Human Spaceflight

Mission to Mars

Operations & Logistics

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ABSTRACT

The aim of this report is to make a conceptual mission to Mars possible from an operation and logistics point of view. The space craft designed is supposed to take 30 passengers and a crew from Earth to Mars and back, safely. It's supposed to be ready for take-off year 2032 and survive multiple trips. It's assumed that human missions to Mars has been done before with some infrastructure needed already existing.

With the given assumptions, the operations and logistics revolved around the route & time for the mission, operations around planets and the overall communication. The chosen route involved a Venus fly-by and lasts for 540 days including 30 days stay on Mars whilst the operations around planets involved the launch and the landing. The modules for the launch were chosen by the Vehicle & Concept group and the landing capsule chosen for the mission was a modified version of the Orion space craft. Costs for all operations and logistics were roughly estimated to be around 2 billion USD.

A short off-nominal case is also presented in the study which would be a communication failure. Therefore, extra equipment is brought onboard for redundancy.

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1. Introduction

Since the dawn of humanity, mankind has always sought to reach the horizons and thrived in an environment made of challenges. With space crafts like the Hubble Telescope and Chandra X-ray Observatory, the sky is no longer is the limit.

This project has the limit set on Mars. A team of about 20 people, divided into 5 smaller groups oversee coordination, vehicle & concept, propulsion, human aspects and operation & logistics to make the mission come to life.

The operations and logistics role was to design the mission route, include operations around planets and the overall communication system. First, the mission route was designed in order to optimize the number of trips to Mars. Thereafter the operations around the planets could be decided to gain better understanding of the different parts of the mission. Lastly the internal and external communication system was presented. Mass, power and costs have been roughly estimated with available data. And an off-nominal case of potential loss of communication was presented with a suggested solution.

The infrastructure including inflatable habitats, farming[15][16] and other necessities on Mars is assumed to already exist since other human Mars missions is an assumption.

2. Route & Time

2.1. Long stay

For a long stay, the way to go to Mars with a manned spaceship is by using a conjunction class trajectory, which means that the transfer takes place when the Earth and Mars are in the same side of the Sun. This route is following a Hooman transfer between the Earth and Mars, with a total mission time of 900 days[3], *see figure 1* for trajectory. This time includes the trip to go to Mars (260 days), the time the for the stay on Mars (about 500 days) and the trip to come back to Earth (260 days). With this route, the spaceship IMS Trident would have to stay one year and a half orbiting Mars without doing any operations.

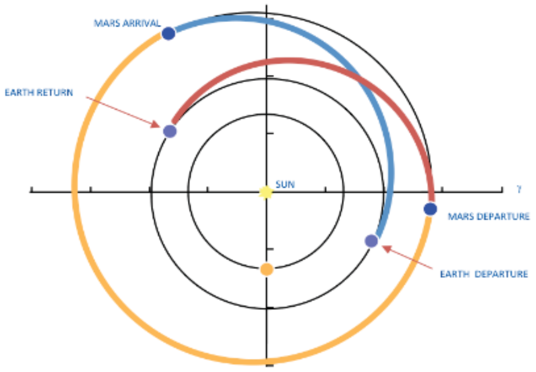

Figure 1: *The Conjuction Class trajectory*

2.2. Short stay

The second choice of route for the spaceship to go to Mars is using an opposition class trajectory from Earth to Mars[1][3], *see figure 2*. This route is possible when Mars is ahead by 75 degrees on its orbit compared to Earth. A Hooman transfer is also used for this case to go to Mars but the time to go there is reduced slightly from 260 days to 220. The biggest difference between the Long and Short Stay mission is that the time left on mars is only around 30 days compared to the 500 days, which means that the spaceship would only stay in orbit around Mars for $^1/_{16}$ times the one of the long stay. The return trip is lightly longer, around 290 days, and involve a Venus fly-by to get some gravity assistance.

