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Simulation of a LEO orbiting microsat on Simulink

MSc in Space Engineering

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Abstract

La presente relazione di prova finale intende dare una descrizione dell'endoreattore F-1 prodotto da Rocketdyne. Cinque di questi motori vennero installati sul primo stadio S-IC del vettore Saturn V che portò il primo uomo sulla luna. L'obiettivo di questo stadio era quello di portare il razzo ad una quota di 61 km, fornendo un $\Delta v \simeq 2300$ m/s. Questo primo requisito verrà mostrato attraverso un modello matematico che simula il volo dello stadio S-IC.
Di seguito verranno analizzati i principali sistemi per un singolo motore, partendo dal sistema di storaggio e alimentazione dei propellenti costituito dai serbatoi e dalla turbopompa, passando per il sistema di generazione di potenza che comprende il gas generator e la turbina. Passando dalla camera di combustione si arriva infine al sistema di espansione gasdinamico e allo studio del suo raffreddamento. Si provvederà inoltre a dare una descrizione qualitativa e quantitativa delle scelte progettuali applicate ai tempi.
La discussione dei processi di combustione del gas generator e della camera di spinta si basa su dati provenienti da simulazioni eseguite con i programmi CEAM e RPA.

Contents

1. Symbols

1.1. Analisi della missione

$\boldsymbol{A_e}$	$[m^2]$	area di efflusso totale
$\boldsymbol{\phi}$	$[rad]$	angolo di traiettoria del razzo

1.2. Analisi della missione 2

$\boldsymbol{A_e}$	$[m^2]$	area di efflusso totale
$\boldsymbol{\phi}$	$[rad]$	angolo di traiettoria del razzo

2. Requirements

2.1. Mandatory requests for simulation

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3. Framework Analysis

3.1. Satellite characterization

3.2. Orbit characterization

4. Dynamics

The equations of the dynamics rotating body motion used throughout the simulation are the Euler equations since rigid body motion assumption is made. The set of equations are referred to the principal axis frame of the satellite. This frame will be also called reference frame $\mathcal{B}$, it is described by three unit vectors $\{\boldsymbol{x_b}, \boldsymbol{y_b}, \boldsymbol{z_b},\}$, that are in the direction of principal inertia axis.

$$\boldsymbol{I}\dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \times \boldsymbol{I}\boldsymbol{\omega} = \boldsymbol{M_d} + \boldsymbol{M_c}$$

In the above equation the external torque has been divided in to 2 contributions, with clear distinction. M_d describes the disturbance torques that act on the spacecraft due to environment and presented in the previous section, while M_c is referred to the control torque that the actuators are generating to perform the tasks required by the control logic.
With particular reference to the Simulink model, two configurations of the satellite were considered: undeployed configuration (for detumbling phase) and extended configuration (for slew and pointing phases). As a consequence, the mass distribution and hence the inertia matrix are different in terms of numerical values. This fact has been taken into account by implementing a logic in the dynamic block of Simulink, that switches between the two matrices using a flag based on the activation of the De-Tumbling control. This istantaneous switch is not completely realistic since the extraction of the panels would require some finite time, and in some way could influence the real dynamic of the satellite. Anyhow, for the microsat considered, the retracted configuration allows a faster detumbling, and also inertia loads and stresses are reduced on the solar panels.

4.1. Disturbances analysis

In order to make a realistic simulation of the rotating motion of the spacecraft, the environment distrubances has to be taken into account. The preliminary study of these external torques is crucial for a realistic simulation. In the following paragraphs a brief introduction will be done for all the main disturbances, then the simulation of the specific satellite and orbit will be presented, mainly to choose the two most relevant disturbances. This choice is reasonable since there are always two predominant effects of disturbance, while the other can be supposed small (usually some order of magnitude smaller, but always depends on the specific case).

