Mission to Mars

Vehicle concept and design

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Introduction

Background

Since the dawn of the space program, the challenge of transporting the human race to distant moons and planets has been a cornerstone of many countries' missions. Following the famous Apollo 11 mission that first took us to the Moon almost fifty years ago, the next destination for human spaceflight is Mars. THe red planet offers many possibilities for further research, commercial travel, and perhaps even colonisation in the future. In this report, the vehicles outlined are intended for a commercial passenger mission, with plans for multiple flights looking forwards.

Mission and design goals

Every design starts by looking at the mission requirements. Objectives at hand are the following, their importance is somewhat given by the order, starting with the most important:

- Transport 30 passengers and necessary crew members to Mars.
- Ready to depart by 2032.
- Spacecraft should be re-usable.
- Technology used should be reasonable and realistic within the given timeframe.

With these very few requirements it is up to the whole red team to choose the most interesting design that integrates the best features from each subcategory. Reusability and modular designs will allow us to achieve a well thought-out and efficient vehicle concept.

Vehicle concept group goals

The vehicle concept group will provide the rest of the team with all spacecraft design related specifications including its size, layout and overall concept.

Pre-design phase

Defining a mission

Since the design depends heavily on its intended use it was decided to start by considering various options and then selecting one more specific mission plan together with the operations team. This provided vehicle concept group with more details to base the design on as well as useful numbers for the rest of the team to base their work on.

Mission concept

There are endless number of ways to get to Mars and every route, both distance and time it takes, depend mostly on the propellant cost. Therefore delta-v is a very useful concept when talking about space travel as it describes spacecraft's capacity to change its velocity. So for example to achieve low earth orbit one needs an orbital velocity of around 9 km/s plus extra fuel to fight gravity and atmosphere to get at 300 km altitude. This makes for a total of 11 km/s delta-v required for a spacecraft intending to achieve low earth orbit. This use velocity change requirement combined with low efficiency launchers has been the main barrier for human space exploration but now more things are happening in this area due to private investment. As SpaceX and other companies are designing re-usable launchers, payload to LEO cost has been lowered almost tenfold, provided humans with easier access to space. **Therefore it was decided to start the mission from LEO (300-350km)**. Building the spacecraft in space will allow for a more efficient design since the 11 km/s required to achieve LEO will not be included in the design. Available launchers operated by other entities will be used since designing a new one takes around a decade and costs in order of several billion dollars.

Reusability being another key feature it was decided that the spacecraft should transport passengers to and from Mars. This would allow a more convenient travel/trade with Mars as well as make the **spacecraft more economically feasible as it will be utilized more often**. Transporting humans outside Earth's magnetic field means increased radiation, particularly the cosmic background radiation which consist of high energy particles capable of damaging human cells as well as DNA. That together with the negative effects of prolonged exposure to microgravity means that the **travel should be as short as possible.**

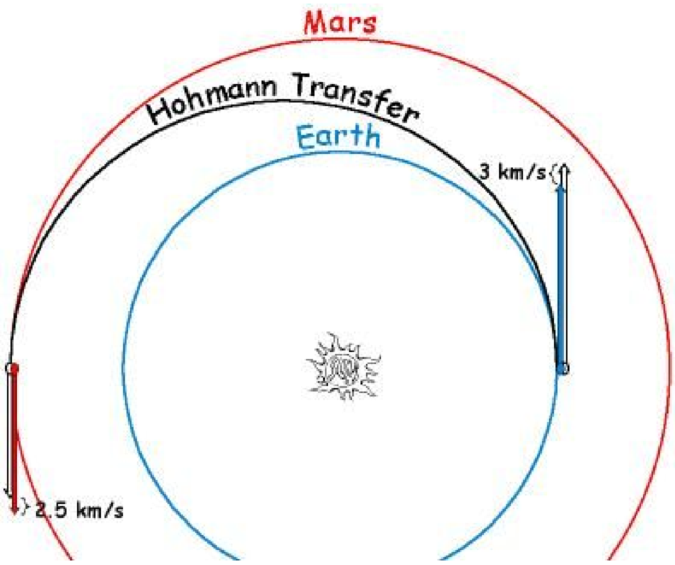
Several mission concept alternatives were considered and due to similarities in these missions same vehicle design could be applied for both cases. Below are the short summary of both mission concepts. Chosen mission details are in underlined or bold text.

Synodic Hohmann transfer

This is the most obvious mission because it is one of the most commonly used space travel techniques, described in every textbook and computable by hand. Majority of missions to Mars propose of using Hohmann transfer despite its drawbacks such as low launch frequency with narrow launch window and long travel times. It is extremely delta-v efficient and two-impulse transfers pair very nicely with the high thrust chemical propulsion technology currently used. However it is not feasible for electric propulsion or other low-thrust technologies. This mission profile would require approximately 10 km/s delta-v if no aerobraking is ever performed and around 6 km/s if it is utilised like in all previous and planned space missions.

Scenarios	**Initial burn(days)**	**Relative V (AB)**	**Stay at Mars**	**Return burn**	**Relative V (AB)**	**Total (AB)**
Standard	3.8 km/s (200)	2.3 km/s (partially)	544 days	2.3 km/s (189)	3.8 km/s (yes)	9 km/s (7)
Venus flyby	4 km/s (190)	2.4 km/s (partially)	38 days	3 km/s (372)	5 km/s (yes)	12 km/s (8)

Average values taken from the Human Spaceflight Mission Analysis and Design.



