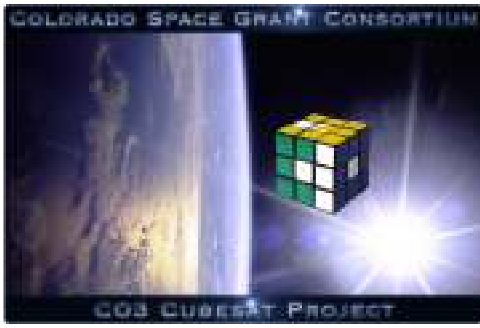

CO^{3} Hermes CubeSat FCC Experimental License Application Narrative

SYS116.00

Revision	Date	Authored By	Description
Initial Release	3-2-2008	Philip Zanin Holtzman	Additional Information for FCC Experimental Application

Approvals

Systems Engineer: Philip Holtzman Date: 3/2/2008

Philip.holtzman@colorado.edu Aerospace Engineering 720-427-5456

Lee Jasper

Project Manager: Lee Jasper Date: 3/2/2008

Lee.jasper@colorado.edu Aerospace Engineering 303-204-1156

1.1 *Introduction*

The following is included as an overview of the Hermes CubeSat project and gives some technical details about the different aspects of the satellite. The most important sections for this discussion are the "Mission Objectives" which outline the importance of this project to the CubeSat community and beyond. The "Justification for Application" section explains why an Experimental License from the FCC is necessary for this project and the first subsection of the "Subsystem Synopsis" section details more about the two onboard communications systems.

1.2 *CubeSat overview*

The Colorado Space Grant Consortium, in affiliation with the University of Colorado at Boulder, is currently developing a single-unit (1U) CubeSat named Hermes. It follows the dimension and mass requirements as outlined by California Polytechnic Institute in the CubeSat Design Specification (Rev. 10). Hermes will be the University of Colorado's first fully developed CubeSat.

Outlined in more detail below, the mission goals and objectives of the Hermes project are the creation of an extensible bus capable of supporting future missions and payloads, the on-orbit testing and verification of a high-speed communication system, the collection and characterization of external and internal environmental data, and the provision of hands-on engineering experience to undergraduate students.

The estimated satellite hardware cost is US$10,600. This includes the expense of the physical hardware as well as hardware development and testing costs. Launch costs and labor costs are provided from other sources are not accounted for in the US$10,600 budget for the project. As a result of the limited budget for the project, a large emphasis has been placed on the utilization of common off-the-shelf (COTS) components. While not designed for space applications, COTS components offer significant monetary savings and if implemented properly, can function successfully in spacecraft.

Hermes has passed the Critical Design Review phase and the team is finishing development of flight hardware. Individual subsystem testing is well under way and intersystem FlatSat testing has begun on many fronts. The completion date of the project is set at May 1st, 2008, at which point the satellite will be ready for delivery to the launch provider.

After analyzing possible launch opportunities, the following mission parameters were chosen as the optimal flight conditions. Hermes is designed for a nearly circular, 680km orbit with an inclination of 98 degrees; these orbital conditions are based upon the launch profile of the Dnepr rocket from ISC Kosmotros. Hermes is capable of operating at any altitude from 400km to 800km and virtually any inclination greater than 40 degrees.

1.3 *Specific Mission Objectives*

From a program perspective, the most important mission goal for Hermes is the development and successful implementation of an easily extensible satellite bus that will be used on future CubeSat missions. This means that not only will the design succeed for this mission, but that it can easily be modified for larger or slightly different applications for future missions. This will allow future projects to focus on more complex scientific endeavors without having to reengineer many of the subsystems.

The second mission goal is the implementation and characterization of a high data-rate CubeSat-scale communication system. This communication system operates at 2.4GHz in the S-band frequencies and has been estimated to produce about 50 times the data rate of many traditional UHF/VHF communications systems. The intent is to demonstrate that this system is capable of replacing a standard UHF/VHF system on a CubeSat, providing higher data rates and allowing more mass, volume, and power for science missions. A handful of other universities are utilizing the same system in their satellites and knowledge gained from the Hermes mission will be shared openly with the CubeSat and small satellite communities.

