WildCATS: Wildcats Cubesat Ablator Testing System

Nathan A. Wright, Jonathan Wenk and Alexandre Martin

Dpt. of Mech. Eng. & Ctr. for Comp. Science, University of Kentucky, Lexington, KY

October 20, 2012

Abstract

As space travel becomes more and more commonplace, inching ever closer to industries of all shapes and sizes, the need for more improved and diverse material for thermal protection will be required.

Although laboratories experiments and numerical models are able to provide a very good estimate, there remains a need to validate with flight data. The same can be said about diagnostic tools and sensors: it is of great value for engineers to be able to prove, with an experiment, that the device they built is able to sustain the harsh conditions of re-entry. In order to very efficiently and inexpensively achieve that goal, a new testing standard for re-entry into Earth's atmosphere with a given TPS is necessary.

The proposed senior design project involves re-entering a CubeSat from orbit for the purpose of testing new TPS—up to four different TPS at a time. The eventual goal being to create a standard for economically efficient tests of new TPS and new sensors.

In the one year of requested funding, it is the goal of the team to design and test the parts necessary to develop a standardized "test-bed" for re-entry testing of TPS, and potentially build a full-scale, functioning prototype. The idea is to generate enough material to assemble a proposal to NASA'S Educational Launch of NanoSat program by the end of the 1 year project.

Introduction and motivation

One of the issues regarding the design of Thermal Protection Systems (TPS) for atmospheric re-entry vehicles is the difficulty of rapidly and efficiently testing novel materials. Current design cycles involve experimental tests in a laboratory and numerical modeling. Although these necessary steps provide a valid estimate of the actual behavior of the material, there still remain an uncertainty that can only be cleared by flight experiment. Recently, a NASA led project, SPRITE (Small Probe Reentry Investigation for TPS Engineering)[1–4], has been initiated for that exact purpose, with the motto "Test what you fly, and fly what you test". The shape of SPRITE follows the usual sphere-cone design, but the radius is small enough that the whole vehicle can fit in an arc-jet. This shape, however, complicates the launch into orbit, and although it will generate an accurate set of experimental data, it is not convenient for rapid design purposes.

The idea of using CubeSats for re-entry science is not unique. Many teams[5–7] over the years have proposed designs and built prototypes, but, to the best of our knowledge, none have had an opportunity to fly. This senior design project will build upon these other projects to propose a CubeSat design especially for testing TPS during re-entry. It is hopeful that because of the form factor used, and the requirement of low orbit for testing, the system will not be expensive, and will therefore allow for multitudes of launches. Moreover, the system will also allow the testing of sensors and electronics in a real re-entry situation.

It is safe to say that the entirety of this project will not be able to be performed over the one year period of a senior design project. However, it is expected that a prototype will be constructed, and that the generated expertise and preliminary data will be enough to be able to submit a proposal to the ELeNa project.

Preliminary design

The first design presented here uses a size 3U CubeSat. The nose of the vehicle is expected to be covered by an already proven TPS (will henceforth be called "end-TPS") so that the CubeSat has the best chance of survival. Figure 1 presents a schematic of the preliminary design of the re-entry craft. As can be seen on this illustration, four other TPS test sections, especially designed for material testing, are present on the side of the vehicle. During launch and orbit, these "wings" will be tucked in the side of the vehicle around midway up the length of the vehicle. When de-orbiting begins, a worm-gear system driven by a small servo inside the vehicle forces all four TPS out each side of the vehicle simultaneously, preparing them to engage the atmosphere upon re-entry.

The test-TPS is shaped in a manner that will allow the results of the test to be extrapolated concerning how the test-TPS will behave over a variety of different geometries. The shape of each test-TPS can also be different on one vehicle if desired (i.e. each test-TPS could be the same material, just a different geometry to test explicit geometrical effectiveness).

Once the CubeSat begins re-entering the atmosphere, the TPS on the vehicle (the end-TPS and the four test-TPS, respectively red and yellow on Fig 1) will be subjected to an increasingly high convective heating. Sensors behind the test-TPS will "map" the shape of the TPS repeatedly during the journey, and this data will be stored in the vehicle. The