Simplified illustration of two-impulse interplanetary Hohmann transfer.

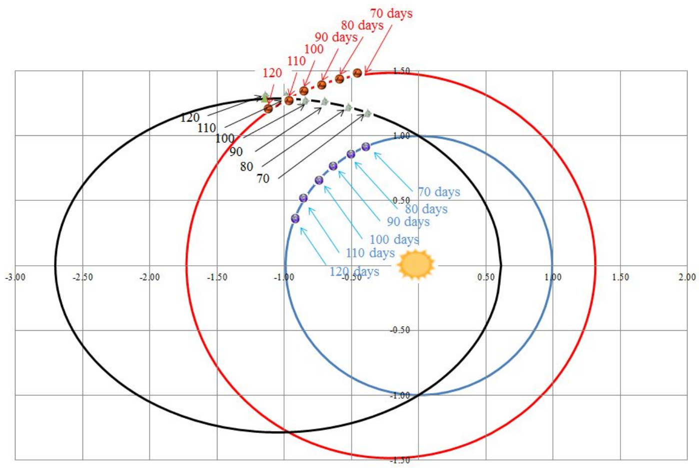
Cycler orbits

There are potential orbits that would allow spacecraft to pass Earth and Mars without stopping and therefore saving fuel for slowing down the main habitable ship (aka palace) for capture. Smaller taxi spacecraft could deliver passengers to planets and wait for the next cycler to pass in order to catch a ride back home. Aldrin's Up-Down Escalators are the most interesting as they offer shortest trip times with better frequency than the Hohmann transfer. Below are results of 4 versions of the Martian cycler orbits that scientist from Purdue university have investigated. These results were used as a reference because no other numbers were available due to the theoretical nature of these orbits. Main drawback of this concept is that delta-v requirements of these highly elliptical orbits are large due to high relative velocities at encounters.

Key Parameter Comparison of VISIT and Escalator Orbits

Parameter	VISIT-1	VISIT-2	Up Escalator	Down Escalator
Frequency of Earth encounters (yrs)	5.0	3.0	2.14	2.14
Frequency of Mars encounters (yrs)	3.75	7.5	2.14	2.14
Earth-to-Mars flight time (yrs)	0.5-3.0	1.0-2.4	0.43	1.71
Mars-to-Earth flight time (yrs)	0.7-3.3	0.6-2.1	1.71	0.43
Earth encounter V_∞ (km/sec)	4.2-4.8	3.7-4.0	5.7-6.2	5.4-6.0
Mars encounter V_∞ (km/sec)	3.7-4.1	2.6-2.8	6.1-11.7	6.6-11.6
Earth encounter distance (R_E)	6.9-SOI	8.3-SOI	1.2-1.9	1.2-1.8
Mars encounter distance (R_M)	1.5-40.7	2.0-18.5	1.3-29.1	1.3-9.4
Midcourse adjustment, 15 years (km/sec)	0	0	1.7	2.0
Max. Earth access ΔV, 14 days (km/sec)*	5.5	5.2	4.8	4.7
Max. Mars access ΔV, 14 days (km/sec)*	2.9	2.2	9.4	9.2

* Sum of ideal injection and rendezvous maneuvers



Up-Escalator orbit.

After much discussion, computations and number manipulations it was decided to got with the easier and more conservative approach of **Hohmann transfer** as it gives a much more precise specification and poses smaller delta-v requirements (even though the cycler could be more efficient in the long run) for the whole mission.

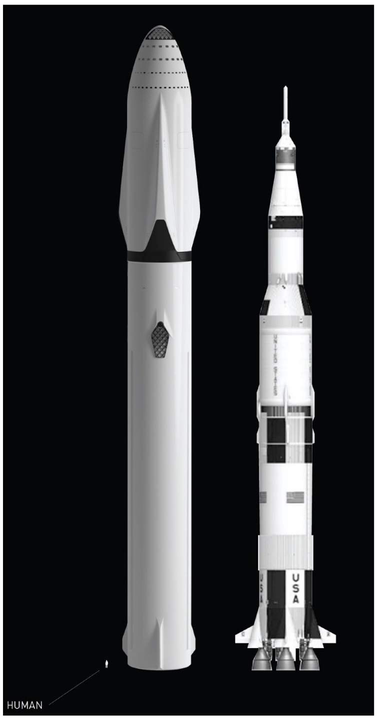
Launcher vehicle choice

Essentially this is where every space mission starts and this is where most of the propellant is being spent. Human space launcher capacity has gotten worse since the Saturn V times and the current technology doesn't even match it. It's not exactly sure how we got here but the political and economical realities are certainly behind this, there is simply no particular need for it nor there is any easy money to be made in space exploration. Luckily there are some brave pioneers that are not satisfied with the current state and have started building their own rockets. Elon Musk with SpaceX are working hard on this task but even Nasa got a "new" launcher coming. Parenthesis are due to re-using of many old parts from the shuttle, hardly revolutionary stuff but hopefully more cost-effective. Here are details of the currently available or planned alternatives.

