Project Report
Red Team - Coordination
SD2905 Human Spaceflight

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Spring 2017

Contents

INTRODUCTION

Team Red was assigned to design the concept for a Mars passenger ship which should serve the purpose of an interplanetary transportation system. The ship should accommodate 30 passengers and be ready by the year 2032. It is assumed that by then already several missions to Mars will have been performed. The Reports main purpose is to give the reader an overview of the Red Teams' overall concept for the mission. It is also investigating mission budget and crew selection. Then, an off-nominal case is presented. Finally, some reflection on political and societal aspects of the scenario is given.

1 Overall Concept

To begin with, one needs to consider the trajectories and distances to overcome in order to arrive on Mars. The distance between Mars and Earth varies between 55 and 400 million kilometers. The Red Team took into consideration two possibilities: A short stay (38 days) and a long stay (544 days) on Mars. The goal was to consume as low energy as possible for the trip. After comparing Δv and travel time for both configurations it was decided to choose the long stay mission profile called "Hohmann". The decisive factor was the very high Δv value to overcome when escaping from Lower Mars Orbit (Δv = 4.11 km/s). This would require more fuel volume and therefore mass. In addition, the travel time for the return trip is reduced by 50% which leads to less radiation exposure time for passengers. The mission time line is presented in Table 1. Table 2 shows an estimated Δv budget for the mission.

Earth - Mars	199	days
Stay on Mars	544	days
Mars - Earth	189	days
Total	932	days

Table 1: Mission profile (Hohmann)

Escape from LEO	3.62	km/s
Mars capture	2.40	km/s
Escape from LMO	2.23	km/s
Earth capture	3.64	km/s
Total	11.89	km/s

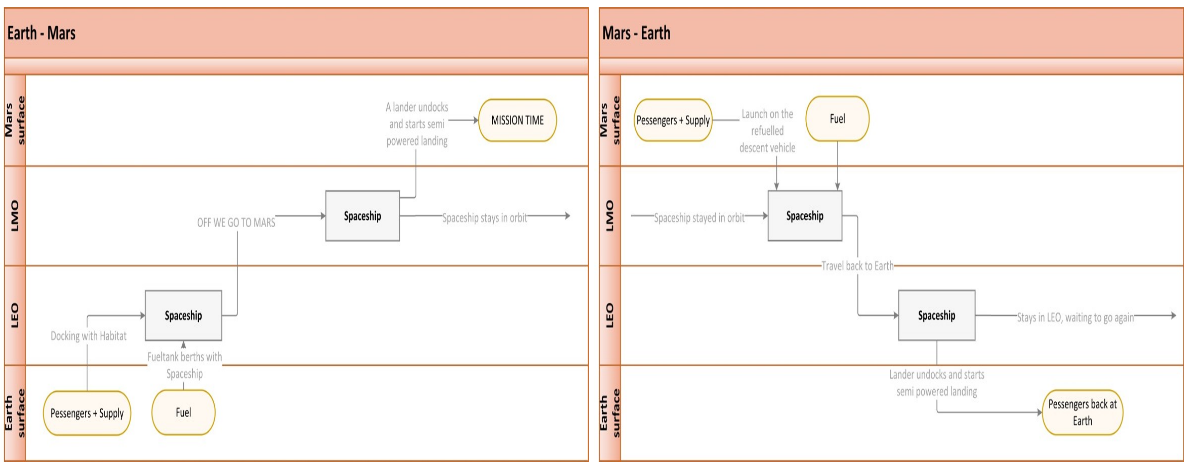
Table 2: Estimated Δv budget (Hohmann)

1.1 Propulsion System

To meet δv requirements the team decided to choose a Nuclear thermal propulsion system for the trip to Mars. More specifically a bimodal nuclear thermal rocket with 25kW per engine. 5 power units are supposed to support a thrust to weight ratio of 2.3. The propulsion system is designed to be two-fault tolerant. This means that even if two power units fail, the mission can still be conducted . A two unit failure would lead to a thrust to weight ratio of 1.4, which is comparable to the initial space shuttle value (1.5). A detailed discussion about the propulsion system can be found in the report of the propulsion subteam.

