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Issues in the Management of the Geostationary Orbit

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Abstract

Actions taken at end of mission in Geostationary orbit (GSO)are essentially irreversible and will have effect for many millennia since the forces which perturb the trajectory do not remove energy. Management of the GSO environment is necessary if it is to remain economically useful for the indefinite future. Two measures are necessary to protect the GSO region - displacement of the kinetic energy of spacecraft and rocket bodies to a burial region that does not intersect with or interfere with operations in the GSO and then removal of all the stored chemical energy so that there are no inadvertent explosions which create debris fragments that can cause further impacts in both the burial region and the GSO.

The perturbing forces in the GSO are the lunar and solar gravitational fields, the oblate figure and density variances in the earth's gravitational field and the influence of solar pressure. These forces cause movement of the uncontrolled body in three directions; in altitude or the semi-major axis, north-south movement in latitude and east-west movement in longitude. In disposal maneuver the dimension subject to the least costly control is altitude.

The equations of motion for each of these effects are well known and straightforward even though the combined effects can be quite complex over the 53 years of the cycle before the interactions repeat. The major issue is not the calculation of the numeric values for a particular body but the strategy that one wishes to implement. Components of the strategy might properly include: displacement sufficient to leave a relocation corridor for the repositioning of satellites, displacement sufficient to assure that the fragments of low energy events will not significantly contaminate the GSO region and sufficient variance in the disposal of each body such that the spatial density of the GSO is not replicated in the burial region.

Present practice ranges from minimal elevation reorbiting to reorbiting to several hundreds of km above the GSO arc. Some consensus standard would enhance the effectiveness of the actions of each operator's actions.

Introduction

Since the first GSO launches in 1963 there have been ~700 objects placed in the GSO region (5, 6, 7, 10, 23). Not all of these are currently tracked because some of them are too small to be readily detected and tracked; other tracks are not reported for national security reasons. The current catalog population as of January 1, 1996 lists 657 objects, 179 of them rocket bodies. Of this number 152 are active communication satellites and another nine are synoptic weather satellites. Another 117 communication satellites are scheduled for launch in the next five years.

Current Status

Figure 1 illustrates the Number of objects deployed in GSO by year. The sharp reduction in 1986 in attributable to multiple launch systems failures which caused a limitation on launch capability. When compared with Figure 2 it can be inferred that the size and capability of the systems being launched have been increasing with time and that is in fact the case. Not only have spacecraft been increasing in size but their operating lifetime has been increasing from three to five years for the early spacecraft to seven years in the 70's and to ten to twelve years in the late 80's and early 90's. Since station keeping propellant is ~20% of the total deployed mass, it obviously increases with extended operations. There has not been a linear increase, however, because in 1986 the International Frequency Regulation Board of the ITU relaxed the station keeping requirements to allow inclined orbit operations which do not demand so many maneuvers.

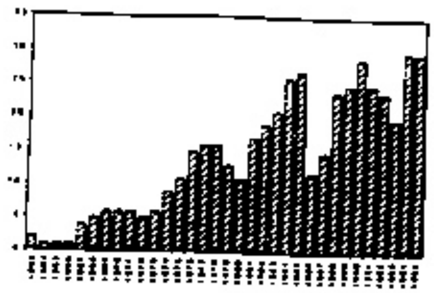

Figure 1. GSO Payloads by year

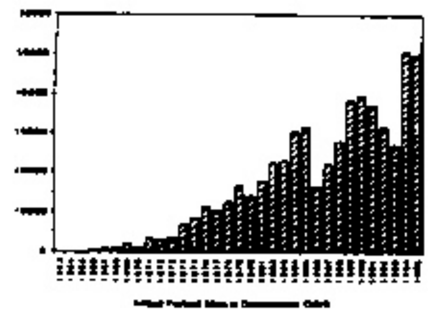

Figure 2. Payload Mass by year

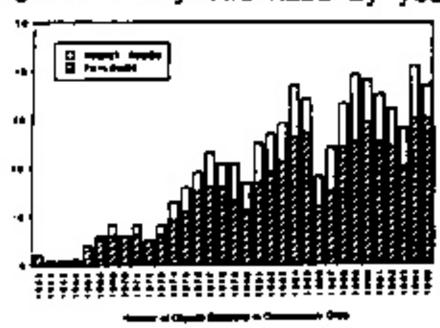

Figure 3. Objects in GSO by year

Figures 4 and 5 illustrate the cumulative payload number and mass data.

