KARI Recent Activities on SSA & STM

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ABSTRACT

KARI is the national space development organization of South Korea and it has a role in secure operation of space assets. Since Chinese ASAT, KARI has been including SSA activities as a major part of satellite operation and so far, KARI has been working to expand SSA and STM activities in various fields. These activities can be categorized into six items: Mitigation, Measurement, Protection, Disposal, Remediation and International Cooperation.

First item is mitigation. Currently, KARI is operating conjunction assessment tool all the time. It can download the TLE and CDM data from CSpOC automatically and performs conjunction assessments. If there is specific risky event, it sends e-mail and mobile message to inform operators. In fine assessment, KARI CA tool can send precise orbit or maneuver information to CSpOC and it also can generate optimized collision avoidance maneuver. Meanwhile, if the risk object is operational object, we can contact the owner or operator of secondary object and directly exchange relevant information to minimize collision risk. KARI have been collaborated with other space agencies in SSA & STM area so far.

Second item is about measurement. Generally, radar measurement is useful for LEO objects and other agencies are now operating radar sensor for SSA & STM. KARI don't have the radar sensor so far, but we have been performed related research to prepare the design and operation of radar sensor. KARI have radar facility located in Jeju island of Korea for tracking of Korean launch vehicles. KARI performed an experiment for tracking space objects having large RCS. Now we are trying to research on increase of maximum tracking range of the Radar in Jeju island. The related research includes ISAR image measuring test with Fraunhofer TIRA radar and the development of space object surveillance sensor simulator.

Third item is about protection. There are several upcoming space programs and among them, KOMPSAT-6 and KOMPSAT-7 started to consider the space object environment in their mission orbit. We determine whether space mission can satisfy the international guidelines using NASA and ESA space environment models and tools. And if the proposed space mission can't satisfy the international guidelines, such as NASA safety standard, we reconsider to design process and enhance the vulnerability. For example, additional shielding parts installed to protect critical parts from hypervelocity objects.

Fourthly, removal and disposal are also important activity. Now lots of space agencies are trying to comply with removal or disposal guidelines and 25 years rule is representative international guidelines. KOMPSAT-2 is LEO satellite and it can be first candidate for post mission disposal because its operation was officially terminated at 2015 but now it represents good health conditions, such as fuel and battery. We performed the research about post mission disposal plan with given satellite resources and operational constraints. And we tried to find the optimum plan that minimizes remain orbital lifetime even if international guidelines are already satisfied. Furthermore, additional reentry analysis, such as survivability and impact location analysis, also performed.

Fifth item is remediation. To remove large space object, KARI is performing research about active debris removal technologies. Five degree of freedom ground-based test bed has been developed to demonstrate proximity operation algorithms and now small satellite, which is about six-unit cube satellite, is being developed. Furthermore, on-orbit test is also planned using target and chaser satellites in the future.

Last item is international cooperation. KARI joined IADC in 2014 and have been participated steering and working groups. And we performed several IADC re-entry test campaign. Last year, Chinese Tiangong-1 was campaign target and we shared the re-entry prediction. Moreover, KARI participated SpaceOps community and space debris conference, such as AMOS, to understand and discuss the global issue and new technologies related to SSA & STM.

In this paper, current activities of KARI were introduced in 6 categorized SSA & STM area.

1. INTRODUCTION

Currently, KARI is operating six satellites, which are including four low-Earth orbit satellites and two geostationary satellites as shown in Figure 1. Furthermore, KARI is also developing next generation satellites for various missions. To operate these space assets safely, KARI defined the Space Situational Awareness (SSA) and Space Traffic Management (STM) activities as a KARI's Articles of Association (AoA).

