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## Using High-Altitude Ballooning to Give Freshmen a Hands-on Introduction to the "Space" Side of Aerospace

**Dr. James Flaten, MN Space Grant / Univ. of Minnesota**

Dr. James Flaten is the associate director of the Minnesota Space Grant Consortium, a NASA higher education program whose goals include promoting interest in space science and space exploration. Though housed in the Aerospace Engineering and Mechanics (AEM) Department at the University of Minnesota – Twin Cities, Dr. Flaten's academic background is actually in experimental physics and he has also taught many physics, astronomy, and basic engineering classes in the past. He enjoys using high-altitude ballooning and high-power rocketry as relatively low-cost means of giving students hands-on experience building and flying space-related hardware.

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### Abstract

It is challenging to provide undergraduate students with meaningful, hands-on activities on the “space” side of aerospace due to the complexity of spacecraft and the tremendous expense of launching them into outer space using rockets. Helium-filled (or hydrogen-filled) latex weather balloons, also called high-altitude balloons, can carry miniature spacecraft designed and built by students to altitudes in excess of 80,000 feet into the stratosphere. The view and environmental conditions in this part of the atmosphere are quite similar to outer space, so these balloons are said to travel to “near-space.” Student participation in the entire near-space mission, including the launch, tracking the balloon using GPS-enabled radios, and post-flight data analysis, makes high-altitude ballooning an engaging, yet relatively inexpensive, microcosm of full-scale spaceflight programs that is well-suited for undergraduate education.

The Aerospace Engineering and Mechanics (AEM) Department at the University of MN – Twin Cities / Minneapolis campus (henceforth just called the U of MN), in conjunction with NASA’s Minnesota Space Grant Consortium (MnSGC), has developed a freshman seminar entitled *Spaceflight with Ballooning* and offered it four times since 2008. This no-prerequisites class is part of a suite of curricular and extracurricular aerospace activities offered by the MnSGC to complement the AEM undergraduate program. Students in the class of about 20 work in teams of 4 or 5 to design, build, and test a robust near-spacecraft to take photos or video and to use sensors to collect basic atmospheric data which is saved on HOBO data loggers and on miniature flight computers which the students solder together and help program. Each team must also perform one unique student-generated science experiment, built within weight and cost budgetary constraints. Over the course of the semester student teams do a series of three oral design reviews and submit three revisions of a written report, to document their payload. The final oral presentation and report submission are due after the balloon mission has flown and emphasize data analysis. The course also includes mini-lectures on full-fledged outer space flight, plus explicit time for discussion about what it means to be a freshman and how to thrive in college.

This paper will discuss the results from the four times this seminar has been offered, including both the joys and the challenges of doing genuine aerospace design/build work with freshman, all of whom are interested but some of whom have limited science and math backgrounds. It will also describe how this class fits into a larger suite of high-altitude ballooning activities, for a wider range of ages, as well as a broader set of aerospace freshman seminar offerings, to engage students in aerospace engineering build activities without necessarily waiting for completion of calculus and physics prerequisites. Such classes can motivate interested students to stick with the program, despite early non-aerospace class hurdles. They can also engage and capture the imagination of students who were not considering majoring in aerospace-related engineering or science fields.

## Introduction

Challenges inherent in aerospace engineering undergraduate education include the complexity and expense of building and testing actual aerospace vehicles, as well as the substantial math and physics background required to understand aerospace theory. The AEM Department at U of MN in Minneapolis typically does not work with students until late in their sophomore year, by which point many talented students have selected other majors despite their original interest in aerospace engineering. Offering engaging classes to freshman on aerospace topics is one way to motivate students to persevere until they reach upper-level aerospace engineering classes.

High-altitude ballooning (AKA weather ballooning) in which payloads weighing up to a few pounds are carried into the stratosphere (AKA near-space) by balloon is a cost-effective way to give students experience building and flying actual hardware for the “space” side of aerospace. High-altitude ballooning involves using latex weather balloons filled with helium (or hydrogen) to lift miniature spacecraft, typically containing science experiments, to altitudes of 80,000-100,000 feet above the ground where the environmental conditions (and the view!) are much like those in low-Earth orbit. Balloon missions to near-space parallel many of the challenges of actual outer-space flight, but at a tiny fraction of the cost of suborbital or orbital rocketry. These challenges include (a) surviving the mechanical rigors of the flight such as potential jet stream turbulence on ascent, fall-induced turbulence (AKA “post-burst chaos”) during the descent, and a parachute landing, (b) operating successfully in the harsh conditions of near-space including low pressure, low temperature (at certain altitudes), and high cosmic radiation levels, (c) tracking the flight using GPS-enabled radio systems, (d) recovering the payloads safely from all sorts of terrain, including trees, tall crops, and open water, and (d) analyzing the experimental data, most of which is logged on-board rather than being transmitted to the ground during the flight. For an overview of high-altitude ballooning at institutions of higher-education see the AJP article by Shane Larson, John Armstrong, and the late Bill Hiscock (of the MT Space Grant).<sup>1</sup>

Interestingly enough, the U of MN has a long history in the area of stratospheric ballooning, including manned flights in the 1930s using balloons constructed and piloted by aerospace professor Jean Piccard and his wife Jeannette. Current weather ballooning efforts, sponsored by the MnSGC, were originally inspired by the *Starting Student Space Hardware Programs (using Ballooning)* summer workshops offered from 2002 to 2006 by the CO Space Grant.<sup>2</sup> MnSGC director, professor William Garrard, attended the 2002 ballooning workshop and conducted several launches, starting in 2003. However when the author joined the MnSGC in 2005 those original students had graduated and there was no on-going ballooning activity. The author attended the last summer ballooning workshop for Space Grants in Colorado, in 2006, then has been doing balloon flights with undergraduates since the summer of 2007.

