Hackers Space Lunch System (SLS): A high altitude balloon platform design rooted in the "Maker" culture

Space Blimp-7

Launch: April 14, 2018, Strasburg, VA, Nomination Category – Best Design

Nancy C. Wolfson, Project Manager

Rockville Science Center[1] : Samarth Chugh, David R. DeLalio, David Bengtson; HacDC[2]: Enrique Cobas; Unallocated Space[3]: Roger Klein;

Independent Contributors: Andrew Reed, Ariella Mansfield, Nicholas Beauregard, Erik Jensen, Gerald Shields, Avi Zajac, Alberto Gaitan

Abstract

Figure-1 (left to right):a. Balloon undergoing fill and lift measurements on 14 APR 2018, Strasburg, VA. b. The lunch box payload with a small Tesla car on the side

Hackers SLS – Spaceblimp7 is a community project to bring the maker and student community closer together to connect them to space activities. Our unique collaborative approach created an inclusive base of energized volunteers including independent specialists and members of three makerspaces from the DC/Maryland area (Rockville Science Center, HacDC, and Unallocated Space). Our HAB project also coordinated an educational initiative addressing the interests of students of multiple ages to interact in the same learning space. In this intergenerational hands-on environment, they are able to advance their understanding together.
The team was dedicated to going beyond the requirements of the challenge and experimented with new technologies. The group was able to launch several payloads from multiple makerspaces and people simultaneously. Concurrently with the technical effort of HAB development, we implemented a new outreach program directed to community groups and schools. In just a short startup period we developed an educational plan, a sample curriculum, and reached out to students and adult sponsors from three states (DC, MD, and VA). Our current approach integrates the science and mechanics of HAB activities, with hands-on interaction with those specialists involved in launch programs. We introduce people to the technology via the popularity of the "maker" culture. Our presentations to partners endeavour to show near-space activities, such as HAB, as achievable, cost effective, and accessible to all. To grow our base and better understanding of HAB work, the team also participated in multiple science and technology-related public events, including the USA Science and Engineering Festival 2018 in Washington DC attended by 300,000+ visitors.

Introduction

Hackers Space Lunch System -SpaceBlimp-7 is a collaborative high altitude balloon project in the Washington DC metro area and Maryland area, designed to bring people together for a shared interest - going to space. The launch parameters were kept within the CFR 14-101.1(A) section so that the project is relatively simple to operate and cost effective. A Kaymont-1500 gm balloon was chosen to lift the payload to beyond 100,000 ft. There were two payload boxes attached serially - a lunch box and a Control moment gyro (a test system to minimize payload rotation using gyroscopic effects). We have observed through previous launches[1] that the elementary, ubiquitous and uncomplicated lunch box is an inexpensive and effective way to shield our payloads from the near-space environment. Hence, we placed our two transmitters along with some other payloads in this box to ensure traceability throughout the flight.
Besides these, we also flew other payloads onboard - 2 GoPro cameras, 1 Wing Cam HobbyKing camera, Raspberry Pi based environmental sensors and a small Tesla toy car with the full English language Wikipedia dataset downloaded onto SD Cards - a homage to the Tesla car sent to space by SpaceX with Isaac Asimov's Foundation Trilogy. This lunch box based launching platform, in turn, also lends name to our team Hackers SLS - Space Launch Systems!

Project, Educational and Outreach Design

Our integrated and multidisciplinary approach made collaboration between Independent specialists and members of Rockville Science Center (RSC) makerspace in MD, Unallocated HackSpace in MD, and HacDC in DC possible. In December 2017 the team named Hackers Space Launch System (Hackers SLS) – Spaceblimp7 was officially formed. Even though some of the participants had previous experience in HAB launching, with 6 previous launches in their record, organizing a project of this magnitude proved to be challenging and many hours were dedicated to logistics and communication - over 50 documents were written and disbursed during the process.

Project Scope	**Organizational Process**
Understanding the challenges in organizing a group from different backgrounds, work-environment styles, communication styles, and locations was crucial for ensuring the success of the project. To keep the project inclusive, educational, research-oriented, and functional, the mission's objective, requirements, and expected results had to be flexible, and to a certain degree, "organic" (based on the individuals' capacity) in order to achieve the mission's scope within only five months.	We adopted a "hierarchical" group structure, but with a twist. It was only adopted to designate responsibilities and for accountability where required. Self-management was encouraged in order to avoid bureaucratic obstacles. We divided the roles and responsibilities between technical and non-technical subjects, giving the participants options to get involved and make commitments according their own skills, availability, and interests and the project.

Project Objectives

The project had technical, logistical, educational, outreach goals as well as to foster creativity connecting participants to space concepts and to the "maker" culture. Here, we concisely describe the main planned course of actions and achieved goals in the course of five months, from December 2017 to April 2018.

Technical, Logistical, and Educational Objectives (Full Details in Appendix)	**Achieved**
To connect three Makerspaces across two states	YES
Outreach Program. Reach out to potential sponsors, and the general public via informational booths, talks, interviews, videos, publications, etc)	YES
Educational Program, Reach out to educational organizations,. An inclusive, safe environment where children and adults can learn about HABs	YES
Documentation, to record requirements, processes, logistics, and technical progress through detailed documentation , photos and videos	YES
Participation & Communication, Operating a team spread across multiple locations was challenging. We used a mixture of initiatives to stay connected, such as conference calls, organizing meetings in all participating locations, maintaining a Google group and Google Drive account.	YES

[1]Rockville Science Center, Johns Hopkins University, Montgomery County Campus 9601 Medical Center Dr, A/R Suite 320, Rockville, MD 20850; [2]HacDC 1525 Newton St NW, Washington, DC 20010; [3]Unallocated Space 512 Shaw Ct #105, Severn, MD 21144

Assignment of tasks, responsibilities and setting up of teams	YES
Test new technology, launch multiple payloads simultaneously and successful payload recovery. This was the first time that participant launched multiple payloads. We recovered the payload successfully with the assistance of our drone.	YES

Educational Program

Our intent is to provide an engaging, hands-on educational curriculum for students and volunteers heavily focused on STEM. All volunteers learn about buoyancy, atmospheric composition, density, radio propagation and weather prediction. Our unique approach provides an educational, inclusive environment where grade school students and adults, either with technical or non-technical knowledge, can learn about the HAB process and be inspired to stay connected with space activities.