Launcher	**Availability**	**Tons to LEO**	**Fairing diameter**	**Cost [10^6 €]**
Saturn V	1967	140	6.6	1160
Energia	1987	100	7.75	vodka
Ariane 6	2020	30	5.4	90
Falcon 9 FT	2012	23	5.2	62
Falcon Heavy	2017	54	5.2	90
ITS Launcher	2020	300	12-17	500
SLS	2018	130	8	60
New Glenn	2020	50	7	?
March 5	2016	28	3.8	70

All information has been gathered from their respective wikipedia pages. Green highlight are for currently available vehicles, yellow for those in development and the red ones are discontinued, just as a reference. ITS launch vehicle is the most ambitious one here due to it's insanely low price compared to payload, this is due to plan to reuse the same launcher a 100 times. Other agency's designs (except for New Glenn sponsored by Amazon CEO) are expendable launcher meaning that they are one time use and leave some large orbital debris behind.

SpaceX with their ITS would be the best companion for a Mars travel venture as they are planning to offer the most cost efficient service and huge payload launchers which are especially attractive for the massive fuel tanks and the habitat module. Choosing the ITS option removes worries about logistics micromanagement and there is no need to invent new vehicles for solving them. Therefore ITS preliminary values will be used in the whole vehicle design and hopefully Elon and his team will deliver this monster machine in time because without it Mars colony is a nothing but a dream.



Exact launcher payload fairing dimensions are:

Base radius	**6 m**
Average radius	**15 m**
Max radius	**17 m**
Height	**50 m**
Usable volume	**8000 m^3**

These specifications set an upper limit to how big each individual module can be. This together with maximum payload mass of 300 tons set a realistic constraint on the design that will be used by the vehicle design team as well as others.

Initial design

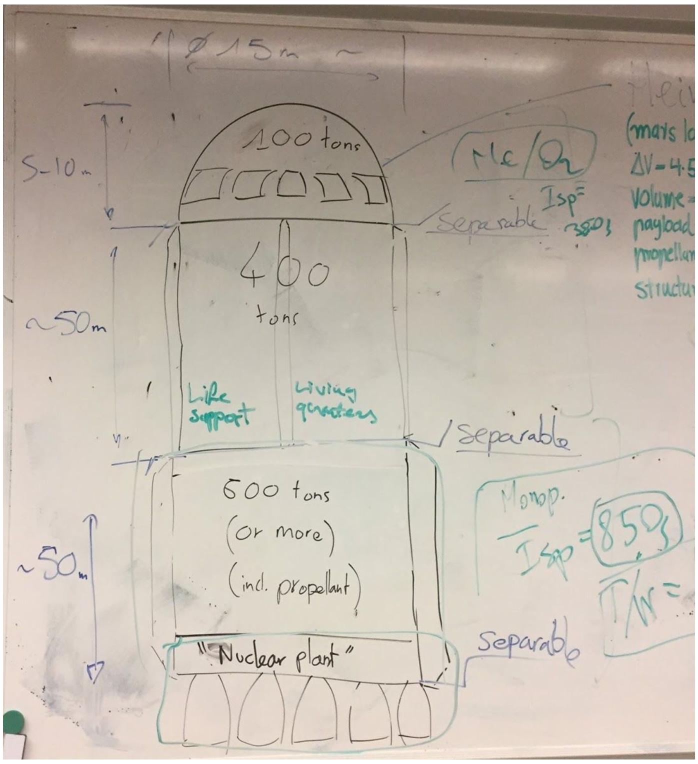
Vehicle concept

With the mission more clear and specified it was possible to begin working on the spacecraft itself. Delta-v requirement is one of the most important numbers here because it determines the overall mass fraction of propellant required. Naturally propulsion technology has to be chosen and therefore work here converges with the propulsion team. Similarly human aspects team will have a lot to say in overall design of living space (habitat), volume requirements and potential artificial gravity implementation. Finally the vehicle should be easily accessible, serviceable and ultimately financially feasible which is something operations and coordination groups would be interested in.

Few decisions were reached fairly quickly and these are:

- ★ Spacecraft will be modular, built from separate parts that could eventually be replaceable or upgradable.
- ★ A lander module will be used to deliver passengers and some cargo to Mars surface as well as bring them back to the orbiting main spacecraft.
- ★ Lander will be refueled on Mars surface since we assume a base already present.

With these few factors in mind it is easier to produce a representative sketch of the spacecraft concept. Below you see a lander of 100 tons, habitat of 400 tons and propulsion module of 500+ tons using nuclear thermal propulsion with Isp in range of 850s.



These initial numbers were based on the use of ITS launcher, capable of bringing 300 tons of oversized (15m diameter) cargo to LEO. Habitat would be put together of at least 2 parts so two ITS launches would be needed. Propulsion module could act as a second stage on the launcher but then would have be refueled at another launch at LEO. Propulsion mass indicated includes fuel. These were only rough calculations to give an idea of how different parts can be sized but naturally these numbers should evolve. Full comparison of available launchers is also performed separately.

Nuclear propulsion for the big spacecraft was hinted at due to its superior efficiency (850-950/s) compared to chemical propulsion. At our given delta-v numbers it would yield total propellant mass fraction of 0.6. Its downsides are low thrust to weight ration due to heavy core and shielding required. Also it's very difficult storing liquid hydrogen propellant and due to that it has never been used for space missions outside LEO. Even though the NTR technology was developed and tested during the 70s and 80s it has seen little use due to fear of launcher nuclear rockets in orbit. Choosing this option for the spacecraft would involve hopes of more public acceptance and research in nuclear technology by 2032, otherwise it would be hard bypassing treaties prohibiting nukes in LEO.

