Analysis of Aerodynamic Control in VLEO

V. Cañas and J. Becedas*

Elecnor Deimos Satellite Systems
Francia 9, Pol. Industrial La Nava, 13500 Puertollano, Spain
Telephone/Fax: + 34 926 44 35 78
***Contact: valentin-jose.canas@elecnor-deimos.es**

Abstract

Flying a satellite in a very low Earth orbit with an altitude of less than 450 km, namely VLEO, is a technological challenge. The atmospheric density at low altitudes has serious consequences for the manoeuvrability of a satellite because significant aerodynamic torques and forces are produced. Thus, an analysis of the feasibility of the attitude control and the manoeuvers is required. In this work, different satellite geometries were considered to study aerodynamic control: 3 axis control with feather configuration and 2 axis control with shuttlecock configuration. It includes the main disturbances affecting the spacecraft and evaluates the following manoeuvers: detumbling or attitude stabilization, pointing and demisability.

Keywords: VLEO, aerospace simulations, modelling, satellite manoeuvers.

1. Introduction

The advantages of Very Low Earth Orbits (VLEO) has given rise to a growing interest in the exploitation of these orbits. Aerodynamic forces and torques are the most significant disturbances experienced by a spacecraft in very low altitudes, due to the interaction with the residual atmosphere. The analysis of viable aerodynamic control strategies is required and affects the design of the spacecraft: geometries, materials and control methods.

The use of aerodynamic torques and forces has subsequently been proposed for a number of different applications in spacecraft orbit and attitude control. In order to implement these control applications a range of control techniques and associated geometries have been studied.

2. Materials and methods

To implement orbit and attitude control methodologies a previous analysis of their feasibility is required. Xcos is a graphical modelling application that enables the design and simulation of a system. This tool facilitates the simulation of a spacecraft in VLEO environment conditions and all the disturbances and control algorithms to compensate them.

The following models were used in the simulations to calculate the disturbances: Drag Temperature Model 2013 (DTM213), International Geomagnetic Reference Field (IGRF12) and Horizontal Wind Model (HWM14). Two geometries, shuttlecock and feather, were studied. In both cases the main body of the satellites is a 3U CubeSat.

