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A Multipurpose Mars Vehicle for Payload Delivery and Surface Operations

Thomas A. Hockenberry
Sasakawa International Center for Space Architecture - University of Houston, United States of America
Email: THockenberry1@gmail.com

Abstract

The research that went into this paper was the result of a yearlong collaboration between SICSA and Boeing into the design of a multifunctional Mars lander. The starting point of this project was to design a lander that is capable of delivering both human assets and separate supply caches to the surface of Mars. The paper presents research and analysis of project elements that included delivery of payloads to Low Mars Orbit (LMO), descent to the Mars surface and ascent back to the transfer vehicle. The study explored mission architecture options including delivering of crew and cargo payloads to the surface, the allocation of those payloads on the surface, and their individual missions before, during, and after the astronauts' arrival. The Boeing-SICSA collaboration resulted in a mission architecture that utilized the most well suited variables optimizing mission safety, efficiency and success. Key elements of this mission architecture are:

- 24-7 communication capabilities with a transfer vehicle in LMO;
- Power beaming from an orbiting satellite;
- Three strategically arranged supply assets that are delivered before the crew arrives.

This research resulted in a lander design that strayed from the tradition of past mission architectures and looked at a lander that can be optimized to satisfy every aspect of the mission. This design approach offers several benefits: the lander design uses three legs support instead of four providing better stability on an uneven surface, a centralized payload capability that allows for multiple shroud diameters, and the lander triples its functional uses as the ascent vehicle and rover. Adding roving capabilities allows crew to utilize the lander throughout the mission duration, giving the crew an anytime abort capability. This new era lander is derived from the successes and failures of incorporating various mission elements that allow for a lander that utilizes a more flexible design to achieve a high percentage of mission success.

I. INTRODUCTION

The hopes of one day visiting Mars is an accomplishment and feat that humans have searched long and hard for. Sufficient technology and mission planning is vital to achieving this goal. This paper will explore some of these elements and present them for discussion and debate, in hopes of allowing the space community to move closer towards walking on Mars. These necessary elements include:

- Prepositioning of Supply Caches
- Near Mars Orbit Staging
- Surface Concept of Operations
- A Multipurpose Payload Delivery Vehicle

For each of these topics there are underlying themes of flexibility, in order to achieve a high percentage for mission success.

II. BACKGROUND

The footprints of this design lay with the collaboration between the Sasakawa International Center for Space Architecture (SICSA), within the College of Architecture at the University of Houston and members of Boeing. For the duration of two college semesters, the two groups have discussed, debated, and designed crucial elements of a Mars mission architecture. The product of which is a cumulative mission scenario that is presented in this paper and showcases many key elements of that collaboration.

III. THE MISSION

The crew consists of four members: three will make the trip to the Martian surface, while the fourth remains in orbit to relay valuable information to the surface crew. The mission time will provide for a 1000 day trip starting when the crew sets out from an undetermined Lagrangian point in near earth orbit. Using a Variable Specific Impulse Magneto Plasma Rocket or VASIMR type engine, the mission will gradually spiral outward away from the gravitational pull of the Earth. The crew will arrive at Mars after enduring a 200 day interplanetary transfer period between Earth and Mars. With a 400 day total transfer time, the crew is allowed a 600 day surface stay to coincide with the interplanetary transfer window between Earth and Mars. The required orbital elements that will be in position before the crew makes their way to the surface include:

- Interplanetary Transfer Vehicle
- Command Control Module
- Crew Transfer Vehicle
- Three Orbiting Communication Satellites

The crew will make the trip to Mars orbit via the Interplanetary Transfer Vehicle and will gradually use this ship to come into a highly elliptical parking orbit with Mars. The Interplanetary Transfer Vehicle will remain parked in this orbit for the duration of the time in Mars until the crew returns and the ship takes them and the valuable cargo back to Earth.

Once parked in an elliptical orbit the crew will use the Command Control Module and launch themselves towards low Mars orbit. Using several passes to bounce off the Martian atmosphere, the ship will break into a synchronized low mars orbit over the surface operations site. This vehicle will remain occupied throughout the duration of the surface stay and is responsible for several key elements for the success of the surface operations mission.

