Scilab and Xcos for VLEO satellites modelling

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Introduction

Very Low Earth Orbits (VLEO) gathered interest due to the advantages of flying in lower altitudes, such as higher signal to noise ratio in the communications, possible reduction in the size, mass and cost of imaging payloads, less space debris in the orbits or lower propagation delay, among others. However, at these altitudes the aerodynamic forces and torques become the predominant disturbances and it must be considered in the design of the spacecraft. In this work atmospheric, magnetic and wind models were implemented in Xcos blocks to calculate the disturbances that affect the spacecraft and a panel method was implemented to study the aerodynamics with different geometries. The results of pointing maneuvers and attitude stabilization simulations comparing feather and shuttlecock geometries are presented. The models implemented in C and Scilab were used to create Xcos blocks that will be part of a toolbox.

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Methods and results

Environment disturbance torques acting on a satellite in orbit include gravity gradient, solar radiation, aerodynamic torque and Earth's magnetic field. In VLEO the aerodynamic disturbances are significant due to the increase in the density of the atmosphere. The interaction between the atmospheric particles and the surfaces of the spacecraft is responsible of these torques and forces. In this analysis Sentman's [1] equations were used to model gas surface interactions (GSI). An implementation of a panel method was used in order to calculate aerodynamic forces affecting the spacecraft. The spacecraft surface was modelled as a composition of flat plates. The forces and torques produced by GSI were calculated for each panel and after that they were combined to obtain the overall component. The panel method can be used to calculate aerodynamic forces and torques in convex surfaces.

In order to calculate the disturbances the following models were used in the simulations: Drag Temperature Model 2013 (DTM213) [2], International Geomagnetic Reference Field (IGRF12) [3] and Horizontal Wind Model (HWM14) [4].

Scilab 6.02 was used to get the results presented in this paper. The attitude dynamics were modelled on Xcos. Models of the actuators were implemented, including the magnetorquers, reaction wheels and the aerodynamic fins. The simulated external torques were the following: the gravity gradient, dipole magnetic field, the aerodynamic torque and the internal torques generated by the mobile parts. The controller in charge of managing the aerofins was a PID (Proportional Integral Derivative) controller.

Figure 1 shows the geometries of the satellites used in the simulations. Two configurations were analyzed. One of them is a shuttlecock configuration, based on a badminton shuttlecock, and the other one a feather configuration, similar to a dart or an arrow. In both cases the fins can be moved to take advantage of the aerodynamic forces and torques to perform maneuvers.

