Evolution of the CubeSat Program at the University of North Dakota

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Background

Within the past several years, the University of North Dakota (UND) School of Engineering & Mines (SEM) has been developing a focus on spacecraft design, particularly in the area of sensor data acquisition. The school has been collaborating with the Upper Midwest Aerospace Consortium (UMAC), also headquartered at UND, in taking an incremental approach towards reaching its goal of launching an Earth-observing, remote sensing satellite by the end of the decade.

Undergraduate and graduate engineering students at UND have already built and launched three spacecrafts via weather balloons, and they are currently involved in several more-advanced remote sensing development efforts. The first of two spacecraft projects in a series known as “Scorpio” was completed during the summer of 2000, in which seven undergraduate students built a remote sensing payload that was suspended from a moored weather balloon. This payload was able to collect and transmit real-time health and atmospheric data. The second Scorpio payload, built during the 2000-2001 academic year, was launched using a free-flying weather balloon. This payload was again able to downlink health and environmental data in real time, with the significant addition of transmitting a picture taken by an on-board digital camera. The

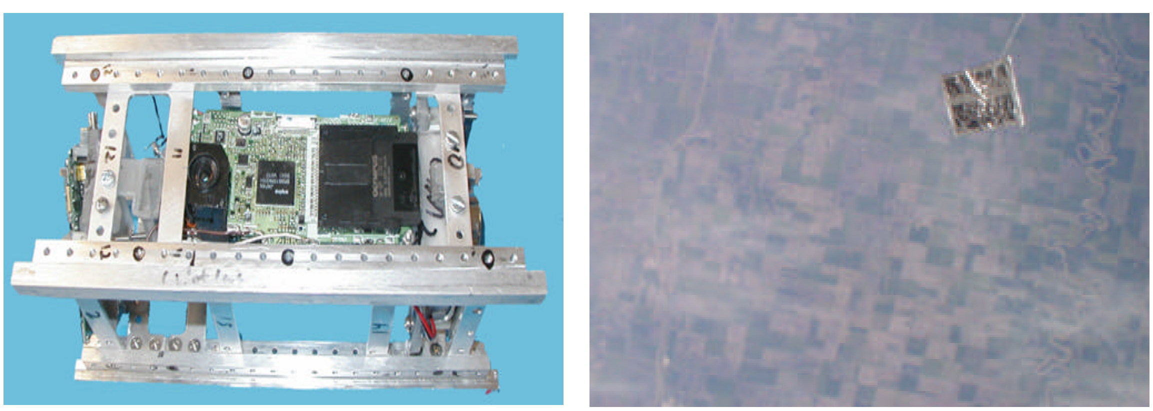

Figure 1: *ZAMBONI airborne unit and in-flight digital picture at 96,400 ft.*

third spacecraft, the Zippy Aerospace Module Broadcasting Observed Not-so-bad Images (ZAMBONI), was based on a double-size CubeSat developed during the 2002-2003 academic year. This payload was successful in acquiring digital images and transmitting them over amateur radio frequencies in real-time. ZAMBONI was launched twice using a free-flying weather balloon in the spring and summer of 2003. These projects are evidence of the growing systems engineering capability within UND SEM Engineering, necessary for the design of small satellites. Figure 1 shows ZAMBONI in its balloon testing enclosure, along with a digital picture captured during the June 2003 flight [1].

Undergraduate and graduate students within the UND SEM are currently involved in three remote sensing projects, which will result in professional-grade instruments:

1.) The Student Tracked Atmospheric Research Satellites (Starshine) project, initiated by the United States Naval Research Laboratory (USNRL), gives middle-school, high-school, and college students an opportunity to assist in the construction of an orbiting satellite and to receive telemetry data.

2.) The Airborne Environmental Research Observational Camera (AEROCam) project, operated with UND SEM, UMAC, and the John D. Odegard School of Aerospace Sciences at UND, is a four-band, multi-spectral digital imaging system which is installed and operated in a Piper Arrow single-engine aircraft.

3.) The Agricultural Camera (AgCam) project, a joint venture between UND SEM and UMAC, is a two-band multi-spectral digital imaging system that will be mounted inside the pressurized International Space Station's Window Observational Research Facility (WORF). It is anticipated that AgCam will be shipped to NASA in early 2004 for a launch on the Space Shuttle.

These systems engineering projects have been extremely educational for both students and the faculty. In order to build a professional-quality remote sensing instrument, expertise is required from many disciplines, especially electrical and mechanical engineering. To date, all projects have involved students and faculty from UND Electrical and Mechanical Engineering, with assistance from students majoring in Computer Science, Space Studies, and Business Administration [3]. As a National Science Foundation Research Experiences for Undergraduates (REU) site, UND has been able to bring students in from around the country to work on these aerospace projects.

