10 or 20 years in the future. At the same time it may represent an enormous motivation for younger generations to refocus their interest from the dominating social networks and IT culture to space progress and development.

In fact Inspiration Mars could be the more appropriate name for this mission that can, by itself, as we would like to propose, alter the space plan drivers and represent the first phase of an ongoing ambitious program whose goal is the fast development of an affordable space infrastructural and transportation system to be operational and open up the final frontier for thousands of private initiatives.

To implement MP technological capability is not sufficient, commercial, business and financial skills must also be developed in order to render the mission not only affordable but also profitable for its proponents and change the rules of the game in space activities.

That is the scope of this proposal, which will be outlined in following pages, a mix of what is needed to implement as the first step of a more ambitious and far reaching plan. Space must be conquered, its enormous opportunities and resources be utilized.

Mars Plus would be an essential game changer step forward.

## **Mission overview**

The purpose of MP proposal is to bring a clear vision of a realistic crewed mission to Mars with existing (or coming) commercial technologies.

***The Mars Plus mission will land a human pioneer [26] at Mars in 2018, and after staying at Mars more than 500 days performing different activities in the search of life (past or present), collecting high valuable scientific mars-samples, and after demonstrating in situ several key technologies, the pioneer will return safely to the Earth, accomplishing successfully in this way the longest stay in deep space and the first interplanetary crewed mission.***

The conceptual mission described in the following pages due to the short time available is unprecedented by its nature, and it is understood that could be strongly criticized by nay sayers and bean counters that will analyze this mission under the current and not

sustainable paradigm of expensive programs and non affordable “flag & footprint” missions.

The MP proposal is designed to be an affordable mission that could be backed mainly by visionary privately held companies and venture capital investors. Major funding from governmental agencies will not be required; however the invitation to participate and to collaborate in this great endeavor is firmly open.

Collaboration from NASA will be required in order to track-receive-analyze-and interpret an incredible amount of high valuable scientific data in the fields of: physiology (deep-space impact in humans), planetary sciences (areology), exo-biology, and in situ resources utilization (ISRU) technologies, as it others.

Following an entrepreneurial spirit, this mission could be accomplished by a nongovernmental organization or private company, an existing or a new one created for this purpose, which accepts the challenge of managing all the stages of this project and provides a way of synergy among stakeholders.

Parallel design and business goals are developed for the mission. With this point of view in mind, design goals can be as follows:

- Set-up of an entirely reusable and affordable Earth-Mars transportation system.
- Demonstration and validation of equipment to represent a first step of an expandable and profitable future space business activity.
- Minimize risks to the crew.
- Utilize equipment that could be considered standard for future missions.

While from the business point of view:

- Set-up and utilize the available system for the development of space infrastructures and transportation system.
- Utilize MP as first phase of a more ambitious and integrated space plan.
- Develop terrestrial and lunar orbital capabilities together with cycler transportation systems.
- Show possibility of private space missions to become profitable business ventures.

Using similar words as the expressed by the Inspiration Mars Foundation (IMF):

This unique window of opportunity will be open to push the envelope of human experience, while reaching out every youth to expand their views of their own futures in space exploration.

Revitalizing interest among worldwide students in Science, Technology, Engineering and Mathematics (STEM) education will be also a vital part of this mission. Inspiring humanity to reach for their dreams and dare to invent their future.



In these pages is implicit the possibility of moving America farther and faster toward its destiny of being the world leader in technical innovation, space transportation, science, exploration and discovery.

### **Preliminary outline of mission architecture**

This mission architecture will be based on three launches with rendez-vous and docking to compose the spaceship, but will allow the entire reutilization of the cycler vehicle for future missions; it could be utilized on an Earth-Mars cycler or even in a profitable Earth-Moon cycling trajectory.

#### ***Mission 1***

The first mission will consist of launching the already assembled vertical 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.

#### ***Mission 2***

Consists of the launching and docking of the martian hab lander. Such vehicle will represent a payload of 10 tons.

Once in orbit this vehicle will rendez-vous 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 rendez-vous with the stack and man the mission.

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.

As soon as the cruiser is directed to the martian destination the crew will manufacture and assemble the interiors of the Hab module with all its functional components. Such activity is estimated to take a week plus-minus a few days.

The cruiser will proceed to Mars with its final configuration fully functional, including the start of the food production hydroponic cultivations.

#### ***Mission 4: martian landing***

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

### ***Mission 5: surface activities***

The lander will descend to the selected site with a manned crew and start all planned activities. The initial days the crew will live in the descent capsule and start unloading the water, air producing equipment, the communication and solar generated power system. After they are located and functioning in their planned location, the crew will unload, locate and inflate on the ground the inflatable hab modules. At the same time, once emptied, also the mars lander non detachable part will be reassembled with 3d printed building components to become a crewed Hab.

The modules will consist in a hab and lab unit, a service and food production unit, a connector and a rover storage-maintenance unit. An airlock for the crew and vehicles will complete the outpost.

All interior partitions and the rover vehicle will be manufactured through the 3D printer, previously utilized and transferred to the martian lander. After inflation of units the crew will start manufacturing the needed components and properly assemble them according to design sequence.

### ***Mission 5: Return to Earth***

Once the planned mission will be finished the crew will board the martian shuttle on top of the hab. While the lower part will remain on Mars the upper crew capsule will take – off to rendez-vous with the orbiting cruiser.

Once docked with the orbiting cruiser the entire stack will leave the martian orbit and head back to Earth. The return to Earth will follow a Hohmann trajectory when the planets will be in the right opposition phase.

At Earth vicinity the crew capsule with its passenger will leave the cruiser, that will remain in a cycler orbit with Mars or redirected to an Earth-Moon cycling orbit for future utilization, and splashdown or land in a platform in a designated sea location where the astronaut will be picked up together with the capsule and its martian samples for further studies and tests.

### **Landing site**

The landing site selection for this mission will go beyond the "follow-the-water" strategy of recent Mars exploration. We understand that the ideal landing site should have clear evidence of a past or present habitable environment.

The site will have a favorable areologic record, as well as evidence of past water. The ideal landing site should also have the elements essential to life as we know it, all located within a relatively smooth, safe landing area.

Within the Mars Science Laboratory (MSL) program, Mars scientists from around the world attended workshops and compiled a list of 100 potential landing sites. After using the most powerful cameras and spectrographic instruments aboard of Mars Reconnaissance Orbiter (MRO) four candidates were down selected in 2008. [5]

The landing site proposed for Mars Plus mission is Holden Crater. [Fig. 1-2]

Holden (26.37°S, 325.10°E) is a 140 km wide crater situated within the Margaritifer Sinus quadrangle (MC-19) region of the planet Mars. This ancient areologic formation is notable for many features that seem to have been created by flowing water, including Uzboi Vallis, an outlet channel that begins on the northern rim of the Argyre basin and cuts through several craters before ending at Holden Crater. It is hypothesized that great amount of water went through this area which is filled with sediments. Just to the north east of Holden Crater is Eberswalde Crater which satellite images shows that once contained a large delta.

This landing zone satisfies all engineering constraints. [6]

### **Launch window and trajectory**

Studies performing round-trip and flyby Mars missions were explored several times by different authors. Trajectories that minimize initial mass required from Low Earth Orbit (LEO) for cargo and piloted missions were also summarized. In these studies the 15 to 17 year cycle for optimal conditions for missions to Mars was clearly identified, resulting in optimal launch window for missions for both types in 2018. [7] [Fig. 3]

There are two major mission profiles; the short-stay mission, often referred to as an opposition-class mission, and the long-stay mission with minimum energy, usually referred to as a conjunction-class mission. Each one possesses unique characteristics such as flight trajectories, energy requirements, travel times, and surface stay times.

A conjunction-class mission provides Mars stay times up to 500 days with a round trip total time of about 900 days. The energy requirements for this mission are lowest than opposition class profiles; the trade-off is the resulting long transit time, around 250 days.

However, if new advances in propulsion, such as Variable Specific Impulse Magnetoplasma Rocket (VASIMR) or Nuclear Thermal Rocket (NTR) technologies are available and validated by the date of assembly in earth-orbit, could be considered a derived long-stay mission with fast transit, similar to the minimum energy long-stay profile providing long surface stay times. With sensible increases in propulsive energy, the travel times to and from Mars can be reduced by up to 100 days each way (one-way travel times range from 120 to 180 days), resulting in an increase in surface stay times to a total of 600+ days. Total round trip time for a fast transit mission is typically under 900 days.

Conjunction class trajectories provide Earth-Mars transfers for three mission scenarios: Direct, Semi-Direct, and Stop-Over. For Stop-Over missions, the crew begins on Earth, but the transfer vehicle leave for Mars, where the crew lands and the transfer vehicle is placed in orbit. Following another in-orbit rendezvous, the crew and transfer vehicle depart for Earth, where the crew lands and the transfer vehicle is placed in Earth orbit for reuse. [8] [Fig. 4]

The Mars Plus, first human expedition to Mars in 2018 will perform a conjunction class trajectory for a Stop-Over mission.