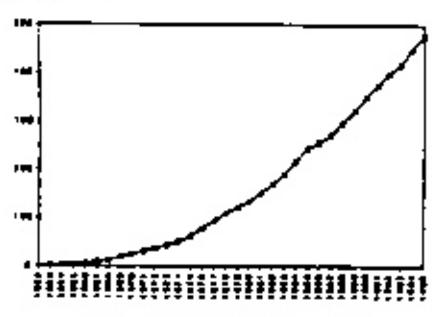

Fig. 4 Cumulative payload number

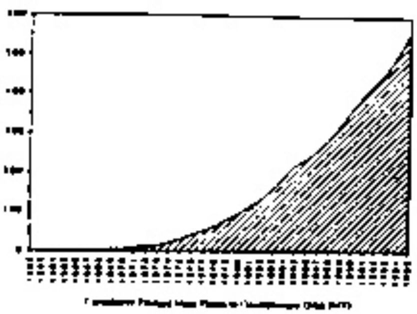

Figure 5. Cumulative payload mass

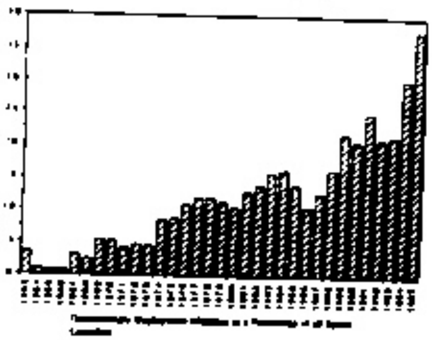

Figure 6. GSO fraction of all launches

Figure 6 Illustrates the traffic to GSO as a percentage of all space launches and reflects the growth of the GSO services to include not only the fixed satellite services but also the increasing importance of Direct Broadcasting and Mobile Satellites Services. This trend may not continue to increase as low earth orbit communication constellations begin to deploy.

Figure 7 illustrates the range of the dispersion of satellites around the GSO semi-major axis of 42164 km and period of 1436.2 minutes. Not all spacecraft are in perfect orbits, though more than two thirds are within ± 75 km of the nominal arc.

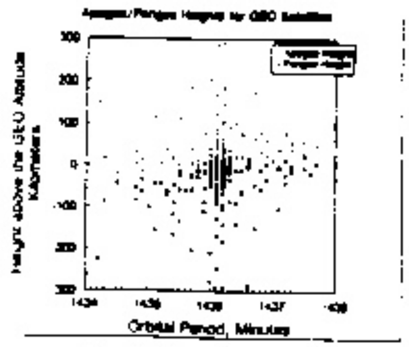

Figure 7. Relative H_p and H_A in GSO

Figure 8 illustrates a different view of the dispersions about the equatorial plane. Those on the or near the 0° line are the actively station kept, while those above and below 5° are objects not actively station kept which are now in more highly inclined orbits due to solar-lunar perturbations.

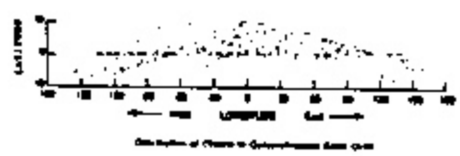

Figure 8 Objects in GSO

Environmental Protection

As the population of objects has grown there has been increasing attention paid to the probability of collision among objects in GSO (9, 15, 17, 18, 19, 20, 21, 22). The topic became a major issue in the ITU Working Group 4, Fixed Satellite Services, when the it was proposed that there be adopted a recommended reboost of 52 km above the GSO arc (16). Many operators were already boosting satellites to significantly higher orbits but the objective of the proposal was to establish a consensus minimum that imposed the minimum penalty on operators.

This proposal did not consider all of the forces that need to be accounted for to clear the GSO arc. The significant forces are: the geopotential term - zonal, sectoral and tesseral terms up to the fourth order which drive eccentricity leading to changes of the order of 45 km in altitude and has reduced influence as the orbit altitude increase away from the harmonic resonance at the GSO arc, the solar and lunar gravitational effects which influence the changes in inclination up to 15° over 27.4 years and also influence eccentricity, solar radiation pressure which influences perigee drift and eccentricity and Poynting-Robertson drag which influences the orbit lifetime of very small objects such as solid rocket motor exhaust products.

Studies done by ESA (3, 4) and by NASA (1, 2, 8, 12) and Chobotov (14) indicated that the minimum useful reboost needed to be to at least 300 km above the GSO to preclude interaction with objects in GSO. The greater distance is required to preclude the abandoned object from coming back into the GSO during the 53 year cycle of motion due to the solar, lunar, earth oblateness and solar pressure effects. Operators in Japan and Russia had in several cases made explicit calculations for particular spacecraft considering all of the perturbing forces and determined that less than 300 km was adequate for the cases considered but one of the considerations omitted was a margin for error(27).

