International Journal of Engineering, Management and Humanities (IJEMH)
Volume 5, Issue 2, Mar.-Apr., 2024 pp: 106-113 ISSN: 2584-2145
www.ijemh.com

Exculpation of Space Debris From LEO Using A Debris Removal Module – A Preliminary Concept And Overview

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Date of Submission: 14-03-2024 Date of Acceptance: 28-03-2024

ABSTRACT: From the middle of the twentieth century with the launch of Sputnik 1 humans have started exploring space for their research, study and exploration. Since then they have started polluting space with space debris and continuing till date. These unwanted objects orbiting earth are not only harmful to the working satellites in earth orbit , but also to the orbital bodies that will be launched in future. So, at this present moment clearing them for safe and secure future space missions are of utmost importance. This paper focuses on clearing these space junks from Low Earth Orbit(LEO) using a Debris Removal Module(DRM).

KEYWORDS: Low Earth Orbit, Debris Removal Module, Robotic Refuelling.

I. INTRODUCTION

At present day more than 9500 active satellites and 25000 space junks greater than the size of 10 cm are orbiting earth. This unwanted bodies in earth orbit are too much dangerous and hazardous to the other satellites in orbit and upcoming satellites. In the year 2009, a collision between an active communication satellite and an inoperative satellite with a speed of 11.7 km/sec created thousands of small debris in earth orbit at an altitude of 789 km. In fact between 2015-2017 the European Sentinel-2 satellite enlisted more than 8000 collision alerts. After that in 2019, a satellite of European Space Agency(ESA) performed an emergency manoeuvre for avoiding accident with a communication satellite.

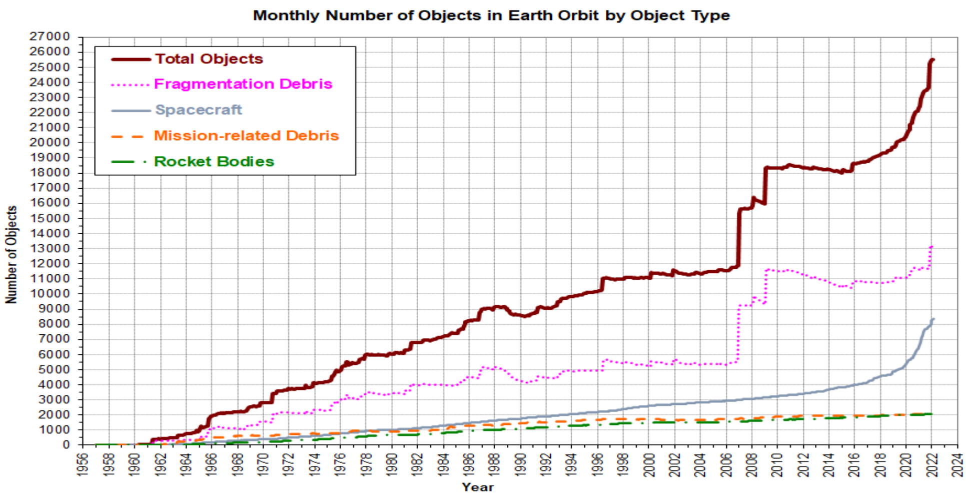

FIG. 1. CHART SHOWING NUMBER OF OBJECTS >10 CM IN LEO

The historical growth of the space debris are shown in above FIG. 1. This figure is generated by LEGEND, a NASA software model.

The International Space Station(ISS) perform several orbital manoeuvres to eliminate collisions with space junks. To be more precise, the

Low Earth Orbit(LEO) ranging from the altitude of 200 km to 2000 km is the most heavily populated area. A study of several simulations says that if all the space launches are stopped today, then also the number of debris will continue increasing exponentially in LEO. This kind of uncertainty in LEO are of great threat for future missions. The technique of Active Debris Removal(ADR) is the only way out at this situation. ADR aims to remove 5 to 10 orbital debris per year, eventually it is an effective way to bring the pollution caused by space debris in control. In this paper we have focused on ADR technique using a Debris Removal Module(DRM), which has a capability of refuelling from the Robotic Refuelling(RR) module.

