Design and Analysis of a CubeSat

A Major Qualifying Project

Submitted By:

Robaire Galliath

Oliver Hasson

Andrew Montero

Chistopher Renfro

David Resmini

Submitted To:

Professor Michael A. Demetriou

Submitted to the Faculty of the Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science in Aerospace Engineering.

August 2019 - March 2020

Contents

List of Tables

List of Figures

Abstract

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Cras ac condimentum eros. Sed quis est eu ante ultrices rhoncus. Praesent a odio eget dolor hendrerit tincidunt. Proin ullamcorper lacus odio, nec dignissim enim hendrerit vitae. Quisque quis risus tellus. Sed sit amet lectus non massa accumsan malesuada. Aenean purus erat, fringilla id ante et, finibus vehicula ex. Sed a ex mi. Duis nec libero ex. Donec aliquam eu tortor quis sodales. Nulla vel urna vitae tellus accumsan bibendum ut quis purus. Sed at ipsum nibh. Fusce erat nulla, aliquet pretium tempor ut, facilisis non sem.

1 Introduction

The goal of this project is to design and conduct analysis of a 6U CubeSat on an extreme low earth orbit (eLEO) mission. The satellite will be carrying a mass spectrometer to conduct atmospheric observation. Following deployment from the ISS the satellite will enter a 250 - 600 kilometer orbit and maintain the orbit as long as possible. The overall project is composed of three separate MQP teams, each responsible for a different aspect of the satellite design and analysis. This portion of the overall project is focused on the attitude determination and control, orbital determination, and command subsystems of the satellite.

1.1 CubeSat Background

Cube satellites (CubeSats) are miniature satellites used for space research and technology development. They are a particular type of nano-satellite that was developed by the California Polytechnic State University and Stanford University in 1999 in order to promote the design, manufacture and testing of satellite technology in low earth orbit. Layouts vary but the most common types are 1U and 3U satellites. In Recent years, larger CubeSats have been developed to increase on-board technology capabilities. 6U and 12U CubeSats are becoming more frequent, but pose new challenges to designers. Typically, CubeSats under 3U are deployed by a Poly Picosatellite Orbital Deployer (PPOD). PPODs are attached to various launch vehicles and offer an easy way to deploy CubeSats into space. However, PPODs are only big enough to store 3U CubeSats. For satellites over that size, different deployment methods are necessary. For example, for CubeSats up to 6U, the Nanoracks CubeSat Deployer (NRCSD) is frequently used. NRCSD is a deployment mechanism from the International Space Station (ISS) off of the Japan Aerospace Exploration Agency (JAXA) Multi-Purpose Experiment Platform.

1.2 Educational and Social Impacts of CubeSats

The continual expansion and development of CubeSatellite opportunities has yielded a variety of positive social, economic and educational effects. Since CubeSats were first theorized and developed by CalPoly San-Luis Obispo, many universities and even high schools have started similar micro satellite programs as a result of their affordable cost, in addition to a flux of new commercial companies.

The CubeSat industry has already had a large impact on the space industry, which has seen a surge of space start-ups in the last five years. From 2000 to 2014, space startups received a sum total of $1.1 Billion in venture capital Investments. That number increased exponentially in the following 3 years, with more than 120 investors contributing $3.9 billion to space start-ups in 2017 ALONE! A majority of these start-ups reflect new technologies and abilities related to CubeSat Components, Development, or Launch and Integration. CubeSats have also created a shift from cost plus to fixed cost payments, which are less risky for the government or investors and maintains performance control of contractors.

One of the major benefits of CubeSats is their versatility. CubeSats themselves are a significantly cheaper method to test new technologies so that they can be developed further and flight tested before integration on larger missions. This is because of their low mass and thus low launch cost. Their smaller, modular size also simplifies development and testing, as many subsystem components are available off-the-shelf from different suppliers. Often CubeSat projects can be flight ready within one or two years. Many Universities and Institutions develop CubeSats with a specific payload in mind, including but not limited to remote sensors to communications modules.

