UDC 55
AGRIS P01
https://doi.org/10.33619/2414-2948/64/02

THE IMPACT OF RENDEZVOUS PROXIMITY OPERATIONS MISSION ON SPACE DEBRIS TOWARD SUSTAINABLE SPACE ACTIVITIES

©**Susanti D.,** *ORCID: 0000-0003-0829-6566, Center for Aerospace Policy Studies of National Institute of Aeronautics and Space (LAPAN), Jakarta, Indonesia, diniwijonarko@gmail.com*

ВОЗДЕЙСТВИЕ ОПЕРАЦИЙ СБЛИЖЕНИЯ НА КОСМИЧЕСКИЙ МУСОР НА ПУТИ К УСТОЙЧИВОЙ КОСМИЧЕСКОЙ ДЕЯТЕЛЬНОСТИ

©**Сусанти Д.,** *ORCID: 0000-0003-0829-6566, Центр исследований политики в области воздушного и космического пространства Национального института аэронавтики и космоса (LAPAN), Джакарта, Индонезия, diniwijonarko@gmail.com*

Abstract. In the last thirty years, the encounter and approach of Rendezvous Proximity Operations (RPO) of human made space objects have developed. This development indicated by the developments in field of technology. The focus of this study is regarding RPO as a mission that has potential to increase the amount of space debris. This study aims to analyze the RPO activity as a potential hazardous mission in increasing the space debris population. Moreover, this research aims to analyze RPO activity as a potentially vulnerable mission to increase the space debris population. In this study, the method was carried out descriptively, by exploring data and information about RPO. The results of this study indicated that RPO activity still limited to LEO due to the high difficulty level for the GEO orbit. The results of this study indicate that RPO activity is still limited to LEO due to the high difficulty level for the GEO orbit. This is actually because in LEO orbit have more space debris (75%) than GEO orbit and it has a higher risk of falling to Earth. Based on the results obtained, it can be concluded that RPO activities are double-edged and therefore greater supervision needs to be carried out especially to safeguard Indonesia’s interests in space.

Аннотация. За последние тридцать лет были разработаны методы взаимодействия и подхода к выполнению операций по сближению с созданными человеком космическими объектами. В исследовании отражено развитие технологий. Основное внимание уделяется операциям сближения как миссии, которая может увеличить количество космического мусора. Это исследование направлено на анализ деятельности операций сближения как потенциально опасной миссии с точки зрения увеличения количества космического мусора. Более того, это исследование направлено на анализ деятельности операций сближения как потенциально уязвимой миссии для увеличения количества космического мусора. В этом исследовании приводятся данные об операциях сближения. Результаты исследования показали, что деятельность операций сближения по-прежнему ограничивается низкими околоземными орбитами из-за высокого уровня сложности для геостационарных околоземных орбит. Фактически это связано с тем, что на низких околоземных орбитах больше космического мусора (75%), чем на геостационарных околоземных орбитах, и он имеет более высокий риск падения на Землю. На основании полученных результатов можно сделать вывод о том, что деятельность операций сближения является неоднозначной, и поэтому необходимо осуществлять более строгий надзор, особенно для защиты интересов Индонезии в космосе.

Keywords: RPO, space object, space debris, GEO orbit.

Ключевые слова: операции сближения, космический объект, космический мусор, геостационарная околоземная орбита.

Introduction

In the last thirty years, the encounter and approach of *Rendezvous Proximity Operation* (RPO) of human made space objects have developed. This development indicated by the developments in field of technology. Nowadays, humans have been able to land their objects on Moon, Mars and Titan. This achievement consider as relative easy because it is dealing with relative static objects. However, a moving object landing mission that needs to be preceded by RPO has also been carried out. Europe has successfully landed its rocket at Comet 67P Churyumov-Gerasimenko. This mission nearly failed because Philae lander suffered two bounces before finally landing solidly on the comet. Besides, the space shuttle has brought back and forth various materials such as supplies and astronauts to and from space stations such as MIR and ISS. In the future, Japan has planned the Hayabusa 2 landing on 1999 JU3 asteroid in 2018, while China has embarked on lunar landing and NASA missions to Europe. This development is accompanied by diversity of problems faced. For example, Space Shuttle faced with many problems that previously not found when carrying out similar missions in Gemini, Skylab, Apollo, and Soyuz missions [1].

RPO contains two concepts that often go hand in hand, Rendezvous and Proximity Operation. RPO contains two concepts that often go hand in hand, namely Rendezvous and Proximity Operation. Rendezvous Operation is a situation where two space objects meet in the same orbit of close proximity. Meanwhile, an operation is said to be a Proximity Operation if one or more spacecraft carries out activities close to RSO (Resident Space Object). Close means has the distance under 1 kilometer from RSO. Proximity Operation activities can be include observing RSO measurements, carrying out a scientific re-sample mission, or carrying out repairs [2].

Based on the type of operation, RPO can be classified into 13 types of operations: (1) short-distance rendezvous, (2) long-distance rendezvous, (3) docking, (4) undocking, (5) robotic capture, (6) robotic release, (7) berthing, (8) de-berthing, (9) ORU operations, (10) system orbit transfer, (11) fuel / fluid transfer, (12) traveling around, and (13) capture [3]. Long-distance rendezvous operations have separation distance of 5 km to 300 meters from RSO, while short distance rendezvous operations have a separation distance lower than 300 meters. During the long distance, the chaser only needs to adjust its orbit to RSO orbit, while at short distance; the chaser also has to make behavioral adjustments such as position, orientation and velocity. ORU (Orbital Replacement Unit) operations are the activities of replacing components such as batteries or fuel tanks, opening or closing doors, installing refueling interfaces, and others [3].

RPO's mission, included its expansion such as RPOD (Rendezvous, Proximity Operation, and Docking) and AR&C (Autonomous RPO and Capture), can occur on space object made by a country against other space object (whether artificial or natural) cooperative or non-cooperative RPO's mission. Cooperative encounters are definitely occurred with artificial objects while non-cooperative encounters can occur either in natural objects (asteroids, comets) or artificial objects (debris, active objects of other countries). Moreover, the problem begins from non-cooperative encounter. Although it is useful for efforts to clean up space debris or research on near-Earth objects, it can also be misused as an attempt to spy, block satellite access from an opposing country, or, most natural cases as the addition of space debris objects.

