Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 53 (2014) 474–489

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Impact of the orbital eccentricity on the attitude performance before and after the deorbiting phase for Alsat-1

R. Roubache [a,b,*], M. Benyettou [b], A.M. Si Mohammed [a], A. Boudjemai [a], A. Bellar [a]

[a] Centre of Satellite Development, BP 4065 Ibn Rochd USTO, Oran, Algeria
[b] USTO-MB, Laboratoire de Modélisation et Simulation, BP 1505 El M'Nouar, Oran, Algeria

Received 17 June 2013; received in revised form 13 November 2013; accepted 15 November 2013
Available online 25 November 2013

Abstract

Due to the presence of periodic forcing terms in the gravity gradient torque, orbit eccentricity may produce large response for the roll, yaw and pitch angles. This paper investigates the influence of the orbit eccentricity on the performance of the attitude determination and control subsystem (ADCS) pointing of passive Low Earth Orbit (LEO) satellites stabilized by a gravity gradient boom or having long appendages before and after the deorbiting operation. The contribution of this work is twofold. First, the satellite attitude dynamics and kinematics are modeled by introducing the orbit eccentricity in the equations of motion of a LEO satellite in order to provide the best scenario in which satellite operators can keep the nominal functionality of LEO satellites with a gravity gradient boom after the deorbiting operation. Second, a Quaternion-based Extended Kalman Filter (EKF) is analyzed when the orbit eccentricity is considered in order to determine the influence of this disturbance on the convergence and stability of the filter. The simulations in this work are based on the true parameters of Alsat-1 which is a typical LEO satellite stabilized by a gravity gradient boom. The results show that the orbit eccentricity has a big influence on the pointing system accuracy causing micro-vibrations that affect the geocentric pointing particularly after the deorbiting phase. In this case, satellites have no orbital correction option. The Quaternion-based Extended Kalman Filter analyzed in this paper, achieved satisfactory results for eccentricity values less than 0.4 with respect to pointing system accuracy. However, singularities were observed for eccentricity values greater than 0.4.

Keywords: Spacecraft attitude dynamics; Kalman Filter; Gravity gradient torque; Eccentricity

1. Introduction

At the end of their lifetime, the non-operational satellites constitute a threat of collision with operational satellites thereby creating debris. These satellites might be re-orbited to an altitude where they will constitute no threat to other satellites, or be de-orbited and burned up in the atmosphere.

De-orbiting operation does not mean the end of the satellite operational life. Some satellites after the de-orbiting phase continue their missions in spite of the absence of the attitude and orbit control elements. This is the case of the Algerian satellite Alsat-1 which is an earth observation satellite launched on November 28, 2002 and de-orbited by early 2009.

In the last decades, many authors have investigated in the simulation of the attitude and control satellite subsystem, by considering the gravity gradient effect on a LEO satellite with an elliptic orbit and several cases have been intensively approached in the literature. However, the majority of the works considered in this area focused on a spacecraft with a special shape and mass properties.

* Corresponding author at: Centre of Satellite Development, BP 4065 Ibn Rochd USTO, Oran, Algeria. Tel.: +213 41620324; fax: +213 41620320.

E-mail addresses: rimaroubache@yahoo.fr (R. Roubache), Med_Benyettou@yahoo.fr (M. Benyettou), Arezki_s@yahoo.fr (A.M. Si Mohammed), a_boudjemai@yahoo.fr (A. Boudjemai), a_bellar@yahoo.fr (A. Bellar).

0273-1177/$36.00 © 2013 COSPAR. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.asr.2013.11.030

Roach (1968) referred to the failure of its implementation of three-axis gravity gradient stabilization on ATS-2 satellite due to improper modeling of the gravity gradient disturbance as well as the neglected orbit eccentricity factor. Frik (1970) investigated the stability of a rigid body satellite in a circular orbit in the presence of aerodynamic and gravitational torques when both have the same order of magnitude. Ravindran and Hughes (1972) performed active control analysis based on gravity gradient and aerodynamic torques assuming a circular orbit and no variation in the moment of inertia of the satellite. Shrivastava and Modi (1983) and Ashenberg and Lorenzini (1999) analyzed the effect of an elliptical orbit on the dynamics of the satellite and concluded that in the existence of an elliptical orbit, the system could experience periodic excitation in yaw, roll or pitch depending on the geometry of the spacecraft. Chen et al. (2000) combined the gravity gradient torque and the aerodynamic torque in order to reach three axes stabilization. Zanardi and Real (2003) made a comparison between the two satellites to show the effect of the gravity gradient, the solar radiation, the aerodynamic and magnetic torques at a specific altitude in a circular orbit and the cross product of moments of inertia were ignored. Alsaif and Al-dakkan (2005) have investigated the influence of the products of inertia magnitude and orbit eccentricity on the attitude response and the stability of a satellite (for a passive mode i.e., without actuators) due to gravity gradient moments.