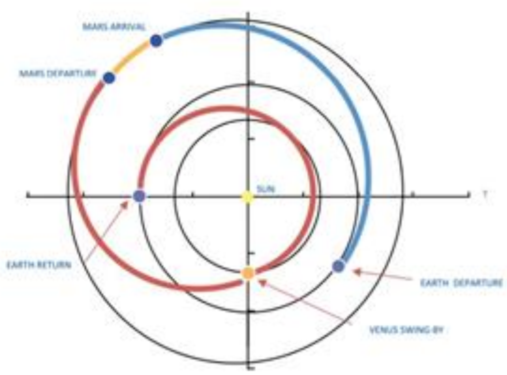

Figure 2: *The Opposition Class trajectory.*

2.3. Route choice

As our mission is a commercial one, by transporting passengers to mars back and forth, the short stay mission has many assets. The first one is the time of the mission. With the Long Stay route, the total mission duration is around 900 days, with half of this time spend on Mars. On the contrary, the time spent around Mars by the Spaceship would be 30 days with the Short Stay route. When this could be a huge drawback for one-time science-oriented mission, it is a big advantage here, because multiples trip can be achieved in a shorter period. However, the short stay route implies a Venus fly-by, which means that the spaceship and the passengers will be exposed to high doses of radiation during this part of the trip. Hence the ship will need additional shielding to protect the passengers from it. The shielding for the chosen stay by the team is presented by the Vehicle & Concept group.

To conclude, the opposition class mission has been chosen for our commercial mission, mainly because of the time of the mission since the short stay route allows more mission to be done. The passengers will then go to Mars, spend around 30 days on Mars and then return to Earth with the next mission, *see table 1* for details of the time duration.

2.4. Launch Window

Since the opposition class route has been chosen, the next step is to study the launch window, i.e. when can such a mission be launched from Earth[4]. As specified in the previous part, the trajectory used is a Hooman transfer. To meet the planet Mars, the spaceship must depart the Earth at the right time, so energy can be saved and no extra maneuver needs to be done approaching the planet. For the route that have been chosen, Mars should be ahead by 74 degrees on its orbit relatively to the Earth when the spacecraft initiates the first Hooman maneuver[3]. Thus, such a configuration is available every two years and two months. Another parameter is how long the launch window will last. For this kind of mission, it will last approximately three weeks. It means that in case of a bad weather for example the launch can be retarded or advanced during this period of three weeks. On the way back to Earth, the same principle occurs. The most efficient way to go back is to depart Mars thirty days after arrival if everything is on schedule. If not, the date of departure can be readjusted to keep the minimum energy trajectory, and thus the duration of the stay on Mars may vary if it needs to. As explained later in this report, the passenger transfer is very efficient and quick. Thus, an anticipated departure from Mars can be rescheduled at any time.

Finally, the main figures of the trajectory of the mission for the IMS Trident spaceship are presented in the table below.

Table 1: *The chosen duration of the mission.*

Trajectory Class	Duration
Earth-Mars travel time	220 days
Time Spent on Mars	30 days
Mars-Earth travel time	290 days
Total Mission time	540 days
Launch Window	Every 2years & 2 month

3. Operations around Planets

3.1. Operations around Mars and Earth

First, the two propulsion modules chosen by the Propulsion group, the hydrogen tank and the Deep Space Habitat (DSH) are launched separately and assembled in High Earth Orbit (HEO, 407-2100 km). The unmanned ship will dock to a Solar Electric Propulsion system (SEP) as shown in *Figure 3*, which has been sent in HEO prior to the different ship parts, providing power to spiral to a Lunar Distance Earth Orbit (LDEO, 407-380000 km). Because the crew and passengers is not launched until the stack is assembled, the time constraints on the positioning of elements are not as significant as for the crewed portion of the mission. The crew will be set to space in an arranged 20-people Orion capsule to LDEO directly and dock to the ship before Mars departure. The coast will last 177 days until Mars orbit is reached. The choice of a LDEO orbit is motivated by a lower required ΔV to escape Earth gravity using this highly elliptical orbit[4].

