# Services and Maintenance of Satellites in Orbit

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***Abstract*—Today there are about 2000 active satellites in orbit around Earth. Every year tens of fully functioning satellites are retired due to lack of propellant. If companies could somehow increase the lifespan of their satellites and maybe even increase their ability to transfer information, they would increase their revenue drastically. This could for example be done through refuelling satellites in orbit and by upgrading them with more antennas. The possibility of this kind of mission is investigated and a mission plan is suggested where satellites in GEO are targeted. The conclusion is that it would be possible to perform services for up to four different satellites in orbit in one single mission spanning over around 20 days. A servicing spacecraft would dock to the satellite to be serviced, and perform upgrading and refuelling. Astronauts would install upgrades, perform eventual repairs and if needed help with the refuelling, while ground controlled robotic arms performs the refuelling. Another different type of service that could be considered is the assembly of a telecommunication satellite or a space telescope in orbit, which would be beneficial since it neglects size limitations since components can be put into orbit in separate launches. Lastly, the off-nominal case of what could be done if the docking to a satellite is unsuccessful is considered. The proposed solution to this would be to do an extra EVA where the astronauts manually grabs the satellite and docks it to the spacecraft.**

***Index Terms*—Services in Space, Satellite Maintenance, Satellite Refuelling, Satellite Upgrading, In-Space Assembly**

***Abstract*—Idag finns det cirka 2000 aktiva satelliter i omlopp runt jorden. Varje år tas tiotals fullt fungerande satelliter ur bruk på grund av brist på bränsle. Om det satellitägande företaget på något sätt kan öka livslängden hos sina satelliter och kanske till och med förbättra förmågan att överföra information så skulle de öka sina intäkter drastiskt. Detta kan till exempel göras genom att tanka satelliter i omlopp och genom att uppgradera dem med fler antenner. Möjligheten till denna typ av uppdrag undersöks och en uppdragsplan föreslås där fokus ligger på satelliter i geostationär omloppsbana. Slutsatsen är att det skulle vara möjligt att utföra denna typ av tjänster för upp till fyra olika satelliter i omlopp i ett enda uppdrag som spänner över cirka 20 dagar. I detta uppdrag dockar en rymdfarkost till den satellit som ska betjänas, och uppgradering och tankning utförs. Astronauterna installerar uppgraderingar, utför eventuella reparationer och vid behov hjälper till med tankning, medan markstyrda robotarmar utför tankningen. En annan typ av tjänst som kan övervägas är montering av en telekommunikationssatellit eller ett rymdteleskop i omlopp, vilket skulle vara fördelaktigt eftersom att man kan bortse från storleksbegränsningar då komponenter kan sättas i omlopp i separata uppskjutningar. Slutligen beaktas problemet som kan uppstå om dockningen till en satellit misslyckas. Den föreslagna lösningen på detta är att låta astronauterna göra en rymdpromenad där astronauterna manuellt griper tag i satelliten och dockar den till rymdfarkosten.**

## I. Introduction

TODAY there are about 2000 active satellites counting in Low Earth Orbit (LEO), Middle Earth Orbit (MEO), and Geostationary Orbit (GEO). Out of those, about 560 is in GEO handling a lot of Military, Governmental, and commercial communication [1]. In this report possible services on some of the 330 satellites in geostationary orbit handling communication will be discussed.

Services on geostationary satellites is something yet to be perfected, but service on satellites in other orbits have, mainly in LEO, already been performed several times. For example as early as 1992, the space mission STS-49 (which also was the maiden flight of the space shuttle *Endeavour*) was directed too be performed on the satellite Intelsat-603, a satellite that was intended to be in geostationary orbit, but had a fail during the launch, leaving the satellite only half way in LEO. After four successful EVAs the goal was achieved, to replacing a motor on the satellite and it was able to enter GEO the same year [2].