A third mission goal is the collection of environmental and system performance data. This is accomplished through the use of a 3-axis magnetometer for the measurement of the Earth's magnetic field, temperature sensors throughout the satellite for measuring the effectiveness of the thermal system, and current sensors within the power system for characterizing power system efficiencies and solar input power.

Finally, as with any student-run university program, this project has a large emphasis on education. The project has been managed and developed by undergraduate engineering students from multiple engineering disciplines including computer science, electrical, electrical and computer, mechanical, and aerospace. Supervision is provided by faculty advisors, both within and outside of Space Grant, as well as industry mentors. It is the intent of Space Grant to continue this type of project dynamic where students are in charge of their project and seek outside help when necessary.

1.4 *Data Collection and Purpose*

In support of the third mission goal specified above, Hermes will be carrying a suite of sensors to record the environment of low-earth orbital flight. Current and voltage sensors will monitor and record the input power into the satellite via the solar panels. Other voltage and current sensors will be located throughout the satellite's power distribution system to monitor the efficiencies of the power subsystem from collection to distribution. These sensors will also show the degradation of the solar panels from beginning of life to end of life and help characterize what to expect from solar cells in on-orbit conditions.

Magnetometer readings will also be taken to determine the spacecraft attitude relative to the earth's magnetic field. Thermal data will be collected through temperature sensors distributed throughout the satellite to validate the spacecraft's thermal design and verify that temperatures remain within specified temperature ranges. S-Band (HSCOM) and UHF (PCOM) communication system performance data will be collected through analysis on the ground of communication passes and the onboard storage of some status data such as dropped packet frequency.

Once the data has been collected and down linked to the ground station at Boulder, the data will be analyzed and used in various ways. The magnetometer data will be used to model the satellite's attitude and response to torques in orbit. This will help verify the passive attitude control subsystem's performance. The temperature data collected will be used to verify the thermal model used for the satellite as well as validate the thermal system.

Sensor data is also used in real-time to autonomously monitor the system performance and take emergency action in case of off-nominal behavior. One example of this scenario is if the Command and Data Handling system detects a current surge on a sensor, it can immediately shut down that part of the circuit to prevent permanent damage to the spacecraft.

The data collected on this mission will be made publicly available in accordance with amateur radio regulations. All data and analysis will be reported on the Space Grant CubeSat's website (http://spacegrant.colorado.edu/co3sat/) and will be provided to the CubeSat community.

1.5 *Justification for Application*

For the S-band communications system to operate, a link margin of 10 dB is required as specified by the manufacturer of the MHX 2400 modem. In order to obtain this amount of link margin, it is necessary to both transmit at 1W on both the satellite and ground station sides of the link, as well as use a high-gain antenna on the ground. With a 1W output, any dish gain of 6 dB or greater puts the Effective Isotropic Radiated Power (EIRP) at over 36 dBi, violating FCC regulations, and thus necessitating an Experimental Application. With the 18 meter parabolic dish ground station antenna reported on this form, the system will have a sufficient link margin in order to sustain communications. The use of such a large dish also helps alleviate concerns about the fidelity of the Attitude Control System which are detailed in the appropriate subsystem section below. A secondary ground station with a 10 meter parabolic dish is also currently being investigated but no formal commitments have been made.

1.6 *Subsystem Synopsis*

CO^3 Hermes: Communications

The primary communications (PCOM) system, operating with the AX.25 protocol at 435MHz in the UHF frequency range, uses a COTS Yaesu VX-3R transceiver and an Atmega AVR microcontroller based terminal node controller (TNC) developed in-house. Frequency coordination with the International Amateur Radio Union (IARU) was obtained in July of 2007, securing a specific frequency for Hermes use. Due to the importance of the TNC for mission success, redundant microcontrollers are used for its implementation. Each has the ability to do packet formation, error checking, and packet decoding independently and CDH has the ability, through discrete FETs, to switch the active TNC if one appears to have failed. To comply with FCC regulations against interfering transmissions, the system will pause occasionally during any communications in order to receive a shutdown command from a ground station.