Space debris in LEO area can be categorized metaphorically as bullets, wheels and cars. Bullets are small pieces of trash with diameter about 1 cm, have a really high and deadly speed. This type of space debris is the most difficult to avoid and detect. The amount waste 98% of space debris. Wheels junk waste about 2% and can be traced because they have size bigger than 10 cm. Cars junk even has less amount and most easy to be tracked. However this junks is a source of new bullets. Because of it large surface area, it become the targets of bullets [4]. Space debris in LEO region consist of three risks: (1) damaging satellites and active objects in area, (2) falling to Earth's surface, and (3) producing large waste due to collisions.

RPO mission mostly generated at LEO orbit area. In this area, RPO can be performed automatically, using sensors and precise algorithms, include reliable navigation filters. If the object cooperatively encountered or approached, it will make the mission of RPO easier.

Space debris in GEO orbit have different characteristic. It does not fall to Earth. Thus, it gives the risk that will be damaged satellites and active objects in its area and causes Kessler effect that produces the higher amount of garbage. The first debris of GEO orbit is Syncom 1 which launched at 14 February 1963 that failed to enter the orbit [5].

The potential risk of adding space debris objects from RPO comes from its complex nature. RPO missions can be more complex when they involve elements such as long duration flights and extravehicular activities. This high complexity demands careful consideration and avoid the mistakes to occur. A small mistake can be fatal. In the context of RPO, this mistake allows the release of certain components or collisions among objects and will produce space debris.

Based on the explanation above, therefore the main focus of this analysis is about *Rendezvous Proximity Operation* (RPO) that can be said as potential mission to develop the population of space debris (space debris). Moreover, this research aims to analyze Rendezvous Proximity Operation (RPO) activity as a potentially vulnerable mission to increase the space debris population.

Methodology

In this research, the method was carried out descriptively, by exploring data and information about Rendezvous Proximity Operation (RPO). The data or information that has been collected is then analyzed by describing or describing how the Rendezvous Proximity Operation (RPO) is a vulnerable mission that has the potential to increase the space debris population. The data or information that has been collected then analyzed by describing Rendezvous Proximity Operation (RPO) is vulnerable mission that has potential to increase the space debris population. The data collection technique used is library method through books as references, scientific journals, and other sources.

Result and discussion

RPO Vulnerability in Generating Space debris

RPO vulnerability in generating space debris can occur in situations that intentional or unintentional. A deliberate situation related to the use of space for non-peaceful purposes. In its development, there are several types of potential RPO for non-peaceful purpose. As explained below:

1. Parasitic micro-satellites. Parasitic micro-satellites can conduct RPO to attach themselves to satellites or other spacecraft and destroy and damage the satellites. Despite the geopolitics problem, damage or destruction caused by this weapon becomes a space debris problem for the

inhabitants of Earth. It was reported by Hong Kong newspaper in January 2001 that China was developing an ASAT system which has the capability of parasitic micro-satellite.

2. Manipulation of Space Object. Another inhospitable model is how RPO used to manipulate the orbits of other objects to destroy certain objects or even hit certain points on the surface of Earth. This capability was demonstrated when Russian object 2014-28E was detected on RPO mission with a rocket-level remnant that helped the object arrived at the orbit. Another incident was detected by Pentagon when two MiTEx micro-satellites were found maneuvering near the satellite junk at GEO orbit in January 2009 [6]. Therefore, a mechanism for the Notification of Outer Space Activities has been created, one of which is asking the countries involved to inform the schedule of maneuvers that have potential to approach space objects, whether it is the member countries or not [6].

3. Space defense system. The potential for RPO in generating space debris can also come from the objects that encountered or approached. It has been mentioned that RPO can be performed on non-cooperative objects. This non-cooperative characteristic can arrive at an extreme point where the encountered object responds by taking destructive actions on RPO object. The Cold War demonstrated this potential. The Soviet Union's Almaz space station, which operated from 1960–1970s, was equipped with a cannon that capable to destroy the satellites or planes that trying to get close.

The RPO potential to produce space debris accidentally arises from the peaceful use of space. Several mechanisms that cause the case to be happen such as:

1. Counting delay. Theoretically, RPO mission is failure prone, especially if it was carried out in high orbit. Collisions with space debris or encountered and approached objects are a major source of this failure. This critical situation was experienced on 27 October 2014 when Cosmos-2251 shard that was created in 2009 was detected to pass the ISS within a distance of 4 km. On a more careful calculation, it was found that the difference between the distances from ISS was only 320 meters [7].

2. Frequency interference. Calculation failures can also arise from the situation of frequency interference. If two objects are in close proximity using same frequency, there will be frequency interference happen [6].

3. RPO missions on primitive objects. The referred primitive objects on celestial objects that are not under human control such as comets or asteroids. The level of uncertainty of parameters is quite high. This comes from the shape and distribution of mass that is not similar, the gravitational field is weak and uncertain, and interference from solar radiation pressure [8]. It complicates RPO efforts whether it floating, landing, or briefly touching [8].

This vulnerability can cause a collisions or destruction in bigger space debris. The meaning of multiplying cannot even be interpreted as usual because it tends to be exponential. An uncontrolled space debris can collide further with other debris and produce more space debris by chain reactions.

The risk of improve the space debris in RPO missions has been factored into a number of NASA RPO missions. April 1991 RPO Atlantis mission (STS-37) was initially aimed at radar angle reflectors. However, this has potential to generate space debris due to re-contact and the target is changed to Compton GRO (Gamma Ray Observatory) satellite. Previously, the RPO STS-41B mission in February 1984 was canceled because of IRT (Integrated Rendezvous Target) balloon burst and shards that could threaten the Space Shuttle. On the STS-132 mission in May 2010, the main laptop (RPOP1) almost produced fragments because it broke and was immediately replaced with RPOP2 [9].

RPO vulnerability to the risk of collapsing space debris

Apart from being able to produce space debris, RPO itself can be a target for space debris. During its flight mission, NASA has learned difficult causes of collision effect on shards. After repeatedly neglecting the loss of shuttle tiles due to broken foam or computer damage due to micro-fragments entering the aircraft's electronic circuit, Columbia tragedy was occurred on February 1, 2003. this tragedy occurred due to the release of foam tube which produced shards and detonated plane [10].

