**Final Project Draft**

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# Acronyms and Nomenclature

DSN – Deep Space Network

BWG – Beam Wave Guide

BER – Bit Error Rate

FOM – Figures of Merit

DOD – Depth of Discharge

BOL – Beginning of Life

RTG – Radioisotope Thermoelectric Generator

HGA – High gain antenna

MGA – Medium gain antenna

LGA – Low gain antenna

Mbps - Megabits per second

# Overview of approach

The first step in this procedure would be to identify all constants in both the power and communication problems and verify that all numbers are correct. Then, gather all of the appropriate equations needed to solve the communication and power problems and identify all possible variables that need to be solved for. Use the orbital mechanics study when calculating power requirements. Identify all design variables and reason what course of action to take on each variable, using a combination of the FOM and reasonable factors. More detail can be found in the design variables section of this document, if more information is needed. The next step would be to solve for the required power for transmitting signal from mars and minimize the mass for the orbiter using common minimizing techniques for the appropriate variables. Once mass of the orbiter is at a minimum value, the Monte Carlos simulation will be run to verify that the transmitting signal will be able to be received with a high level of confidence. Then any remaining mass left can be used for the mass of the lander.

# Design variables

## Communication design variables

In this trade study, maximum tolerances are used to calculate the needed equipment for communication and power. The maximum distance from the Earth to Mars will be 2.52 AUs away, which will only happen a fraction of the time, but since the Figures of Merit put Scientific data return as the highest priority, the sizing of the communication system will use this distance for calculations. Communication with Earth from the orbiter will need to be through the Deep Space Network, which restricts what frequencies that are used. There is also another restriction which states that all future space missions will not be allowed to use the S-Band carrier frequencies, which forces this craft to use X-band or Ka-band. For this mission, since the transfer bitrate is low X-band will work, and is preferred to the higher frequencies, since they suffer from more atmospheric and space loss. This allows the use of the 34m BWG DSN dishes with frequencies between 7.142 and 7.235 GHz for uplink and 8.4 and 8.5 GHz for downlink. These frequencies are more than enough to support a bitrate of 256 kbps to Earth, since typical bandwidth for this carrier frequency is several Mbps. Since we have the ability to transfer several time faster than the orbiter-Earth maximum speed required and the fact that this data isn’t just video and is presumably important scientific data, the BER that can be tolerated can be up to 10^-6. Since there is such a high priority on scientific data and reliability in the figures of merit, there is a need to push the required Eb/No down to the lowest possible for the data transmission, by using QPSK at a coded rate of 0.8, the required Eb/No can be pushed down to 3.9 dB. In order to account for small misalignments in the attitude, a pointing error of 0.25 degrees will be used, which will provide higher reliability for the data transmission to Earth by providing a relativly large window of rotation. Estimating the implementation loss and margin for the communication system, a value of 3 dB and 1.95 dB were used, respectively. Using the maximum typical ranges in each of the previous values provides for a more robust communication system. One of the last issues to consider when looking at communication with Earth is the atmospheric loss that can attribute to the attenuation of the signal back to earth. The atmospheric loss falls under -7 dB 99.8% of the time, while a loss of -2 dB is a clear day. Since getting the scientific data transferred back to earth reliably is of such importance, a loss of -7 dB should be used when sizing the equipment. The last design variable that should be considered is the size of the high gain antenna, this will directly affect mass of the orbiter, but it can also change the gain significantly. This should also be considered when sizing the batteries and solar arrays, to minimize the mass of the system.

## Power design variables

When considering design variables for the power subsystem, many options will affect the mass of the overall orbiter. First when sizing the batteries, a battery that has a lot of heritage and is known to be reliable is the most important for this mission. A Li-Ion battery with a low enough DOD to last for 4 years is needed, using this type of battery will allow for reduced mass in the obiter. Since the orbit will at maximum only be in the shadow 10% of the time, the batteries will be sized with that in mind. The size of the batteries will also need to take into account the power draw from the system at any given time. There will need to be three different modes of operation that the satellite can operate in, which will reduce the maximum power draw on the power subsystem. Allowing for different modes will reduce the overall mass of the batteries and solar panels. Since the mission is relatively close to the sun, solar panels can be used effectively and with less mass than using RTGs. Ultra Triple Junction GaInP2/GaAs/Ge solar panels with 330 W/m^2 BOL performance will be used for the mission. These panels provide high efficiency and reliability while keeping the mass density relatively low.

