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RESEARCH ARTICLE

SELECTION OF AN ORBIT FOR COMMUNICATION SATELLITE BASED ON INCLINATION AND ECCENTRICITY

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ABSTRACT

The work mainly deals with the design of a geostationary orbit for a communication satellite. The mission and requirements are determined by the ΔV budget calculation been done for four different cases and obtained the low ΔV total which will be more efficient for the fuel consumption. Six Keplerian Orbital elements and orbital perturbations for the low earth parking orbit and finally attained geostationary orbit is been calculated theoretically and shown. Further using GMAT software, the simulation of the geostationary orbit is attained and various analysis (Iterations, Differential corrector, Report and Ephemeris files, Graphs) are done based on the altitude of the orbit. In this paper a brief introduction is given for communication satellites and its importance and detailed study about various orbits which helps in obtaining a result of choosing a suitable orbit based on eccentricity and inclination classifications. Detailed explanation is given for the chosen orbit for communication satellite.

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INTRODUCTION

The importance of communication satellites in our day-to-day life become more prominent and as evidence increase in the usage of mobile networks, Global Positioning System (GPS), homes equipped with antenna used for reception of satellite television and radios. Satellite communications began in October 1957. The first artificial Earth satellite was launched by USSR named Sputnik I. it does not have a communication capability because it carried only a beacon transmitter but it demonstrates how the satellites could be placed in orbit by powerful rockets. Telstar I and II, the true communication satellites were launched in July 1962 and May 1963(M. Richharia, 1999). It has been launched into medium Earth orbit with periods of 158 and 225 min. but the orbit chosen for the satellite took them through several bands of high energy radiation which causes early failure in the electronics on-board. However the work has begun to develop launch vehicles that could deliver a payload to geostationary orbit and the value of communication satellite to provide useful communication capacity. 99% of satellites been launched in LEO in mid-1963 because LEO and MEO were much easier to reach than GEO with small launch vehicles available at that time. Thus the issues rather than on payload capabilities, the intense debate was eventually settled on launcher reliability. At the time of launch failures, 48 launchers were envisioned to guarantee 12 operational satellites in orbits, continuous 24 hours coverage could not be offered without 12 satellites in orbit which is a necessary requirement for 24/7 operation to attain successful communication service. But the architecture of GEO systems requires only one satellite to provide 24/7 operational over essentially 1/3rd of the earth. The first Intelsat satellite has been launched which was launched on April 16, 1965 was a success. The value of telecommunications grew rapidly in many countries, not just internationally but also for national systems that provide high quality satellite communications within the borders of large countries (D. Roddy, 2006). Satellites can also link many users who widely separated geographically because very large areas of the Earth are visible from a satellite that the satellite can form the star point of a communication net. These satellite system includes : (i) India's INSAT series (ii) the United States GOES (iii) the Japanese Himawari (iv) Chinese Fengyun (v) Metosat which is been launched by the European Space Agency and it is operated by the European Weather Satellite Organization, EMUETSAT. Most commercially used satellite such as communication, broadcast and SABS satellites operate in geostationary orbits. For Commercial satellite communications industry, large GEO satellites have always been the backbone. It can cover 1/3rd of the Earth's surface, carry up to 4GBPS of data and can transmit up to 16 high power direct broadcast satellite television signals.

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Types of orbits

Centric classifications

a. **Galactocentric orbit:** An orbit about the centre of galaxy. The sun follows this type of orbit about the galactic centre of Milky Way.

b. Heliocentric orbit: An orbit around the sun. In the solar system, all planets, comets, asteroids are in such orbit, are as many artificial satellites and pieces of space debris.

c. Geocentric orbit: An orbit around the planet Earth, such as that of the Moon or many other artificial satellites.

d. Lunar orbit: An orbit around the Earth's Moon. It is also known as selenocentric orbit.

e. Planetocentric orbits: An orbit around any planet in the universe.