Inspired by the Colorado Space Grant’s *Gateway to Space* class,<sup>3</sup> a more-advanced class (not aimed at freshmen) discussed at their workshop, and by the *High-Altitude Research Platform (HARP)* curricular-implementation-of-higher-education-ballooning initiative at Taylor University in Indiana,<sup>4</sup> partially funded by the IN Space Grant, the author developed a freshman seminar and has taught it each fall from 2008 to 2011. The freshman seminar route was selected because (a) it did not interfere with the existing AEM major course sequence, (b) there was a desire for more engineering-themed freshman seminars, and (c) “amateur spaceflight” using

high-altitude ballooning fits in exceptionally well with the overall goals of Space Grant – to motivate college students to learn more about aerospace (and NASA) and to pursue studies in STEM (Science, Technology, Engineering, and Mathematics). Freshman seminars are general-elective classes with no prerequisites, so there was no expectation that this seminar would recruit students to major in aerospace engineering. However nearly all participants who entered the class as “undecided” regarding their major reported being positively influenced by the experience toward STEM studies in general, and toward both aerospace and engineering in particular. The seminar has also been useful in recruiting students to participate in extra-curricular high-altitude ballooning, and other MnSGC-sponsored aerospace projects (see Appendix A), in subsequent semesters.

## **Freshman Seminar Organization**

*Spaceflight with Ballooning (Freshman Seminar)* has the following (brief) course description:

Outer space, sometimes called the Final Frontier, has always been difficult to reach due to the tremendous expense of rocket launches and the limited number of launch opportunities. In this hands-on course we will design and build mini-spacecraft and use (relatively) inexpensive helium-filled weather balloons to carry them into “near-space” – the upper reaches of the atmosphere which has many of the same physical properties as outer space. The launch and recovery will be a required class activity tentatively scheduled for the last Saturday in October (this activity is weather dependent, so the actual flight day may need to change). The remainder of the semester will involve data analysis from the balloon mission as well as discussions and activities associated with full-fledged (i.e. outer space) spaceflight, including the scientific accomplishments and engineering challenges of past, current, and future missions.

The class meets once a week, for 2 hours, and is worth 2-credits (not quite a “full” 3-credit course). In-class time is divided between (a) working in teams on a near-spacecraft project, (b) mini-lectures on real (outer-) spacecraft, and (c) sharing ideas and practicing skills (writing, time-management, etc.) useful for succeeding in college. Grading is evenly weighted between individual-work (homework, quizzes, etc.) and team-work (building, testing, flying, and analyzing data from a near-spacecraft). Teams deliver a series oral presentations (AKA Design Reviews), as well as multiple-submission, team-written report on the construction, testing, flight, and data analysis from their payload. Some sample course documents and student presentations/reports are posted.<sup>5</sup>

Here are class topics in the approximate order they occurred in the fall 2011 seminar. Brief succeeding-in-college discussions and activities were interspersed throughout.

- Introduction to outer-space and near-space – environment, spacecraft, spaceflight
- Anasonde (Morse-code-transmitting mini-balloon) activity to motivate use of ballooning
- Overview of main payload assignment; discussion of hardware and past student payloads
- Demonstration of cameras, HOBOT data loggers,<sup>6</sup> flight computers, weather sensors, etc.
- Announce teams (selected by instructor); team-building activities – mock-up a “flat-sat”
- Templates and discussion of team oral presentations and team-written documentation
- Learn to solder activity (individual) and solder resistive heater circuit (as a team)
- Oral Proposal/Conceptual Design Review, distribute requested hardware for payloads

- Solder one Verhage BalloonSat EAsy flight computer and 3-sensor weather station<sup>7</sup>
- Watch movie “BLAST” then write an essay on science/engineering, work with peer editor
- Construction of payload shell – integrate camera, HOBO, flight computer, heater, etc.
- Program HOBO and flight computer, test camera, conduct “Day in the Life” testing in lab
- Intersperse building with mini-lectures on Spacecraft Systems and Systems Engineering
- Submit “Rev. A” of Team Project Doc. – includes Design, Predicted Budgets, Test Plan
- Structural/strength testing (drop test, yank test) and thermal testing (cold soak) of payload
- Oral Flight Readiness Review then finalize and submit payloads for final weigh-in
- Run flight predictions, discuss logistics associated with the launch day field trip
- Launch date – leave early; launch, track/chase, and recover; return time uncertain
- Class time for data extraction from payloads, data analysis tips, start data analysis
- Mini-lectures on Gravity/Orbits/Mission Design and (Outer Space) Launch Vehicles
- Submit “Rev. B” of Team Project Doc. – includes Payload Build Photographs, Actual Budgets, Expected Science Results (from literature reviews), Results of Payload Testing
- Mini-lectures on Telemetry/Communications and Re-entry/Landing Systems
- Finish data analysis, Oral Final Team Presentations about entire near-space mission
- On-the-spot design of ballooning mission to explore Venus (done in 1980’s by USSR!)
- Submit “Rev. C” of Team Project Doc. – includes Flight Data Analysis, Lessons Learned
- Public exhibit of payloads, flight photos/video, data analysis, team project documentation
- Course evaluations, wrap-up discussion of opportunities – “Where do we go from here?”

## Student Payloads – Hardware and Experiments

Here are the contents of a handout giving an overview of the main payload-build assignment:

### A. Required basic components

- Payload box, built from materials provided (it must be light (no more than 2 lb before rigging), strong (survive potentially-rough flight and landing), and thermally insulating).
- Heater circuit (solder it yourself).
- HOBO<sup>6</sup> (monitor internal temp (at least) and external temp (probably); might also plug in one other sensor with voltage cable (like a solar panel)). Learn to program this.
- On-board data logging with BallonSat Easy flight computer and weather station<sup>7</sup> (solder both yourself). A BASIC program will be provided – tweak it for your experiments.
- Camera (still or video). Point it up, down, or out, depending on your experimental needs.
- (Optional) You may send analog voltage data (up to 8 channels) to the ground during the flight using a Zigbee radio, but this radio will occupy a chunk of your weight budget.

### B. Required science/engineering experiments

- Characterize external temperature, pressure, relative humidity of atmosphere using the weather station. Associate data with altitude values (from GPS system) after the flight.
- Document internal temperature (as an indicator of general spacecraft “health”) and monitor relative humidity within the payload box with the HOBO data logger.
- Use your camera to do an interesting science experiment, not just “take pretty pictures.” – Some ideas: Layers of the atmosphere (possibly using filtering), curvature of the Earth, spectral content of sunlight using a diffraction grating, characterize balloon size with altitude, analysis of balloon burst and/or post-burst chaos, landform identification or mapping, vegetation identification (possibly using filters), photograph solar corona, etc.