Because of the enormous amount of money invested in geostationary orbit, over $300 Billion in GEO, and big scientific progress, services on these satellites in a near future is relevant. The project can be divided into several different parts. Firstly, in order to know how specific services can be performed some satellite targets needs to be selected. After that, the methodologies of refuelling and upgrading on these targeted satellites are described. Furthermore, the action of assembling taking place in orbit is investigated and lastly an off-nominal case is presented.

## II. Target selection

There are a lot of costs considering launching a space mission. These costs are why it is important to consider doing as thorough service as possible on as many satellites as possible in every mission. This is why it also is essential to look at the location of all satellites in geostationary orbit when the mission is designed. The satellites in geostationary orbit (or geosynchronous equatorial orbit) are following Earth's rotational direction, so when choosing targets for the mission the main factor is that they are longitudinally close to each other.

Satellites to be taken into consideration for these kinds of missions should be retired approximately at the same time. Since the lifetime of a satellite is mainly limited by the fuel keeping it in orbit as well as the quality of the battery connected to all the necessary electrical systems in the satellites, these are the main factors when determining the lifetime of it. The first mission will be launched in 2030, which is when the first targets are planned to be retired.

One example of potential targets for the first mission could be the four satellites seen in table 1, Intelsat 20, Intelsat 22, Intelsat 33 and Intelsat 36, all by the same operator, Intelsat [1].

As seen in table I, these four targets uses two different bus platforms, LS-1300 [3] and BSS-702MP [4]. Satellites with the same bus platform are usually built in the same way when it comes to the location of essential parts, like transponders, solar panels, batteries and antennas, which will make the mission more easy when it comes to the actual services too be done.

The perigee shows the altitude for when the satellite is nearest to the Earths center, while the apogee shows the altitude for when the satellite is farthest away from Earths center. The Longitudinal degrees are constant at all time since these satellites are geostationary and therefor above the same place of Earth at all time and the satellite follows the Earth rotational orbit at the same angular speed. The targeted satellites are also expected to be retired in 2030 and 2031.

## III. Refuelling and upgrading

In this section two of the three mission focus areas that have been identified for the realisation of this project will be explained. The reasons that give rise to the implementation of these services will be exposed, as well as the challenges they imply and the measures taken to overcome them. In addition, since both can be carried out at the same time on the same objective, the necessary steps for these activities will be explained in detail.

### A. *Refuelling*

The most common reason for a satellite to be taken out of service is lack of fuel [5]. When a satellite in GEO is retired it uses the last fuel to send itself to a graveyard orbit at an altitude of a few thousand kilometers above GEO where it is left to drift forever. If the satellites could be refuelled it would be able to operate further, which in the long run increase revenue for the company owning the satellite and decrease the amount of space junk in the graveyard orbit. The targeted satellites are not designed to be refuelled which means that there is no easy way of doing it. The refuelling task includes a lot of steps because of this, however none of these specific tasks are too complex for a robotic arm to perform so the refuelling part of

TABLE I
POTENTIAL INTELSAT TARGETS

| Satellite | Intelsat 20 | Intelsat 22 | Intelsat 33 | Intelsat 36 |
|---|---|---|---|---|
| **Bus** | LS-1300 | BSS-702MP | BSS-702MP | LS-1300 |
| **Longitude [°]** | 68.5 | 72.0 | 60.0 | 68.5 |
| **Perigee [km]** | 35 780 | 35 781 | 35 549 | 35 781 |
| **Apogee [km]** | 35 790 | 35 792 | 36 152 | 35 801 |
| **Date of launch** | 8/2-12 | 25/3-12 | 8/24-16 | 8/24-16 |
| **Expected lifetime [yr]** | 18 | 18 | 15 | 15 |