In the incident aftermath, NASA became very detail oriented on its shuttle flights. Besides redesigning the aircraft, for example by thickening the walls, NASA also calculating the risk that space debris could hit the plane and have an effect that potentially has a big impact as Columbia incident. Before and after the launch, space debris need to be cleaned up and the fractional potentials are checked. As the plane docks of ISS, it is inspected by astronauts for possible damage from a collision with micro meteorite.

On average, a spacecraft is hit by more than 1000 micro meteoroids and space debris [11]. These caused in replacement of more than 100 windows, the improvement of hundreds locations on radiators, and improvement of aircraft wings. A collision event was observed in STS (Space Transportation System)-50 in 1992, where titanium waste hit windows and created a crater 0.57 mm deep and 7.2 mm in diameter and paint debris produced craters on the temperature control band and the plane's face sheet. A collision was observed in STS (Space Transportation System)-50 in 1992, where titanium debris hit a window and created a crater with the deep of 0.57 mm and diameter 7.2 mm, and the debris that came from paint produced a crater in the temperature control and fuselage. A collision of crater was also found on the payload bridge door of STS-73 (1993) by the diameter of 17 mm as a result of an impact with circuit board of 1.2 mm in diameter. STS-86 (1997) experienced a collision which caused the wall of aircraft radiator cooling tube. A number of collision events were also continuously observed in subsequent flights [11].

Based on the stated reasons above, space debris was seen as the greatest risk faced in both space flight and its operations [12]. Several numbers of corrective steps were carried out by mathematical modeling, design and component modifications, operational changes, and detection and repair of damage in orbit.

The threat of space debris has also been observed in a number of RPO missions. The RPO mission of Gemini VII with Titan II in 1966 was not well implemented because the first appearance of space debris in Tital II ventilation which caused the vibration of plane. During SL-2 mission (1973) that was visited Sylab, one of the wings of solar panel array could not be fully stretched due to the risk of collision with space debris.

Various threats of RPO mission imply that RPO planning have to involve consideration of potential for collisions with space debris. For example, when docking at ISS, the aircraft is affixed in such a way that the vulnerable components of aircraft are protected from possible collision with space debris. Moreover, the efforts were made for spacecraft to fly on its orbit and RPO situation therefore space debris does not hit the front part of aircraft, which is more important [12].

During the RPO on geostationary orbit such as HST (Hubble Space Telescope), the total consideration that was made by NASA include trajectory design, flight control, power generation, space debris, robotics, temperature control, structure, and EVA (Extra Vehicular Activity). In the STS-125 mission, Atlantis conducted RPO by HST, placed Atlantis in elliptical orbit to reduce the risk of collision with space debris. Besides, HST should be re-boosted by jet from the shuttle to a safer position. After landing, an impact crater was found on the right OMS engine nozzle [9]. On

February 10, 2001, the space shuttle pushed the ISS to escape from Electron 1 debris. A month later, on March 14, 2001, the shuttle continue to pushed the ISS to maneuver in order to avoid two objects, a fragment of Kosmos rocket body and a garbage that caused by their own RPO activity.

The explained cases above show that the potential of RPO to receive space debris collisions depends on the ability to detect space debris situation. Nowadays, there are three methods to detect space debris:

The first way is Earth observation from station. The method that used by earth observation stations is the optical method by directly observing space, either on optical or infrared spectrum or by radio observation method, such as emitting radio waves into the sky and examining the back reflection of radio waves. Several observatories have been built for this purpose such as NASA Orbital Debris Observatory, EISCAT, Cobra Dane, and the ESA Space Debris Telescope and Haystack Observatory. Haystack's radar is capable to detect the space debris with the diameter up to 5 mm.

The second is Observation Station of Space; the latest space observation station that was developed is DRAGONS (Debris Resistive Acoustic Grid Orbital Navy-NASA Sensor) which was tasked on making observations of space debris environment around ISS.

The third method is Estimate. Experiments which carried out by sending special satellites that intended to receive space debris impacts. The LDEF (Long Duration Exposure Facility) satellite was taken into space by STS-41-C and retrieved by STS-32 after 68 months. Meanwhile, EuReCa (European Retrievable Carrier) satellite was also sent by STS-46 in 1992 which was picked up a year later by STS-57. The collision profiles received by two satellites include HST impact data, spacecraft windows and radiator impacts, SFU (Space Flyer Unit), MIR impact data, and ISS (International Space Station) impact data, are examined to see the behavior of sub-millimeter-sized space debris. Include the distribution of direction and composition [13].

The existence of various detection methods which mentioned above still has to be developed in sustainable activity because there will be other debris exist in the future, there will be space debris that has not been detected but is exist, as well as various technical limitations each observer currently faces. This becomes more important considering that 98% of space debris still undetected bullets and maneuvers are not quite helpful except for large objects [14].

Point of Views of Spacefaring Countries on RPO Practices
in the Framework of Sustainable Space Activities

In general understanding, a nation can be said as a part of space faring state if it already has its own satellite. At least 50 countries included in this category, including Indonesia. The large space pharyngeal not only has its own satellites, but also capable to place any objects in orbit. There are 11 nations in this category, including Iran, North Korea and South Korea. If the definition is narrowed again by including an active space flight program, there are three superpower space faring nations, which included US, Russia, and China [15].

The space faring nations increased depend on satellite systems for various needs. The practice of RPO according to space faring countries depends on various factors such as economic, political, or geopolitical. From an economic point of view, it is not only space faring nations that depend on satellite systems, but also developing countries. Developing countries need satellites to fulfill their domestic needs. Because, the nations did not own any supporting capability, they will try to reach the spacefaring nations [16]. This launch support provides economic incentives, especially for space-faring liberal countries where the private sector took really important role in satellite development and other similar aspects. The need for profits from various companies in spacefaring nation encourages spacefaring nations to provide more flexibility in RPO practices which carried out by private parties.

In terms of politics, spacefaring nations are generally democracy countries. In this situation, the government being pressured by public to immediately gives a real impact of space program [17]. The strong Pressure can encourage governments to implement any rash act. Rather than considering the safety aspects of RPO, they can immediately push the program and there will be neglect on some aspects which can be very crucial.

