

Mars Direct 3: A Safe, Resilient and Cost-Effective Architecture for the first Crewed Mars Mission

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ABSTRACT

Thanks to the current revolution in the space sector, led by SpaceX, a human Mars mission seems once again within reach. There is will, there are resources and there will soon be technology to allow such an endeavor. Now, there is need for a detailed plan for a SpaceX (or otherwise) crewed Mars mission architecture.

Mars Direct 3 offers a modular approach to solving the many challenges such a mission presents. This includes the development of a new Mars lander -based on SpaceX's Starship vehicle- to serve as the crewed ship, while keeping the Starship as a cargo ship, though a Starship-only approach is also considered.

This mission accounts for four vehicles launched to the surface of Mars within the timeframe of two launch windows, one of them with a crew of 6 astronauts set to stay on Mars for one and a half years and depart to Earth with locally produced fuel.

With safety being the primary goal, the plan is built with a number of back-ups and contingency plans to account for the failed landing of three of the four ships, month-long global dust storms, crash landings, failed ISRU and other incidents that may occur, while still returning astronauts safely to the Earth.

This paper intends to prove the remarkable safety and logistics benefits of the Mars Direct 3 approach using both the Starship vehicle (or an equivalent) and a smaller lander for such a mission.

As a modular approach, Mars Direct 3 offers a number of ideas and contingencies which may be used separately as part of other architectures, while also providing a unified architecture.

All proposed vehicles and technologies -spacecraft, rovers, machinery etc.- are explained. Design, development and testing for these are needed, but no significant new technologies are required. The plan is built around methalox fuel for propulsion and solar panel technology for energy collection, though small-scale surface nuclear fission reactors are also considered.

This paper will also discuss a lunar version of this architecture, which offers significant commonalities.

1- INTRODUCTION: HERITAGE, GOALS AND MOTIVATIONS

Ever since the Apollo lunar landings, a human mission to Mars has been part of the collective imagination. Unfortunately, it has rarely been anything else.

With space programs focusing on Low Earth Orbit, there has been an astonishing lack of in-depth Mars mission architectures being seriously considered.

To be viable, a Mars mission architecture needs to be simple, sufficiently detailed, affordable and safe. All while staying within the reach of current technology. So far, of the plans that have been seriously considered, only the original Mars Direct architecture -conceived by Robert M. Zubrin, David A. Baker and Owen Gwynne in the 1990s- has fulfilled all of the above. (Zubrin et al., 1991)

More than 30 years have passed since the publication of Mars Direct. Since then, a new era of space industry has started. Inspired by Mars Direct and the vision of Mars colonization, SpaceX is leading a revolution in the space sector, with partially and soon fully reusable rockets lowering costs of payload to orbit and super heavy launch vehicles once again opening the possibility of ambitious crewed missions beyond Low Earth Orbit.

Crucial discoveries have also been made by robotic missions, such as the confirmation of large deposits of water ice beneath the surface of Mars in mid latitudes.

As of the writing of this paper, SpaceX is preparing for the first orbital mission of their Starship system, which they intend to use for their Mars missions.

However, they have not publicly disclosed a detailed architecture for such mission, and have stated that their focus is on the development of the vehicle.

Their outlined plan is to launch Starships to the surface of Mars with on-orbit refueling, deploy large amounts of solar panels on the surface, extract ice from the Martian underground, use it to produce methalox fuel and go back to Earth.

In 2019, Dr. Robert Zubrin presented Mars Direct 2, a modification of SpaceX's plan suggesting the use of the Starship system as a heavy launch vehicle to launch a different -smaller- vehicle to Low Earth Orbit or a highly elliptical orbit nearing Earth escape. This smaller ship would finish the trans-Mars injection and land there.

This high orbit alternative would require on-orbit refueling and would still allow the smaller vehicle to deliver a significant payload to the surface of Mars. (Zubrin, 2019)

The main reason for this change is to reduce the amount of power required to create the fuel needed for the return to Earth. The proposed "Mini-Starship" would require around a factor of five less fuel while delivering, in the elliptical orbit configuration, around a third of the cargo.

There are, however, three main concerns on these architectures that Mars Direct 3 attempts to address:

1.1- Concern 1: Reliance on water extraction and processing to produce the fuel for the return trip

The extraction and processing of large amounts of water from the Martian soil may seem like a manageable task. Large deposits have been found and the chemical processes (water electrolysis, carbon dioxide electrolysis and the Sabatier reaction) are well-known. Nevertheless, there are a number of risks associated with these operations.

- The machinery may have been damaged on the trip from Earth to Mars.
- Ice may be found to be inaccessible or scarce on site.
- Major damage caused by human error may not be recoverable.
- Soil contaminants in the water may damage the machinery if not filtered correctly.

These issues may appear at any point during the 400 days these operations would take to process hundreds of tons of water. And, however unlikely they may be, they would prevent a return to Earth.

1.2- Concern 2: Large energy requirement

Assumptions based on information disclosed by SpaceX:

- Only solar energy is used.
- Fuel is produced with ISRU using underground water ice and atmospheric carbon dioxide.
- The cargo bay of Starship is approximately 650 cubic meters in volume.

Pioneer Astronautics demonstrated a reactor capable of producing 1 Kg a day of methalox fuel from hydrogen and carbon dioxide while consuming a power of 700W. For 710 tons in 400 days that is 1.89 MW. (Zubrin et al., 2013)

Assuming 400 days to produce the 710 tons of fuel needed, 352 tons of water (for electrolysis) and 1.89 MW of power would be needed. Using the methods and assumptions detailed in section 4.3 (including a 20% margin for safety), the solar infrastructure would be:

- 229.2 tons in mass.
- 3437.4 cubic meters in volume.
- 57290.1 square meters in area.

The deployment would require 5 to 6 Starships (volume constrained) and significant deployment operations and maintenance. Power remains one of the most significant challenges of a Mars mission architecture that accounts for the return of the astronauts. As with issue 1, failure in this area would result in loss of crew.

Mars Direct 2.0 significantly reduces this requirement.

1.3- Concern 3: Lack of detail

SpaceX's focus is currently on the development of the Starship system. Only the fundamentals of a Mars mission have been publicly disclosed.

This is not necessarily bad, -hardware development is crucial-, but is insufficient.

A number of companies and organizations are working on different technologies regarding Mars missions. From spacecraft to rover concepts, agroponics, base simulators and colony concept designs.

But this is far from a coordinated approach. Apart from Starship, no technologies or hardware are being developed for any specific mission profile.