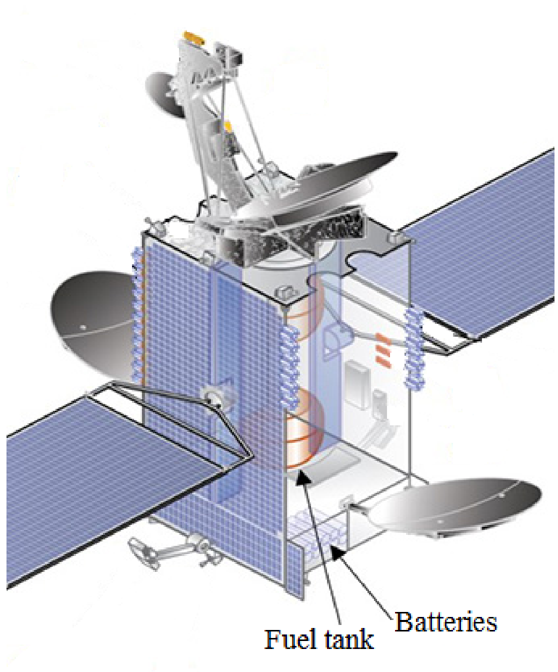


Fig. 1. Schematic view of a typical telecommunication satellite [3]

the mission can be entirely done by robotic arms controlled from ground. This is beneficial for the mission since the astronauts can focus on their EVAs and upgrading mission. If everything goes as planned there is no need for having a manned spacecraft for refuelling a satellite. However, it is a good safety measure to have the possibility for human interference if some operation experience unexpected difficulties.The amount of fuel varies between different satellites but a rough estimate per satellite is between 200 and 500 liters of fuel depending of size of satellite and its fuel tanks [6]. Assuming hydrozine as fuel would give a payload of up to 2000 kg of fuel as payload every mission if the goal is to refuel 4 satellites. This payload would of course vary between respective mission and when choosing targets one could take this into account to for example avoid having to bring more than 1500 kg per mission to more evenly distribute the payloads if the payload would be a restriction. For these missions there is an orbiting module in a parking orbit between LEO and GEO where excess fuel could potentially be stored for later missions. Costs, increased revenue and sustainability for refuelling is not presented in this report, but is presented by the Management Team in Red Team in their report.

*1) The procedure of refuelling:* As earlier mentioned there are plenty of tasks included in refuelling [7]. The service spacecraft has to successfully dock to the satellite to be serviced. This is done with the help of a robotic arm that grabs the satellite, which is seen in Figure 2. After this the refuelling can take place. Firstly, a part of the thermal blanket needs to be removed by cutting through it. In Figure 1 this blanket is already removed to get a better view of the inside of the satellite. Then the robotic arm would approach the fuel tank and cut through lock wires that secure the bolts fastening the fuel cap. Next step is then to remove and stow away the fuel caps. Now the robot can enter the valve and establish a seal. It is important that there are no leaks since the fuel tank is pressurised and the fuel is highly reactive. When all of this is done the right amount of fuel can be transferred. Next, the fuel cap is put back and the valve is resealed carefully, and a leak check must be done. The final step in the refuelling is for the thermal blanket to be reestablished. This initiation of this last step might be a little delayed due to the replacing of the battery, which depending on the satellite would be easiest with the thermal blanket removed. As seen in Figure 1 the battery is not necessarily in the same chamber as the fuel tanks but they might very well share the thermal blanket. The battery will be replaced by the astronauts in one of their EVAs.

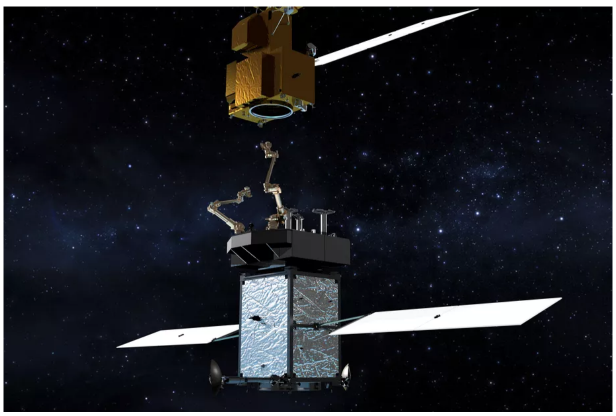

Fig. 2. Illustration of a refuelling spacecraft approaching a satellite [8]

