Dartmouth GreenCube 6, Year 1

Strategic University Research Partnerships Annual Report

JPL Task # SP.14.0003.004

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A. OBJECTIVES

The goals of the GreenCube project are (1) to maintain a scientifically interesting, student-driven CubeSat development and flight program in Dartmouth Physics; (2) to incorporate new design features into small payloads for Low Cost Access to Space (LCAS) auroral sounding rocket proposals by Professor Lynch; and (3) on a longer timescale, to incorporate designs into future plans for small orbiters, which potentially could include student-designed CubeSats. This has been the seventh continuous year of our JPL-funded GreenCube project, and we hope to continue this constructive project.

A specific GreenCube6 objective is to focus on the concept of a swarm of sensorcraft: how to design, build, test, communicate with, and assimilate the data from 15-20 autonomous vehicles. We have made use of, and continued to refine, prior-year development of GreenCube hardware and data analysis infrastructure, for our balloon-borne sensorcraft. Our Arduino-based GreenCube, outfitted with GPS and digital gyrocompasses and telemetry as well as onboard memory (our present payload) together with onboard sports video cameras, now has an additional co-processor and a more capable inertial measurement unit. The payload has been used as a balloon payload (two flights this past year, with another upcoming flight early this fall term); as a sounding rocket payload (part of a NASA-funded development program for small deployable telemetered payloads); and as the start point for a JPL TeamX cubesat study in spring of 2014, described below.

Students involved in GreenCube this past year (with their graduation year noted) are: Peter Horak (2014) (senior honors thesis, 2014), Todd Anderson (2014) (senior honors thesis, 2014), Jacob Weiss (2016), Dana Wieland (2017), Ann Carracher (2017), Nick Thyr (2017), Greg Partridge (2017), Rob Cueva (2017), Rob Clayton (PhD candidate).

B. STRATEGIC FOCUS AREA

Topic Area:
Science Instruments, Observatories and Sensor Systems
[x] Science Mission Directorate Technology Needs

C. RELEVANCE TO STRATEGIC FOCUS AREA

This proposal addresses JPL's interests in enhancing student preparation for a professional career in space systems/science at JPL or elsewhere. The students gain field experience with instruments of particular interest to JPL, such as GPS, magnetometers, and low-resource processors, as well as with analysis techniques for multi-point in-situ geophysical observations, such as STK (Systems ToolKit). GreenCube graduates can now be found in various space

careers including SpaceX (Sean Currey, Max Fagin), UCB/SSL (Parker Fagrelius (PhD candidate), Amanda Slagle (engineer), Rachel Hochmann (PhD candidate) , Dr Lauren Blum), and Stanford (Dr Alex Crew).

D. APPROACH AND RESULTS

Specific proposed schedule milestones for the past year included:
Summer 2013: Version 2 of the BobShield; investigation of possible higher-sensitivity accelerometers. This was done, and we are further moving from BobShieldv3 to BobShieldv4 this fall (2014).
Fall 2013: *Balloon flight with more sports video cameras, and the new BobShield; development of an algorithm to roughly despin the video; further STK mission design.* These were all completed (with the exception of the video despin), with a balloon flight in Nov 2013.
Winter 2014: Analysis of Fall2013 flight data; ongoing STK and instrumentation/analysis studies; BobShieldv3. March 2014: JPL/CAP-funded design study of the CubeSwarm mission. All of these were done; we planned a spring flight with additional pressure sensors to investigate further the turbulence seen in the Nov2013 flight.
Spring 2014: Second flight with a refined sensor configuration and better weather conditions if necessary; senior thesis projects by Horak and Anderson. Completed; flight in May 2014.
Summer 2014: Analysis of second flight, focussing on comparing pressure sensors, and understanding communications difficulties. We now think we understand the DNT difficulties and plan a reflight in Sept/Oct of 2014.

Longer term goals for years two and three of the proposal will include a continuing focus on moving toward orbital swarm possibilities, including development and flight of first a single 1.5U cube, followed by the full swarm proposal as a 3-month demonstration mission. We look forward to potential collaborations with JPL as this project evolves.

The sections below summarize the students' contributions to the GreenCube project over the past year.