Final mission and vehicle design summary

So in short, construction and full refuelling of the spacecraft (Half tank for lander) are performed @ LEO by using ITS launchers and then the mission can start. After the first burn is finished lander/propulsion and habitat modules undocked from each other while a long tether is extended between them. This will now act as an arm for supporting circular rotation that will create a centrifugal effect on the habitat producing artificial gravity. It will stay like this for the whole 200 days trip to Mars. On arrival the modules are redocked again and perform a braking burn to get into low Mars orbit. Here the habitat is left while the lander proceeds with entry maneuvers and eventually lands on Mars surface in a semi-powered fashion. On the ground the landing and ascent vehicle is refueled and can be used for returning back to mothership or potentially exploring Phobos and Deimos. Refueling for return to Earth can also be performed by a regular ITS or falcon launcher operating from Mars surface, leaving the lander free for more interesting missions. When it is time to leave lander docks with habitat with its refilled propellant tanks and performs a Earth transfer burn. Then the spacecraft can go into the centrifuge mode once again until it is time for Earth arrival burn. At LEO travellers can descend back to Earth with a combination of gliding, parachutes and some retro-burning. Ready to refuel and launch the next mission!

Different parts of the vehicle concept were worked on by different ground members, so that deeper analysis, calculation and cooperation with other groups could easily take place. The following responsibilities were taken up by each group member:

- ★ Lander module in cooperation with propulsion and operations group. (Lukas)
- ★ Habitat module in cooperation with human aspects and operations group. (Aarish)
- ★ Overall structure and integration of modules as well as communication. (Rémi)

Lander module THOR

Transport Humans to Orbit and Re-enter

Ascent and landing module will perform all transportation of passengers between planet's orbits and surfaces. Also the propulsion group requested to have a single united propulsion system and the launcher will carry it all.

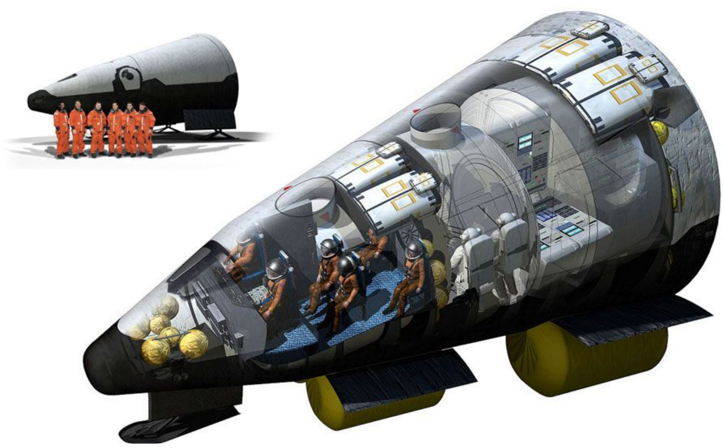
For initial sizing following assumptions were made:

- ★ Payload of 15 tons. (Passengers, their cargo and a rover or two).
- ★ Structure mass of 10 tons (Includes H2 propellant tanks).
- ★ Heatshield mass of 10 tons (Radiatively cooled, re-usable).
- ★ Propulsion system with mass of 10 tons (Nuclear thermal rocket).

This boils down to approximate total mass of 45 tons when dry. Landing on Mars requires much less fuel than ascent due to utilization of atmospheric drag so Mars-bound THOR will have to carry less propellant, making the heatshield "cost" of 10 tons a worthy investment.

Geometry

There are many different configurations for the lander/ascent vehicle, each with it's own pros and cons in various aspects of the mission. The most important design driver was chosen to be vehicle's reentry performance and landing precision due to the extremely precious (40 humans) and dangerous (nuclear reactor) payload onboard. Development and operational costs were deemed less important to avoid the familiar expandable capsule designs that are not very future-proof. Therefore a number of alternatives, from spherical capsule to a shuttle-like aircraft, were compared with the main design drivers in mind.

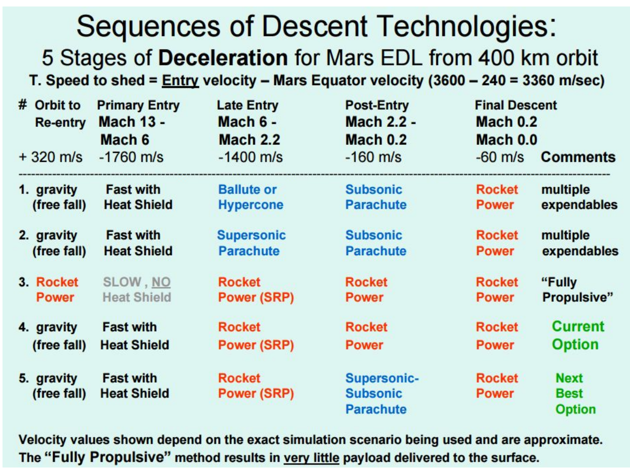


One of the design alternatives is a biconic vehicle that blends shapes of the early symmetric capsules with the modern lift-producing space shuttle.