The third factor is geopolitics. Modern developments show the increase distant geopolitical situation from bipolarity. Bipolarity as what happen during the cold war was actually advantageous because it facilitated space regulation. There are only two countries involved: US and Soviet Union. Today, there are many space faring nations with their own interests. There are already many space faring countries with their own interests. Space arrangements become more complex and depend on political dynamics of the countries involved in competition. The involvement of private sector in the competition on its role to leads the RPO practices in order to pursuit any profit, beside the pursuit of defense and security issues by RPO programs developed in several countries, The pursuit of short-term profits is certainly a problem for space protection. On the other hand, the efforts to maintain sustainability seem to have not reached the space issue except after cases that attracted international eyes.

Space faring nations realize that space activities are very risky and have been proven by the ASAT China test. Therefore, space-faring nations try to work collaboratively to protect and use the space domain. It is stated in International Code of Conduct for Outer Space Activities (ICOC) which was initiated by European Union.

However, international law is mild law which means that it is only obeyed under an agreement. There is no law enforcement and the law can be violated during the conflict. Unfortunately, spacefaring nations include as a big nation which means they have their own way to declare themselves as a country. It reach its tension crest in three strong nations; Russia, China, United States of America.

There are two ways to maintain a balance, which is by maintaining transparency in the use of space and encouraging cooperation between countries. In terms of transparency, it included in the state of negotiation. The United Nations has formed the Group of Governmental Experts on Transparency and Confidence Building Measures in Outer Space Activities (GGE-TCBM-OSA). However, until today, US still suspicious of Russia and China's space activities because there is no transparent information about the use of space [18–19].

Indonesia's Perspective on Sustainable Space Exploration

Indonesia currently has 12 satellites. However, only four are still active (Palapa C2, Palapa D1, Telkom 1, and Telkom 2) and all of them are leased satellites. The other two satellites are partial. LAPAN-Tubsat, a GEO satellite, is collaboration between Indonesia and Germany, while Garuda-1 (Aces 1) is a collaboration satellite of Indonesia, Philippines and Thailand. Furthermore, Indonesia will continues to try developing homemade satellites within the efforts of LAPAN's research. There are still a lot of requirements for Indonesian satellites, especially to obtain Indonesia's maritime vision, overcome environmental problems, monitor climate, and maintain national unity.

Within the international transparency, it is hoped that RPO activities will be carried out especially in countries with an interest of Indonesia's orbit. This mainly arises from the use of GEO (GSO). GEO is an orbit that crosses all equatorial countries, including Indonesia. As of July 2014, there are 458 active satellites at GEO and 900 space debris objects [20]. 384 of the objects is a satellites junk. Although the amount space debris in GEO orbit is less than LEO, and RPO activities are more difficult to carry out, GEO orbit is strategic and important area for Indonesia and other countries. GEO orbit is characterized by the importance of this orbit to communicate because it is in an ideal orbit to cover the entire planet and allows satellite to remain stay in its orbit [21].

12.82% of GEO routes are located above Indonesia [22] however, Indonesia only has five satellites in GEO, one of which is a collaboration satellite with Philippines and Thailand (Garuda-1) and one (Palapa D1) is not even located above Indonesian GEO (UCSUSA, 2014). Indonesian representatives at UNCOPUOS session repeatedly reminded other countries that GEO is an important issue for Indonesia, GEO is a limited area and the countries under it must be prioritized. This is more important considering that Indonesia is an archipelago country with a dense population and it is need satellite to support people communications. This effort is always expressed in the annual session of UNCOPUOUS, although it is rarely ignored by other countries that have taken advantage of GEO for a long time.

Table 1.

INDONESIAN ACTIVE SATELLITE LIST

Name	*Location (BT)*	*Massa (kg)*	*Launch date*	*Comment*
Palapa C2	112,99	3.014	15/05/1996	30 C-band, 6 Ku-band; voice communication and view on the wider area to the boundary of Iran, Vladivostok, Australia, and New Zealand
Palapa D1	150,97	4.100	31/08/2009	The third-tier rocket is released in a low transfer orbit it is capable of maneuvering and reducing the life of satellite.
Telkom 1	108,01	2.763	12/08/1999	Indonesian TV broadcast has reached the age limitation of 15 years old (2014).
Telkom 2	118,02	1.930	16/11/2005	24 transponder C-band; Provide the internet, data, voice, and video services for Indonesia.
LAPAN-Tubsat	0	60	10/01/2007	Micro satellite video camera monitoring; based on the German DLR-Tubsat; will conduct behavioral control experiments and earth observations. It is exist in LEO orbit.
Garuda-1 (Aces 1)	123,03	4.291	12/02/2000	L-band; phone cellular communication

Source: UCSUSA, 2014.

Indonesia has been considered enough to change its stance regarding the status of orbit GEO. Before, spacefaring nations stated that GEO orbit is owned by the country that capable to reach and positioning their satellite in GEO orbit by the principle of first come first served. Equatorial countries responded to this by stating that they should be prioritized because GEO is located right above their country.

GEO as an area that can be utilized by any country regardless the economic level, science and technology since 1982 International Telecommunications Convention. Despite, Indonesia still strives to place GEO as a sovereign territory. Besides being grateful for the decision to create GEO as a neutral area, Indonesia also affirms the commitment along with other equatorial countries continue to establish the special interests of equatorial countries towards GEO. This commitment was also supported by the Group of 77 at Unispace 1982 [23]. Therefore, the area of GEO continues to be maintained under the Law Number 3/1989 and Law Number 36/1999 concerning

Telecommunications, and the word aerospace was used in Law Number 3/2002 concerning on State Defense, although it does not explicitly state the existence of GEO. Inside the Law Number 36/1999, it is stated that GEO is part of a satellite orbit and the users of this orbit are obliged to pay for rights (article 34 (2)), It is prohibited for being used by foreigners unless it is related to the problem of state security, safety, disaster, distress, epidemics, navigation, and should be fully monitored (articles 35 and 36).

Inside the 44th UNCOPUOS trial of 2001, majority of countries agreed that GEO is part of outer space [24]. Indonesia had to agree to the cooperation agreement. This was emphasized in Law Number 16/2002 regarding the ratification of Treaty on Principles Governing Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, 1967. Likewise, Article 5 Law No 43/2008, Law No. 21 of 2013 regarding the Space has no longer mentions about GEO. Therefore, it is no longer a part of sovereign area; however Indonesia still required the need for equator country to obtain special treatment regarding the GEO.