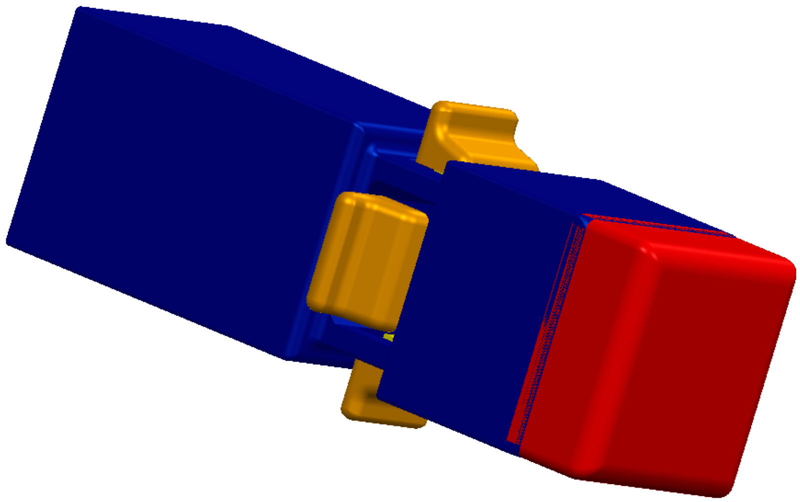

Figure 1: *Preliminary design of the WildCATS CubeSat Ablator Testing System.*

"holders" underneath the test-TPS securing the test-TPS to the vehicle will be shielded with a somewhat thin, non-ablative TPS in the event one of the four (or more) test-TPS disintegrates from the vehicle. This will prevent the vehicle from proceeding into a catastrophic tumbling effect by still enabling an air resistance around the vehicle that assists in bringing the vehicle down to Earth in a controlled manner.

At a time shortly after re-entering the atmosphere, the back section of the CubeSat will break away, allowing a Kevlar-encased radio cable to trail behind the vehicle sufficiently far enough away to transmit data around the plasma generated by the vehicle during re-entry. The data will be that of the TPS mapping from above, as well as data from any other instrumentation that will be on board. In the event the vehicle is lost for any reason, the data recorded up to that point will still be preserved, as it will have already been transmitted to a ground location.

However, it is the intent of the project to have a recoverable vehicle after testing so that a physical TPS can be further viewed for any post-processing of the mission. Because of this intention, the radio cable will be broken away from the craft at a certain altitude in order to make way for a small parachute. This parachute will be just big enough to prevent shock damage to the internal vehicle components when the vehicles crashes into a predetermined body of water. Shortly after the parachute deploys, the small servo inside the vehicle will again rotate, but this time in reverse, and retract the test-TPS, protecting the test-TPS from the direct contact force of crashing into the water.

A floating mechanism will, of course, be present, as well as a GPS locator (optional). This will allow for easy recovery of the vehicle. But even if the vehicle is damaged upon hitting the water, the data (except for the few seconds between cutting away the radio cable and parachute deployment) would have already been transmitted.

Spectroscopy modules, pointed at the wings, will also be included in the body of the

CubeSat. These will allow to directly measure the gaseous emission of the surface. Any other instrumentation the project team deems appropriate for this mission will also be included.

A side-effect of how the current prototype functions is the ability to expose the test-TPS at a certain altitude, and then retract it at another altitude. This can allow a physical sample to be recovered of TPS that has only been exposed to a certain part of the re-entry journey back to Earth. In terms of improving current numerical methods, this can be invaluable.

For the funded period, the following specific goals are expected to be achieved:

1. Digitally model several prototypes
2. Run CFD analysis, using the results to refine the overall vehicle body shape and test-TPS shape
3. A physical prototype of the vehicle body and test-TPS will then be built to the specifications of the best model identified
4. Identify the diagnostic system, instrumentation system and sensors to integrate
5. Plan the electronic system necessary to run the vehicle
6. Develop a suitable data transmission system that will allow for recovering the data after re-entry begins

Alignment with NASA mission directorate

The proposed research activity would be in line with the objectives of the *Human Exploration and Operations Mission Directorate* (HEOMD), as it would eventually provide a low cost solution for TPS testing. More specifically, flight data would be obtained so that numerical models can be calibrated or validated, and instrumentation technologies would have the ability to be tested in actual flight.

The project is also aligned with the objectives of the *Office of the Chief Technologist* (OCT), as the project could provide a useful technology to NASA and other partners within a few years.

Anticipated outcomes

The goal of the senior design project will be to acquire sufficient expertise, and design a CubeSat to a readiness level that will allow the group to submit a ELENA proposal in November 2013. ELENA, which stands for Educational Launch of NanoSat, provides an opportunity for a university to launch CubeSats a no cost. As directly stated by the project description, “Small satellite missions provide NASA with valuable opportunities to test emerging technologies and economical commercial off-the-shelf components that may be useful in future space missions”.

Throughout the funded period, it is expected that the students involved will be in contact with NASA scientists that were involved in similar projects, or those that could benefit from the results. The students will also participate in at least two workshops: *10th Annual CubeSat Developers' Workshop 2013*, in April, and the *2nd Interplanetary CubeSat Workshop*. The technological progresses, will also be presented at the Dayton-Cincinnati AIAA conference.