(a) Peter Horak did his Dartmouth Senior Honors thesis on the development of hardware and analysis for low-resource inertial measurement units for small autonomous spacecraft, including balloons, sounding rocket subpayloads, and potential CubeSat use.

GreenCube student Peter Horak's effort has been the development of a rigid-body-motion modeling algorithm for converting the data taken aboard a generic sensorcraft carring an inertial measurement unit, into an inertial frame. This is necessary for the interpretation of magnetometer or accelerometer data as representative of changes in the ionospheric environment, and for relative positioning information for small payload arrays. Peter has applied his algorithm to the recent "MICA" auroral sounding rocket flight magnetometer data, and extracted field-aligned current signatures. His rigid-body-motion algorithms are used also to develop analysis tools for the motion of the GreenCube balloons for both interpreting the sharp acceleration regions we see in the turbulent atmosphere, as well as to properly interpret the sports video camera data taken from the moving platform of the balloon. Peter's analysis techniques, like Jon Guinther's assimilation tool last year, provide a valuable data analysis platform for our

development of data interpretation techniques, so that we can understand the challenges and limitations of the in situ data which could be collected by the CubeSwarm.

Peters's senior thesis is entitled "Attitude Estimation for Rocket-Borne Sensorcraft" and is based on his work for GreenCube.

(b) Todd Anderson did his Dartmouth Senior Honors thesis STK analysis of the coherence of an ionospheric "swarm" of cubesats for auroral research.

GreenCube student Todd Anderson has learned to use Satellite ToolKit (STK) as a mission modeling tool, focusing on swarm issues, such as how such a swarm could evolve in time over a 3-month mission. His thesis work was a study to see whether we can achieve a desired swarm configuration without on-orbit maneuvering other than that provided by drag and Kepler's equations. Todd also investigated how long it will take for the CubeSats to become ram-looking (important for the RPA sensor). His STK simulations (and also the separate analyses of the TeamXc study) of the swarm show that swarm cohesion is extremely sensitive to satellite pointing, i.e. we require greater than 0.1 degree pointing precision to maintain the swarm over the 3 month mission. Alternatively, active drag control could be used to rendezvous escaping satellites with the swarm. Prof Lynch is presently recruiting a new student to pick up this effort.

Todd's senior thesis is entitled "Orbital dynamics model of a CubeSat swarm under aerodynamic torque in LEO" based on his work for GreenCube.

(c) Jacob Weiss has improved and refined and electrical designs for the Arduino-based "Bob" payload, particularly adding a co-processor board to make it more powerful and more flexible.

During GreenCube5, Jacob designed, produced, tested, and programmed a new printed circuit board design ("BobShield") using the Eagle PCB design software from Cadsoft. The new version of the BobShield now supports an onboard flash (NAND) memory, a GPS chip, a bipolar 12V power system for instrumentation, a separate co-processor chip, the DNT radio system and its power handling, support for various sensors such as pressure and temperature sensors, and support for two analog-data-generating instruments. This year he will work on improving the ADC and DAC capabilities of this shield board, which will be used for our upcoming auroral science sounding rocket mission, as well as for the balloon flights.

Jacob is also developing a real-time data visualization tool, for plotting the received data from the balloons in real time.

(d) All the students participated in planning for, and Horak, Weiss, Clayton travelled to JPL for, the CAP-funded JPL TeamX study of our CubeSwarm mission concept in April 2013.

The GreenCube group continues to expand its efforts toward planning a lower ionospheric "CubeSwarm" of thirty-two 1.5U CubeSats in a localized swarm for the investigation of auroral ionospheric behavior. This long-term goal of the Lynch Rocket Lab has been increasingly supported by the GreenCube technology development efforts.

Lately our focus has been on a localized (spread over a few hundred to a thousand km) lower ionospheric (300-400 km altitude orbit) short-duration (three-month) demonstration mission of thirty-two CubeSats. This CubeSwarm would investigate auroral ionospheric responses using a

combination of low-resource sensors: ion retarding potential analyzers (RPA) to look at thermal plasma response, magnetometers for Birkeland current signatures, and possibly accelerometers for neutral upwelling signatures, focusing on the auroral zones. In support of this mission, the GreenCube project works on three aspects of this development : (a) data interpretation and assimilation; (b) mission design focusing on "swarm" issues; and (c) electronics and subsystem design, focusing on manufacturability. The GreenCube balloon flight infrastructure allows us to test a variety of these issues in a flight environment. In April of 2013, JPL provided CAP funding for a TeamXc study of our mission concept, providing valuable technical information to our team.