1.2 Overall mission plan

The idea is to have a main space ship that is used for traveling between planets. It is not supposed to land itself but to stay in the orbit of each planet. When the ship is orbiting in lower earth orbit (LEO) two separate rockets are launched from Earth. One rocket brings all 30 passengers and supply to the ship and docks with the habitat. The second rocket supplies the main ship with fuel by launching fuel tanks into LEO which then berth with the main ship. Both boosters return back to earth. Being ready, the ship travels to Mars for 199 days. Arrived at Mars the ship is inserted in Lower Mars Orbit (LMO). A lander undocks and starts semi-powered landing on Mars surface. At this point the team assumes a passenger handover. After a 544 days stay on Mars, the passengers enter the lander for the return trip. On Mars, in situ propellant production is assumed. The descent vehicle is refueled and launched into LMO to dock with the spaceship again. Another Rocket is launched to supply the spaceship with the fuel needed to go back to Earth. Being prepared, the main ship returns back to Earth. In LEO the lander undocks and starts semi-powered landing. After passenger handover the next trip can begin. A graphical illustration of the described mission plan is presented in Figure 1 a) and b).



(a) Mission plan Earth - Mars

(b) Mission plan Mars - Earth

Figure 1: Overall mission plan

1.3 Human Aspects and Life Support System

Due to the harsh space environment humans, need a pressurized cabin with life support systems to survive in space. As can be seen in the mission timeline (Table 1), life support systems need to be designed for roughly 200 days of journey in deep space. The system mainly uses technology available today. For oxygen production, the Sabatier process together with electrolysis reactors are used. In addition, a reactor for pyrolisis is used to split methane in hydrogen and carbon. The hydrogen can then be reused for oxygen production in the Sabatier process. For water production, a closed loop system is installed with efficiency rate of roughly 90%, assuming a daily consumption of water of 5kg/person. There will be no showers, only rinseless shampoo. Passengers are expected to clean themselves with disposable damp towels. Safety and reliability were driving factors for this decision. Dehydrated food is brought from earth. There will be 2 weeks cycle meals. The passengers can select their menu before launch. Food will be prepared by themselves.

In deep space radiation from Cosmic Galactic Rays is a concern for human health. The total radiation exposure limit was set to 625.5 mSv which corresponds to 10000 chest X-rays. From this a maximum of 100 mSv was set to come from the nuclear propulsion system. A polyethylene material is used for radiation protection (total mass around 50t).

In order to mitigate muscle and bone loss in space, artificial gravity of 0.4g is considered for the main space shuttle. In addition 4 flywheel-based machines with 2 interchangeable bars and 2 low-gravity compatible treadmills are installed in the habitat module.

1.4 Passenger selection

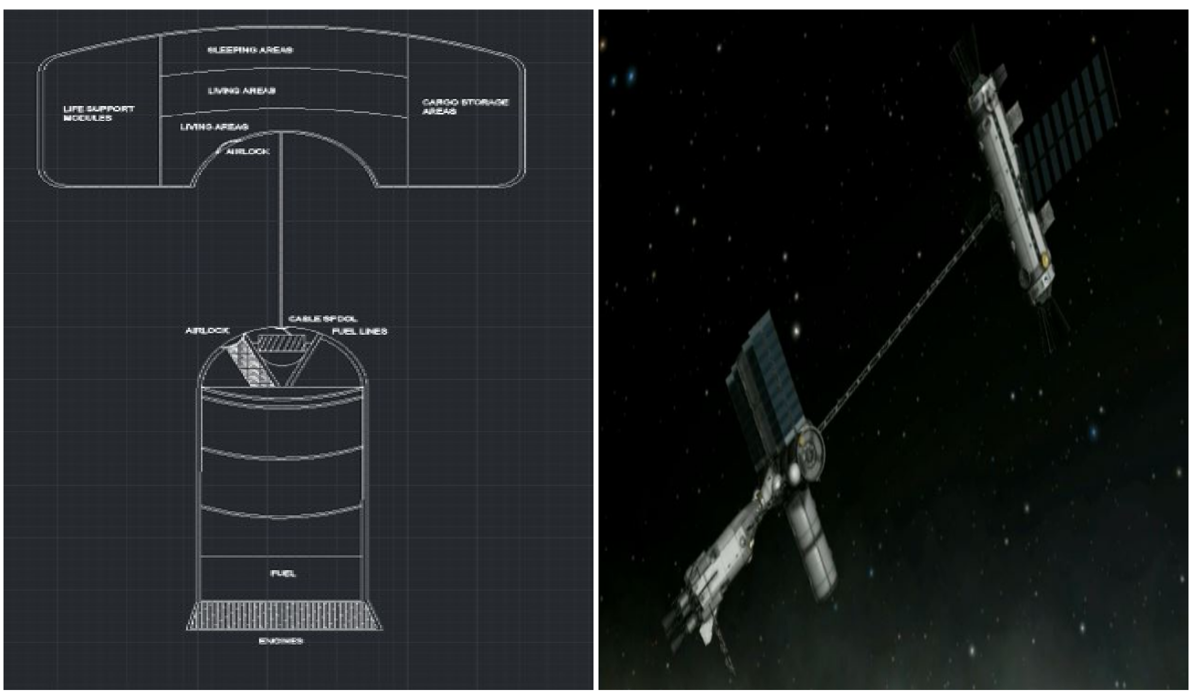
In order to be a passenger on the spaceship one must fulfill the following perquisites:

- 25-40 years old (male or female)
- Good level of English
- Open-minded and social skills
- Medical check-up (by a psychologist, a doctor: check effective dose of radiations, vision, heart and brain condition (epileptic), general health ...) including dental clearance

There is no special educational level required. Couples are allowed. There will be a selection process. All applicants will have to send an online application with cover letter, resume and general information. When passed, an interview will be held in English with the applicant combined with a medical check-up.

1.5 Vehicle Design

To support the mission plan, two vehicles are required. A habitat module and a landing module. The habitat module is designed for the main journey and provides living space for the passengers and crew. The landing module transports all passengers between the planets surface to orbit. As described earlier, the habitat module needs to provide an artificial gravity level of 0.4g. Considering given requirements, the main habitat module was designed and can be seen in Figure 2.



(a) Habitat Module "Valhalla" cross section (b) Tethered design to allow artificial gravity

Figure 2: Habitat module "Valhalla"

The habitat module is called "Valhalla" and consists of a cockpit($2.25m^3$/person), personal cabins ($2.53m^3$/person), logistic rooms ($43m^3$) and common rooms($27m^3$/person).

The landing module was combined with the main engines (5 power units) and is called THOR (Transport Humans to Orbit and Re-entry). Figure 3 shows the concept of THOR.

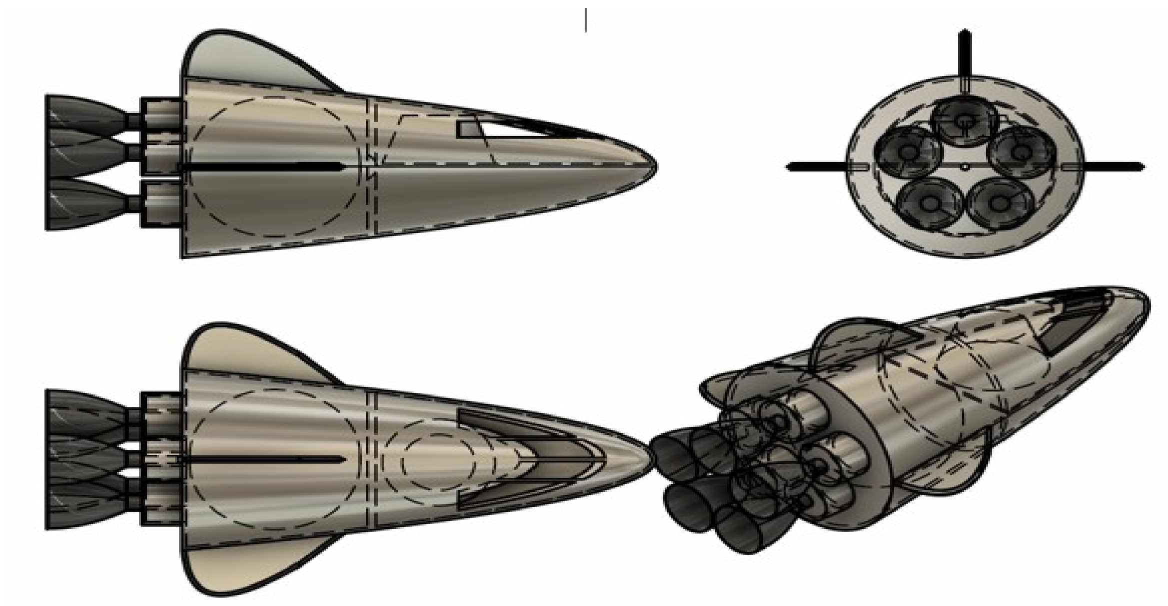


Figure 3: Main engines and landing module "THOR"

2 Crew Selection and Training

A passenger trip to Mars is unique in many ways. Not only that you are going to Mars but also in the fact that you will travel for months in a very cramped space with no ability to turn back or make an emergency stop. This makes the psychological effect on both crew and passengers considerable so when deciding how many crew members that are needed you must take this into consideration. Possible exhaustion due to the long trip is another thing that must also be considered.

First of all the crucial tasks must be handled by at least one crew member and preferably have a backup if for whatever reason the crew member are unable to perform the task in question. So first a list of the crucial tasks we could think of were made. The list layout was inspired by the "Training Challenge - Task Distribution" by ESA [3] but not as detailed with more general fields that include several different tasks under that field this mainly applies to the "engineer" fields in the figures below. After making the list we tried to decide the absolute minimum amount of crew members needed to fill all the crucial tasks without getting to many responsibilities and not being overworked.

Tasks	No of specialists	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Commander	1	C				