The departure date from earth-orbit for MP mission is May 8, 2018 and arrival date to Mars is November 4, 2018. The Mars departure date is June 12, 2020 and Earth arrival date is December 9, 2020. [Fig. 5]

The MP mission will allow to the crew a stay time of 586 days exploring Mars, and adding 360 days of traveling in deep space, this result in a preliminary 946 days duration trip, thus the first and longest interplanetary mission ever attempted. [9]

## **Orbital mechanics**

Due to the challenging purpose of this mission, the planning of the orbital mechanics required to be performed not will be as simple as a flyby mission. To accomplish successfully the MP landing will be necessary the following stages:

- Unmanned assembly at LEO
- Spiral out maneuver & Trans Mars injection
- Mars orbit injection & Aerocapture
- Spiral out maneuver & Mars orbit departure
- Earth vicinity arrival & Cislunar orbit

These stages are briefly analyzed and outlined as follows.

### ***a. Unmanned assembly at LEO***

Some of the previous proposals that we have seen in the latest decades have based its architecture in the launch of heavy hardware conformed in a single vertical stack, or big and heavy surface habitats, and for these reasons these proposals would require the use of inexistent, by the moment, powerful launcher systems.

Due to an increasing in modularity, standardization of magnetic docking system, and advances in unmanned capabilities, current spacecrafts can be assembled in a fully autonomous mode at LEO.

The assembly at LEO of the hardware required for the MP mission, in an orbit to be defined, poses the advantage of only require existing, or coming, commercial launch systems.

Also the great possibility that brings an autonomous assembly in orbit is the advantage of running a full test of the whole system and subsystems, several weeks or months before, prior to the arrival of the crewed spacecraft that will have the utility of Descent-Ascent-Vehicle (DAV).

The orbit to be used for the assembly of the MP stack must be congruent to the solar system's plane of the ecliptic, and could be situated in the range of 350/400 km. altitude (perigee), which is a similar but a slightly lower altitude than the used by the International Space Station (ISS), which is a proven reachable altitude by current commercial spacecrafts.

The possibility of utilizing ISS orbital facility for assembly and test of the MP stack is not contemplated in the scope of the MP proposal, at first, ISS's orbit inclination is not congruent to the solar system's plane of the ecliptic, and second, by the cost associated that would imply such decision, however if NASA's decision makers consider that this issue could be put into the collaboration package at no cost for MP organizers, such decision will be welcomed.

#### ***b. Spiral out maneuver & Trans Mars injection***

The orbit to be selected for the assembly of the MP stack should be elliptical, with a perigee altitude in the range of 350/400 km. and an apogee among 1500/2000 km. or it is possible Highly Elliptical Orbit (HEO) with an apogee reaching Geostationary Earth Orbit (GEO) at a range of 35000 km. altitude.

The reason of selecting a HEO option to locate the MP stack, while it is assembled and tested, is because the orbit raising maneuver, or Hohmann transfer performed by the Solar Electric Propulsion (SEP) of the spacecraft from HEO would be more efficient than if it is performed from a circularized orbit.

The trans-Mars-Injection (TMI) will be performed using a Low-Energy-Transfer trajectory. This route will allow to the MP spacecraft to reach Mars orbit with little expenditure of delta-V with the subsequent important savings in fuel consumption.

#### ***c. Mars orbit injection & Aerocapture***

The Hohmann Transfer maneuver required for a successfully Mars orbit injection should be performed at the lowest altitude possible in order to capitalize the savings in delta-V when this maneuver is performed in this scenario. A further possibility to perform a successful Mars orbit injection could require an aerocapture maneuver.

Aerocapture technology is a flight maneuver that inserts a spacecraft into orbit around a planet or moon by using the destination's atmosphere like a "brake." The dense

atmosphere creates friction, which is used to slow down a spacecraft, transferring the energy associated with the vehicle's high speed into heat. This allows for a quick orbital capture without the need for a heavy load of on-board propellant, which increases launch cost. [10]

Aerocapture utilizes the same analysis, hardware and systems engineering methods as Entry-Descent-Landing (EDL) systems, so much of what is needed for Aerocapture exists and has been flown in space. In fact the MSL entry Guidance-Navigation & Control (GN&C) algorithm has the same foundation as aerocapture guidance, so we can argue that once MSL accomplished a successful entry, Aerocapture at Mars is essentially proven. [11]

The aerocapture maneuver won't necessary if the MP spacecraft utilizes VASIMR or NTR engines for propulsion. The Hohmann transfer maneuver for Mars orbit injection could be performed positioning the MP spacecraft in inverse and firing its engines in order to decelerate the spacecraft.

#### ***d. Spiral out maneuver & Mars orbit departure***

At the moment of the Mars orbit departure the MP spacecraft will fire its engines in pulses, raising in this way the orbit progressively, and most importantly for to transform a circularized orbit into a elliptical orbit and then into a highly elliptical orbit with the less expenditure in delta-V and the subsequent saving in fuel consumption.

#### ***e. Earth vicinity arrival & cislunar orbit***

At arrival to the Earth vicinity, the MP spacecraft will have to perform a Hohmann transfer from the low-energy-transfer trajectory from Mars into a very highly elliptical orbit with a perigee in LEO and an apogee that reaches Moon orbit.

The reason why the MP spacecraft should be parked in a cislunar orbit is to perform in a near orbit a right assessment of potential biohazards due to the Mars samples that the crew will bring back to Earth, besides to assess the health of the crew.

After finishing the MP mission, the MP spacecraft could be used as a cislunar outpost, deep space laboratory, and also as a cruiser in an Earth-Moon transportation route. Then, when the new synodic period is available and after to be expanded with more modules, could be launched again into a TMI to perform the Earth-Mars transportation route.

### **Entry – Descent – Landing (EDL) maneuverings**

The EDL maneuverings are the more difficult and risky part in such a mission. However improvements in rocketry and algorithms for GNC are increasing the acceptance of new ways to approach this crucial part of the mission.

Prior standard approach relayed on the use of parachutes to reduce the entry velocity. However MSL demonstrated that also could be successfully used retrorockets in order to hover the payload and in this way to attain a soft landing.

The new current approach totally relies on the use of retrorockets in all the phases of EDL maneuvering. That means in the hypersonic, supersonic, and subsonic phases, to finally accomplish a safe and accurately landing. [12] [Fig. 6]

#### ***a. Mars landing***

Hybridizing a variant of the SpaceX Dragon spacecraft, that may include a modified and pressurized trunk as a Mars Lander, with a hypersonic guidance strategy on the JPL MSL mission, open a pathway to commercially provided landing of heavy payloads on Mars with 10 km landing accuracy. [12]

The architecture relies on SpaceX's SuperDraco engines for supersonic retropropulsion that would decelerate the Dragon-variant spacecraft from supersonic speed to a soft landing on the surface of Mars. Such an approach could deliver 1000/2000kg payload to high elevations and also high latitudes. [12]

#### ***b. Mars Lander/Ascending orbit rendezvous***

Prior concepts of crewed mission to Mars have been proposed with an architecture that involves the use of different spacecrafts for different and unique use, one to descent, and other to ascend. Some of these proposals even are sketched like "matryoskas" with one spacecraft inside the other.

The MP mission is based on the premise of reusability. Thus, we propose that the Dragon spacecraft that will transport the crew will be a multipurpose Descend-Ascent-Vehicle (DAV).

Once finalized the scheduled mission at Mars surface, the crewed DAV will liftoff from Mars surface to reach orbit, and then rendezvous back with the cruiser that have been parked at low mars orbit at the initial stage of the mission.

#### ***Spacecraft design & Hardware selected***

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 the demonstration that with due financing such mission could be possible, with the breakthrough application of 3d printing technology it would even be possible to propose a more ambitious mission that could consist in the actual 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 in the following pages such possibility.

The Mars Plus mission will be a project, it won't be a program. On the contrary of previous unaffordable concept missions, MP mission is designed to utilize only developed or under development technologies. No further development of expensive ad-hoc vehicles or technologies will be needed. MP will be a mission demonstrator.

As we have pointed in previous lines, the MP concept relies on the premise of reusability. Other basic premise utilized is the use of available (or coming) commercial developed technologies. Both premises are fundamental in order to perform a realistically and affordable crewed Mars mission.

#### ***a. Launchers***

For the minimal configuration of the mission three launchings will be scheduled. In one configuration, the first one will carry the stack that comprehends the complete Cruiser vehicle, the second will transport the martian lander and the third and final the crew capsule. The second configuration comprehends the launching of the complete Cruiser with a Dragon V2 capsule full of cargo, a second launch that carries more cargo, and finally the third one that is the crew command capsule. The capability of potential launchers have been analyzed. [Fig. 7]

To comply with International Traffic in Arms Regulations (ITAR) restrictions, the selection of launcher systems that will be utilized in the MP mission will must to be only developed by U.S. companies. The selected launch pad also must to be in U.S. territory.

The most promising company that meets all these parameters, and also will provide in a coming future reusable powerful launch systems is SpaceX, from Hawthorne CA.

#### ***1. SpaceX's Falcon 9***

The SpaceX's Falcon 9 (F9) is a launcher situated in the medium-lift range of launch systems.

This family of rocket-powered spaceflight launch vehicles consists of two-stage-to-orbit vehicle burn liquid oxygen (LOX) and rocket-grade kerosene (RP-1) propellants. The current version of F9 can lift payloads of 13,150 kilograms (28,991 lb) to LEO, and 4,850 kilograms (10,692 lb) to geostationary transfer orbit (GTO).

The F9, and Dragon capsule, won a Commercial Resupply Services (CRS) contract from NASA to resupply the ISS under the Commercial Orbital Transportation Services (COTS) program. Recently SpaceX presented Dragon V2, which will have human-rated capabilities for transporting astronauts under NASA's Commercial & Crew Development (CCDev) program in the coming years.