The first section of this paper contains introduction, section II contains the background of study, section III contains the scientific modules, section IV contains the mission concept, section V contains the advantages of the proposed mission and section VI is dedicated to the conclusion.

II. BACKGROUND OF STUDY

Between 1990 and 2005 several studies were conducted regarding the growth of debris population in LEO based on analytic, semi-analytic and numerical path, assuming that no other satellites would launch after 2005. The observation, analysis and conclusion of all the studies were more or less same. They all concluded that the maximum debris generation in LEO would be caused by collisions and the generated debris parts would work as a feed back to other collisions. According to European Space Agency(ESA) there are more than 170 million objects greater than the size of 1 mm are orbiting earth. These objects are orbiting earth with a huge velocity, and posses a sever threat to future space missions. From the past few years several proposals were presented based on ADR such as collective active debris removal; tether-based active debris removal; ion beam shepherd-based active debris removal; dynamical systems-based active debris removal and many more, but none of them have a real life implementation.

As at this present moment it's not feasible to remove all the debris from LEO so, few orbits are selected from simulations where the chances of catastrophic collisions are maximum. These orbital locations are regarded as orbital hotspots , due to their higher debris density and higher chances of catastrophic accident in next 200 years. These hotspots lies at three different altitudes of LEO. These are :

[1]. Altitude of 1000 km (±100 km), with an inclination of 82° (±1°).

[2]. Altitude of 800 km (±100 km), with an inclination of 99° (±1°).

[3]. Altitude of 850 km (±100 km), with an altitude of 71° (±1°).

A total number of 317 objects have been identified from location 1, and their mass varies between the range of 500 kg to 1500 kg. The location 2 is a sun synchronous orbit, these orbits are generally used for scientific research and commercial applications. In this region the mass of the objects are almost distributed equally. And the location 3 has the upper stages of rocket and satellites with maximum masses and larger cross-sectional area.

The European Space Agency(ESA) is working on a technology to capture a dead rocket body and then de-orbit it to be burnt in atmospheric re-entry. This mission is named as CLEARSPACE 1 and scheduled for the year 2025. The module is aiming to capture an ESA owned debris named as VESPA(Vega secondary payload adapter) at an altitude of 664 km perigee and 800 km apogee , with an inclination of 99.5°.

III. SCIENTIFIC MODULES

Capturing a debris body and then de-orbiting it is a very crucial and challenging work to perform. It requires an efficiency near to 100% . In this mission objective we have placed an idea of using a Debris Removal Module(DRM) with robotic arms, multiple number of Thrust Deorbit Kit(TDK), in orbit cryogenic fuel transfer technology to deorbit 5 to 10 orbital debris per year. Before moving to the concept and methodology of the mission, it's important to have an idea about the scientific technologies required in this mission such as TDK modules, robotic arms, Robotic Refuelling(RR). These are explained in the below subsections.

[1]. The TDK module stands for Thrust Deorbit Kit module. It is a solid fuel reserve used to increase or decrease the orbits of any orbital body. Here TDK module is to used to reduce the orbit of the space debris. It provides the required velocity to reduce the perigee of the orbital debris. The amount of the solid propellant required to decrease the orbit varies with the mass of the targeted debris and its orbital parameters.

For example a PSLV rocket body with a mass of 912 kg at an altitude of 789 km perigee and 839 km apogee requires 51.5 kg of TDK propellent to reduce its perigee to 238 km, where as a IRS-P2 rocket body with a mass of 912 kg at an altitude of 807 km perigee and 877 km apogee requires a TDK module of 53.1 kg to reduce its perigee to 238 km. The variation of TDK propellant mass with respect to debris mass and orbital parameters of some rocket bodies are shown below. And two plots are also shown in the below figures(FIG. 2, FIG. 3), the first is between mass of the debris versus TDK propellant mass and the second is between perigee altitude versus the mass of TDK propellent. The data of the orbital parameters are obtained from NORAD TLEs.