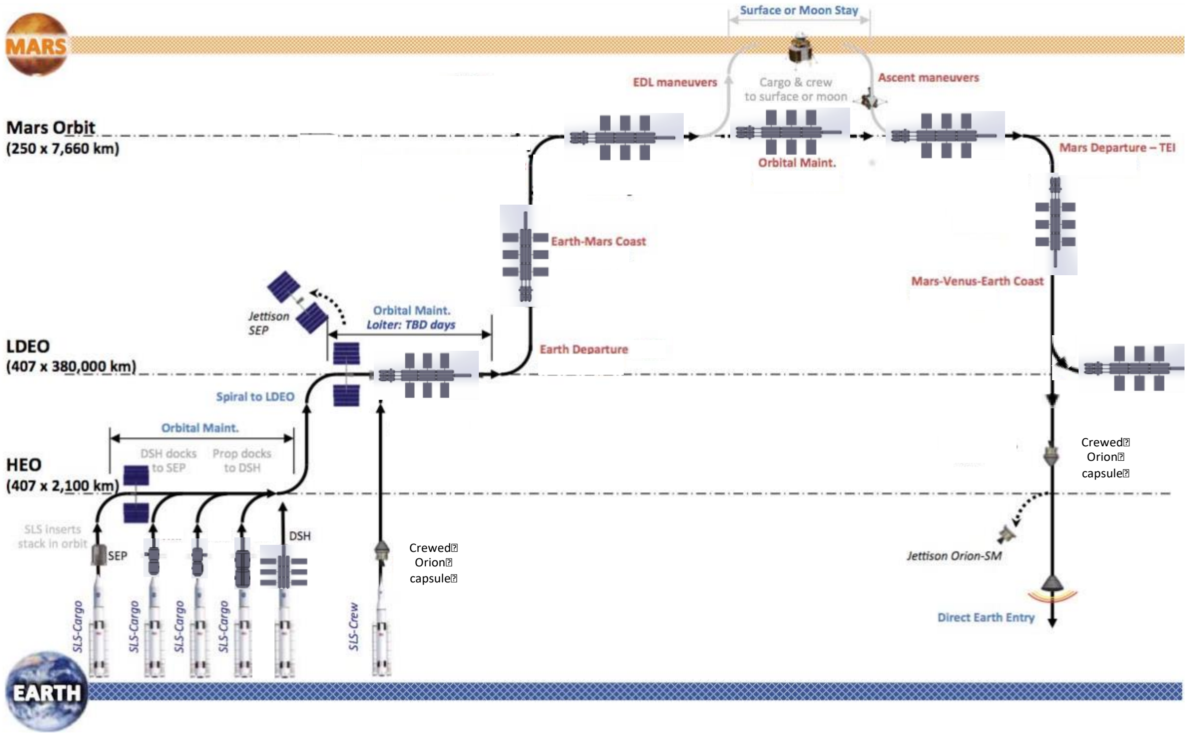

Figure 3: *An illustration of the mission operation.*

A total of six Space Launch System (SLS) Block 2 launches are needed: one for the SEP system, four for the spaceship, and one for the crew.

The cost is estimated to be about 0.5 billion USD per launch[4] and for six launches it adds up to 3 billion USD.

3.2. The Orion capsule 2.0

The spaceship IMS Trident will travel and dock between space ports that will be in orbit around Earth and Mars. The capsule transporting people from Mars space port to the surface of Mars will be a modification of the spacecraft called Orion capsule[5]. The NASA Orion Multi-Purpose Crew Vehicle (MPCV) is designed for four people, see *figure 4*. It's assumed that the technology will enable this MPCV to transport twenty people by the time of the departure of the mission. Therefore, two trips are needed for the capsule to transport the whole crew.

It takes 2 hours from ISS to Earth
and 6 hours from Earth to ISS. Using this data as a reference for the landing operation, it would take about 8 hours for all passengers and crew to reach the surface of Mars.

The Orion capsule will be launched with SLS technology as well.

The cost for one launch is estimated to 1 billion USD[4].