- Do at least one additional unique experiment of your own choosing (must propose an experiment and get explicit permission; no live vertebrate animals; stay within size and weight limitations; if electrical, consider monitoring with the external channel(s) of the HOBO). Paul Verhage's *Near Space* column in the magazine "Nuts and Volts" is a good place to look for ideas for ballooning experiments.<sup>8</sup>

Students were provided with, or needed to build, the following "basic" hardware for potential use in their payloads – see posted photos.<sup>5</sup> (Note – the types of cameras used and computers built evolved somewhat from year to year.) Unique experiment(s) needed to be done using this same hardware, or other hardware students provided and/or received permission to buy.

1. One Flip (video) camera or one Canon Powershot A570 IS (programmable, still) camera.
2. Solder one electrical resistive heater (with a switch; powered by a 9-volt 3-battery pack).
3. One HOBO U12-013 data logger with internal temperature and relative humidity sensors plus 2 channels for external sensors (e.g. external temperature probe, raw voltage cable to monitor a solar panel, etc.).
4. Solder one BalloonSat Easy flight computer with 3 channels to monitor external sensors (e.g. weather station). Has relays to trigger camera/experiments and a servo output port.
5. Solder one "weather station" with temperature, pressure, and relative humidity sensors.
6. Zigbee radio to send experiment data to the ground during the flight (optional).
7. If measuring radioactivity levels (optional), RM-60 Geiger Counter, monitored either with a BalloonSat Mini flight computer or a Geiger-enabled zigbee radio.
8. If measuring acceleration (optional), HOBO "Pendant G" 3-axis accelerometer.

Here are some of the "unique experiments" student teams have attempted, with various levels of success, over the four iterations of the seminar. Photographs of, and data from, some of these payloads appear in the next section and in Appendix B.

1. Ideal Gas Law (IGL) – monitor the temperature and pressure in the balloon envelope with sensors threaded through the neck, deduce the balloon volume photographically (this involves interesting geometric corrections), then check the fit with the Ideal Gas Law
2. Mirror boom – get up/out/down still photos all in a single view, with no moving parts
3. Rotating filter wheel – distinguish types of (crop) foliage photographically through filters
4. Fresnel lens – increase output of solar panels using a Fresnel lens solar concentrator
5. Geiger counter – study the way in which cosmic radiation varies with altitude
6. Audio recordings – study how sound propagation and characteristics change with altitude
7. Solar panels – study how solar panel output/efficiency changes with reduced temperature and increased exposure to sunlight at high altitudes
8. Rotating filter wheel – see if layers of the atmosphere are more evident through filters
9. IMU – monitor orientation of the payload with an off-the-shelf inertial measurement unit
10. Diffraction grating – document changes in sunlight in the stratosphere versus at ground level by taking photographs through a diffraction grating
11. Peltier cell – generate electricity using the temperature difference between the inside and the outside of the payload (and compare it to power generation using solar panels)
12. Look-up video – study the expansion then the popping (rip-propagation) of the balloon then the parachute deployment using a video camera pointed up
13. IR camera – comparing infra-red photos, taken using a hacked still camera, with visible light photos by a second still camera pointing in the same (sideways) direction

14. Acceleration – learning about motion during the ascent (sometimes with very violent pre-flight turbulence), burst, post-burst “chaos”, and landing from 3-D accelerometer records
15. Bacterial mutation – studying radiation-sensitive bacteria, shielded in various ways during the flight, with un-flown controls to look for flight-induced radiation mutations
16. Darkness – photographically characterize the way in which the sky color changes during the ascent to near-space
17. Water phase diagram – drive water around its phase diagram during a balloon flight, monitoring phase changes (especially interested in direct solid-to-gas (sublimation))
18. Solar photography – try to capture images of the Sun’s corona with a shaded camera mounted on a turntable controlled by a servo motor and light sensors
19. Magnetic field strength – monitor magnetic field to deduce payload orientation and also to study changes in Earth’s magnetic field at altitudes up to about 90,000 ft
20. Mapping – use knowledge of payload altitude (continuously changing) to determine the distance to and size of land features appearing in photographs

### Sample Photographs and Data from 2008-2011 Freshman Seminars

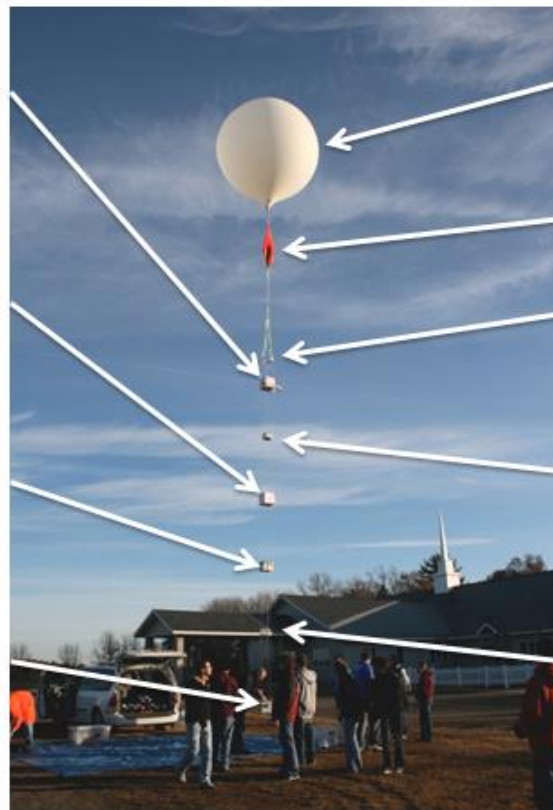
Here are representative photographs and graphs from the four iterations of the freshman seminar. Additional photographs and data appear in Appendix B.

Rockettes payload with mirror boom and cable up to sensor pack in the balloon above.

Random Guys payload with Geiger counter experiment.

BBBC payload with look-up video and audio recorder.

Team Sweetness payload with look-down camera and filter wheel.



1500 gram helium-filled latex weather balloon (AKA sounding balloon).

