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Disposal Strategy and Collision Probability of BDS MEO Satellites

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Contents

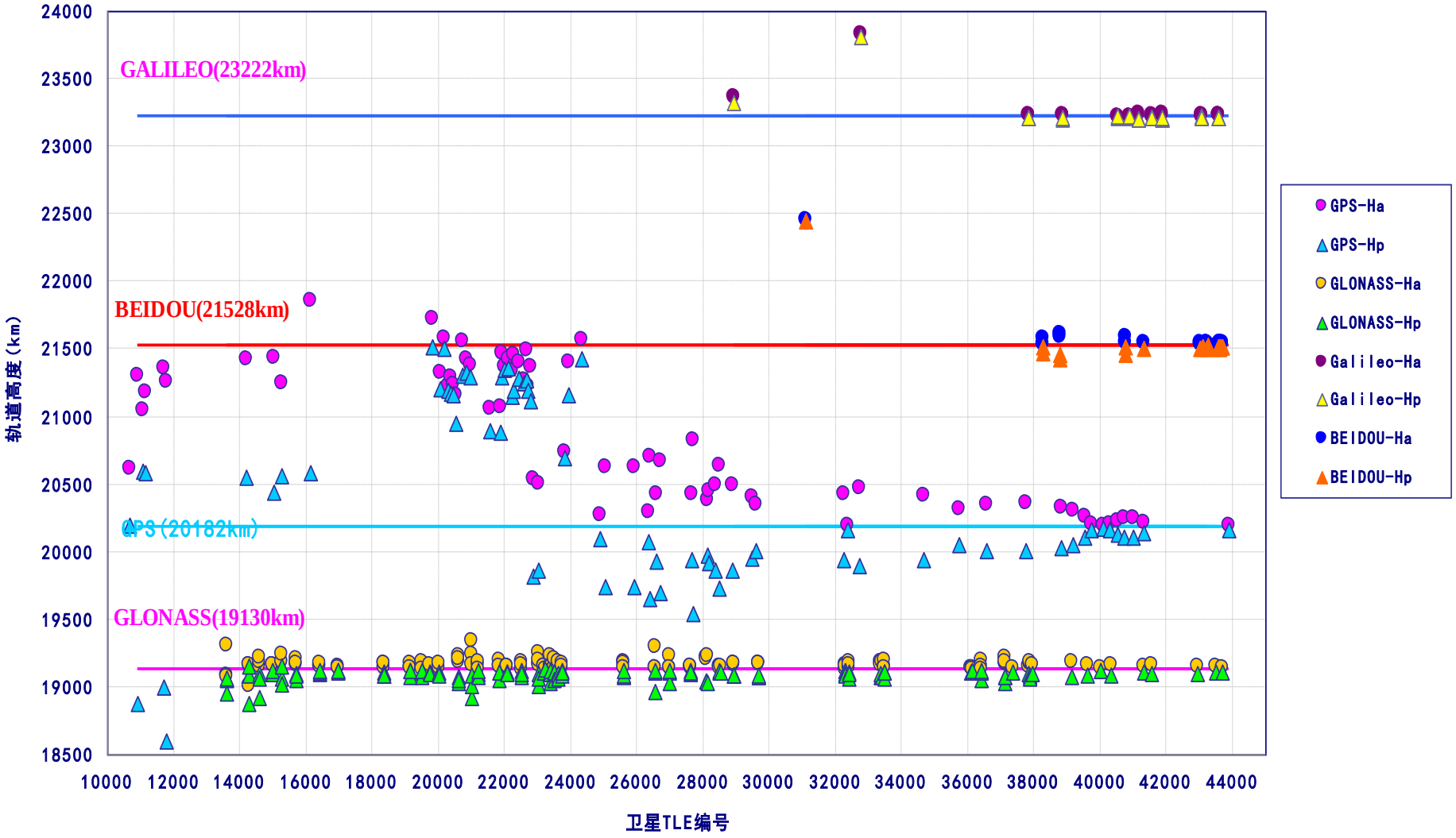
GNSS Space Debris Status and International Guidelines

GNSS/RNSS Satellites in Orbit

Constellation	Nation/Area	Number of SVs *			
		GEO	IGSO	MEO	Total
GPS	USA	0	0	71	71
GLONASS	Russia	0	0	133	133
Galileo	Europe	0	0	28	28
BDS	China	13	10	26	49
QZSS	Japan	1	3	0	4
NAVIC	India	3	6	0	9

