15th Meeting of the International Committee on Global Navigation Satellite Systems

Study on Disposal Options of BDS EOL Satellites

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Study Progress Related to the Issue of Orbital Debris

I. June 2020, ICG WG-S Subgroup Meeting

As there was a the discussion about the interference posed to GEO protected areas by disposal orbit of IGSO in ISO 24113(space system- space debris mitigation requirements), BDS has given some recommendations on this issue.

II. Oct 2020, IADC report was sent to ICG

IADC has been working on the subject of exploring different MEO disposal options and the resulting benefits and risks. The first results of this work-the IADC report "Benefits and Risks Associated with MEO Disposal Options" was delivered to ICG.

III. Jun 2021, Planning and Organizational Meeting for ICG-15

BDS has introduced the main conclusions of the IADC report and suggested system providers to have a detailed and further discussion with IADC.

IV. Aug 2021, ICG WG-S Subgroup Meeting

In WG-S Subgroup Meeting, BDS has introduced the constraints and limitations of current MEO satellites based on the different disposal options and given some suggestions.

Feedback to IADC report

I. Main contents and conclusions of the IADC report

- Benefits and risks of disposal options(including passivation in the operational orbit, maneuver to a stable orbit and to an unstable orbit) for MEO were analyzed in the report.
- Effective disposal is needed to assure the long-term sustainability; stable disposal orbit could minimize the collision risk with MEO constellation and unstable disposal orbit increase the overall sustainability of MEO operations.

II. Recommendations on the IADC report

- Due to the limitation of propellant and lack of low-thrust electrical propulsion system, it may be unrealistic for the on-orbit MEO objects to have a directed de-orbit.
- Based on the analysis the orbital lifetime of stable and unstable disposal orbit is much longer than 25 years, which is the lifetime limitation for MEO objects from IADC.
- As the disposal strategy, capability of collision risk prediction and long-term evolution of each GNSS system may be different, it is necessary for GNSS system providers to pay attention to the collision risk and carry out regular communication and coordination with IADC and ICG.