8-foot dia. parachute.

Shroud lines and shroud ring.

APRS tracking package (GPS and ham radio #1).

ARPS tracking package (GPS and ham radio #2).

Fig. 1 (2008) The payload stack with 4 freshman-built payloads, plus radios, from the 2008 seminar. Late-October weather was ideal for the launch. The winds were calm so the stack could be raised vertically without the use of launch lines (not the case some other years).



Fig. 2ab (2009) Payloads landed in trees about 30 ft off the ground after a 90-mile flight.

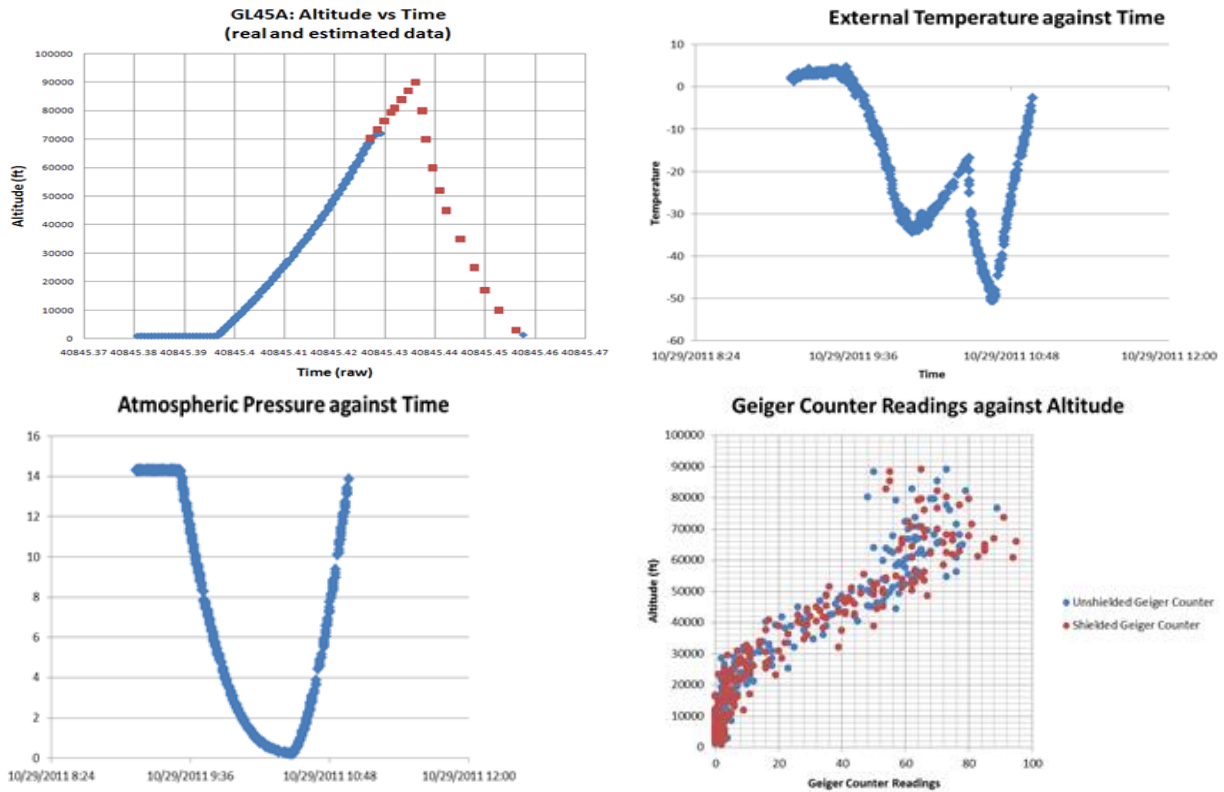


Fig. 3abcd (2011) Graphs of altitude vs. time and some experimental sensor data. Turbulence during the ascent knocked out both tracking radios, so some altitude data had to be estimated.

### Balloon Launching and Tracking

As currently organized, the seminar focuses mostly on payload building, testing, operation, and data analysis from a near-space ballooning mission, and less on the logistics of handling and launching weather balloons and using GPS-enabled radio systems to track missions in flight. Class members help do balloon flight predictions and monitor tracking systems. They are required to attend the launch, pitch in with inflation, and accompany the chase/recovery.



However turning over primary responsibility to an outside launch provider for launching, tracking, and recovering the payload stack is definitely preferable, if possible. For example, the *Gateway to Space* classes in Colorado use Edge of Space Sciences (EOSS)<sup>9</sup> to conduct their class balloon launches. Here in Minnesota there are no weather balloon launch providers for hire, so members of the MnSGC Ballooning Team assist with freshman seminar launches (and then recruit some class members to join their ranks, for additional ballooning adventures).

Suggestions for handling and launching latex weather balloons appear elsewhere (see Ref. [1], for example) so will not be reiterated here. Launching weather balloons does require investing in some hardware, such as regulators for dispensing gas from high-pressure tanks, plus having access to vehicles for transporting helium (or hydrogen) tanks and people. The best way to learn is probably by attending a training workshop that involves launching weather balloons, not just workshops on building payloads and/or curricular implementation of ballooning. Working with an established ballooning group is another option in some parts of the country. Also pick up techniques and hardware for recovering payloads from trees, open water, etc. Every recovery is unique (and some can be quite difficult) so creativity and persistence are useful traits to cultivate.