On comparison it was soon found that a vehicle's lift-to-drag ratio (further L/D) is the most important factor for reentry performance and landing accuracy. As the vehicle enters the atmosphere drag starts decelerating the spacecraft, exposing its structure and payload to massive g-forces. By allowing geometry to generate lift in addition to drag it is possible to minimize these forces and even use them to control the spacecraft (now aircraft), therefore greatly improving landing site alternatives and precision. Lower deceleration also means lower peak heat flux but higher overall heat flux experienced. Capsules typically have high drag and low lift (low L/D) giving a very short re-entry time and experiencing high instantaneous deceleration and peak heat flux levels. Both approaches have their own merits and shortcomings but the lifting body (L/D of 1 or higher) design was deemed more appropriate for a reusable spacecraft design.

	Blunt capsule	Biconic	Lifting body	Winged body
L/D	0 to 0.4	0.5 to 0.7	1.0 to 1.4	1.4 and higher
Maneuverability	Low	Moderate	Good	Excellent
Volume utilization	Good	Excellent	Moderate	Good
Heat shielding	Simple	Moderate	Moderate	Complex
Cost	Cheap	Moderate	High	Very high

This comparison chart is based on information from the Human Spaceflight Mission Analysis and Design book, chapter 12. Given the chosen design drivers it is clear that winged body design delivers the best performance. However in the book horizontal landing at runway was considered. For such landing on Mars the wings would have to be impractically large and therefore powered vertical landing is the only feasible option. Parachutes are another alternative but these are heavy, not 100 percent reliable and not a truly reusable alternative.



Sequences of Descent Technologies:

5 Stages of **Deceleration** for Mars EDL from 400 km orbit

T. Speed to shed = Entry velocity – Mars Equator velocity (3600 – 240 = 3360 m/sec)

#	Orbit to Re-entry + 320 m/s	Primary Entry Mach 13 - Mach 6 -1760 m/s	Late Entry Mach 6 - Mach 2.2 -1400 m/s	Post-Entry Mach 2.2 - Mach 0.2 -160 m/s	Final Descent Mach 0.2 Mach 0.0 -60 m/s	Comments
1.	gravity (free fall)	Fast with Heat Shield	Ballute or Hypercone	Subsonic Parachute	Rocket Power	multiple expendables
2.	gravity (free fall)	Fast with Heat Shield	Supersonic Parachute	Subsonic Parachute	Rocket Power	multiple expendables
3.	Rocket Power	SLOW , NO Heat Shield	Rocket Power (SRP)	Rocket Power	Rocket Power	"Fully Propulsive"
4.	gravity (free fall)	Fast with Heat Shield	Rocket Power (SRP)	Rocket Power	Rocket Power	Current Option
5.	gravity (free fall)	Fast with Heat Shield	Rocket Power (SRP)	Supersonic-Subsonic Parachute	Rocket Power	Next Best Option

Velocity values shown depend on the exact simulation scenario being used and are approximate.
The "Fully Propulsive" method results in very little payload delivered to the surface.

Various Mars landing techniques and their requirements. Option 4 was chosen.

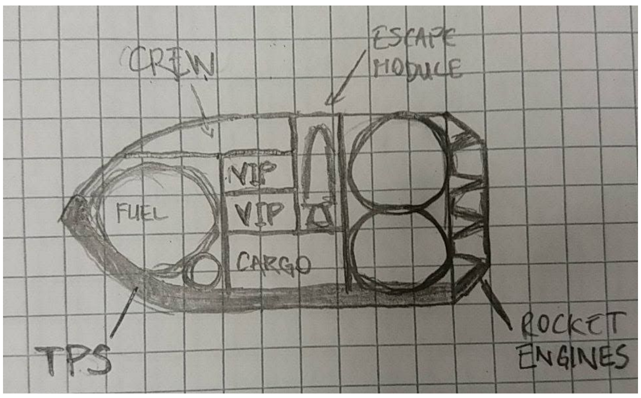
Earth return is quite different due to higher relative velocity at approach, higher gravity and much thicker atmosphere. However since the whole spacecraft will be put into orbit by means of propulsion THOR only need to de-orbit from LEO, just like the space shuttle did with an exception of vertical landing in the final descent phase. In this case it would also make more sense to employ a radiative heat shield that does not melt away like the ablators capsules typically use.

Abort mission

A small escape module could be integrated as part of the passenger and crew space. Usually these are impractical due to the need of an additional spacecraft within the main spacecraft. However given the generous ITS launcher's payload dimensions and already very large hydrogen tanks it would not add that much of additional volume. The escape capsule could be part of the "waiting room" during the ascent and descent phases. This way all passengers could be immediately ejected in case of a critical failure while the crew would only have a chance is the mission abort is planned. Small solid rocket stage could aid in leaving THOR, adjusting orbit, performing ballistic reentry with help of parachutes and landing with help of more solid propellant retrorockets. Heavy g's comes with that but astronauts have managed to survive such ballistic landings before and it is the best alternative.