SL NO.	OFFICIAL NAME OF ROCKET BODY	APOGEE (KM)	PERIGEE (KM)	MASS OF DEBRIS (KG)	DISPOSAL ORBIT (KM)	MASS OF TDK PROPELLENT (KG)
1	SL-6	807	790	892	285	46.0
2	ARIANE 40+	774	758	1764	295	82.0
3	PSLV	839	789	912	238	51.5
4	THOR BURNER 2	848	781	65	320	4.3
5	ARIANE 40	799	777	1764	295	85.2
6	ARIANE 5	801	754	1190	335	50.1
7	ARIANE 1	791	771	1318	297	63.0

Data from the above table clearly shows that the mass of the TDK propellent depends upon the orbital parameters of the dead rocket body such as perigee altitude, mass of the rocket body and the disposal altitude of the rocket body after firing. The disposal orbit denotes the unstable orbit from where the rocket body will slowly re-enter earth's atmosphere and end up with burning.

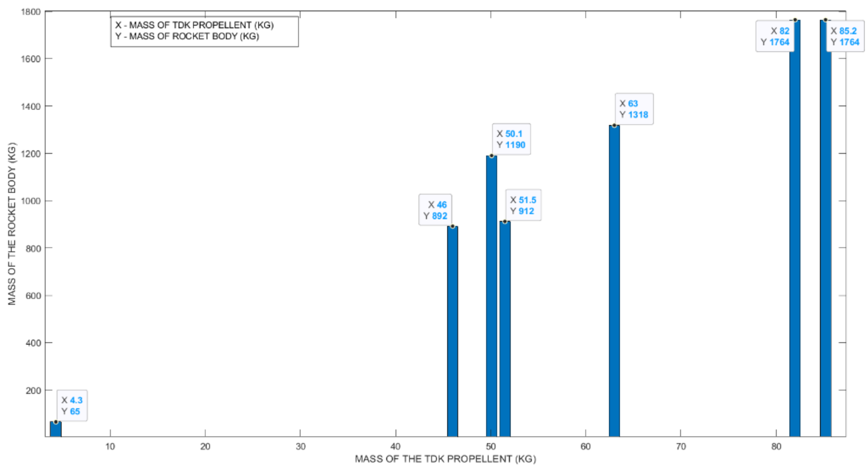

FIG. 2. PLOT BETWEEN THE MASS OF THE TDK PROPELLENT AND THE MASS OF THE ROCKET BODY.

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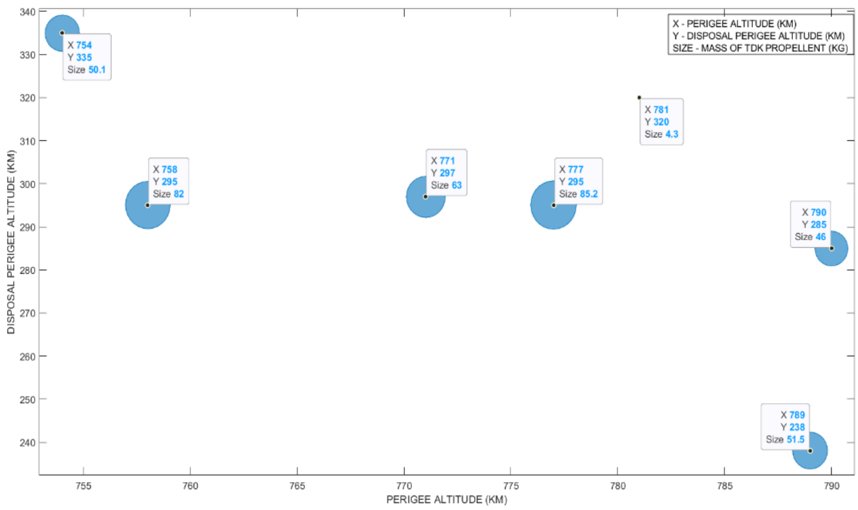

FIG. 3. PLOT BETWEEN THE ALTITUDE OF PERIGEE AND THE DISPOSAL ORBIT AFTER TDK FIRING. THE SIZE OF THE CIRCLES DENOTE THE AMOUNT OF TDK MODULE REQUIRED IN KG.

[2]. The robotic arms are a part of the DRM, this is used to capture the orbital debris with grip and stop the angular rotation of the debris body. The design of the robotic arms are somewhat different of that are used in space. Space based robotic arms are highly fragile, mobile and they have a degree of redundancy. The design of the robotic arms is one other critical work. Based on the requirements the design of these robotic arms varies such as the structure, the number of joints, geometry e.t.c.