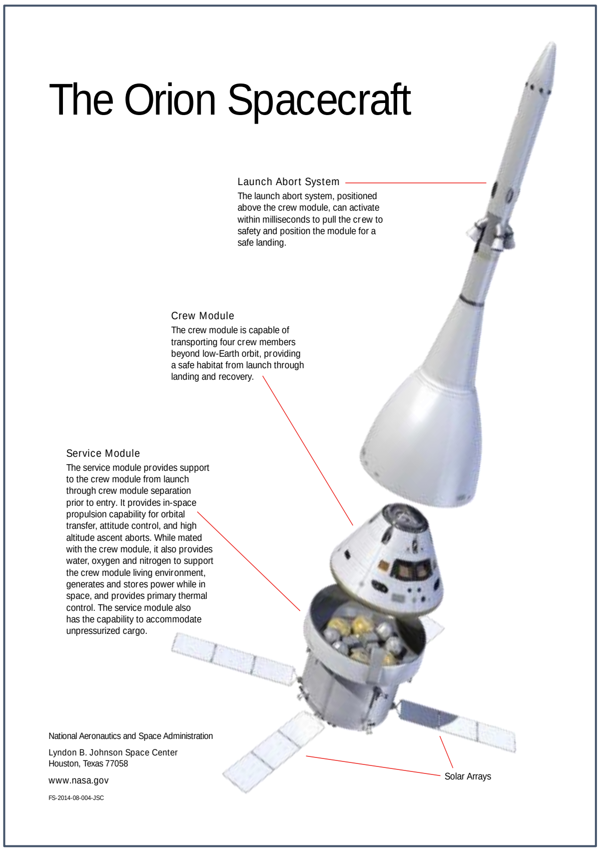

Figure 4: *The current Orion capsule layout.*

4. Communication

4.1. Internal & External Communication

A communication system is a necessity for all kinds of audio, video and other data transfer. The "internal communication" (IC) refers to communication within the spacecraft, amongst the crew and passengers for the whole cruise, including a potential Extra Vehicular Activity (EVA). The IC is assumed to demand a neglectable power and cost since the power needed depends on distance and the distance within the craft is a lot smaller than the one from Earth to Mars.

The "external communication" (EC) refers to communication with ground control (GC) on both concerning planets and contact between passengers and family, friends etc. Since it's assumed that human missions to Mars have been done before this tourist-mission, two things are vital for the EC. The first is a pre-established infrastructure on Mars in form of GC on both planets. An international base structure for communication between Mars and Earth already exists on Earth, NASA's Deep Space Network (DSN), it makes GC on Earth possible. The current DSN is also used for navigation for the spacecraft as it tracks the spacecraft motion and uses X-, S- and Ka-band[7]. A band is an interval of frequencies, *see figure 6*.

DNS satisfies the needs for both IC and EC. To compensate for Earth's rotation, 3 bases exist in Spain, Australia, and US (about 120° apart) to make sure that continuous EC and observation is possible[6], *see figure 5*.

The only thing missing right now is the GC (with DSN antennas) base on Mars which is assumed to exist in time for the mission. The GC on Mars will probably need to be scattered all over the planet in the same way as on Earth as Mars become more and "colonized". Because of the varying distance from Earth to Mars is 100 to 400 million km, there's a delay of 3-21 minutes which makes real time or interactive communication impossible. With GC on both planets the delay time can be cut in half and docking at space ports can be done with direct interactive communication with GC to increase security.

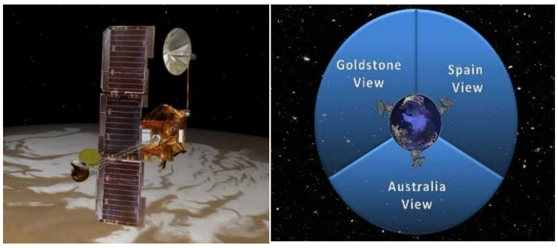

Figure 5: *A picture of Odyssey on the left and the DNS bases on Earth to the right. Pictures taken from [5] [13].*

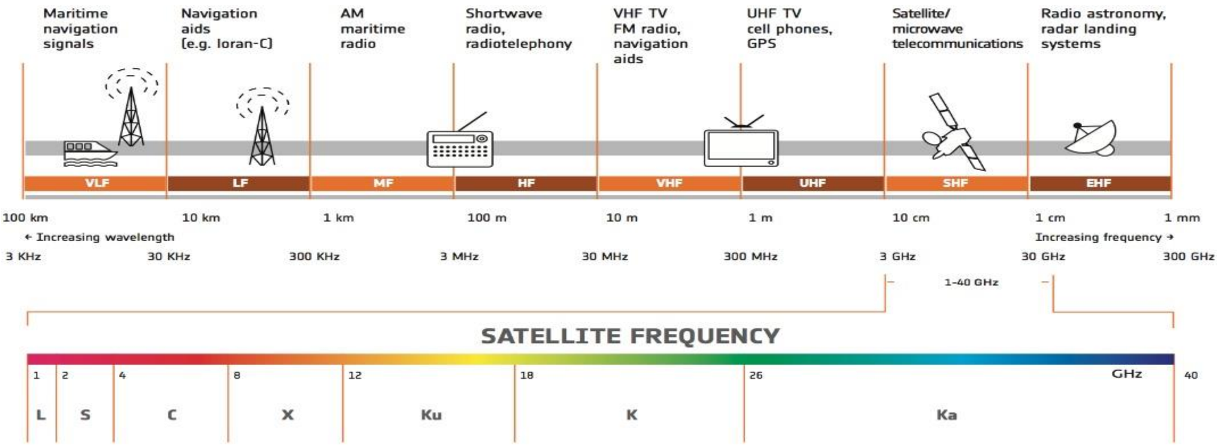

Figure 6: *An illustration of frequencies used by different technologies. Figure taken from [12].*