Whether rovers will be needed or not, pressurized or not are relevant questions regarding the development of hardware. The same applies to a hub, agroponics, possible use of hydrogen (as proposed in the original Mars Direct), how long the transfers between planets would be, oxygen supply, number of ships per mission, cargo delivered, etc.

1.4- Safety as the primary goal

Death is certainly a possibility in a mission to Mars. And even though Astronauts are elite professionals who are willing to risk their lives for a bigger cause, the loss of the crew could result in the cancellation of the entire program. This risk is aggravated if the program is funded by the government, as this funding would be dependent on public support.

A human mission to Mars would be the most important event of the moment. Billions of people, including children, would watch as their heroes and hopes quickly or slowly perish. A total failure would result in the death of the crew and do great harm to public morale. This disaster must be avoided.

For that reason, Mars Direct 3 is built with safety at its core, with a set of contingency plans that would ensure the survival of the crew in almost every conceivable event. The crew would survive the failure of water extraction, the crash landing or failure of operation of every single cargo ship, landing far from the intended area, a month-long global dust storm with only solar power and limited batteries and even a non-lethal crash landing of the crewed ship that would render it inoperable.

All of this with only 4 ships landing on the surface of Mars and no significant new technologies needed, ensuring an affordable price. This mission profile is also designed to facilitate future missions and the creation and expansion of a colony.

2- VEHICLES AND HARDWARE FOR THE MARS DIRECT 3 ARCHITECTURE

2.1- Starship and the Caravel Mars Lander

As in the case of the second, the third iteration of Mars Direct makes use of the Starship vehicle in its cargo configuration in order to launch a smaller Mars lander to Earth Orbit.

But one of the key differences of Mars Direct 3 is the use of Starship as a cargo ship to the Martian surface as well.

These Starships would not be pressurized or return to Earth. The combination of a bigger cargo ship and a smaller crewed vehicle is a key innovation for solving the problems described in section 1 of this paper. This is the *Big Ship-Small Ship* strategy.

The mission profile for cargo Starships landing on Mars would be that described by SpaceX. A Starship is launched to Low Earth Orbit by a Super Heavy rocket and then refueled by 5-8 Starship tankers (depending on the final cargo capacity of Starship). Once fueled, it performs a trans-Mars injection and finally lands on Mars 6-8 months later using a heat shield and propulsive landing. The final capabilities of the Starship are yet to be determined, but hardware and estimates are reliable enough to make decent projections.

The Caravel Mars Lander (previously referred to as Mini-Starship) is a scaled down version of Starship, using the same materials, engines, propellants and heat shield tiles to minimize development cost. This crew rated vehicle would be launched to orbit by a cargo version of Starship.

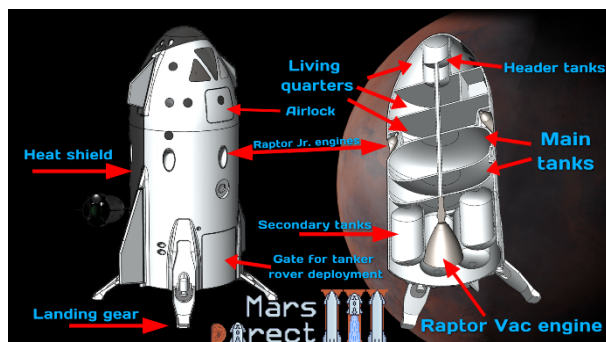
The size, mass and design of the Caravel are subject to change. The preliminary design is for visual purposes.

SpaceX has stated that Starship will be able to carry 100 to 150 tons of payload to Low Earth Orbit and to the Martian surface (with the required orbit refueling). A cargo capacity of 125 tons will be considered onwards.

All calculations will be done with these numbers. For uncertain values, conservative estimates will be made.

	Starship	Caravel
Dry mass	120 tons	32 tons
Fuel capacity	Liquid Oxygen: 858 tons Liquid Methane: 242 tons Total: 1100 tons	Liquid Oxygen: 140,4 tons Liquid Methane: 39,6 tons Total: 180 tons
Size	Height: 50 meters Radius: 9 meters Habitable: ~650m ³	Height: 16 meters Radius: 6.4 meters Habitable: ~170m ³
Tons to Mars	125 tons	26,5 tons
N° of Engines	Raptor Atm: 3 Raptor Vac: 6	Raptor Vac: 1 Raptor Jr: 6*
Specific Impulse	378 seconds (Musk, 2021b)	378 seconds (Musk, 2021b)

*The Raptor Jr. engine will be explained in section 2.4



The Caravel ship will have 3 sections. The habitable quarters, the main fuel tank area and the engine area - around which will be additional smaller tanks for extra fuel-, an unpressurized cargo section and a tanker rover.

2.2- Tanker Rover (fuel)

With a dry mass of up to 3 tons, the goal of this unpressurized electric rover is to transport liquid methane and oxygen between ships. For that purpose, it would be equipped with wires and fuel pipes that astronauts can manually connect to the ships.

The rover would consist of a wheeled platform containing a battery and one of the smaller lower fuel tanks of the caravel, which are detachable and could serve as replacement. The rover would be charged by manual plugging to a ship or solar panel grid. It would be equipped with redundant fuel cells to produce power from the liquid methane and oxygen contained in the tanks.

Given the similarity in the temperature conditions that liquid oxygen and liquid methane require, both can be stored in the same tank (one at a time). This rover fits and is transported on the lower cargo bay of the Caravel ship, next to the main engine, and lowered to the ground via a crane. The rover can be radio controlled by astronauts.

2.3- Tanker Rover (water)

The same as 2.2, but instead of cryogenic fuel, it would transport water extracted from the Martian ice. As will be discussed later, failure would not result in loss of crew.

2.4- Raptor Junior

Even with only one Raptor engine throttled down to 40%, a Caravel landing on Mars would still have a thrust to weight ratio of 4.1, resulting in a high G force suicide burn for landing. There is also founded debate around the risk of excavating a hole in the soil when landing with such a powerful engine firing so close to the ground.

A solution to this is already present in the designs of the lunar Starship concept in the form of smaller, less powerful engines situated higher in the structure of the ship that are used for the landing, though the nature of these engines planned by SpaceX has not yet been disclosed. This approach would be necessary for Starship-like vehicles landing on the Moon, as the risk of terrain instability is higher.

Mars Direct 3 proposes a small methalox engine used for landings, thus not needing to optimize for high efficiency. Throttle range is necessary, with a maximum thrust per engine of 8 tons (78.45 kN) and a throttle limit of 40%. Caravels would be equipped with 6 of these engines and be able to land with 4 if required for engine-out capacity. This allows for a number of contingencies which will be discussed in section 7.