The command control module will provide continuous communication support with the orbiting satellites. In the event of an unforeseen danger, the module can provide real time support in these instances. If a threat or emergency becomes imminent, the module will allow the crew to abort at any time and find sanctuary in low mars orbit. At the end of the mission, the Command Control Module will ferry the crew back to the Interplanetary Transfer Vehicle. The Command Control Orbiter will have a direct uplink to Earth at all time (with a standardized time delay) with the help of the Three Orbiting Communication Satellites, which will be prepositioned before the crew arrives.

IV. Multipurpose Mars Payload Delivery Vehicle

The primary focus of the Multipurpose Lander design is to deliver a separate crew and supporting cargo payloads to the surface of Mars. The crew and cargo are delivered in two separate lander missions to help distribute the weight of all the required logistics. Both crew and cargo missions will use the same Multipurpose Lander design while delivering different sized payloads to the surface. In order to determine the most appropriate design for the Multipurpose Lander, we looked at the roles and responsibilities each lander is required to perform during the course of the two occupations.

Cargo Delivery

Before the crew embarks on their journey, the cargo mission will have delivered its payload to the surface of Mars. In achieving the highest percentage for mission success, we will be able to verify that the supporting logistics have safely arrived and are intact before the crew mission is sent on their journey. To take advantage of the Multipurpose Payload Vehicle's flexibility and ability to be mass produced, we are able to split up the one large cargo delivery into three separate landers. The three landers are tasked with identical cargo deliveries that will utilize identical lander designs. This advantage will allow us to disperse the risk of losing the cargo mission in one failed attempt and disperse the risk into three separate descent missions. It also provides three times the chance to complete at least a third of a mission success, rather than a total mission failure. If one or two of the cargo landers is compromised, the added flexibility will allow the crew to retain the ability to visit the surface of Mars and utilize the time remaining. However, the highest percentage for mission success is to successfully land all cargo landers. This scenario gives the mission enough flexibility to achieve the desired outcome.

Surface Operations

The time on the surface is the most crucial and sensitive aspect of the mission. The surface operations are planned for maximum 600 day stay and for this reason, we will allow the assets that we have prepositioned to perform the bulk of the preliminary investigative research, while the crew is in transit. In this mission architecture the crew will have ample data and research on which areas of the surface require the most attention before they arrive.

In contrast to compiling the logistics in one location and researching a single location for the remainder of the surface stay, the split deliveries will allow the mission to broaden the range of research. The three cargo deliveries will land with equal distances between all three. The distance between cargos is determined by the range to which the crew can safely travel between each, given the amount of designated life support capabilities allocated to the crew surface rover. The placement will create an equilateral triangle between the cargo landers allowing the crew to broaden the landing site by the distance allowed to travel between cargo supplies.

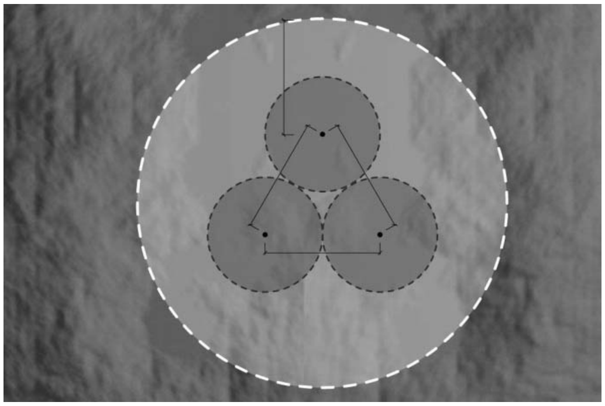

Fig. 1: Surface Operations- A diagram representing the site of each supply cache and the distance from the crew landing site.

To achieve the desired research, multiple reconnaissance probes and robotics arrive with each of the cargo landers. After safely on the surface, these elements will detach and research areas within a reasonable distance of the supply cache.

Each of these prepositioned research and logistics stations are referred to as supply caches. These supply caches will create waypoints for the surface crew to visit. While at each waypoint, the crew will live out of the supply cache using the consumables and life support logistics provided while conducting further research. Once the supplies at each cache have been used, the crew will move on to the next until all of the consumables in each cache are depleted. After the consumables in each cache are used up, the crew will return to the Command Control Module in low Mars orbit. This mission architecture shows how a Multipurpose Payload Lander provides for flexibility in order to achieve a high percentage for mission success.