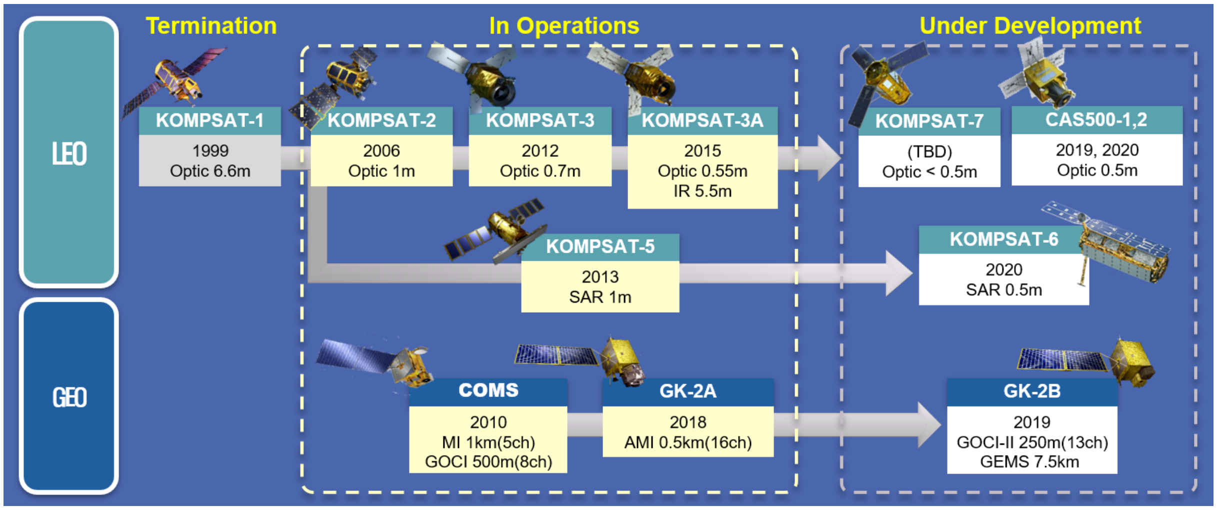

Figure 1. KARI Satellites Constellation

Before Chinese Anti-Satellite Test (ASAT), KARI performed conjunction assessment using Two Line Element (TLE) data for only specific conjunction event but since 2007, conjunction assessment activities became a major part of satellite operations. In 2008, KARI participated SpaceOps conference and started to discuss the space debris problem with other space agencies and KARI began to collaborate with Joint Space Operation Center (JSpOC) for SSA and STM activities in 2009. After then, KARI collaborated with German Space Operation Center (GSOC) and Fraunhofer Institute to expand KARI's SSA and STM capability, especially measurement aspect. In 2011, draft version of 'Operation Manual against the Conjunction Events' was released and conjunction assessment tool KARISMA was deployed in 2013. In 2014, KARI included the SSA and STM activities in KARI's AoA and joined the Inter-Agency Space Debris Coordination Committee (IADC) to solve the space debris problem together with other agencies. In 2017, Conjunction Assessment Flow Automation Support Tool (CA-FAST) deployed to support conjunction assessment process and KARI started to establish the official KARI's space debris mitigation guideline in 2018.

Currently, KARI is performing SSA and STM activities in various fields and still expanding related capability. This paper introduced six major categories in SSA and STM activities that are performed by KARI: Mitigation, Measurement, Protection, Removal, Remediation and International Cooperation.

2. MITIGATION

In order to secure the operational satellite in space, it is essential to monitor a close approach and take mitigation action in a timely manner [1]. The conjunction assessment of KARI satellites against a number of space object consists of flight dynamics system and conjunction assessment system, which is shown in Figure 2.