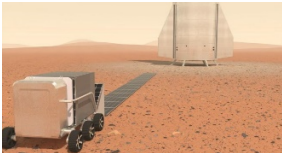
	6 active engines	4 active engines
TWR during landing (little fuel, full cargo)	40% throttle: 0.86 100% throttle: 2.16	40% throttle: 0.58 100% throttle: 1.44
TWR beginning ascent (100% fuel, little cargo)	40% throttle: 0.23 100% throttle: 0.58	40% throttle: 0.15 100% throttle: 0.38
TWR mid ascent (50% fuel, little cargo)	40% throttle: 0.4 100% throttle: 1	40% throttle: 0.26 100% throttle: 0.66

2.5- Pressurized Rover

A pressurized rover of up to 7 tons designed to allow long distance exploration. Powered by a large battery allowing a range of 500 kilometers and extendable solar panels for slow recharge in case of emergency. It is deployed from Starship via a crane.

2.5- Solar panel deployment rover

A half a ton electric rover-controlled from Mars or Earth with the purpose of deploying and cleaning solar panels.



2.7- Other technologies and hardware

All technologies and hardware listed are necessary for total success. The “critical” label is added to those critical for the survival of the crew.

- **Carbon dioxide electrolyzer (Critical)**

The production of oxygen from carbon dioxide in the Martian atmosphere is necessary for crews to breathe and for fuel production. The technology already exists, and a standardized reliable hardware would be needed.

- **Wastewater recycler (Critical)**

The reuse of urine and other waste is vital to reduce water consumption. Such a system is in use at the International Space Station, but a more efficient system is desired.

- **Gas liquefier (Critical)**

Necessary for turning the produced oxygen and methane into usable cryogenic state and vice versa.

- **Functional and comfortable spacesuits (Critical)**

- **Water electrolyzer**

Necessary for the production of hydrogen and oxygen from water extracted from below the surface.

- **Sabatier process equipment**

For the production of CH_4 from H_2 and CO_2 .

- **Crew habitat**

The seed for the first Martian colony. Designed to be a comfortable home for astronauts on the Red Planet.

- **Agroponics**

Agriculture is essential for the sustainability of a colony. This technology will grow in importance in follow up missions. A test version would be included at this stage.

- **Equipment for the extraction of water**

3- CARAVEL SHIP MISSION PROFILE

Before explaining the entire mission, let us go into the mission profile of a single Caravel ship.

3.1- Launch and Mars injection

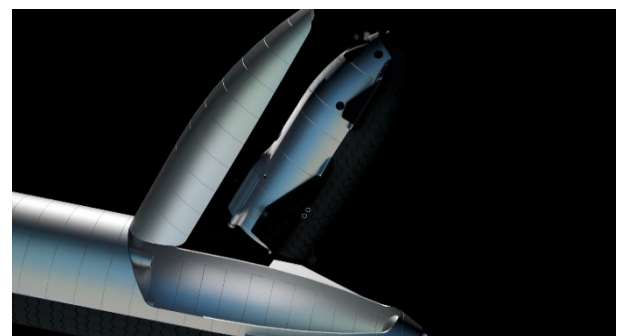
The Caravel ship would be launched inside of a Starship in cargo configuration, to which it is docked and connected through retractable support mechanisms.

At launch, it would contain less fuel than its full capacity, at 64.3 tons. Added to the 32 tons of the spacecraft and the 26.5 tons of cargo, the mass of the ship would be 122.8 tons. This gives the Caravel a Delta V of 2750 m/s.

With the Starship gate open, the crew would access the Caravel, after which the arm retracts and the gate closes. The Starship launches and reaches Low Earth Orbit.



Once in LEO, the Starship would rendezvous with a tanker Starship which has already been refueled once. The tanker would transfer all the fuel not needed for landing to the Starship, after which it would land on Earth. The Starship proceeds to perform a 2500 m/s burn that would position it in a highly elliptical orbit. After this, the Caravel would separate from the Starship.



The Starship would return to land on Earth. The Caravel would perform an 1800 m/s burn that sends it on a 6-month trajectory to Mars, then deploy solar arrays.

This makes a total of three launches (2 being tankers), which could be reduced to two if on-orbit-refueling was possible between a Starship and a Caravel. After a fuel transfer of 115.5 tons of fuel, the Delta V in LEO would be 5210 m/s, which is within margins. Option one will be considered onwards as to remain conservative, but option two is possible and would further reduce cost and complexity, while slightly increasing cost and complexity of the Caravel.

The 6-month trajectory is ideal for various reasons. Reducing it from the 9-month maximum reduces the radiation exposure of the astronauts at a reasonable Delta V cost while giving them 3 more months on the surface. But, most importantly, this is a free return trajectory, giving the possibility to abort the mission and return to Earth at minimum Delta V cost without landing on Mars.

Further reductions in the duration are more expensive in terms of Delta V and result in the loss of the free return.

3.2- Landing on Mars

The entry profile would be more conservative than that designed by SpaceX for Starship. The Caravel would aerobrake and perform a propulsive landing using 500 m/s of Delta V via the Raptor Jr. engines. This would give the ship hovering margin and capacity.

As seen before, in case one of the 6 Raptor Jr. failed (or even two, depending on the distribution), the remaining four are capable of landing the ship.

In the unlikely case of more Raptor Jr. failures, the main Raptor engine could perform a suicide burn to land.

3.3- Launch from Mars and Earth injection

After one and a half years on the Martian surface, the Caravel is full with 180 tons of fuel and 5 tons of cargo, giving it 6550 m/s of Delta V. This is a conservative estimate of the Delta V required for the trip from the Martian surface to trans Earth injection.

As stated by Elon Musk, Raptor version 2 is projected to have 230 tons of thrust. (Musk, 2021a) At 217 tons, this gives the Caravel a thrust to Martian weight ratio of 2.79 at launch. A high thrust to weight ratio is essential to reduce Delta V losses due to the Martian gravity.

The Caravel would launch to Low Martian Orbit, deploy its solar arrays and perform the trans-Earth injection burn.

3.4- Landing on Earth

A Raptor Vacuum engine cannot operate in the Earth's lower atmosphere, and the Caravel does not have enough fuel for a propulsive landing. Instead, it aerobreaks into a highly elliptical orbit, then rising the perigee to 300 Km using maneuvering thrusters at marginal Delta V cost.

At this point, a cargo Starship is launched to Earth Orbit empty, thus having the Delta V necessary to reach this orbit and rendezvous with the Caravel in one launch. The Caravel would dock to the Starship the same way it was when it launched. At 37 tons, the Caravel is within the 50-ton cargo limit that the Starship can land on Earth. Finally, the Starship would land with the Caravel inside.