The F9 family of launchers will be the base for the Falcon Heavy launch vehicle. For this reason, it is shortly expected that SpaceX will update the F9 launchers with deceleration and turnaround maneuvering capabilities for controlled descent and



landing. This new family of reusable rockets will be named as F9R. At least, the launch of two F9R will be required to insert in the assembling orbit and to berthing with the MP spacecraft; two unmanned Dragon V2 spacecrafts for cargo. [Fig. 8]

## **2. *SpaceX's Falcon Heavy***

The SpaceX's Falcon Heavy (FHR) is a reusable spaceflight launch system currently at design and manufacturing stage. The FHR is a two-stage-to-orbit vehicle derived of the F9R, FHR will consist of three F9R rocket cores, and two of them will be added as strap-on boosters.

The current design of FHR can lift payloads of 53,000 kilograms (116,845 lb) to LEO, and 21,200 kilograms (46,738 lb) to geostationary transfer orbit (GTO).

The first launch is expected by 2014/15.

The payload to LEO falls into the "super heavy-lift" range of launch systems under the classification system used by a NASA human spaceflight review panel.

The launch of only one FHR will be required in order to lift the main components of the MP spacecraft; the Cygnus spacecraft (as a service module) and the crewed Blue Dragon V2 (crew Command) with the inflatable habitat module (BEAM) which is stowed in its unpressurized trunk. [Fig. 8]

### ***b. Mars Transfer Vehicle (Cycler/Cruiser)***

On the contrary of other mission concepts, and following the premise of reusability, the design and lay-out of the MP spacecraft, also known as Mars Transfer Vehicle (MTV), Cycler, or Cruiser will consider the problem from a more holistic point of view and not only from this single mission.

This opportunity must be utilized to become the basis of a new, renovated and ambitious space development plan. For this purpose, in parallel with the MP proposal, we are introducing a standardized space component system that may change the rules of the game in space since they will be simple, affordable, manufactured in series, reusable and allowing incremental expansions. Such standardized modules should represent the basic components of the MP proposal.

The system will be composed of few basic modular components, that can be added to the first one and allow any type of expansion.

The MP spacecraft will be assembled in LEO by performing unmanned berthing operations of the main modules implied, each one with a clear and specific purpose.

The required MP spacecraft will be composed mainly of a service module that includes a solar electric propulsion (SEP) and an inflatable Habitat (HAB). Following such basic initial mission, and in further development of this system, it will be possible to add further capabilities such as a food production module, and or even an asteroid servicing

module, composed of a storage volume utilizing an inflatable structure with additional modular facilities for mining and mineral processing.

Once the system is operational it could be expanded and perform multiple missions through the addition of special standardized modules and will operate, as a cycler or cruiser, on cyclical trajectory with several destinations (Moon, Mars, NEOs as others) as needed. [Fig. 9]

### ***1. Cygnus Spacecraft (enhanced version)***

A service module (SM) will be required, which will contain the following critical hardware:

- SEP engines
- Fuel tanks
- Main power generation
- Avionics, GN&C
- Communications

Several alternatives of spacecraft designs has been proposed across the years, however we believe that it is not necessary to design a specific service module for this proposal.

We propose the use of a Cygnus spacecraft, with the pertinent update or modification according to the required on-board specific hardware. [Fig. 8]

The Cygnus spacecraft is an unmanned resupply spacecraft developed by Orbital Sciences Corporation as part of NASA's COTS developmental program. It has been designed to transport supplies from Earth to LEO, being ISS its first destination due to the retirement of the American Space Shuttle.

The spacecraft required will contain two basic components; the unpressurized SM that will contain the SEP, fuel tanks and power generation system, and the pressurized cargo module (PCM) enhanced version, in which will be allocated the critical computerized hardware for avionics, GN&C, and communications, all in racks and accessible from the interior.

This module being an essential part of the MP spacecraft, will also require to be used as a node module, therefore it must be provided with four added docking ports in it laterals (nadir, port, starboard, and zenith), besides the main docking port in the front (ram) of the spacecraft.

In order to simplify and to mitigate risks, precursor mission concepts have not considered the addition of an airlock to conduct extra vehicular activity (EVA) in the hardware selected. Given that the vacuum of space is the harshest environment for living beings, we certainly agree with the general opinion that states that EVA should be conducted only if it is necessary. However, we argue that all missions, no matter what simply are, it should allow the EVA capability.

One of the four lateral docking ports, nadir or zenith, of the SM should permit to conduct EVAs. Once the crew being inside of the PCM closes all the hatches, this improvised airlock could be used in several scenarios; for science reasons, i.e. retrieve experiments etc, or at least for use in emergencies, i.e. replace or repair something not accessible by the inside. Or perhaps, for inspirational motives such as an “astronaut selfie” in Mars orbit.

## ***2. Inflatable habitat Module (BEAM)***

The inflatable Habitat Module (HAB) is the other essential component of the MP spacecraft. In this module the crew will live during the transit Earth-Mars-Earth, therefore it must provide all the required capability to sustain life and work. [Fig. 8]

With the premise of reusability in mind, we must consider that initially this HAB will be used by only one person, but due to the extended period of use beyond this mission, the HAB might be used by more crewmembers. Furthermore the HAB might be assembled in a different position into the future enhanced spacecraft layout for being used for other activities, therefore all the interior divisions, floors and walls, every “furniture” or equipment that are not part of the HAB’s structural components should be printable, removable, and recyclable.

There are two limiting factors in a rocket launch: weight and physical size. The proposed HAB represents an original approach to the problem. A commercial solution for this purpose is the Bigelow Expandable Activity Module (BEAM) an inflatable module that is being developed by Bigelow Aerospace, from Las Vegas, Nevada.

In 2015, a BEAM module will be transported within the unpressurized trunk of a SpaceX Dragon during the SpaceX CRS-8 cargo, with the purpose of being tested at ISS for a period of two-year. [13]

The HAB, an enhanced version of the BEAM module, consists of an inflatable 5m long, 6.50 m diameter (interior dimensions when inflated) system, which will be transported to orbit inside the cargo trunk of a SpaceX Dragon capsule. However, our vision is that the Dragon’s trunk shouldn’t be only a way of transfer; this enhanced version of Dragon’s cargo trunk should be an inseparable component of the BEAM, allocating in its remnant space all the needed equipment and components to sustain life and work, i.e. Draco thrusters and fuel tanks for orbital and berthing maneuverings, avionics for GNC, Environment Control and Life Support System (ECLSS), electrical power by Solar Array Winds (SAW) and batteries, pressurized breathable air in tanks for BEAM inflating, etc. [Fig. 10]

The HAB should have two berthing ports, both using (international) Low Impact Docking System (iLIDS), one in the front of the BEAM module, and the other in the opposite side; in this case the iLIDS will be allocated at the base of the enhanced trunk. This layout will allow further expansions in accordance with its design capabilities.

Inside a compacted 2.50 m diameter polystyrene core consisting of all stacked partitions, floors, walls, needed equipment and furniture, of 4.60 m long. The two HAB levels will consist of:

- Ram level (upper):
  - 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.
- Aft level (lower):
  - 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 assemble the habitat by utilizing all stored components as shown. The floors and walls would be composed of ribbed panels 18 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 finished by a glass fiber net smoothed by a cement based coating and painted by water based colors. The entire system is fireproof and non toxic.

The goal is to reduce its weight compared to existing technology. By utilizing polystyrene components such weight could be reduced significantly. The design goal is a total weight of 2500 Kg. This module will be designed with components (walls, furniture, and equipment) to be flexible and interchangeable. Such concept would allow modifying its interior layout for different utilizations by the crew. For that reason this component can be standardize for several utilizations and missions. In case of bigger requirements it could be built on three levels for additional functions. The core is designed to contained stacked, all components, including furniture and equipment.

### ***The 3D printing option***

The utilization in zero gravity environment of the 3D printing technology is currently explored by an innovative company named Made in Space from Mountain View, CA. This company has been awarded with NASA contract to test 3D printing space technology at ISS, with the idea to provide equipment that could make tools and parts onboard. [14]

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.

As soon as the hab is inflated the crew will manufacture the building components with the 3d printer left inside the hab and using the PET material also stored. As the components are being manufactured they will be installed in a planned sequence to build the two floors of the Hab module.

Specialized modules would contain most furniture and equipment such as a toilet, kitchen, personal space, fitness and more functions. In this way being filled with air, the system will have minimum weight compared to conventional systems with a load reduction estimated at over 90%.

In space, the PET type material, with due highly resistant structural shapes, extremely light and thin, can manufacture the needed building components, such as the PrintBuild System to complete the HAB, its structure, its building components, (walls, floors, ceilings, ) its furniture. [24] The work will be performed by the crew that will stay in the access capsule, during the HAB construction that 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 to reinforce radiation shielding.

### ***The Hydroponic option***

A bioregenerative life support system could be allocated in three sectors of the lower level. This area will be 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. [15] [16]

### ***Payload requirements***

To sustain the life of the crew, critical payload requirements should be met, such as air, water, food, thermal, waste and human accommodations. For the Environmental Control and Life Support System (ECLSS) of a single astronaut [26], the basic system mass and consumables mass have been calculated in the order of 2800 kg. [17] [Fig. 11]

### ***4. Hypersonic Inflatable Aerodynamic Decelerator***

If the MP spacecraft requires to perform an aerocapture maneuver in order to insert it in Martian orbit, would be necessary the use of a Hypersonic Inflatable Aerodynamic Decelerator (HIAD).