In recent years, CubeSats have seen expanded use with the ISS as a result of the Japanese Experiment Module Small Satellite Orbital Deployer, and have even flown with missions to the moon and to Mars. The first commercial entity to utilize the ISS as a deployment option was NanoRacks LLC in 2013. With NASA and JAXA, NanoRacks developed and launched a deployer directly tied to the Japanese Experiment Module, allowing CubeSats to be checked by astronauts before deployment. This is a quick and efficient method of launching CubeSats into LEO. Between 2014 and 2017, NanoRacks deployed a total of 176 CubeSats from their deployer on the ISS, and plans to ramp up these numbers in the next few years.

The many advantages and developments of CubeSats has attracted more start up companies in recent years. As of 2018, 51% of CubeSats are developed by the private sector, showing CubeSats are no longer just for research by institutes and universities. The larger commercial flux has led to many impressive satellite technologies, including the first commercial optical communication downlink system (Analytical Space, Inc.) and the first CubeSat to employ a new hybrid (dual-purpose) antenna and solar power system. Technological developments can be found in a variety of topics, including and space physics, Earth Science and applications from space, planetary science, astronomy and astrophysics, and biological and physical sciences in space. From 2000 to 2015, the number of publications on Cubesats has risen to 536 publications total outlining the many advances made.

Expansion and promotion of CubeSat use has also helped NASA and the ESA collaborate with interested schools and students to further promote the benefits of the space industry. CubeSats inspire students from many levels of education to pursue STEM fields and take part in an innovative and exciting new part of the space sector. These programs teach students about the many components in a CubeSat as well as the many fields of knowledge needed, organizational skills and communication necessary to efficiently design and build a CubeSat.

CubeSats have both positive and negative societal implications. Examining their effects on society is an important consideration for every mission. CubeSats serve as a strong educational tool that can help to teach young students about the aerospace industry. Due to the simplicity of CubeSats (relative to other technology in the industry), middle and high school aged students can design, develop and build model CubeSats using cheap over the counter components. NASA has offered numerous programs to help fund these sorts of endeavors. Similarly, they also offer a program where students can submit a formal proposal detailing their intended mission. If NASA deems the mission useful to their research, they will allow that CubeSat to be launched on a PPod during an upcoming mission.

While CubeSats provide students with an innovative way to learn more about engineering, they also add on to the growing space debris problem. Currently, CubeSats make up a significant portion of space debris and have moderate failure rates, meaning there is a higher possibility of a CubeSat immediately becoming debris than any other space technology. Figure 1 illustrates the percentage of successful CubeSat launches from 2005 to 2018. Collisions between functioning satellites and debris can ruin missions. The international Space Station is particularly at risk due to its size and similar orbital location to many CubeSats.

1.3 Project Constraints

1.4 Motivation

2 Attitude Determination and Control

2.1 Subsystem Overview

The purpose of the attitude determination and control subsystem (ADCS) is to properly position and orient the spacecraft within the given mission parameters. In order to effectively control the spacecraft, a variety of on-board sensors and actuators are used. Actuator performance is governed by control laws that are derived to meet specific requirements using onboard sensor readings.

2.2 Pointing Requirements

The satellite must be capable of pointing within plus or minus five degrees of its velocity vector. Angular deviations greater than five degrees risk atmospheric drag inducing a torque that is too great for the on board actuators to overcome. Equation 1 describes the torque experienced by the satellite.

$$T_d = \frac{1}{2}\rho A C_D V_{rel}^2 (c_p - c_g) \tag{1}$$

Relative velocity, V_{rel}, is a function of the orbital velocity and the pointing angle of the spacecraft. As the relative velocity increases, it is evident that the torque increases as well.

2.3 Sensor and Actuator Selection

The components selected for the attitude determination and control subsystem have specific placement, power, and temperature requirements. If these requirements are not met the components within the ADCS will not work effectively and the satellite risks losing control of its attitude.

2.3.1 Magnetorquer Selection

3 References