This approach not only saves Delta V from the Caravel, but also increases safety. Starship is destined to be a multi-purpose ship, and after tens or hundreds of regular and tanker missions, the Starship would at this point have perfected the landing procedure.

4- METHODS AND CALCULATIONS

The rocket equation is used for all Delta V calculations. The Delta V from the Martian surface to Earth injection is conservatively assumed to be 6500 m/s. The values for Starship, Caravel and Raptor used are in section 2.1.

4.1- Fuel requirements and production

With a mass of 32 tons and 5 tons of cargo, the return would require 180 tons of fuel (for 50 m/s of extra margin).

The Raptor engine consumes more oxygen than methane. The fraction of liquid methane in the mix in terms of mass is 0.22, which results in 39.6 tons of methane and 140.4 tons of oxygen.

As the MOXIE experiment on the Perseverance rover has demonstrated, oxygen can be produced from the Martian atmosphere. Hydrogen, however, must be extracted from water ice underground, and the Sabatier reaction can use carbon dioxide and hydrogen to produce methanol fuel. This is likely the best long-term method for fuel production on Mars. However, as explained in section 1.1, this is a risky operation for the first crewed mission.

Bringing the methane from Earth has always been an unrealistically expensive proposition. Even at 22% of the total fuel mass, delivering 39.6 tons of liquid methane to the surface of Mars would exhaust more than the entire cargo capacity of the Caravel.

An alternative to this, used in the original Mars Direct architecture, would be to bring the hydrogen from Earth, thus eliminating the water requirement.

This approach was considered. 10 tons of liquid hydrogen would be needed if not accounting for any losses, and the tank size would be 140 cubic meters. However, the storage of liquid hydrogen for 7 months with reasonably low losses is a challenge at best and an impossibility at worst. In any case, complicated and expensive.

Mars Direct 3 offers a simpler and safer alternative, made possible by the *big ship-small ship* strategy. The only vehicle that needs to return to Earth is the Caravel, so a Starship can deliver the 40 tons of methane inside of its fuel tanks, consuming only one third of its cargo capacity. 45 tons are considered for safety.

This approach makes the refueling process dependent on the ISRU of the Martian atmosphere only, and not the extraction of water from the Martian ice. This is an enormous safety bonus.

4.2- Power requirements for fuel production

There is also a significant reduction in the challenge of the production of electricity by using a smaller ship for the return and bigger cargo ships.

For the return, 140.4 tons of oxygen would need to be produced.

According to engineering studies based on the MOXIE experiment, it is estimated that carbon dioxide from the atmosphere could be electrolyzed at a rate of 1 Kg a day with a supply of 1.714 KW. They proposed a more efficient scaled-up version. Further scaling up to fit MD3, 204.75 KW over a period of 400 days would be needed to produce 140.4 tons of O₂. This conservatively assumes no efficiency gain from scaling bigger than proposed in the study. (Hecht et al, 2021)

4.3- Power production (photovoltaic)

If nuclear energy is not available for this mission, solar energy is the only alternative. These panels have to be deployed, maintained and cleaned for long periods of time. But what is the mass, area and volume of the panels needed?

For the calculation, the following assumptions are made:

- 0.5862 KW per square meter of solar irradiance.
- Night loss of 50%.
- Losses due to weather and latitude of 55%.
- 30% efficiency of panels.
- 4 Kg per square meter of panel.
- Panel thickness of 5 cm.
- 20% margin added to mass and volume for stacking and other uncertainties.

The result is 24.8 tons of panels, covering an area of 6209.4 m². When stacked inside of the Starship, they would occupy 372.6 m³ of the estimated 650 m³ volume of the Starship cargo bay. For Starship, this would be 98 tons, 24501 m² and 1225 m³ respectively.

By using the Caravel as well as Starship, the fuel requirement is for the former while the cargo capacity is that of the latter.

This means that the panels impose a proportionately smaller mass penalty on the mission. What had to be delivered in three launches can now be delivered in one, with room and mass to spare.

4.4- Electricity production (fission reactors)

The same is true in the case of nuclear reactors, which is the only other realistic alternative for the energy supply in a Mars mission.

NASA proposed a fission reactor for these kinds of missions, called Kilopower. It is now (2022) in the hands of the SpaceNukes company, who claims the reactor would continuously produce up to 10 KW for 14 years, having a mass of 1300 Kg.

With a security margin of 20%, this results in 25 reactors (32.5 tons) for the Caravel & Starship variant and 97 reactors (126,1 tons) for the Starship-only variant. With the disadvantage of being heavier, they occupy less volume and require little to no maintenance. They also produce at a constant rate during day and night and are immune to dust storms.

5- MARS DIRECT 3: FIRST LAUNCH WINDOW

Two uncrewed ships would be launched during the first launch window. Names of historic Spanish vessels are given to each ship to ease their identification from this point onwards.

5.1- Starship Victoria (uncrewed)

This is a Starship in a modified cargo configuration named after the Victoria Carrack class naval ship, the first vessel to ever circumnavigate the world.

The main purpose of this vehicle is to be the fuel production facility for this and future missions.

Cargo on board (**Total: 120t**):

- Cranes, pipes, batteries and all operating equipment. **Mass budget: 5t**
- Liquid methane. **Mass budget: 45t**
- ISRU machinery and storage. **Mass budget: 37t**
- **Either:**
- Deployable solar panels: **Mass budget: 30t**
- Panel deployment rovers (6): **Mass budget: 3t**
- **Or:**
- Kilopower-like reactors: **Mass budget: 33t**

For the ISRU, it would carry carbon dioxide electrolyzers, water electrolyzers, gas liquefiers and machinery for the Sabatier reaction, as well as a small water storage tank for logistical purposes.

Even though there was already a 20% margin for the power production, there is further margin in these figures.

The crew must be able to fill or empty both the methane and oxygen tanks, as well as the water tank. For that purpose, pipes reaching the lower part of the ship would connect to each corresponding tank, with redundant pumps and valves for safe operation.

Various sockets would also connect to the ship's electrical grid in order for it to be connected to solar panels, rovers and even other ships.

For all intends and purposes, after the landing, Starship Victoria would become an industrial building for fuel production and storage.

5.2- Caravel Pinta (uncrewed)

This is a Caravel crew ship named after one of the Caravel class naval ships on Christopher Columbus' first voyage to America.

Even though it would not carry people to Mars, it would still be fully equipped with life support, two years of food and supplies, water and waste recycling systems, plenty of room and everything the astronauts would need.