This key technology includes flexible materials that will protect the MP spacecraft from the thermal environments experienced during aerobraking maneuver into Mars's atmosphere, due to its high-strength, lightweight, inflatable bladder capable of withstanding high temperatures.

The HIAD Project demonstrated the viability of thermal resilient materials manufactured in robust configurations to withstand the extreme structural and thermal environments experienced during atmospheric entry. Benefits of using the inflatable decelerator design include mission flexibility provided by the minimal volume and mass requirements to transfer the stowed HIAD to its destination. [18]

### ***5. Cupola***

One of the best places on ISS mentioned by astronauts and public in general, is the Cupola, a windowed octagonal shape module that serves as a visual workstation, providing to ISS crew an observation and work area that gives visibility in the support of the control of the Mobile Servicing System (MSS) (A.K.A Canadarm2) and stunning general viewing of Earth and visiting vehicles.

The module was finally designed and assembled by Thales Alenia Space; it was designed to fully contain at least two crewmembers "floating" side by side in zero-g neutral body posture. It has six side windows and a top window, all of which are equipped with shutters to protect them from damage by micrometeorites and orbital debris. [19]

The idea of having a place where the crew of the MP spacecraft could see with her/his own eyes the immensity where the spacecraft is immersed during the long trip to Mars and back to Earth, seems to be at least not only highly desirable but also mandatory as a way to contribute in the reduction of the negative psychological impact of loneliness and isolation on the crew. [Fig. 12]

Other advantages of having a visual observatory in the MP spacecraft besides astronomical observation during trip, could be for to provide visual assessments of the climatologic status of Mars landing area, also could be used as a bridge command during the de-berthing and departure maneuverings of the first two unmanned cargo descent vehicles, furthermore providing a suitable place to catch and deliver stunning visuals of Mars for media and press releases while the crew is orbiting in the cyclor.

#### ***6. The martian hab-lander***

This vehicle will be connected to the docking module, and it is composed of a cargo lander and a capsule shuttle in the upper part to carry and support logistically the crew during descent and return to the orbiting cruiser for final return to earth.

This module will be launched as the second one in terrestrial orbit to rendez-vous and dock with the cruiser. The lander will be divided in two levels the upper being the crew area, the lower the cargo with all needed equipment at the site including the 3D printing materials and room for the onboard printer.

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. On Mars surface, after Hab completion, also the empty martian lander will be reutilized as a 3d printed Hab facility.

#### ***7. 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

#### ***c. Mars surface operations***

Some well-known previous concepts for crewed mission to Mars have rely on the separately launch from Earth of all the vehicles, habitats and equipments required to sustain life at Mars surface, on the contrary, the MP mission will use the cruiser spacecraft as a way of transport to a Mars orbit of all the required hardware. [Fig. 13]

The intended purpose of this mission is to land a pioneer on Mars; therefore to reach the surface and for Mars surface operations it will be needed specific hardware such as descent-ascent-vehicles for crew and cargo (CC) transfer, and a surface habitat.

This CC vehicles will be required to connect the cruiser with the ground where will be settled the outpost base (name to be defined), in order to provide all the supplies and

equipment needed. Such CC vehicles will represent the standard architecture for future most space-based transportation requirements.

Due to the long stay of the pioneer on Mars, a surface habitat will be required. The proposed hybrid surface habitat, inflatable and with 3D printed components, will set the standard architecture for future human space exploration missions.

### ***1. SpaceX's Dragon V2 spacecraft***

The recently unveiled Dragon V2 (D2) spacecraft, designed to carry astronauts to Earth orbit and beyond, is fully reusable and will be capable of being flown multiple times. SpaceX has anticipated that ten flights will be possible before significant refurbishment would be required, resulting in a significant reduction in the cost of access to space.

Dragon V2's robust thermal protection system is capable of outer space missions. SpaceX currently resupplies the space station under a NASA CRS contract, and has stated that is competing for a contract with NASA to deliver crew-transport missions to the ISS under the third phase of the CCDev program. [20]

Current version of D2 includes an ECLSS for a maximum capability of 7 passengers. Additional upgrades will include autonomous docking capability, impact attenuating landing legs, and a more advanced version of the Phenolic Impregnated Carbon Ablator-X (PICA-X) heat shield for improved durability and performance, this heat shield is designed for hyperbolic entries at Earth and would be capable of withstanding the lower-speed hyperbolic entries at Mars.

Dragon V2's new feature are its high-thrust, throttleable, storable bi-propellant eight SuperDraco engines built into the side walls of the spacecraft that will produce up to 120,000 pounds of axial thrust that serves as a launch escape system and to land propulsively on Earth with high precision, also making possible accurate interplanetary landing.

The analysis to date indicates that D2 is capable of delivering payloads to sites at elevations three kilometers below the Mars Orbiter Laser Altimeter (MOLA) reference, which includes sites throughout most of the northern plains and Hellas.

Some upgrades and modifications would be necessary, i.e. for deep-space communications and navigation, planetary protection, and payload access to the Mars environment.

The EDL maneuverings for safe precision landing will require an improved system of GNC that should integrate existing or coming technologies. Starting with MSL algorithms for supersonic and subsonic GNC, following with SpaceX's proprietary improvements on it Dragon GNC, and also adding the landing technology developed by Astrobotic Inc., from Pittsburgh PA.



The Astrobotic Autolanding System (AAS) provides precise real-time location updates for spacecraft through visual navigation and automatically avoids hazards during landing on unknown terrain. The landing sensor uses two cameras, an inertial measurement unit (IMU), and a scanning laser. AAS technology autonomously aligns real-time data from cameras and laser with existing satellite imagery to navigate to a precise target, identify a safe landing location, and maneuver past hazards to safely touchdown. [21]

Current analysis and feasibility studies indicate that entry, descent, and landing of the D2 capsule at Mars is feasible. [22]

The search for life on Mars is a priority for NASA's Science Mission Directorate, a pivotal question of the Astrobiology Program and the ultimate goal of the Mars Exploration Program. A future human Mars exploration program requires clear demonstration that humans can land and safely operate on the surface of Mars.

The MP mission concept focuses on three key questions:

- Is there life on Mars?
- Are there viable and accessible resources for humans?
- Is it safe to land humans on Mars?

The MP mission seeks to bridge the gap between science and human exploration, at low cost, by targeting key Strategic Knowledge Gaps. However for each class D2 can deliver to Mars more science and technology than previous landing systems. [23]

Given the supersonic retropropulsion capability that enables to decelerate the D2 from supersonic speed to a soft landing on the surface of Mars, and having the capability of carrying up to 2000kg of payload, all the cargo required to accomplish successfully the first crewed martian mission, will have to be delivered in three D2 spacecrafts. The crew will land in the third D2 spacecraft.

### ***I. Red Dragon (preparation)***

The first Dragon V2 to be detached from the cruiser for an autonomous flight to the Mars landing site will be coded and named as Red-Dragon (RD).

At a certain time, after all the required checks of the hardware and systems, and having the assessment of good visuals at landing site, the RD will start the departure in a remotely controlled way by the crew to a safe distance from the cruiser.

From this point, the RD will operate fully autonomously and will perform a free-flight and EDL maneuvering. All navigation and guidance data will be recorded by RD computers and after the successful landing, this critical data will be beamed to the cruiser and retransmitted to Earth control mission.

Besides of to demonstrate and to validate the proposed EDL approach, the purpose of RD is to deliver at landing site the critical equipment that will be necessary to set up the first martian outpost.

The payload of the RD would be as follows:

- 3D printer
- LOX ISRU group
- Liquid water
- PV panels
- Ground to Earth communications system
- Small Stirling Dynamic Isotope Power System (DIPS)
- Small Exploration Rover
- Tools

By limiting space constraints and for saving place inside the RD some of the equipment stowed would need to be assembled by the crew, i.e. rover.

## ***II. Green Dragon (life support)***

The second Dragon V2 that will follow the path of the first one for an autonomous landing at Mars will be named as Green-Dragon (GD).

After the successful landing of the first delivering, and when all the checks were performed, the GD initiates the EDL maneuvering with improved GNC algorithms provided by first landing data.

The GD spacecraft will have to reach the same landing site of the first landed vehicle and after hovering over the outpost it should be landed at the closest position near RD.

Some of the payload delivered by GD would be as follows:

- Food production system
- Inflatable surface HAB
- PET/EPS ISRU group
- Liquid Water
- Compressed Air
- Chemical Lab
- Science payload
- Utensils and equipments

## ***III. Blue Dragon (crewed DAV)***

The third Dragon V2, and the most important due to mission goals, that will follow the path of the previous two capsules for an autonomous landing at Mars will be named as Blue-Dragon (BD).

After the successful landing of the previous delivering, when all the checks were performed, and with improved GNC algorithms provided by the retrieved previous landing data and corrections and/or adjustments beamed from Earth control mission, the Blue Dragon will perform the EDL maneuvering for the first crewed landing at Mars.

The payload delivered by BD would be as follows:

- Crew
- Food
- Liquid Water
- Compressed Air
- ECLSS HAB
- Utensils and equipments
- Contingent Cargo

The BD capsule will be used as DAV as well. After finishing the mission on mars-surface, with all tanks refueled with the remnants of fuel on RD and GD or by ISRU production, the crew will depart from the outpost in the BD to reach mars-orbit and rendezvous with the cruiser.