The prioritization of GEO regarding the interest of Indonesia is quite reasonable. The following two images indicated the GEO satellite population and space debris over equatorial air. There are 787 satellites which were monitored above GEO inside the locations that publicly exposed, whether active or not, of from 787,103 satellites (13.08%) are above Indonesian territory [25]. The other 55 satellites are unknown, as seen in Figure 1 and 2 below.

It is true that space debris in GEO could not crash down to the Earth and hit the country. However, the problem is regarding RPO activities, especially those related to the efforts of disposing the space debris from GEO into graves (even higher) above Indonesia, and it will create its own vulnerabilities. If there is any mistake occurred, thus the collision will happen in this area and create destruction on communication system of GEO satellite above the country (Indonesia). Currently there are two Indonesian satellites in GEO orbit and for the future development, As the economy grows stronger and high demand of satellites in this area, Indonesia's interests may be affected by the collision of space debris that occur at GEO orbit, either in form of satellite damage or the densely populated area with the debris that narrowed the space for satellite to move.

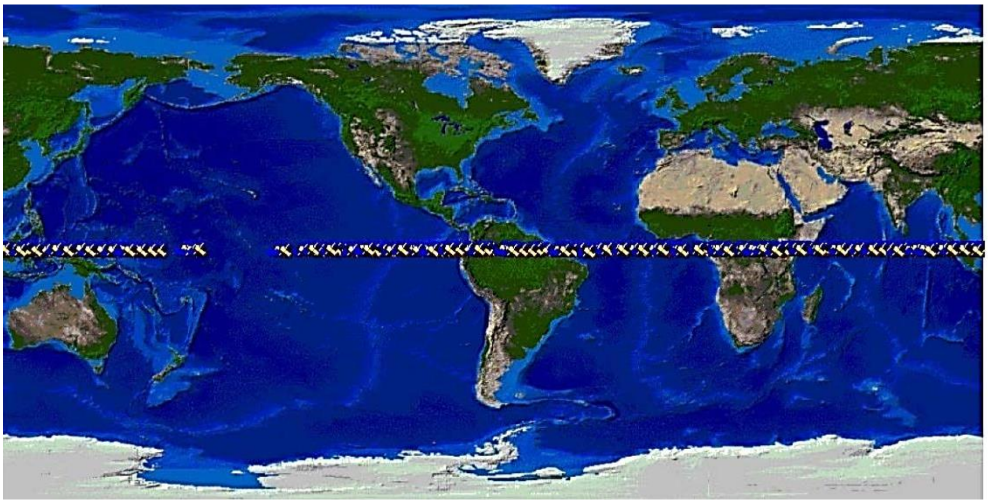

Figure 1. Active Satellite Population of GEO [5].

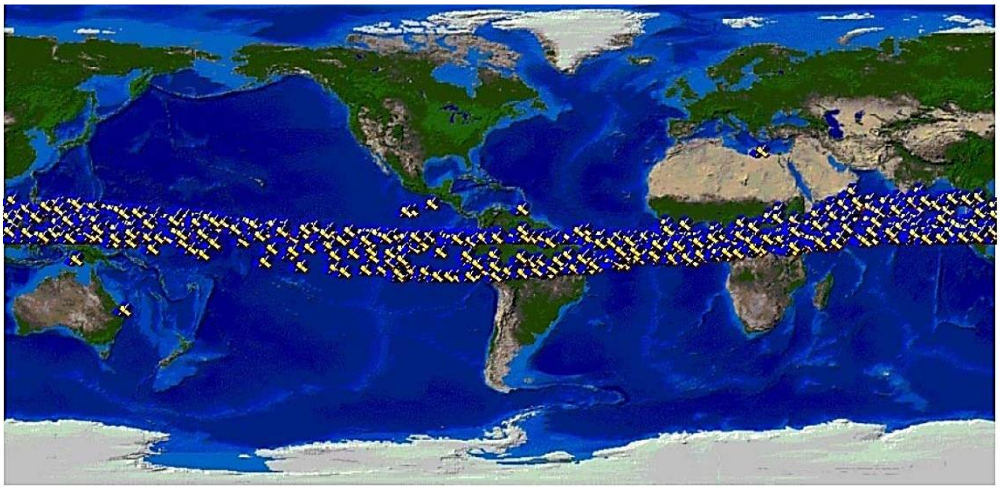

Figure 2. The Debris Satellite Population of GEO [5].

The second interest noted by Defense Industry Daily is regarding the GEO orbit as the orbit that mostly used by military satellites. There are 36 (4,28%) military satellites which was operated at GEO. According to the data from 2014 UCSUSA, even this number reaches 101 active satellites or 22.05% of the active number satellites in GEO orbit area. Compared to the total world military satellites of 531 satellites, the number of military satellites on GEO reaches 6.78%. 19 satellites owned by USA. Compared to the number of military satellites that owned by US, it was places early warning satellites about their ballistic missile launch activities on the top of GEO. Around 2014, US Air Force opens their military secrets about GSSAP (Geosynchronous Space Situational Awareness Program) which utilizes two sensing satellites that continuously monitor the area of GEO based on the point of view of military activities, RPO, spacecraft, and space debris.

This orbit is important for military because it is able to monitor the Earth more comprehensive and does not have good surveillance system. Indeed, Earth observation for military activities can be done anywhere and it is better if it is done at LEO orbit which gives brighter view. However, the activity at LEO orbit is easier to be detected from the ground. While the activity at GEO orbit is harder to be observed because the location is higher. Besides, satellites at GEO can consistently observe the Earth's surface, including Indonesia.

Based on the data from N2YO (2014), among 103 satellites that has been recorded to have locations at Indonesian GEO, two of them include as military satellites. CHINASAT 2A located on Sumatera by the longitude of 98,2° is Chinese satellites that was launched on 26 May 2012. Moreover, KOREASAT 5 that was launched on 22 Augustus 2006, include as the double function satellites that has function as military purposes as well as civilians belongs to South Korea which located on the above longitude of 113,1°BT. Of the 55 satellites which has unknown location at GEO, 20 are military satellites and 19 are owned by US. AEHF1, AEHF2, and AEHF3 are a US military satellite that aims to communicate between the presidents, military commanders, and soldiers on the battlefield. Besides, there are MUOS, SBIRS GEO 1 (USA 230), SBIRS GEO 2 (USA 241), USA 113, USA 142, USA 143, USA 157, USA 164, USA 169, USA 250 (NROL-67), USA 252, USA 99, WGS F2 (USA 204), WGS F3 (SA 211), WGS F4 (USA 233), dan WGS F6 (USA 244) owned by US and SICRAL 1B owned by Italy. Based on the data of 2014 UCSUSA, UFO-2, UFO-4, UFO-6, UFO-7, UFO-8, WGS-1, WGS-2, WGS-3, WGS-4, WGS-5, and WGS-6 all of them are US military satellites located at over the Indonesian GEO. Besides, UCSUSA data on 2014 also states that Chinasat 1A and Zhongxing 20A are Chinese military satellites above GEO Indonesia.