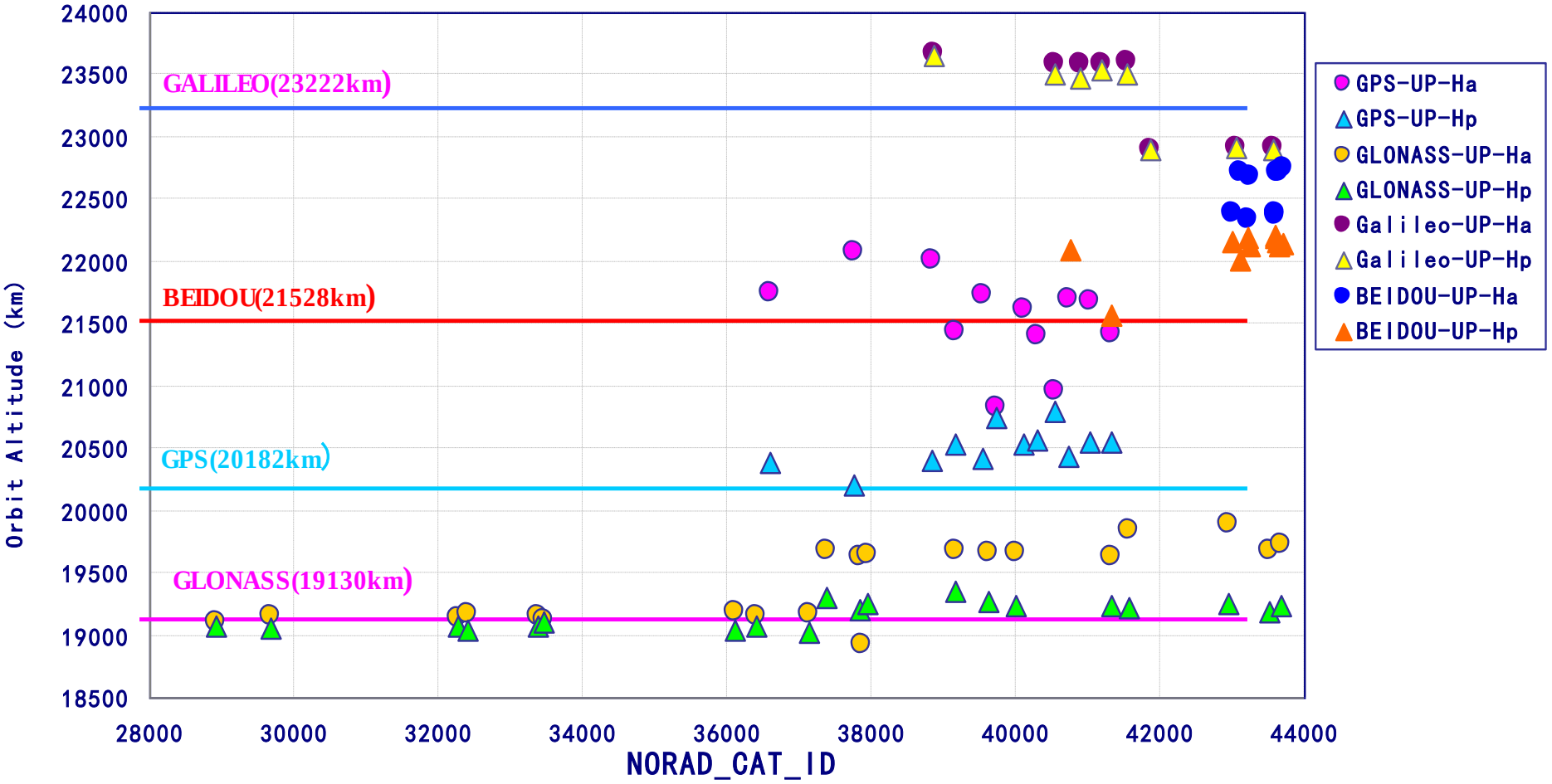
Data collected from www.space-track.org by the end of May 2019

GNSS Satellites Orbit Altitude



Data collected from www.space-track.org by the end of May 2019

GNSS Upper-stage Orbit Altitude



Data collected from www.space-track.org by the end of May 2019

GNSS Spacecraft Disposal Orbit

Constellation	De-orbited Satellites		De-orbited Upper-stage	
	Number	△Ha (Increase in apogee altitude)	Number	△Ha (Increase in apogee altitude) /km
GPS	36	+350~+1700	12	+600~+1900
GLONASS	0*	0*	21	0~+700
Galileo	2	+120~+600	9	+350~+2900 -300
BDS	4(3GEO/1 MEO)	GEO:+140~+300 MEO:+900	11	+200~+6000
QZSS	—	—	—	—
NAVIC	—	—	—	—

*Glonass SVs at the end of life didn't have increase in orbit altitude yet.