THOR sketches and simulations

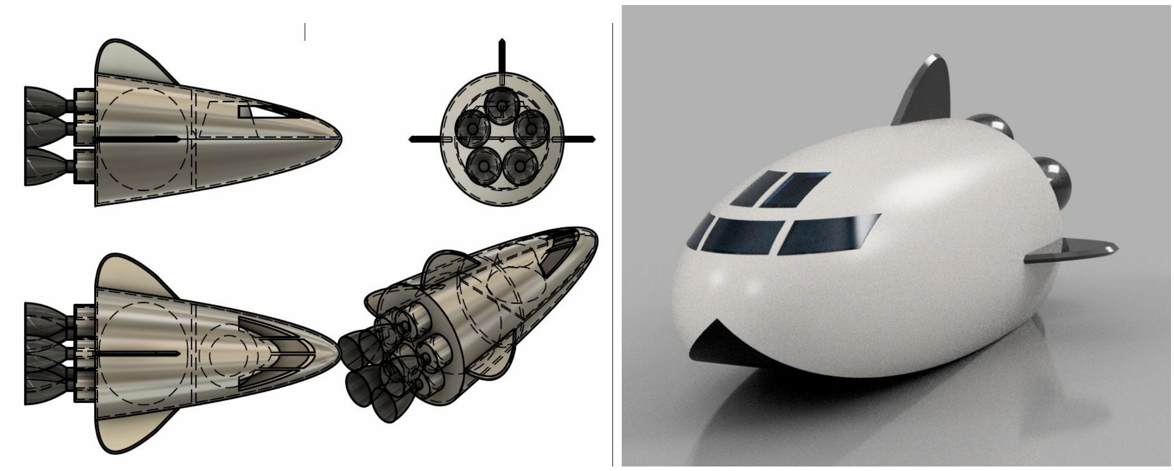
By following the decisions above and adding input from propulsion group it was possible to create a sketch, 3D drawing and a gamified simulation of the spacecraft. This was useful in order to get an overall feel of the spacecraft and find issues that would otherwise be invisible. Below is the first sketch considering the 12 meter diameter, 22 meter length and hydrogen tanks located boft in the front and the rear for better CG location. However it was later calculated that adding small wings in the rear would generate enough lift to balance a rear-heavy spacecraft while at high speeds. At lower velocities THOR will perform landing vertically where aerodynamic surfaces are less important and a low CG is actually a desirable stabilizing feature.



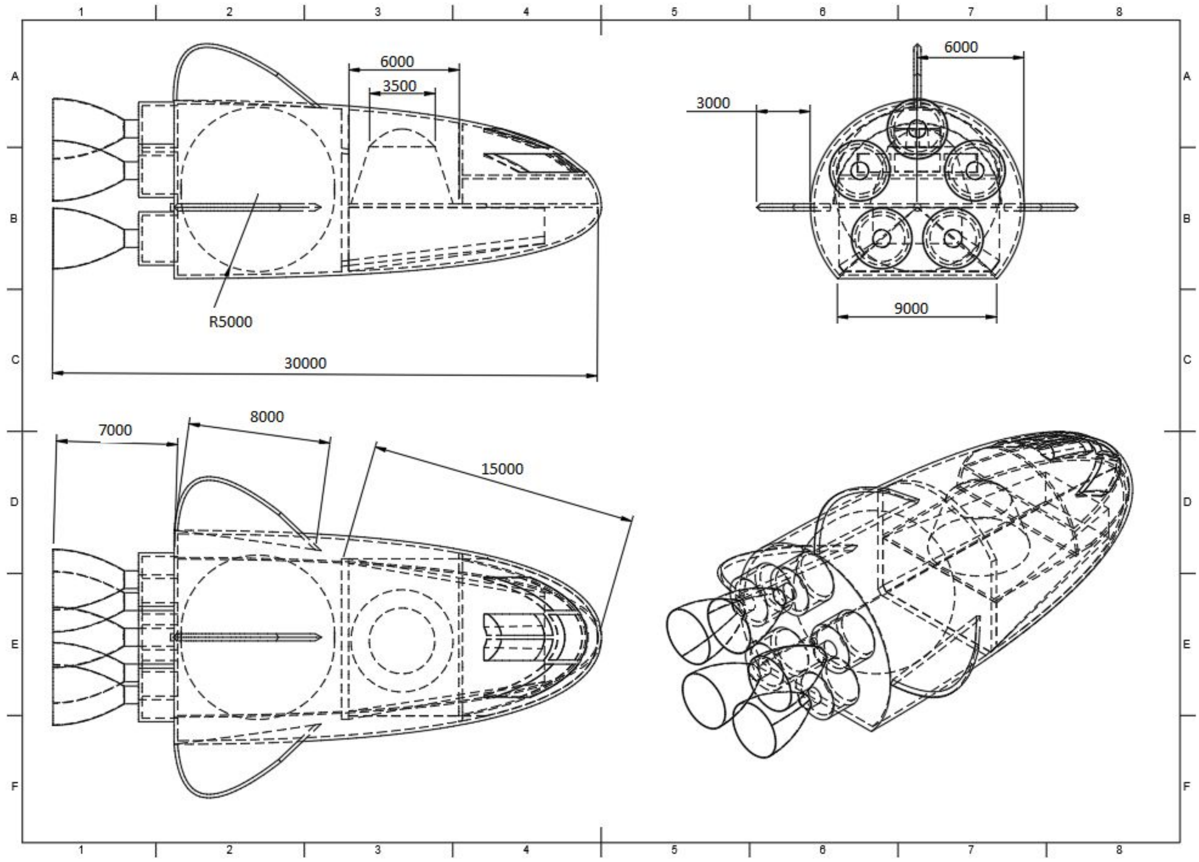
An early sketch on paper.