CONTENT

01

GNSS Space Debris Status Update and International Guidelines

01 GNSS Space Debris Status Update and International Guidelines

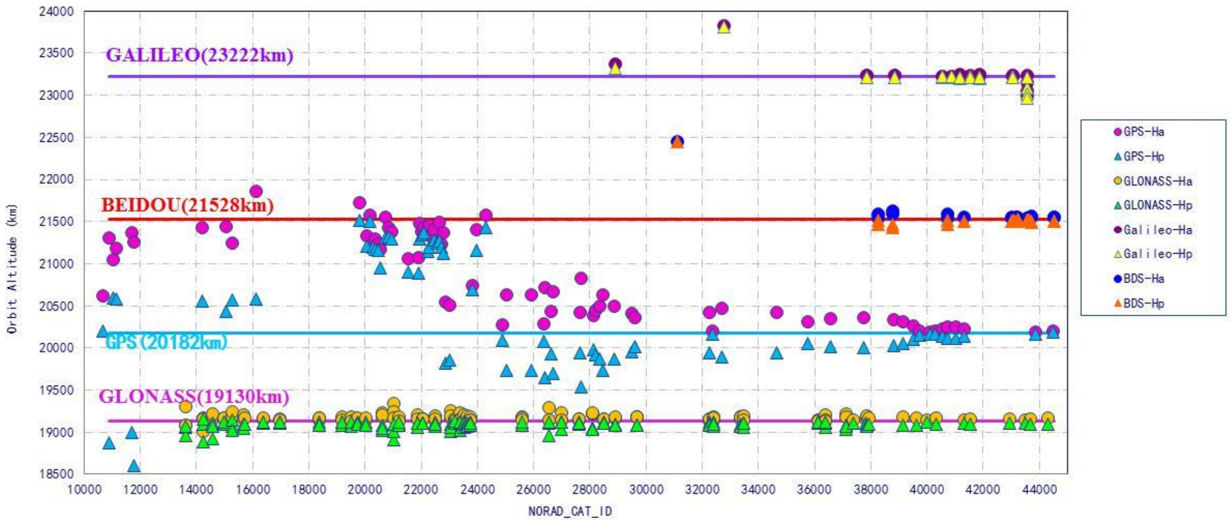
1. GNSS/RNSS Satellites in Orbit

Constellation	Nation/Area	Number of SVs *			
		GEO	IGSO	MEO	Total
GPS	USA	0	0	75	75
GLONASS	Russia	0	0	139	139
Galileo	Europe	0	0	28	28
BDS	China	15	12	32	59
QZSS	Japan	1	3	0	4
NAVIC	India	3	6	0	9

Data collected from www.space-track.org by the end of Aug 2021

01 GNSS Space Debris Status Update and International Guidelines

2. GNSS Satellites Orbit Distribution Status

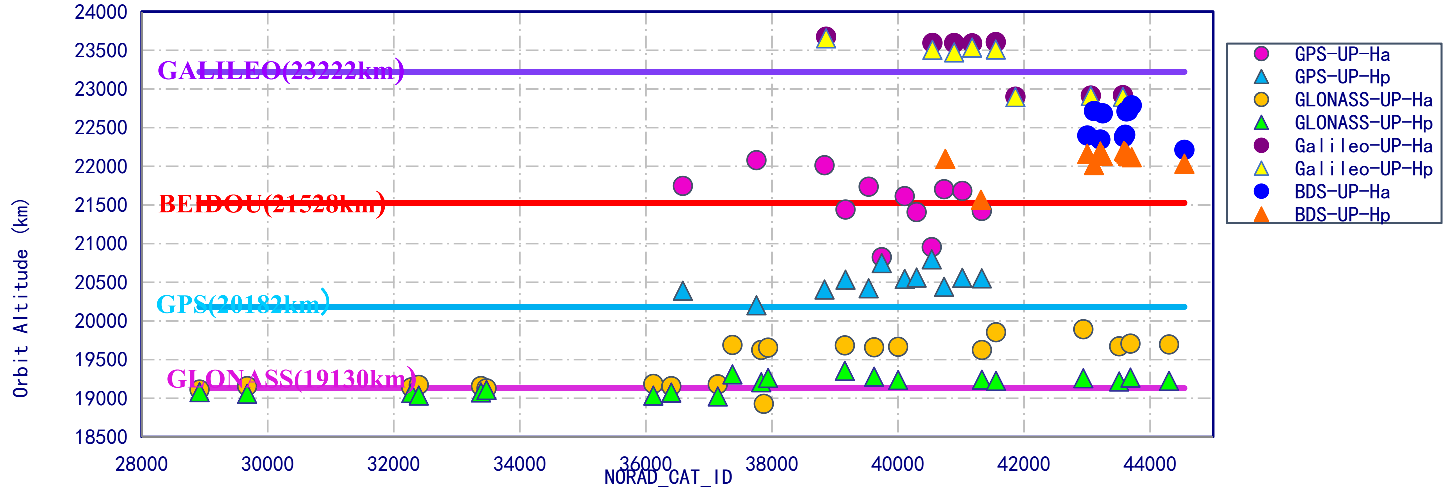


- There are more than 270 GNSS satellites in MEO and the distribution of MEO space debris is becoming more challenging.
- As there are more than 30 GPS EOL satellites crossing BDS operational orbit, the rising of collision risk can't be ignored.

Data collected from www.space-track.org by the end of Aug 2021

01 GNSS Space Debris Status Update and International Guidelines

3. GNSS upper-stage Orbit Altitude



- There are more than 10 upper-stages of GPS crossing BDS operational orbit and one upper-stage of Galileo is very close to the upper-stage of BDS. As a result, we should also pay attention to the safety of GNSS upper-stage.