Table 2.

AMOUNT OF MILITARY SATELLITES ABOVE INDONESIA'S GEO ORBIT

Name	*Country*	*Location (East Longitude)*	*Launching Time*	*Comment*
UFO-2 (USA 95) “UHF Follow-On”	USA	95,4	2003	Electronic intelligence (ELINT).
UFO-4 (USA 108, UFO F4 EHF) “UHF Follow-On”	USA	98	2012	Operated by US Army and its purpose are to provide secure communication services for data and voice data.
UFO-6 (USA 114, UFO F6 EHF) “UHF Follow-On”	USA	100,08	1990	Satellites of UHF communications services for US and Australian Department of Defense
UFO-7 (USA 127, F7 EHF) “UHF Follow-On”	USA	100,9	2010	ELINT.
UFO-8 (USA 138, UHF F/O F8) “UHF Follow-On”	USA	103,28	2006	Voice and video transmission, especially for 2008 Beijing Olympics.
Wideband Global Satcom 1 (WGS-1, USA 195)	USA	103,84	2004	Infrared sensor to detect the heat from missiles and boosters against the Earth's background; capable of detecting small missiles; provides short-range missile strike warnings against the US and its allies.
Wideband Global Satcom 2 (WGS-2, USA 204)	USA	104,21	2011	Part of the constellation compass.
Wideband Global Satcom 3 (WGS-3, USA 211)	USA	113,08	2006	24 Ku-band, 8 SHF-band, and 4 Ka-band transponders for military and commercial use.
Wideband Global Satcom 4 (WGS-4, USA 233)	USA	118	2010	Part of Compass Constellation
Wideband Global Satcom 5 (WGS-5, USA 243)	USA	118	2010	Part of Compass Constellation
Wideband Global Satcom 6 (WGS-6, USA 244)	USA	118	2011	Part of Compass Constellation
Zhongxing 1A (Chinasat 1A, Fenghuo 2)	Chinese	129,84	2011	Zhongxing 22A replacement.
Zhongxing 20A	Chinese	130	2010	It is officially named a communications satellite but is believed by observers as military satellite.
Koreasat 5 (Mugungwha 5)	South Korea	113,1	2014	Space surveillance of GEO satellites
Zhongxing 2A (Chinasat 2A)	Chinese	98,2	2012	Real-time data relay for interceptor satellites.

Source: UCSUSA, 2014.

By the satellite distribution in the GEO which reflects the length of GEO Indonesia area (12,82% vs 13,08%) thus, at least three military satellites above are located at Indonesian GEO and it is certain that two of them are US satellites. The potential can be greater considering that GEO Indonesia is an ideal location to oversee the location near China, which is one of the US's major rivals. Moreover, there are four countries that used GEO orbit as military purposes include USA, Chinese, South Korea and Italy; two of them certainly located above Indonesian area and the other two keep their location a secret. Geopolitically, the area of GEO is ultimately an area of potential conflict that contested by two modern superpowers country, China and US.

In framework of maintaining the sustainable space exploration space, this situation is actually has no benefit for Indonesia. The density of space debris at GEO orbit and the threat of geopolitical conflict in region can threaten the future space exploration. The geopolitical conflict at GEO has been going on since the Cold War. In 1980s, USSR developed the system of ASAT through Naryad program to attack the GEO satellites [26]. China has actively developing ASAT which is capable to reach the orbit of GEO.

Collisions among objects at GEO orbit has a less possibility because the speed is lower than LEO orbit and the satellites are all moving in same direction. However, the object collision that happen on GEO orbit has greater impact than the collision in LEO object. The debris generated can spread within a few days until the half GEO orbit, and it is faster than the junk spread in LEO [27].

The GEO orbit above Indonesia is even more interesting for the addition of satellite population in the future because it is located far from two GEO gravity which can become the bank of space debris (75°BT dan 105°BB). Those two aspects were avoided because the probability of collision was seven times higher than other areas in GEO orbit. Therefore, the rate of GEO objects addition above Indonesia (95 ° East - 141 ° East) will be higher than South Asia and Pacific region.

According to Benedict, RPO activities at GEO can be carried out technically in four ways, such as robotic manipulation, life extension, withdrawal, and inspection [28]. Robotic manipulation activities include the help to remove stuck antennas or solar panels, placing coordinating cable mechanisms back on track, collecting space debris, adjusting misplaced thermal blankets, adding or removing hardware that accessible from outside. Life extension activities can be carried out in form of extending operations by attached momentum fouling modules or station guards, dispatching consumables such as fuel, compressive agents, ion-drive fluids, oxidizing agents or refrigerants. The withdrawal activity was carried out to move the trash object (zombie satellite) out of GEO, push or pull the trash object into grave orbit, help to lift the orbit of shrinking satellite, or vice versa, lower or rotate the satellite's orbital node. Inspection activities can be carried out by examining the damage caused by launch, analyzing hardware anomalies, or imaging the damage that may be caused by space debris.

The RPO phases in the future purposes of orbit GEO will be focuses to decrease the space debris/junk. Currently, NASA has developed the Phoenix program that has an aim of assembling, repairing and extending the life of satellites at GEO [29]. The Phoenix Satellite carries out an RPO program at GEO orbit which is capable to reduce space debris. It is also has geopolitics potential. Phoenix is able to use space debris to create new GEO satellite. It means there is no need to launch new active satellites at GEO orbit and not constrained by financial constraints anymore. Phoenix is able to increase the infinite number of GEO satellites indefinitely. Another RPO to reduce space debris was done by pushing trash out of GEO orbit to the orbit of burial or pushing down the trash from GEO, therefore it falls into the Earth’s burial satellite off coast on Christmas Island which located in Indian Ocean. This step will be taken by Liquidator from Roscosmos (Russia) which is planned to be launched in 2018. Liquidator will proceed at GEO because GEO is more valuable than LEO and has less space debris population than LEO (Interfax, 22 Augustus 2014). Furthermore, RPO strategy also able to encourage active satellites or space debris to be directed as weapons for other active satellites.