Lander Design

To properly design a Multipurpose Lander, we have to consider what is required of landers in their individual occupations. The crew and the cargo landers will use the same design and each will incorporate designed flexibility. The common elements will remain the same across both platforms and have the capabilities of conforming to each lander's unique use. This will allow the addition of elements that will exist on one lander, while having no place on the other. With this sense of flexibility in mind, we start with the design criterion that has been laid out. The elements included are common to each lander and work towards items that present themselves unique to the individual occupation. The elements that will be considered common to each mission's architecture will include:

- Common Payload Bay
- The Frame
- Descent Tanks and Engines

Listed above are three key elements to any typical payload delivery vehicle. The difference is designing these elements to fit a generic mold and allow them to be used in any mission architecture.

Common Payload Bay

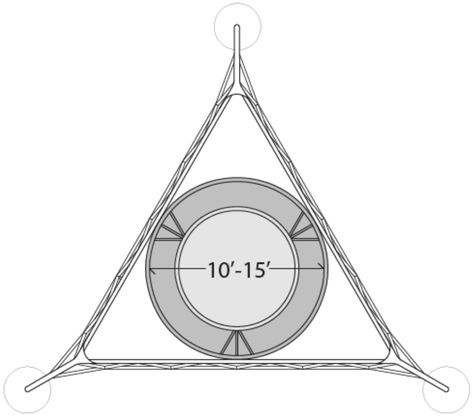

Fig. 2: Payload Bay- Plain view of the lander showing the different payload capacities.

For a generic payload delivery vehicle, the payload is unknown, but we can allow ourselves to place certain dimensional restraints on the size of the payload shroud. Taking an inside out approach we allow the payload to become the dominant factor in the lander design and configure a design that fits the payload rather than designing the payload to fit the lander's capabilities.

For each payload there is a shroud that protects cargo. The logistics may take different forms and capacities but the shrouds of each will have commonality. This allows for standardized physical constant to attach to the lander giving us a starting point for the design of our Multipurpose Payload Delivery Vehicle.

The lander will have the capabilities to incorporate the most common payload diameter of today. The payload diameter is limited by the current rocket technology to lift the payload into low earth orbit. The common payload dimension today is roughly 14 feet or 4.27 meters in diameter. This is taken from the generic module size aboard the International Space Station. With the rapidly changing society, the need to send more and land more is very important. A payload diameter with a greater range of capabilities will insure the lander's design use on future mars missions. Allowing the lander to incorporate a range of payload diameters instead of constraining the payload to fit one, will give this lander design added flexibility. For this reason, the lander will have the capabilities to land payload shrouds of multiple diameters ranging from 4.5 to 6.1 meters. The base lander is designed around the largest diameter and incorporates additional structural attachments to secure the smaller diameter payloads.

The Frame

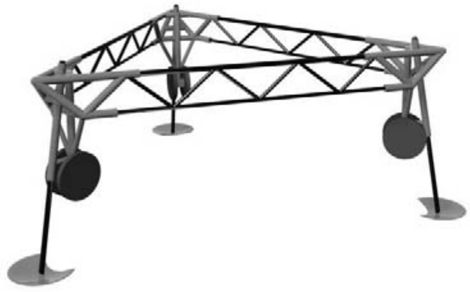

Fig. 3: Lander Frame- with optional rover capabilities.

With the ideas of simplicity and minimalism incorporated into the frame, this gives the lander more flexibility allowing the frame to adapt to more payload capabilities. The frame is the substructure of the lander and takes up the least amount of weight, while allowing the capability to attach external allowances.

The size of the frame is determined by the maximum payload allowance of 6.1 meters. The payload is located in the center of the lander, allowing the lander to have a centralized mass load for easier maneuverability and control. The frame incorporates three horizontal trusses, creating a triangular shape around the payload. The trusses are tasked to withstand lateral forces associated with supporting the cargo payloads mass once it is on the surface. The trusses attach to each other at the three vertices of the triangle to allow for a more structural frame than the traditional square lander. The triangular design of this lander will resist the tearing and shearing effects through the descent and ascent stages of the mission. Along the circumference of the payload bay, we incorporated additional structural elements to keep the three side of the frame in tension.