The robotic arms used in these missions must be reliable and must have longer life. They are such made that they are capable of adverse environments of space. The elements that are used are light in weight as well as they are robust, and have the capability to resist corrosion. And due to the sharp transitions between heat and cold, they are insulated with several layers of insulations. The joints of the robotic arms are so designed that they can rotate almost in all direction and have several sensors to sense and provide feed back signal.

[3]. Robotic Refueling is a technology developed by NASA to demonstrate in-orbit cryogenic fuel transfer from one orbital body to another. It was named as Robotic Refueling Mission(RRM). International Space Station(ISS) is equipped with this technology. The module has two different chambers. The first one is known as the source dewar and the second is receiver dewar. Apart from these dewars there are other components too : CTH(Cryogenic Transfer Hose), CCA(Cryogenic Coupler Adapter), HMD(Hose Management Device), CST(Cryogenic Servicing Tool), e.t.c. These parts are marked in FIG. 4.

The Cryogenic Coupler Adapter(CAA) is normally a flexible transfer line and was designed with a robotic friendly adapter. The CCA are such made that they can be mated and de-mated in the orbit itself, and thus it was launched with a stowed configuration. Just as CAA the Cryogenic Transfer Hose(CTH) is also a bendable transfer line and it was launched in a coiled formation inside the Hose Management Device(HMD) . The HMD positions the transfer line and the Cryogenic Servicing Tool(CST) on orbit. The Cryogenic Servicing Tool(CST) provides a seal against the tubes of the transfer lines to restrict the leakage of the cryogenic fuel during fuel transfer.

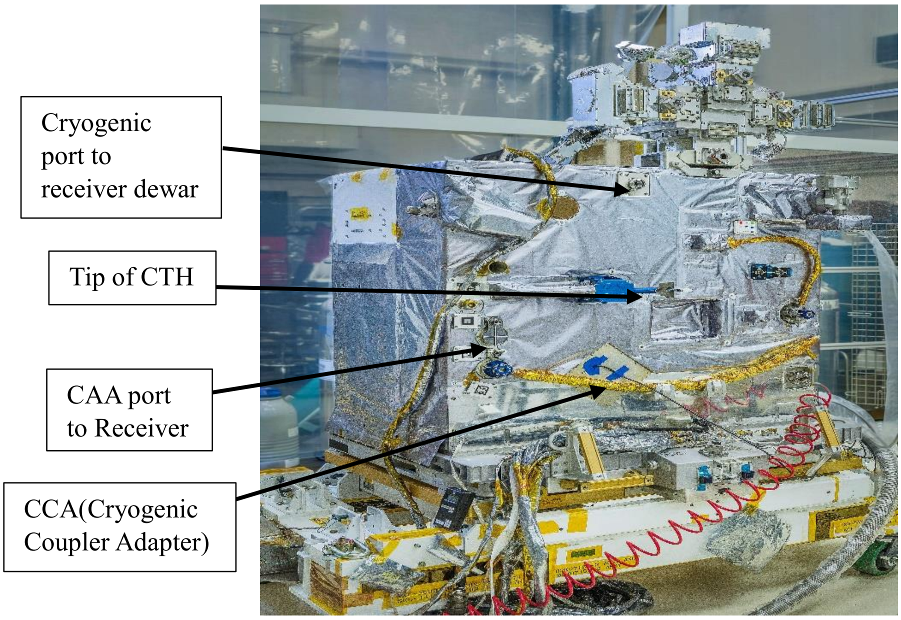

FIG. 4. SHOWS SOME OF THE PARTS OF THE ROBOTIC REFUELLING MODULE.

IV. MISSION CONCEPT

A preliminary concept of the mission have been developed in this section. The main objective of the mission is to remove 5 to 10 orbital intact debris per year from the densely populated area of LEO. The projection of the debris from a higher elliptical orbit to a lower orbit will reduce the lifetime of the debris, leading to an earlier re-entry in earth's atmosphere.

The launch vehicle places the DRM directly to an orbit nearer to the first targeted debris. A general sketch of DRM is shown below in FIG.5.