(e) All the students participated in our two balloon flights over the past academic year, one in November 2013 and one in May 2014.

The students are working to understand the occasionally violent turbulence that the balloon can encounter during our flights. To this end, the spring flight included a second set of pressure sensors in order to decide whether the Nov2013 flight data truly showed pressure dropouts or whether these were artifacts of the turbulent payload attitude.

(f) Rob Clayton (graduate student) works both on GreenCube-specific projects such as the balloon flights and TeamXc studies, as well as related leveraged projects such as our NASA LCAS missions and EPSCoR-funded mission design.

Projects related to GreenCube in our lab include the plasma physics of the ion retarding potential analyzer we aim to use as our primary sensor; the ionospheric physics of auroral structure; and NASA-LCAS funded sounding rocket missions using similar payload infrastructure as the Arduino balloon payload. This past year, graduate student Rob Clayton has worked extensively on our DNT-900 MHz radio configuration, both in its balloon-payload and its suborbital-local-network configurations. Our upcoming flight later this term will include a comparison range test for two different antenna configurations.

The network capabilities of the radios used in previous GreenCube balloon flights is being expanded to include multiple transmitters and receivers, in preparation for a swarm of small sensorcraft to communicate simultaneously. As an alternative to the previously used antennas, we are exploring modified and custom built antennas to boost the effectiveness of the radios.

(g) Rob Cueva analysis, sensor comparisons.

Freshman Rob Cueva joined the group this spring, and worked this summer to analyze and compare the sensor data from the two flights this past year. His analysis shows that what appeared in the Nov2013 flight to be sharp pressure dropouts may be artifacts of the payload motion, since the signatures are not seen on the comparison pressure sensors flown on the second flight.

(h) Greg Partridge, Dana Wieland wind sensors.

A recent goal of the lab has been to implement a generic tool to assimilate and analyze data from multiple sensors, typically a list of locations and times plus the observed values at these points.

In order to generated a "field" of data to use with this tool, various of the early year students are using Arduinos to try to make low-resource sensorcraft measuring, for instance, wind speed at a number of locations. We hope to use the data from this field of measurements to explore data analysis tools such as the support vector regression analysis work done by a previous GreenCube thesis student (Jon Guinther), as proxy observations for exploring issues concerning multiple-point spacecraft missions.

E. SIGNIFICANCE OF RESULTS

The GreenCube team met and exceeded its GreenCube6 technology development goals by extensively expanding the use of the Arduino platform in several iterations to support various autonomous sensorcraft. The team supported a TeamXc JPL study, continued the balloon flight program that we have had for multiple years, and graduated two senior honors thesis students. We plan another flight later this fall term.

The GreenCube program addresses JPL's interests in enhancing student preparation for a professional career in space systems/science at JPL or elsewhere. Previous GreenCube students are now employed at a number of space science laboratories, including UCB/SSL and SpaceX.

F. NEW TECHNOLOGY

List relevant NTR numbers: _____, _____, _____, _____, _____.

(If applicable, please briefly describe any new technology that resulted from this SURP task research.)

(Omission of NTR number(s) will delay clearance)

GreenCube6 is a pathfinder for the Lynch Rocket Lab in terms of finding and making use of commercially available technologies that can be eventually used for low-resource spacecraft. No reportable technology resulted from this task.

G. FINANCIAL STATUS

The total funding for this task was $XX,000, of which $YY,000 has been expended.

H. ACKNOWLEDGEMENTS

Material for this report was assembled by Professor Lynch using input from the named students. The final report was prepared by Drs. Lynch and Mannucci.

I. PUBLICATIONS

[A] Peter Horak, Dartmouth College Senior Honors Thesis, May 2014, "Attitude Estimation for Rocket-Borne Sensorcraft"

[B] Todd Anderson, Dartmouth College Senior Honors Thesis, May 2014, ``Orbital dynamics model of a CubeSat swarm under aerodynamic torque in LEO"

[C] Group Wiki page, including "launch list": http://northstar(dash)www.dartmouth.edu/~klynch/pmwiki(dash)gc/index.php?n=Main.HomePage

[D] JPL TeamXc Cubesat study for "Ionospheric CubeSwarm Pathfinder", April 2014.