During the design process for this lander, we look at three and four-legged lander deigns. The comparisons between the two yield a better result with the three-legged lander design for a few different reasons. Having a three-legged lander means the shape of the lander will need to be a triangle. The triangle has been shown to structurally be one of the most efficient and stable shapes in nature. With three legs we give ourselves a more stable lander on the surface. With a four-legged lander on an uneven surface we experience the same teetering effect that we see in uneven table legs. With three legs we allow ourselves the ability to give the lander three points of contact with the uneven surface so that no one leg is ever out of contact. Requiring one less leg cuts down on the overall structural support and hardware needed for the extra leg, which will give us an added mass advantage. When we examined the frame diameter of each design, we found that the overall diameter of a frame with four legs was less than one with three. But this type of frame allowed for less functional space to incorporate the remaining lander logistics. This required those elements placed on the exterior of the lander frame and increased the diameter greater than the lander with three legs. Adding these elements internally to the four-legged lander reduced the center of mass. Whereas the lander with three legs, we are able to place the same elements closer to the center of mass.

Each of the three legs of the lander will be place at each vertices of the frame. The legs will provide the lander with increased elevation on the surface and will allow for additional functions to be placed beneath the lander. At full length, these legs will give the lander an elevation of 14.5 feet (4.4 meters) above the surface and ground clearance of 3 feet (0.9 meters). This elevation gives the crew room to by-pass larger obstacles that might give landers with lower elevations greater difficulty. To give the lander a more compact presence in the aero shell during delivery, the legs retract during descent and then telescope down to the surface just before landing.

The triangular shape of the frame will give the lander more structure and stability. This design will allow the various elements of the lander to naturally incorporate into and around the frame design. These element placements will allow the lander to have a centralized mass load between the payload, the engines, and descent tanks.

Descent Tanks and Engines

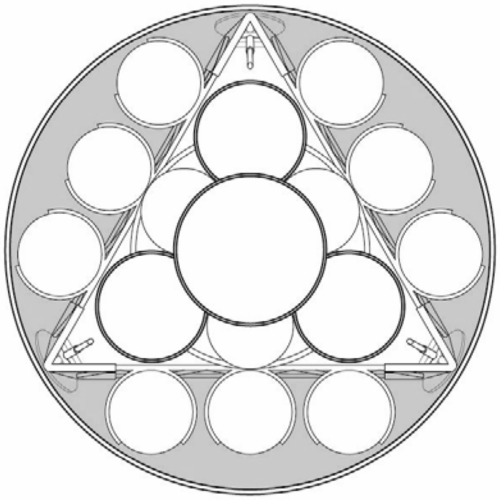

Fig. 4: Descent Tanks- The frame accommodates for descent tanks around the exterior of the frame to utilize the vacant space in the aero shell shroud

The descent engines are located on the underside of the frame in the vacant space between the centralized payload bay and the vertices created by the frame. Using three engines will allow for more control over the lander during the burn stages. Each of the three engines has its own allocation of three fuel tanks feeding them during this burn stage of descent. The fuel tanks attach to the exterior of the three frame trusses. Allowing the tanks to be placed on the exterior of the frame will utilize the vacated space between the frame and the diameter of the aero shell transport shroud.

Lander Applications

With the basic lander design laid out, we see how it may incorporate itself into the different payloads that it will deliver to the surface. For this collaboration, we require two different payload deliveries to the surface. The cargo deliveries will carry with them the supporting consumables and logistics for the time on the surface. The second payload will deliver the manned mission to the surface and incorporate the anytime abort capabilities and an ascent stage designed to fit the base lander design.

Cargo Lander

Fig. 5: Cargo Lander

As discussed, the mission will include delivery of three supporting supply caches to the surface, each will use the same base lander and payload designs. For this payload, the base lander design will not need any additional supporting elements. The payload shroud size will include the maximum 6.1 meters in diameter and will incorporate an air lock beneath the centralized payload for easier access to the surface. During each caches occupation, the crew will live out of the cache module, so an inflatable habitat is incorporated into the design. After the crew has spent that cache's consumables they move onto the next cache.