## B. Upgrading

On-orbit satellite upgrading has a vast array of benefits and challenges. But there is no doubt that, after being demonstrated its feasibility, it can come up as a transformative and disruptive capability that provides operators with unprecedented flexibility and room for improvement for their space assets. As with the refuelling service previously explained, the major components here include an advanced spacecraft with a specialised toolkit and robotic arms for capturing, interacting with, and manipulating the different pieces to help the astronauts during the spacewalks, software for managing semi-autonomous servicing tasks, and an advanced sensor suite for careful rendezvous and proximity operations.

The application area of on-orbit satellite upgrading can be very broad. Since mainly communications satellites have been identified as targets for this project, one of the most important characteristics for this type of service has been identified as potential to be improved: the capacity. Each satellite has a number of parabolic reflectors, each of them providing an amount of information beams. Figure 3 shows a schematic of the information beams provided by one satellite parabolic reflector:

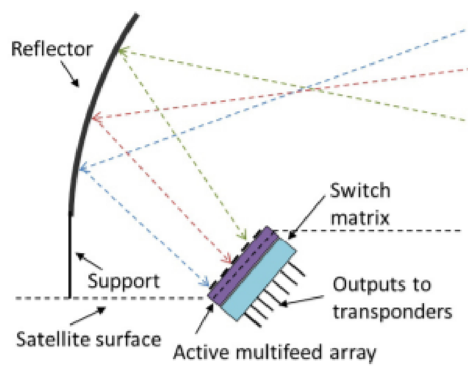


Fig. 3. Multiple-beams reflector antenna configuration

Consequently, the number of parabolic reflectors installed in the satellite will determine the amount of information beams that such satellite will offer. Therefore, by adding several antennas to the target satellite, the number of information beams will increase (as it can be observed in Figure 4), thus providing more capacity and better quality of service.

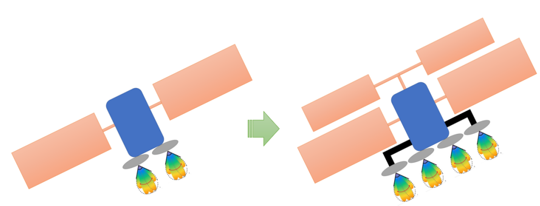

Fig. 4. Upgrading satellite schematic

These new parabolic reflectors will be attached to the satellite by means of clamping structures, as it can be seen in Figure 4. These pieces will be glued to the satellite using a new type of adhesive recently created that becomes tremendously sticky in dry environments, such as that of outer space [9]. This material can also operate in the chilly temperatures and vacuum that characterise Earth's orbit. Since the centre of gravity of the satellite will be altered by adding these new elements, it will be necessary to place a counterweight. Thus, the satellite will be balanced again, allowing the right performance of its attitude control.

Another issue to take into account is the power balance. Since two new antennas will be operating, there will be a higher power consumption. To overcome this problem, new solar panels can be added (see Figure 4). Then, the battery will have to be replaced by one that can easily withstand the power generated.

One of the major challenges when performing this activity is how to connect the electronics of the new parts to the electronics of the satellite. It will be a difficult task since current satellites have not been designed to be upgraded, but technology advancements and miniaturisation will allow to add the data path coming from the new antennas to the whole satellite circuitry, as well as the incorporation of the new power system paths.