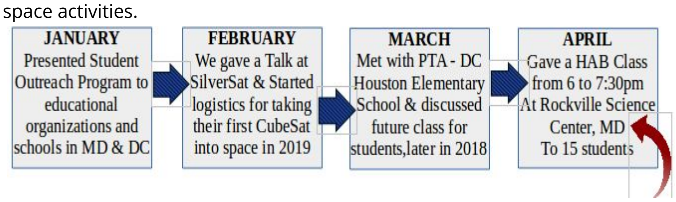


Figure-2 (left to right): a. HAB class organized at Rockville Makerspace, b. Student Program Timeline.

On April 9th we implemented our original HAB curriculum. This included: Introduction of HAB concepts, Initial Q&A Assessment, Technical Concepts, #1 Activity-Drones, #2 Activity-HAB Mock-up, #3 Activity-Launch Day & Teamwork. We, also requested all parents present to actively participate in the class, seven students and eight adults. Our approach proved to enhance the connection between parents and their children as they learnt together. For example, one of the parents said while leaving the class: "I know tonight I'll be talking with Sophia about big balloons in space instead of watching TV." Sophia gave her a big smile! This group of students is ready to join us in our next launch.

Outreach Program

Our outreach team focused on networking and reaching out to any population which might not otherwise have access to the services provided. We worked alongside our sponsors to coordinate the public exhibitions, Informational booths, dissemination of videos and print publications. During the design, construction, and launch process, thorough photographic documentation provided a visual record of every step taken during the project. In addition, movies and photos provided the team with an excellent method for community outreach by showcasing the people and the passion behind the data and reports.

EVENTS - 2018	EVENT'S INFORMATION
MAKER FAIRE NOVA	March 18th -11am to 5pm – George Mason University, Fairfax, VA
USA SCIENCE & ENGINEERING FESTIVAL	April 6th, 7th, & 8th - 10 am to 5 pm - Walter E. Washington Convention Center Washington, DC.
ROCKVILLE SCIENCE DAY	April 22th - 10 am to 5 pm – Montgomery College, MD
ROBOT FEST	April 28th - 10 am to 4 pm – National Electronic Museum, MD

Figure-3 (left to right): a. Hackers SLS at the US Science and Engineering Festival 2018, b. List of events in 2018 where the project was showcased

Our Exhibit, is a ⅓ scale 100g mockup of the full balloon and payload. An on-board wireless camera floats with it, simulating the multiple amateur radio technologies we employ in the real HAB Launch. Our display included HAB hardware along with information about how students and adults can get involved. We plan to continue reaching people in a positive way, and help them connect to space concepts and the activities of makerspaces in their areas.

Technical Design

The current launch took place on 14 April 2018 at 11:08 local time from Strasburg, VA. The design of various systems used to conduct a safe and effective flight is summarized in this section.

Balloon filling, Parachute and Flight Simulation

Kaymont is a popular distribution choice for Totex brand used in high altitude ballooning. A 5 ft model rocket parachute was chosen since it would provide an asymptotic landing velocity of a bearable 5-10 m/s for our payload weight as per basic drag calculations. We aimed for a 3.3-3.4 kg neck lift using a 1500 gm balloon so that the balloon can lift the 2.4 kg payload to 33 km (108000 ft) and land northwest of Mount Airy, Maryland. Lift weight calculations and simulations were carried out using UKHAS's website[2]. The flight path was planned such that we avoid all major airports and flight restricted regions in the heavily controlled DC metro region. However, our data clearly showed that we underfilled the balloon possibly due to ground winds creating artificial drag or the filling tube weight not being measured properly.

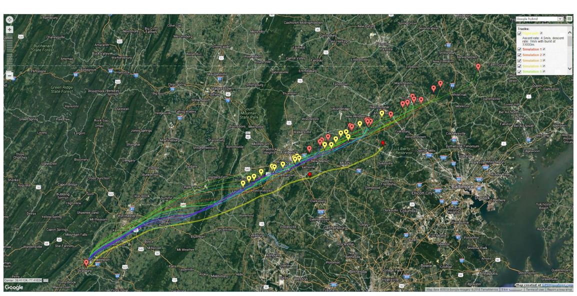
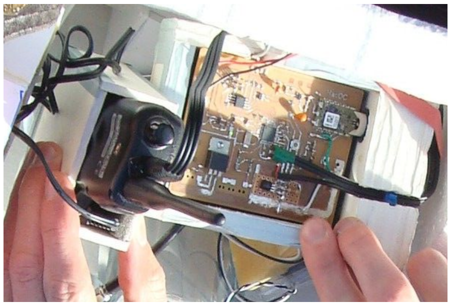


Figure-4 (left): We plotted three data sets: Red: HabHub balloon prediction based on 3.3 kg lift just before the flight, Yellow: Multiple ASTRA predictions based on 3.3 kg lift , Orange: Multiple ASTRA predictions based on 3 kg lift

Note: Habhub[2] does not allow historical simulation so we could not go back and re-run based on launch location and time. ASTRA[3] however, allows you to go back a few days and re-do simulations.

The simulations also concur with our most accepted hypothesis for the usually long travel: We had underfilled the balloon and the actual lift was actually 3 kg and probably a little bit even lower since the landing location (Prettyboy reservoir, northwest of Baltimore) is still not in the middle of the simulation for 3 kg lift. For the next flights, besides the fish scale, we plan on developing alternative measurement methods e.g using Ideal gas law, image recognition (finding volume of balloon visually, etc.). Secondly, we plan to be more cognizant of the ground winds and plan launches accordingly.