J. REFERENCES

None

K. APPENDIX: TITLE OF THE APPENDIX *N/A*

L. FIGURES

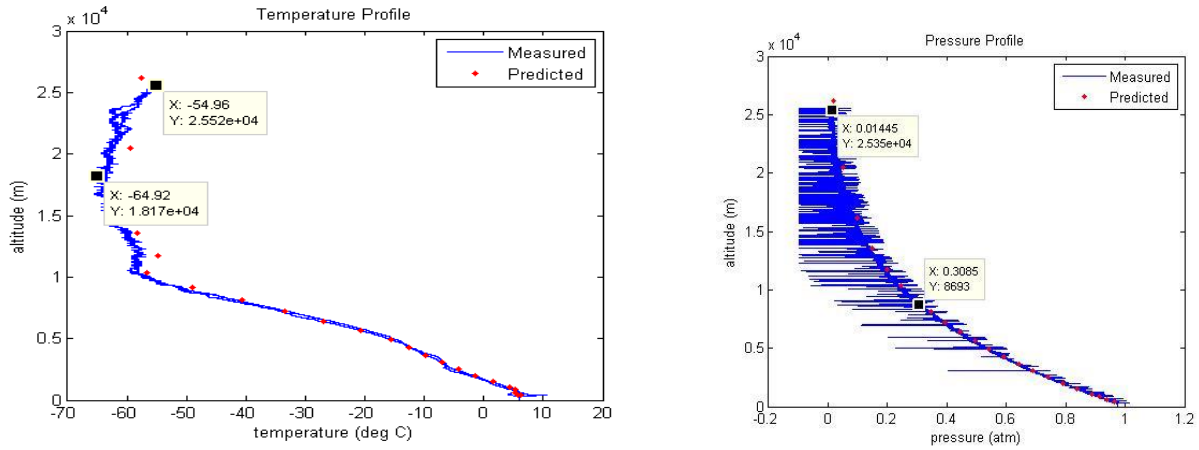

Figure 1. November 2013 balloon flight data, showing strong apparent dropouts in pressure which were related to highly turbulent motion of the payload.

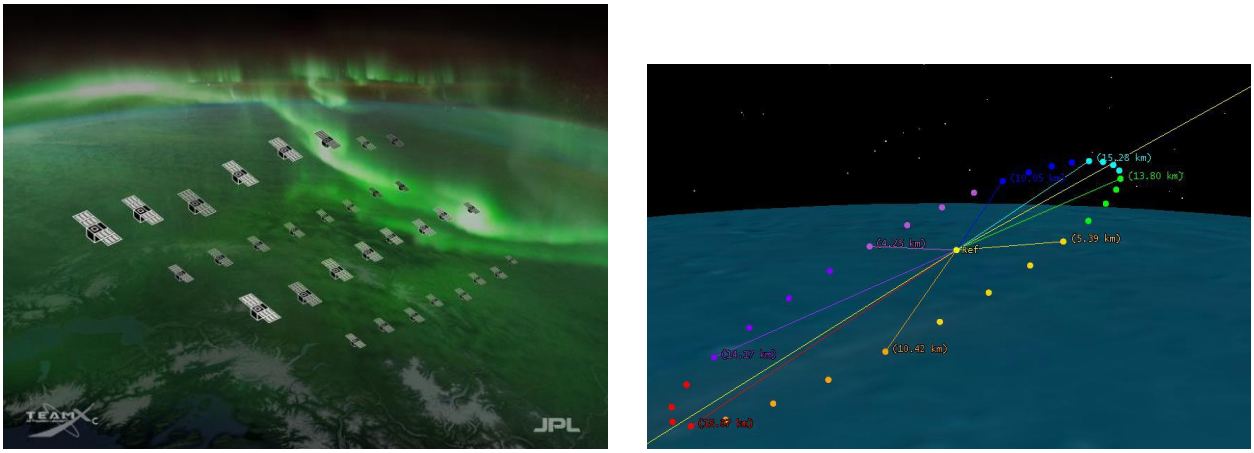

Figure 2. Images from TeamXc study report (left) and Anderson thesis (right).

M. COPYRIGHT STATEMENT