Conclusion

RPO activities are still limited to LEO due to the high difficulty level for GEO orbits. This needs more concern because LEO orbit has more space debris (75%) than GEO and it is in danger of falling to Earth. Besides, there has not been any RPO activity directed at cleaning up space debris, even though the amount of junk has been piling up due to the spaces activities such as ASAT (Anti-Satellite) and accidental collisions. Apart from the risk of being exposed to space debris, RPO activities are capable to produce space debris and have been recorded in several numbers of incidents. Indonesia itself has great importance for GEO area that is more strategic for Indonesia's archipelago geography. Beside continue to strive for special position at GEO, GEO that positioned over Indonesia has been shown to be used for military interests of various countries, including US, China and South Korea. It is highly like that RPO activities in the future will occur because this area has a large economic and military value. Every RPO activities are double-edged and has greater supervision needs to be carried out especially as safeguard of Indonesia's space interests.

Acknowledgment

We would like to thank the Head of the Center for Aerospace Policy Studies, LAPAN and the editorial team who have supported this research so that this KTI can be published.

References:

1. Goodrich, M. K., Buchalter, A. R., & Miller, P. M. (2012). Toward a history of the space shuttle.

2. Brunner, A. F. (2007). Spacecraft Proximity Operations Used to Estimate the Dynamical & Physical Properties of a Resident Space Object.

3. Rekleitis, I., Martin, E., Rouleau, G., L'Archevêque, R., Parsa, K., & Dupuis, E. (2007). Autonomous capture of a tumbling satellite. *Journal of Field Robotics*, *24*(4), 275-296. https://doi.org/10.1002/rob.20194

4. Pearson, J., Levin, E., Oldson, J., & Carroll, J. (2010). *Electrodynamic debris eliminator (edde): design, operation, and ground support*. STAR TECHNOLOGY AND RESEARCH INC MOUNT PLEASANT SC.

5. Schildknecht, T. (2007). Optical surveys for space debris. *The Astronomy and Astrophysics Review*, *14*(1), 41-111. https://doi.org/10.1007/s00159-006-0003-9

6. Jaramillo, L., & Weber, A. (2013). Bond yields in emerging economies: it matters what state you are in. *Emerging Markets Review*, *17*, 169-185. https://doi.org/10.1016/j.ememar.2013.09.003

7. Keating, S. E., Machan, E. A., O'Connor, H. T., Gerofi, J. A., Sainsbury, A., Caterson, I. D., & Johnson, N. A. (2014). Continuous exercise but not high intensity interval training improves fat distribution in overweight adults. *Journal of obesity*, *2014*. https://doi.org/10.1155/2014/834865

8. Furfaro, R., Gaudet, B., Wibben, D. R., Kidd, J., & Simo, J. (2013). Development of non-linear guidance algorithms for asteroids close-proximity operations. *AIAA Guidance, Navigation, and Control (GNC) Conference, 4711*. https://doi.org/10.2514/6.2013-4711

9. Goodman, J. L. (2006). History of space shuttle rendezvous and proximity operations. *Journal of Spacecraft and Rockets*, *43*(5), 944-959. https://doi.org/10.2514/1.19653

10. Hale, W., & Lane, H. W. (Eds.). (2010). *Wings in orbit: scientific and engineering legacies of the Space Shuttle 1971-2010*. Government Printing Office.

11. Kelly, J. (2005). Debris Is Shuttle’s Biggest Threat. *Fla. Today*.

12. Nishida, S. I., Kawamoto, S., Okawa, Y., Terui, F., & Kitamura, S. (2009). Space debris removal system using a small satellite. *Acta Astronautica*, *65*(1-2), 95-102. https://doi.org/10.1016/j.actaastro.2009.01.041

13. Nikanpour D. (2009). Space Debris Mitigation Technologies.

14. Johnson, N. L. (2010). Orbital debris: the growing threat to space operations.

15. Krepon, M., & Thompson, J. (2013). *Anti-satellite weapons, deterrence and Sino-American space relations*. Naval postgraduate school Monterey CA center on contemporary conflict.

16. Dhanji, N. (2002). Prospects for Involvement in Space Activities in Developing Countries via Small Satellites. *Smaller Satellites: Bigger Business? 307-314. Springer, Dordrecht*. https://doi.org/10.1007/978-94-017-3008-2_35

17. Pavek, M., & Stephenson, R. (2002). Report on Panel Discussion 4: Launch and Support Services for Micro/Nanosatellites. *Smaller Satellites: Bigger Business? 267-268. Springer, Dordrecht*. https://doi.org/10.1007/978-94-017-3008-2_30

18. David, L. (2013). Mysterious Actions of Chinese Satellites Have Experts Guessing. *Space. com*, *9*.

19. Wall, M. (2014). Is Russian Mystery Object a Space Weapon? *Space. com*, *19*.

20. Perek, L. (2012). Actual Situation in the Geostationary Orbit. *Proceedings of the Institute of International Space Law, Eleven International Publishing, The Hague*.

21. Dougherty, K. (2014). Crowded space: The problem of orbital debris. *Issues*, (106), 18. https://search.informit.org/doi/10.3316/informit.497113170613249

22. Rahayu, M. (2007). *Pendidikan kewarganegaraan*. Grasindo.

23. Pramono, A. (2011). *Dasar-dasar hukum udara dan ruang angkasa*. Ghalia Indonesia.

24. Diederiks-Verschoor, I. H. (2008). An introduction to space law.

25. Chen, X., Xiang, S., Liu, C. L., & Pan, C. H. (2014). Vehicle detection in satellite images by hybrid deep convolutional neural networks. *IEEE Geoscience and remote sensing letters*, *11*(10), 1797-1801. https://doi.org/10.1109/LGRS.2014.2309695

26. Hsu, J. (2014). Global Conflict Could Threaten Geostationary Satellites. *Scientific American*, *31*.

27. Finkleman, D., & Oltrogge, D. (2002, January). Consequences of Debris Events in Geosynchronous Orbit. *AIAA/AAS Astrodynamics Specialist Conference and Exhibit*, *7375*. https://doi.org/10.2514/6.2008-7375

28. Benedict, B. L. (2013). Rationale for need of in-orbit servicing capabilities for GEO spacecraft. *AIAA SPACE 2013 Conference and Exposition*, *5444*. https://doi.org/10.2514/6.2013-5444

29. Barnhart, D., Sullivan, B., Hunter, R., Bruhn, J., Fowler, E., Hoag, L. M., ... & Vincent, K. (2013). Phoenix program status-2013. *AIAA SPACE 2013 conference and exposition, 5341*. https://doi.org/10.2514/6.2013-5341

Список литературы:

1. Goodrich M. K., Buchalter A. R., Miller P. M. Toward a history of the space shuttle. 2012.

2. Brunner A. F. Spacecraft Proximity Operations Used to Estimate the Dynamical & Physical Properties of a Resident Space Object. 2007.