Near-space missions are typically tracked using GPS-enabled radio systems which require more instructions than can be included here, but here are some general comments about options:

The most common, and lower-cost, method is to use GPS receivers and ham radios (a ham radio “Technician” license is required to purchase and operate this equipment<sup>10</sup>) that transmit latitude, longitude, altitude (and sometimes some sensor data) in APRS (Automatic Packet Reporting System) format. Such transmissions can be received and interpreted by ham radios in the chase vehicle(s) and superimposed on maps on laptops using software such as APRSPoint<sup>11</sup> with MapPoint mapping libraries. One advantage of APRS tracking is that transmissions are also posted to the internet by ham radio operators, so flights can often be tracked on-line in real-time at websites like <http://aprs.fi> by entering the call sign of the flight radio(s). However on-line APRS tracking is often limited to altitudes above a few thousand feet since the launch site and/or the landing site may not be close enough to a ham radio i-gate posting APRS transmissions to the internet. Thus you are **strongly** encouraged not to depend solely on internet tracking of APRS transmissions, even though such tracking only requires an internet connection and no additional ground-tracking hardware. Losing transmissions from a payload at 3000 ft on the way down leaves a lot of ground territory to search, especially if the payloads land in woods, deep corn, or open water, where visibility and/or access are limited. In general, it is much better for chase vehicles to be able to receive transmissions directly from the payloads after they land, so the recovery team knows exactly where to go. Our current favorite APRS transmitter for near-space missions is the Big Red Bee “BeeLine GPS (2-m high power, mobile package)”<sup>12</sup> which sells for about \$300. Note: It is best to fly at least two tracking radios on every flight, for redundancy.

A much more capable, but much more expensive, tracking option is the proprietary StratoSAT turn-key system from StratoStar Systems,<sup>13</sup> who also offer training workshops and lots of ideas for curricular implementation at the college and pre-college level. StratoSAT command pods use 900 MHz radios (no license required to purchase and operate those) and can communicate with multiple experiment pods using a ZigBee radio network and “interface modules,” thereby allowing experiments to send down multiple channels of analog and digital sensor data while in

flight, in addition to latitude, longitude, and altitude. However this data can only be received by a 900 MHz ground station radio – it does not get posted to the internet – so only people with such a radio can see it (and presumably most/all of them are out chasing, so they might be too busy to pay attention to the data stream in real time). StratoSAT systems cost several thousand dollars each, so they typically are flown with at least one APRS radios as a backup. However a StratoSAT command pod can send down and log a wealth of sensor data during a flight, so if a payload is lost (hopefully only temporarily), data from experiments can still be analyzed. StratoSAT command pods have been used for freshman seminar flights, but are not necessarily recommended for institutions just getting started with ballooning because they are so expensive.

## **Joys and Challenges**

There are both joys and challenges associated with doing high-altitude ballooning and with implementing near-space missions in college contexts. The following remarks stem from the *Spaceflight with Ballooning* seminars, but joys and challenges are likely to be specific to the type of ballooning (especially curricular vs. extra-curricular), the age and background of the students involved (especially freshman vs. upper-classmen), buy-in from the institution where the activities are taking place (this will require support of departmental administration, at least), and perhaps most importantly of all, the weather conditions and geographic location of the school. Some schools can do launches right from their campuses. However institutions in metropolitan areas, including the U of MN, may need to travel far from campus to conduct launches. Depending on the weather, which in turn is influenced by the time of year, flights can be carried upwards of 100 miles and potentially land in difficult terrain such as woods, mountains, or even in the ocean (if launching from coastal locations). Here at the U of MN high-altitude balloon missions typically rack up from 150 to 300 miles of driving, making them all-day affairs.

The author finds high-altitude ballooning with freshman as particularly enjoyable, despite the students' wide range of backgrounds. They are enthusiastic and (usually) not-yet-jaded by college. Most are willing to work hard and try new things and, with encouragement and coaching, they pitch in for the good of their team on build-activities and on their team oral presentations and written reports. They also generally appreciate advice and feedback about succeeding in college. However they are still coming to grips with time-management issues and may be reluctant to attend out-of-class events, such as the launch and chase (a required all-day commitment) because of the other campus events (such as sporting events) that they do not want to miss. For example, the 2008 class launch happened to fall on Homecoming weekend which led to a lot of issues with students who were convinced that Homecoming events were vital to their college experience. There were fewer such issues in later iterations of the seminar after potential scheduling conflicts were discussed explicitly in lecture on Day 1.

Not unexpectedly, many of the challenges are related to logistics of the day-long field trip for the class launch. It is possible to ensure student teams are making timely progress toward having their payloads ready using a series of pre-flight oral presentations and/or written checkpoints. The biggest uncertainty every year is the weather, but as long as the total payload weight is under 12 pounds balloonists are not required to seek pre-approval of launches from the FAA nor scrub launches in the case of overcast skies. Here the primary procedure for dealing with inclement weather and/or an awkward jet stream is a willingness to move the launch site as needed and the

ability to fly “hot” (i.e. fast ascent – less total time in the air). In the four iterations of the seminar the class always managed to fly on the primary launch date, though one year it was windy and snowing (non-ideal launch conditions) and one year the jet stream carried the payloads over 150 miles. Class policy states that the primary launch date is an all-day required class activity (though if there is a major evening sporting the students are assured that they will be back to campus by late afternoon, whether or not the payloads have been recovered – this actually happened in 2011 when ascent turbulence knocked out both tracking radios and the payloads were not recovered till after the class had returned toward campus). Class policy also states that back-up flight dates are optional, as long as each team sends along at least 2 members to tend to their payload and help with the launch. Luckily enough, interest in attending the launch is very high by this point in the semester so the majority of the class will probably still attend the launch even if it shifts to an alternate date because of weather.

When doing ballooning missions in a class context, it is prudent to do at least some planning for the possibility that one cannot launch, due to weather, spring flooding, etc, or the possibility that the payloads are not recovered, or at least not found in time for students to analyze their data and present it by the end of the term. Most launch issues can be dealt with by having backup dates in place and/or being willing to drive far enough to find suitable flight conditions. One solution to the lost payload possibility, in addition to using multiple, reliable, transmitters, aiming for good landing zones, and trying to be ready to deal with all sorts of landing conditions, is to use flight radios that send experiment data to the ground during the flight, like the StratoSAT system sold by StratoStar.<sup>13</sup> A less-expensive option is to use an APRS RTrak-HAB unit<sup>14</sup> which can send up to 5 analog channels of experiment data down with its APRS transmissions, though is not too reliable as a GPS tracker. In either case, as long as the transmissions are carefully logged, the students will have at least some experimental data to analyze even if the payloads are not recovered in a timely manner. Logging radio transmissions is a good practice regardless, though the students might be too busy during the actual flight to use them in real time. But on-board data loggers can typically log data more frequently than telemetry options, so telemetry data sets are at best a back-up. Transmitting photos and video to the ground during the flight is a higher-level challenge, probably beyond what can be accomplished in a freshman seminar setting, so such data would be lost if the payloads are not recovered. Another option, albeit a less satisfying one, might be to provide the students with data from a different flight that used similar sensors, so that they at least gain some data analysis experience.