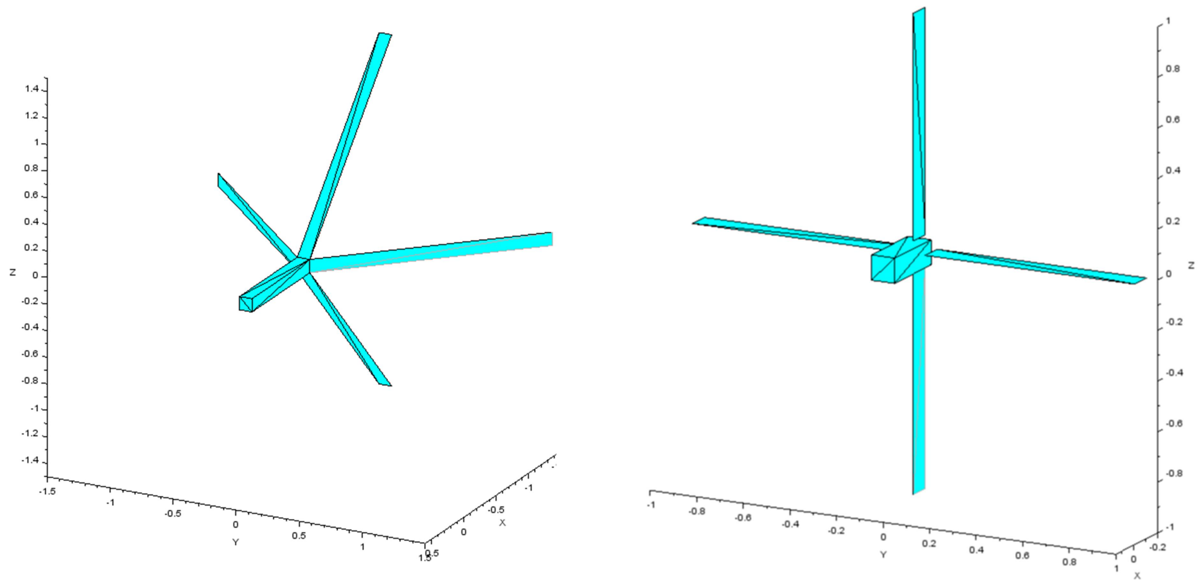

Figure 1: Shuttlecock configuration (left) and Feather configuration (right)

The orbit parameters are defined in Table 1. A VLEO orbit at an altitude of 350 km was considered for the calculations.

Table 1: Orbit parameters

Type of orbit	Altitude (km)	Inclination (degrees)	Argument of Perigee (degrees)	Mltan (hh:mm)	Eccentricity
VLEO	350	50	90	12	0.001

The attitude stability of the feather configuration is studied in pitch, raw and yaw axes. A simulation was performed for each axis. Figure 2 shows the results for each simulation in the same graph. The settling time was considered the moment when the difference between the signal and the reference is lower than one degree. The maximum maneuverability is reached in roll axis, with a settling time of 172 seconds. Pitch and yaw axes behaved similarly and showed a settling time of 607 seconds and 812 seconds, respectively. In this configuration, mainly lift is used in the maneuvers. Additionally an effect not considered on these simulations was that an oscillating steady state of small amplitude appears depending on the precision of the fins movement.

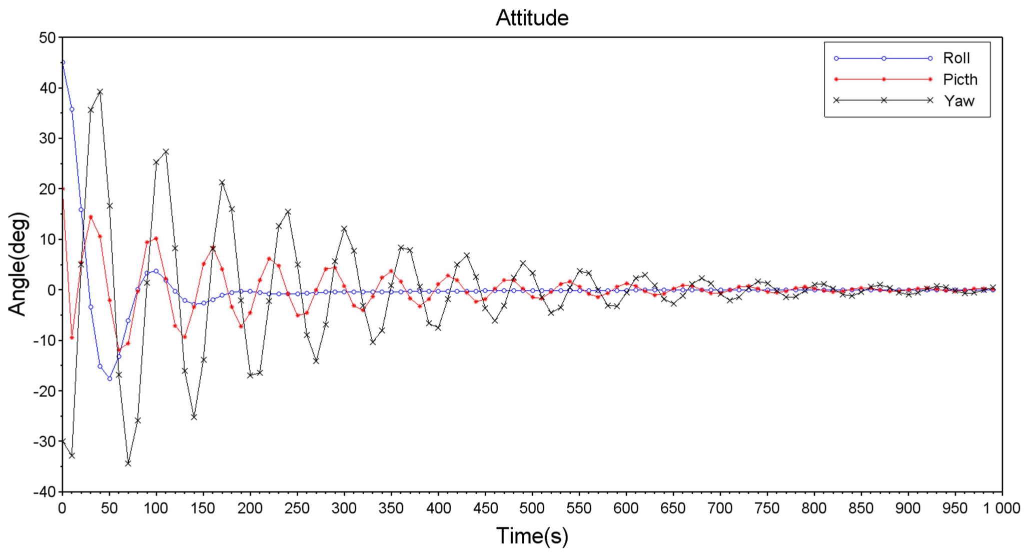

Figure 2: Attitude stabilization for feather configuration

Table 2 shows the results obtained for a pointing maneuver. The target angle was 15 degrees. The settling time and the overshoot are presented for different accommodation coefficients. The accommodation coefficient [5] characterizes the behavior of the particles when they impact a surface. It depends on the material used for the fins, the temperature and the roughness of the surface. By considering different values of accommodation coefficient the results change. The higher the accommodation coefficient the higher the settling time and the overshoot found.

