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Mit castor satellite: Design, implementation, and testing of the communication system ☆

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ABSTRACT

Cathode Anode Satellite Thruster for Orbital Reposition (CASTOR) is an orbital manoeuvre and transfer micro-satellite bus developed at MIT Space System Laboratory. The technical objective of the mission is achieving 1 km/s of delta-V over a 1 year mission in Low Earth Orbit (LEO). This will be accomplished using a novel electric propulsion system, the Diverging Cusped Field Thruster (DCFT), which enables high efficiency orbital changes of the ESPA-ring class satellite. CASTOR is capable of improving rapid access to space capabilities by providing an orbital transfer platform with a very high performance to mass ratio, thus greatly reducing launch costs and allowing for highly efficient orbital manoeuvre. Furthermore, CASTOR is highly scalable and modular, allowing it to be adapted to a wide range of scales and applications. CASTOR is developed as part of the University Nanosatellite Program (UNP) funded by Air Force Research Laboratory (AFRL).

In order to accomplish CASTOR mission objective, a highly optimized, scalable, light weight, and low cost communication system needed to be developed. These constraints imply the development of trade studies to select the final communication system architecture able to maximize the amount of data transmitted, while guaranteeing reliability, redundancy and limited mass, power consumption, and cost. A special attention is also required to guarantee a reliable communication system in cases of tumbling, or in case of strong Doppler shift which is inevitable due to the high delta-V capabilities of the vehicle. In order to accomplish all the mission requirements, different features have been introduced in the design of the communication system for this mission. Specifically, customized patch antennas have been realized, and a customized communication protocol has been designed and implemented. The communication subsystem has been validated through an intense testing campaign which included software tests in the laboratory, hardware tests in anechoic chamber, and in flight tests through a balloon experiment.

The article presents an overview of CASTOR mission, a presentation of the trade studies analysis and of the final communication architecture selected, a description of the customized antenna developed, of the customized protocol designed, and a presentation of the results of the tests performed.

1. Introduction

Cathode Anode Satellite Thruster for Orbital Reposition (CASTOR) is an orbital manoeuvre and transfer micro-

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satellite bus developed at MIT Space System Laboratory. The technical objective of the mission is achieving 1 km/s of delta-V over a 1 year mission in Low Earth Orbit (LEO). This will be accomplished using a novel electric propulsion system the Diverging Cusped Field Thruster (DCFT), which enables high efficiency orbital changes of the ESPA-ring class satellite. The DCFT is a customized engine developed at MIT Space Propulsion Laboratory, and it will be the primary payload for the mission. Due to this novel propulsion system, CASTOR is capable of improving rapid access to space capabilities by providing an orbital transfer platform with a very high performance to mass ratio, thus greatly reducing launch costs and allowing for highly efficient orbital manoeuvre. Future missions that aim to achieve rapid orbital transfer capabilities will take great advantage from this technology. Furthermore, CASTOR is highly scalable and modular, allowing it to be adapted to a wide range of scales and applications. This mission is in fact the first of a series of missions. When the capabilities of the thrusters will be demonstrated in orbit, upgraded versions of CASTOR will be launched carrying different scientific experiments.

CASTOR has been developed entirely at MIT during two cycles of a three terms capstone class in which students learn thorough hands-on experience how to design and build a space vehicle. This class is part of the CDIO project which is focused on: '*helping MIT's undergraduate engineering students to develop the skills, tools, and character they will need as future leaders in the world of engineering practice*' [1].

CASTOR has also been part of the sixth University Nanosatellite Program (UNP) Competition [2]. This competition is funded by Air Force Research Laboratory (AFRL), with the goal of increasing the development of students' built space missions.

In order to accomplish CASTOR mission objective, a highly optimized, scalable, light weight, and low cost communication system needs to be developed. These constraints imply the development of trade studies to select the final communication system architecture able to maximize the amount of data transmitted, while guaranteeing reliability, redundancy and limited mass, power consumption, and cost.

Specifically, coverage and feasibility study have been realized to prove the capability of the system of transmitting all the science data required to accomplish the mission. Also, great emphasis has been given to system redundancy. The current design is fully redundant: three antennas and two transceivers provide a completely reliable system while guaranteeing a complete coverage of the spacecraft. A special attention has been given to guarantee a reliable communication system in cases of tumbling, or in case of the strong Doppler shift which is inevitable due to the high delta-V capabilities of the vehicle. To reduce cost, the system has been realized exclusively with custom made or COTS products.

Moreover, in order to accomplish all the mission requirements, different features have been introduced in the design of the communication system for this mission. Specifically, customized patch antennas have been realized, and a customized communication protocol has been designed and implemented.

In terms of space heritage, our system shares some similarities with previous university projects. Specifically, our transceiver (MHX2420) has been already successfully tested in different space missions (Genesat [3], Pharmasat), even at high data rate (MAST [4]). These missions proved the high reliability of this transceiver. Consequently, we selected it as well as other missions currently under development (Oculus [5], Yusend [6], Hermes [7]).

For the antenna's design, different university projects are currently developing customized antenna (helicoidally [8] or patch [9]). Our design is similar in the methodology followed in [9], but it is highly optimized for our mission.

Current protocol development efforts in small satellite mission include the work done by CanX-2 [10] mission with the new NSP (nanosatellite protocol), a customized version of DLC. Differently, our customized protocol is focused on transport level (the first layers are standardized through 802.11g standard), and it provides the efficient feature of a different ARQ mechanism in function of the type of packet sent.

The communication subsystem described in this article has been validated through an intense testing campaign which included software tests in the laboratory, hardware tests in anechoic chamber, and in flight tests through a balloon experiment. The communication system has also been successfully integrated with avionics, power and propulsion, and it is ready to be tested in orbit when the satellite will be launched. The launch date of the satellite has not yet been selected: the team is pursuing different launch opportunities for the next few years.

The article presents an overview of the communication system, and it is organized as follows: first an overview of the mission is given, than the communication system design is presented, hardware components are described, and the software developed is presented. Finally tests' results are discussed.

2. Mission overview

The mission of CASTOR is to characterize the on-orbit performance of the DCFT. This characterization will be accomplished using a broad spectrum of analysis techniques. The primary traits of the DCFT to be characterized are its thrust produced, efficiency, and operational lifetime.

The CASTOR satellite (Fig. 1) has a volume constraint of $50\ cm \times 50\ cm \times 60\ cm$, which greatly limits the maximum power it can generate with solar panels. This limitation leads to constraints in the amount of time the thruster can be operated. To maintain power positive operations and maximize the frequency and duration of the DCFT's operation, the orbit was divided into the following segments: eclipse, charge batteries, and fire thruster. These orbital segments can be seen in Fig. 2. The optimum time for firing the thruster was determined to be approximately 10 min, which equates to a firing angle of 20°. It was chosen to operate the thruster around orbital noon because during this time the most power can be generated by the body fixed solar panels while the spacecraft follows the velocity vector.