## ***2. Inflatable habitat***

The mars-surface-habitat (SHab) will be transported on-board of GD capsule. In the same way than all the delivered cargo, the SHab will be de-stowed by the crew, positioned at site and inflated. [Fig. 14-16]

The Shab will be only a pressurized vessel. To bring a comfortable accommodation the crew will have to assemble inside the SHab all the critical equipments required such as ECLSS, an also will require to 3Dprint the interior terminations and furniture.

The rough materials for PET and EPS production will be harvested by ISRU from martian atmosphere and subsurface ice. The application of a combined approach of ISRU and 3D printing technology will save great amount of weight to be launched from Earth as payload, and will set the standard for exploration class missions, demonstrating and validating critical technologies required for sustainable Mars settlements.

## ***Engines & Electrical Power systems***

Election of electrical power systems and engines for deep space propulsion are a critical part in mission architecture.

While chemical rockets for deep space propulsion has been demonstrated to be inadequate for low cost missions, on the other hand efficient designs of ion thrusters are being successfully tested in ground and in space in unmanned missions and are seriously considered for crewed flights to near asteroids such as the planned by NASA.

Though it is beyond the scope of this analysis, for MP mission we propose the use of a specifically designed Solar Electric Propulsion (SEP) also known as ion thruster, understanding that this technology would be an excellent solution for a mission of this nature.

However the utilization in MP mission of new propulsion technologies such as VASIMR or NTR are open if a prototype of this class achieves enough maturity or is validated as useful and can go into the tight schedule.

To provide electrical power for MP spacecraft solar arrays seems to be the most affordable option. Since every module of the assembled spacecraft has its own solar arrays, these arrays could provide enough power for all systems, including the SEP.

For mars surface operation the deploying of solar arrays can be used as well, however since one of the MP mission is to start the construction of an outpost for mars developing activities, the use of most reliable and 24/7 alternative power source such as a Small Stirling Dynamic Isotope Power System (DIPS) should be considered for in space and in surface power generation as well.

Having successfully flown on several earlier space missions, free-piston Stirling technology has the potential to achieve, as an isotope engine, the high reliability that is required for years of unattended remote operation. Hermetically sealed inside a container, there are typically only two moving parts and no sliding seals of any kind. Incorporating non contacting gas bearings or flexures, there is no wear between the moving parts. Terrestrially, Stirling engine convertors have demonstrated virtually unlimited service life-in test, one radioisotope heated unit has achieved over 110 000 hr continuous operations. On Mars the small Stirling DIPS offers the benefit of being able to operate exposed to the atmosphere without degradation. [24]

## **Conclusion**

Considering the actual possibility of sending a crewed spacecraft to a mars-flyby in 2018, relying on the premise of reusability, a recent breakthrough could allow us to expand such mission to include the first human landing and back with the same schedule.

The expansion of the original Inspiration Mars mission consists in the synergy and utilization of available flying hardware, 3d printing technology during the flight and in mars-surface, and demonstration of in situ resources utilization capabilities.

The mars-landing hardware that will be transported by the reusable cruiser will land on Mars and after the mission's goals are achieved, the crewed capsule will return to the cruiser in martian orbit and back to Earth, demonstrating in this way an important capability that it is not now considered by the Mars One proposal.

New assumptions on the design of the habitat needed for the Earth-Mars round trip will be revolutionary being manufactured and assembled in space into the inflatable

structure that will be sent empty with the exception of the 3D printer and sufficient amount of printable plastic material needed for the building components.

Such system will drastically reduce the entire load to a fraction of a conventional one. In mars surface as well, the crew will deploy inflatable Habs to be equipped with lightweight 3d printed components and utilize the same process for the rover that will be assembled on the surface of Mars.

The effective application on this mission of 3D printing technology will save great amount of weight to be launched from Earth as payload, and will set the standard for exploration class missions, demonstrating critical technologies required for sustainable off-earth settlements.

As it has been shown in this paper, the proposed Mars Plus mission will be the initial milestone of martian development, becoming the basis of a new, renovated and ambitious space development plan.

New non space related technologies may help space development when applied to such plans. 3D printing technology is one of them while its applications are endless. It can be applied in spaceships to manufacture needed equipment, facilities, furniture when dimension and weight would not make that possible and in other bodies where it can manufacture most equipment and facilities utilizing, local resources.

3D printing will revolutionize future space missions. The first application could be a manned mission to Mars by 2018. [Fig. 17]

Figures and Tables

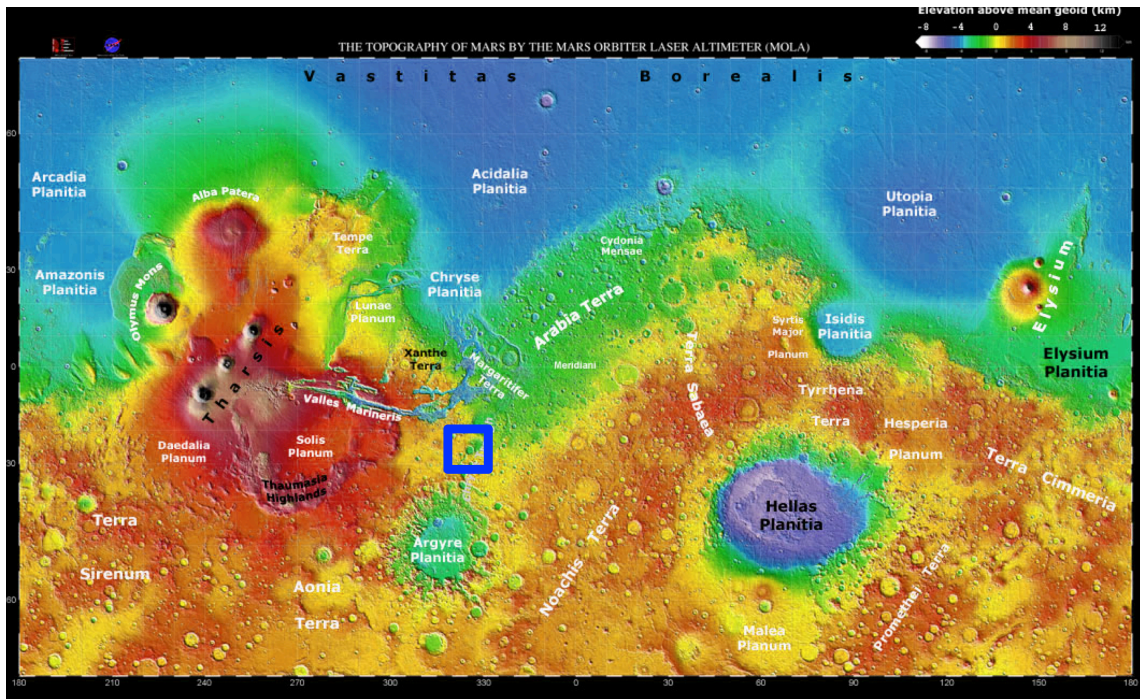


Fig. 1: Location of Holden Crater.

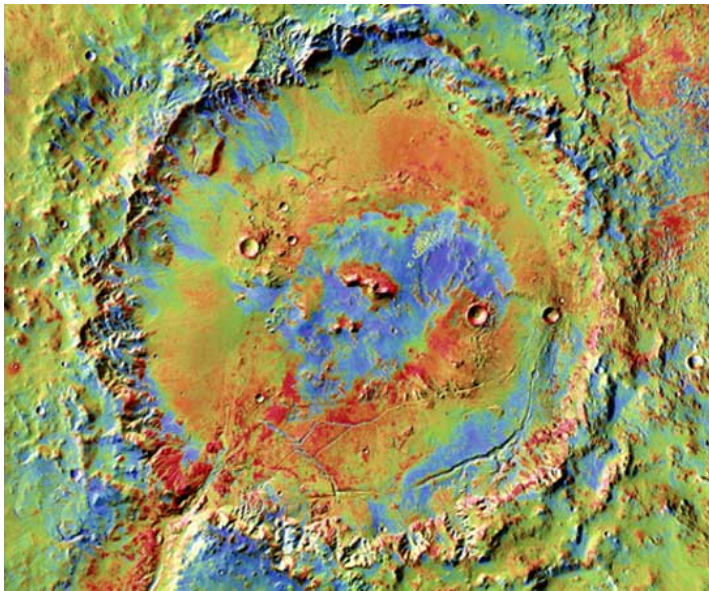


Fig. 2: Holden Crater. Image credit: NASA/JPL-Caltech/ASU

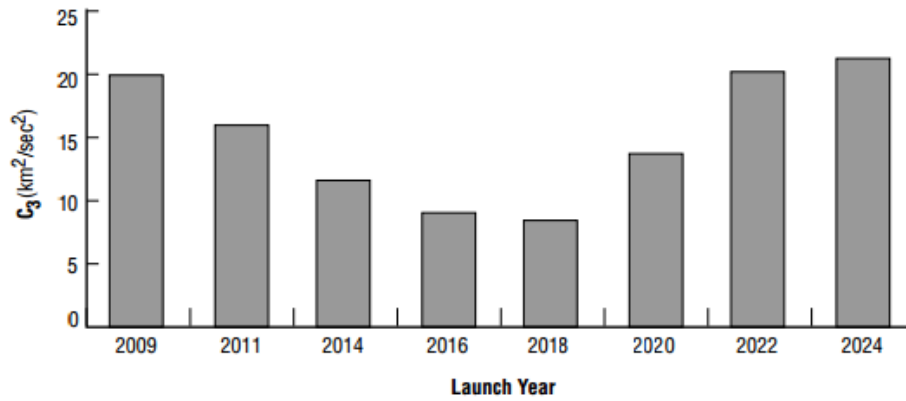


Fig. 3: Piloted optimal departure energies, 2009–2024.