## **Conclusion**

High-altitude ballooning is a relatively low-cost way to give undergraduate students, and others, a hands-on taste for spaceflight, albeit near-spaceflight rather than outer-spaceflight. In addition to curricular implementations, ballooning is done by many higher-education institutions for research purposes and for outreach (see survey results on this topic in Ref. [17]). College-level curricular implementations may include just a ballooning module within an upper-level physics laboratory course, for example, but this article describes a no-prerequisites high-altitude ballooning seminar for incoming freshman at a large public institution. The class was offered successfully for four successive fall semesters and has led to the development of two additional freshman seminars and earned a central role in the portfolio of activities used by the MnSGC to promote interest in aerospace among both college and pre-college audiences.

This hands-on seminar provides students from a broad range of backgrounds with a literally “out-of-this-world” near-space experience – a streamlined version of the development and operation of a real spacecraft system. Students who do not end up pursuing aerospace-related majors report finding the class motivational regarding opportunities beyond conventional college coursework. And students who continue with aerospace-related studies have a leg-up on their peers, especially on the “space” side of the field. Every year several seminar students were able to use this experience as a springboard into earlier-than-usual engagement with more-complex aerospace projects such as additional ballooning with the MnSGC Ballooning Team and also undergraduate research in AEM and in other science/engineering departments at the U of MN.

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10. <http://www.ar1.org/>
11. <http://www.aprspoint.com/>
12. <http://www.bigredbee.com/>
13. <http://www.stratostar.net/>
14. <http://rpc-electronics.com/rtrak-hab.php>
15. [http://www.anasphere.com/multipurpose\\_radiosonde.php](http://www.anasphere.com/multipurpose_radiosonde.php)
16. <http://laspace.lsu.edu/hasp/>
17. James Flaten, “*National survey of high-altitude ballooning by higher education institutions*”, 3<sup>rd</sup> Annual Academic High-Altitude Conference Proceedings, Trevecca Nazarene University, June 2012.

## Appendix A – Other MnSGC-Sponsored Aerospace-Build Activities at the U of MN

The *Spaceflight with Ballooning* freshman seminar is part of a portfolio of activities used by the MnSGC at the U of MN to promote interest in aerospace among both college and pre-college audiences. Here is a brief overview of other MnSGC-sponsored activities at the U of MN, and how they relate to *Spaceflight with Ballooning*.

1. The potential of using balloons to loft weather sensors into the upper atmosphere can be motivated in as little as a 1-hour session with groups ranging from college age to elementary school children (as young as 2<sup>nd</sup> grade) using Morse-code-transmitting Anasonde 3M radio kits<sup>15</sup> lofted by 3-ft-diameter paddle balloons. Non-flight kits were modified to snap together so they can be built over and over with different groups of students.
2. Extra-curricular weather ballooning constitutes the bulk of the MnSGCs ballooning program, with over 60 missions flown to date. (Note – There have only been four freshman seminar balloon flights.) The MnSGC has funded an extra-curricular Ballooning Team at the U of MN every summer since 2007. Since the start of *Spaceflight with Ballooning* in 2008, about half the students on the MnSGC Ballooning Team have gotten their start in the seminar.
3. The MnSGC Ballooning Team has regularly helped interested groups, mostly pre-college teachers and their students, build ballooning payloads provided them with a ride to near-space. The biggest such effort involved offering a workshop to teachers from about 10 local middle schools in the summer of 2010, then helping them build and fly one student payload from each school for each of the next two years.
4. During the 2012-2013 academic year the author offered an upper-level technical elective class entitled *Space Vehicle Systems* with lectures about outer-space vehicles plus a more-complex high-altitude ballooning activity than would be possible in a freshman seminar. That more-advanced class will be finished by the summer conference, so general comments about how it went will be included with the oral presentation.
5. For the past two years the U of MN has built a science payload (a miniature x-ray detector) to fly on HASP (High Altitude Student Platform),<sup>16</sup> an opportunity organized by the LA Space Grant to fly research-oriented science and engineering experiments under an 11-million-cubic-foot zero-pressure balloon with multiple hours of float time at altitude (35-37 km). The HASP team involves both graduate and undergraduate students. That payload is more complex than class-built or extra-curricular weather balloon payloads.
6. The success of *Spaceflight with Ballooning* has led to the development of two additional freshman seminars offered by the AEM Department. *Model Aircraft Design, Flight Test, and Analysis* has been offered annually since the spring of 2011. In that class students learn the basics of fixed-wing flight and build, test, and fly radio-controlled model aircraft. *High-Power Rocketry* was offered (instead of ballooning) in the fall of 2012. In that class students built high-power rockets, learning basic rocket aerodynamics in the process. Launches were hosted by the local high-power Tripoli Rocketry Club.

**Appendix B – Additional Photographs and Data from 2008-2011 Freshman Seminars**



Fig. 4 (2008) The “Rockettes” team with their mirror boom and Ideal Gas Law (IGL) payload.



Fig. 5 (2008) Interior of “Random Guys” payload: video, HOBOT, Geiger Counter.



Fig. 6 (2008) Up/out/down simultaneous views using the mirror boom from 37,000 ft.



Fig. 7 (2008) Students examine payloads after exceptionally short flight – only 40 miles.



Fig. 8 (2009) Inflating balloon in moderately windy conditions. Cold, with snow flurries.

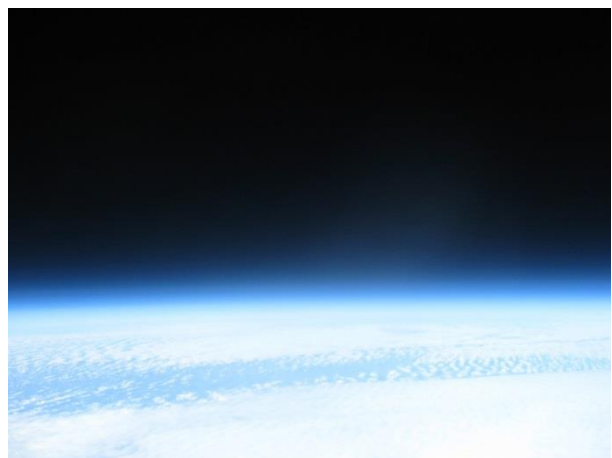


Fig. 9 (2009) View from 112,000 ft – highest freshman seminar flight (3000-gram balloon).