Co-pilot	2		S	S		
Electrical engineer	2	S	S			
Propulsion engineer	0		O	O		
Structure engineer	1	O		S		
Trained in EVA's	3	S	S	S		
Medic - Generic	1				S	O
Medic - Psychologist	1				O	S
Safety - Police	1	S			O	
Training	1				S	O
Food consumption	1				O	S

Figure 4: Minimum crew

The minimum amount of crew members needed were after some discussion decided to be five. In the Figure 4. *C* is captain, *S* is specialist and *O* is operator. The captain is the person in charge overall. Specialist has in depth knowledge of the system/task and can perform complex assignments like repairs and troubleshooting. Operator has not as deep knowledge as the specialist but can do some assignments and more advanced assignments with help from a specialist or the control center. The captain and the co-pilots work in three shifts with eight hours in each shift. The medic and psychologist works when needed.

When taking the psychological effect, the risk of fatigue and the fact that the crew are responsible for 30 passengers, five crew members felt a bit risky. Questions that were raised was, can five crew members handle an emergency and the passengers at the same time? If one crew members gets sick or incapacitated can the rest fill in without problem? We couldn't be sure so for the actual trip we decided to go with eight crew members.

Tasks	No of specialists	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5	Crew 6	Crew 7	Crew 8
Commander	3	C	S	S					
Co-pilot	3				S	S	S		
Electrical engineer	1					O	S		
Propulsion engineer	1				O	S			
Logistics/Operations Engineer	1			O	S				
Structure engineer	1		O	S					
Human aspects engineer	1	O	S						
Trained in EVA's	4		S	S		S	S		
Medic - Generic	1							S	O
Medic - Psychologist	1							O	S
Safety - Police	1	S			O				
Training	1							S	O
Food consumption	1							O	S
Time training		36						6	
Prequisite		At least co-pilot status and Masters degree in one of the engineering fields						Medical degree with specialization in psychology	

Figure 5: Crew

This number seems more safe with less workload and higher crew to passenger ratio. In Figure 5 below the list of tasks there is also stated how long training they go through and what experience and skills we expect the crew to have before going through the training. The training consists of a six month basic training where you get to know the ship and the systems on board, basically how to live on the ship. This is all the training the medic and the psychologist goes through. For the commanders and co-pilots the remaining 30 months of training consists of spacecraft controls for both the main ship and the landing module, more in depth systems knowledge and EVA training. After some completed trips you can evaluate more accurately how many crew members that are needed and maybe reduce the crew number if it proved to be to many and some persons became redundant.