It would have two redundant carbon dioxide electrolyzers for oxygen production. In its lower cargo bay, it would carry a fuel tanker rover.

Cargo on board (**Total: 26.5t**):

- Fuel tanker rover. **Mass budget: 4t**
- Food, water and supplies. **Mass budget: 5.5t**
- Solar panels (20KW). **Mass budget: 2t**
- Scientific equipment, batteries, carbon dioxide electrolyzers and other. **Mass budget: 15t**

5.3- Landing and fuel production

Caravel Pinta would go on a 6-month trajectory, while Victoria could take longer. They would land on Mars within a range of two kilometers of each other. These landings would demonstrate the capacity of the ships to land on Mars.

Once all systems have been checked, Starship Victoria would start deploying the solar panel rovers and loading them with stacks of panels.

The rovers would connect a hanging wire socket from the ship to the grid and charge their batteries in a similar way by connecting themselves to the grid.

The carbon dioxide electrolyzers as well as the gas liquefiers aboard Victoria would start operation, slowly filling the liquid oxygen tank for the next 400 days.

During this process, the small rovers would clean the panels from dust. If this was successfully completed, the second wave of ships would launch from Earth.

6- MARS DIRECT 3: SECOND LAUNCH WINDOW

Two ships would launch in the second launch window. One crewed and one uncrewed.

6.1- Caravel Niña (crewed)

This is a Caravel crew ship named after one of the Caravel class naval ships on Christopher Columbus' first voyage to America.

It would launch 6 astronauts in a 6-month free return trajectory to Mars and carry similar cargo as the Pinta.

Cargo on board (**Total: 26.5t**):

- Water tanker rover. **Mass budget: 3.5t**
- Food, water and supplies. **Mass budget: 6t**
- 20 KW of solar panels: **Mass budget: 2t**
- Scientific equipment, batteries, carbon dioxide electrolyzers and other. **Mass budget: 15t**

6.2- Starship Santa María (uncrewed)

This is a Starship named after one of the Carrack class naval ships on Christopher Columbus' first voyage to America. This ship was dismantled to make the first Spanish settlement in the New World.

Cargo on board (**Total: 120t**):

- Cranes, batteries and all operating equipment. **Mass budget: 8t**

- First Martian habitat, including crew quarters and a common area. **Mass budget: 34t**
- Pressurized Rover. **Mass budget: 10t**
- Water extraction/ice mining machinery. **Mass budget: 20t**
- Extra water and supplies: **Mass budget: 12t**
- Additional solar panels/fission reactors. **Mass budget: 36t**

This ship would launch on a 7.5-month trajectory, arriving one and a half months after the Niña.

It is important to note that the uncertainty of the mass capacity of Starship and the mass of the cargo requirements listed makes this an estimate that is subject to change. Conservative estimates have been made, and thus high precision of these estimates is not required to the success of the mission.

6.3- Human landing and Phase One

Six months after the departure, the crewed Niña ship lands on Mars close to the other two. During the landing, the crew is wearing their space suits.

The crew spends a few days inside of the ship getting used to the gravity and making safety checks, after which they open the airlock and set foot on the Red Planet.

For one and a half months (Phase One), the astronauts plant flags, deploy solar panels (enough for the ship to operate), explore the area and research samples.

They would inspect the ship for any sign of damage and walk to the landing site of the Victoria Starship and the Caravel Pinta, where the fuel tanker rover is deployed. They would deploy solar panels, inspect both ships for damage and, if no damage is found, the astronauts would decide which Caravel they would use for the return trip.

At this point, both the Pinta and the Niña are fully functional habitats for the crew, and they may choose to live in one, the other or alternate between both.

When the decision is made, they use the fuel tanker rover to take the liquid methane and liquid oxygen from Starship Victoria and fully fuel the chosen Caravel. Once the Caravel is fueled, the tanker rover remains connected to its power grid, and both the ship and the rover use the energy provided by the solar panels to keep the fuel in a cryogenic state.

6.4- Landing of Santa María and Phase Two: Cargo deployment

One and a half months after the crew lands, the Santa María Starship would land close to the other ships.

The pressurized rover and one ton of (stacked) solar panels are deployed to the ground automatically via the cranes using battery power. The crew walks there and inspects the vehicle to check if it is functional, after which they deploy the panels. During the following weeks, the crew would aid in the deployment of the cargo inside.

6.5- Phase Three: Exploration and ice mining

The crew can use the rover to explore a larger area for scientific purposes and prospecting in search of large underground ice deposits.

Once a deposit is found that is abundant in ice and reasonably close to Starship Victoria, the crew marks the spot and returns to Starship Santa María. There, the rover is equipped with a towing and the crew uses it to transport the extraction machinery and the necessary solar panels to the location. The remaining ones are installed in the main solar farm next to Starship Victoria.

When the extraction and filtering is tested, the crew returns to the Niña, deploys the water tanker rover, drives it to the water extraction machinery and connects the water pipes to it.

Water is pumped in and, once full, the tanker rover is driven to Starship Victoria, where the water is pumped in for the electrolysis process to begin. This step is repeated multiple times as the water is electrolyzed and the Sabatier reaction reacts atmospheric carbon dioxide with the produced hydrogen to create oxygen and methane, which are liquefied and stored in the tanks.

This fuel is *not* mission critical, but the successful demonstration of this technology is key for future missions, as this should become the long-term solution for fuel production. Fuel produced during this time would be available for future missions, avoiding the need to land 45 tons of liquid methane each time.

A fraction of the water can be purified for drinking and stored for oxygen production via electrolysis. This will be useful after Phase Four.

6.6- Phase Four: Construction

The crew travels to the Santa María and tows the components of the base to a spot near Victoria and the main solar farm. There, the crew constructs/deployes the habitat. Whether it is an inflatable base, a modular one or another design exceeds the aspirations of this paper. Once constructed and tested, the crew *can* stay on it for the rest of the mission. Again, this is not mission critical.

Machinery (3D printing and/or chemical reactions) are used to make basic bricks from in situ resources. They are tested and, if they work, they are used to cover the habitat for radiation protection. At a safe distance from all structures, these bricks can also be used to make landing pads for future ships.

6.7- Phase Five: Return

After one and a half years of productive construction, exploration and experimentation, the astronauts prepare for their return home. The preparation would consist of the following steps:

- Another safety check is done on the Caravel.
- The astronauts detach the carbon dioxide electrolyzers from the Caravel for mass

reduction. They are no longer necessary and may be valuable as spare parts in future missions.