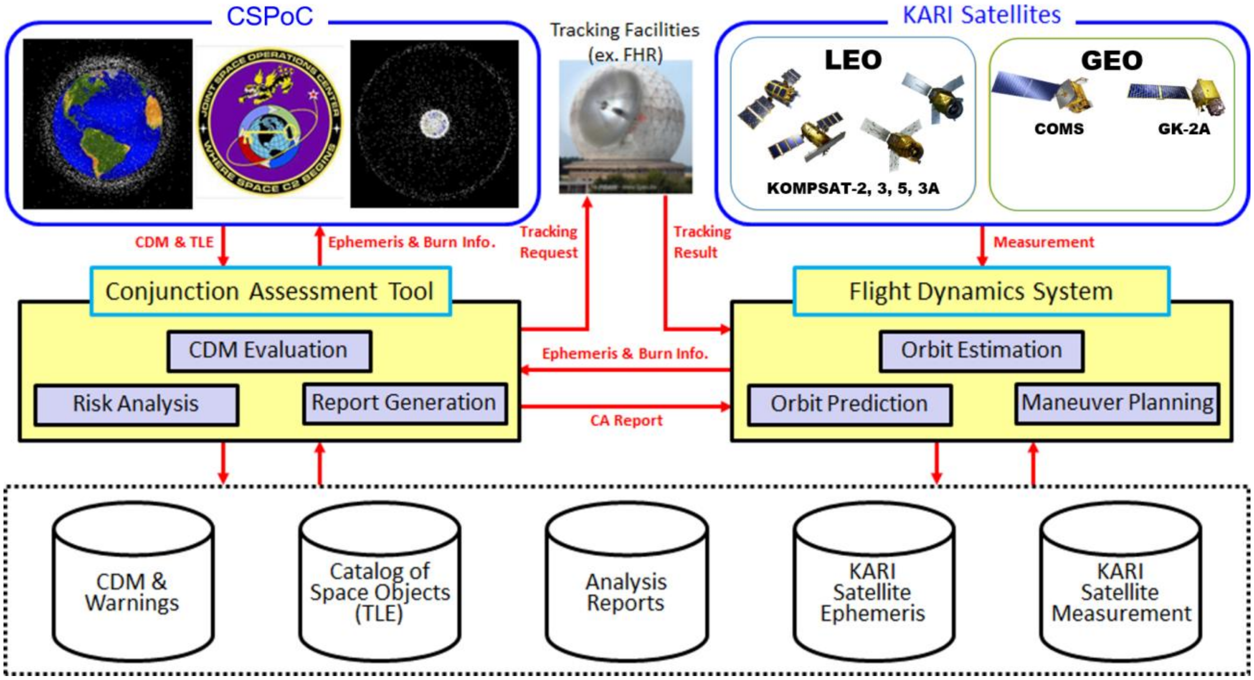

Figure 2 Overview of KARI Collision Risk Mitigation Activities

Basically, flight dynamics system estimates the satellite operational orbit by using satellite on-board GPS (Global Positioning System) navigation solutions data as well as ground-based antenna tracking and ranging data. It also generates a variety of orbit data which includes orbit stack data, TLE, orbit propagation data for the antenna tracking and mission planning activities, respectively. And, the flight dynamics generates orbit maneuver request for mission orbit acquisition and reference orbit maintenance. The flight dynamics also estimates the precise orbit by using both on-board GPS raw data and the IGS (International GNSS Service) data for the enhanced image processing. On the other hand, the conjunction assessment tool provides the function of CDM evaluation, risk analysis, and report generation. And, ephemeris data, maneuver information and CA (Conjunction Assessment) reports are exchanged between flight dynamics system and conjunction assessment system. Data sources for conjunction event include TLE and CDM (Conjunction Data Message) from CSPOC (Combined Space Operation Center), ground based tracking data, and in-house precise ephemeris. In addition, the operational manual had been also prepared in accordance with upper-level government document. The first version was released in 2010, and it is being updated as required. This document provides the comprehensive instructions with respect to the detail activities against the conjunction events. Overall procedure for conjunction assessment consists of following activities:

1) Stage 1 – Automated Screening
2) Stage 2 – Detailed Analysis
3) Stage 3 – Collision Avoidance Maneuver Planning
4) Stage 4 – Collision Avoidance Maneuver Execution
5) Stage 5 – End of Conjunction Mitigation

The conjunction assessment system is supposed to access the CSPOC server (www.space-track.org), and check any new CDM files every 30 minutes and new TLE files on an hourly basis. Once getting a bulk of new data, it analyzes the time of closest approach, minimum distances, and collision probabilities for the next 7 days (1 week). And, any events which violate the criteria (minimum range is less than 1km, radial distance is less than 300m, and maximum probability of collision is more than 1/10,000) are dealt with more thoroughly in terms of the risk management. The trend analysis of some key parameters, covariance analysis, and re-evaluation by using precise ephemeris were conducted. And, risk mitigation maneuver for collision avoidance is planned, if required.

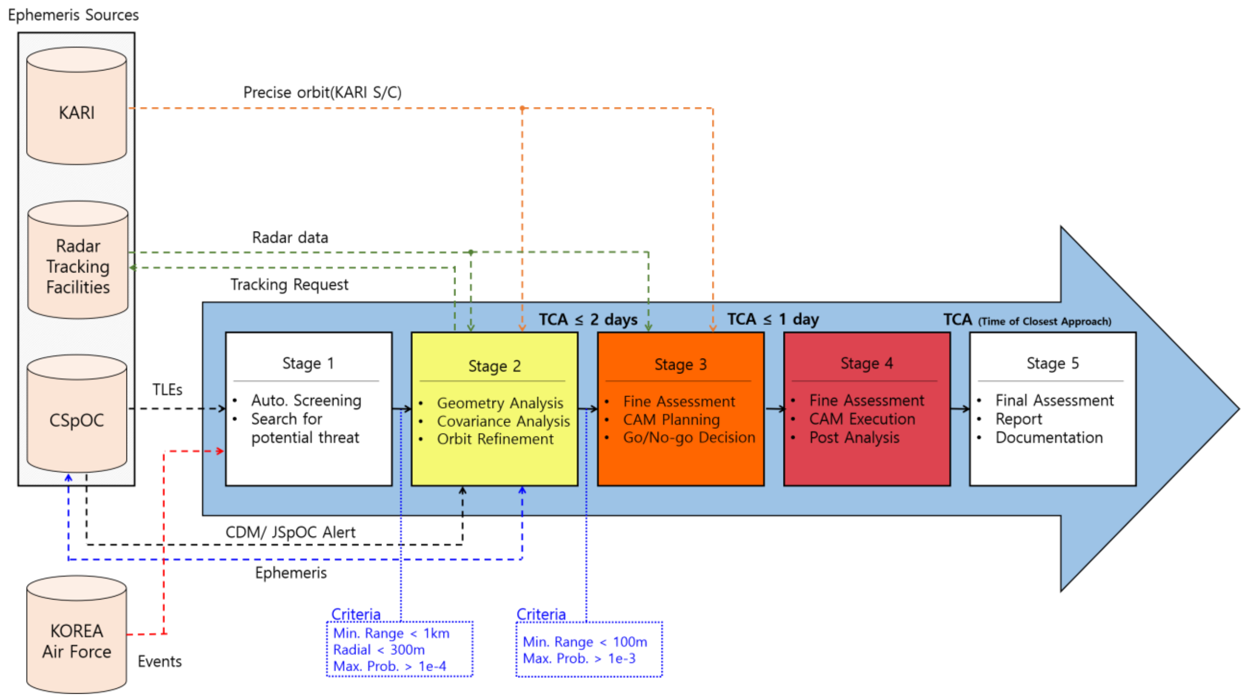

Figure 3 Procedure for Conjunction Assessment

Statistics in 2018 shows that there is large amount of conjunction events between KARI satellites and space objects [2]. For example, 43,478 CDM files were released for KARI satellites in 2018, which is less than the advanced screening volume, 0.5km, 28km, 29km in LEO and 20km, 20km, 20km in GEO along with the radial, in-track, and cross-track direction, respectively. The number of conjunction events are 2,860 as shown in Figure 4. The frequency of KOMPSAT-2 and KOMPSAT-3 is dominant due to high spatial density of space object in their altitude. Among these events, there was single collision avoidance maneuver for KOMPSAT-5. Chinese debris ‘CZ-4 DEB’ approached to KOMPSAT-5 in July 9th with 19m of distance and 2.3E-03 of collision probability. The collision avoidance maneuver plan was established that increases its altitude around 20m and then collision probability decreased to 7.1E-04. In this case, collision risk mitigated and the maneuver cycle for normal operation also postponed through collision avoidance maneuver because collision avoidance maneuver plan included KOMPSAT-5 ground track boundary for normal mission.