Tracking Systems - Onboard and Ground



We used two onboard trackers operating at different frequencies to ensure redundancy. One is a custom built tracker operating an UHF (WhereAVR, Callsign: KJ4VTM) and the second is a purchased tracker module called Tracksoar (manufactured by Santa Barbara Makerspace, Callsign: KC3JWB). The WhereAVR tracker is based around an Atmega328p AVR microcontroller, running code derived from an open source AVR based APRS tracker called the WhereAVR[4]. By updating the sine wave generation code to use filtered 7-bit pulse width modulation in place of the 4-bit resistor network, tone quality was improved with a reduced part count. An I2CEEPROM for local backup of flight data was also added. To keep things light, compact, and simple, a surface mount circuit board to integrate all of the trackers components with a Falcom FSA03 GPS module was designed and connected to a 1W Yaesu VX-1 HT which acted as the transmitter. The board was fabricated using the toner transfer method and hand soldered. This tracker had flown in previous flights and, hence, only basic pre-flight tests were carried out.

Figure-5 (left): Custom built WhereAVR tracker with Yaesu VX-1HT transmitter

Tracksoar[5] is an open-source GPS transmitter for high altitude ballooning manufactured by the Santa Barbara Hackerspace[6] using the Trackuino[7] framework. The SpaceBlimp team stumbled upon it while searching for a backup tracker and decided to purchase considering it was open source and developed keeping high altitude environments in mind (low weight, small form factor, power efficiency etc.) . The unit uses a UBLOX MAX-M8Q GPS receiver and a Radiometrix 300 mW transmitter using the APRS 144.390 MHz amateur frequency band. In addition, the tracker has a BME280 pressure, temperature and humidity sensor whose data is appended to the GPS information received by the ground stations directly or via the APRS network.

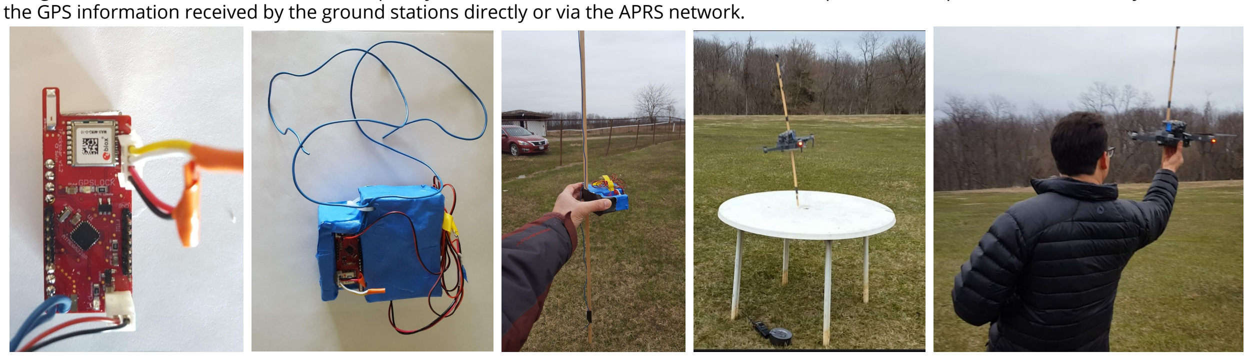
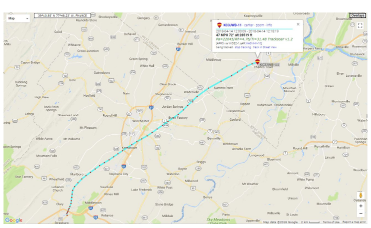


Figure-6 (left to right):a. Tracksoar outside its protective casing. b. Tracksoar nestled inside its styrofoam casing with attachments for the battery and the dipole antenna c. Tracksoar in a custom built styrofoam casing with the dipole antenna held vertical using Balsa wood. This configuration was used to execute the APRS I-Gate repeater test using a Drone. d. The drone with Tracksoar taking off to reach an altitude of 400 ft. e. Dom Perez from CASA (Capital Area Soaring Association) catching the expensive drone in the air since it couldn't land without damaging itself due to the antenna setup

Multiple tests were carried out to confirm the viability of this new tracker before being allowed to fly: The time to get a GPS lock was determined in various locations: open fields, while driving at speed in a car, in the payload box etc.. Battery tests were carried out by running the tracker overnight and monitoring the GPS data received. In addition, the tracker had difficulty reaching any APRS repeater station because of absence of line of sight in the sub-urban environment we were working in and the low wattage of the transmitter. Hence, we used a drone to take the transmitter to 400 ft in the air and observed the data received on APRS.fi. The tracker's signal was picked up by a receiving station in Warrenton, VA (W4VA-10) which is about 50 miles from the drone location (Rockville, MD)!



On the launch day, the systems started off fine obtaini ng a GPS lock within a couple of minutes of system bootup. During flight, the first one hour went fine but then the GPS connection was lost over Charlestown, VA for both trackers. This event coincides with other equipment in the payload performing abnormally. We eventually started receiving UHF during descent which helped us track the balloon. The investigation to understand this issue is currently in progress.

Figure-7 (left): Balloon packets received and plotted on APRS.fi (call sign: KC3JWB-11)

The DC area presents a challenge in planning balloon flights. Balloons need to be launched so that DC never falls in the path and we also need to avoid the major airports (DCA, BWI and IAD) and other military installations (e.g. Camp David).

