­­Hannah Spooner

CRESST Summer 2012 Internship Report

An Overview of the Progression of the BETTII/RUBBLE Project

My mentors, Drs. Rinehart and Barry, are working on a project known as BETTII: the Balloon Experimental Twin Telescope Infrared Interferometer. Although I was originally intending to work on this project, they quickly let us know that all of the interns would be given tasks within an off-shoot project that afforded us all greater autonomy and exposure to real world engineering challenges. Whereas most of the other interns within the CRESST program had the opportunity to work with science data that had already been gathered from previous missions, we got to work on designing and building a payload that aimed to meet a specific set of engineering (not scientific) goals.

BETTII, amongst its plethora of highly specialized science instruments, will be flying a star tracker of relatively novel design. Not only are star trackers not commercially available, but most designs call for a relatively simplistic camera usually contained within a pressure vessel. Because BETTII’s science goals require a high degree of pointing accuracy and knowledge of orientation, the previous group of interns had selected a specialized CMOS camera used exclusively for science applications. What they had designed did not include a pressure vessel and their plans had matured enough that we were committed to this basic concept.

Because of the camera’s exorbitant cost and unverified design, the BETTII team thought it necessary to conduct a high altitude test of all the components necessary to the operate the star tracker in the environment in which it will eventually be used. They tasked this round of interns with designing and building the payload package for this system to hitchhike on the BOBCATT high altitude balloon to be launched late this September.

They also wanted to use this opportunity to test a handful of smaller components and experiments that will fly on BETTII, such as a laser metrology set up, sensor circuit to measure the temperature gradient within a sample carbon fiber tube, and a highly critical rotary stage.

I was given the role of lead engineer and was responsible for organizing the team of four other interns to work together to design, build, and fly this test package. Spencer Gore worked on our thermal management system and helped with component testing, Bryan Hoffman worked on mechanical design and construction, Pedro Nehme worked on electronics and sensors, and Lucas worked on software. What we eventually achieved we have christened RUBBLE: the Representative Unit for BETTII/BOBCATT Limited Experiments.

To begin, we were given were the previous interns’ star tracker designs as well as some of the corresponding hardware and some parameters to fit within the BOBCATT flight requirements (100 kg maximum and on/off uplink only). These designs entailed a handful of relatively simplistic drawings showing a plate and mounting mechanism that would hold the camera, lens, and autofocus mechanism. They had already received the pco.edge camera, 300mm Nikkor telephoto lens, Griffin rotary stage, and linear actuator for the autofocus mechanism. Nothing else, however, was completed.

Over the next few weeks, the RUBBLE team designed a 2’x3’x2’ box that housed all of the star tracker components, a flight computer, and the sensor suite. During this time, I simultaneously went between the RUBBLE and BETTII teams to lay down what our minimum success requirements should be based on what BETTII wanted and what RUBBLE could do given our time constraints. They are as follows:

* + Capture at least one in focus frame with the star camera.
    - Requires possible execution of autofocus program.
    - Include mechanical design so that camera images open sky (rather than balloon).
    - Store results on data recorder.
  + Ensure safe return of camera body and data recorder.
    - Entails not only mechanical consideration so that critical/expensive components can withstand a 10g load, but ensuring that the sun and long focal length lens do not burn out camera chip.
  + Must be completely autonomous. BOBCATT and CSBF (Columbia Scientific Balloon Facility) can only provide us with an uplink for on/off commands.
  + Capability to determine what other components can withstand the near-space environment.

In addition, I also developed a handful of secondary goals to be pursued if and when we had given satisfactory attention to all aspects required for minimum success. These included:

* + Including a sensor suite to both characterize aspects of ascent and float conditions as well as providing data in the event of component failure.
    - Include at least an inclinometer, accelerometer, compass, and temperature transducers.
  + Conduct a carbon fiber tube temperature gradient experiment.
    - Log the temperature gradient on the surface of a BETTII sample carbon fiber tube.
  + Laser metrology experiment.
    - Conduct a “proof of concept” laser metrology experiment to eventually be used on BETTII consisting of a quad cell sensor, laser, and reflecting mirror.

To effectively incorporate these requirements and those given to us by BOBCATT into a coherent package with the greatest chance of success, I set up weekly meetings where those on BETTII who wished to be more involved in RUBBLE could be. It was during these times that we submitted our various ideas and drawings for approval and addressed major areas of concern. After a few weeks, we had outlined our basic design and begun work on ordering, testing, and building.