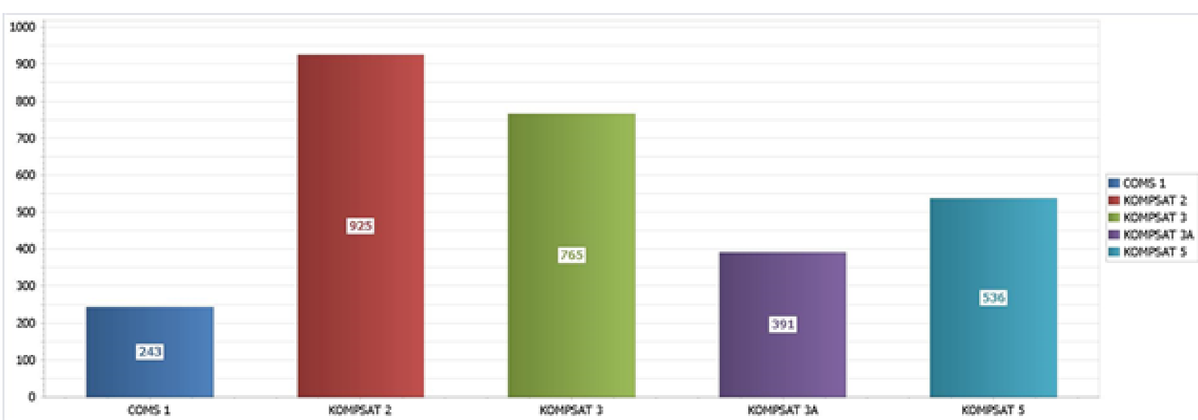

Figure 4 Conjunction Data Message received from CSpOC in 2018

3. MEASUREMENT

KARI uses the TLE and CDM from CSpOC and precise orbit ephemeris data in case of fine assessment. This means that the most precise orbit data combination is in-house orbit of KARI satellites and CDM data of secondary object. However, there are still large orbit uncertainty in the CDM especially small Radar Cross Section (RCS) objects. Generally, CDM data is updated 20 times for low-Earth orbit objects but additional precise data also still required for next decision making, such as collision avoidance maneuver.

Basically, radar facility requires enormous development and operation cost and there is no radar facility for SSA and STM in KARI. So, KARI continues to find the ways in which can get the precise orbit data of secondary objects.

For this reason, KARI started to perform the investigation and research about measurement field. In case of low-Earth orbit, radar measurement has more effective value than optic measurement, so KARI focused on radar measurement.

For three years from 2016, space object surveillance sensor simulator was developed for the preparation of space surveillance radar design and performance assessment. Precise tracking mode and wide scan mode can be simulated with different types of antenna and Inverse Synthetic Aperture Radar (ISAR) also can be supported as shown in Figure 5.