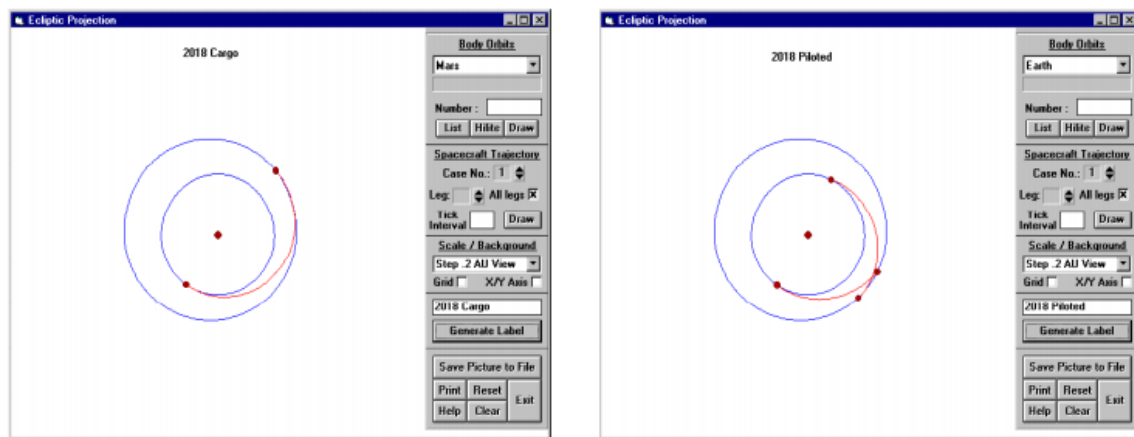


Fig. 4: 2018 Conjunction class Cargo and Piloted trajectories.

Mission Type	TMI Date (m/d/yr)	TMI ΔV (m/s)	Velocity Losses (m/s)	Mars Arrival Date (m/d/yr)	Outbd Flight Time (days)	Mars Stay Time (days)	Mars Departure Date (m/d/yr)	TEI ΔV (m/sec)	Return Time (days)	Return Date (m/d/yr)	Total Mission Duration (days)
Piloted <sup>1</sup>	5/8/18	3,641	97	11/4/18	180	586	6/12/20	1,314	180	12/9/20	946
Cargo 1	5/17/18	3,615	87	1/8/19	236	—	—	—	—	—	—
Cargo 2	5/17/18	3,635	108	1/8/19	236	—	—	—	—	—	—
Piloted	5/18/18	4,019	132	9/10/18	115	651	6/22/20	1476	158	11/27/20	924
Piloted <sup>2</sup>	6/13/18	4,019	132	12/10/18	180	569	7/1/20	1,476	180	12/28/20	929

- 1) Optimal piloted trajectory (minimum initial mass)  
2) Latest possible launches designed to 2011/180 dayC<sub>3</sub>s

27-day Earth-Mars Departure Window:

Depart: TOF      Arrival:  
5/18/18    115      9/10/18  
6/13/18    180      2/10/18

10-day Mars-Earth Return Window:

Depart: TOF      Arrival:  
16/22/20    157      11/27/20  
7/1/20      180      12/28/20

Fig. 5: 2018 opportunities summary.



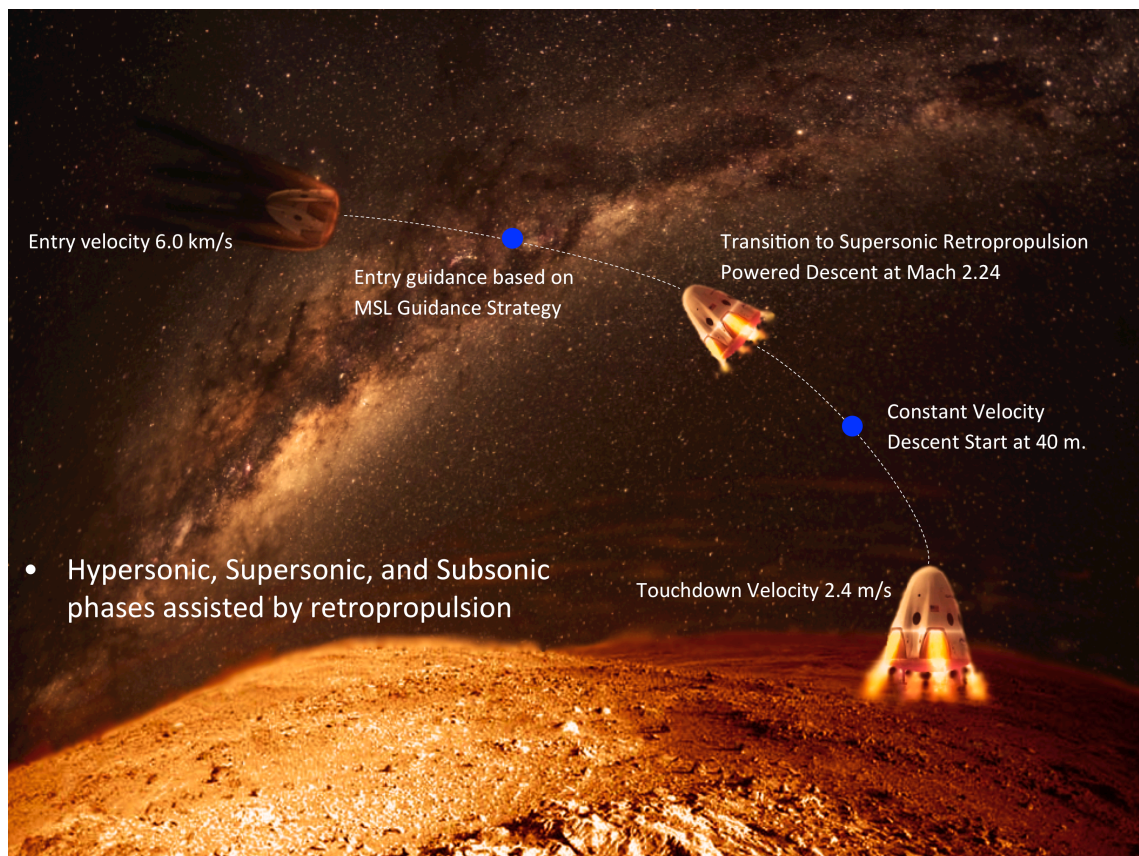


Fig. 6: Red Dragon-MSL Hybrid landing architecture. Credit [10]

Launcher	Organization	Country	LEO payload Kg	GEO payload Kg	translunarpld Kg	Notes
SLS	NASA	USA	70/130000	30/70000	18/30000	under development
Falcon Heavy	Space X	USA	53000	21200	13200 Mars	1000\$/Kg under development
Zenit	YDB	Ukraine	13700	5200	-	3667\$/Kg
Ariane	Arianespace	EU	16000	10500	-	available
Atlas V	Boeing	USA	29000	13000	-	available
Heavy Delta	Lockheed	USA	27600	13000	-	available

Fig. 7: Capability of potential launchers.



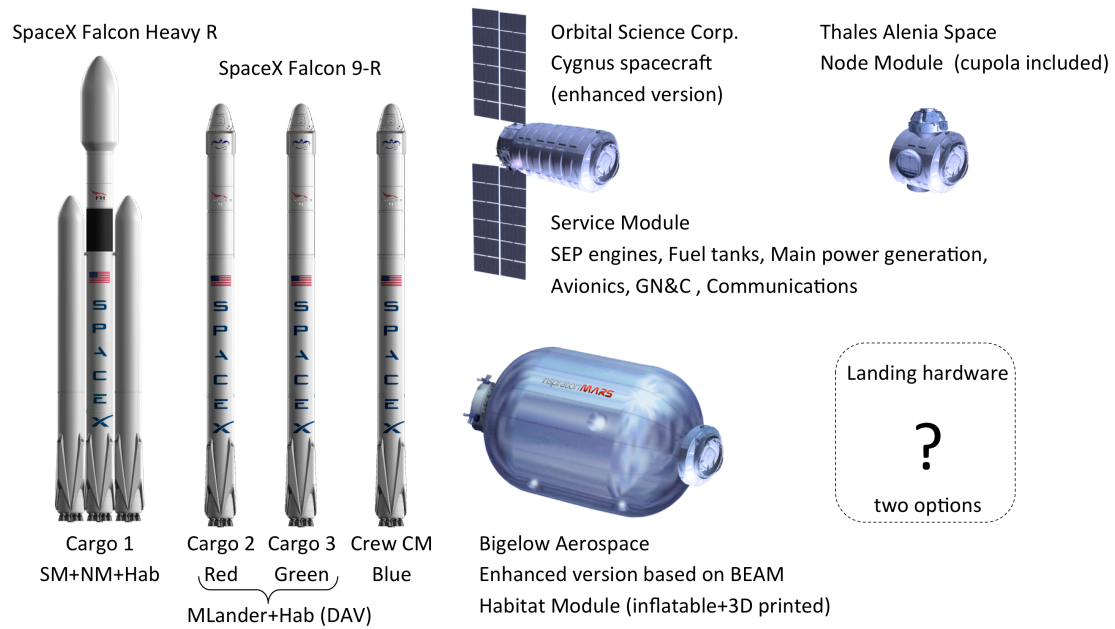


Fig. 8: Hardware selected.