3 Budget

A human space mission to Mars would have not only a high demand on technology and development but also a high cost. For the untrained eye space missions have a high cost even for the smallest of satellites but all personnel working in the space business, either private or state financed, know that the complexity involved has a price.

In order to accurately and clearly portray the overall cost of our mission has been split into several categories:

- Development and built cost
- Operational cost
- Launch cost

A missions lifetime of 26 years has been chose because it yields 10 trips to Mars and back thus transporting 300 people. Some other inputs used are: vehicle weight, fuel wight for ΔV required to go to Mars, vehicle weight, personnel on board and ground, time of mission, no cost to refuel from Mars. There have been some projects that have had a high cost per mission overall goal. Two of those such projects have been the International Space Station and the US Space Shuttle Programme. On the other hand Space X is known to have the least expensive launchers. The build cost has been derived from the average cost to build the 7 Space Shuttles[4], the International Space Station [1] and the Space X Interplanetary Spaceship [7], based on price per ton. Some coefficients have been introduced to account for the research purpose technology on-board the ISS and other to account for the fact that the Space Shuttle orbiter was actually a high alpha winged re-entry vehicle and not a conventional ”headlight” shape vehicle. The operational cost has been derived from a broken down ISS operational cost [5]. The launch cost, meaning cost to deliver all payload to orbit, is set only by the projected launch cost of the Space X ITS launcher [7]. The mission is presented in Table 3, in comparison with other vehicles:

	ISS	US Space Shuttle	SpaceX ITS	Red Team	
Price to build	143.9	155.4	1.5	74.8	M$ per ton
Price to build	98	101.8	0.2	16.2	B$ overall
Price to operate	250	330	N/A	200	M$ per year
Price to launch	38	97	0.054	1	B$ overall
Total	138	206	2.8	23.4	B$ overall

Table 3: Project cost comparison

The obtained results project a price of 77.9M$ for a two way ticket. One might think that is a high price but currently the US pays around 75 M$ for a Soyuz seat for their astronauts [8]. Elon Musk said that the Space X seat price might go for even as less as 200 k$ [7]. The total cost if the SpaceX ITS accounts to a 26 year lifetime, with 10 trips to Mars and back as Red Team but with a bit difference: SpaceX will transport 100 people per trip. Our overall project cost has been estimated to be around 23.4 B$ which can be compared to NASA’s yearly budget which was 18.5 B$ for FY 2016 [6].

4 Political and Societal Aspects

Such a trip to Mars involves several potential impacts on human society, and implies that a lot of political powers will probably try to intervene.

4.1 Societal Impacts

Nowadays, most people believe that going to Mars is just a crazy idea and that it will not happen in the near future. The impact of a travel to Mars on society can be even bigger if it comes as a form of surprise for a majority of people.

First of all, a race to Mars by different private companies will be the source of a lot of technological innovations. What happened during the Space Race is a proof of that. Building satellites was not the main goal and yet, today the number of satellites in orbit is impressive. And so is the number of different applications of these: communication, observation, navigation, weather prediction are a few examples. In the same way, go to Mars will probably generate technologies which were not made for Earth at first, but that will have a huge impact on society and on any human’s daily life.

Second of all, going to Mars is really inspirational. Looking at the increase of number of diplomas in Science in the United States during the Space Race is enough to realize that. Humans are naturally curious, and even if some do not admit it, if we manage to reach Mars, everyone will identify themselves to this success of humanity. And this could be what humans need. Find faith in what humanity is able to achieve, believe again in humans’ power, in order to be able to face the other challenges on Earth.

Finally, such an event would unite people on Earth. In 1969, hundred millions of people were watching the first steps on the Moon at the same time. In the movie *The Martian*, millions of people are watching how the astronaut survives on Mars. Well, if humans go to Mars, humans on Earth will probably be interested in their adventure to the unknown, and such an accomplishment will unite people watching the travel.

4.2 Political Aspects

Politics have a major role in the development of technologies related to space flights. A proof of that is the famous Space Race that occurred during the Cold War. If all of a sudden, in only a few decades, humanity managed to go to space and even to reach the moon, it was due to the tensions between the United States of America and the Soviet Union. They both wanted to show their power by accomplishing something that no one had ever done before, something really visible everywhere in the world. And nowadays, since there is no such tension to justify major investments in space flights, the space industry seems to develop far slower than before. However, there are still a lot of different political reasons to keep writing the history of humanity in space, by trying to go to Mars.