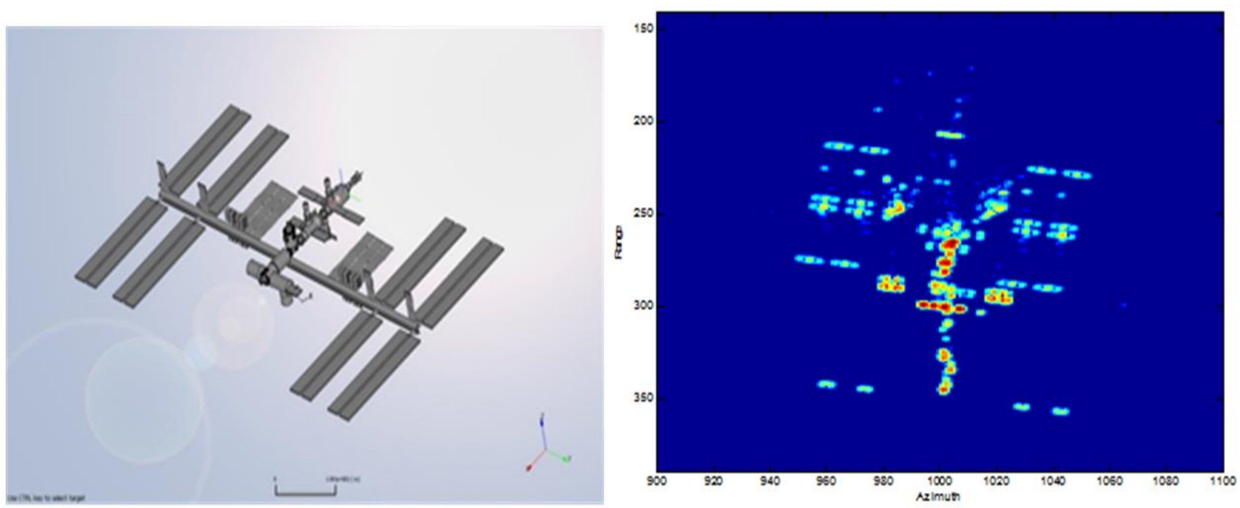

Figure 5 ISAR simulation results for International Space Station

In this simulator, precise tracking radar includes beam peak scan mode, two types of active tracking mode (Beam Peak & Track and Que & Track) and ISAR mode. And wide scan radar has wide scan mode, Track While Scan (TWS) mode and active tracking mode (Scan & Track). Various radar operation scenario, such as on-orbit break-up, collision avoidance maneuver and new launch events, were also defined.

Major functions of simulator are shown in below.

- 2-dimensional display for radar performance
- 3-dimensional display for radar operation environment, orbit of target object and on-orbit break-up simulation
- Radar transmitting and receiving function, Beam modeling and Simulated orbit of target object generation
- Microwave reflection modeling, ISAR reflection modeling

This simulator developed in 2018 and various candidate radar has been simulated so far.

There is another on-going research about measurement field. Currently, KARI is operating radar tracking facility for the launch vehicle in Jeju and Goheung. The research includes that observation feasibility assessment, signal processing of radar measurement and orbit determination [3].

Figure 6 Jeju radar tracking facility

First step is observation feasibility assessment. The radar that used in research designed only for the launch vehicle and have relatively short detect range. So, ISS was defined as a tracking target and several successful tracking achieved. The orbit from orbit determination represented acceptable difference with ISS orbit. Now research about signal processing techniques is performing to tracking smaller size and higher altitude objects in given radar specification.

4. PROTECTION

Space debris environment analysis for under development satellite program also are performed. There are lots of international guideline for sustainable space environment and KARI is also proceeding the KARI's space debris mitigation guideline establishment. Currently, Debris Assessment Software (DAS) of NASA and MASTER2009 space environment model of ESA are used for space debris environment analysis [4, 5].

Figure 7 DAS 2.0 and MASTER 2009 for space debris environment analysis

When the candidate mission orbits are defined, space debris environment of mission orbit are analyzed. Space object characteristics, such as object type, average size (diameter), approaching angle and relative velocity, can be represented as shown in Figure 8. These results used for spacecraft structure analysis that includes space debris shielding design.

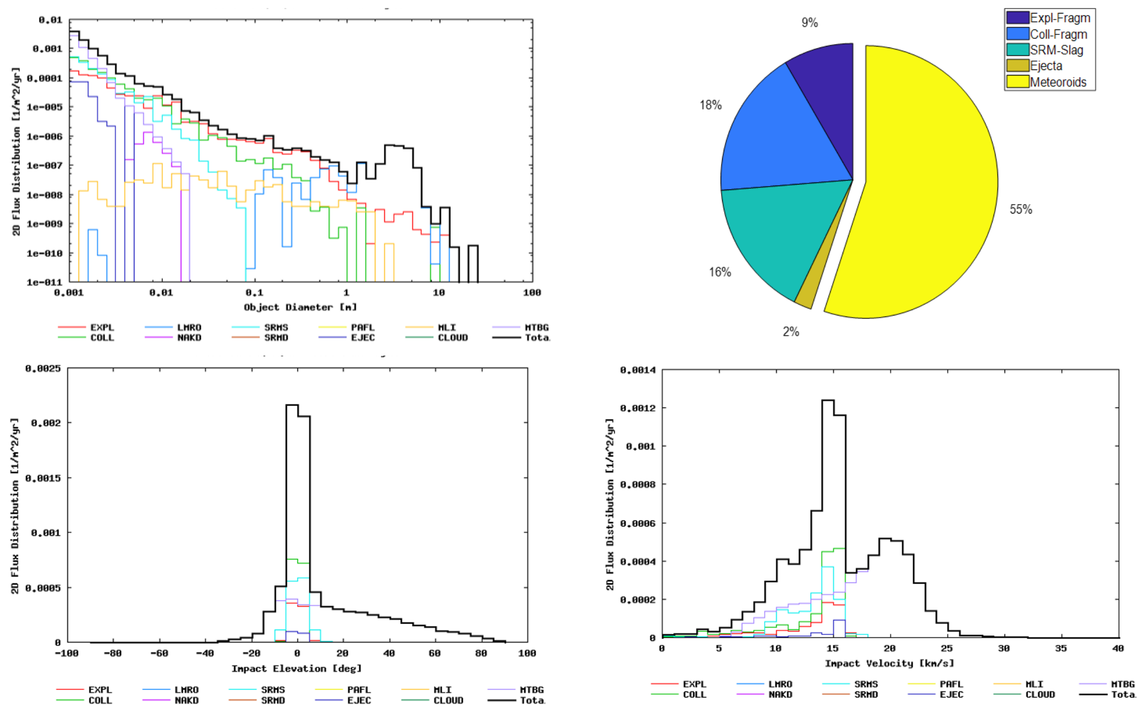

Figure 8 Space object characteristic that exist or approach the candidate mission orbits

The below requirements are included in NASA technical standard 8719.14. Especially, (Requirement 4.5-1) and (Requirement 4.5-2) are important items for space debris protection analysis and most space debris mitigation guidelines include similar requirement or guideline item.