At this point, a question may come to us: why not send a new satellite directly? To answer this question, we must rely on the argument that the geostationary orbit is a limited resource. Each point of this orbit has unique characteristics with respect to the Earth. For this reason, the position of each communications satellite in the geostationary orbit has been carefully calculated. That is, if another satellite were launched, it would not have the same features with respect to its position. Therefore, if we want to improve the performance of the service, on-orbit satellite upgrading would be a solution for companies both in terms of economic and technological feasibility, getting at the same time to have less space junk since this satellite would not have to be sent to the graveyard orbit. Moreover, the fact that more than one satellite will be serviced per mission will make this activity attractive and profitable for companies that make the service and, therefore, customers will benefit.

The idea of on-orbit upgrading facilitates cheaper and faster development of satellites and enables upgrade missions which improve the performance of the satellite as technology advances. Old satellites can continue to be useful, even for new missions, which will help to reduce space debris and the cost of launching new systems.

### *C. Refuelling and upgrading services procedures*

In previous sections, the reasons why it is useful and profitable to perform the refuelling and upgrading services have been explained, as well as the technological challenges presented by each of them and the way to overcome such challenges. In addition, the fact that both services can be performed simultaneously on the same target satellite is an advantage that should be exploited. This section aims to explain in detail all the necessary steps to carry out both services on a satellite that is out of fuel and that, at the same time, it is useful to make improvements to increase its capacity.

As explained above, the refuelling part of the mission will be entirely performed by two fine and short robotics arms controlled either from ground or from inside the service spacecraft. If the robotics arms are led from ground, the efficiency can increase, but it will be necessary to face longer signal delays. On the other hand, managing the robotics arms from inside the service spacecraft will solve the problem with the delay, but that means an increase of the workload for the crew.

Regarding the upgrading service, two EVA will be necessary to perform it. Thus, it will be possible to exploit advantages of humans like dexterity, tactility, vision, experience and intelligence, which will result extremely useful for this kind of activity.

Figure 5 shows the configuration of the different robotic arms explained above for the development of such refuelling and upgrading services.

Below are the main steps and procedures necessary when developing these two services, from the rendezvous to the target satellite until the beginning of the preparation to serve the next target, going through the most significant actions during the development of each of the EVA:

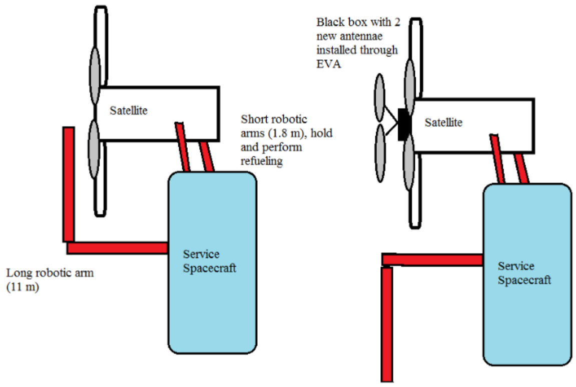


Fig. 5. Robotic arms configuration.

- Rendezvous and docking to the target satellite with the help of one of the short robotic arms. This activity will be led from inside the spacecraft, so it will be relatively fast. Moreover, while this step is taking place, an inspection of the state of the satellite will be made with the camera of the long robotic arm.
- The other short robotic arm performs refuelling task. It is estimated that the duration for such refuelling activity is four days, so it will allow to perform the upgrading task at the same time.
- EVA 1 (estimated time: 8 hours): The aim of the first EVA is to install the solar panel. To do that, it is necessary to follow the next steps:
  - Prepare the circuitry of the satellite in order to be connected to both the new solar panel and the new parabolic reflectors.
  - Apply glue to satellite surface.
  - Attach the solar panel to the satellite structure.
  - Connect the electronics of the solar panel with the satellite circuitry.
  - Replace the battery and its circuits.
- EVA 2 (estimated time: 8 hours): The objective of the second and last EVA necessary when servicing the target satellite will be the installation of the new parabolic reflectors. This work can be summarised in the following steps:
  - Apply glue to the satellite surface where the clamping structures should be.
  - Place these clamping structures with the aid of the long robotic arm. When bolts and nuts are adjusted, the robotic arm can start grabbing the first parabolic reflector.
  - Install the first parabolic reflector with the aid of the robotic arm. As with the previous step, the robotic arm can start grabbing the next parabolic reflector when the electronics of the satellite and the new parabolic reflector are being connected.
  - Connect signalling systems and circuits of the parabolic reflector.
  - Attach the second parabolic reflector to its corresponding clamping structure with the aid of the long robotic arm.
  - Connect signalling systems and circuits of the second parabolic reflector.
  - Check that antennas position.
- Last day: Finish refuelling and decoupling.
- Prepare for the next target.