# Output metrics (min/max)

In the end, the mass of the orbiter will need to be minimized, which in turn can maximize the lander’s mass. Several options, many of which are coupled, need to be taken into account in order to minimize the orbiters mass. These options include the mass and or size of the orbiters HGA dish. Although there is a need to increase the gain of the of the transmitting signal, this comes at a cost of extra mass, space, and possibly complexity. The other option would be to increase the available power in the system by increasing the size of the solar panels and battery capacity, this would allow for a higher-powered transmitter. There is a coupling between these two equations that need to have an overall minimum mass.

# Design alternatives for subsystem choices

Some design alternatives include choosing a different atmospheric loss value, which could allow for communication a fraction of the time based on weather. This could be compensated by saving the satellite transmission until the orbiter receives a confirmation that the signal was received by the DSN successfully. Allowing something like this would reduce the overall power needed to transmit a message, but could cost more power in storage, and could be more likely to lose data. Another alternative could be a different battery type, like Ni-Cd or Ni-H2. These batteries can still be used for the mission but were not chosen because of their lower energy densities and energy efficiencies. The one advantage that Ni-H2 has over Li-Ion in terms of this mission is the cycle life, but over the duration of this mission, the Li-Ion batteries will be enough. As far as power goes, the last consideration for an alternative was the choice between Solar panels and RTGs for a main power source. Since Mars is only 1.5 AUs away from the sun on average, it doesn’t make since to use RTGs for the orbiter since the mass per watt will be higher at that distance. RTGs are also very expensive and hard to acquire, so solar panels are the clear choice. Now for the communication, a BER of 10^-6 was chosen because of previous missions to mars that had similar data transfer rates, and the fact that a large majority of the data that is being transferred looks to like images. These bit rate errors are perfectly tolerable in this situation. If we wanted to be more careful and be sure to get less of an bit error rate, a BER of 10^-11 could be used, but this would push the Eb/No requirements to higher number. The last alternative that could be used is to switch communication frequencies to the Ka-Band. This would allow for a higher bandwidth and more data to be transferred back to earth, but would require a higher power requirement to overcome space and atmospheric losses.

# Discussion of Figures of Merit

When looking at the figures of merit, it deems scientific data return as the highest priority, which is why many of the options I have taken are swayed very heavily in this direction. Now I have also tried staying with equipment with more heritage and high reliability, and this seems to go almost hand-in-hand with the concept of science return. I have not taken into consideration any schedules. The only option I took because of cost reasons is the solar panels, but reliability or scientific return did not suffer because of this.

# Monte Carlo Analysis

The Monte Carlo simulation that will be run for this trade study will be varying atmospheric loss, system noise temperature, and antenna pointing error. This will provide a confidence level with the parameters that have been chosen for this mission, and perhaps persuade a change if the confidence level is too low.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table 1: Monte Carlo Variables** |  |  |  |
| Variable | Distribution | Nominal | 1 sigma or Min Max |
| Atmospheric Loss | Uniform | 25 K | [18 40] K |
| System Noise Temperature | Uniform | -4.5 dB | [-2 -9] dB |
| Antenna Pointing Error | Normal | 0 deg | 0.75 deg |
|  |  |  |  |

# Orbital Mechanics study

For this type of a mission, the parameters for the orbit around Mars are set, a periapsis of 4990 km and an eccentricity of 0.76. The mission will need to span a time of 4 years, which will have mars rotate about the sun at least twice over the mission. With this in mind and the fact that this trade study only focuses on the power and communication, the orbit only affects how long the craft will be in the sunlight at any given time. In order to cover all situations, the battery will need to be sized for the worst possible orbit, with respect to time that the sun is in view. There are other ways to account for this, like shutting off communication with the lander for a period of time, but since the Figures of Merit determine that Science return to be the highest priority, this is not a reasonable option. Now that the established course of action would be to size the battery appropriately, the longest time the orbiter will be in shadow is when the apoapsis point is exactly in the middle of the shadow cast by Mars. Since the orbit is relatively far from the sun, the shadow that is cast from mars can be simplified to be a column instead of a cone shape. Using this simplification and the properties of the orbit, the worst-case scenario for time spent in a shadow for this orbiter is 9.88% of the orbit, or around 2.5 hours in a 25-hour orbit. This can be approximated as 10%. The only other aspect of the orbit that can affect this trade study is communication, which is figured into other constraints, like the minimum transfer rate. This orbital period was probably chosen to closely match the spin rate of mars about its axis. The period has a difference of less than an hour, so this may have another implication, but I’m unsure of what it is.

# References

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5. Lecture 4 and 8 slides for ASE 119M