- **(Requirement 4.5-1) - Limiting debris generated by collisions with large objects when operating in Earth orbit:**
  For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001.

- **(Requirement 4.5-2) - Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit:**
  For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable post mission disposal requirements is less than 0.01.

For above requirement 4.5-1, collision probability of entire mission phase can be calculated by using spacecraft mission life, cross-sectional area and space debris flux, which exist or approach mission orbit. In the most cases, this requirement has been sufficiently satisfied. However, additional information and analysis are required to investigate about requirement 4.5-2. This requirement is related to critical items of spacecraft, such as star tracker, fuel tank and lens of optical payload. In some case, requirement 4.5-2 couldn't comply because there was no sufficient shield for fuel tank. After this simulation, additional shield was designed newly while considering related equation like a Figure 9 and finally complied the requirement 4.5-2.

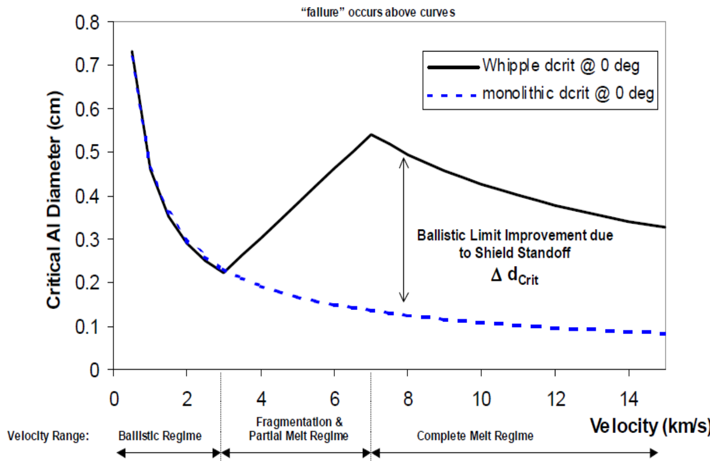

Figure 9 Shield failure curves for space object collision

5. REMOVAL

Removal activity after end of mission is the most realistic measure for reducing space debris. There are several options for removal: 'Direct Reentry', '25-year Decay' and 'Disposal Orbit'. 'Direct Reentry' means that specific satellite performs maneuver to decrease its altitude. Generally, LEO satellites (<1,000km in altitude) use this option and most part of satellite break up due to atmosphere drag and aerodynamic heating. This disposal maneuver plan should be established and verified before re-entry to minimize ground impact casualty.

If there are not enough resources for direct reentry, '25-year Decay' can be alternative measure. '25 Years Rule' limits space object lifetime after its mission and this means that specific space asset can meet the '25 Years Rule' if its orbital lifetime is less than 25 years, even if it can't enter the atmosphere directly.

Relatively high-altitude LEO region object, MEO and GEO object should move to graveyard orbit after end of mission. This is 'Disposal Orbit' option and specific satellite shouldn't enter protected region within 200 years after disposal maneuver.

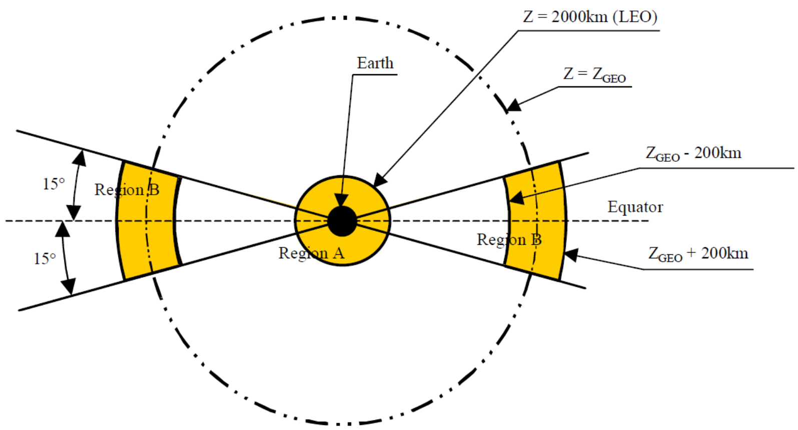

Figure 10 Protected region

KOMPSAT-2 launched in 2006 and official mission is completed in 2015. It still has fine health status and enough fuel so it is performing extended mission. But adequate disposal maneuver planning should be established because satellite bus system, sensor, payload and ground system are getting older during extended mission lifetime.

KOMPSAT-2 have sun-synchronous orbit in 685km altitude and 45kg fuel for maneuver so ’25-year Decay’ or ‘Direct Reentry’ are available options.

To establish disposal maneuver planning, previous disposal maneuver cases were studied. There were lots of disposal maneuver cases already and disposal cases that have similar orbit, satellites physical properties and condition analyzed. In LEO region, perigee decreasing strategy was most commonly used strategy and casualty probability were minimized by performing controlled reentry.