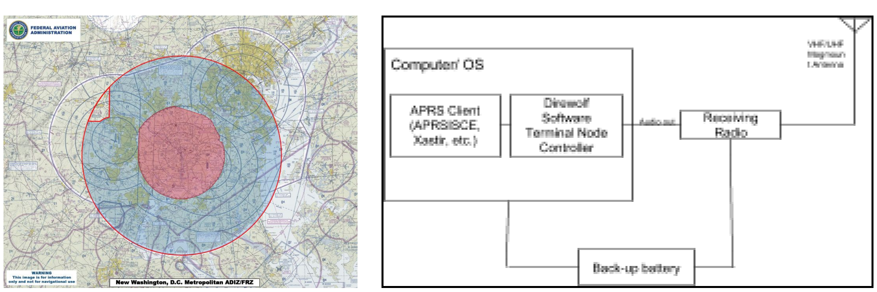


Figure-8 (left to right): DC Flight Restricted Zone (FRZ)[8] , Receiving station setup

In accommodating these constraints, we have to end up launching from remote areas where internet connection is patchy so we cannot rely on APRS.fi website alone to track our balloon. In addition, our secondary tracker is running on a UHF 432.225 MHz band. The APRS I-Gates are not setup to receive at this frequency. Hence, we set up receiving stations in at least three cars so that they can listen to the balloon directly at both frequencies. The setup of the receiving station was approximately the same in the three cars and consisted of the components shown in the figure above. In addition, each of these three cars ensured that at least one Ham radio license operator was also available in the car in order to communicate with the other members of the chase crew at 146.5 MHz simplex frequency.

Payload Details

Raspberry Pi Sensors

Multiple Raspberry Pis were used to capture environmental data and capture photos and videos (besides the dedicated cameras). Overall, there is a nearly continuous record of pressure, temperature, illumination, light color, heading and acceleration during the flight. The pressure falls as expected and allows a rough estimate of altitude. The temperature bottoms out at -39C at a particular altitude (both during ascent and descent) but rises again at high altitudes. The sky illumination and the blueishness of the illumination both fall at high altitude as expected from a black sky.

There is a short (5 minute) gap in the data about 107 minutes into the flight where the PiZSensor computer rebooted. The reboot occurred at about 57,000 ft (see below), which is close to the peak cosmic ray effects termed the Pfotzer-Regener maximum[9,10]. Reliable cosmic ray flux measurements will have to wait for the scintillator detector payload to be ready.

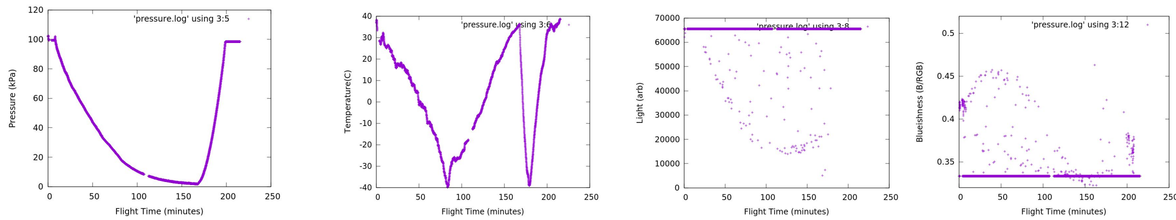


Figure 9 (left to right): Profiles with respect to flight time: Pressure, Temperature, Illumination and "Blueishness"/ RGB spectrum

The pressure readings begin near 101kPa (ambient pressure) at 0 minutes (15:00 UTC) and fall to a minimum of 1.684 kPa at 167 minutes later. The datasheet for the pressure sensor on the Pimoroni EnviroPHAT lists the accurate range as 30kPa and up so additional tests are required to verify this data is accurate below that range. Nevertheless, if we trust the data, online calculators[11] equate this lowest pressure to 94,000 ft.. This is close to the expected burst altitude of slightly above 100,000 ft.

Temperature readings fall steadily from ambient ground temperature about 29.7 C to -39.9C at 16:20:19 UTC when the pressure reading was 17,568 Pa or about 40,300 ft calculated altitude. It then rises again to 36.3 C at 167 minutes before falling sharply. The peak temperature coincides with the minimum pressure recorded. The reason for the heating is probably decreased convective cooling in the thin upper parts of the atmosphere combined with continuous heating from sunlight striking the relatively dark PCB. The next experiment should try to insulate the PCB from solar heating. (the payload is in the sun and there's less convective cooling with less air).

The sky illumination sensor reports data in arbitrary units from 0 to 65535. Direct sunlight saturates the sensor, accounting for the majority of data points at 65535. A small proportion of the data points were not in direct sunlight (e.g. in the shade of the Nylon straps on either side of the payload as it rotated). These measurements show the darkening of the sky from readings of 65353 at launch down to near 14,000 at 125 minutes into the flight. The minimum of the illumination occurs 30 minutes before the balloon burst. (except for two measurements taken shortly after the burst). Unfortunately neither the sunshade nor the payload rotation were designed or controlled (many measurements may have been taken in part-shade or when the sensor was entering or leaving shade). During the descent phase after 167 minutes, all measurements were close to the saturation limit. This probably indicates that the payload was spinning too fast in descent to acquire a complete measurement in the shade.

The light sensor had discrete Red, Green and Blue sensors. Here we use those to quantify the color of the sky as a function of flight time (and altitude). As direct sunlight saturates the sensor (yielding 0.33 B/RBG ratio) only the other data points, presumably acquired in the shade of the payload straps, are considered. As can be seen, near ground level at 0 minutes, the Blue signal accounts for 42 percent of the total light reaching the sensor. For the first hour of ascent this increases until blue light accounts for 45 percent of the total. About an hour into the flight this trend reverses and 140 minutes into the flight the Blue accounts again for no more than a third of the light. At the highest altitudes (140-170 minutes into the flight) the illumination is actually slightly reddish. It's not clear if that's a result of the latex balloon and parachute colors or a result of a partial measurement of direct sunlight (short enough time to avoid saturating the sensor).