After that the module rendezvous with the debris and during closer approach maneuvers, it synchronizes with the attitudinal dynamics of the debris in order to reduce its relative angular rotation. With the use of the GNC systems present on-board, covering the different phases it approaches the debris, then captures it and stabilizes the attitudinal dynamics. The DRM uses four robotic arms in this procedure, two to mate with the debris and the other two to fix the TDK module with it. After completing all this process , DRM releases the target and activates the command sequence to the attached module. Subsequently the DRM targets another debris and starts approaching towards it to carryout the similar operation. It carryout the previous operations as long as its fuel are about to burn up.

At the end moment when the DRM is left with a very minimal fuel, it starts approaching towards the International Space Station(ISS) to re-fuel its tank from the Robotic Refueling Module present on-board with the ISS. After refueling it will again continue to operate according to the plan. These whole processes mentioned above are discussed in the next subsections.

[1]. The launch vehicle directly injects the DRM in the orbital plane of the first targeted debris(usually to a lower orbit just below the targeted location). As the two orbital bodies have different orbital period, so at first the DRM reduces the phase angle between them. When the distance between them two are almost 1 km, it uses it's Guidance, Navigation and Control(GNC) systems and performs operations based on absolute navigation phase.

[2]. The navigation process initiates as the DRM enters the rendezvous. The set of sensors and control systems present on-board starts tracking the targeted debris and provides relative information and data. One of the most important parameter of this phase is to sustain with the same orientation towards the target. The far and near view optical cameras helps in calculating the distance between the two bodies, and this feed back becomes more important as the distance between them two decreases. A good intensity of lighting are required for the proper operation of the cameras. The DRM would not receive accurate feed back from the

cameras if the orbital bodies enters eclipse phase (incase of LEO, this phase continues for about 100 minutes).

As the distance between them decreases, the near view optical cameras along with the sensors starts mapping the debris body in detail and calculates the attitudinal dynamics of the debris more precisely for appropriate capture. At this moment if the system predicts any danger then it has the capability of aborting the operation immediately.

[3]. After reaching the debris, the operation of the robotic arms initiates. Along with clutching it reduces the angular rotation of the debris. The arms are also equipped with several sensors, to provide feed back data about capture, attaching TDK module and releasing phase.

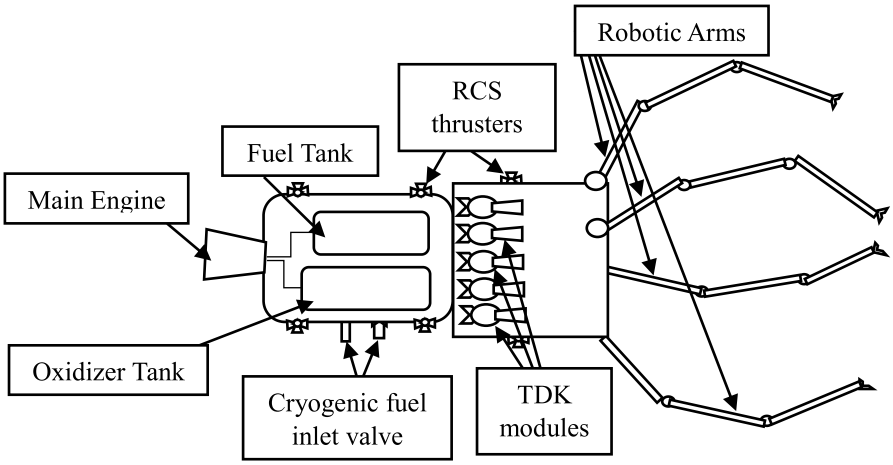

FIG. 5. SHOWS A GENERAL SKETCH OF THE DEBRIS REMOVAL MODULE.

[4]. After a precise and controlled capture of the debris body it's time to attach the TDK module with it, so that it can reduce it's perigee. While two arms grasp the debris tightly, the other two picks up a TDK module to attach with it. It precisely calculates the center of mass of the body to eliminate any kind of wrong firing and then places the kit. A sketch of this operation is shown in FIG. 6.

After that the DRM orients the debris in a proper direction of deorbiting. This operation is carried out with the help of the RCS thrusters. RCS thrusters are used for controlling attitude of any orbital body, by proving low thrusts. When all these operations are met, the DRM slowly releases the debris module by stretching it's arms. As there are some slight difference in attitudinal parameters between them, so it automatically moves to a safe distance from the debris. On achieving all the orbital parameters the TDK module ignites, and after a successful firing it gets placed to an orbit with lower perigee altitude. On the other hand the DRM targets another debris and starts phasing with it, to carryout the similar operations.