01 GNSS Space Debris Status Update and International Guidelines

4. MEO Disposal Requirements of IADC

Disposal Action	MEO Navigation Satellite Orbit
25-year decay	Not recommended due to large ΔV required
Disposal orbit	TBC: 1.Minimum long term perigee of 2000km,apogee below MEO 2.Perigee 500km above MEO or nearby operational region and e≤0.003;RAAN and argument of perigee selected for stability
Direct Reentry	Not recommended due to large ΔV required

Requirements from IADC-04-06'Support to the IADC Space Debris Guidelines' in Dec 2019

02

Disposal Options of BDS Satellites

02 Disposal Options of BDS Satellites

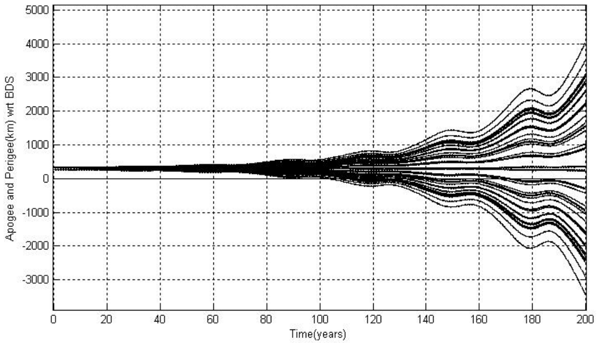
1. Disposal Safety Restrictions for BDS satellites

- Based on research of international organizations, disposal for GNSS satellites should ensure low collision risk with operational orbit and nearby constellations within 200 years.
- Considering propellant limitation and isolation from nearby satellite orbits, the increase in altitude of BDS EOL satellites should be more than 300km.
- The variation of altitude after disposal should be minimized over 200 years, or the disposal orbit should decay as early as possible.

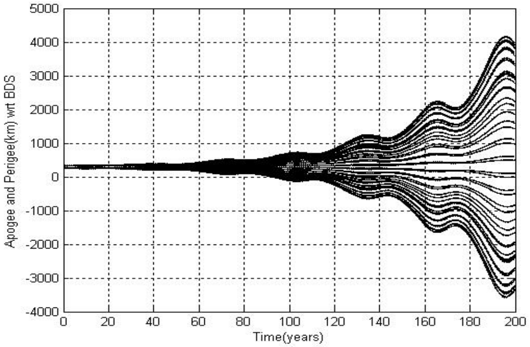
02 Disposal Options of BDS Satellites

2. Evolution of BDS MEO Satellites

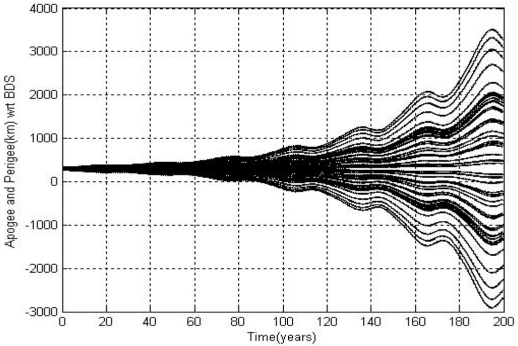
- Minimum eccentricity growth strategy: ω0=190/320/240 deg, the disposal orbit is very stable (perigee remains above BDS constellation within 200 years)
- High eccentricity growth strategy: ω0=290/70/350 deg, the disposal orbit eccentricity grows significantly (perigee crosses the BDS constellation but does not reach GEO within 200 years)