The basic design and operation of RUBBLE is as follows: It consists of a 2’x3’x2’ “box” that will contain every component needed to take in focus frames. Within this, at one end of the housing, is a frame angled 25° off the vertical (seen on the left side of the system image). To this we mounted to Griffin. To the Griffin we mounted a large plate to hold the camera body, lens, and baffle. The angled frame will orient the entire star tracker system such that we can ensure that it will never image the balloon. Given our separation from the balloon and its predicted diameter in float conditions, we figured that this avoidance angle would be enough to prevent any portion of the balloon from entering the frame. The “top” of the box would be half open to the sky. To store the star tracker in a “safe” position, the Griffin rotary stage would rotate the camera so that it’s exposed to the enclosed part of the housing, thus preventing any unsafe exposure to the sun. When we were ready to begin observing, our flight computer would send a command to the Griffin to rotate the entire assembly a maximum of 30° such that it’s looking out of the open part of the housing. This command would only be sent once the sun had sunk below a certain maximum elevation.

To predict when this time would be, we wrote a code that can predict the maximum elevation of the sun based on the date. Based on these results, the computer’s onboard clock would then determine when to command the Griffin to rotate. We needed to calculate these times because we could not risk moving the camera into an observing position if the sun was too high in the sky; that is to say, if the sun was high enough that there was a chance, however slim, that the chip may be directly exposed, then we did not want to begin observations.

We needed to develop a program that could integrate the commands for the Griffin with those for the camera as well as interpret the results from the previously mentioned sun elevation code. For this we wrote a program called “Mint” that not only can satisfactorily complete these tasks, but includes a number of redundancies that will allow it to proceed in the event of an error.

This program was run on a computer that we custom built, known as RUBBLEComp. At the time of its design, both the BETTII and RUBBLE teams thought that we would need significantly more processing power than we ended up needing (we all thought that we would have any excessively high frame rate, however, we later decided that that can be dialed back). To achieve these early goals, we selected a server class Intel processor with an excessively high amount of processing power. We also decided to use error correcting memory in the elevated chance that we would encounter cosmic rays. This, too, required server class hardware.

As a result, we had a very capable, very power hungry computer. Although these demands could be met by the batteries, we knew that the heat generated could not be easily dissipated, especially without a pressure vessel. We developed and explored a number of different options, including designing a back-up pressure vessel. At this time of this writing, our two main heat dissipation method options are either submerging the entire computer in a mineral oil bath or attaching custom made heat pipes to the hottest components and conducting the heat to a large radiator panel. We abandoned the pressure vessel designs because of the high cost and long lead times, however, we simultaneously developed everything that would be needed to integrate either the heat pipes or oil bath. The heat pipes did have a bit of a lead time and our final decision is pending a number of further tests to determine how well this set-up works. However, it’s worth noting that when we do make a final decision, either system can simply be dropped in.

We’ve already done extensive testing with a vegetable oil bath (which has nearly identical properties to mineral oil) and shown that, although messy, it is a viable option. It can satisfactorily keep the CPU and heatsink temperatures within operating limits, however, it requires the use of a watertight box that will contain both the oil and the computer. We do have concerns about containing this oil once the payload is subjected to the 10g load (encountered when the parachute opens) and the possibility that oil may spill onto our optics. We have purchased a latching aluminum dry box that should withstand this acceleration, however, the heatpipes are more desirable. To integrate this dry box into our structure, we then need to attach it to one of our large radiator panels (also made of aluminum) in such a way that it affords good thermal contact. This step has not yet been completed.

We also were able to include an extensive sensor circuit. We are placing a number of temperature sensors around the structure, including one inside a sample carbon fiber tube. The circuit also includes an accelerometer, GPS, and inclinometer. The GPS will not only provide location information, but will also send time information to the computer so that it knows when turn activate the Griffin and can time stamp the photos. Although the computer has a built in clock, we are considering removing its battery because we are unsure of how it will behave in the near space environment. Thus, we need to provide some way to measure absolute time.

Because of the large number of temperature transducers, we constructed two different circuits. All sensors are controlled by Arduino Megas (which have been verified at high altitudes) and one of the Arduino’s is dedicated solely to collecting data from the temperature transducers. The other Arduino controls the GPS, accelerometer, inclinometer, and quad cell sensor. Here, we decided to diversify our data storage methods. The obvious, although difficult solution would be to send the data from each of these sensors to the SSDs that’s storing our picture data (we do not anticipate taking so many pictures as to use its entire capacity), however this would store *all* sensor and image data in the same location. Instead, each Arduino will have an SD card datalogger shield that will write each Arduino’s respective sensor data to an SD card. Each file on the card contains readings taken approximately every second as well as time data routed from the GPS. If the computer fails, even though we will have failed to meet our minimum success requirements, not all of our data will be lost. We should still be able to retrieve sensor data from some of the secondary requirement experiments.