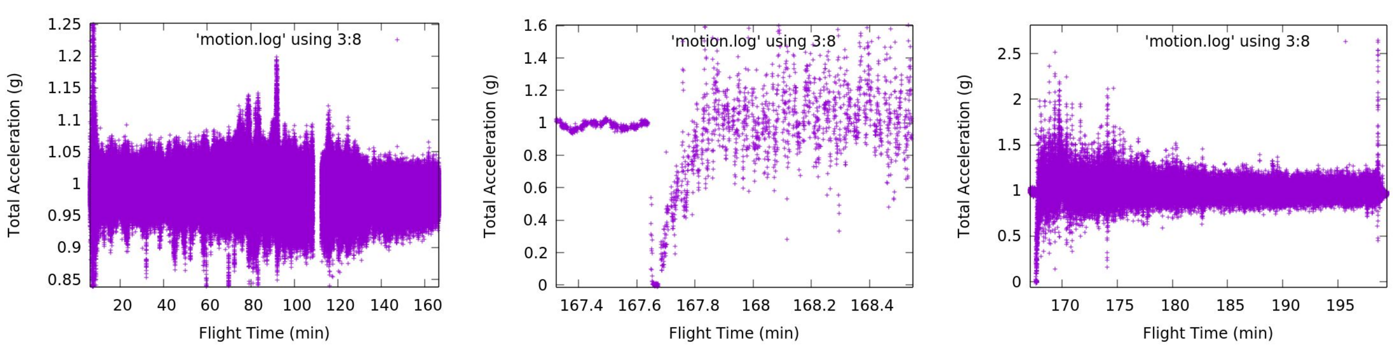


Figure 10 (left to right): Profiles with respect to flight time: a. Accelerations till the burst time b. Accelerations near the burst time c. Accelerations near the landing time

Accelerometer data was acquired at about 40 Hz, putting most measurements 26ms apart. There are regular pauses of 555 ms presumably where data gets saved to the SD card. There are probably more decimal points than is reasonable to expect from the sensor. There is a global offset of +0.08g in the raw data. The balloon burst happens between near 17:12 UTC (Flight time 167.6 min) after where the vertical (and total) acceleration changes from 1.0g to 0.1g. However that period happens to include a longer 555ms pause interval during which some data may have been missed. Right at that point there's an upwards bump up to 1.67g that lasts at least two data points (52ms) but less than 610 ms. This upward acceleration needs to be studied further. Freefall was very brief, only about 2 seconds. Vertical acceleration picks up again gradually and within 10 seconds of the burst is back at about 1g, meaning close to some terminal velocity. Since the pressure was about 1.7% of atmosphere this is presumably pretty fast even after 5-10 seconds. Landing (presumed) is a 2-2.9g spike at 174317 UTC that lasts about half a second which is potentially a fairly gentle landing in a tree.

CMG/ Attitude Adjuster Payload

The Attitude Adjuster payload is an experiment to see how well a hobby-scale Control Moment Gyro (CMG) pair can fight back against torsional forces to maintain attitude control of a low mass payload. Since the experiment is suspended from a balloon in the yaw axis, control via CMG is an ideal application of this spaceflight technology. The concept is based on the NASA BETTI[12] project and a pair of Cosmos Pioneering's[13] Hobby scale CMGs, a payload that will provide positive attitude control operable in the harsh conditions of the upper atmosphere.

To reduce excessive spin, we command the CMG's to "actuate", gradually expanding momentum, as onboard sensors monitor the decreasing levels of spin. Given a payload mass of approximately 400 grams and the mass of each CMG gyro is a mere 8 grams, it seems counter-intuitive that something so small could affect a larger mass. It's not magic though but just the law of the conservation of energy at work! The 400-gram payload consisted of the following key components: Atmega 328P-AU Micro Controller running Arduino code, PCA9685 I2C 16 channel PWM IC, Two Control Moment Gyros (5g servo, gyro motors & Mi-3A ESCs), MPU6050 I2C Gyro/Accel, HMC5883L I2C Digital Compass/Magnetometer, MS5611 Air Pressure/Altimeter sensor, etc.

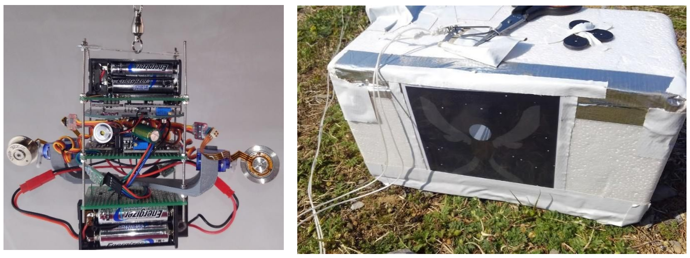


Figure 11 (left to right): a. Attitude Control (compete assembly). B . The complete assembly in its styrofoam payload box ready for launch.

Prior to launching, a rigorous barrage of system tests was performed, including: Weight Manipulation, Power, State Machine, Payload Spin and CMG Servo. The first and most important test was performed on the stationary payload, where positive torque transfer was observed (and measured). The chart below shows the degrees/sec (vertical axis) recorded by the payload across the full CMG gimbal angle range.