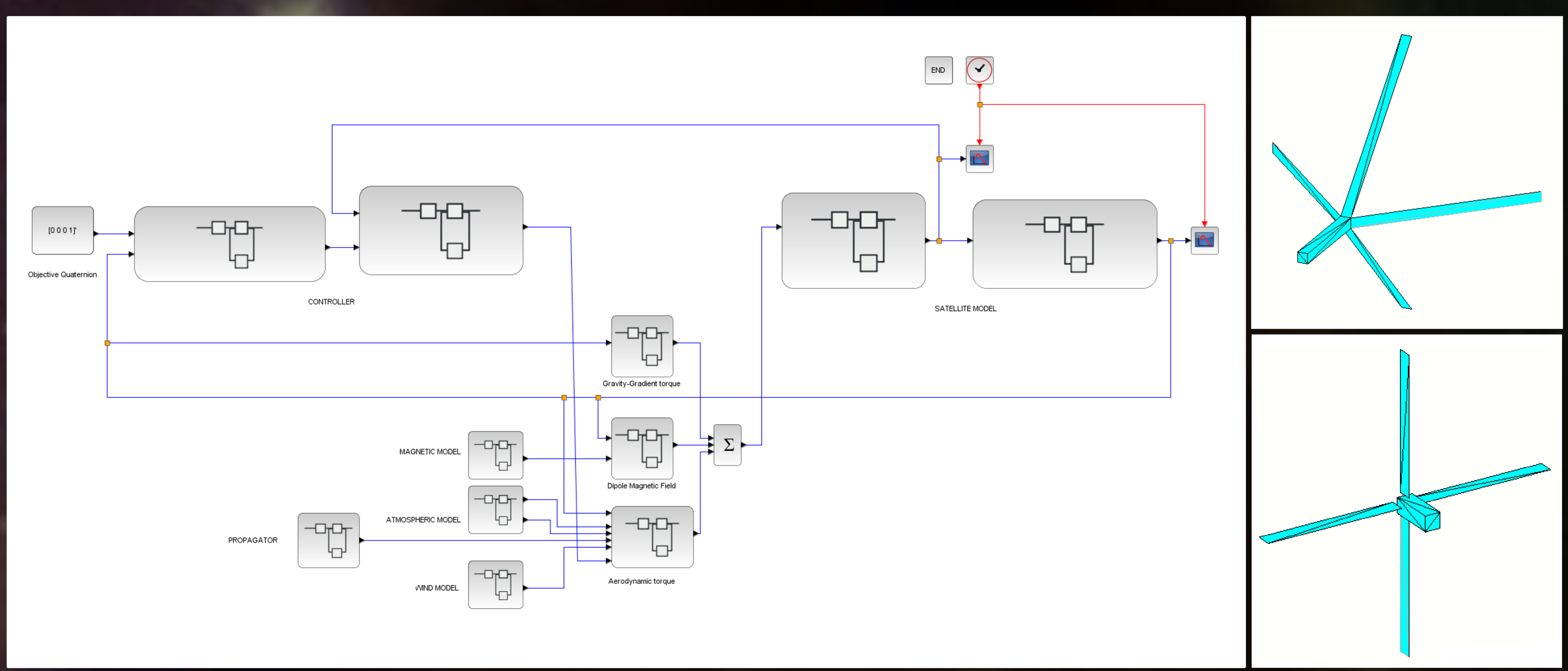


Figure 1: Xcos system model and geometries

Sentman's equations were used to model gas surface interactions (GSI). A panel method was implemented in order to calculate aerodynamic forces and torques. In order to perform the simulations of the manoeuvres analysed, stabilization and pointing, a PID (Proportional Integral Derivative) controller through a Jacobian formulation was selected.

3. Results

The attitude stability (Figure 2) was studied in three axes for feather configuration (left) and in two axes for shuttlecock configuration. The settling time was considered the moment when the difference between the signal and the reference is lower than one degree. For feather, mainly lift is used in the manoeuvres and the maximum manoeuvrability is reached in roll axis. For shuttlecock, drag is mainly used in the manoeuvres. The stabilization is faster than with the feather configuration. However, this configuration lacks roll controllability.