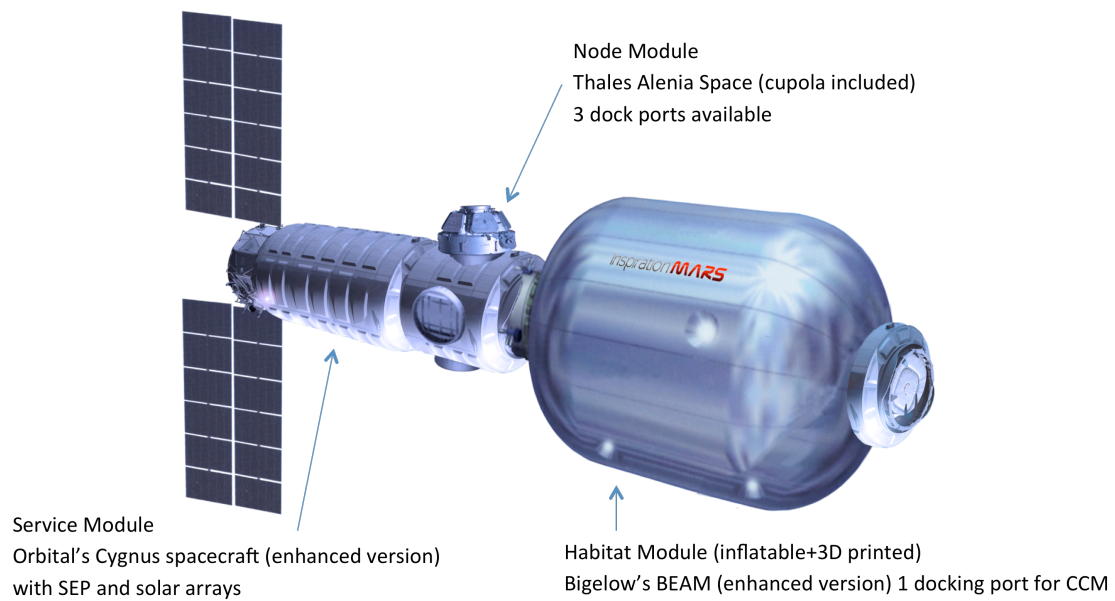


Fig. 9: Preliminary spacecraft design.

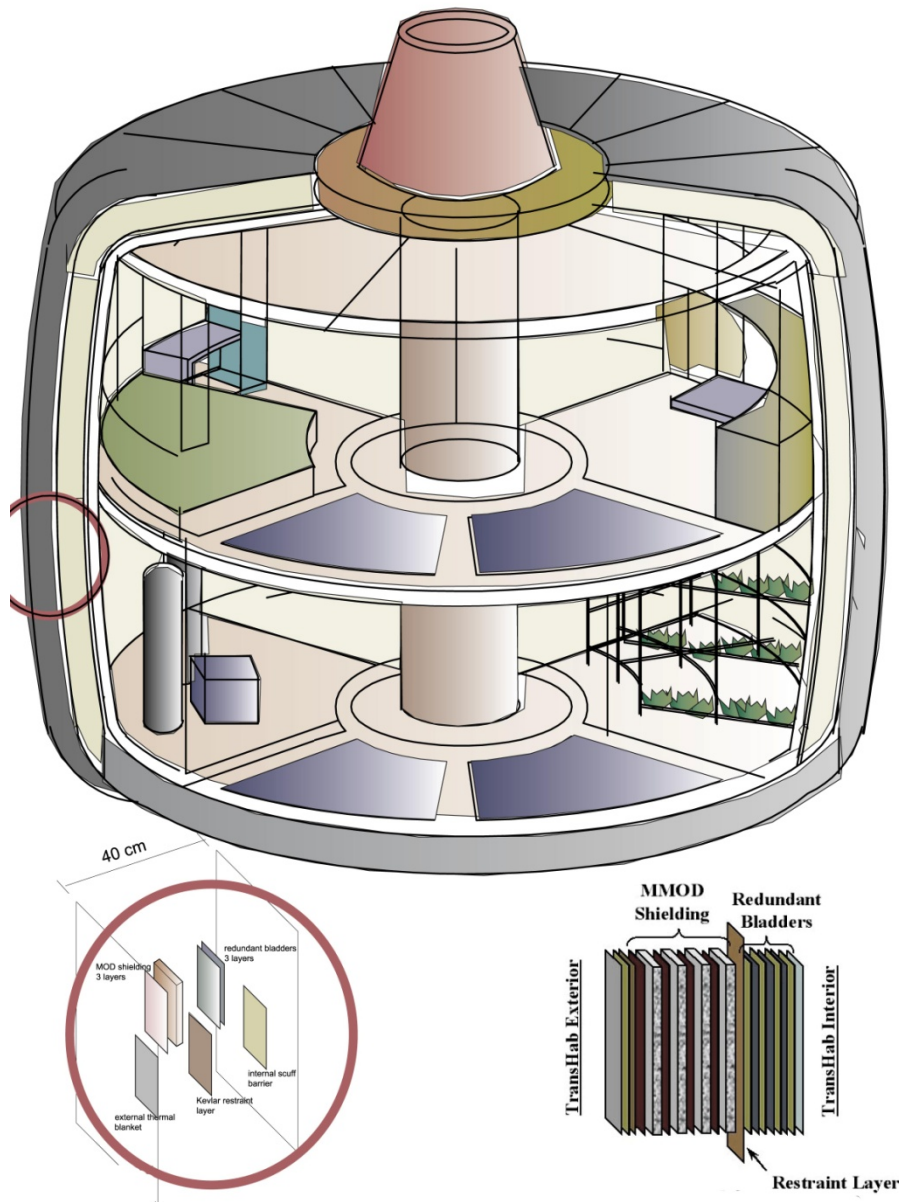


Fig. 10: Orbital Hab.

Component	Mass* kg
1-Air (high press storage, mole sieve, Sabatier, electrolysis)	448,50
2-Water (tanks, multi-filtration, ion exchange, distil, catalytic oxidation)	1117,50
3-Food (dry packed, storage, water heater)	692,00
4-Thermal (nominal redundant single loop)	239,50
5-Waste (urine, feces, and vomitus collection, and solid waste stabilization/storage)	129,50
6-Human Accommodations (clothing, hygiene, medical provisions, radiation shelter, etc.)	173,50
<b>Basic System (3+4+5+6):</b>	1234,50
<b>Consumables (1+2):</b>	1566,00
<b>Total estimates per person:</b>	<b>2800,50</b>

Fig. 11: ECLSS Master Equipment List



Fig. 12: View over Ophir Chasma, a region near Valles Marineris. Credit Ludovic Celle.

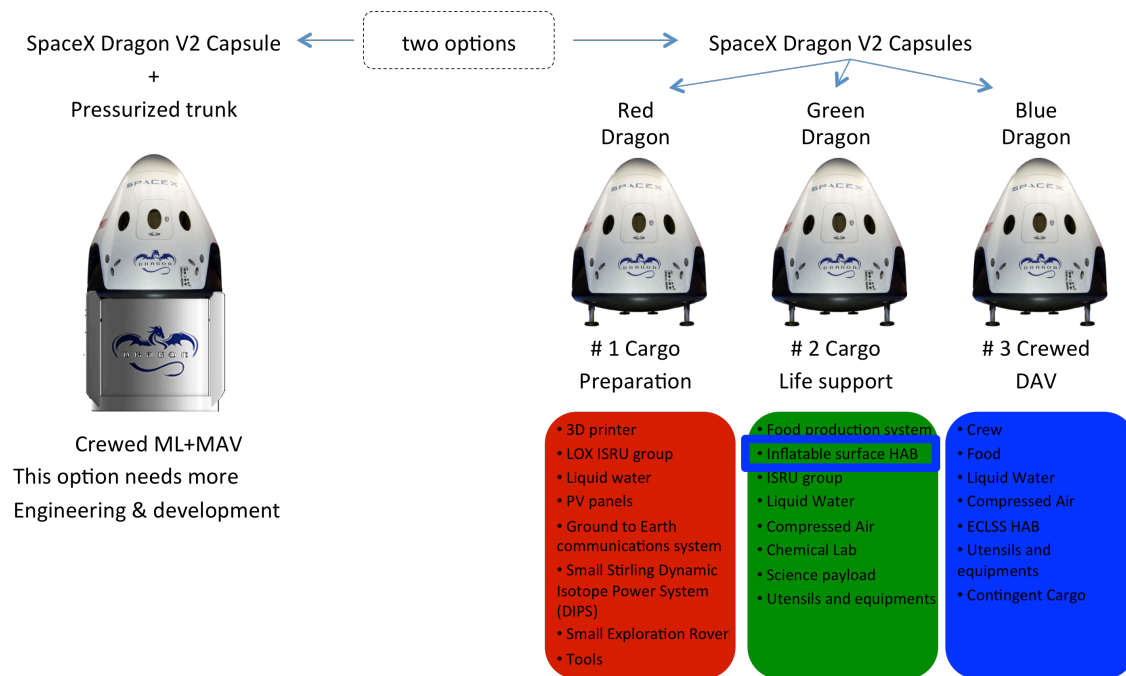


Fig. 13: Landing hardware alternatives.

