# Chaotic motion of 3U Cubesat with deployable side panels

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**Abstract.** The attitude motion of a small satellite with deployable side panels designed for passive aerodynamic stabilization in a rarefied atmosphere is considered. The influence of the aerodynamic and gravitational torques on the motion near the unstable and stable equilibrium positions at altitudes of 300–650 km is studied. The presence of the unstable equilibrium position and flexible elements is the cause of chaos. The equations of planar motion of the satellite with deployed flexible panels are obtained. A relationship between the satellite parameters is found, determining the range of altitudes in which the chaos is possible. The results of this paper can be used to assess the limits of applicability of passive aerodynamic stabilization for small satellites with deployable side panels.

## 1. Introduction

Currently, nanosatellites, such as Cubesats, are widely used in space flight missions. Cubesats come in different sizes, which are based on the standard unit — a 10 cm x 10 cm x 10 cm cube (1U). Popular sizes are the 1.5U, 2U, 3U, and 6U. There are a lot of science and technology applications of Cubesats [1], i.e. in Earth observation [2], astronomy [3], biology [4], etc. For most applications, stabilization of the satellite relative to the velocity vector is important. Some aspects of Cubesats dynamics and stabilization were studied by Timbai and Belokonov [5]. One way of stabilization is passive aerodynamic stabilization (PAS) using deployable side panels. When not in use, the panels lie against the sides of the satellite. After deployment, the panels stay fixed at some angle to the sides, as shown in Figure 1. Rawashdeh [6] has made a notable contribution to understanding this type of stabilization.

The stabilizing deployable side panels are inevitably flexible and, while the satellite oscillates under the action of the aerodynamic and gravity gradient torques, they also oscillate at different frequencies. When studying a spacecraft with flexible appendages [7–9], it is convenient to define the undisturbed motion, which is the attitude motion of the satellite without taking into account the oscillations of the flexible appendages. Then the motion of the satellite taking into account the flexible appendages can be considered as disturbed motion. If there are unstable equilibrium positions (saddle points) in the undisturbed motion, then the elastic oscillations of the panels can cause chaos in the disturbed motion. In this case, instead of stabilizing the attitude motion of the satellite, the side panels may destabilize it due to chaos. The possibilities and conditions of occurrence of chaos are studied in this paper.

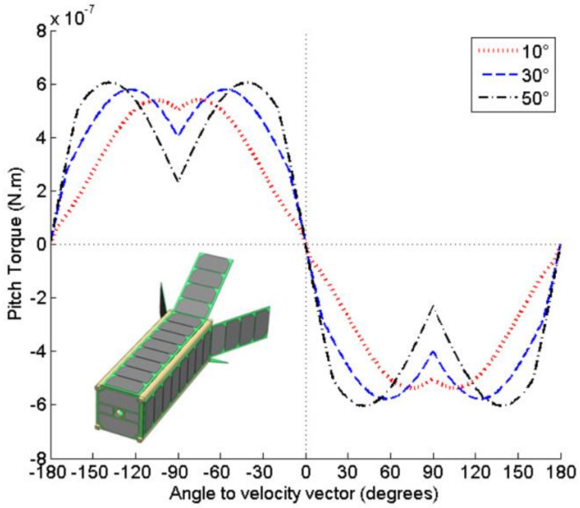


**Figure 1.** 3U Cubesat with deployable panels and its torque profiles at 400 km altitude [6].

In this paper, we impose the following assumptions:

1. The orbit of the satellite remains circular.
2. All motions take place in the orbital plane.
3. Center of mass of the satellite lies on its longitudinal axis.
4. The aerodynamic characteristics of the satellite do not depend on the oscillations of the panels and Mach number.
5. The aerodynamic damping is negligible.
6. Air density changes with altitude according to the US Standard Atmosphere 1976 [10].

