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# Human service/repair missions to GEO satellites

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SD2905-HUMAN SPACEFLIGHT
School of Aerospace Engineering
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# LOGISTICS AND OPERATIONS - BLUE TEAM

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## 1 Introduction

Today there are circa 450 active Geostationary Orbit (GEO) satellites - mainly for communication and Earth observation, like monitoring weather. However, there are other possibilities in GEO also, including possible manufacturing. There seems to be a potential business performing service and/or repair of satellites in GEO with human missions. The project presented here consists in the study and design of a system that could offer service and repair missions to GEO with humans.

To perform this study, several groups worked on different aspects of the mission. This report focuses on what has been done by the logistics group. The main tasks assigned to this group were:

- What type of mission is best (orbit, type of spacecrafts).
- How astronauts and equipment required are put in orbit.
- When are operations occurring (scheduling).

These different aspects and the choices made will be explained hereafter, starting with a general presentation of the mission scenario. Launchers and launch sites are then compared to select the most appropriate one. Schedules are given and discussed and ground related logistics are finally investigated.

## 2 Scope of the mission

In this section, the objectives of the mission are given and the decisions made by the logistics group are explained. Different scenarios have been considered for the mission, they are presented here with the will scenario chosen. A Delta V budget has also been investigated for this particular scenario.

### 2.1 The different scenarios

Two main characteristics of the mission are discussed here: the orbit where to place the spacecraft(s) needed and the type of spacecraft needed.

The target GEO orbit is situated at an altitude of $35,786km$ above Earth's surface, and in the equatorial plane. Above this GEO orbit, a graveyard orbit is used when satellites have achieved their end of life limit. It is between between $200km$ and $500km$ above the GEO altitude. Satellites here are tracked but cannot be maneuvered, so caution must be taken when crossing this area. The whole Geostationary region is located in the second Van Allen belt, meaning that a high density of radiation can cause damage to spacecrafts and humans passing through or staying there. The density and hence dangerous nature of the radiation varies with altitude. It is particularly dangerous below the GEO orbit. These circumstances will thus have to be taken into consideration in order to determine if the mission should take place below, at or above GEO.

As for mission logistics, the core concept of the mission will determine the different types of spacecraft to be used for satellite servicing. Different scenarios were considered and their characteristics carefully studied:

- Spacecraft based: this method would consist of having a single space vehicle, that would carry crew and materials from one satellite to the next, and perform a re-entry when mission was finished, much like a Space Shuttle. The satellites would be serviced on site.
- Space station based: this method would consist of a Space Station, where crew and tools would orbit preferably close to GEO. Satellites would be carried from their location to the station by unmanned retrievers, and placed back into their spot after servicing.
- Hybrid solution: this method would include aspects of both previous mission layouts. A Space Station would be used as living quarters and tools storage, but then a Space vehicle would carry the astronauts to the designated satellites to performe the servicing on site.

## 2.2 Chosen scenario

Considering the different possibilities available, as well as their individual advantages and disadvantages,the final scenario chosen was the Space Station model. A station is to be built and placed in orbit at $5,000km$ above GEO. This altitude has been chosen so that the radiation level are acceptable to do several EVAs in terms of human aspects. Moreover, having the station directly in GEO would lead to several difficulties when maneuvering to reach a targeted satellite. In this solution, as the orbital period of the GEO orbit and the station orbit are different ($24h$ and $28.3h$), the station would complete a relative orbit around all GEO satellites every $6.4days$, which was considered an acceptable maximum waiting time for the mission.

As the station passes by the satellite, this satellite has to be brought to the station to be repaired. This is the task of the retrievers. A retriever is a small spacecraft that will depart from the station at a precise time and perform a Hohmann transfer to reach the targeted satellite. It will therefore cross the graveyard orbit: attention will have to be brought on tracking well all satellites in this orbit to avoid collision with the retriever. This transfer will take around 13 hours. Once in GEO orbit, the retriever grabs the targeted satellite and waits for the right time (5.8$days$) to perform a new 13-hours Hohmann transfer and get back to the station. The whole operation takes around 7 days, and it will be further explained in detail in following sections. For this reason, 2 retrievers will be used.

There is no need of astronauts in the station for operating the retrievers as this is done part autonomously and part from ground. Therefore, one of the retriever can depart before astronauts arrive at the station so that the satellite to repair is available quickly after the beginning of the mission. The astronauts will be brought to the station with a human space vehicle discussed by the Vehicle group. The same vehicle will bring them back to Earth and another one will be used for cargo ship. A sketch of the altitudes of the station and the retrievers is given in Figure 1.