GNSS Disposal Orbit Interference

Operating Orbit	Disposal Satellites Intersected the Operating Orbit		Disposal Upper-stage Intersected the Operating Orbit	
	Number	Disposal Satellites	Number	Disposal Upper-stage
GPS 21200km	0	—	0	—
GLONASS 19100km	3	GPS	0	—
Galileo 23200km	0	—	0	—
BDS 21500km	>30	GPS	10	GPS

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 'Support to the IADC Space Debris Guidelines'

Proposed Disposal Strategy of BDS MEO Satellites

Disposal Safety Restrictions for BDS MEO satellites

To protect nearby constellation and follow-up MEO satellites operational safety, restrictions for EOL disposal of BDS MEO satellites are suggested as follows:

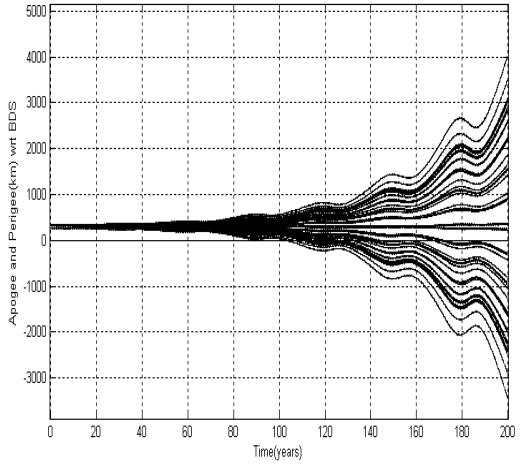
① Based on research of NASA and other organizations, disposal for post mission MEO satellites should ensure no collision risk with operational orbit and nearby constellations within **200 years**.

② Considering propellant limitation and isolation from nearby MEO satellite orbits, the increase in altitude at the end of re-orbiting maneuver of MEO satellites should be **more than 300km**.

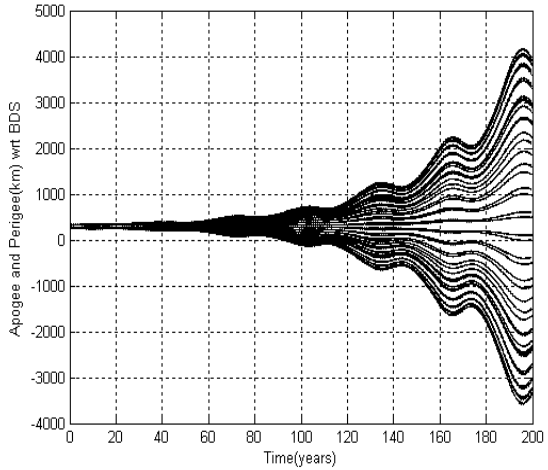
③ The variation of altitude after disposal should be minimized over 200 years, and the variation of orbit altitude should be **less than 200 km within 200 years**.

Evolution of BDS MEO Satellites with Different ω_0

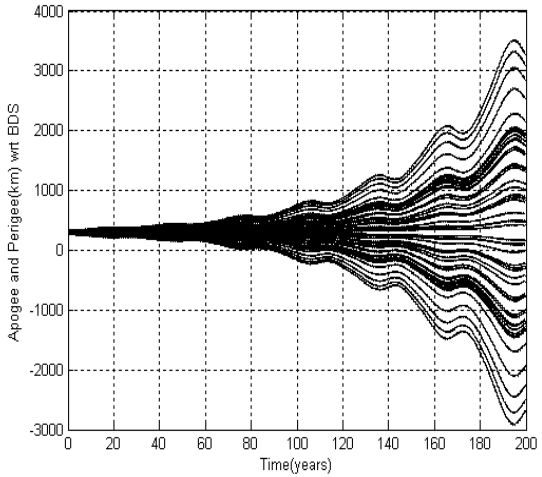
- Minimum eccentricity growth strategy: ω0 = 190/320/240 deg, the disposal orbit is very stable (perigee remains above BDS constellation within 200 years)
- High eccentricity growth strategy: ω_0 = 290/70/350 deg, the disposal orbit eccentricity grows significantly (perigee crosses the BDS constellation but does not reach GEO within 200 years)