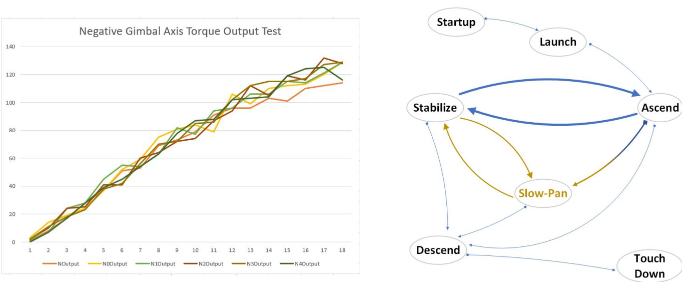


Figure 12 (left to right): a. Negative Gimbal Axis Torque Output test (vertical axis: deg./sec ; horizontal axis: 10x PWM value (i.e. – "18" = 85deg gimbal angle). b . State Machine Flow diagram

The State Machine test simulated every mission stage from startup to touch down. In fact, for three days the payload ran through this test while on display (while also being touched and disturbed by observers) at the USA Science and Engineering Festival held in Washington D.C. It appeared to perform as expected, shifting from the ascend state to the stabilize state once the spin rate exceeded a predetermined spin rate. During the three-day presentation, flaws within the state machine progression began to emerge, which would ultimately drive a decision to exchange the BMP180 pressure sensor for the MS5611 that would measure above the BMP180's 3000m limit. Despite further testing prior to launch, this component replacement would prove to be the payload's Achilles heel and ultimately caused the payload to fail to step through the states shown above. Therefore, the payload itself failed to collect meaningful data from its sensors and cameras, rendering its primary mission for this flight a failure. While many lessons can be learned from flight failures, analysis of the primary payloads data quickly got our attention. The primary payload was able to successfully record, via video (a Raspberry Pi looking down towards the CMG payload) and, hence, the in-flight performance characteristics of this secondary payload. The primary payload was also able to successfully record its yaw axis spin, which can be correlated with the video of the secondary payload, and thus, typical spin rates and payload performance can be calculated and a ground-based test to simulate these can be created. Also, this flight will be recorded as our "control" flight for future reference, where the payload's performance is based on environmental disturbances, only.

Wikipedia on a Tesla Toy Car

Figure-13 (left): A Tesla toy car with SD cards containing English language Wikipedia

There are a number of stratospheric balloons programs being launched as part of the Global Space Balloon Challenge around the world, but this is the first to successfully fly a balloon in near-space carrying a toy Tesla car and an entire copy of English-language Wikipedia. The Wikipedia payload was a set of electronic copies of the entire set of English Wikipedia articles on SD cards. This Wikipedia payload consists of 2 mini SD cards of 64GB holding a copy of the whole compressed English Wikipedia articles and 1 mini SD card of 128GB with a copy of the uncompressed entire set of articles. This is a homage to the SpaceX launch of the Falcon Heavy carrying a real Tesla car and five small crystal disks containing Isaac Asimov's Foundation series of books.

Recovery, Conclusions and Future Work

Figure-14 (left): The drone hauling a rope across the payload stranded 50 feet up on a tree

Similar to our launch, our landing was dramatic too. The UHF tracker, thankfully, established good connection during the last phases of descent and took us northwest of Baltimore (tens of miles away from our predicted landing site). The payloads landed in a tree 50 feet high in a wooded area and it took a fair bit of engineering trying to bring them down. We got a rope hauled across the payload boxes using a drone skillfully maneuvered between tree branches by our team drone pilot (see images in Appendix).

In conclusion, the group was able to launch several payloads from multiple makerspaces/ people simultaneously and conduct outreach- all without raising substantial capital. In addition, these payloads , and the project in general, set an example of science and creativity working together - embodying the "maker" movement itself. From electronics, mechanical design to physics, the interconnectedness of disciplines taught us all a lesson in engineering and teamwork.

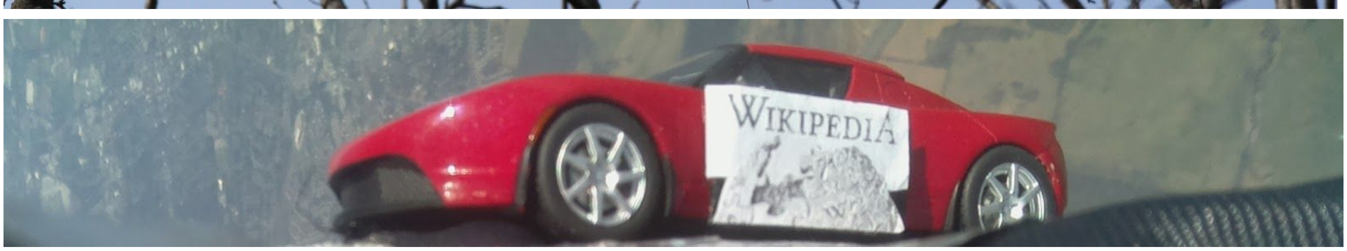
We wish to bring more makers- inside schools and outside - together using this unique platform to pursue the final frontier and have some lunch!

Appendix

Point of Contacts

- Project Manager: Nancy C. Wolfson lessonsbynancy@gmail.com,
- Rockville Makerspace: Samarth Chugh (Technical Manager) samarthchugh7@gmail.com

