Orbital Perturbation

Lecture # 5

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Orbital perturbations

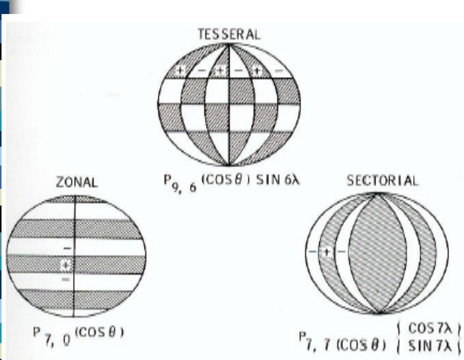
- In this chapter we will discuss the most important disturbances. This is necessary to do because we want to know the lifetime of the satellite before it will tumble down to earth.
- We will also see how the orbit changes due to the different disturbances.
- One important thing to remember is that these calculations are for a cause to do the predicted orbit and lifetime more accurate.

Orbital Perturbations

- There are two types of Orbital Perturbations
  - gravitational, when considering third body interaction and the non-spherical shape of the earth.
  - non-gravitational like atmospheric drag, solar-radiation pressure and tidal friction.
- These can also be classified as conservative or non-conservative disturbances forces. Where conservative forces depends only on the position, while non-conservative forces depends on both position and velocity.

The Non-Spherical Earth

- The earth is far away from perfectly spherical.
- One depends on the rotation, making the radius from center of the earth to the equator larger than from the center of the earth to the poles.
  - **Gravitation potential**
  - **Gravity harmonics**
  - **Force approach**



Atmospheric disturbances

- Although the atmosphere is almost empty you have to consider it. This is the most important disturbance, because it is the main cause in determining the lifetime of the satellite.
- The drag that can be calculated is an empirical function based on Cd which is a constant depending on the shape of the body.
- The also necessary density of the atmosphere depends on some different environmental factors such as the activity of the sun. The major part of the atmosphere below 1000 km consists of O_2, N_2, and He.

- The minor representative parts are O_3, CO_2, H_2, NO,electrons, and both positive and negative ions.
- The difficulty to determine the density is because of the chemical reactions especially photochemical reactions. These are driven by the sunlight, and therefore the activity of the sun is important.
- The other chemical reaction in the atmosphere is diffusion. The minor constituents are controlled by photochemical processes and therefore the density depends on the sunlight.

- In this case we use a mean value of the density.

$$a_D = -\frac{1}{2}\rho g_0 V^2 \frac{C_D A}{W} i_v$$

a_D = atmosphere drag acceleration vector
ρ = atmosphere density
V = Velocity of the satellite
g_0 = Earth gravitation at sea level
A = The projected satellite area
W = Satellite weight at sea level
i_v = unit vector of satellite velocity

CD is the drag coefficient depending on the shape and surface but the best value is given in an actual test flight. But the value for a sphere is 2.2 and for a cylinder it is 3.0. Usually 2.2 is considered to give a conservative result.

Solar radiation and solar wind

- Solar radiation is all kind of electromagnetic field emitted by the sun, from X-rays to radio waves.
- The solar wind consists of particles emitted by the sun, mainly ionized nuclei and electrons.
- Because of the charged particles in the solar wind it does not penetrate the magnetopause, except at the magnetic poles. The magnetopause starts about 10 earth radii from the center of the earth (Re = 8371) km. Therefore, the sun is more or less active. It has an activity cycle of 22 years between two

- Therefore the solar pressure is also not constant, but it fluctuate by < 1%. The pressure is, P0 = 4.7 · 10-6 [Pa]. The perturbing forces can be calculated by:

$$\frac{a_p}{g_0} = 4.7 \cdot 10^{-6}(1+\beta)\left(\frac{A}{W}\right)\left(\frac{a_\odot}{r_\odot}\right)^2$$

a_p = the acceleration due to the solar radiation pressure
g_0 = the gravitation at the surface of the earth
β = optical reflection constant
β = { 1 total reflection (mirror); 0 total reception (black body); -1 total transmission (transparent) }
A = effective satellite projected
W = total satellite weight
$r_\odot$ = radius of the earth's orbit around the sun
$a_\odot$ = semi major axis of the earth's orbit around the sun

- The effect due to the solar radiation pressure is, for a LEO, not that big.
- The aerodynamic drag has a more disturbing effect. But at altitudes above 1000 km and an orbit close to the ecliptic plane it has a more distinct effect.

Third body interaction

- How do the other planets disturb the satellite?

Attitude Perturbations

- The disturbance in orientation or attitude is important to look at because we want to keep the orientation so it can perform the tasks
- Here we consider the atmospherically drag, the solar pressure and the magnetic disturbance.