The second vital assumption is that a couple of satellites orbit Mars in the same manner that the telecom satellites orbit the Earth. Three existing spacecraft orbit Mars right now, ESA's Mars Express, NASA's Mars Reconnaissance Orbiter (MRO) and Mars Odyssey. Communication from Mars to Earth can be done from these.

Odyssey was launched 2001 and has been orbiting Mars since, *see figure 5*. Though the main mission for this craft was to detect thermal radiation in search of evidence of water, it works for communication between the Mars Science Laboratory (also known as the Mars Rover or Curiosity) and Earth as well[5]. All 3 Mars obiters do.

Curiosity communicates with the help of 3 antennas, one Low Gain Antenna (LGA), one Ultra High Frequency (UHF) antenna and one High Gain Antenna (HGA). Antenna gain is a property of antennas. It combines direction capability and electrical efficiency. In other words, it's a way to measure how well the conversion of input power to radio waves is[11]. LGA is for Direct from Earth (DFE) contact and is used near Earth, it needs to be directed towards Earth for data transfer while HGA is for Direct to Earth (DTE) contact. The UHF antenna is for both receiving and sending data to Earth via the Mars orbiters, *see figure* 7 for schematics. LGA and HGA uses the X-band with the power consumption 15 W during DTE contact and can download data with a rate of 800kbps for download and 100kbps for upload[6]. Although the rover only sends 30 Mb twice per day.

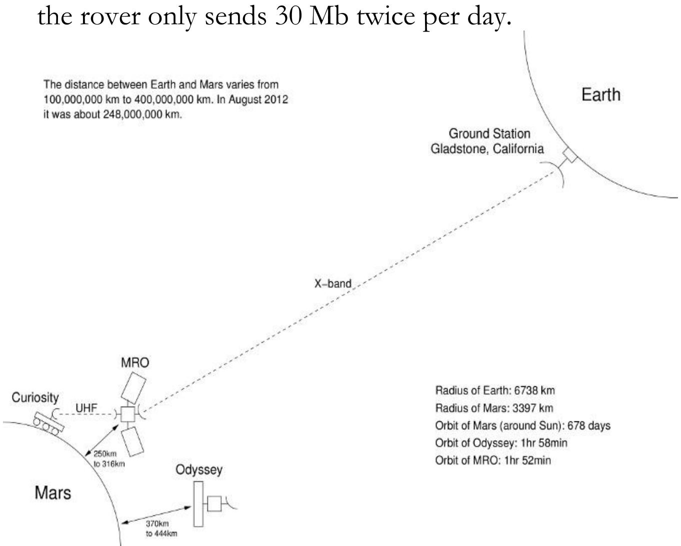

Figure 7: *An illustration of how contact between the Mars rover and Earth is accomplished. Figure taken from[9].*

MRO was sent to conduct science experiments concerning climate and geology on Mars, find water and act as a communication relay for the rover. It's in an orbit at about 250-316km, *see figure 7*. It has four antennas, two of them are LGAs attached to the one HGA that operates in X-band for Earth communication during launch, cruise and orbit in form of a parabolic dish antenna. Another one operates in Ka-band to handle performance data without receiving data. A third one is a UHF antenna for communication between rover and MRO. MRO can transfer data of X-band with the power consumption of 100 W. It can send 500 kbps DTE when the signal is at its weakest point. The signal gets weaker as the distance gets larger. When the signal is strong it can send 6Mbps with a 16 hours transfer window. MRO can allocate 5 GB data per day.

Odyssey works like a back-up to MRO at an orbit of 370-444 km, *see figure* 7. It has one UHF antenna and three X-band antennas with the power consumption of 12 W. It can send 128-256 kbps DTE and receive 4-8 kbps[9]. The antennas have the same functions as the antennas on MRO, *see figure 7* for schematics. The spacecraft for this mission will use a HGA for EC based on Odyssey and MRO.