More Pictures

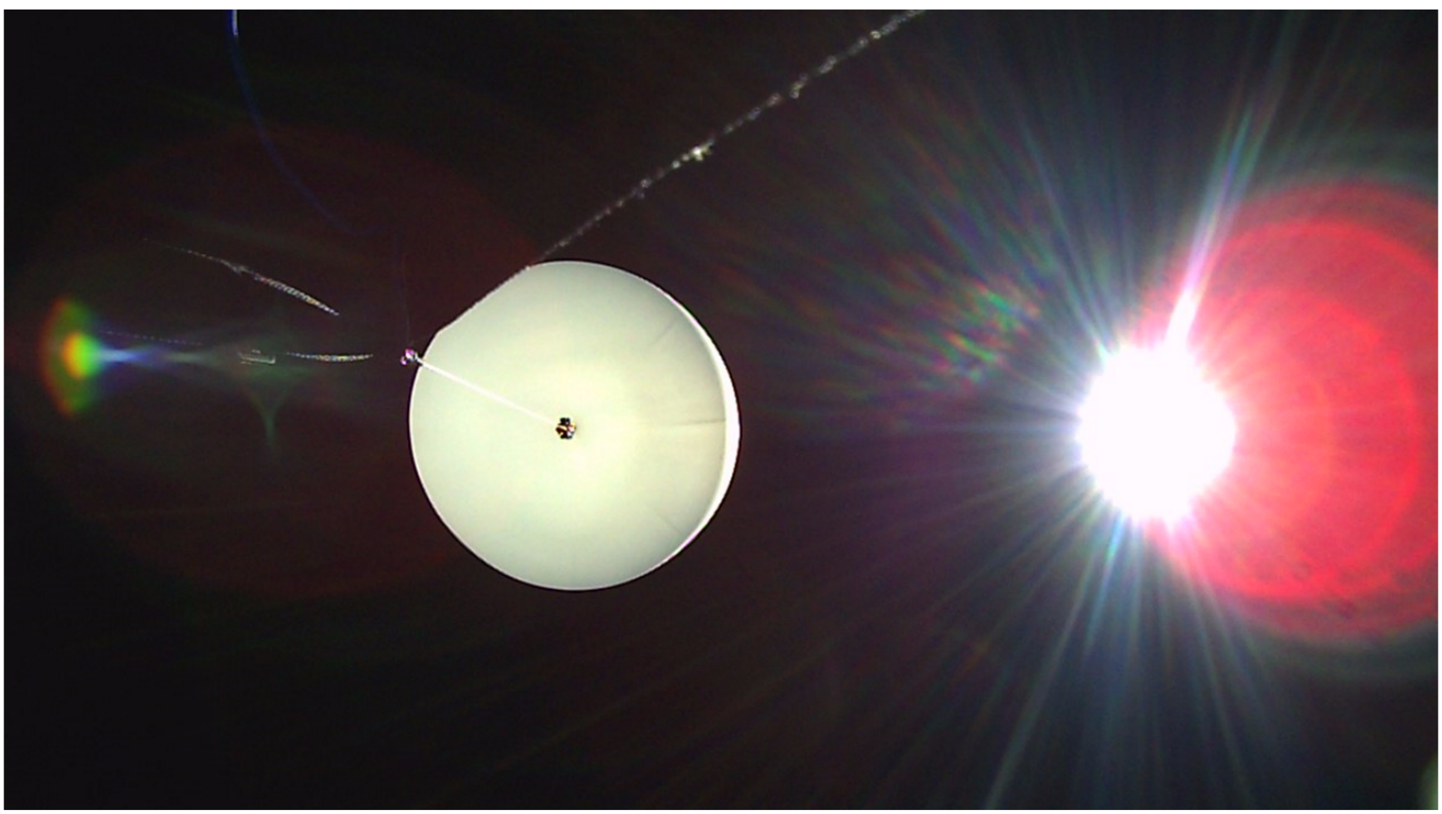










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Misc. Specifications/ Acknowledgments

1. HAB Launching experience: Some of the participants had previous experience. SpaceBlimp -1 to 6 were executed by some members at HacDC
2. Alberto Gaitan for assistance processing the Raspberry Pi sensor log files in Python
3. Tesla/ Wikipedia Payload: Gerald Shields, photographer and 2014 award winning Wikimedia DC volunteer, had the idea to carry the Wikipedia payload. Enrique Cobas proposed the idea to carry a toy Tesla car while Nancy C. Wolfson, downloaded the compressed set of articles into two 64GB mini SD Cards and downloaded the uncompressed set of article in a 128GB mini SD cards
4. Andrew Reed for the CMG/Attitude Control payload
5. Buddy H. from Unallocated Space for co-organizing the involvement of the hackerspace into the HAB project.
6. MARC (Montgomery Amateur Radio Club) and other local HAMs for guidance and assistance with tracking equipment (especially - David Bern W2LNX, Eliud Bonilla N3QYJ, Zachary Amodeo (N2ZPA) and Paul FitzGerald N3RQV

Project, Logistical, and Educational Objectives Details

(Lead Designer Nancy C. Wolfson)

Technical, Logistical, and Educational Objectives	Achieved
To connect 3 Makerspaces across 2 States. *Supporting Documents: Participation "Protocol" (Makerspaces & Individual's), Representations and Logos	YES
Outreach Program. Reach out to educational organizations, potential sponsors, and the general public via informational booths, talks, interviews, videos, publications, etc) * Documents: Project Description & Objectives, Logistics, Outreach Program Description, and Website Protocol	YES
Educational Outreach Program, An inclusive, safe environment where children and adults can learn about HABs . *Documents: Full Curriculum, Customized Curriculum.	YES
Documentation, to record requirements, processes, logistics, and technical progress through several documents, photos and videos * Meeting Agenda, Technical information- archive and Post launch, Google Group and Google Drive	YES
Participation & Communication, Operating a team spread across multiple locations was very challenging. We maintained contact with each location through a mixture of initiatives - having regular conference calls, organizing meetings in all participating locations, maintaining a Google group and Google Drive account. *Documents: Meetings Procedure, MeetUp Description.	YES
Assignment of tasks, responsibilities and setting up teams *Documents: Roles and Responsibilities, Chase Team, Agenda & Meetings Notes	YES
Test new technology, launch multiple payloads simultaneously and successful payload recovery., This was the first time that participant launched multiple payloads.. *Documents: Technical Aspects, Payload Information, Checklists, System Status	YES

Tracker GPS and Other Metadata (Some selected transmissions only)

Drone Test (Transmitter: Tracksoar 144.390 MHz, Receiver: I-Gates, data as reported to APRS.fi)

2018-03-27 15:07:31 PDT: KC3JWB-11>APRS,WIDE2-1,qAR,KI4NBS-1:/220730h3906.64N/07708.25WO000/000/A=000618/Pa=10022/Rh=48.41/Ti=12.64 Tracksoar v1.2

2018-03-27 15:08:32 PDT: KC3JWB-11>APRS,WIDE2-1,qAR,KI4NBS-1:/220831h3906.63N/07708.25WO000/001/A=000831/Pa=99687/Rh=50.68/Ti=11.31 Tracksoar v1.2