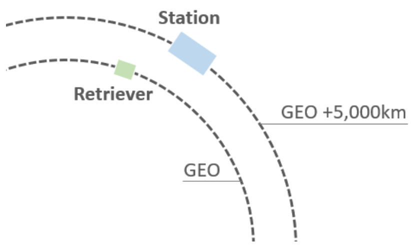


Figure 1: Chosen altitude for the mission

### 2.3 Delta V budget

Two different Delta V budgets have to be considered: one from ground to station orbit and one from station orbit to GEO. The first one, presented in Table 1, corresponds to what will have to be achieved by each crew vehicle going to the station but also during the launches for station construction. The second one, in Table 2, corresponds to the Delta V needed for the retriever to transfer to GEO and get back to the station orbit. This has to be done twice for each satellite: to go and take it from GEO and then put it back in GEO and come back to station.

| | |
|---|---|
| from ground to LEO (700 km) [1] | 9.2 km/s |
| inclination change in LEO | 0.8 km/s |
| from LEO to GEO+5000 km (Hohmann transfer) | 3.8 km/s |
| total Delta V from ground to GEO+5000 km | 13.8 km/s |

Table 1: Delta V budget from ground to station orbit

| | |
|---|---|
| from GEO+5000 km to GEO | 0.17 km/s |
| from GEO to GEO+5000 km | 0.17 km/s |
| total Delta V for servicing one satellite | 0.68 km/s |

Table 2: Delta V budget from station orbit to GEO

# 3 Schedules

## 3.1 Construction of the station

The first phase of the project, before servicing missions can begin, is to build and equip the new Space Station. This includes all modules, including the habitat for the crew, the work station module for the tools and controls, the service module, and the external parts like robotic arm and solar panels. The two retrievers must also be ready to function, and the station should have supplies for the all first year missions.

The altitude of the chosen orbit, at $40,786km$ above the surface of the Earth ($5,000km$ above GEO), favored building the station on site, rather than building it at LEO to then be carried to its final altitude. This second option could have proven efficient for other altitudes, but the amount of power needed to push the finalized station for tens of thousands of kilometers proved to be highly inefficient.

The process was then divided into two launches. They would both carry all the parts of the station to the target orbit, and once there the coupling would take place automatically. The weight distribution was planned as follows:

- First launch:
  - Habitat module.
  - Service module.
- Second launch:
  - Work station module.
  - Retrievers.
  - First year supplies.

This results in an even mass distribution, that will be looked in detail in the launcher selection section. The two launches will take place within a few days, just enough time to check the first launch is successful and all systems are nominal, before launching the second part. Once in orbit, the coupling of the two parts will be automatic and supervised from Mission Control Center. The overall Space Station building schedule is depicted in Figure 2.

## 3.2 Retrieving of the satellites

Since the retriever will perform a Hohmann transfer in order to change the orbit from the station to the satellite in GEO, the transfer is dependent on an exact positioning of the satellite relative to the station (see figure 3).

When the retriever leaves the station into a transfer orbit to GEO, the satellite must be 16.25° behind the station.