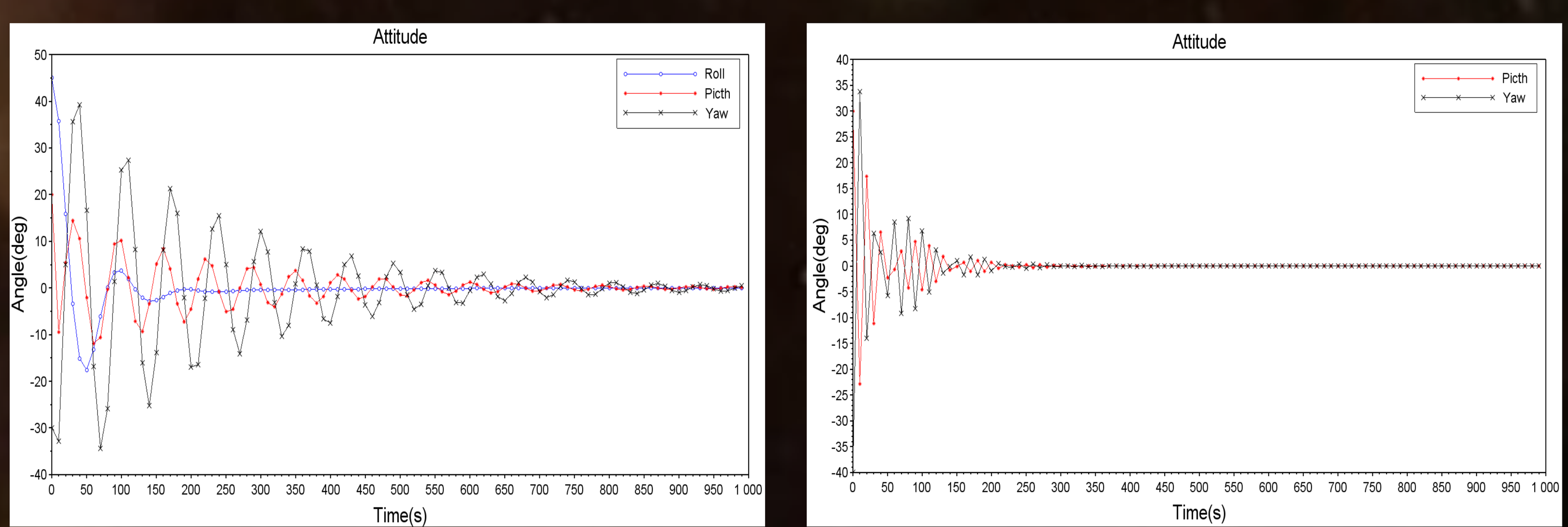


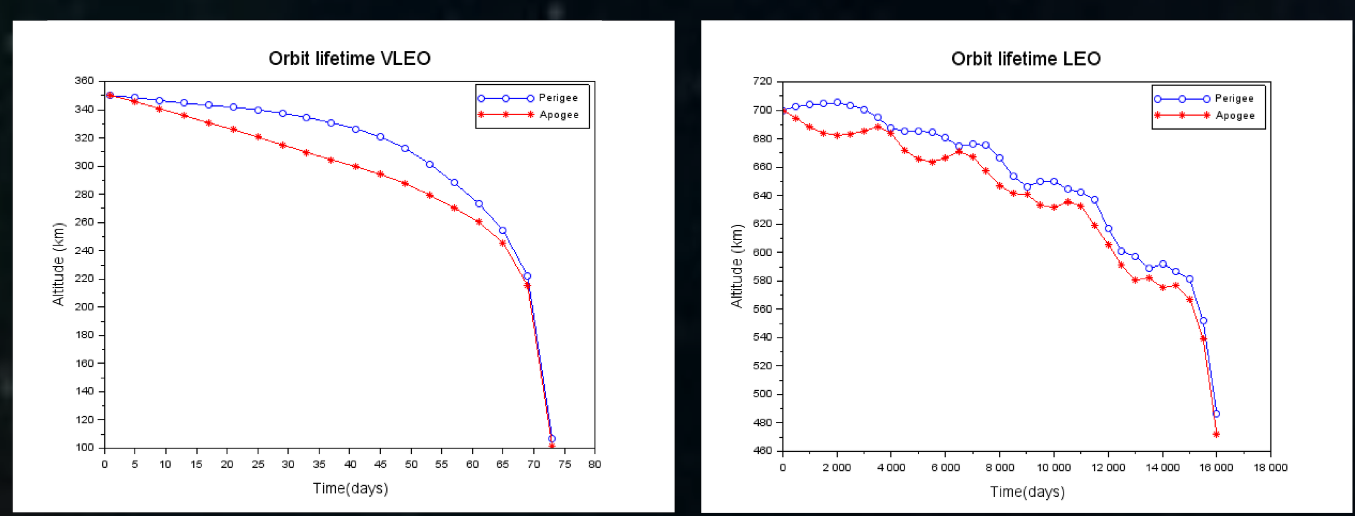
Figure 2: Attitude stabilization for feather (left) and shuttlecock (right)

Table 1 shows the comparison of the pointing manoeuver for both configurations, feather and shuttlecock with different pointing angles. The settling time was lower for the shuttlecock configuration but the overshoot was higher. The range of the pointing angles that can be achieved was lower in feather.

	Feather		Shuttlecock	
Pointing Angle	Settling Time	Overshoot(%)	Settling Time	Overshoot(%)
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	-	-	-	-

Table 1: Pointing manoeuver

Figure 3 shows the apogee and perigee altitude along the lifetime of the 1U satellite for LEO and VLEO respectively. No deorbiting manoeuvres were considered. The satellite re-enters after 40 years in the LEO scenario and 73 days in the case of the VLEO.



	LEO	VLEO
Altitude (km)	700	350
Inclination (degrees)	50	50
Arg. Perigee (degrees)	90	90
Mltan (h)	12	12
Eccentricity	0	0

Figure 3: Comparison of orbit lifetime in VLEO and LEO

Figure 4 depicts the time that different CubeSat configurations require to re-enter when flying at different altitudes. To establish the comparison, the mass to area ratio was considered. This is the relation between the frontal area of the satellite and its mass. All the satellites were considered to be flying with constant attitude, in which the frontal face was perpendicular to the tangential direction of the orbit..

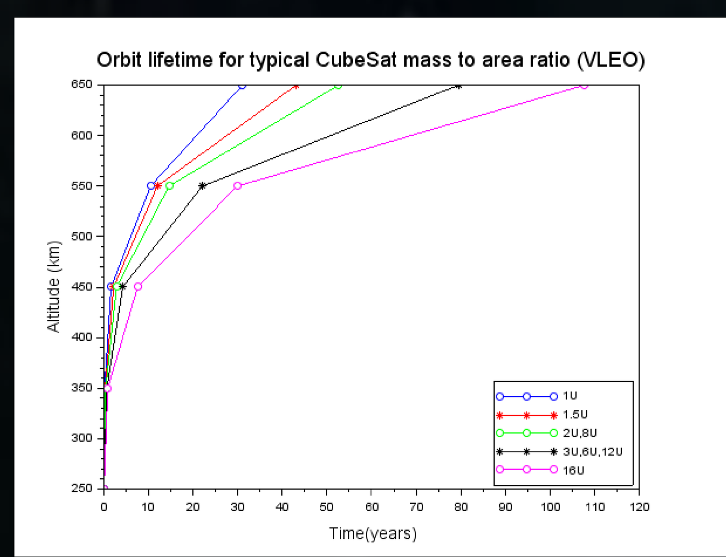


Figure 4: Orbit lifetime in VLEO (350 km) for several types of CubeSats

4. Conclusions

The results show the importance of the geometry to take advantage of the environment in VLEO orbits. Aerodynamic forces and torques can be used to carry out attitude control and stabilization maneuvers. Demisability was proved since the mass to area ratio of both Shuttlecock and Feather configurations is lower than in the case of a 3U CubeSat, being then the orbit lifetime less of 5 years in VLEO. As major result, aerodynamic stabilization and pointing maneuvers were demonstrated to be feasible on VLEO using controllable aerodynamic surfaces.

5. References

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