<u>Ongoing Work</u>

UND has a goal of launching and operating its own orbiting remote-sensing satellite by the end of this decade. However, the university needs to start with a relatively low-risk and inexpensive orbiting spacecraft. The UND CubeSat Project fills this gap in the evolution from airborne to space-borne remote sensing. CubeSat To Accept Any Payload (CTAAP) is the second iteration of UND's CubeSat Project. It will contain many similar components as a commercial satellite, but it will be developed at a much lower cost (under $10,000) and with a significantly lower risk than its more expensive counterparts. If mission failure occurs, the loss will not be as substantial due to the smaller initial investment. The CTAAP and ZAMBONI projects represent a significant step in the growth of spacecraft systems engineering at the University of North Dakota.

Mission

Although size and weight must be carefully conserved on a CubeSat mission, important experiments are possible with this picosatellite. ZAMBONI was a good stepping stone to begin the CubeSat project at UND. While the satellite was functional, the goals of ZAMBONI were not practical due to the following reasons:

1.) The expense of launching a double CubeSat is beyond the scope of a university-funded program
2.) Transmission through amateur packet radio was too slow for satellite-imaging to be practical
3.) The structure was bulky

Because of these problems, the ZAMBONI project was abandoned and CTAAP was conceived. CTAAP will be a standard size CubeSat with a mass of 1 kg and dimensions of 10 cm x 10cm x 10cm. A graphical representation of CTAAP is shown in Figure 2. This picosatellite will be a vehicle to accept various payloads using industry-standard transfer protocols. It will be designed with a fully functional communications system, budgeted power, mass, and volume for a funded payload. The primary goal with the completion of CTAAP is to achieve a launch through sponsorship by a company or U.S. Government laboratory. Payloads will most-likely require low-earth environmental testing in an orbit.

Potential payloads include:

1.) Various sensors to measure temperature, voltage, current, radiation, etc.
2.) Microchips and GPS sensors for developmental and environmental testing
3.) Low cost environmental testing of materials
4.) Attitude control system

CTAAP will be designed to accept a payload with:

1.) Volume: 6.35 cm x 7.62 cm x 1.59 cm (2.5 in x 3 in x 0.625 in)
2.) Mass: less than 200 g (7 oz)
3.) Power Consumption: less than 250 mW

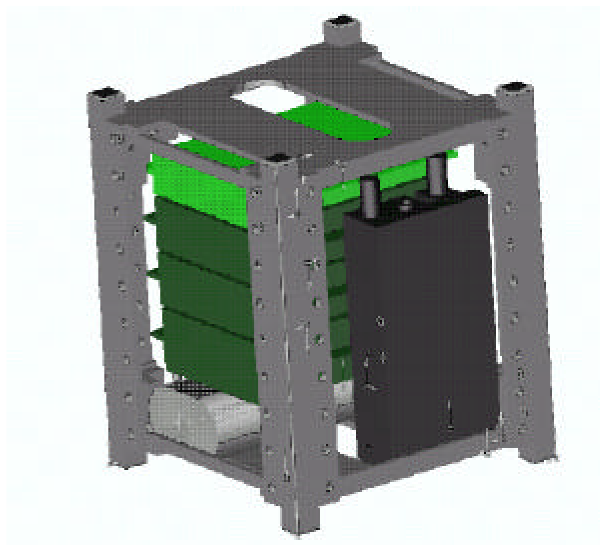

Figure 2: *Pro/E drawing of CTAAP*

Engineering Design

Figure 3 shows the planned subsystem interfaces for CTAAP and its ground control station:

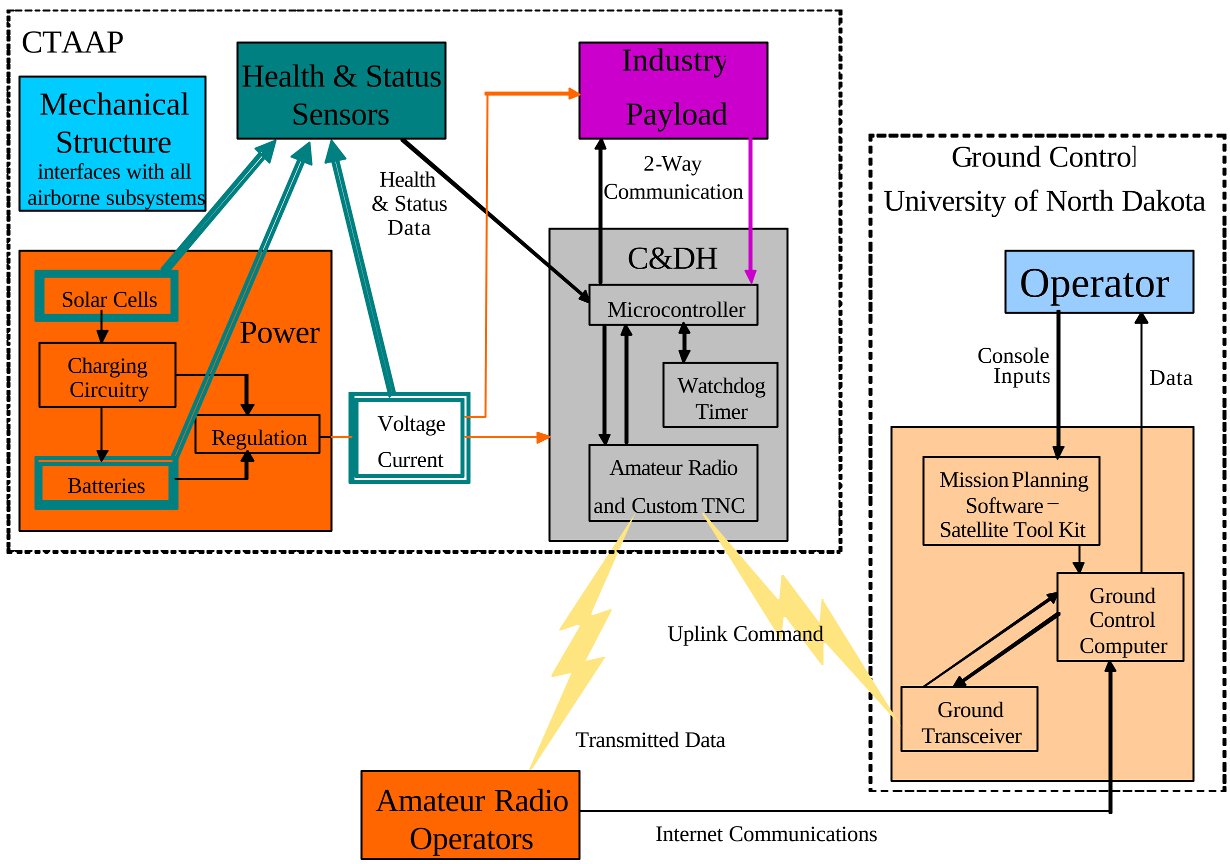

Figure 3: *CTAAP subsystem interfaces.*

Telecommunications will be conducted using custom and commercial-off-the-shelf (COTS) components, with uplink and downlink frequencies in the UHF/VHF amateur frequency bands. The use of the amateur radio frequencies will allow operators from around the world to receive CTAAP's data using commercially-available equipment. If necessary, the communications system may be modified to utilize frequency bands beyond those of amateur radio in order to allow encryption protecting of proprietary information. The ability to transmit uplink telecommands will be restricted to designated personnel.

Testing

Testing plays a crucial role to ensure the reliability of any engineering project within its intended operating environment. Commercial testing typically involves an extensive amount of time and money, both of which are extremely limited in an academic institution. A commercial test chamber to test temperature, pressure, and humidity costs approximately $50,000 [5]. An inexpensive means of environmental testing is necessary for university-funded space project.

At the University of North Dakota, high-altitude balloon launching has been adopted as a primary means of system testing. Balloon launching has proven to be a very effective, yet inexpensive approach to simulate space conditions. The balloon launches conducted by UND have provided students and faculty with valuable design experience and evaluation data for various environmental parameters while operating a remote-sensing system.

Balloon launches enable a payload to travel beyond the troposphere and into the upper stratosphere, with altitude ranges of approximately 30 ~ 40 km (100,000 ~ 130,000 ft). The atmospheric conditions at approximately 30 km (100,000 ft) are 1 kPa and -50°C. At this altitude, the payload is exposed to a pressure of 0.0098 atm. A balloon launch is an accurate method of testing a payload in the following space environments: cold, pressure, radiation, solar-power output and communications link. However, it is not an accurate means of testing vibration, heat, and outgassing. The materials for a typical balloon launch conducted by UND High Altitude Balloon Group carry a cost of less than $500. The cost of a 3000 g meteorological balloon is about $200 while the helium required to launch an 8 kg payload costs $130. The balance includes travel costs to and from the site, and costs associated with tracking the balloon.

Figure 4: *Second ZAMBONI Launch*

The University of North Dakota has conducted four successful balloon launches focusing on spacecraft design, particularly in the areas of sensor data acquisition. Each balloon launch had its successes and failures. The failures have assisted in the follow-on designs, creating a more robust, reliable system with each iteration.

The
most recent ZAMBONI balloon launch in June 2003 was the most successful of all the UND SEM launches made possible by the experience gained from previous launches. In the first launch of ZAMBONI, the satellite did not function as expected. This was attributed to the communications subsystem and electrical connections failing in the extreme cold. A system shutdown and restart occurred due to an electrical connection failure, causing the communications subsystem to remain offline. All electrical connections were replaced, and an automatic power-up for the communications subsystem was developed. After these problems were addressed, ZAMBONI was launched for the second time resulting in flawless operation.

Launch and Future Directions

While a full-scale free-flying satellite project is still a long-term goal of UND, the CubeSat project is immediately attainable. A launch of CTAAP will be coordinated along with other university-built CubeSats from around the world [4]; each team expects that launch costs will be approximately $40,000. In order to gain sufficient design, build, integration, test, launch, and operations expertise, UND Engineering foresees several builds of CTAAP prior to embarking on the development and launch of a small satellite. The future iterations of CTAAP will provide the designers with a relatively low-risk, low-cost means of testing various systems in space, such as a nanotechnology-based attitude control system or constellation satellite communications and control cannot be fully tested on the ground. When UND eventually kicks off its remote sensing satellite development mission, the project will commence with confidence that it can be successful from both scientific and engineering perspectives.

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