The High Speed communications (HSCOM) system, operating in the S-band frequency range at 2.4GHz, utilizes the MicroHard MHX2400 modem. One modem will be onboard the satellite and an identical modem will be a part of the ground station. The MHX2400 utilizes frequency-hopping to achieve data transmission rates over 50kbaud.

Both communications subsystems have deployable, quarter wave monopole antennas and transmit at 1 Watt of power.

Space Grant has developed a Ground Tracking station with two Yagi antennas at the University of Colorado for UHF and VHF systems. A separate team is currently working on verifying the tracking abilities of the ground station to ensure its accuracy and precision.

The PCOM system is currently undergoing full-scale testing of the TNC. The transceiver is in the first stage of a "stripping down" process that aims to remove all excess components to minimize power draw and mass. Extensive antenna modeling has been done and antenna testing will commence in the near future.

The HSCOM system has undergone extensive antenna modeling as well as preliminary antenna testing. The modem has flown twice on high altitude balloon missions with encouraging results, leading to a good understanding of the operation modes of the modem.

A ground software team is also currently at work to ensure the success of the ground station and data flow from satellite to usable format on the ground. For example, one focus of ground software is the creation of the software required for the attitude determination algorithm with magnetometer and solar panel current sensor data.

CO3 Hermes: Attitude Determination and Control (ADC)

The ADC subsystem on Hermes is a passive system using a permanent magnet and hysteresis rods to align the satellite properly during communication passes. The control component of this subsystem is currently behind schedule due to staffing issues but steps are being taken to accelerate the development to meet the May 1st, 2008, deadline. Currently, a Simulink model is in the final stages of completion, at which point sizing can be done for both the magnet and the hysteresis rods.

The determination component of this subsystem is implemented with a Honeywell HMC2003 three-axis magnetometer. This sensor will be used, along with current sensor data from the solar panels, to determine the attitude of the satellite and validate both the system design and the accuracy of the Simulink model.

CO^3 Hermes: Command, Data Acquisition and Data Handling (CDH)

The CDH system uses a Microchip PIC24HJ256GP610 microcontroller as the onboard command center with COTS SD cards for data storage. This system has the capability to toggle power to the other subsystems through discrete field effect transistors (FETs) to limit power consumption. Toggling power will also be utilized in the event of a temporary subsystem failure or latch-up. CDH has the ability to reprogram the majority of its code space, allowing for recovery from radiation induced bit flips and other events. The onboard watchdog timer is also enabled in the interest of preventing radiation induced failures.

This subsystem is responsible for organizing, storing, and eventually transferring sensor and status data to the communication systems for downlink.

The system also includes three real time clocks (RTCs) in order to maintain accurate time onboard the satellite. A backup battery is included with the RTCs in order to maintain time accuracy even during a full system power down. Due to power concerns, the satellite is not capable of being in communications receive mode for the entirety of its orbit and needs to keep track of time accurately in order to enable communications receiving at the correct time.

The CDH system is currently entering its third FlatSat revision and flight layouts for printed circuit boards (PCBs) have begun.

CO^3 Hermes: Flight Software

The flight software will be executed on the PIC microcontroller and handle all data handling, system tasks and modes, timing, power distribution and software error checking. The SalvoPRO Real Time Operating System (RTOS), kindly donated by Andrew Kalman and Pumpkin, Inc, is used to simplify code development and takes care of many low-level tasks.