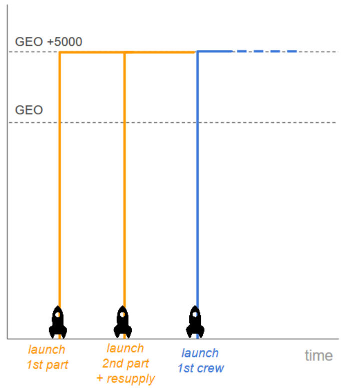


Figure 2: Schedule of the construction of the station

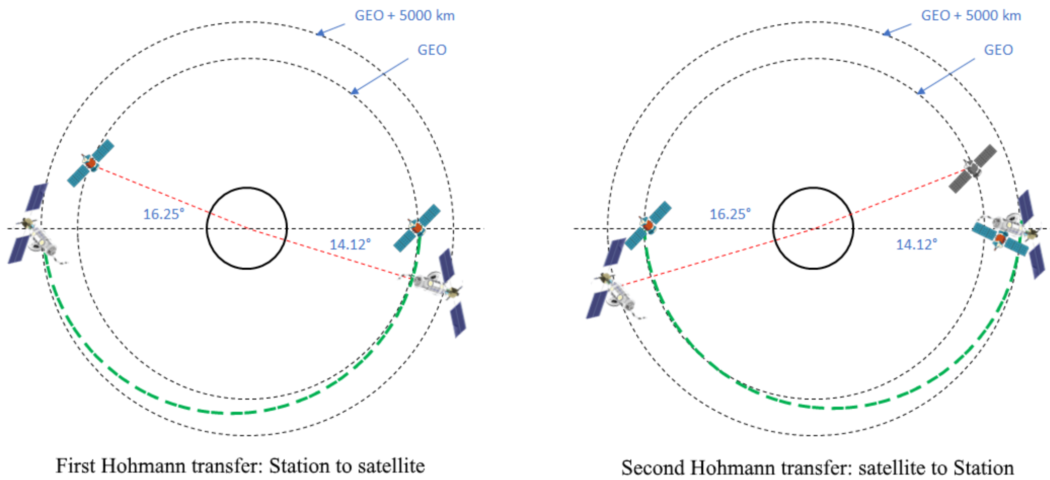


Figure 3: Hohmann transfers for retrievers.

Upon arrival, about $13hours$ later, the satellite will have passed the station and is located 14.12° in front of the station since the velocity is higher in the lower GEO compared to the station's orbit.

In order for the retriever to bring the satellite back to the station, the retriever must once again be 14.12° behind the station. This means that upon arrival to the satellite, the retriever must wait for almost an entire relative orbit (331.76°) in order for the new Hohmann transfer to be aligned, and then thrust back to the station. The total waiting time for the retriever upon arrival to the satellite until it is possible to travel back to the station will be $5.8days$, which brings the total time for retrieving a satellite to $7days$.

The impact of this time can however be minimized if the retriever leaves the station automatically before the repairing crew gets sent up to the station. Then the satellite can be ready at the station upon arrival of the repairing crew. Similarly, the second retriever will depart towards the second satellite before repairing of the first one is finalized, so that it is ready to return to the Station as soon as the servicing is finished.

## 3.3 Mission schedule

The standard length of a mission will be two months. The average case is to be able to repair three different satellites in this time window. In Figure 4 below an overview of a classical mission is displayed. The mission starts with one of the retrievers leaving the station, before the launch of the crew, and initiating the retrieve of the first satellite. When the crew arrives to the station, there will be a one-day preparation margin to get ready before the first satellite arrives.

The crew will then have a 5.8 days window in which they can repair the satellite and still have time to send it back in the first launch window. If however more time is needed to repair the satellite the crew can wait until the second launch window to return the satellite, and thereby get an additional 6.4 days. If one extra window is needed for one of the satellites, there is still enough time to service three of them in the two months mission time.

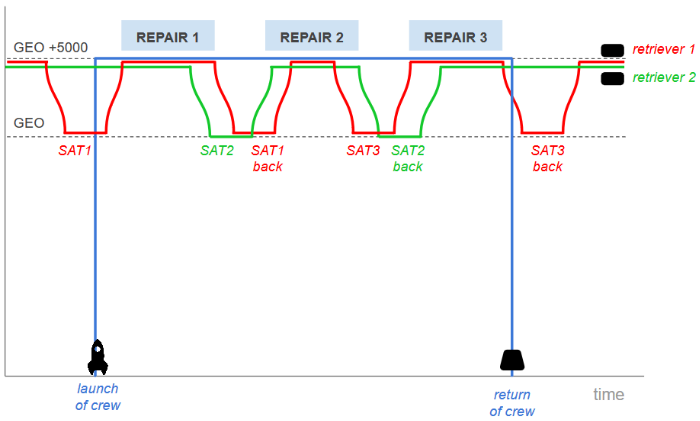


Figure 4: Schedule of a standard mission

Before the first satellite is sent back to its orbit, the second retriever will leave to get the second satellite. As seen in Figure 4, the crew then gets a few days of rest and preparations before the next satellite arrives, which depends on the relative position of the satellites around the GEO orbit. Assuming an extreme scenario with 3 satellites separated by 120° from each other, the waiting time will be $2.7 days$. When the third satellite is repaired, the crew begins the reentry, as the last satellite is placed back into orbit by the retriever. The full detailed mission can be found on Appendix 1.