The flow chart that represents the Organization of the Project:

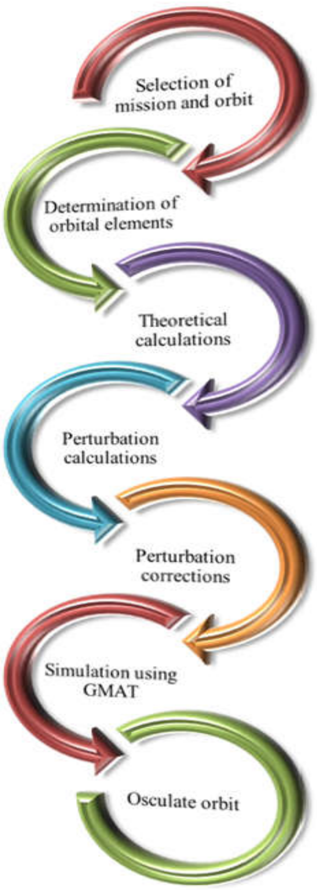

Figure 1. Organization of the project

Analysing

Importance of inclination and eccentricity

In an inclined geosynchronous orbit, the satellite is no longer in geostationary, thus it completes one orbit around the Earth in every 24 hours. Due to the gravitational effects of other stellar bodies such as Sun and Moon, the orbit would appear to trace out a small ellipse which exhibits a slight influence over the satellite. As a result, the accumulation of time becomes an analemma with lobes oriented from north-south. Regular manoeuvres are actively taken to counteract the gravitational forces. This is mainly done by fuel of the satellite (hydrazine). If thus manoeuvre is not taken, the satellite can experience a major change in the inclination over time. The inclination and eccentricity both must be reduced to zero to obtain a complete geostationary orbit but if only the eccentricity is reduced to zero we can only get a geosynchronous orbit rather than geostationary orbit. It is because due to$\Delta \boldsymbol{V}$, which is required for a plane change is proportional to the instantaneous velocity. Inclination and eccentricity usually change together in a single manoeuvre at apogee where the velocity is lowest.

Inclination

Inclination of an orbit is the angle between the orbital plane and the Earth's equatorial plane. It is measured at the ascending node from the equator to the orbit which goes from east to north. It is denoted by 'I'. It will be monitored that the greatest latitude, north to south, reached by the sub-satellite path is equal to the inclination.

Inclination classifications

a. Inclined orbits: If the orbit exhibits an angle other than zero degree with respect to the equatorial plane then the satellite is said to occupy an inclined orbit around earth. This is orbit's inclination.

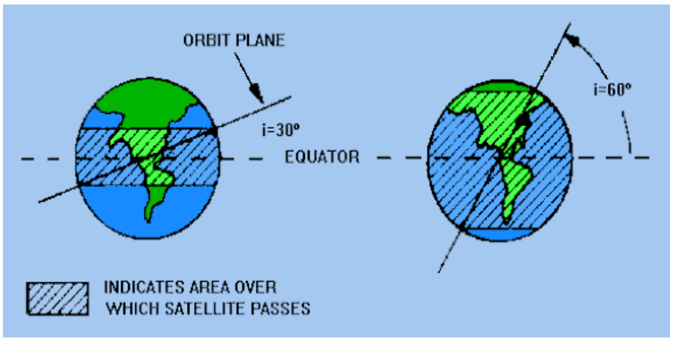

Figure 2. Inclined Orbit[Source: http://www.tpub.com/ neets/ book17/76.htm]

b. Polar orbits: An orbit in which the satellite passes above or nearly above the both north and south poles of the Earth being orbited on each revolution. Therefore, it has an inclination very close to 90 degrees to the equator. In a polar orbit a satellite will pass over the equator at a various longitude on each of its orbit.

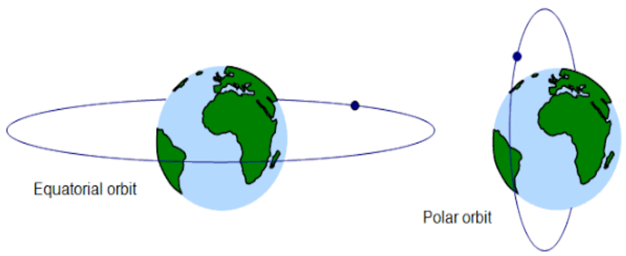

Figure 3. Polar orbit and Equatorial orbit [Source: http://www. schoolphysics.co.uk/age11-14/Astronomy/text/artificial_ satellites/index.html]

Polar sun synchronous orbit (SSO): Satellite placed in SSO passes through the equator at the same local solar time on every pass and useful for image taking because shadows will be same on every pass.

c. Non-inclined orbit: This orbit is contained in the plane of reference, and for the prograde the inclination is 0°, for retrograde the inclination is 180°. It happens in the case, which the satellite in the prograde orbit moves in the same direction as the Earth's rotation. While in retrograde orbit satellite moves in a direction counter to the Earth's rotation. Most satellites are placed in prograde orbit because the Earth's rotational velocity provides part of the orbital velocity with a consequent saving in launch energy.

d. Near equatorial orbit: Orbit which lies close to the equatorial plane of the object orbited. This orbit allows for rapid revisit times of near equatorial ground sites.