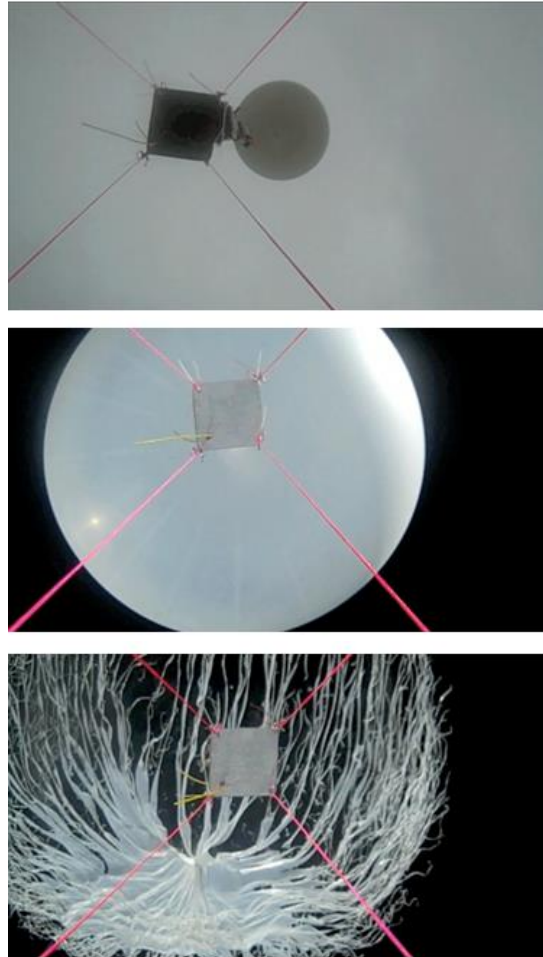


Fig. 10abc (2009) Video frames showing balloon grow from ~10 ft to ~50 ft dia. then burst.



Fig. 11 at left (2010) Inflating a 1500-gram weather balloon – a more-standard size.



Fig. 12 (2010) Payload stack in flight, just after release into a cloudless sky. One payload made use of a horizontal boom with a small balloon attached – another IGL experiment



Fig. 13ab (2010) Comparing photos taken with standard vs. infrared-enhanced still cameras

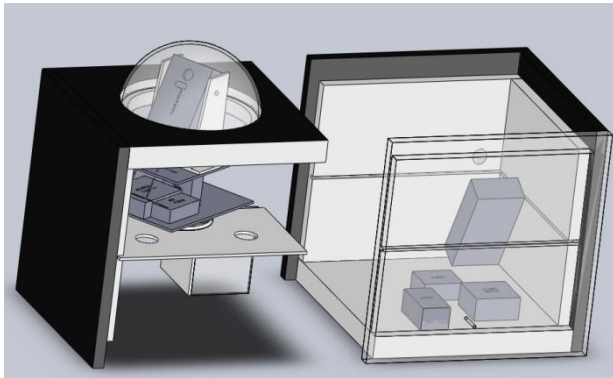


Fig. 14 (2011) CAD of camera-on-turntable payload to photograph the solar corona.

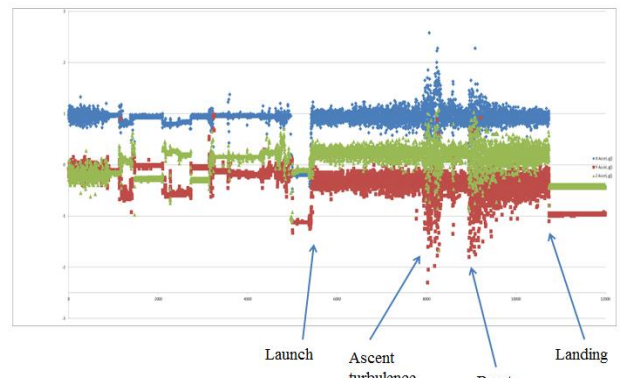


Fig. 15 (2011) 3-axis accelerometer record showing dramatic turbulence during ascent