Complete spacecraft assembly at LEO and LMO.

It was much easier to build a detailed model in a game as most of the necessary parts were readily available. This allowed for simulation of every mission stage, including a successful landing on Mars. 3D Cad model is a much more challenging task as every single part and subsystem have to be draw from scratch. Therefore a simplified model was made just to illustrate how it could look and what it's dimension could be. From this model a 2D drawing was derived where all final geometrical values are given. Hopefully these will provide guidance for engineers at the manufacturing & assembly departments.



Initial drawing vs the final model featuring a flat lifting body bottom part.



THOR dimensions in milimeters. Dry mass is 45 tons, wet mass is 65 tons.

Habitat Module: Overview

The Habitat module is the main living area, designed to fully support thirty passengers and ten crew while travelling between Earth and Mars Orbit. It features nearly 2000 cubic metres of space, divided into living, sleeping, and cargo areas. This gives a relatively large area for day-to-day activities on board. The dimensions and mass of the module are as follows:

- 18m in length
- 113 square meter internal cross-sectional area
- 1922 cubic meters of pressurised volume
- Wet Mass: 171 ton

This module also contains the life support systems, communication systems, and solar power systems.

Artificial Gravity System:

The use of artificial gravity on board the ship negates the dangers of spending time weightless while in space. Long exposures to zero gravity can cause muscle loss and bone degeneration. On the ISS, this is offset by astronauts performing several daily hours of exercise to reverse muscle loss and limit bone damage. However, for passengers this was considered to be too demanding, particularly as there can be lasting bone damage if they spend too long in microgravity. Implementing a system to mimic the effects of gravity on board allows both a more comfortable and a safer voyage for both the crew and passengers. Artificial Gravity is achieved through the use of the separable structures.

Once under way and up to speed, it will be possible for the two sides of the ship to separate, while connected by a strong tether cable. Once extended, the whole ship begins to spin at a constant speed using the maneuvering thrusters, providing artificial gravity. This design negates the high weight and huge size required by most artificial gravity designs. It allows a huge effective radius of spin with only the weight of the cable being added. A large radius of 95 metres is needed to make sure the speed of spin is relatively low, so that the passengers are not affected by the motion of the ship.
The two parts of the ship extend outwards while travelling from Earth orbit to Mars orbit, then retracts when entering the Mars atmosphere. Compared to a traditional ring-shaped centrifuge that has been commonly suggested for Artificial Gravity implementation, this allows for a compact design, is easily manoeuvrable when retracted, and is far easier to launch into space than an immense ring or other proposed solid rotating designs.

Off-Nominal Situation: Cable Snapping

Given that the artificial gravity tether cable is such an important structural component, it is worth giving some thought to what would happen in the extremely unlikely event of it snapping or fraying. This could occur due to debris or micrometeoroid impact, although given that the cable is only exposed outside of Earth’s atmosphere, the chance of space debris impact is minimal.

Given the Habitat Module has its own limited power systems in the form of solar cells, the continued operation of the life support systems is not a huge concern. In addition, the monopropellant-fuelled thrusters that are used to start and stop the spin of the spacecraft are located on both the habitat and the engine module. It is entirely possible to remedy a damaged cable component through redocking the two components in space. This process would be controlled through various redocking modes relating to manual and automatic operation, as well as for various stages of cable damage.

Structural Considerations:

The habitat structure uses various layers in the outer shell in order to provide the required structural integrity, strength, impact and abrasion protection, and radiation shielding. The main material used for the habitat shell is carbon fiber. This allows for significant weight savings compared to aluminium alloy, while providing a stronger structure. Polyethylene is used as a layer to provide radiation shielding, with NASA’s PICA material used as a heat shield for atmosphere entry on Mars.

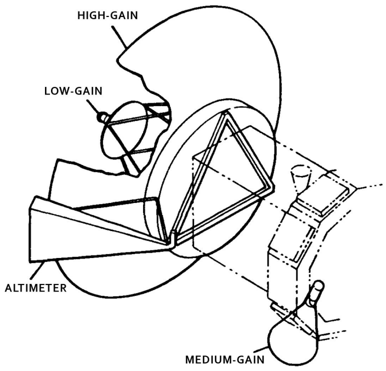
Structural design and communications

Communication systems

High Gain Antenna (HGA)

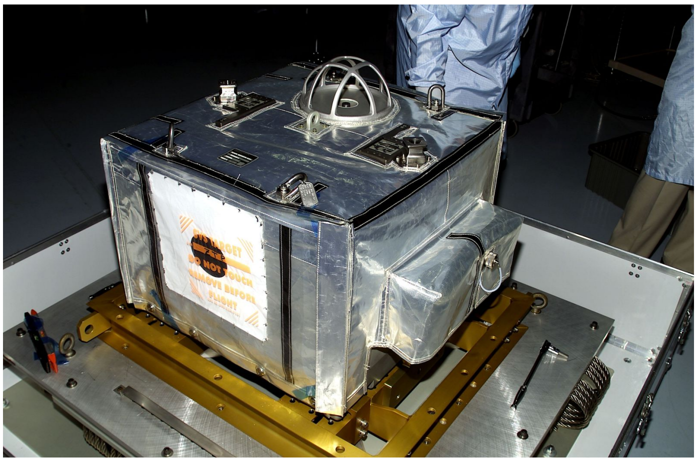
To transmit a lot of information, we have to use a HGA. The antenna will provide a “beam”, so it’s really powerful but directional : you have to aim at your target (the earth), so you have to be able to move your antenna, thanks to a gimbal mechanism.
It need a high power, but have a large bandwidth. The radius of our antenna will be approximately 4m, and the power around 1kW.
On earth, we use the DSP (Deep Space Network) to receive and send datas. Thanks to that, we will be able to stay in communication with earth all the tim.