The study presented in this paper investigates the influence of the orbit eccentricity on the performance of the attitude determination and control subsystem (ADCS) of a LEO micro-satellite stabilized by a gravity gradient boom, namely ALSAT-1 satellite, after the de-orbiting operation. In this situation, satellites are in front of a critical situation regarding the ADCS pointing performance and the satellite's nominal operation. The study focuses on a complete analysis of the performance of the ADCS subsystem and gives the different satellite orbital configuration cases and behavior in the presence of the orbit eccentricity in order to provide the best scenario in which the satellite operators can keep the nominal functionality of the satellite after the de-orbiting operation. In the case of high eccentricity orbits, the micro-satellites with a gravity gradient boom have orbital micro vibrations problems generated by the boom oscillations, which degrade the satellite mission until its failure. Furthermore, as part of the ADCS task, a Quaternion-based Extended Kalman Filter (EKF) is also analyzed when the orbit eccentricity is considered. The goal of this analysis is to determine when the EKF filter resists at this disturbance and maintaining the nominal performance of the mission, and on the other hand to understand at what stage the filter diverges or becomes unstable under a maximum stress with respect to the eccentricity value.

2. Alsat-1 satellite description

Alsat-1 (Algerian satellite) is an earth observation satellite with 90 kg mass launched by a COSMOS 3 M vehicle from the Plesetsk Cosmodrome in Russia on the 28th November 2002. The platform is measuring $640 \times 640 \times 680$ mm. The spacecraft is cubical in shape with four body-mounted panels, with the remaining sides including the spacecraft launch adaptor, sensors, payload apertures and antennas. It is placed at a 686 km altitude on a circular heliosychronous orbit inclined 98.2° to the equator at the beginning of the satellite life time. The micro-satellite is Nadir-pointing (see Fig. 1). These requirements specify several operating constants for the EKF.

The Alsat-1 attitude determination and control system uses a pitch momentum wheel and yaw reaction wheel, cold-gas thrusters, gravity gradient boom (6 m + 3 kg tip mass) and 3-axis magnetorquer rods. Two vector magnetometers and four dual axis sun sensors are carried to determine an attitude better than $\pm 0.25°$, but because of the wide swath of the prime instrument, the control is relaxed to $\pm 1°$ (Si Mohammed et al., 2009). Precise orbital knowledge is obtained using an antenna GPS receiver supported by an on-board orbit estimator. The Alsat-1 attitude determination and control system is shown in Fig. 2.

The existing ground station supports communications in S-band. It is implemented in the Centre of Space Techniques building, located in Arzew, west of Algeria. It includes a 3.7 m parabolic dish and radio equipments for receiving and transmitting the S-band signal (Bekhti and Sweeting, 2008). All the telemetry data of Alsat-1 satellite were down-

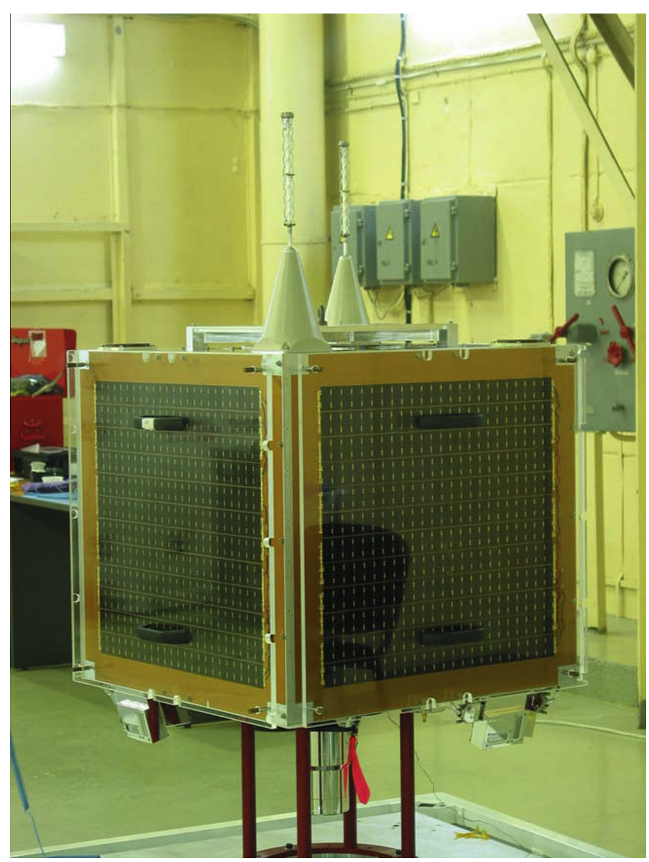

Fig. 1. Alsat-1 microsatellite.