- If possible, the water is renewed.
- Important samples are selected and boarded for study back on Earth.
- The fuel tanker rover is unplugged from the Caravel, then driven and connected to Starship Victoria. There, the liquid methane and oxygen are transferred to the ship's tanks.

Finally, a few days prior to the launch window, the crew is on board and ready. The Raptor engine propels the ship in a high G-force ascent profile to Low Martian Orbit and then finally towards Earth.

This would not in any way be a flags and footprints mission. The astronauts would leave behind an initial base, a fully functional fuel production system, significant energy infrastructure and fuel for future missions.

This is a strong starting point for a Martian colony, which is the ultimate aim of the program.

7- MARS DIRECT 3: CONTINGENCY PLANS

All plans work in paper and Power Point. But sometimes, reality gets in the way and things do not go as planned. Thus, it is the job of the planner to take that into consideration, especially given the consequences of failure to the crew and society as a whole. Flexibility is key for adapting to such issues, and Mars Direct 3 is prepared to adapt to the harshest situations while keeping the crew alive.

This is a list of contingency plans with the aim of making a failure a bad day, not a tragic one.

7.1- Contingency Beta: Failure of the first wave

What if Starship Victoria and/or Caravel Pinta crash?
What if fuel production or panel deployment fail?

ISRU is more unlikely to fail in MD3, given that only the atmosphere needs to be harvested, and redundant instruments are carried which have already been tested by Perseverance. Nevertheless, it must be accounted for.

The solution is simple, the crew would not launch from Earth in these circumstances, meaning that the risk posed to the lives of the crew in this scenario is zero.

Result: Mission postponed; crew safe.

7.2- Contingency Gamma: Victoria or Pinta fail while the crew is on-route to Mars

This would be an unlikely scenario, as it would imply that, after completing all objectives and being in standby, any of the first wave ships on Mars has a critical failure. Another trigger event would be a non-critical failure in Caravel Niña that would make landing on Mars too risky, or other event such as an ongoing global dust storm.

In this event, the free return offered by the 6-month trajectory would be utilized. Essentially, the Caravel

would travel to Mars and, with little maneuvering, would be placed in an Earth-bound trajectory. The crew would safely arrive on Earth two years after their departure.

Result: Mission postponed; crew safe.

7.3- Contingency Epsilon: Engine failure on landing

What if one of the Raptor Jr. engines fails on landing?

In that case, the symmetrically opposite Raptor engine would shut down, with the remaining 4 increasing thrust to compensate and making a controlled landing. At full thrust, these 4 Raptor Jr. would have a maximum thrust to weight ratio of 1.4, thus allowing the landing.

Result: The mission may proceed normally.

7.4- Contingency Zeta: Critical engine failure on landing

In the very unlikely case of more than one Raptor Jr. engines failing (if they are not symmetrically opposite), then all Raptor Jr. engines would shut down. The main Raptor engine would then attempt a suicide burn on the Martian surface.

Result: The mission may proceed normally.

7.5- Contingency Delta: Crash landing of the Caravel

There is one situation in which death is unavoidable and no amount of planning could save, and that is a hard crash landing of the crewed ship. Previous contingency plans have already made it an unlikely event, but there is a variation that may also cause death if not accounted for.

The ship may suffer an issue during landing causing a non-fatal crash landing. That is, a crash that the crew can survive but which would render the ship inoperative.

This would unquestionably be a dire situation, resulting in the loss of crew in most conceivable architectures. Mars Direct 3 offers a real possibility for survival.

In this event, the crew would withstand the possible depressurization held by their seatbelts. A day of oxygen would be accessible to the crew via backpacks and/or life support systems if they have survived the crash.

If the landing location is within a few kilometers, the crew may attempt walking to Caravel Pinta, which is equipped with everything the crew would need for their stay on the Red Planet and the completion of the mission.

There is a chance that the crew may not be able to walk this distance in time due to injury or not adapting to the gravity in time. Another option is viable.

The crew may remotely deploy and control the fuel tanker rover situated inside Caravel Pinta and drive it to their location to ease the transport to the backup ship.

Result: A lot of uncertainty is associated with contingency Delta. The most important factors would be severe injury or death of crew members or whether the water tanker rover can be made operational.

Thus, the results may vary from the possibility of partial survival of the crew to total mission success. However, in this event, as long as one crew member is not incapacitated, the crew would likely return safely to Earth.

7.6- Contingency Iota: Crew ship lands far away

Mars-bound ships are set on precise trajectories to their destinations with the aid of mid-course corrections. Thus, it is highly unlikely that the crew aboard Niña could find themselves landing on the other side of the planet.

It is possible, though, that it would land several hundred kilometers away from its intended landing location.

In this event, Phase One would proceed mostly as normal. The astronauts would be safe inside the Niña and perform experiments and explore safely.

There are two variants to this contingency.

A- The Niña has landed within the range of the pressurized rover (approximately <500 Km).

In this event, one and a half months after the landing of the crew, the Santa María would land next to the first wave ships. The pressurized rover would then be autonomously deployed and remotely controlled by the crew to complete the trip to the Niña.

Once there, it would be plugged to the solar panel grid deployed by the crew and fully charged. Finally, the crew would move to the Pinta and continue the mission as normal.

Result: The mission may proceed normally.

B- The Niña has landed within twice the range of the rover (approximately <1000 Km).

In this event, the Santa María would make corrections to land between the Niña and the other two ships. The rover would again be deployed and controlled by the crew to pick them up. Once charged, the rover drives the crew to the Santa María, where the astronauts deploy a small solar power farm to charge the rover and complete the journey to the Pinta.

The cargo inside Santa María may be hard or impossible to access.

Result: Mission not fully complete, crew safe.

7.7- Contingency Kappa: Santa María crashes or failure of the water ISRU

This would substantially undermine preparation for future missions.

However, unless contingency Iota was needed, the loss of the Santa María would not significantly endanger the lives of the crew, as methane was already provided.

A tragedy was avoided by not relying on water ISRU.

Result: Mission not fully complete, crew safe.

7.8- Contingency Lambda: Global dust storm

The most dangerous weather event on Mars are global dust storms, which can cover the sky for months. The most important risk associated with this situation is in case the energy supply relies on solar panels, as most of the sunlight would be blocked by the dust.

Having battery capacity to last for months is unreasonably costly. Mars Direct 3 offers a simpler alternative, for which the astronauts would have a few days to prepare due to satellite early warning of the formation of a dust storm.

The crew would board the Caravel, which, as described in 6.3, would have the full fuel tanker rover plugged to its power grid. It is also described that the rover has redundant fuel cells to produce electricity from liquid methane and oxygen.