4.1.1 Magnetic Disturbance

4.1.2 SRP Disturbance

SRP radiation torque is the disturbance generated by electromagnetic waves that impacts on the spacecraft panels and generate a force. These forces acting on some of the panels could give rise to a net torque around the center of mass of the spacecraft. Only sun radiation will be considered in this case, a more deep analysis should consider infrared Earth radiation and reflected Earth radiation. In addition, no eclipse condition will be analyzed during all the simulation, a reasonable assumption for the sun-synchronous case orbit.
The formula to calculate the force acting on each discrete panel is:

$$\boldsymbol{F_i} = -PA_i\left(\hat{S}_B \cdot \hat{N}_{B,i}\right)\left[(1-\rho_s)\hat{S}_B + \left(2\rho_s\left(\hat{S}_B \cdot \hat{N}_{B,i}\right) + \frac{2}{3}\rho_d\right)\hat{N}_{B,i}\right]$$

In order to simulate this kind of disturbance the coefficients of absorption, specular reflection and diffusion has to be decided. These values clearly depends on the material that will be choosen to construct the main body of the spacecraft, and the solar panels. Since these parameters are related through an energetic balance, we could only decide two of them and the third follows. In order to determine the force on each surface, also the geometry of the panels of the satellite has to be given, in particular size of each panel(fully defined in section ...) and direction of the normal of the panel in $\mathcal{B}$ frame. The direction of sun $\hat{S}_B$, has been firstly modeled in ECI frame considering the obliquity ϵ of earth's rotation axis with respect to the ecliptic plane, then through attitude matrix, the unit vector $\hat{S}_B$ has been computed. Lastly, to caluclate the torque we should known where the resulting force on each panel acts (i.e. the centre of SRP force for each panel). No detailed calulation has been made on this aspect, it is assumed as first approximation that the forces acts on the geometric center of the corresponding plate. Also, in order to correctly calculate the total torque a shadow check must be performed, this is simply implementated in Simulink by checkin the sign of the dot product of the normal versor of the plate and the sun direction.

4.1.3 Drag Disturbance

Over extended periods, the spacecraft's engagement with the higher strata of Earth's atmosphere results in the generation of a torque around its mass center. This influence may not be trivial. At altitudes less than 400 kilometers, the aerodynamic torque is the predominant factor, though its significance diminishes considerably beyond 700 kilometers altitude.

$$T_{AERO} = \begin{cases} \sum_{i=1}^{n} \vec{r}_i \times \vec{F}_i, & \text{if } \vec{N}_{bi} \cdot \vec{v}^b_{rel} \geq 0 \\ 0, & \text{if } \vec{N}_{bi} \cdot \vec{v}^b_{rel} < 0 \end{cases} \text{ with}$$

$$\vec{F}_i = -\frac{1}{2}\rho C_D v_{rel}^2 \vec{v}^b_{rel}(\vec{N}_{bi} \cdot \vec{v}^b_{rel})A_i \quad \text{n=number of faces}$$

4.1.4 Gravity Gradient Disturbance

The gravity around the spacecraft is not uniform, hence a non-negligible torque will arise from there. Studying the torque generated by an elementary force acting on the elementary mass dm the equation for this is obtained:

$$dM = -\mathbf{r} \times \frac{Gm_t dm}{|\mathbf{R}+\mathbf{r}|^3}(\mathbf{R}+\mathbf{r})$$

Where $\mathbf{r}$ is the distance of dm from the centre of mass and $\mathbf{R}$ is the distance of the centre of mass from the centre of the Earth. Approximating this equation, and expressing the position vector of the centre of mass as the product of magnitude (R) with the direction cosines, it's possible to centre this torque in the principal inertia axes. Integrating this equation the final form is achieved.

$$M_x = \frac{3Gm_t}{R^3}(I_z - I_y)c_2 c_3$$
$$M_y = \frac{3Gm_t}{R^3}(I_x - I_z)c_1 c_3$$
$$M_z = \frac{3Gm_t}{R^3}(I_y - I_x)c_1 c_2$$

The c_1, c_2 and c_3 are the direction cosines of the radial direction in the principal axes. Therefore if one of the principal axes is aligned with the radial direction the torque will be zero because only one of the direction cosines is non-zero.