One first reason is obviously the same as during the Space Race, but for different countries. It is for example the case of China. China is now known for being an economic superpower, but Chinese decided to also show their technological and scientific power. And in a certain way, they succeeded, since they managed to send the first Chinese in space in 2003. They also have their own space station (Tiangong) and their own crew vehicle (Shenzhou), which is nowadays the only crew vehicle working with the Russian Soyuz. So going to space and managing to stay there is still synonymous of scientific power, which can be an important reason to invest in the space industry.

Another reason for a country to invest to go to Mars could be a cultural one. The United States for example, have tried along their history to be, or at least to look like a country of pioneers and progress. It was the first country to send humans to the moon for example. To improve what some call their “soft power”, that is to say, their cultural influence over the world, they could also want to be the first country to send people to Mars. As a consequence, there are a lot of potential investors to finance our project.

Then, from a more practical point of view, there could also be an economic interest. Not in the near future because the costs to go to Mars are for now way too high, but maybe later. That is one of the reasons some private companies, like Space X, are working on a project to go to Mars. Imagine a company that would develop its technology in such a way (for example using a new propulsion system to make the trip to Mars shorter) that they can develop a form of space tourism to Mars, and be the only one to provide this kind of service. That could be the source of huge benefits, which also is a motivation for a Mars project. Moreover, it could have the same effect than the Apollo missions in the US and stimulate economic growth.

A final reason to go to Mars and try to colonize it on the long-run is, as Elon Musk said, to have an “insurance policy”. Something could happen to Earth, any big catastrophe, that could put an end to humanity. In this case, the best would obviously be to have already colonized Mars, in a way that humans could keep living there without any resupply coming from Earth. Then, even if humanity ends on Earth, humanity will keep existing on the Red Planet.

Nevertheless, if private companies succeed in going to Mars and want to start to colonize it, some questions have to be raised. What kind of pressure will governments and states that may have partially financed this project exert on these companies? If we succeed in going to Mars, it is hard to believe that they will have no conditions, like taking a certain person there, or conditions on the form of governance that should exist on Mars. This is another point that should be thought before going. If it is decided to start colonizing Mars, will all the humans on Mars be free to do whatever they want? What will be the laws that will apply there? Will there be a form of government? Thus, there are a lot of important issues related to taking humans to Mars.

5 Off-Nominal Case: Crew member or Passenger having psychosis or anxiety attack

With such a long trip of going to Mars,probably a strange feeling of solitude and boredom, the human mind can react in weird ways. Several experiments have been conducted on this matter and one experiment carried out recently that got a lot of attention was the "Mars-500" [2]. In this experiment the object was to simulate a Mars trip and how the six persons selected for the experiment reacted. The experiment moved along without incidents although problems with sleeping, isolation and other peculiar behaviour was recorded after. During regular flights there are several incidents reported on passengers having panic attacks and trying to open doors during the flight, being aggressive or just making the other passengers uncomfortable. So the risk of this happening on a Mars trip is real even though the passengers goes through a screening and the crew has extensive training.

So if a passenger has a psychosis what do you do? First of all the most important thing is to get the person under control. By violence or other methods you must stop the person before doing harm to other persons or crucial systems on board. After the person having a psychotic attack is under control you must confine the person for the duration of the psychosis. Do you confine the person for the entire remaining duration of the trip or just until the psychosis ends? This depends of course on the evaluation of the psychologist and the amount of discomfort other passengers and crew feels towards having this person around them since the person can be deemed untrustworthy. So it is a case by case decision.

Important steps in preventing such an incident to occur is to keep track of the state of mind of the crew and passengers. Talking regularly with the psychologist, and family for the passengers and also the ground control for the crew and of course among themselves. A more severe incident would be a crew member suffering from a psychosis or anxiety attack since this would have an impact on the operations of the ship. The worst case scenario would be if the psychologist himself had such an event since he is the expert on how to handle situations like this or the captain since he is supposed to be in charge. If this would happen the rest of the crew must fill in for the person impaired by the effect of the disorder by the best of their abilities until that person can function normally or until they land safely.

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