Ω_0=30° ,e_0=0.001,ω_0=0~360



Ω=150° ,e=0.001,ω=0~360°



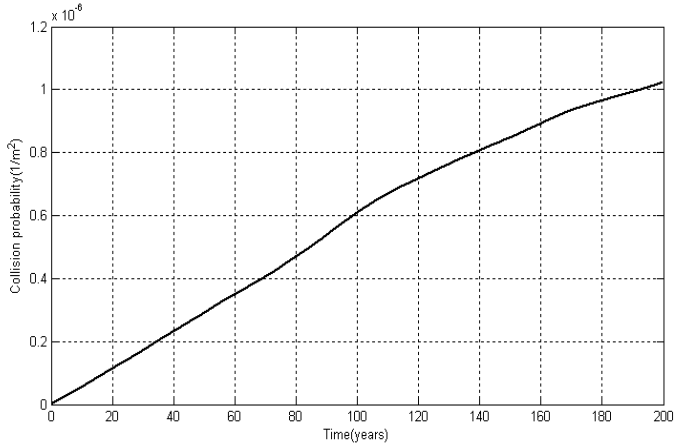
Ω=270° ,e=0.001,ω=0~360°

Recommendations for BDS MEO Disposal Orbit Elements

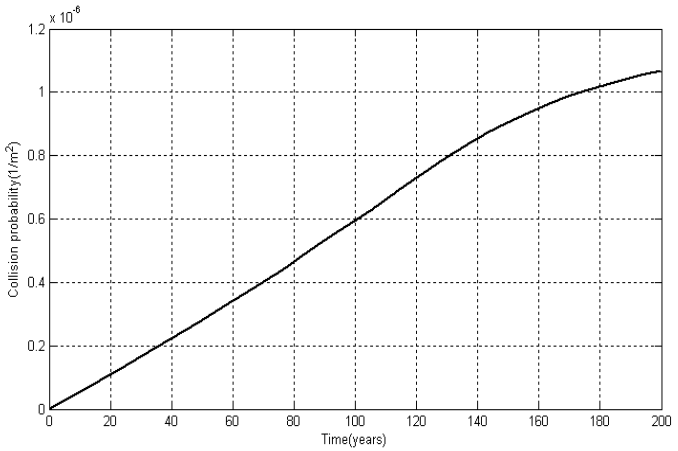
RAAN	Increase in orbit altitude/km	Eccentricity	Minimum Eccentricity Growth		High Eccentricity Growth	
			ω_0 / deg	Max Eccentricity in 200 years	ω_0 / deg	Max Eccentricity in 200 years
30	300	0.001	190	0.002	290	0.16
150	300	0.001	320	0.006	70	0.14
270	300	0.001	240	0.004	350	0.11

Collision Probability Posed to GPS and BDS Constellations

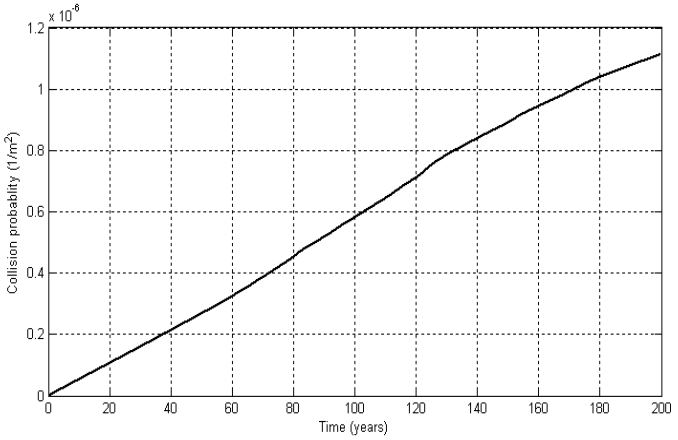
Collision Probability posed to all GPS and BDS Satellites in Orbit