## IV. In Space Assembly (ISA)

Today, most of the objects sent into space are carefully assembled and tested on Earth and as soon as they are put on their orbit they are almost operational. The only tasks which are performed in space are the deployment of antennas and solar arrays. One exception to this procedure is the ISS which has been assembled in space because it is simply too big and too heavy to be assembled on Earth. This is an illustration of why assembling satellites or other spacecraft on orbit is interesting but they are very few examples and the ISS is still unique today. However, recently the ISA has been presented as the future step for satellites and the whole space field [10]. Several studies have been made on the advantages, methods and commercial aspects of ISA [11], [12], [13].

As the present mission is a long term one, with several operations per year, and is supposed to employ astronauts it is interesting to study the feasibility of ISA. This could look like what it is done on the ISS now but dedicated to satellites.

### A. Advantages of in space assembly

As previously said, the main advantage is the absence of any size constraint on the object. This limitation comes from the size and the shape of the launcher. With ISA, bigger satellites can be assembled. According to the study made by the Science and Technology Policy Institute [11], the actual limits on the annual revenue of a telecommunication satellite come from the number of antennas and the size of these antennas. Indeed, most of these satellites have from 3 to 4 antennas. ISA can solve theses issues and be a direct financial interest for companies owning telecommunication satellites. From the same study, research telescopes are limited in their "scientific" revenue by the size of the launcher too. The number of instruments is limited and mirrors and solar arrays need to be folded during launch which imply that complex deployment procedures must be performed on orbit. For example, if the unfolding fails on the future James Webb telescope, this satellite might be completely useless because it will be too far for servicing. This will mean a huge $8 billion loss for NASA.

ISA allows sensitive and fragile structures to be assembled latter. This reduces the risk of failure of the payload because of the vibrations during the launch. Less protective structures are needed which saves space and mass.

Finally, ISA reduces the need for deployment procedures on orbit. These procedures require intensive testing on Earth which take a lot of time and cost a lot of money. For example the James Webb telescope suffered a lot of problem during one test which has delayed the whole project [14].

### B. The mission plan

*1) Initial considerations:* The first point to consider is: what kind of object does the team want to assemble? To establish a business model the mission must be repeatable over a long period of time. Moreover, the service provided here, the in space assembly, will be sold to a company or a state organisation. For them the service must be competitive and profitable. This is the reason why, assembly of telecommunication satellites has been chosen.

Indeed, assembling larger telecommunication satellites can be very interesting for a company such as Eutelsat or Intelsat because one of them could be able to replace at least two old satellites. This being possible because the number of antennas will be bigger. So the mission must be cheaper than the cost of two satellites designed, built on Earth and then sent into space. The details about the cost are given in the Management group report.

The second point to consider is where to do the assembly. LEO could seem to be the right choice at first. However, it would require to design a totally new spacecraft to perform the mission as it could probably be cheaper than a spacecraft designed to work in GEO. Moreover, as the Management group will describe in its report, performing all the missions in GEO allow a month mission to be divided between assembly and refuelling/upgrading which is better from a financial point of view. These two reasons are in favor of doing the ISA in GEO.

The third point is to decide the kind of assembly which will be done. As previously described, the main limit on the annual revenue of a satellite is the number of antennas. So the astronauts and the spacecraft will assemble a bus of a satellite with a given number of antennas. This number being bigger than 4 to deliver a satellite which is interesting for a telecommunication company.