## 2. Undisturbed motion

Since the aerodynamic and gravitational torques acting on the satellite depend only on its orientation, it is convenient to analyze its potential energy:

$$\Pi = -\int \left( M_{\mathrm{a}}(\theta) + M_{\mathrm{g}}(\theta) \right) d\theta, \tag{1}$$

where $\theta$ is the angle of attack, $M_{\mathrm{a}}$ is the aerodynamic restoring pitch torque,

$$M_{\mathrm{a}} = \frac{1}{2}\rho(h)V^2 AlC_{\mathrm{m}}(\theta), \tag{2}$$

$M_{\mathrm{g}}$ is the gravity gradient torque,

$$M_{\mathrm{g}} = 3\left(C - A\right)n(h)^2 \cos\theta \sin\theta, \tag{3}$$

$C_{\mathrm{m}}$ is the aerodynamic restoring pitch torque coefficient, $h$ is the altitude, $\rho$ is the air density, $V$ is the orbital velocity, $A$ and $l$ are the reference area and length, respectively, $n$ is the mean motion, $C$ and $A$ are transverse and longitudinal moments of inertia of the satellite, respectively.

The critical altitude $h^*$ above which the PAS becomes impossible can be found from the equation $\frac{\partial^2 \Pi}{\partial \theta^2} = 0$ with substitution $\theta = 0$. Figure 2 shows the potential energy of 3U Cubesat with the panels deployed at 10°. The inertial and aerodynamic characteristics of this satellite are taken from [6]. The critical altitude $h^*$ in this case is about 526 km.

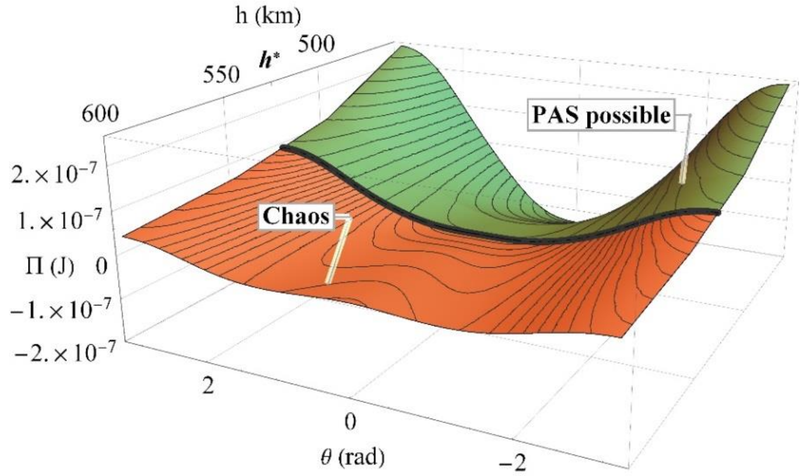


**Figure 2.** Potential energy of the undisturbed planar attitude motion of 3U Cubesat. Critical altitude $h^*$ gives the border (in black) of the region of possible chaos.

## 3. Disturbed motion

Following [7], the disturbed motion of the system can be described by the equations

$$a_\theta \ddot{\theta} + a_{\theta q}\left(\ddot{q}_1 + \ddot{q}_2\right) = M_{\mathrm{a}}(\theta) + M_{\mathrm{g}}(\theta), \tag{4}$$

$$a_{\theta q}\ddot{\theta} + a_q \ddot{q}_1 + c_q q_1 = 0, \tag{5}$$

$$a_{\theta q}\ddot{\theta} + a_q \ddot{q}_2 + c_q q_2 = 0, \tag{6}$$

where $q_1$ and $q_2$ are the generalized coordinates corresponding to the first mode of oscillations of the panels, $a_{\theta q}$, $a_q$, and $c_q$ are coefficients depending on material of the panels, inertial properties of the system, etc.

## 4. Conclusion

This paper considers the attitude motion of 3U Cubesat with deployable panels. It is shown that there is a critical altitude below which the passive aerodynamic stabilization of the satellite is possible. At the same time, at altitudes exceeding the critical one, there is a possibility of chaotic motion of the satellite due to small disturbances caused by elastic oscillations of the panels. The results of this paper can be used to analyze the applicability of passive aerodynamic stabilization for nanosatellites.

## 5. Acknowledgments

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