- Aerodynamic Pressure
  - The pressure due to the atmosphere affects the satellite, although one often think of space as a vacuum it has, or at least the environment where the satellite operates, has some kind of atmosphere. If the center of pressure of the body is different from the center of mass, the pressure acts on the body and the resultant of the forces is not through the center of mass and there are a torque due to the atmosphere. The force on a differential area can be expressed by;

$$\mathrm{d}F = -\rho v^2 \left\{(2 - f_n)(\boldsymbol{v} \cdot \boldsymbol{n})^2 \boldsymbol{n} + f_t(\boldsymbol{v} \cdot \boldsymbol{n})(\boldsymbol{n} \times (\boldsymbol{v} \times \boldsymbol{n}))\right\} \mathrm{d}A$$

$\boldsymbol{v}$ = Unit velocity vector
v = Magnitude of the velocity
ρ = Atmospheric density
$\boldsymbol{n}$ = The normal to the surface of $\mathrm{d}A$
f_n, f_t = The normal and tangential momentum interchange coefficients (typical between 0.8 and 1)

The total torque can be found when integrating

$$\mathrm{d}N = \boldsymbol{r} \times \mathrm{d}F$$

where $\boldsymbol{r}$ is the distance vector from $\mathrm{d}A$ to the center of mass.

Solar Pressure

- Just like the pressure from the atmosphere a torque due to solar pressure act on the satellite. The pressure of the the sun and the difference of the center of pressure and the center of mass causes a torque on the satellite. The force on a differential area can be described with;

$$\mathrm{d}F = -P\left\{(1-\nu)(\boldsymbol{x}_s \cdot \boldsymbol{n})^2 \boldsymbol{n} + (1-\nu)(\boldsymbol{x}_s \cdot \boldsymbol{n})(\boldsymbol{n} \times (\boldsymbol{x}_s \times \boldsymbol{n}))\right\} \mathrm{d}A$$

ν = The satellite surface reflection (unity for total reflection)
$\boldsymbol{x}_s$ = Unit vector towards the sun
P = The solar pressure
$\boldsymbol{n}$ = The normal to the surface $\mathrm{d}A$

The total torque can be found in the same way as for the atmospheric torque.

Earth Magnetic Field

- The magnetic field of the earth has two ways of disturbing the satellite. The first is when the satellite rotates in a magnetic field. The magnetic field induces eddy currents in the shell and due to the resistance of the shell it produces heat. The energy it takes to produce the heat is taken from the rotational energy but the effects are very small. In this case when we have a short life cycle of the satellite we do not have to take this aspect in our calculations. The torques due to eddy currents are;

$$N_{Eddy} = k_e(\omega \times B) \times B$$

- where k_e is a constant depending on the satellite's geometry (see table) and conductivity, B is the vector of the magnetic strength of the earth

Geometry	k_e coefficient
Thin Spherical Shell radius r, thickness, d and conductivity σ	$\frac{3\pi}{2} r^4 \sigma d$
Thin walled cylinder length l, radius r and thickness d	$\pi \sigma r^3 l d \left(1 - \frac{2d}{l} \tanh \frac{l}{2d}\right)$

Limit of Visibility

- When Are Satellites Visible?
  - Whether or not a satellite is visible to a given observer is dependent upon many factors such as observer location, time of day, satellite altitude, and sky condition. Knowing these details may aid an observer in determining the most favorable times for sightings and is most certainly necessary

Factors Affecting Satellite Visibility

- Orbit Altitude And Inclination
- Earth's Shadow
- Ground Track
- Other Factors

Orbit Altitude & Inclination

- GEO
- MEO
- LEO
- HEO

Earth's Shadow

- The Earth's shadow must also be considered. When eclipsed, a satellite is naturally not visible. Such events are dependent upon the satellite's altitude, inclination, the time of year, and the observer's location

Ground Track

- Precession Of course it is not simply a question of watching for a given satellite at the same time each night. Few satellites have an orbital period which is a simple fraction of one day, the geostationary satellites being the obvious exception. The orbital period is dictated by the satellite's altitude. The higher the altitude, the further it has to travel around the Earth and the longer it thus takes. Satellites in low Earth orbit complete one orbit in around 90 minutes, whereas at geostationary altitudes (about 36,000 km) one orbit takes 24 hours.
- Many satellites in low Earth orbit go through a similar cycle of visibility. The cycle varies with orbital inclination, altitude, and observer location.

Other Factors

- satellite suffers greater air resistance the lower its orbit. This bleeds off the orbital energy, lowering the orbit yet further as the satellite begins to brush the upper atmosphere at perigee.
- The forces on the satellite due to the Earth (and Moon, Sun, etc.) vary throughout its orbit giving rise to continual change in the orbit.

Ref. web-address; Non-Spherical Earth + satellite

- www.particle.kth.se/group_docs/admin/docs/eriksson.pdf
- http://aerial.evsc.virginia.edu/~jlm8h/class/orbits2.html
- www.ee.surrey.ac.uk/SSC/G7/P3
- www.dlr.de/iaa.symp/archive/PDF_Files/IAA-B4-1308P.pdf
- http://www.avionics.com/www/books/SatcomBooks.html
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