Some off nominal cases include servicing of satellites taking longer than anticipated, or losing availability of one of the retrievers. If the servicing of a satellite takes too long, there is margin for an extra $6.4 days$ extension while still complying with the 2 month time frame. If the satellite seems impossible to repair, the solution will be to put it back into its position in GEO the way it was before it was retrieved or with the part of the service that was possible to perform. In the case of losing capabilities in one of the retrievers, the mission would have to take place entirely with one retriever. This, however, will be enough to service two satellites instead of the three that were intended. A new retriever can then be sent up with the next re-supply mission.

### 3.4 HeRMeS overall schedule

The overall schedule for the first year in service can be seen in Figure 5 below. The first step is to send up the two parts that together will construct the repair station, and the first years supply.

The construction of the space station will be done, as previously mentioned, automatically, and in a short time frame. Therefore, shortly after being constructed, the first launch with the crew will be ready to operate.

The first set of crews will then be up and working at the station for two months before returning to earth. Between the return of the first crew and the launch of the second, there is a one-month preparation time. This leads to a possibility of four service missions per year. This corresponds to the estimated demand for GEO satellites in the first 10 years of the project, which corresponds to 12 satellites per year. The mission time margins and the time between missions could however be maximize to adapt to a potential market increase, achieving more than 20 repairs per year. In the end of the year, the annual re-supply mission will take place. This mission carries materials, tools, and crew maintenance for the following year. The subsequent years will follow the same schedule pattern for crew and resupply launches.

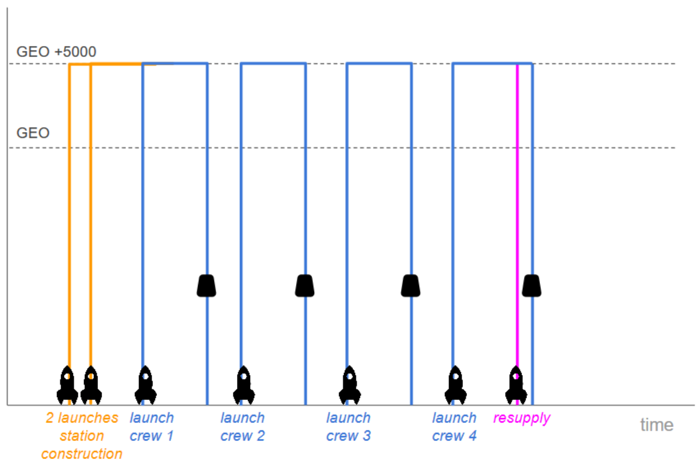


Figure 5: Schedule of the overall HeRMeS mission (first year)

## 4 Launchers and Launch sites

This section will discuss the choice of the rockets used for the mission. First, all the mass considerations will be collected from other groups and summarized, before comparing different launchers and selecting the most adequate one given costs and payload capacity constraints. Finally, several launch sites will be considered, and the most suitable choice will be selected, taking into account the political aspects that have been studied by the coordination group

## 4.1 Mass considerations

The total mass to be sent to GEO for the mission is first determined by the combined masses of the station, the required fuel, the spacecraft and the repairing tools. For this part the estimations were given from both the Space Vehicle Design team and the Services group. Another aspect that has to be taken into consideration is the life support systems, equipment and daily supplies. Those also represent an non-negligible percentage of the total mass that would be send for a repairing mission in GEO. In this case the mass estimates came from the Human Aspects group.

Each group considered the mass distribution among the different types of launch that are being performed (station construction, servicing mission, and the resupply mission). The final breakdown of masses is shown in Table 3. In particular we can note that the overall station would be built in two missions requiring two different launches. Those calculations are made based on some assumptions :

- The resupply mission will happen once a year.
- There will be 4 astronauts per mission.
- Seven satellites will be refueled every year (out of 12 serviced).
- The total number of EVAs per year will be around 40.

Further details and breakdown of the different masses shown here are explained in the corresponding groups report.

Table 3: Division of masses (in kg) for the different types of mission

| Mission | Building station mission | Repairing mission | Resupply mission |
|---|---|---|---|
| Services | - | - | 6700 |
| Life Support System | 0 + 3200 | 1500 | - |
| Space Vehicle | 22 000 + 18 000 | 30 000 | 12 000 |
| Total | 43 200 | 31 500 | 18 700 |

## 4.2 Comparison of launchers

In order to choose the suitable launcher for the different missions, a study of the state of the art for different rockets was made. It was particularly focused on those which are currently being used or developed, and it is shown table 4. Given the great amount of masses that will need to be send in GEO, it was possible to narrow the catalog to four different rockets :