Table 2: Pointing maneuver time in function of the accommodation coefficient

Accommodation coefficient	Settling time (s)	Overshoot (%)
0	4281	32.73
0.2	5426	32.86
0.4	9022	33.01
0.6	22513	33.13
0.8	68319	36.06

0.95	-	-

The same analysis was carried out for the shuttlecock configuration. Figure 3 shows the results of the attitude stabilization for that geometry. In this case, drag is mainly used in the maneuvers. The stabilization is faster than in the feather configuration. Pitch and yaw axes had a settling time of 183 seconds and 197 seconds, respectively. The configuration of the fins does not allow the stabilization in the roll axis. It can be achieved by using reaction wheels or magnetorquers.

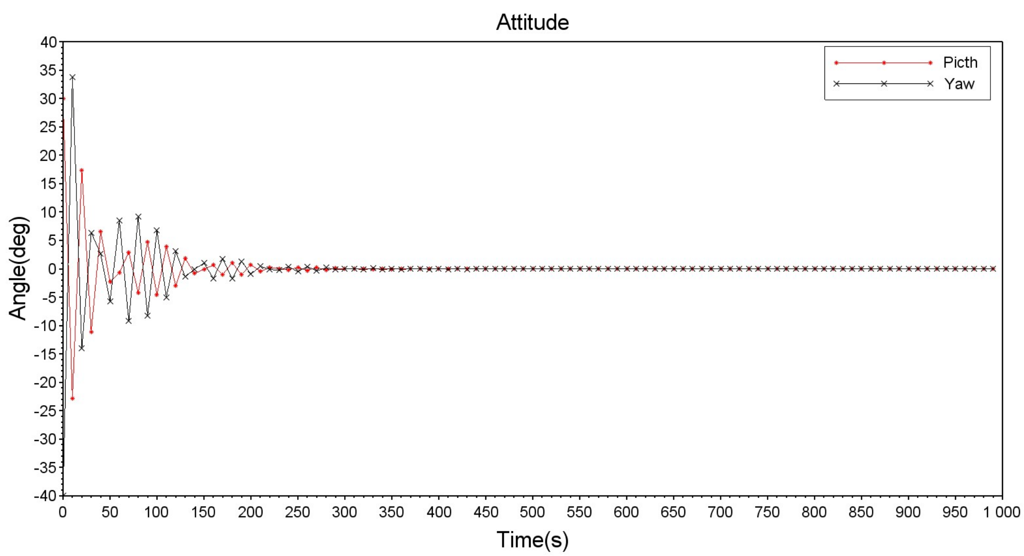

Figure 3: Attitude stabilization for shuttlecock configuration

Table 3 shows the comparison of the pointing maneuver for both configurations feather and shuttlecock with different pointing angles. The settling time was lower for the shuttlecock configuration but the overshoot was higher. In the case of the feather configuration the range of the pointing angles that it can achieve was lower than in the other configuration. From a pointing angle of 18 degrees this configuration cannot reach a steady state using a PID controller for the fins.

Table 3: Comparison of pointing maneuver for feather and shuttlecock configurations

	Feather		Shuttlecock	
Pointing Angle	Settling Time	Overshot(%)	Settling Time	Overshot(%)
5	3523	37.8	253	79.3

10	3271	35.7	261	77.8
15	4116	29.5	272	73.7
20	-	-	279	69.1
25	-	-	312	62.1
30	-	-	433	51.5
35	-	-	673	42.1
40	-	-	-	-

With the models used in this work to analyze the behavior of satellites flying in VLEO was feasible. The different parts implemented in the models can be used to create blocks that can be included in a toolbox. For example, the reaction wheels, magnetorquers, blocks that calculate the torques or blocks that integrate environmental models, such as the atmospheric model or the magnetic field model. Xcos is a useful graphical tool that allows the implementation of complex models and run simulations.

A Xcos toolbox with the blocks used in this analysis is in development and will be released at the end of the project. Figure 4 shows some of the blocks implemented for the toolbox. The blocks were generated in three ways:

- Integrating existing C or Fortran code in the blocks.
- Generating C code from a Xcos superblock and integrating it in the blocks.
- Generating a block from Scilab code.