And then, disposal maneuver plan was established using current propellant of KOMPSAT-2 and verification was also performed to find out whether the international guidelines are satisfied [6]. As a result, the lifetime of KOMPSAT-2 was 3.6 years when 45kg propellant was used to decrease perigee altitude to 300km. And if more than 14.5kg propellant consumed for same strategy, KOMPSAT-2 can satisfy the international guidelines.

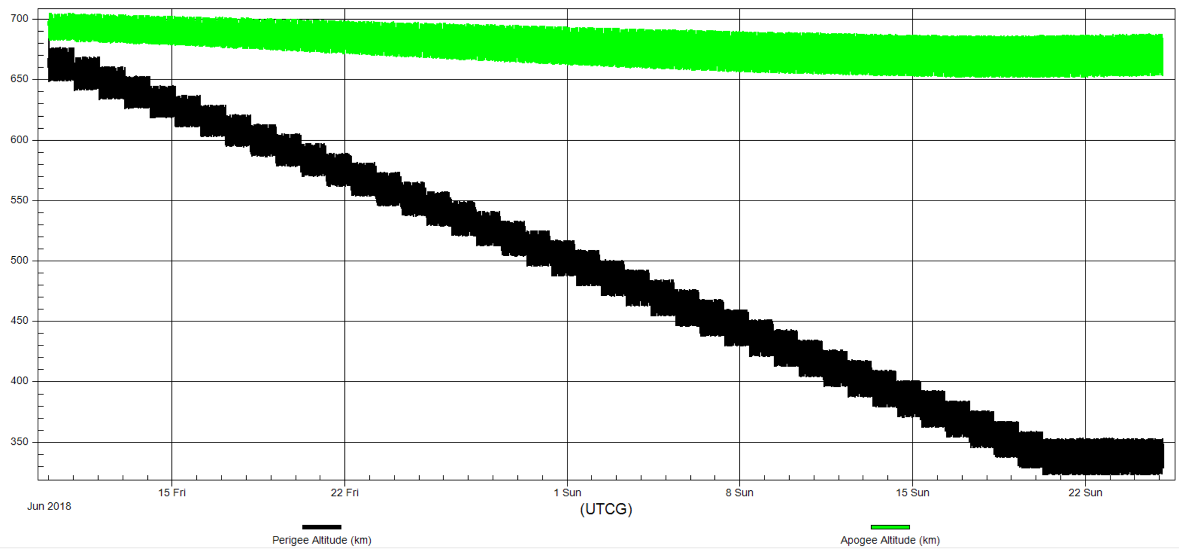

Figure 11 KOMPSAT-2 apogee and perigee altitude during disposal maneuver

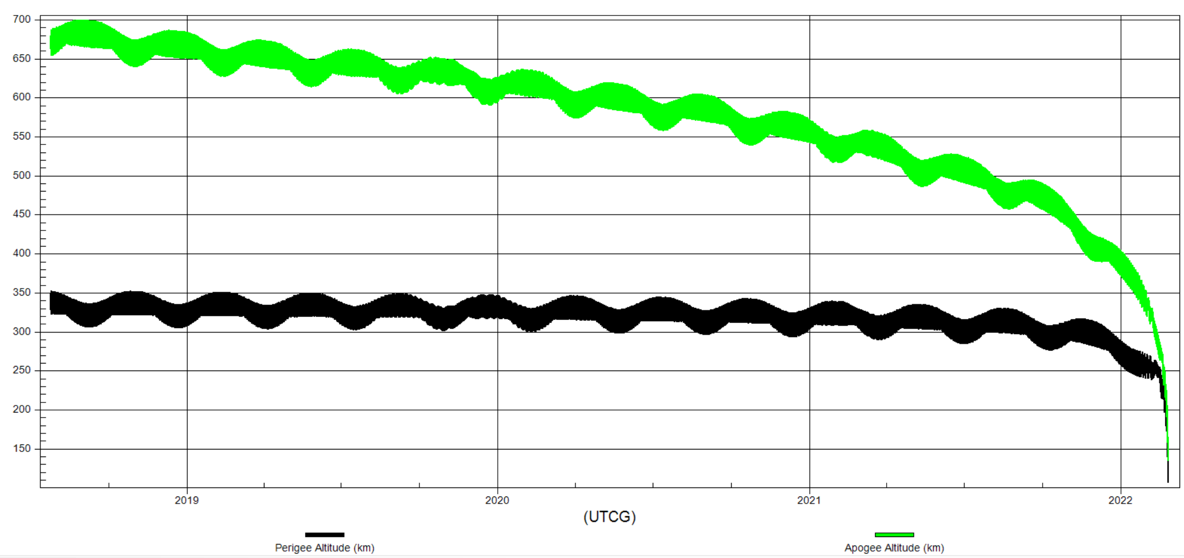

Figure 12 KOMPSAT-2 apogee and perigee altitude evolution after disposal maneuver

Finally, re-entry survivability analysis was performed and it represented that heat resistant objects, such as propellant tank and reaction wheel, could be survived but total ground casualty probability was less than international guidelines.

