Space Engineering 3

Assignment 1

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Orbit Simulation and Determination

Lydia Drabsch
311217591
ldra3557@uni.sydney.edu.au

STUDENT PLAGIARISM: COURSE WORK – POLICY AND PROCEDURE

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Name	Signature	SID	Date
Melissa Mitrevski		440207636	05/06/2015
Meg Flannery		440291196	05/06/2015
Lydia Drabsch		311217591	05/06/2015

Contents

List of Figures

List of Tables

Introduction

Write an intro here

1. Simulation of Orbits with Classical Elements

1.1 Introduction

- keplers three laws
- perifocal frame
- The true anomaly θ is the angle taken at the focus of the perifocal frame to the satellite from the perigee. The eccentric anomaly E is the angle taken at the centre of perifocal frame to the satellite from the perigee.
-The mean anomaly M_t is the mean number of orbits per day.
- LEO,MEO
-TLE's

1.2 Methodology

From Kepler's second law, the mean anomaly at time t is calculated using the mean motion n from an epoch time described by $M_0(t_0)$.

$$M_t = M_0 + n(t - t_0) \tag{1}$$

To solve for the eccentric anomaly, newtons method was used

$$E_{i+1} = E_i - \frac{f(E_i)}{f'(E_i)} \tag{2}$$

$$E_{i+1} = E_i - \frac{E - e\sin(E_i) - M_t}{1 - e\cos(E_i)} \tag{3}$$

The true anomaly was calculated using

$$\theta = 2\tan^{-1}\left(\sqrt{\frac{1+e}{1-e}}\tan\left(\frac{E}{2}\right)\right) \tag{4}$$

The general equation for the radius of an ellipse

$$r = \frac{p}{1 + e\cos\theta} \tag{5}$$

The two parameters, θ and r can completely define the orbit in the perifocal frame as polar coordinates. The conversion to cartesian coordinates in the perifocal frame are as follows:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{perifocal} = \begin{bmatrix} r\cos\theta \\ r\sin\theta \\ 0 \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix}_{perifocal} = \begin{bmatrix} -\sqrt{\frac{\mu}{p}}\sin\theta \\ \sqrt{\frac{\mu}{p}}(e + \cos\theta) \\ 0 \end{bmatrix} \tag{7}$$

$$\tag{8}$$

The perifocal parameters were transformed to the ECI frame to animate the 3D model of the satellite orbit around the Earth using the function ***orbit2ECI***. From the ECI coordinates, the ECEF and LLHGD coordinates were calculated for the ground trace.

1.2.1 Calculation of Period

autocorrelation based on Wiener-Khinchin Theorem

1.3 Results/Discussion

1.3.1 Van Allen Probes

The satellites Van Allen Probes, previously known as the Radiation Belt Storm Probes (RBSP A and B), are in a highly eccentric orbit. RBSP-A was modelled based on TLEs from spacetrack.com, see Table 1.1. It was launched on 30th August 2012

The Van Allen Belts are regions of plasma that surround the Earth that are contained by the Earth's magnetic field. The highly energetic particles become trapped in the Earth's magnetic field by travelling along the field lines to a pole and being reflected back and travelling to the opposite pole. This phenomenon is called a magnetic mirror, and is the reason the Van Allen belts have a torus shape about the Earth's magnetic axis. Therefore, the radiation is at the highest intensity about the magnetic equatorial plane, currently at 11.5° inclination. The satellite was put in an orbit close to this inclination at about 10°, with the mission objective to be in an orbit of no greater than 18°. The inclination has fluctuated between 9-11° over the course of it's mission.

The orbit was highly eccentric in order to cover the entire radiation belt region. The perigee altitude is 500 km, which is below the inner radiation belt and the apogee altitude is 30600 km, which is above the outer edge of the outer radiation belt.

1.3.2 TDRS-12

1.3.3 Orbital Properties

Table 1.1: Orbital properties of simulated satellites. (* indicates data taken directly from TLEs)

Orbital Properties	Variable Name	Units	Van Allen Probe A	TDRS-12
NORAD ID				39504
*Julian year/day data was taken	t0	year/day	2016 68.37507029	2016 82.54758936
Semimajor axis	a	m		
*Eccentricity	e	-	0.6813430	0.0001458
*Inclination angle	inc	degrees	10.1687	6.4245
*Right ascension of the node	Rasc	degrees	46.5607	336.8061
*Argument of Perigee	omega	degrees	77.2770	330.7916
*Mean Anomaly	Mt	degrees	346.0491	29.1253
*Mean Motion	MM	orbits per day	2.681033090	29.1253
Analytical Period				
Computational Period				
Altitude at Perigee				
Altitude at Apogee				

2. Simulating Perturbations

2.1 Introduction

Different perturbing sources acting on Van Allen Probes - earth oblateness, gravity harmonics, solar/lunar gravity forces, aerodynamic drag, solar radiation

2.1.1 Non-Spherical Earth

- perturbation vs inclination

2.1.2 Earth oblateness

For the standard simulation model in Question 1, it was assumed that the Earth was spherical. A perfectly spherical mass has an inverse square relation of the gravitational field to the force applied on a body. However, the Earth is slightly oblate, as it is flatter at the poles and wider at the equator than a sphere. As the difference in the force is small compared to the total force, it can be mathematically treated as a perturbation. While this method is only an approximation it works well.

Unlike using the keplerin model of Question 1, the classical orbital parameters change through time.

Newtown's second law and his law of gravitation results in

$$\ddot{\boldsymbol{r}} + \frac{\mu \boldsymbol{r}}{r^3} = a_p \tag{9}$$

2.2 Methodology

Equinoctial elements were used to remove the possible singularities that affect classical elements. The

2.3 Results/Discussion

3. Orbital Determination

3.1 Introduction

3.2 Methodology

The perturbation model from Question 2 was used

3.3 Results/Discussion

http://vanallenprobes.jhuapl.edu/mission/conversation/overview/index.php
Three networks are used to communicate with the Van Allen Probes. The main communications ground station is at the Applied Physics Laboratory in Washington, US.
http://www.scf.jhuapl.edu/
The LLH coordinates are 39.10N 76.53W 140 AMSL
For backup, the satellite communicates with the United Space Network with ground stations in Hawaii and Australia. The data rates that can be achieved with this network is high enough to gather scientific data from the probe. Also as a backup, the NASA program Space Network is used for monitoring data, which relays through geosynchronous Tracking and Data Relay Satellites (TDRS).

4. Conclusions

References

5. Appendix