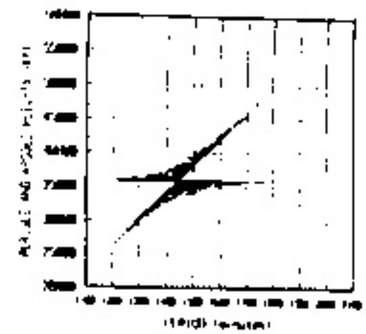

Figure 9. Gabbard diagram distribution of 423 objects >10cm from a collision at 500 m/s

Figure 9 illustrates the debris distribution for a 500 m/s collision event producing 423 fragments larger than 10 cm. Such a moderately energetic event spreads out over hundreds of kilometers. It is clear that no disposal orbit that is practical can be sufficiently removed to protect against such an event.

The maneuver of choice is to use multiple burns alternately raising the apogee and perigee until the fuel is depleted. The multiple burn strategy is adopted to protect against uncertainties in the propellant remaining at end of mission when gauging errors are largest.

The cost of such maneuvers is 3.6 m/s/100 km or 1.69 kg/1000 kg of mass to be maneuvered (I_{sp}~240), which at end of mission is normally ~80% of the initial mass at deployment. For each 100 km the elevation is increased above GSO a westward drift rate of 1.28°/day is established.

In recent years it has become standard practice for many operators to reboost at the end of mission and to make the spacecraft inert once reboosted. Intellsat (13), Canada (20), ESA (4), NOAA (28), and the U.S. (14, 25, 26) have moved spacecraft to disposal altitudes significantly above the recommended minimum of 300 km. Many of the new spacecraft acquisitions require planning for disposal at altitudes substantially above the requirement. If the increase is sufficiently great, at some time the westward motion should eventually gain energy by momentum transfer from the earth's rotation as does the moon. If so the final disposition might be provided for over millennia.

Not all end of mission dispositions have been supersynchronous. In several instances degradation of the spacecraft systems have put the spacecraft in a lower orbit because that was the only thruster active (ATS6), IUE because there was no longer attitude control authority and a few others. This is not a desirable practice because these objects can interfere with access to the GSO.

System Provisions

The second considerations in protecting the environment from breakup events, after avoiding collisions is the elimination of explosions from propulsion systems, batteries or any other stored energy source. While these are small energy sources compared to the kinetic energy in the spacecraft itself they can nonetheless create debris that can be a threat to operating systems. Delta velocities of as little as 5.4 m/s can spread debris back from a 300 km disposal orbit to the GSO, which means that for a typical low energy explosion more than 70% of the fragments with retrograde Δv would transit GSO (35% of total).

This is not a theoretical possibility since there have been two observed breakup events in GSO; a propellant tank explosion on a Titan Transtage and a battery explosion on an Ekran satellite(11). There is always the possibility of a propellant explosion when engines are operated but the reliability has been improving over the years. In current designs the greater danger of an inadvertent breakup may be batteries. Nickel Hydrogen cells with operating pressures at 600 to 1200 psia at beginning of life have pressures that increase with use. To reduce the pressure at end of life some "letdown" load needs to be placed across the batteries to reduce the pressure to near zero.

Observation and Modeling

Because of the distance from earth to the GSO there has been substantially less observation of the GSO. If the rate of breakup events in GSO is comparable to that in LEO one would expect sixteen to twenty events as opposed to the two observed to date. Many agencies are now focusing more attention to such observations in order to better understand the current environment.

Preliminary observations have detected a significant number of uncatalloged objects in GSO. To further study the region NASA has developed a Liquid Metal Mirror Telescope with a 3 m reflector and a CCD detector. This instrument can detect objects of a few centimeters at GSO because of the long integration times available

As illustrated in figure 10 the pattern of motion of various classes of objects is different and can be discriminated by differencing successive frames of the CCD imagery. The observations are best done in the dark of the moon so observing periods are limited but the technique has been demonstrated in the preliminary observation campaign

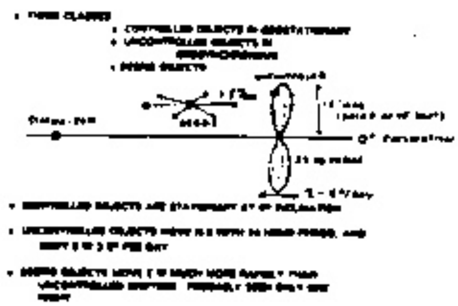

Figure 10. Discrimination among types of objects in GSO

Conclusions

It is desirable to take appropriate actions to protect the future GSO environment. The disposition of the kinetic energy is the most critical because it is so much greater than the stored energy. The stored energy, however, is not to be ignored because while it creates less debris in an inadvertent explosion, the products are of sufficient mass and velocity to damage operating spacecraft. Currently there is no disagreement on the need for these actions and only minor variance on the approach to planning such maneuvers. It is another example of the space community acting in enlightened self interest to protect its future options.

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