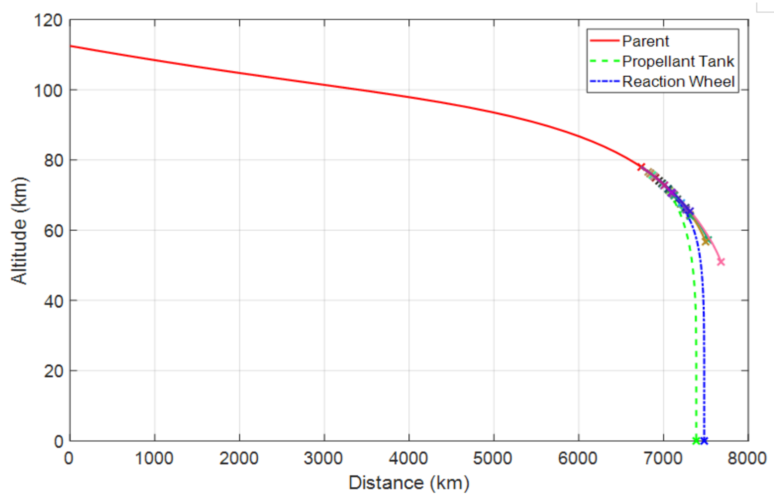

Figure 13 Demise or impact altitude of all object of KOMPSAT-2

6. REMEDIATION

KARI also started to research about space debris active removal system since 2014 [7]. 5 DOF ground based test-bed for capture system was developed and vision-based navigation algorithm, which is running on smart phone processor, was validated using ground test-bed. Ground test-bed was built on plate glass and target and chaser satellites had pressurized gas tank so that near zero fraction environment could be achieved.

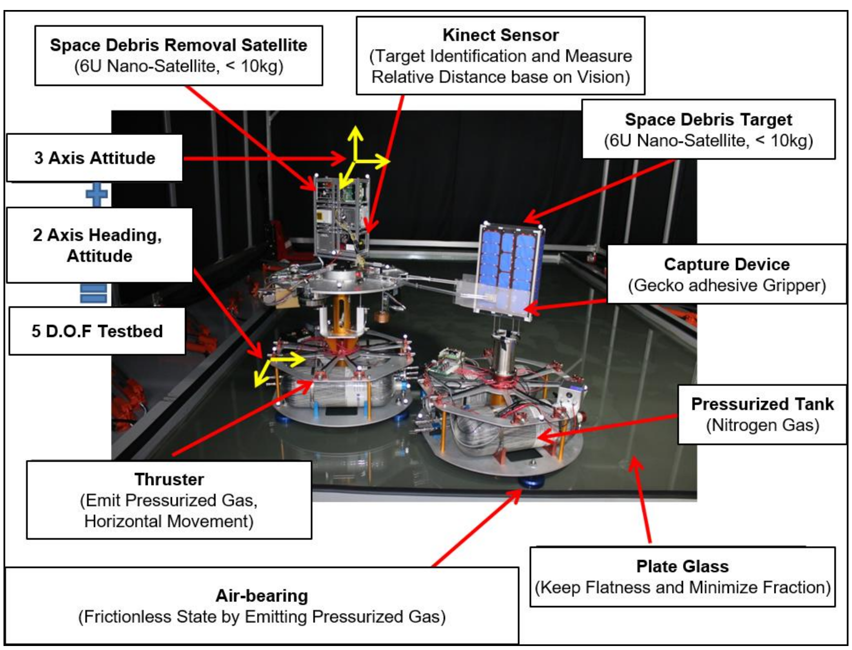

Figure 14 Overview of 5 DOF ground based test-bed for capture system

6U nano-satellite was designed as ‘Chaser satellite’ and it contains 3 axis attitude and 2 axis heading control capability. On the frictionless plate, ‘Chaser’ moves to ‘Target’ horizontally using thruster and Kinect sensor with navigation algorithm. Gecko adhesive gripper or electro-adhesive gripper also considered for capturing ‘Target’.

7. INTERNATIONAL COOPERATION

Last item is international cooperation. KARI joined IADC in 2014 and have been participated steering and working groups. And KARI performed several IADC re-entry test campaign. Last year, Chinese Tiangong-1 was campaign target and we shared the re-entry prediction time results. Moreover, KARI participated SpaceOps community and space debris conference, such as AMOS, to understand and discuss the global issue and new technologies related to SSA & STM.

Figure 15 International cooperation activities: IADC annual meeting

8. CONCLUSION

Currently, KARI is performing SSA and STM activities in various fields and still expanding related capability. This paper introduced six major categories in SSA and STM activities that are performed by KARI: Mitigation, Measurement, Protection, Removal, Remediation and International Cooperation.

As a national space development organization, KARI will proceed major space programs according to long-term space development plan. Also, Towards Long-term Sustainability of Space Activities, KARI keeps on conducting the SSA & STM related research activities, especially conjunction assessment, radar measurement facilities, the basic research on active debris removal, and the disposal maneuver plan for satellites. KARI pursues the expansion research capacity from typical SSA area to STM area based on controllability and observability on space assets.

9. REFERENCE

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