Prior experience

This project will directly involve two research group at the university. The Space System Lab, headed by Dr. James Lump (Electrical Engineering) will be able to provide all the expertise necessary to launch the CubeSat and track it. Over the years, the Space System Lab has participated in multiple satellite launches. The Gas-Surface Interaction Lab, directed by Dr. Alexandre Martin (Mechanical Engineering) will be able to provide all the modeling necessary to validate the re-entry conditions, as well as design the heat shield. Dr. Martin's expertise resides in hypersonic aerothermodynamics and material response modeling. He has worked in that particular field for the last 5 years, in close collaboration with NASA. Dr. Michael Winter (Mechanical Engineering) will also be able to provide an expertise on the instrumentation and diagnostics necessary to test the TPS during re-entry. Dr. Winter worked at NASA for 3 years prior to current, where he ran plasma diagnostic experiments on TPS materials. Finally, Dr. Jonathan Wenk (Mechanical Engineering) will be able to provide structural modeling expertise, and therefore provide insights in finding a way to make sure that the CubeSat survives landing. Nathan A. Wright, a fourth year student at the University of Kentucky, will be in charge of the team. He runs a small R&D company, which requires him to work extensively with others, and understand the requirements necessary to complete a project. He currently holds four patents applications, and is expanding his company into aeronautics.

Schedule

Because of the strict design project nature of what is proposed being in partial requirements to fulfill a graduation requirement at the University of Kentucky, there are actually no deadlines, besides the main deadline of completing all the above in the time period from January to December of 2013. There are no other external intermediate deadlines.

It is important to point out that it is hopeful that this project will spawn a university club, and that various students, over the coming years, will participate in this endeavor.

References

[1] D. Empey, G. Swanson, M. Winter, E. Venkatapathy, D. Prabhu, K. Peterson, P. Agrawal, K. Skokova, S. Gorbunov, and N. Mangimi. *Small Probe Reentry Investigation for TPS Engineering (SPRITE)*. American Institute of Aeronautics and Astronautics, 2012.

[2] P. Agrawal, D. Prabhu, and Y.-K. Chen. *Thermal Analysis of Small Re-entry Probes*. American Institute of Aeronautics and Astronautics, 2012.

[3] K. Skokova, D. Empey, E. Venkatapathy, and G. Swanson. *Development of an Integrated Data Acquisition System for a Small Flight Probe*. American Institute of Aeronautics and Astronautics, 2012.

[4] D. Prabhu. *Flowfield Analysis of a Small Entry Probe (SPRITE) Tested in an Arc Jet*. American Institute of Aeronautics and Astronautics, 2012.

[5] G. Bailet and J. Muylaert. Re-enstat, an atmspheric triple unit re-entry cubesat. In *9th annual CubeSat Developers' workshop*, 2012.

[6] D. Dalle and S. Spangelo. Preliminary design of very small satellites for venus reentry. In *Interplanetary CubeSat Workshop*, Cambridge, MA, 2012.

[7] www.qb50.eu. QB50 Project, Oct. 19 2012.

National Aeronautics and
Space Administration
Ames Research Center

Reply to Attn of: Ioana Cozmuta

October 14, 2011
Dr. Susanne Smith
Director NASA Kentucky
NASA Kentucky Space Grant Consortium and EPSCoR Programs
University of Kentucky
Lexington, KY 40506

Dear Dr. Smith:

It came to my attention that an enthusiastic group of students from the University of Kentucky under the mentorship of prof. Alexandre Martin at the Department of Mechanical Engineering teamed together to participate in the Space Grant Team Project competition with the proposal entitled "WildCATS: Wildcat Cubesat Ablator Testing System".

I salute this initiative: we should encourage the new generation of students to not only generate creative ideas but also attempt to make them happen. This is a great opportunity for a hands on learning for the students: they will have to thoroughly understand the problem, define a broad range of parameters that will need to be varied to enable a concept study, learn about the technical and financial challenges of building the system, integrating the various components and have a unique hands-on expertise in building flight hardware with a long term opportunity to see it fly!

For the past several decades it has been one of NASA's challenges to acquire flight data with statistical significance. It is pretty obvious at this point that flying large missions is not only time consuming but also extremely costly. Small-scale concepts not only provide the so-desired frequency of flight but also look budgetary attractive. As such, they are a promising option for gathering a statistical significant set of data for TPS testing and certification, failure analysis, model validation and with possible future applications in other areas of interest to NASA (debris disintegration, lunar exploration, etc.).

I therefore strongly endorse this initiative and hope that you will favorably decide to fund it. Please do not hesitate to contact me for any additional questions.

Sincerely,

Ioana Cozmuta, Ph. D.
Senior Research Scientist, Science and Technology Corporation
NASA Space Portal/Emerging Space Commercial Office
NASA Ames Research Center, Mail Stop 555-3 (Building 555, room 103)
Moffett Field, CA 94035
(650) 604-0993
IOANA.COZMUTA@nasa.gov

10/18/2012