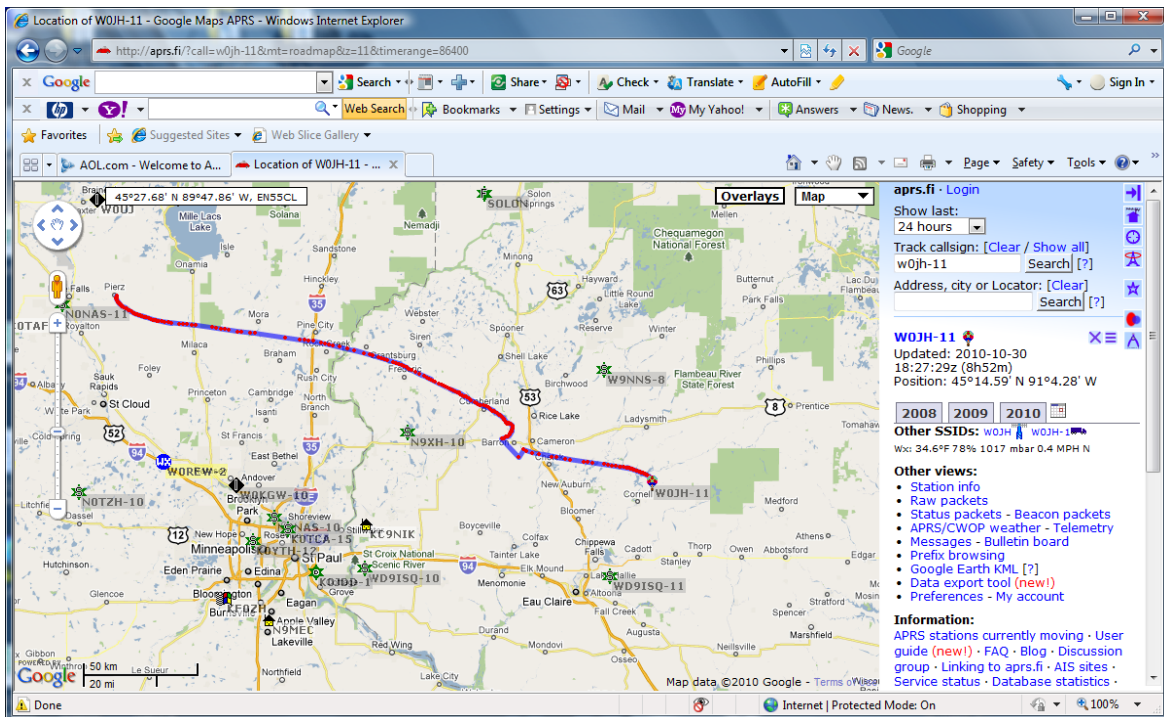
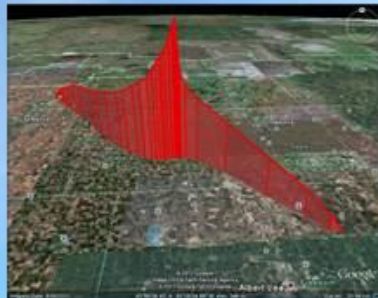
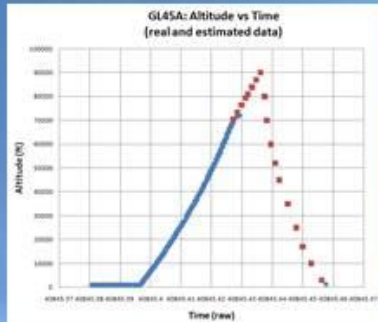
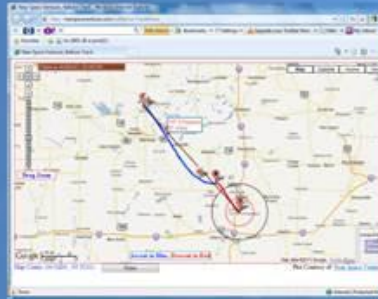
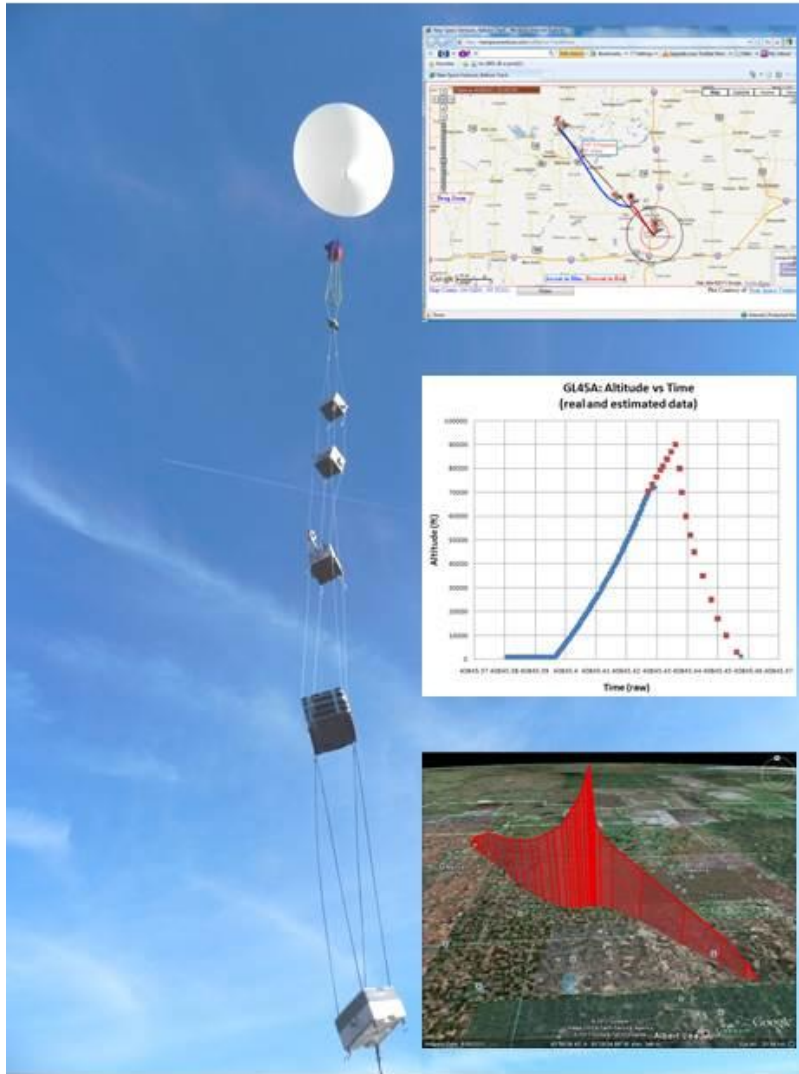


Fig. 16 (2010) Tracking map from this longest of the freshman seminar flights – over 150 miles.



# AEM 1905 Freshman Seminar High-Altitude Ballooning Exhibit

**Akerman Hangar, Tuesday, Dec. 13, 2011**  
**3:15 (inflation demo.) to 4:30 p.m.**



**All are welcome to join us for**  
**Hot Cocoa and Conversation.**

Questions? Contact Prof. J. Flaten – [flaten@aem.umn.edu](mailto:flaten@aem.umn.edu)

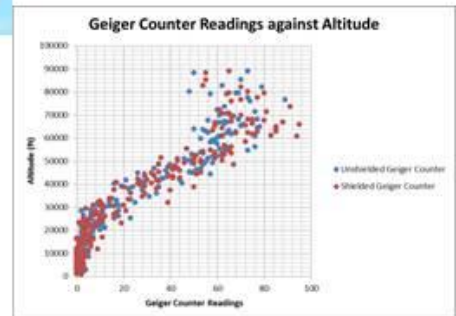


Fig. 17 (2011) Flier for a post-flight public exhibit of class payloads and results.