*2) The service provided:* The company which owns the satellites will pay to launch the different parts that will be assembled. The same spacecraft used for the refuelling/upgrading mission with a team of 3 astronauts will be launched and will reached the package containing the parts. The trajectory and manoeuvres are the same and they are described in the report written by the Logistics group. The spacecraft, here, will only need to carry the astronauts and some tools.

For example, if the launcher Ariane 6 is used by the company, one can fit one large satellite bus of 8 m x 3.8 m x 3.2 m, which is similar to a large satellite such as the Intelsat 33e, and 12 large antennas with a diameter larger than 3.2 m.

For the upgrading service, changing two antennas require an EVA of 8 hours. Here the operations should be easier and faster because the satellite is designed for this in space service. One can consider that 5 EVAs should be enough to complete the assembly. So the total time required to assemble one large telecommunication satellite will be 10 days: 1 to reach the parts and prepare the first EVA, and then an alternation of 1 EVA and 1 day for rest. For a one month mission two satellites could be assembled, or the other possibility is only one satellite assembled and two upgrading/refuelling.

### C. *Assembly of a telescope in space*

Assembly of spatial structures in GEO does not only include that of telecommunication satellites even though it probably is the most likely to generate a fortune in a near future. One could also consider the assembly of a space telescope in GEO. Assembling of a telescope has been done before with the Hubble telescope which orbits the Earth in LEO [15] so the technology and knowledge for this kind of mission already exist. The main advantages with a large telescope operating in GEO is that it can observe more than a third of Earth, and it stays there all the time. Therefore only 3 Earth observing (for example meteorological) satellites would be enough to observe the entire Earth except for the extremities at the poles. These kind of telescopes already exists, for example United States have 5 operating meteorological satellites [16]. However, through assembly in space, such satellites could have much larger lenses which would give a much better resolution and more accurate measurements. An in space assembly would require several astronauts to perform over possibly several missions, but this increase in expenses might very well be worth it for the increased performance. Another thing worth noting is that a few of these satellites could possibly replace a big part of the 160 satellites orbiting in LEO that measures selected climate parameters and a satellite in GEO can continuously take measurements of the same area [17].

## V. Off-nominal case

Many different off-nominal cases was considered, but the chosen scenario which to look deeper into and solve was ultimately decided as the case in which the service spacecraft is unable to dock to the targeted satellite as planned. The reason to overlook this case is due to its importance, since if the spacecraft is unable to dock with the target the whole mission fails and no services can be performed.

If this scenario would occur in which the spacecraft is unable to dock with the satellite, this would be solved by the on board astronauts performing the docking manually during an EVA. Similar tasks has been performed before as during NASA mission STS 49 [2].

The task was performed by astronauts, which would stand with foot restraints on the space craft and its robotic arm securing their positions and grab the targeted satellite.

Being prepared for this scenario significantly decrease a major factor that would endanger the missions goal to refuel and installation services.

## VI. Discussion

### A. *Future design of satellites*

As one can see through the 3 services presented here, in-space servicing can be really promising for telecommunication companies and can be seen as one of the future step for the space industry [18], [11]. For example, ESA has launched some studies about a spacecraft which could be able to perform tasks "*such as refuelling high value satellites reaching the end of their lives, adding new equipment to them, or attaching to them to move them to new orbits*" [19]. If servicing satellites becomes more and more common in future years, either developed by sate agencies or by a commercial company the next generation of satellites will be designed differently. Indeed, they will be built specially for this, which will in turn make servicing missions easier, faster and cheaper. This will raise questions such as will humans be still needed or will robotic arms be enough to perform the mission ? How long can a satellite be serviced and still be efficient ?