Eccentricity

It describes the shape of the ellipse and how much it is elongated when compared to a circular orbit. In keplerian orbital elements, eccentricity is a non-negative number that defines its own shape.

Following are the values of the eccentricity for various orbits:

Table 1. Eccentricity Variations

Eccentricity of various orbits	Values
Circular orbit	$e = 0$
Elliptic orbit	$0 < e < 1$
Parabolic orbit	$e = 1$
Hyperbolic orbit	$e > 1$

Eccentricity classifications

a.Circular orbit: It has an eccentricity of 0 and whose path traces a circle. Orbital path of the satellites placed in circular orbits gets affected by the satellite's altitude i.e. height above the Earth. The reason behind this is satellites in GEO are always in a high earth orbit whereas the satellites in polar, sun-synchronous or equatorial orbits are placed in MEO or LEO.

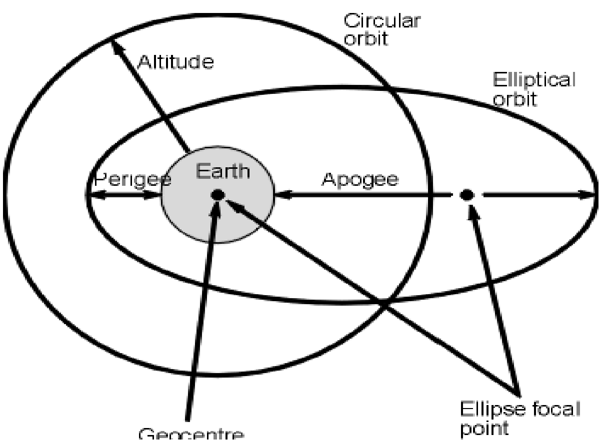

Figure 4. Circular orbit [Source: http://www.radio-electronics.com/info/satellite/satellite-orbits/satellites-orbit-definitions.php]

b.Elliptic orbit: Its eccentricity will be greater than zero and less than one whose orbit traces the path of the ellipse. Satellites will make its move faster when it is at perigee and move slower when is at apogee. This orbit that allows the satellite to travel over a specific zone for a long portion of its orbit.

i. **Geostationary or Geosynchronous Transfer Orbit:** An elliptic orbit where the perigee is at the altitude of a LEO and apogee is at the altitude of a GEO. Its inclination is equal to the latitude of the launch site and the direction of launch.
ii. **Hohmann transfer orbit:** It is an orbital manoeuvres, transfers satellite from one circular orbit to another using two impulsive burns. To move from its original (small circular orbit) to its final orbit (larger orbit), it takes two accelerations, one at perigee and one at apogee.

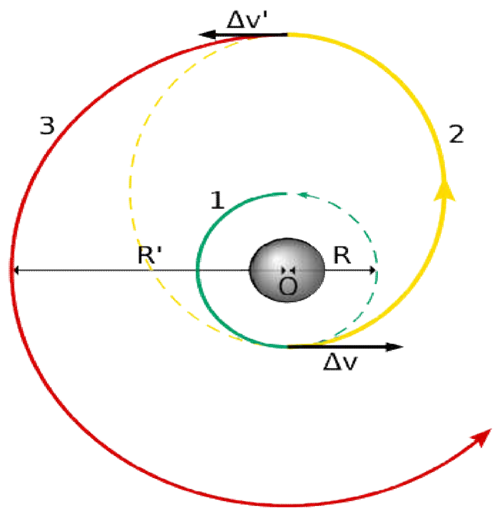

Figure 5. Hohmann transfer orbit [Source: publication- 11th September2009, https://en.wikipedia.org/wiki/Hohmann_transfer_orbit]

RESULTS AND TABULATION

Altitude classifications for geocentric orbits respect to its equitorial plane

a.Low Earth orbit (LEO): Altitudes from 160 to 2000 km are considered as geocentric orbits. Below 160 km a very rapid orbit decay and altitude loss will be experienced by the satellites. About 7.8km/s of mean orbital velocity is required to maintain a stable LEO, but mainly it reduces with increased orbital altitude. Satellites in low Earth orbit are the simplest and cheapest for the satellite placement. Examples of satellites in LEO are remote sensing satellites, earth observation and spy satellites, the international space station etc.

b.Medium Earth orbit (MEO): This orbit is also known as intermediate circular orbit. Altitudes that ranges from 2000km to just below geosynchronous orbit at 35,786km which is in between LEO and GEO. Communication, navigation and geodetic/space environment detecting satellites are most commonly used in this region. The satellites at an approximate altitude of 20,200km yields an orbital period of 12 hours, as used for GPS. The orbital period of MEO satellites that ranges from 2 to nearly 24 hours.