Ω=30°,e=0.001,ω=0~360°



Ω=150°,e=0.001,ω=0~360°



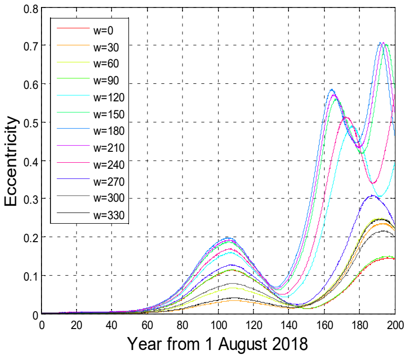
Ω=270°,e=0.001,ω=0~360°

02 Disposal Options of BDS Satellites

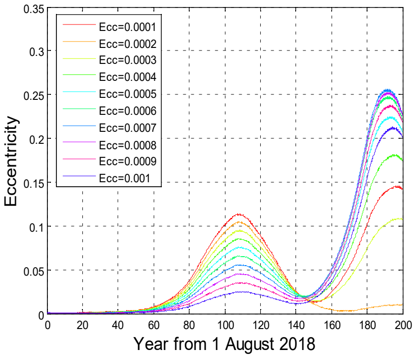
3. Evolution of BDS IGSO Satellites

- Minimum eccentricity growth strategy: ω0=0/0/120deg, the disposal orbit is very stable (perigee reaches GEO or MEO within 200 years)

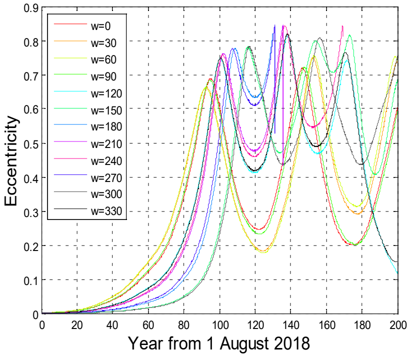
- High eccentricity growth strategy: ω0=180/270/270deg, the disposal orbit eccentricity grows significantly (perigee reaches MEO or has a reentry within 200 years)



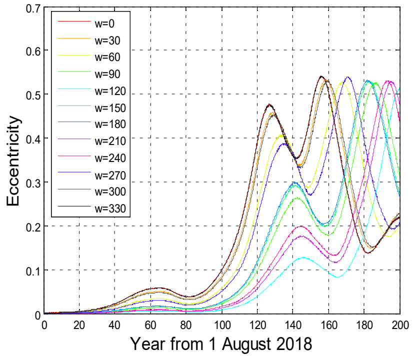
Ω=70° ,e=0.001,ω=0~360°



Ω=70° ,e=0.0001~0.001,ω=0°



Ω=190° ,e=0.001,ω=0~360°



Ω=310° ,e=0.001,ω=0~360°

02 Disposal Options of BDS Satellites

4. Recommendations for BDS Disposal Orbit Elements

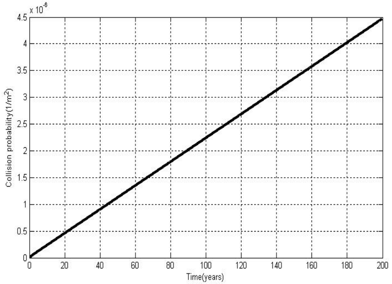
ORBIT	RAAN	Increase in orbit altitude/km	Eccentricity	Minimum Eccentricity Growth		High Eccentricity Growth	
				ω_0 / deg	Max Eccentricity in 200 years	ω_0 / deg	Max Eccentricity in 200 years
MEO	30	300	0.001	190	0.002	290	0.16
	150	300	0.001	320	0.006	70	0.14
	270	300	0.001	240	0.004	350	0.11
IGSO	70	300	0.0002	0	0.01	180	0.71
	190	300	0.001	0	0.72	270	0.82(decay in 130 years)
	310	300	0.001	120	0.52	270	0.55

03

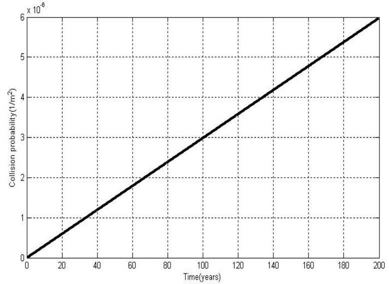
Long-term Collision Probability Analysis

03 Long-term Collision Probability Analysis

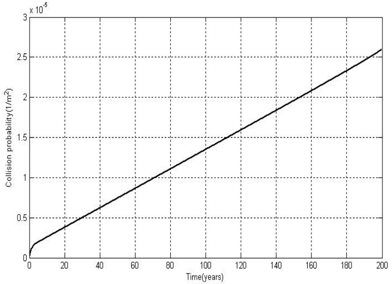
1. Collision Probability posed to GPS, Galileo and BDS and graveyard orbit