Today only one satellite has been designed to be serviced on-orbit, it is the Hubble telescope. Five missions have been performed on Hubble, from 1993 to 2009, in order to repair, upgrade or install new equipment on the telescope. These missions have been successful because they have transformed a satellite which had some defects into a still up to date scientific device. However, the comparison between the Hubble telescope and a telecommunication satellite, for example, is not simple. Indeed, Hubble cost around $4.7 billion at the time of the launch and with the servicing missions the total cost now is about $10 billion [15] while a telecommunication satellite only cost about $200 million. It is clear that it is easier to motivate the choice of servicing Hubble than sending a new telescope because the first one has failed. However, and this is what this study argues, several servicing missions can be performed on cheaper satellites and still be profitable. This study is based on the repeatability of a few services on a great number of satellites.

Moreover, servicing could allow the space industry to be cleaner and more ecological as it could reduce the number of launches per year and decrease the number of satellites built every year.

### *B. Evolution of the In-Space Assembly service*

As explained above, the design of the next generation of satellites could evolve a lot in order to allow for on-orbit servicing. Moreover, robotic arms and sensors will continue to be improved in the future. It is interesting to see what this could mean and change for the In-Space Assembly. For a telescope or a satellite with a scientific payload, this might make the mission easier and faster but humans will still probably be needed as instruments can be really delicate and expensive. If the satellite cost billion, one wants guarantee and humans are more adaptable than robots. However, the mission described previously, the assembly of a bus and some antennas, could be different. Astronauts might not be needed anymore, because this mission is quite simple: the tasks are always the same and they do not require to open the bus. Furthermore, these satellites cost less money so failure is more tolerable.

### *C. Repairing*

Initially when deciding which services to be performed repairing was one of the main categories along with upgrading assembling and refuelling. However it was excluded as a main part of the missions. This is because it is relatively rare that satellites need repair and are repairable. Between 1990 and 2006 there occurred 64 instances where a satellite was unable to operate due to anomalies other than running out of fuel [20]. This is on average four satellites per year compared to the annual amount of around 90 satellites that run out of fuel, assuming an average lifespan for a satellite of 15 years and more than 1350 active satellites [21]. Note that these numbers do not include GPS satellites and satellites for military use. Because of the lack of potential targets for repairing compared to refuelling the decision was taken that

Another reason why repair was excluded is that there is a large amount of different ways a satellite might need to be repaired in if an anomaly occurs. The damages can be mechanical failures when deploying solar arrays, circuit or cell interconnect failures, battery failures, darkening of glass or reflectors and plasma discharge events to mention a few [20]. Since the satellite might not be able to assess damages or communicate properly it might be hard to know how severe damages are before reaching the satellite for inspection. So all in all, instead of having to educate astronauts in many different repair scenarios before even knowing if it is possible to repair a satellite to fix a few satellites per year, the final decision was to avoid pure repair missions. However, it is worth mentioning that if an anomaly is found when the service spacecraft arrives at a satellite for refuelling and upgrading that is possible to fix, then of course it can be considered then and there.

## VII. Conclusion

The goal of this project is to present manned missions performing maintenance in geostationary orbit around 2030. The services considered are refuelling, upgrading, in-space assembly and repair, but the latter was decided to not be included as a main part of missions due to the variety of different tasks that would have to be considered, and the inconsistency in potential targets. The refuelling mission and the upgrading mission can be combined since they do not disturb each other. By providing the service of in-space assembly companies might be interested to develop much larger telecommunication satellites to be assembled in orbit, or scientific institutes might want to develop larger space telescopes. There is still a lot of research and testing to be done before these kinds of missions can be launched on a regular basis, but considering the time frame of 10 years until the first launch it will be feasible if enough resources are spent on this project.

## VIII. Division of work

Darío was in charge of upgrading and its procedures. Valentin worked on the in-space assembly of a telecommunication satellite and the discussion. Viktor contributed with information regarding refuelling and investigated the off-nominal case. Nils supplied the refuelling, repair, assembly of a telescope in orbit as well as the abstract. Joacim selected targets and composed the introduction.

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