[5]. The debris after TDK firing are placed in such a orbit that doesn't initiate any further collision. A general method is to put the debris is a orbit that decays faster. This is only possible with a very low perigee orbit, so that it re-enters earth's atmosphere easily due to huge atmospheric drag.

The disposal orbit for all the debris are not same because of their difference in masses and orbital parameters.

[6]. The DRM module continues the process until it's fuel comes to an end. With a limited fuel left in it's tank, it starts approaching towards the International Space Station(ISS). Similar to as capturing a debris it phases with the attitude dynamics of the ISS and starts moving towards it. After mating all the parameters it mates with the ISS for fuel transfer using the Robotic Refueling Module(RRM).

The mating can be done using a docking adapter. The International Docking Adapter(IDA) allows any orbital body with a docking adapter to dock with it. After a successful docking the fuel transfer takes place. On completion, the DRM undocks from the ISS and targets different debris location in LEO to clean them.

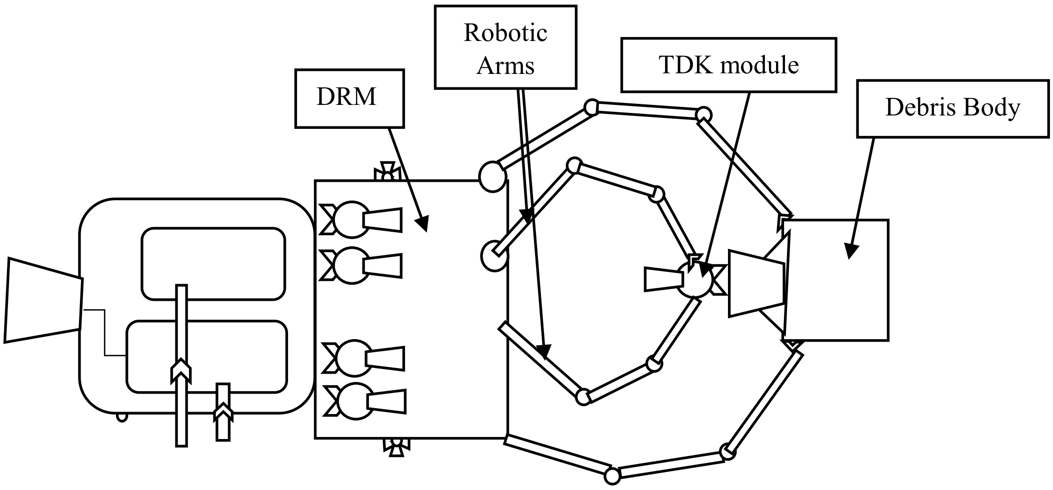

FIG. 6. SHOWING THE GENERAL SKETCH OF THE DRM ATTACHING A TDK MODULE WITH THE DEBRIS.

V. ADVANTAGES OF THE TECHNOLOGY

The effects of the space debris are much more alarming than predicted from the studies. The objective proposed in this paper allows the reuse of a single DRM module in multiple Active Debris Removal(ADR). The advantages of this technology are mentioned below:

- The proposed technology plays an active role in clearing space debris.
- The technology is cost effective.
- It assures a safe and secure future space exploration.
- It allows the reuse of a single DRM to achieve multiple Active Debris Removal(ADR).
- It uses the least amount of resources to carryout the objectives.

VI. CONCLUSION

Active Debris Removal(ADR) is a challenging job, and requires the person with maximum experience. A minute mistake while capturing a debris can lead to the destruction of both the orbital bodies into several fragments. The concept of this paper is drawn from several other proved technologies in past, such as Robotic Refueling Mission(RRM). The concept presented in this paper deals with the debris removal technique by using the least amount of resources. This is achieved by refueling the DRM from ISS, instead of using another fuel re-supply from earth. Eliminating the re-supply mission from earth automatically reduces the costing of the mission.

This technology will have a great positive impact on future space programs and will work as a pathfinder to future satellites.

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