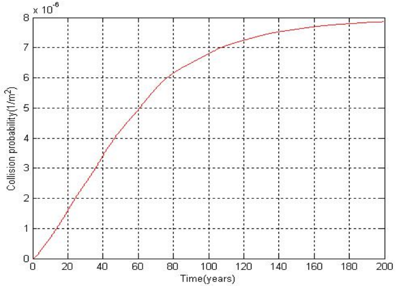
Collision probability posed to GPS by BDS MEO with stable disposal orbit



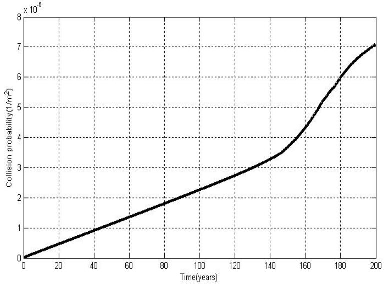
Collision probability posed to Galileo by BDS MEO with stable disposal orbit



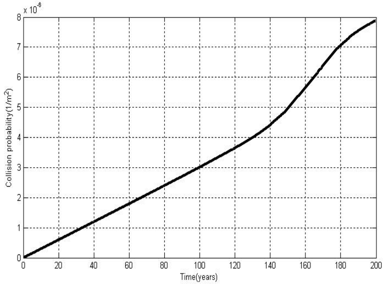
Collision probability posed to BDS constellation by the stable disposal orbit



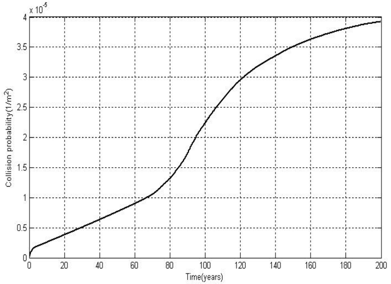
Collision probability posed to the graveyard by BDS MEO with stable disposal orbit



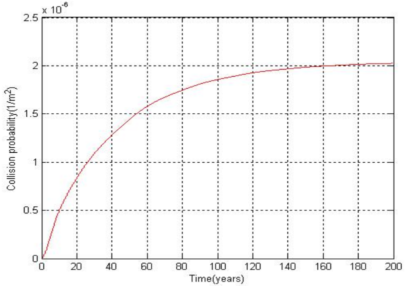
Collision probability posed to GPS by BDS MEO with unstable disposal orbit



Collision probability posed to Galileo by BDS with MEO unstable disposal orbit



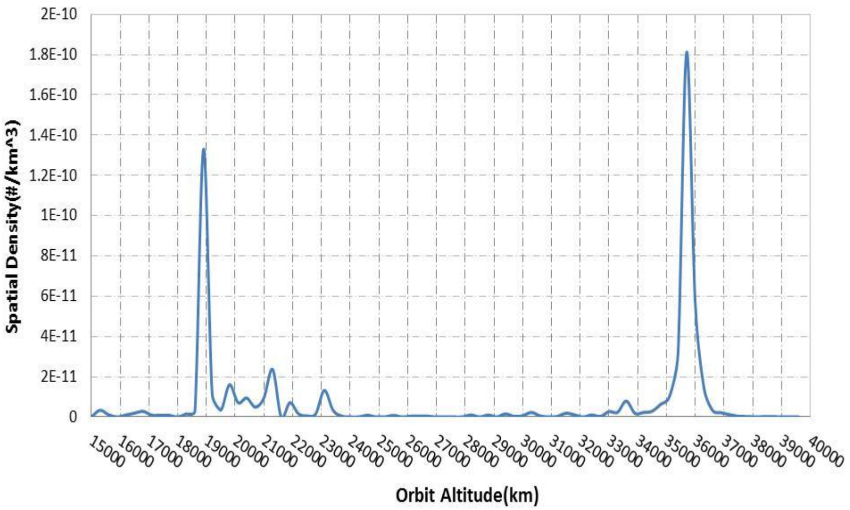
Collision probability posed to BDS by MEO unstable disposal orbit