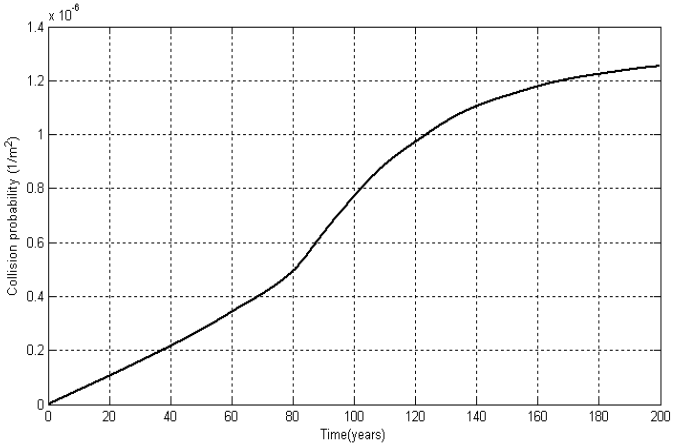
Collision probability posed to all 63 GPS satellites in orbit by one disposal satellite with minimum eccentricity growth strategy



Collision probability posed to all 63 GPS satellites in orbit by one disposal satellite with high eccentricity growth strategy

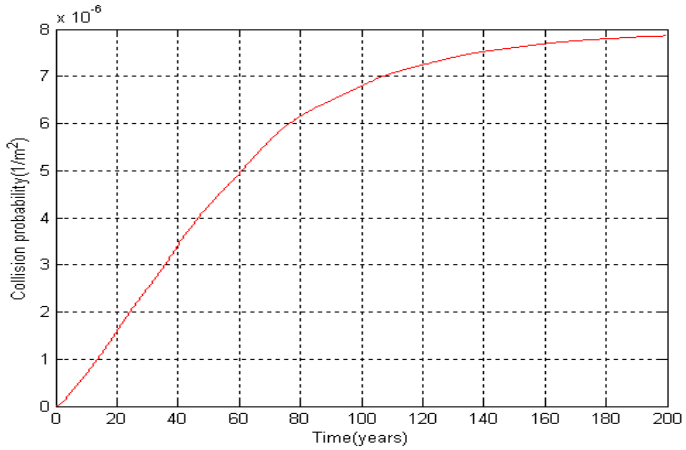


Collision probability posed to all 25 BDS satellites in orbit by disposal satellite with minimum eccentricity growth strategy

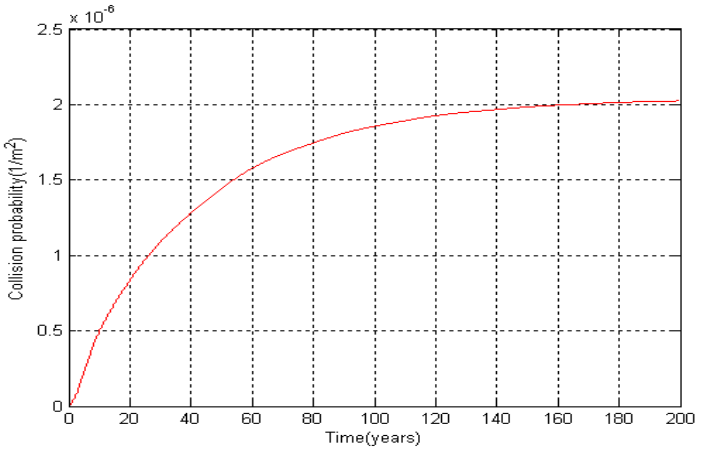


Collision probability posed to all 25 BDS satellites in orbit by disposal satellite with high eccentricity growth strategy

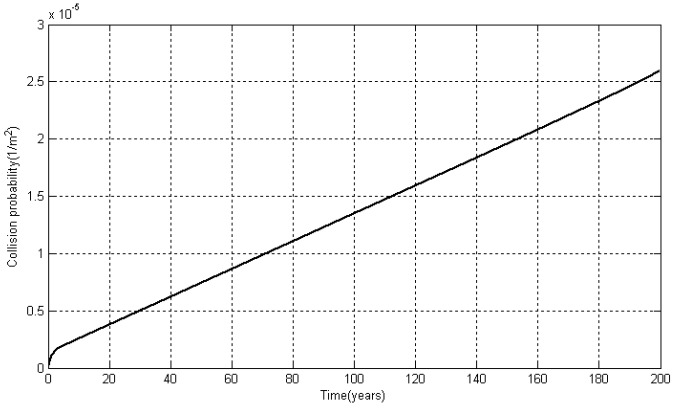
Collision Probability posed to the Graveyard Orbit and BDS Operational Constellation