- SpaceX rockets : Falcon Heavy and Falcon 9

- European Space Agency (ESA) rocket : Ariane 6
- United Launch Alliance (ULA) rocket : Vulcan

Some other rockets such as Blue origin or the Chinese Long March were taken into consideration, but due to limited information, such as price or payload mass, and due to some political considerations (especially with China) they were quickly dismissed

Table 4: State of the art of different launchers

| Launcher | Payload GTO (kg) | Payload LEO (kg) | Cost / launch (M$) |
|---|---|---|---|
| Falcon Heavy (expendable) [2] | 26 700 | 63 800 | 150 |
| Falcon Heavy (reusable) [2] | 8 000 | 57 000 | 90 |
| Falcon 9 [3] | 8 300 | 22 800 | 62 |
| Ariane 6 | 11 500 | 21 650 | 102 |
| Vulcan | 16 300 | 34 900 | 99 |

One important aspect when choosing the launcher was the launch cost. Indeed, increasing the launch price might make the investors reluctant about investing into the project . Therefore it was essential to find a good ratio between payload capacity and price. With this in mind, the following launcher choices were made for each phase, based on the mission requirements :

- For the Building missions: It concerns two launches that require to send around $22,000kg$ up to GTO. The only rocket that is suitable for that is the Falcon Heavy expendable.
- For the Repairing mission: The Orion capsule that would be used only requires to be sent to LEO (The choice of the capsule will be detailed in the Space Vehicle Design's team report). Therefore the Falcon Heavy reusable seems to fit best those requirements.
- For the Resupply mission: The Dragon Capsule will be used and it will also need to be send in LEO. Therefore, the Falcon 9 rocket seems to suit best.

## 4.3 Costs estimates

A quick summary of the different launch costs per mission is made in table 5 below :

Table 5: Cost for different missions

| Mission | Building station mission | Repairing mission | Resupply mission |
|---|---|---|---|
| Launcher used | Two Falcon Heavy expendable | Falcon Heavy reusable | Falcon 9 |
| Price(M$) | 300 | 90 | 62 |

Assuming that there will only be 4 repairing missions and one resupply per year, that raises the annual costs for launchers to $332M\$$ in addition to the $300M\$$ to build the station.

### 4.4 Selection of a Launch site

Finally, once the launchers had been selected, it was then necessary to look into the different launch sites. On one hand it would be fair to look into Space X regular launch sites since their rockets are being used. The agency currently uses Cape Canaveral in Florida, VandenBerg Air Force Base in California, and Kennedy Space Center in Florida. They are also building a new one in Boca Chica Village in Texas [4].

On the other hand, their latitudes are around 30° and that would increase the overall $\Delta v$ budget for the mission due to the change of the inclination plan. Therefore the Kourou site (5° latitude) would be more suitable since it would only increase the overall budget by 0.8 km/s). This is also a good location because it might enhance the international cooperation by making Europe and the US work together.

## 5 Ground Logistics

In this section, we will consider communication between the station and the ground and will discuss the Mission Control Center (MCC) logistics.

### 5.1 Communication

The station will directly communicate with the MCC on the ground. With an orbit of GEO+5000, it will take 28 hours and 30 minutes for the station to rotate around the Earth. Therefore, the station is going to move around and change location relatively to the Earth due to these extra 4.5 hours. Given the fact that geostationary satellites can communicate with one third of the Earth, at least three antennas in different locations on Earth will be required. Therefore, the antennas and communication systems that are going to be used are ESA's, NASA's and JAXA's. Indeed, each one of those organization has antennas in its country (or in Europe), so it would be possible to cover all areas. In addition, inter-center communication will be able thanks to the operation network. Finally, it is important to note that it takes about $0.27 seconds$ to communicate in ground-station-ground, which will cause small lags.

### 5.2 Mission Control Center

In addition to the Lauch sites or Launch Control Cetner (LCC) it is necessary to have a MCC on the ground to operate our missions and monitor various technical aspects of a space mission in real time. For this particular mission the chosen MCC will be in ESOC (European Space Operation Center) in Germany, allowing to use public-private partnership between companies and ESA. In this MCC, there will be a Flight Director who will have the overall operational responsibility for the different missions. Additionally, there will also be some flight controllers as follows:

- Flight Operation directorate (FOD)
- Spacecraft Communicator (CAPCOM)
- Public Affairs Officer (PAO)
- Flight Surgeon
- Attitude Determination and Control Officer (ADCO)
- Biomedical engineer (BME)
- Extravehicular Activity Officer (EVA)
- Inventory and Stowage Officer (ISO)
- Integration systems engineer (ISE)
- Operations Planner (OPSPLAN)
- Operations Support Officer (OSO)
- Plug-in port utilization officer (PLUTO)
- Remote Interface Officer (RIO)
- Robotics Operations systems Officer (ROBO)
- Trajectory operations officer (TOPO)
- Visiting vehicle officer (VVO)
- Communications RF onboard networks utilization specialist (CRONUS)
- Environmental and thermal operating systems (ETHOS)
- Station Power, articulation, thermal, and analysis (SPARTAN)

Thus 20 seats need to be occupied 24/7. Assuming 8 hours shift, that would mean that at least 60 people will be needed to operate. Finally by considering double checking, absences due to sickness and holidays, that would raise the total ground team to around 80 people fully occupied per day.

# 6 Conclusion

This report focused on the mission, operational and logistical aspects for the human service/repair mission project. The selected scenario included a Space Station, to serve as living quarters for the crew, as well as materials and tools storage, orbiting at an altitude of $40,786km$ ($5,000km$ above GEO). This altitude was selected as the most efficient trade-off between radiation levels, thrust needed to travel to GEO orbit, and orbital period relative to GEO orbit. The mission plan, involving two separate retrievers to bring satellites to the station, allows for versatile and time efficient missions, which are initially planned to service a total of 12 satellites per year, but can be adapted for a higher demand in the future. The Delta V budget for each phase of the mission was calculated, and the launchers were selected according to the mass budget obtained from other groups. Finally, a launch site and Ground Control Center were chosen, to fulfill all logistical requirements.

The report was completed with defined schedules for all phases of the project, including building of the space station, individual servicing mission schedule, and overall yearly schedule. Some off-nominal cases were considered, to account for safety margins and emergency response capabilities.

All logistical and operational aspects for this conceptual project, estimated to be ready by 2030, are analyzed and defined to, in conjunction with all other groups, provide the reader with an in-depth understanding of the fundamentals of the project and the decided strategy.

# 7 References

## References


[1] Carol Norberg. *Human Spaceflight and Exploration*. Springer.

[2] *Falcon Heavy*. URL: https://www.spacex.com/falcon-heavy.

[3] *Falcon 9*. URL: https://www.spacex.com/falcon9.

[4] *SpaceX capabilities*. URL: https://www.spacex.com/about/capabilities.

# 8 Appendix 1

| Event | Time (days) | Period |
|---|---|---|
| | | |
| **Retriever 1** departs from station | -6.93 | |
| **Retriever 1** arrives at P1 | -6.38 | |
| Crew launch | | |
| Crew arrival to LEO | | |
| Crew arrive to Station | | |
| **Retriever 1** departs from P1 | -0.54 | Preparation 1 day |
| **SAT1** arrives at station | 0 | |
| First window for returning SAT1 | 5.84 | |
| **Retriever 2** departs from station | 8.05 | Repair 1 12.26 days |
| **Retriever 2** arrives at P2 | 8.59 | |
| Second window for returning **SAT1** | 12.26 | |
| REST | | |
| **Retriever 1** places SAT1 in P1 | 12.8 | Rest 2.72 days |
| **Retriever 2** departs from P2 | 14.43 | |
| **SAT2** arrives at station | 14.98 | |
| **Retriever 1** departs from P1 | 18.64 | |
| **Retriever 1** arrives at statin | 19.188 | |
| First window for returning SAT2 | 20.82 | Repair 2 12.26 days |
| **Retriever 1** departs from station | 23.03 | |
| **Retriever 1** arrives at P3 | 23.57 | |
| Second window for returning **SAT2** | 27.24 | |
| REST | | |
| **Retriever 2** places SAT2 in P2 | 27.78 | Rest 2.72 days |
| **Retriever 1** departs from P3 | 29.41 | |
| **SAT3** arrives at station | 29.96 | |
| **Retriever 2** departs from P2 | 33.62 | |
| **Retriever 2** arrives at station | 34.17 | Repair 3 12.26 days |
| First window for returning SAT3 | 35.8 | |
| Second window for returning **SAT3** | 42.22 | |
| Crew return to Earth | | |
| **Retriever 1** places SAT3 in P3 | 42.76 | |
| **Retriever 1** departs from P3 | 48.6 | |
| **Retriever 1** arrives at station | 49.15 | |

Figure 6: Detailed schedule of a standard HeRMeS mission.