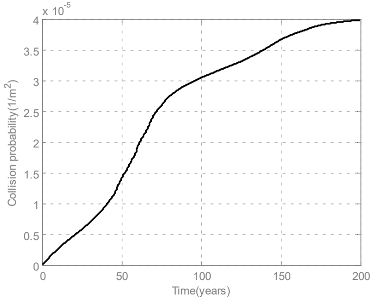
Collision probability posed to the graveyard by BDS MEO with unstable disposal orbit

03 Long-term Collision Probability Analysis

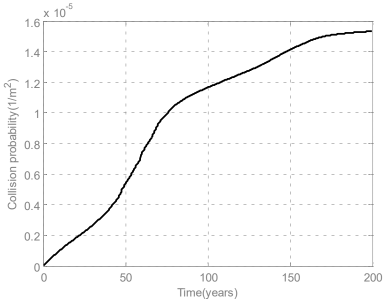
2. Collision Probability posed to the GEO Protected area and graveyard orbit by BDS IGSO



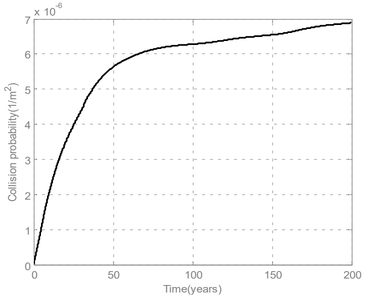
Spatial density of current space debris



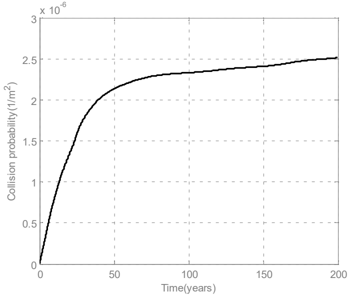
Collision probability posed to GEO protected area by BDS IGSO with stable disposal orbit



Collision probability posed to GEO graveyard by BDS IGSO with stable disposal orbit



Collision probability posed to GEO protected area by BDS IGSO with unstable disposal orbit



Collision probability posed to GEO graveyard by BDS IGSO with unstable disposal orbit

03 Long-term Collision Probability Analysis

3. Proposed disposal strategy based on collision probability

- The collision probability posed to operational orbit or graveyard orbit is of a 10^{-5}-10^{-6} order of magnitude, which is less than the 0.001 threshold for LEO crossing objects.
- As for BDS MEO EOL satellites, the stable disposal strategy results in a lower collision probability to the nominal constellations of BDS, GPS and Galileo; Consequently, the stable disposal strategy would be proposed for BDS MEO satellites.
- As for BDS IGSO EOL satellites, the unstable disposal strategy results in a lower collision probability to the GEO protected area. Consequently, the unstable disposal strategy would be proposed for BDS IGSO satellites.

04

Conclusions and Recommendations

04 Conclusions and Recommendations

- The distribution of GNSS space debris is becoming more challenging. There are no final guidelines for GNSS MEO satellites post-mission disposal from international organizations (IADC), while post-mission disposal strategy and safety restrictions of GNSS EOL satellites are not exactly the same.

- The analysis showed that the collision probability posed to operational orbit or graveyard orbit by BDS MEO/IGSO disposal satellites within 200 yeas is of a 10^{-5} ~10^{-6} order of magnitude, which is less than the 0.001 threshold for LEO crossing objects.

- Although the collision probability among MEO/IGSO space debris is less than 0.001, the collision risk will increase as there will be more GNSS/RNSS satellites deployed in the future. As a result, ICG members should continue to pay more attention to the safety of MEO and IGSO space debris.

- System providers should try to establish the GNSS/RNSS space debris guidelines together with IADC and continue to exchange information on their GNSS/RNSS satellites post-mission disposal plans and implements in WG-S.

Thank you

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