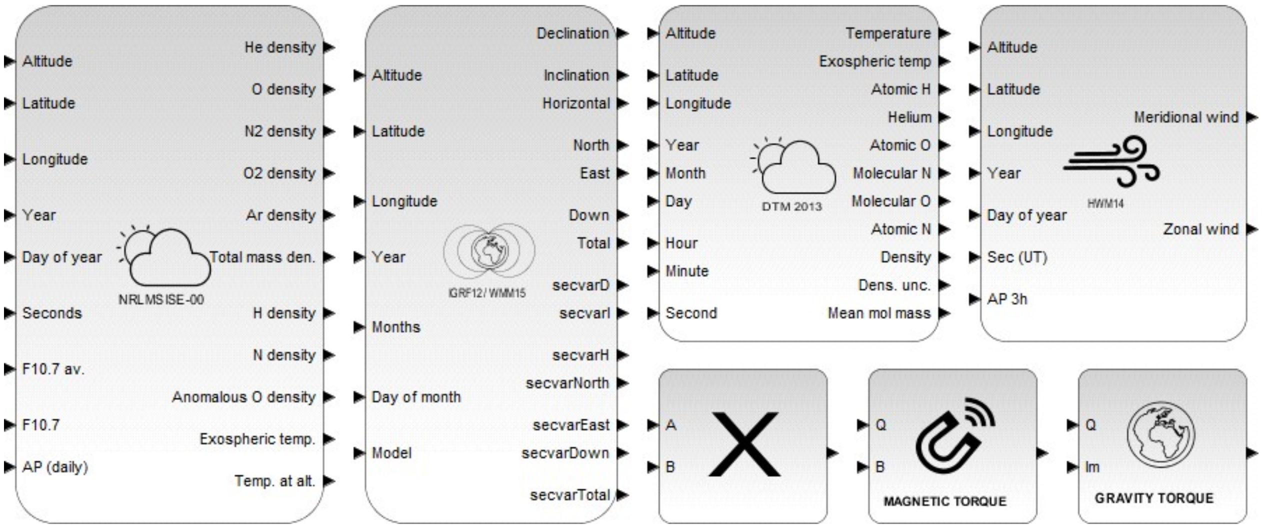

Figure 4: Blocks of the toolbox

Summary

The results presented in this paper remark the importance of the of the geometry and the material used to build a spacecraft to take advantage of the environment in VLEO orbits, where the atmospheric fluid behaviour has to be considered as a free molecular flow, having important implications when modelling the system. Aerodynamic forces and torques can be used to carry out some attitude control and stabilization maneuvers. Aerodynamic stabilization and pointing maneuvers were presented in this work.

The available open source software tools allowed implementing the models in blocks that can be used to simulate and design the control system. The work carried out reveals that the set of blocks available can be extended to create a tool set with all the required functions to model a VLEO spacecraft system.

References

[1] L. H. Sentman, «Free Molecule Flow and its Application to the Determination of Aerodynamic Forces,» Lockheed Missiles and Space Co. Inc. Technical report LMSC-448514, Sunnivale California, 1961.

[2] S. Bruinsma, “The DTM-2013 thermosphere model,” *Journal of Space Weather and Space Climate,* vol. A1, p. 5, 2015.

[3] E. Thébault, C. C. Finlay, C. D. Beggan, P. Alken, J. Aubert, O. Barrois, F. Bertrand, F. Bertrand, T. Bondar, A. Boness, L. Brocco y Canet, «International Geomagnetic Reference Field: the 12th

generation,» *Earth, Planets and Space,* pp. 67-79, 2015.

[4] D. P. Drob, J. T. Emmert, J. W. Meriwether, J. J. Makela, E. Doornbos, M. Conde y J. D. Huba, «An update to the Horizontal Wind Model (HWM): The quiet time thermosphere,» *Earth and Space Science,* vol. 2(7), pp. 301-319, 2015.

[5] P. Hughes, Spacecraft Attitude Dynamics, Mineola, New York: Dover Publications, 2004, p. 275.