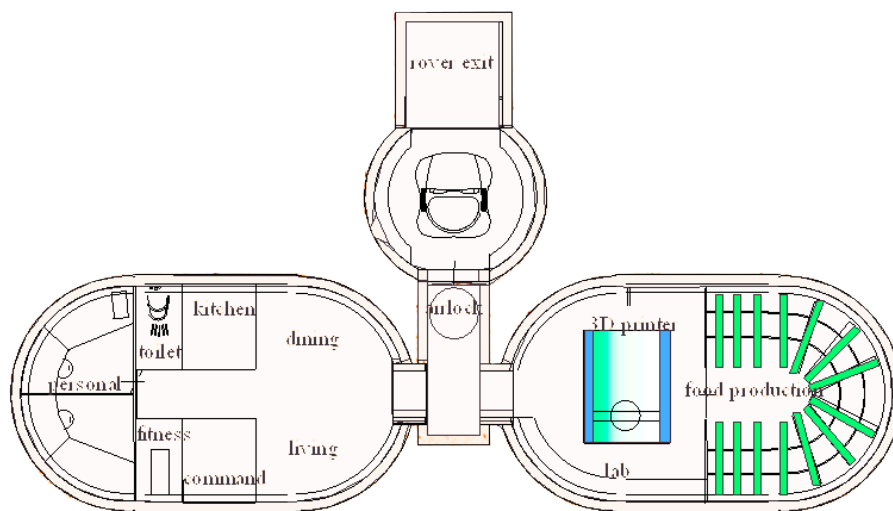


Fig. 14: Outpost Layout.



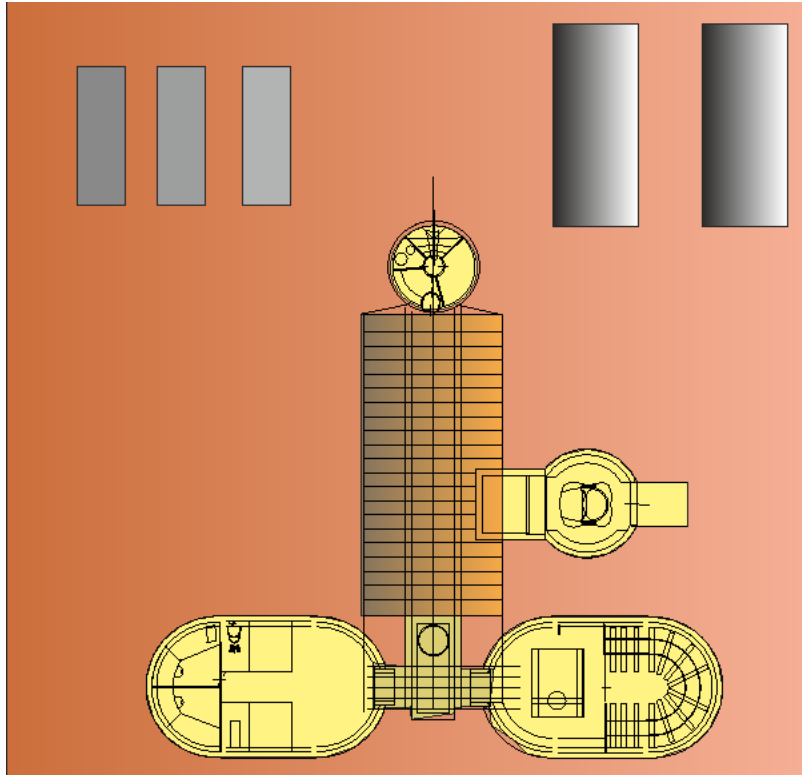


Fig. 15: Outpost (extended version) Layout.

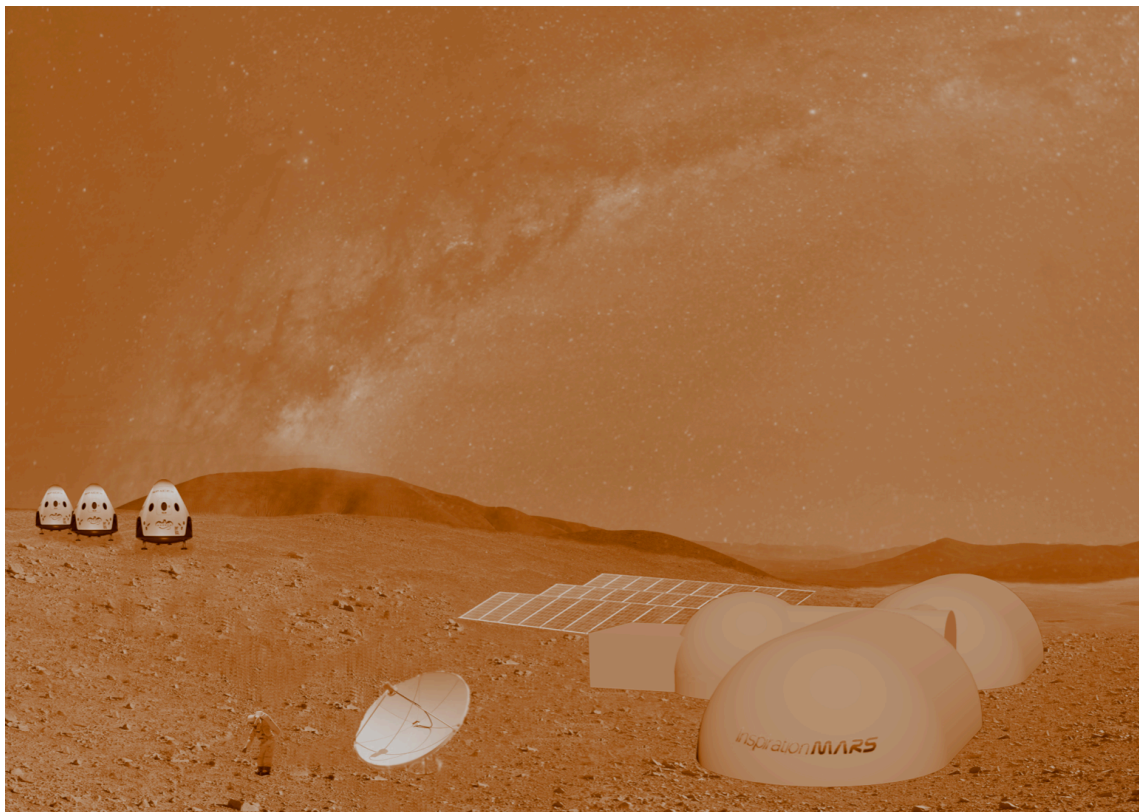


Fig. 16: Outpost rendering.

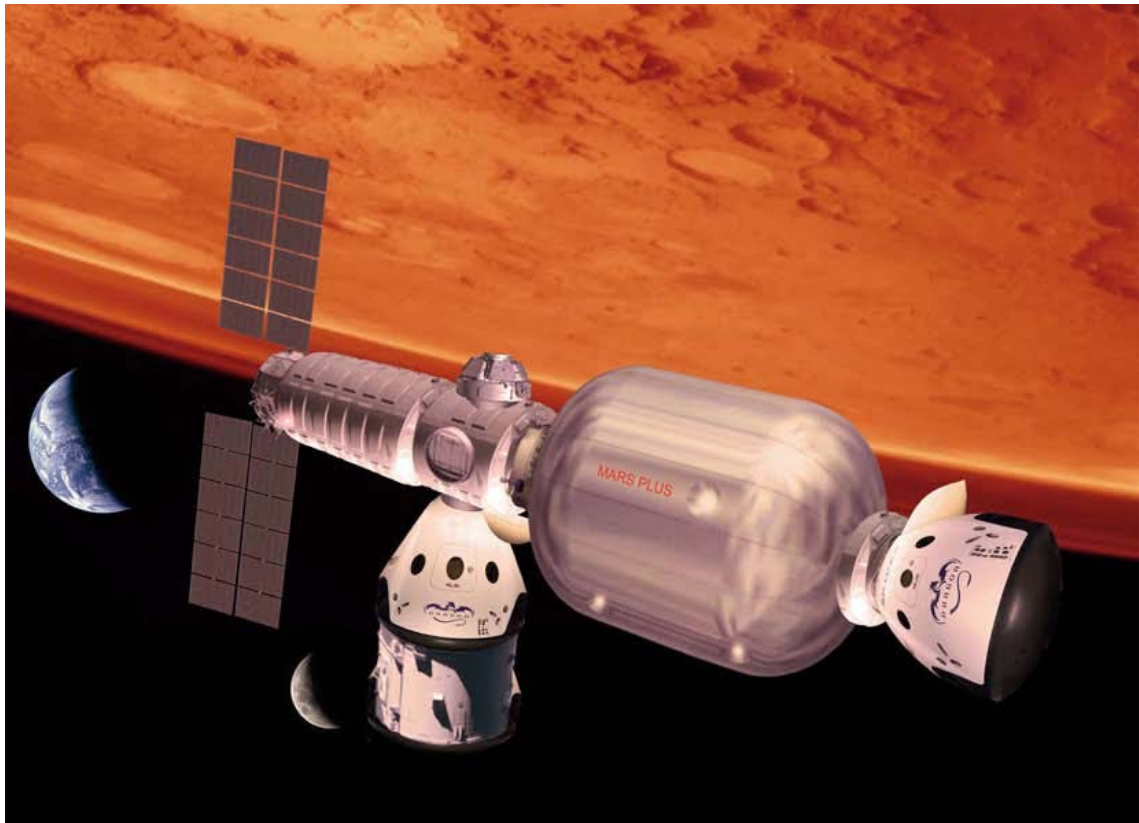


Fig. 17: Rendering of Mars Plus Spacecraft on preliminary concept mission.

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