The Caravel would switch to essential power only mode and consume the power produced by the rover's fuel cells. Assuming that the rover has 2 tons of combustible methane and at least the stoichiometric oxygen to combust it and that the fuel cell is 20% efficient, the rover is essentially a 5625 KWh battery.

Assuming a power consumption of 200 KWh per sol, the fuel in the rover would last for 28 sols. In the remote case that the storm lasted longer, up to 5.2 tons of the methane fuel of the Caravel could be consumed thanks to the extra stock of methane still stored at Victoria, increasing the duration to a total of 101.23 sols. If more fuel had been produced at that point with local water, this may increase further. Lower power consumptions and higher fuel cell efficiency would increase the time and vice versa.

Nevertheless, with most global dust storms lasting between two and six weeks, it is more than enough to survive any dust storm scenario.

After the storm, if fuel from the Caravel was consumed, the crew would fuel it again using the tanker rover and the remaining fuel stored at Starship Victoria.

Result: Time would be lost, but the crew would survive and the mission may still be fully accomplished.

7.9- Contingency Mu: Global dust storm close to departure

What if the already unlikely global dust storm started just when they were about to leave the planet?

If a global dust storm was suspected to be forming within three months of the departure, contingency Mu would be triggered. This would not be possible in an architecture that relies on preparing the fuel during the entire mission.

With the Caravel already fully fueled, the crew would prepare for lift off. If the storm continues growing and getting closer, the crew detaches the carbon dioxide electrolyzers and takes off. Once in Low Martian Orbit, the crew would wait until the launch window and safely return to Earth.

Result: Mission shortened; crew safe.

7.10- Contingency Omicron: Raptor engine failure

What if the Raptor engine fails during the return's ascent phase?

Depending on when the failure occurs, a different variant is activated:

- A- **Instant failure:** The Caravel would not lift off, but would no longer be capable of returning to Earth. Depending on the failure, the fuel may still be accessible.
- B- **Early stage:** The six Raptor Jr. engines would activate, rising the time until impact on the ground while burning to reduce weight as fast as possible. The results would vary from a safe landing to a dangerous and possibly fatal crash landing (if it happens before ~30s since launch).
- C- **Mid stage:** After two minutes and twenty seconds of burn time of the Raptor engine, the thrust to weight ratio of the six Raptor Jr. engines surpasses 1, making a soft landing possible. The C variant could be accomplished for an earlier failure, as the smaller engines could burn fuel while increasing the apoapsis to exceed a thrust to weight ratio of 1 before reaching the ground. The ship would land outside of the reach of the rover.
- D- **Late stage:** At this stage, a safe landing could be attempted. Instead of landing, the Raptor Jr. would complete the orbit insertion. From orbit and with excess fuel, the ship could maneuver for days and attempt a landing near the base.
- E- **Before Mars escape:** If the Raptor engine fails before escaping Mars' sphere of influence, aerobraking and orbit maneuvers can allow a landing near the base.
- F- **During trans-Earth injection burn:** The ship has left Martian Orbit but the Raptor Jr. engines cannot safely complete the Earth injection burn. The ship immediately turns around. The Raptor Jr. engines fire and reverse the trajectory into a highly elliptical Martian orbit.

Result: Varies depending on the moment of failure.

Assuming the correct execution of all other procedures, the only variants which may result in the death of the Crew would be B and F.

B would only occur if the engine failed after approximately between 5 and 30 seconds of burn time.

Variant F is considered very unlikely. At this point, the engine would have performed well throughout the entire mission, passed inspections and functioned well for minutes after spending one and a half years on Mars.

If a successful landing was performed with the Raptor Jr. engines near the base and enough fuel had been produced with local resources, another launch may be attempted with the remaining Caravel. Otherwise, contingency Omega would be triggered.

7.11- Contingency Omega: Cannot return to Earth

Given that only the atmosphere needs to be harvested, that the harvesting would be done with tested and redundant systems and with all other contingency plans in place, contingency Omega is a remote last-resource possibility.

The crew would have enough supplies to survive until more ships arrive from Earth.

Many options are possible depending on the cause of failure, but they range from sending replicas of the failed ships to landing the entire fuel requirement of a Caravel using two Starships or more if mission control wants to take no risks. Until then, the crew would have food to eat and more science to do.

8- ALTERNATE AND FOLLOW UP MISSIONS

8.1- Mars Direct 3: Third launch window

The architecture for missions beyond the first Mars Direct 3 mission depends on the outcome of said mission.

If all mission objectives are accomplished, future missions would focus on expanding the colony and fuel production, as well as ISRU of local materials. Agroponics and mining as well as 3D printing should be the focus. In the long term, these technologies would make the colony less reliant on Earth.

Thus, a larger number of Starships would carry redundant ISRU machinery for fuel production as well as habitation and agroponics modules for the expansion of the base.

8.2 Small-scale Mars Direct 3 (2 ships)

This is the MD3 version of a flags and footprints mission.

Once regular missions are sent to Mars and rescue missions are always available (even rescue missions from the colony via suborbital flights), missions to explore other locations could be conceived using only two ships. One Starship (similar to Victoria) and one Caravel. This is useful for exploring multiple locations if one wants to make sure that the colony is built at the best location or for reasons of further exploration.

The non-reliability on ice mining and the reduced number of ships (failure points) would still make it safer than the SpaceX-proposed Starship-only system.

8.3- Beyond Mars Direct 3

After the colony is functional and fuel production is secured, a larger number of ships would increase the scale, population and self-sufficiency of the colony.

Eventually, return trips using Starships would become viable, and regular crewed routes to and from Mars would be carried out using a crewed version. If the Caravel wasn't used for exploration missions elsewhere or for lunar exploration, it would be rendered obsolete. This is the goal of the Caravel, but one needs to build the railroad before the horse cart is obsolete.

9- COMPARISON TO A STARSHIP-ONLY ARCHITECTURE

The Caravel ship is one of the core ideas of Mars Direct 3. However, the mission could be accomplished using only Starships. Both options are analyzed and compared in terms of cost and safety

9.1- Cost of the Caravel ship and MD3 default

The current or final cost of the Starship program is not yet known. Elon Musk has estimated a range between 2 and 10 billion \$, which is a tremendous margin of error. Consequently, estimates are not precise. Nevertheless, a decent qualitative assessment can be made.

- Increase.

The proposed Caravel ship would use the same main engine as Starship, be made out of the same steel material and use the same heat shield tiles as Starship.

Given that a Raptor Jr.-like engine needs to be developed for the lunar Starship, the Caravel would not need any additional piece of technology.