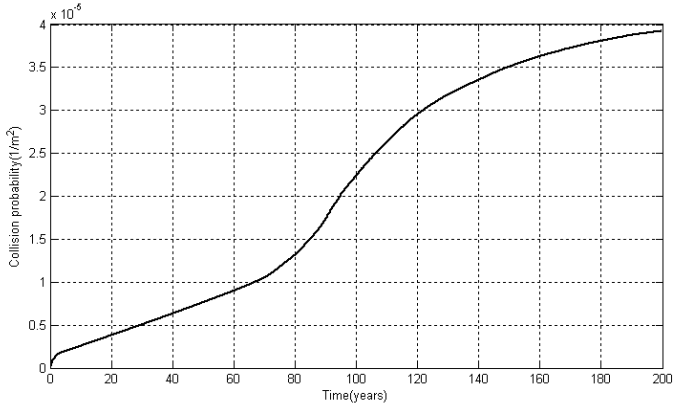
Collision probability posed to the graveyard orbit by all the disposal satellite with minimum eccentricity growth strategy



Collision probability posed to the graveyard orbit by all the disposal satellite with high eccentricity growth strategy



Collision probability posed to the nominal BDS constellation by the disposal satellite with minimum eccentricity growth strategy



Collision probability posed to the nominal BDS constellation by the disposal satellite with high eccentricity growth strategy

Comparison of the Collision Probability

	Cumulative Collision Probability after 200 years	
	Minimum eccentricity growth strategy	**High eccentricity growth strategy**
Posed to all 69 GPS satellites in orbit by one BDS disposal Satellite	1.02×10^{-6}	1.08×10^{-6}
Posed to all 25 BDS satellites in orbit by one disposal satellite	1.1×10^{-6}	1.25×10^{-6}
Posed to graveyard orbit by one BDS disposal satellite	7.9×10^{-6}	2.0×10^{-6}
Posed to nominal constellation by 24 BDS disposal satellites	2.6×10^{-5}	3.9×10^{-5}

- 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.
- The high eccentricity growth strategy results in a lower collision probability to the BDS graveyard orbit than the minimum eccentricity growth strategy.
- The minimum eccentricity growth strategy results in a lower collision probability to the BDS nominal constellation than the high eccentricity growth strategy.
- As for BDS MEO EOL satellites, the minimum eccentricity growth strategy would be proposed.

Summary

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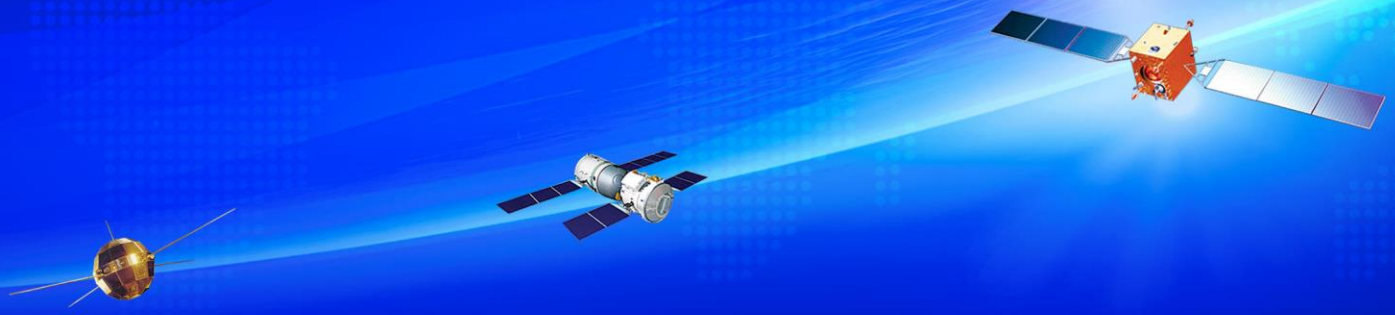
① There are **no final guidelines** for GNSS MEO satellites post-mission disposal from international organizations (IADC), while post-mission disposal strategy and safety restrictions of GNSS EOL satellites are not exactly the same.

② As there will be more GNSS satellites deployed in the future, there will be more intersections among the GNSS constellations as well. As a result, further investigations of the collision probability after disposal of GNSS MEO satellites with own constellation and nearby constellations should be carried out by all system providers.

Summary

③ ICG members should pay more attention to the safety of MEO and IGSO space debris:

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



Thank you for your attention !