This circuit also has the added job of powering up the entire system. Most of our components had to be modified to run on the batteries’ DC current and we need a way to power everything on simultaneously without physically flipping a switch. Both of the Arduino’s will receive a signal from the BOBCATT CIP box. From here, the two Arduino’s will send signals to relays controlling each major piece of hardware (computer, camera, Griffin), at which point they’ll be turned on. The drawback to this design is that we have no downlink to verify that each item turned on and operating properly. The relay control is split between the two Arduinos for the same reason that we stored the sensor data on independent cards. Should one Arduino fail to initialize it’s components, then we won’t necessarily lose the whole system. We should, hopefully, still be able to collect some data, even if it’s not the exactly we wanted.

BOBCATT, and by extension RUBBLE, is aiming to launch in late September. Therefore, we need to deliver our payload to the BOBCATT team for integration onto their structure no later than September 12. It will be assembled at Goddard then shipped for launch to Fort Sumner, New Mexico. We still have a few weeks remaining before this deadline and, at this point, the entire structure is completely assembled and we’ve begun preliminary testing with the computer and heat pipes. We’ve made some minor alterations to the camera body to allow copper braids to be passed to the internal heatsink so we can radiate that heat away and we’ve completely assembled the star tracker, including the large baffle. We are currently working on refining the controls for the Griffin and doing some system-level testing to verify that the computer and Mint program can satisfactorily control the camera and Griffin. We also need to test how well it responds to a number of “induced” errors. It should be able to reset and resume operation without completely freezing up. We are also currently working on building the wiring harness for the sensor and relay circuit. Once we have completed these tasks, RUBBLE will be ready for delivery.

Throughout this process, we needed to conduct a variety of tests on nearly all of the components. While most of the other interns tested their own components individually and discussed their results with me, I oversaw most of the larger, more critical tests. A detailed and extensive testing summary of those tests is available upon request. As an overview, however, I helped to run and oversee Griffin current consumption testing, encoder repeatability and accuracy testing, and lens cold-focus testing.

In short, the Griffin power consumption test was designed to determine how much current the controller and Griffin would draw loaded and unloaded in three forms of motion: continuous rotation, continuous reversal, and park. We wanted to verify that the batteries could supply the necessary power in these conditions. A complete outline of our testing methods and considerations is in the aforementioned summary. We loaded the Griffin with 20 lbs. worth of lead bricks and set its motion. We monitored the current consumption with a clip-on ammeter. After learning first-hand of the Griffin’s limitations, we eventually determined that the batteries would satisfactorily power the Griffin if our designs forewent the pressure vessel.

Perhaps the most illuminating test was the cold focus. For most of the first half of the internship, everyone, including most of those on BETTII assumed that the focal length of the chosen lens would change drastically in float conditions. The previous interns had designed an autofocus system that would turn the lens’ focus screw as a program analyzed the sharpness of incoming photos. We went so far as to develop this program (the previous interns had not written the code) and begin design on the interface between a linear actuator and the focus ring. However, we decided to conduct a test to determine if image sharpness would change with the temperature change.

This test was extremely difficult and our challenges and solutions are expounded upon in the testing report. We used a Styrofoam cooler filled with dry ice to simulate the temperatures at float altitudes and submerged the lens and camera within. We shot a collimated laser beam (to simulate a light source at infinity) into a hole in the cooler and examined the image taken by the camera. We learned that as the lens cooled from 20C to -10C, there was no visible change in the sharpness of the image. We analyzed warm lens and cold lens results with the software ds9. After this point, water vapor in the air caused the focus ring to nearly freeze in place. From this, we concluded that over a 30C temperature change, we saw no visible change in the image focus. After discussing this with the BETTII team, we determined it was reasonable to assume the focus would not change significantly even if the lens cooled a further 20° to float temperatures. Furthermore, it would have impossible to attempt to turn the sluggish focus ring with the linear actuator purchased by the previous interns. Thus, we scrapped the idea of dynamic focus in flight. We will conduct this test one more time just before launch and set the focus screw to the setting that affords the best focus at these low temperature, then lock the screw in place. If the lens warms on the ground, an image *may* be slightly out of focus, however, since observation will not begin until the balloon has reached float altitude, all images taken here should be okay.

This is a general overview of my responsibilities and work as lead engineer on RUBBLE. For all intents and purposes, we planned the entire project from the design phase through construction and testing. This will hopefully include a successful launch. Although there are still a handful of tasks awaiting completion, I had the opportunity to learn about the various aspects required to launch a successful mission. This covered everything from laying out our weekly and monthly schedules, defining our success criteria and how best to meet those goals, and preparing for a real PDR to conducting some of the testing, interpreting the data, and writing testing reports. In all, it was an excellent opportunity to cope with real engineering challenges.