c.Geosynchronous (GSO) and Geostationary (GEO) orbits: These orbits that present around Earth with respect to its

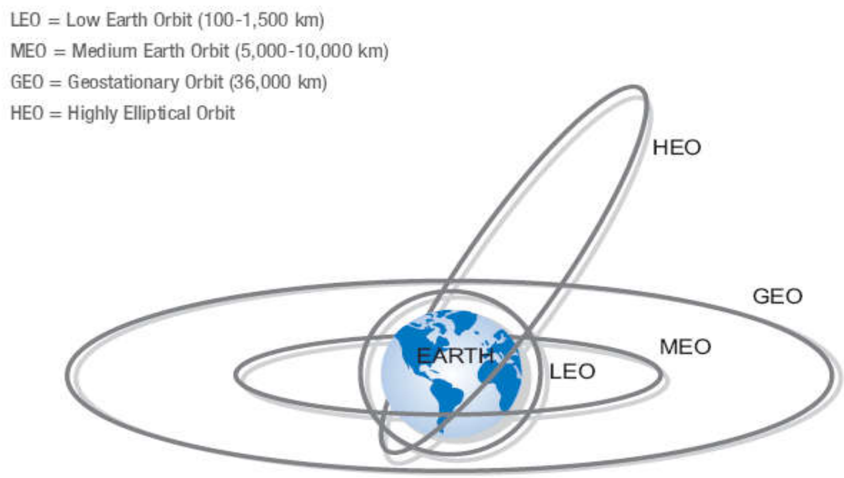

Figure 6. Geocentric orbits with respect to equatorial palne [Source : Space Security 2007, https://www.unz.com/akarlin/ future-war/]

Table 2. Altitude ranges in Geocentric Orbits

Geocentric Orbits	Altitude	Types of Satellite
Low Earth Orbit	160-2000 km	Remote sensing, Earth observation and spy satellites, ISS.
Medium Earth Orbit	Above 2000 km	Communication, navigation and geodetic/space environment detecting satellites.
Geosynchronous and Geostationary Orbits	At 35,786 km	Communication and Operational meteorological satellites with worldwide network.
Geo Transfer Orbit	Does not have a fixed altitude	Transfer satellite from LEO to GEO
High Elliptical Orbit	Above 35,786 km	Communication satellites

equatorial axis matching Earth's sidereal rotation period. All GSOs and GEOs have a semi-major axis which is nothing but the radius of the Earth of about 42,164km. All GEOs are GSOs but not all GSOs are GEOs because a GEO stays exactly above the Earth's equator, whereas a GSO swings north and south to cover more of the Earth's surface. Both orbits that complete a one full revolution of earth per sidereal day. When a satellite lies above the Earth's equatorial plane i.e. in its geosynchronous orbital path, it appears completely stationary relative to the surface of the Earth. This is more convenient for communication satellite to be placed in GEO. Operational meteorological satellites with worldwide network are mainly placed at GEO which is used to provide a visible and infrared images of Earth's surface and as well as its atmosphere. It can only be achieved at an altitude close to 35,786km and directly above the equator. A various combined combination of solar, lunar gravity and oblateness of Earth, causes a precession motion i.e. perturbation of orbital plane of any GEO satellite.

d.Geo Transfer Orbit (GTO): It is an elliptical orbit of the Earth. GTO's perigee is in LEO and its apogee is in Geo. It is a transfer orbit which helps the launch vehicle to launch its payload form LEO to GEO.

e.High Elliptical Orbit (HEO): Geocentric orbits which is above the altitude of GEO, it has an extremely high-altitude apogee and a relatively low altitude perigee. These are extremely high orbit with high inclination. Visibility near apogee can exceed 12 hours, so they are useful for communication satellites because of long dwell times over a point in the sky.

From Figure 6 and Table 2 we can able to see a little altitude changes in the LEO, MEO. GEO, HEO. It is mainly because of mission, launch vehicle, launch sequence etc.

Conclusion

After studying the importance of inclination and eccentricity in satellite communication orbits, we choose to study the orbits under their classifications, and explored various satellite orbit types. Under those various types, GEO is been chosen. Two major ideas developed from the study, they are: (1) Fuel consumption of a launch vehicle to place a satellite in its orbit and (2) Building a constellation in GEO to provide better coverage, more survivability and high reliability if a satellite is lost. Further works will be continued and corrections will be made from outputs.

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