Copies of all flight code are stored in various locations on the systems SD cards. A voting algorithm is implemented to frequently read the stored data, vote amongst it to find the accurate version, and compare it with the code stored on the PICs internal flash memory. If there is a discrepancy, the PIC will reprogram its internal flash to match the accurate copy and prevent a build-up of radiation induced errors. A small sector of the PIC containing the boot loader and reprogramming code is not able to be reprogrammed and therefore is a single-point of failure for the system. The flight software will also have the ability to read the code space of the AVR microcontrollers that comprise the TNC and reprogram them if necessary.

Flight software, despite its late development start, underwent over a month of design process prior to writing a single line of flight code. A subsystem review occurred in November 2007 in the presence of Computer Science and Aerospace faculty and the system passed with only a few concerns. The majority of flight code has been written and is undergoing extensive testing at this time.

CO^3 Hermes: Electrical Power System (EPS)

The Hermes power system is a revolutionary design that fully manages the input power from solar panels, through battery charging, to distribution to the subsystems. The input power first enters parallel boost converters to raise the voltage to 10V, enters the charger manager which interfaces with the Lithium-Ion battery protection and monitoring circuitry as well as the main power bus which interfaces to each of the subsystem buck converters. The charger manager communicates with CDH via the SMBus protocol (similar to I2C) and the CDH system has discrete FET control of each of the buck converters for power regulation. The solar panels are comprised of Boeing SpectroLab TASC triangular solar cells with an efficiency of 27 ± 3%.

The charger manager is another single point of failure for the mission. Investigation was made into a redundant charger manager setup but it appears to be infeasible in the time frame remaining.

The power subsystem is currently undergoing functionality verification and debugging. Some interfacing with CDH has been accomplished but further testing is needed of that interface. Concurrently, flight component layouts are underway as well as solar cell testing and initial solar panel fabrication.

CO^3 Hermes: Structures

The Hermes structure is constructed of Aluminum 6061, has an approximate mass of 275 grams, and has undergone finite element method (FEM) modeling to verify its strength and behavior. It will support the PCOM and HSCOM antennae and mounting systems, as well as solar panels on each side of the structure. The internal components will be mounted using a tiered shelving system where all components are mounted to universal, four point supports close to the corners of the cube. Two of the six cube panels will be anodized to avoid electrical conductivity and cold welding with the launch apparatus (CalPoly P-POD).

The structures subsystem is finishing final component placements and preparing for the first round of vibration testing. Antenna deployment details will be finalized shortly.

CO^3 Hermes: Thermal

From the results of thermal modeling, the thermal system contains no dedicated heating or radiating elements. As the thermal model is verified further, small steps may need to be taken to maintain the temperature within specified ranges. This will be accomplished through the use of thermal paints and possibly internal conductive paths. In a worst case “freeze” scenario, the flight software will interpret temperature sensor readings and use the radio’s gross inefficiencies as an impromptu heat source. Care will be taken to ensure that useful data is transmitted during these times so as to comply with FCC regulations.

CO^3 Hermes: Mission Operations (MOPS)

In contrast to many satellite development schedules, the Hermes MOPS team has been a part of the project since its inception in Summer 2006. MOPS is responsible for all orbit calculations, data transfer requirements, command definitions, and a myriad of other tasks.

The MOPS team is currently focusing on functional failure modes effects and analyses (FFMEAs) with the ultimate goal being a fully comprehensive failure tree that outlines all possible failure modes of the satellite.

CO^3 Hermes: Systems

On an inter-subsystem level, the Electrical Connection Interface Agreement (ECIA) document is complete and locked down and a similar structural interface document is currently being finalized and will be locked-down in the near future. The wiring harness system has undergone a preliminary layout but is not yet complete. Likewise, the ground support equipment (GSE) interface is defined but has not yet been implemented or tested. More analysis needs to be done on the possibility of static charging and discharging due to charged particles in the upper atmosphere and its effect on the satellite. Also, detailed test plans have not been fully drafted or finalized, a responsibility that will fall to both MOPS and Systems.