Low Gain Antenna (LGA)



The LGA will provide an omni-directional beam, but the bandwidth is really lower. It’s useful as a backup for the HGA (if the gimbal mechanism doesn’t work anymore, due to radiations, or failure, you can’t direct it to the target, you will never be able to send information).
They will be used during the emergency situation, like the launch, the assembly of the two spacecraft, or the mars orbit insertion.

Active Charging System and Grounding

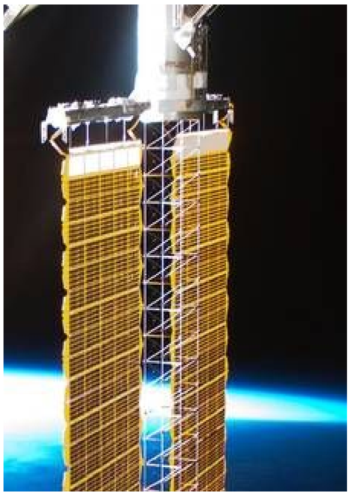


In space, there is a plasma everywhere, surrounding the spacecraft. Due to this plasma, the spacecraft will charge. This is not a problem, while a differential charging doesn’t appear. When the spacecraft present a different charging, there is a possibility of arcing between parts at a different potential. We really want to avoid that, because it can burn or destroy some huge part of the spacecraft.
The differential charging will appear by example when a part of the spacecraft is in the sun, and another in the ombra.
To avoid this phenomena, the first thing to do is to ground all the station.
Then, we will use the same PCU (Plasma Contactor Unit), as actually used on the International Space Station. The PCU will create a “ground wire” to be able to keep the whole spacecraft at the same potential.

Active cooling system

For cooling the habitat module, we will use an active cooling system. It consist of multiple loops of fluid (ammonia), which “collect” the heat from the habitat, and transfer it to the radiator, facing the dark space. Thus, there is a heat transfer between the habitat (human and machine release heat) and the fluid. Then the fluid transfer its heat to the radiators, and those radiators transfer the heat thanks to radiation to the cold space. The radiator are mounted on gimbals to be able to always face the dark space.

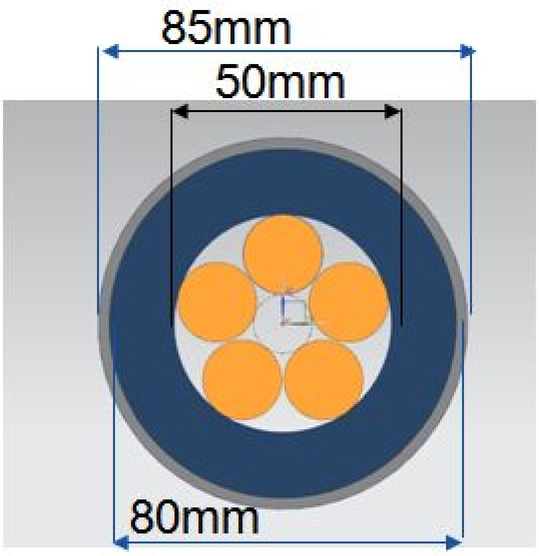
Solar Panels



During the orbital phases around Mars and Earth, the habitat need its own power system. Thus, we will need solar panels. The calculation of it can be found in the "Propulsion and Power part". Here we will discuss about the mounting and the deployment of the solar panel.
So, the solar panels will be deployed during the earth orbit, and when the lander module arrive, they will be retracted. This is done for two reason : as we don't need them during the transfer phase, if we close them we avoid their attrition due to radiation and micrometeoroids. Moreover, they will not be able to resist to the artificial gravity, because it will create a huge momentum at the end of the panel.
The panels will be mounted on gimbals. Thanks to that, they will be able to track the sun.

Cable (connection between habitat and lander)

The purpose of the cable between the lander module and the habitat is twofold. It serves as an artificial gravity tether, as well as supplying power to the habitat module from the lander, where power generation systems are located. In order to achieve this, a hollow steel cable will be used. This allows a strong connection, protects the inner electrical cabling, and features a plastic sheathing layer in order to protect the cable from any possible degradation.



Conclusion

The design of spacecraft for Mars travel clearly requires consideration of many variables, and the end design will always be dependent on the mission profile chosen. The design chosen for this particular passenger voyage required a sizeable habitation space with more comforts than would usually be provided for in space. Use of separate and reusable components for landing and interplanetary transport also allows the design to be modularised for future changes to the voyage. Evidently, the future of human spaceflight lies in increasing the range of our explorations from Earth, and Mars is the next stepping stone in this process. The vehicle design laid out here will allow commercial passengers the chance to venture outside our Earth and experience life on Mars safely and efficiently.

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