The degree of commonality would make the additional cost relatively low.

- Decrease.

There are significant cost reductions associated with the Caravel and Mars Direct 3.

For a similar mission architecture, a Starship-only system would require 3.8 times the methane delivered to the ground (171 tons) and 3.8 times the amount of solar panels (98 tons, 2 Starships due to volume restrictions) as well as scaled up ISRU machinery and more rovers. The alternative would be relying on ice mining and processing as SpaceX currently plans.

An efficient distribution of mass and volume results in four Starships in the first wave and two in the second.

A total of two Starships (and part of the cargo on another one, so we could say two and a half) would be needed to emulate what Starship Victoria can do and four Starships to replicate what a Starship and a Caravel could do. Thus, Mars Direct 3 (Starship-only version) could be accomplished with a total of six Starships. This can vary depending on the final cargo capacity of Starship.

With six tanker flights per Starship and two per Caravel plus one Starship needed to support the return of the Caravel, Mars Direct 3 could be accomplished with 21 launches in the Caravel & Starship variant and 42 for the Starship-only variant.

Even if reusability and chain production lowered the cost of Starship construction, landing a Starship on Mars requires construction, testing, cargo cost + loading, launch, and around five on-orbit refueling missions as well as all the human labor associated with monitoring the trajectory and landing.

It should be noted that any reduction in Starship construction, launch and landing costs would also reduce the cost of the Caravel & Starship variant, making the proportional savings remain somewhat similar.

On another note, there is a significant difference between the development and construction costs of a crew vehicle with a pressurized volume in the order of 600 cubic meters (Starship) than one in the order of 170 (Caravel). Crew-rating the Starship can be a nightmare compared to the Caravel. The extra cost of development would be added to the extra cost of hardware for each launch.

Taking the development cost of the Caravel -given all the commonalities with Starship- and subtracting the marginal cost of developing a crewed Starship version and the cost of the extra launches required during the first years of Mars colonization, the additional cost of the Caravel would not be substantial, and it may even be a cost-saving investment in addition to the safety gain.

9.2- Safety and mission success

- Mars Direct 3 Starship-only version.

An operation on Mars 4 times the scale would require increasing the labor force. With science not depending on the scale, this mission would require 10 to 15 astronauts. With the uncertainties associated with the first missions, this means risking more lives. Requiring three more critical landings and twice the amount of launches would also decrease the chance of mission success.

On the other hand, the same or equivalent versions of most of the contingency plans explored for a Caravel & Starship approach would be viable.

- Starship-only as currently proposed by SpaceX.

In this case, any failure (including in water extraction and processing) would lead to a contingency Omega situation (Crew stranded on Mars). If ISRU did not work, rescue missions would be complicated, expensive and very risky.

Landing 621 tons of fuel on Mars -which would be required for a Starship loaded with ten tons of cargo to have 6500 m/s of Delta V- would require 6 Starship landings (36 more launches). Refueling in Martian orbit may reduce the number to four, but would add another risk factor. Failure would mean loss of crew.

In terms of safety, the risk of the crew being stranded on Mars is significantly higher, would affect a larger crew and the rescue options rely on six successful landings in the next launch window.

If fuel and oxidizer had not been produced, a solar power-based mission would not survive a global dust storm. Each Martian year, a global dust storm has a one in three chance of happening. Having to stay for two Martian years means a 44% chance.

Power (KW)	MD3	MD3 Starship-Only	SpaceX
requirement	204.75	808	1890
Factor	1	4	9

- Conclusion.

The Caravel & Starship variant offers similar effective cargo capacity as a Starship-only system while decreasing fuel and power requirements by a factor of four. The combination of Starship with a smaller ship also allows for a significantly safer mission architecture.

Both Mars Direct 3 variants allow for several contingency plans, making them substantially safer than the currently disclosed SpaceX architecture.

10- MOON DIRECT 3

As in previous Mars Direct proposals, the hardware and methods used for Mars can be applied to a lunar mission with small hardware modification. A lunar version of the Caravel would be considered without heat shield, now assuming a dry mass of 28.5 tons. No ISRU on the Moon is contemplated.

The launch of the Caravel to a highly elliptical orbit from LEO would be similar as the Mars version, but burning 3.25 Km/s instead of 2.5 Km/s, completing the trans-lunar injection burn. After, the Starship would land on Earth.

Each Caravel would land on the Moon, unload 2 tons of cargo, complete the mission and return to a highly elliptical orbit to be docked to a Starship and land.



The small cargo capacity is not an issue. A Starship could land 100 tons of cargo to the surface requiring 7 tankers in LEO (less if at an elliptical orbit) and not return to Earth. Thus, a two-ship mission delivering a crew of up to 10 and 102 tons of payload could be achieved with 13 launches.

	Mars Direct 3	Moon Direct 3
Caravel mass	32 tons	28.5 tons
Fuel at launch	64.3 tons	95.7 tons
Cargo mass	26.5 tons	2.5 tons
Mass at launch	122.8 tons	126.7 tons
Delta V at launch	2750 m/s	5350 m/s*
Boost burn by Starship	2500 m/s	3250 m/s
Tankers needed	2	3
Launches per Caravel landing	3	4
Launches per Starship landing	7	8
Total launches	21	13

*This figure assumes the unloading of 2 tons of cargo on the lunar surface and the loading of 0.5 tons of regolith.

11- THE FUTURE OF MARS DIRECT 3

As in the case of previous versions of the paper, if any errors or areas of potential improvement are detected via revision or feedback, they will be dealt with and corrected in future versions.

For any person who likes the idea and wants to help make it a reality, the best thing to do is to speak about it, spread it with others and try to have it reach the right people.

If Mars Direct 3 is successful in attracting the right attention, the next steps are to go deeper into the design and interior of all of the vehicles, especially the Caravel, as well as specific technologies and human elements associated with the mission.

As mentioned in the abstract, even though Mars Direct 3 is based around the Starship system, many of its core ideas and contingency plans could be adapted to different hardware or even other architectures.

MD3 provides a comprehensive outline for the mission, but its aim is to be useful to the establishment of a continuous and flourishing human presence on Mars. For that to be possible, missions need to be safe and affordable. So, if any idea present in Mars Direct 3 is helpful in designing such missions, it will be considered a success.

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12- CONTACT AND SOCIAL MEDIA

If you wish to contact the author, you may do so on Twitter (@Xene1042).

A video form of this paper can be watched on YouTube, as well as the original presentations at The Mars Society, interviews and everything related to Mars Direct 3: <https://www.youtube.com/c/MarsDirect3>

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