4.2. Costs and other Estimates

A mass estimate for all communication equipment onboard the spacecraft needed is performed. It includes a HGA, a pointing mechanism for the HGA, control box and communication devices and sums up to about 200 kg. This value includes extra equipment in case of the off-nominal case presented in section 6.3 below. The communication devices can be anything, for example a tablet, a smartwatch or even shades like Google Glass (includes a small touchpad on one side for control, a HD camera, and a liquid crystal on silicon-base display).

A power estimate is done very roughly. Since MRO can process 5 GB data every day, the ship should be able to comprehend at least the same with the various speeds presented for the MRO and Odyssey transfers, if not faster by 2032. If the transfer rates are higher, more data could be processed. With ISS communication upgrades, video and payload (scientific) data can be transferred with a download rate of 300 Mbps and an upload rate of 25 Mbps[10]. Although the spacecraft is at a greater distance than the ISS and the more data processed, the more power consumed. The Mars rover sends 30 Mb 2 times a day (so 60 Mb data per day) with 100 W per day[6]. A linear approximation between data processing and power required is made. The power required for 5 GB data transfer (5000 Mb) is therefore assumed to be about 88 kW per day with 5% marginal. The value shouldn't be too unreasonable since a 747-Boeing (small) aeroplane has engines that can generate 150 kW. 5 GB data can consist of 5 hours HD video which would give about 8 min HD video per day, per person. If you have audio or other data, you'd get more minutes.

The cost estimate for the communication equipment and operation onboard is done with the help of a study done on communication for a Mars fly-by mission by the Aerospace Corporate Department of Communication in USA year 2005. The most likely cases presented in the study cost 10-50 million USD[8].

The cost estimate for GC is made by assuming that 100 people are working on GC on both planets with 5300 USD monthly pay for the mission duration time (540 days or 45 months) and a marginal of 5% gives about 25 million USD.

4.3. RISKS

The "off-nominal case" for communication failure (during cruise, EVA etc) can have fatal consequences and regards the loss of both IC and EC. In case of some or all loss of communication, extra equipment is brought on board the spacecraft for redundancy. The extra equipment includes emergency equipment in form of walkie talkies as a temporary solution for IC.

A reason for communication failure can be solar conjunction, that's when the Sun is between the Earth and Mars, *see figure 8*. It can and probably will cause problem. A possible solution can be to put a satellite in orbit around the Sun. A satellite orbiting the Sun could be used for future star research too and therefore be multipurposed.

Although this is hard since the environment and radiation close to the Sun is tough to work with and since a Solar conjunction only lasts about 2 weeks every second year one might consider it unnecessary. Although since a Solar conjunction can destroy communication equipment, extra equipment should always be onboard for redundancy.

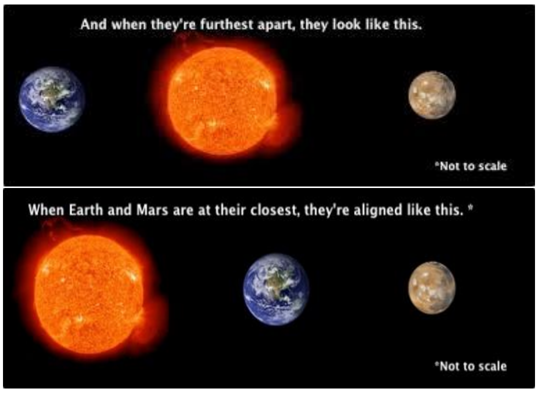

Figure 8: *An illustration of when the distance between Earth and Mars is smallest and greatest and longest. Figure taken from [14].*

5. RESULTS & CONCLUSIONS

The obtained results for the various operations and logistics can be seen in *table 2 and 3*.

Table 2: *A summary of the cost estimates made.*

Description	Cost [USD]
Launch Operations	3 billion
Landing Operations	4 billion
Communication equip.	50 million
Ground Control	25 million

Table 3: *A summary of the other estimates made.*

Description	Value
Mass of com. equipment	200 kg
Communication power	88 kW

As seen in table 2 and 3 the mass is 200 kg and the power needed for the communication is 88 kW whilst the total cost is about 4 billion USD. These values are neglectable compared to the total mass of the ship, 1500t and the the total mission cost of about 400 billion USD. The power required should be met since the chosen propulsion system by the team is nuclear based.

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