2018-03-27 15:09:41 PDT: KC3JWB-11>APRS,WIDE2-1,qAR,KI4NBS-1:/220940h3906.62N/07708.24WO000/001/A=000719/Pa=99705/Rh=51.78/Ti=10.59 Tracksoar v1.2

2018-03-27 15:10:40 PDT: KC3JWB-11>APRS,WIDE2-1,qAR,W4VA-10:/221039h3906.63N/07708.24WO000/001/A=000771/Pa=10209/Rh=55.22/Ti=9.52 Tracksoar v1.2

2018-03-27 15:11:41 PDT: KC3JWB-11>APRS,WIDE2-1,qAR,W4KEL-12:/221140h3906.64N/07708.25WO000/001/A=000953/Pa=14448/Rh=57.61/Ti=9.05 Tracksoar v1.2

2018-03-27 15:15:15 PDT: KC3JWB-11>APRS,WIDE2-1,qAR,W4VA-10:/221514h3906.64N/07708.25WO000/000/A=000879/Pa=14127/Rh=62.66/Ti=8.32 Tracksoar v1.2

Launch Day (Transmitter: Tracksoar 144.390 MHz KC3JWB, Receiver: Receiving Station in Samarth Chugh's car)

Port(DireWolf):Port(DireWolf):2018-04-14T15:06:16.550AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/150616h3859.80N/07821.05WO000/002/A=000598/Pa=99402/Rh=13.11/Ti=48.63 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:07:16.545AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/150716h3859.81N/07821.06WO000/002/A=000559/Pa=99341/Rh=13.16/Ti=48.64 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:08:16.589AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/150816h3859.84N/07821.00WO052/016/A=000943/Pa=98192/Rh=0.00/Ti=49.08 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:09:16.563AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/150916h3859.92N/07820.82WO058/010/A=001908/Pa=95198/Rh=12.56/Ti=48.83 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:10:35.613AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/151035h3900.18N/07820.71WO012/018/A=002850/Pa=84628/Rh=100.00/Ti=49.87 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:12:34.557AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/151234h3900.53N/07820.66WO023/008/A=003918/Pa=88288/Rh=100.00/Ti=48.63 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:13:34.593AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/151334h3900.66N/07820.57WO035/007/A=004455/Pa=86584/Rh=100.00/Ti=48.98 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:14:35.554AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/151435h3900.82N/07820.47WO016/009/A=004942/Pa=84905/Rh=100.00/Ti=48.33 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:15:35.555AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/151535h3900.99N/07820.39WO024/017/A=005589/Pa=83035/Rh=100.00/Ti=48.93 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:16:35.587AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/151635h3901.21N/07820.27WO016/018/A=006233/Pa=81291/Rh=100.00/Ti=48.44 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:17:54.581AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/151754h3901.58N/07820.13WO012/020/A=006873/Pa=73509/Rh=39.14/Ti=48.97 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:18:53.548AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/151853h3901.90N/07820.06WO018/018/A=007335/Pa=78379/Rh=31.79/Ti=48.76 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:19:53.567AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/151953h3902.26N/07820.01WO358/022/A=007776/Pa=77092/Rh=31.08/Ti=47.93 Tracksoar v1.2
Port(DireWolf):Port(DireWolf):2018-04-14T15:20:53.560AGW:AX.25[0]
KC3JWB-11>APRS,WIDE2-1:/152053h3902.66N/07819.96WO002/022/A=008189/Pa=75857/Rh=30.62/Ti=48.29 Tracksoar v1.2

Launch Day (Transmitter: WhereAVR 432.225 MHz KJ4VTM, Receiver: Receiving Station in Samarth Chugh's car)

Port(Dire Wolf):Port(Dire Wolf):2018-04-14T18:09:38.931 AGW:AX.25[0] KJ4VTM-11>APAVR0,WIDE1-1,WIDE2-2:@180937h3937.90N/07648.48WO61./46./A=016704 06 21i 0e Descent
Port(Dire Wolf):Port(Dire Wolf):2018-04-14T18:12:18.419 AGW:AX.25[0] KJ4VTM-11>APAVR0,WIDE1-1,WIDE2-2:@181216h3938.82N/07646.36WO63./31./A=012633 05 20i 0e Descent
Port(Dire Wolf):Port(Dire Wolf):2018-04-14T18:15:43.886 AGW:AX.25[0] KJ4VTM-11>APAVR0,WIDE1-1,WIDE2-2:@181541h3939.72N/07644.65WO0.0/0.0/A=008748 00 3939.7232 07644.6510
Port(Dire Wolf):Port(Dire Wolf):2018-04-14T18:16:06.881 AGW:AX.25[0] KJ4VTM-11>APAVR0,WIDE1-1,WIDE2-2:@181604h3940.05N/07644.38WO17./13./A=006020 07 3940.0592 07644.3854
Port(Dire Wolf):Port(Dire Wolf):2018-04-14T18:16:52.881 AGW:AX.25[0] KJ4VTM-11>APAVR0,WIDE1-1,WIDE2-2:@181651h3940.23N/07644.26WO14./19./A=006017 07 3940.2327 07644.2625
Port(Dire Wolf):Port(Dire Wolf):2018-04-14T19:03:07.498 AGW:AX.25[0] KJ4VTM-11>APAVR0,WIDE1-1,WIDE2-2:@190305h3940.57N/07644.20WO0.0/0.0/A=006007 00 3940.5770 07644.2094
Port(Dire Wolf):Port(Dire Wolf):2018-04-14T19:11:50.907 AGW:AX.25[0] KJ4VTM-11>APAVR0,WIDE1-1,WIDE2-2:@191149h3940.56N/07644.06WO301/0.3/A=000747 07 3940.5616 07644.0641