3. Rekleitis I. et al. Autonomous capture of a tumbling satellite // Journal of Field Robotics. 2007. V. 24. №4. P. 275-296. https://doi.org/10.1002/rob.20194

4. Pearson J. et al. Electrodynamic debris eliminator (edde): design, operation, and ground support. Star technology and research Inc mount pleasant SC, 2010.

5. Schildknecht T. Optical surveys for space debris // The Astronomy and Astrophysics Review. 2007. V. 14. №1. P. 41-111. https://doi.org/10.1007/s00159-006-0003-9

6. Jaramillo L., Weber A. Bond yields in emerging economies: it matters what state you are in // Emerging Markets Review. 2013. V. 17. P. 169-185. https://doi.org/10.1016/j.ememar.2013.09.003

7. Keating, S. E., Machan, E. A., O'Connor, H. T., Gerofi, J. A., Sainsbury, A., Caterson, I. D., & Johnson, N. A.Continuous exercise but not high intensity interval training improves fat distribution in overweight adults // Journal of obesity. 2014. V. 2014. https://doi.org/10.1155/2014/834865

8. Furfaro, R., Gaudet, B., Wibben, D. R., Kidd, J., & Simo, J. Development of non-linear guidance algorithms for asteroids close-proximity operations // AIAA Guidance, Navigation, and Control (GNC) Conference. 2013. P. 4711. https://doi.org/10.2514/6.2013-4711

9. Goodman J. L. History of space shuttle rendezvous and proximity operations // Journal of Spacecraft and Rockets. 2006. V. 43. №5. P. 944-959. https://doi.org/10.2514/1.19653

10. Hale W., Lane H. W. (ed.). Wings in orbit: scientific and engineering legacies of the Space Shuttle 1971-2010. Government Printing Office, 2010.

11. Kelly J. Debris Is Shuttle's Biggest Threat // Fla. Today. 2005.

12. Nishida S. I. et al. Space debris removal system using a small satellite // Acta Astronautica. 2009. V. 65. №1-2. P. 95-102. https://doi.org/10.1016/j.actaastro.2009.01.041

13. Nikanpour D. Space Debris Mitigation Technologies. 2009.

14. Johnson N. L. Orbital debris: the growing threat to space operations. 2010.

15. Krepon M., Thompson J. Anti-satellite weapons, deterrence and Sino-American space relations. Naval postgraduate school Monterey CA center on contemporary conflict, 2013.

16. Dhanji N. Prospects for Involvement in Space Activities in Developing Countries via Small Satellites // Smaller Satellites: Bigger Business? Dordrecht: Springer, 2002. P. 307-314. https://doi.org/10.1007/978-94-017-3008-2_35

17. Pavek M., Stephenson R. Report on Panel Discussion 4: Launch and Support Services for Micro/Nanosatellites // Smaller Satellites: Bigger Business? Springer, Dordrecht, 2002. P. 267-268. https://doi.org/10.1007/978-94-017-3008-2_30

18. David L. Mysterious Actions of Chinese Satellites Have Experts Guessing // Space. com. 2013. V. 9.

19. Wall M. Is Russian Mystery Object a Space Weapon? // Space. com. 2014. V. 19.

20. Perek L. Actual Situation in the Geostationary Orbit // Proceedings of the Institute of International Space Law, Eleven International Publishing, The Hague. 2012.

21. Dougherty K. et al. Crowded space: The problem of orbital debris // Issues. 2014. №106. P. 18. https://search.informit.org/doi/10.3316/informit.497113170613249

22. Rahayu M. Pendidikan kewarganegaraan. Grasindo, 2007.

23. Pramono A. Dasar-dasar hukum udara dan ruang angkasa. Ghalia Indonesia, 2011.

24. Diederiks-Verschoor I. H. et al. An introduction to space law. 2008.

25. Chen X. et al. Vehicle detection in satellite images by hybrid deep convolutional neural networks // IEEE Geoscience and remote sensing letters. 2014. V. 11. №10. P. 1797-1801. https://doi.org/10.1109/LGRS.2014.2309695

26. Hsu J. Global Conflict Could Threaten Geostationary Satellites // Scientific American. 2014. V. 31.

27. Finkleman D., Oltrogge D. Consequences of Debris Events in Geosynchronous Orbit // AIAA/AAS Astrodynamics Specialist Conference and Exhibit. 2002. P. 7375. https://doi.org/10.2514/6.2008-7375

28. Benedict B. L. Rationale for need of in-orbit servicing capabilities for GEO spacecraft // AIAA SPACE 2013 Conference and Exposition. 2013. P. 5444. https://doi.org/10.2514/6.2013-5444

29. Barnhart D. et al. Phoenix program status-2013 // AIAA SPACE 2013 conference and exposition. 2013. P. 5341. https://doi.org/10.2514/6.2013-5341

Работа поступила в редакцию 09.02.2021 г.

Принята к публикации 22.02.2021 г.

Ссылка для цитирования:

Susanti D. The Impact of Rendezvous Proximity Operation Mission on Space Debris Toward Sustainable Space Activities // Бюллетень науки и практики. 2021. Т. 7. №3. С. 17-32. https://doi.org/10.33619/2414-2948/64/02

Cite as (APA):

Susanti, D. (2021). The Impact of Rendezvous Proximity Operation Mission on Space Debris Toward Sustainable Space Activities. *Bulletin of Science and Practice, 7*(3), 17-32. https://doi.org/10.33619/2414-2948/64/02