Acta Astronautica 115 (2015) 121–137

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Review

Lessons learned from the dynamical behaviour of orbiting satellites

Jozef C. van der Ha

Satellite Mission Design and Operations, 5808 Bell Creek Road, Deming, WA 98244, USA

ARTICLE INFO

Article history:
Received 27 April 2015
Accepted 28 April 2015
Available online 9 May 2015

Keywords:
Flight dynamics
Free-molecular flow
Jet damping
Deep-space navigation

ABSTRACT

This paper contains the contents of the 20th John V. Breakwell Memorial Lecture delivered on October 1st, 2014, during the International Astronautical Congress in Toronto, Canada. The paper presents a few valuable and interesting lessons offered by unexpected dynamical performances of orbiting satellites. Sometimes, the observed dynamical behaviour appears to be 'anomalous', at least to an extent, when it does not conform to our a priori expectations. Subsequently, considerable effort is often required to properly understand that the observed behaviour is in fact perfectly natural from a dynamical point of view. The paper presents four examples from the author's background in the field of operational satellite flight dynamics. The first three events belong to the field of attitude dynamics of spin-stabilized satellites and the final case deals with the precise deep-space trajectory navigation of ESA's Rosetta satellite.

Contents

E-mail address: jvdha@aol.com

http://dx.doi.org/10.1016/j.actaastro.2015.04.020
0094-5765/

1. Introduction

John V. Breakwell (1917–1991)

This paper is dedicated to the memory of John V. Breakwell, whose ideas and enthusiasm inspired a generation of astrodynamicists. We are grateful to have had the good fortune to have known him [1–3].

The paper presents four examples of lessons learned from the in-orbit dynamical behaviour of satellites. The first three of these events belong to the field of attitude dynamics of spinning satellites and the last event deals with deep-space trajectory navigation.

The first event happened in May 1979 when ESA's spin-stabilized GEOS-1 satellite performed a 45-min orbit station-keeping manoeuvre [4]. Detailed simulations were carried out prior to the manoeuvre execution in order to verify the dynamical behaviour of the satellite's two flexible cable booms of 20-m lengths. Surprisingly, the simulation results predicted the complete de-spin within 10 min and, as a consequence, the loss of the satellite due to slackness of the cable booms. When examining these results with the help of dynamical models it became clear that the booms were *not* responsible for the mysterious de-spin. It was induced by the rate-coupling in the non-linear rigid-body Euler equations together with the relatively low spin rate of 11 rpm. Subsequently, two short trial manoeuvres were performed on the satellite, which confirmed that the predicted de-spin was real.

The second event happened on 18th December 1981, a few days after the launch of ESA's MARECS-A. During its geostationary transfer-orbit (GTO) phase, MARECS-A was spin-stabilized at a 65-rpm nominal spin rate. When checking the solar-aspect-angle measurements generated by the V-slit Sun sensor, unforeseen jumps in the Sun-aspect angle measurements of about 0.05° were observed around the three perigees [5]. No such jumps had been seen during previous ESA GTO's (e.g., GEOS and METEOSAT). Eventually, we confirmed [5,6] that these jumps were induced by free-molecular flow torques acting during the perigee passages.

The next event deals with NASA's CONTOUR satellite, which was lost during the firing of its solid rocket motor on 15th August 2002. This motor extended far into the satellite so that the lever arm of the jet-damping torque was relatively short. In addition, the variations in the satellite's mass properties during the rocket burn were relatively significant. Therefore, there was a suspicion that the anomaly could have been caused by stability issues during the burn. A representative practical jet-damping model was constructed [7]. This was based on the fundamental hypothesis that the angular momentum lost by the burning propellant must be equal to the momentum carried away by the combustion gases through the nozzle. Also, useful analytical models for the nutation induced by jet-damping and misalignment torques were established. Finally, it was confirmed [7] that the jet-damping torque was not responsible for the loss of CONTOUR.

The last event is relevant to planetary and comet-rendezvous missions, which require precise targeting based on the accurate non-gravitational modelling of the perturbing forces. Therefore, ESA uses high-fidelity models for the small forces induced by the solar radiation pressure acting on the satellite surfaces. Nevertheless, major discrepancies between the predicted and estimated forces were observed during the cruise phases of the Rosetta, Mars Express, and Venus Express satellites. Originally, these discrepancies were corrected by using scale factors for the acceleration components along the