Crew Lander

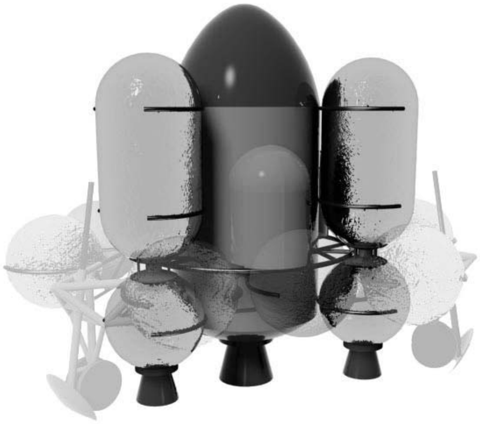

Fig. 6: Crew Lander

The crew vehicle will provide the main source of transportation for the three person crew before, during, and after the surface operations. The crew vehicle will require additional elements attached to the lander to allow for these capabilities. Allowing the lander to have the flexibility to incorporate additional elements for different missions will ensure the landers flexibility to continue its life through future missions. Additional elements that are required to complete the manned mission include:

- Pressurized Crew Transfer Vehicle
- Roving Capabilities
- Ascent Tanks and Engine

The payload shroud for the crew lander is a 6.1 meter diameter crew transfer vehicle. Incorporated into the crew vehicle is a pressurized crew cabin that will sustain the crew during decent, ascent, and transfer stages between waypoints. To venture outside of the crew vehicle, the crew will utilize three suit ports positioned in the space gained by the thinner payload diameter.

The manned crew will use this vehicle as their main source of transportation and allow the crew to carry with them the ascent vehicle throughout the surface mission. Incorporating roving capabilities in the manned lander will allow for the highest percentage for mission success and give the crew a much desired anytime abort capability.

The rover wheels are attached to each leg of the lander and retract during the descent stage for a more compact profile while in the aero shell shroud. Once the crew vehicle is safely rested on the surface, the rover will telescope to the surface and transfer the load from the lander legs to the wheels.

For ascent capabilities, the crew lander incorporates additional ascent tanks. The tanks are placed in three vertical stacks placed atop the three existing engines. The addition of these tank stacks will allow the crew vehicle to take off from the surface of Mars and reconnect with the Command Control Module.

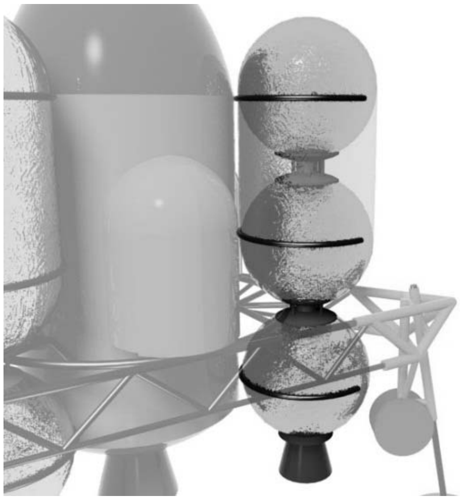

Fig. 7: Ascent Tanks –Showing the ascent tank stack as incorporated with the existing descent engines.

Once the crew has visited all the caches and used up their time allowance window, or in the case of an emergency abort scenario, the crew will use the crew vehicle to ascend back into low Mars orbit. The ascent is a multiple stage ascent, where the crew will lift off into the crew vehicle leaving the frame of the lander on the surface. After the fuel in the three fuel stacks are depleted, they are jettisoned and the remainder of the trip is carried out by a centralized engine and fuel cache added to the Pressurized Crew Transfer Vehicle.

V. CONCLUSION

During the SICSA and Boeing collaboration, we demonstrated how a Multipurpose Delivery Vehicle will one day allow a single lander design to incorporate itself into several unique occupations. Whether it is full success or partial success, the flexibility of this concept of operations and lander design provides the crew with several options to achieve the highest percentage for mission success.

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