4.1.5 Simulation of all disturbances

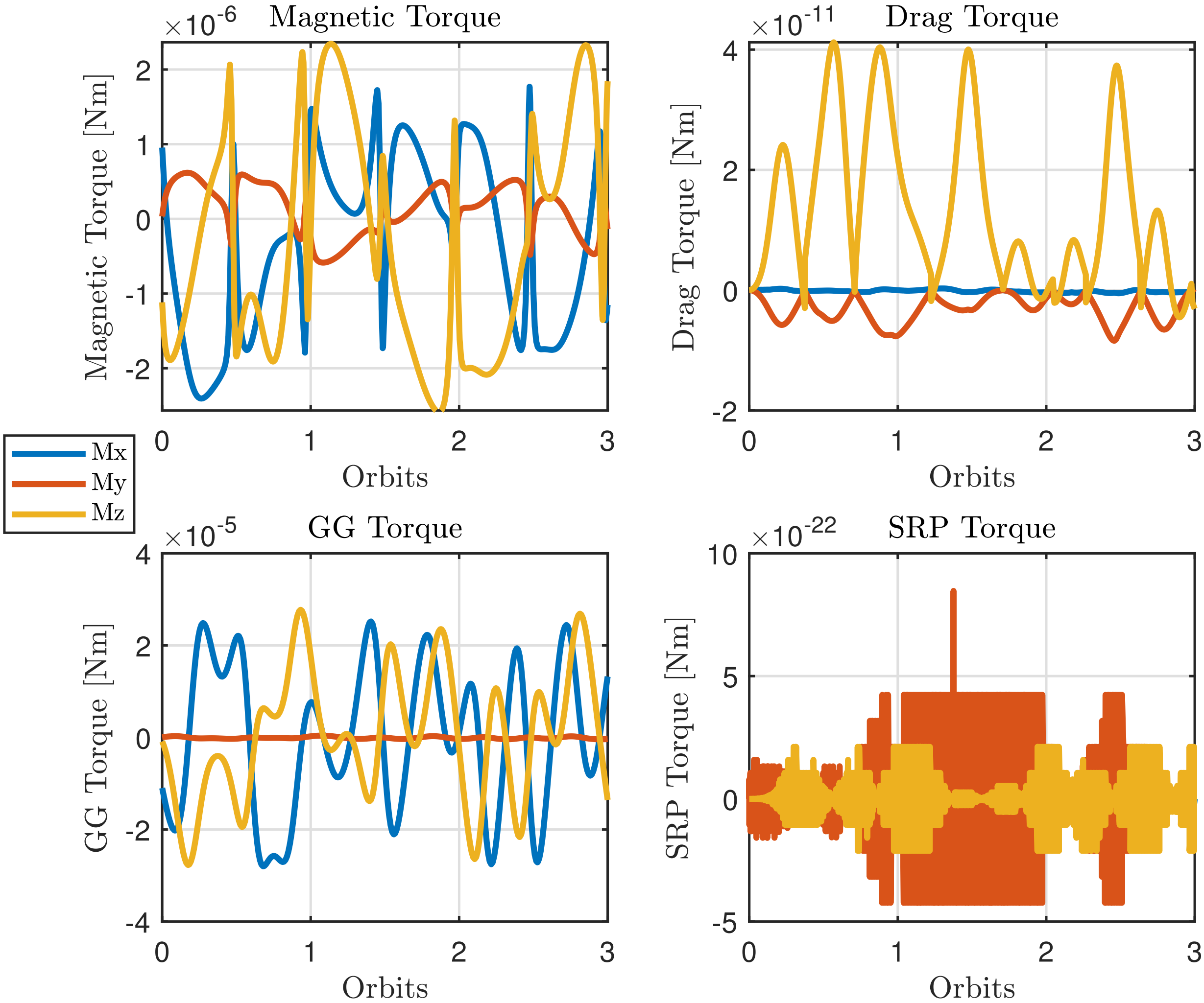

Figure 1: Simulation of all disturbances

Bibliography

[1] Georce C. Marshall Space Flight Center. *Saturn V Flight Manual SA-507*. National Aeronautics and Space Administration, 10 1969.