

EyePod-Mini: Constellations, Urban Launches & Buoy Landings

Hank Voss¹

Taylor University, Upland, Indiana, 46989

Jeff Dailey²

NearSpace Launch Inc., Upland, Indiana, 46989

Small and low-cost balloons using EyePod-Mini IO/radios are ideal for urban and constellation launches and for improving the learning experience. Most of the STEM population live in urban areas, near water, near forest, deserts, mountains, and remote locations and are unable to effectively fly conventional balloon systems. The EyePod-Mini is a professional grade all-in-one data and tracking pod with a mass of 150 g including 2.2 Ahr batteries. Its mass is significantly less than the mass of the balloon and it fits into the balloon neck (3 cm dia.) as an extended tube. It communicates 24/7 globally with Globalstar satellites via the internet. An additional low power 900 MHz tube section and a 2m APRS Ham radio tube section are also available for real-time data and tracking.

Another EyePod-Mini option is its design to float in water as a buoy surface monitor or as a live ground probe in remote regions for additional geo-learning. Because the probe is small it is ideal for balloon constellations making many measurements over an interesting set of time and space coordinates. The EyePod-Mini assembly can be flown in a teardrop shape to reduce drag and improve turbulence and wind measurements. Multipoint measurements help visualize the dynamics of the atmosphere and a better understand weather fronts, thunderstorms, eclipses, and turbulence to improve models and learning. External instrument pods can be attached to the EyePod-Mini as well and the data wirelessly connected between all of the pods.

Use of two small balloons for a launch ensures good linear altitude data collection for ascent and decent (no free fall). Small balloons with small radios are ideal for urban launches near water and forest since the experiments can continue to work as ground probes with the satellite link and solar array charging. It is reasonable to launch the EyePod-Mini without the expense of chase and recovery in difficult terrain. Because the EyePod-Mini is a rod like spear without attachment cords it is much easier to recover from treetop landings. For lake landings data can be acquired on the surface as the payload drifts and sails to the shore for pick-up. Because the Globalstar link works globally, long duration flights are possible using solar cells with useful data over oceans and desolate areas. With smaller balloons the EyePod-Mini is also designed for floating using a valve attached at the nozzle.

¹ Professor of Engineering and Physics, Taylor University, Upland, IN, hnvoss@taylor.edu, and also NearSpace Launch Inc., 9702 E 825 S, Upland, IN 46989, Cell 765 618 3813. AIAA Member, KB9ZNZ,

² Chief Engineer, NearSpace Launch Inc., 9702 E 825 S, Upland, IN 46989, Cell 260 241 0409, jfdailey@nearspacelaunch.com

I. Problem and Introduction

Miniature and low cost tracking and data acquisition systems (3 cm diameter EyePod-Mini) now permit smaller balloons (~3 ft diameter at launch) with: 24/7 coverage and open flight opportunities for urban launches and landings in wooded areas, oceans, lakes, and remote deserts and mountains areas. Mini-balloons would also improve safety and liability concerns because of perceived simplicity, slow decent, and lower mass. The mini balloon concept (<300g) is ideal for teachers or researchers who want to focus on the teaching part and develop their own experiment boxes and not worry about all of the logistics of the tracking, communication link, launch details, software, and recovery. Perhaps the most complex, costly, and demanding part of a high-altitude balloon flight system is coming up with a reliable and low mass flight processor and communication Command Pod system with high performance and a ground segment (capable of producing real-time displays, tracking maps, and archive data storage for analysis).

The EyePod system has been described previously by Dailey and Voss¹. In this paper we present the EyePod-Mini design that is modular and fits into the neck of the balloon for less drag, eliminating most needs for tethered cords with associated tangling and reducing experiment rotation with the EyePod-Mini system. The complete Globalstar EyePod-Mini system cost less than \$600 and can be used many times to amortize per launch cost. The EyePod-3 was the first available All-In-One Globalstar balloon system and is mostly configured in the conventional sense as a small “hockey puck” 8-10 cm cylinder pod attached to tethered cables. Many options are available and discussed.

II. Technology Options and Solutions

A number of Technology options are available for balloon launches (Voss and Dailey^{2,3,4}) depending on the mass of the communication system, processor system, and payload. A number of these options are given in Table 1. Recently the Global Space Balloon Challenge (GSBC) program¹⁴ has also introduced a number of manufactures of balloon hardware systems and has stimulated many educational balloon launches. Many good papers and curriculum ideas for using balloons can be found in the previous five years of AHAC conference proceedings. Many of the technical details for balloon flight can be found the references⁵⁻¹³.

The recent EyePod solution for a low cost Command and tracking Pod that fits into the neck of the balloon (called EyePod-Mini) may be the disruptive technology that will enable most schools to implement successful launches at ease with minimum training. This technology was embolden, in part, due to two previous CCLI NSF grants at Taylor University and the recent spin-off of the company

NearSpace Launch, Inc. (NSL) with the mission of providing near-space Technology, Service, and Education⁶. The All-In-One design of a complete Command POD on a single 1 inch wide Printed Circuit Board (PCB) with antenna that fits into the balloon neck and that is mass produced eliminates many connectors and cables and becomes affordable (About 1/10 of cost of conventional systems when

Table 1: Technology Options for Starting a Balloon Program

Approach and Radio	Performance	Initial Cost	Risk	Data Rate	Ground Station	Need for Training
1) Build from <u>Scratch</u> Ham Radio, ISM, SPOT Tracker	Team up with experienced group, Workshops, May need Ham License, Custom features	Very High	High	Variable	Yes	High
2) <u>Full Flight</u> Turnkey 1W ISM, Zigbee	Real time data, GPS, sensors, Constellations, Service	High	Low	High	Yes	Medium
3) <u>All-in-one System</u> Globalstar/Iridium, ISM, and Zigbee,	Real-time data & SD Card, GPS, sensors, tree cut-down, options Constellations, Research Grade	Medium	Low	High <1 s sampling	No	Low
4) SPOT <u>Globalstar</u> Tracker	GPS, Altitude limited, No data, few tracking points	Low	Low	Medium 10s s	No	Medium
5) <u>Launch for Hire</u> , Full flight system, sensors, Data Base	<u>Globalstar</u> and ISM, Real-time data, common data base, SD card Research Class	Low	Very Low	High <1 s sampling	No	Very Low
6) <u>Tether system</u> Low power ISM	<u>Realtime</u> data, SD Card, GPS, <1000ft height, no Chase	Very Low	Very Low	High <1 s sampling	Yes	Low
7) <u>One-use Low cost</u> <u>Globalstar/Iridium</u>	No chase cost, <u>GPS</u> , fly over poor recovery terrain (water, trees, etc.) Common data base	Very Low	Very Low	Medium 1- 100s sampling	No	Low
8) <u>Data Loggers</u>	Earth and flight support systems, Must add GPS and Radio	Very low	low	High	No	Very Low

including the Ground station and up to 10 times in performance and reliability, (see Dailey and Voss¹).

In general, eight Command and Tracking Pod options are available and compared in the Table 1 tradeoff matrix for balloon flight systems depending on objectives: 1) Build your own system, 2) Buy a full working system, 3) Buy an All-in-One flight data and communication system (e.g. EyePod-3 or EyePod-Mini), 4) Build only the payloads and let a Launch-for-Hire group launch your experiments (while students watch live on the internet), 5) Buy or build a simple tether balloon system for testing experiments and teaching, 6) Buy a low cost disposable data and tracking system (e.g. EyePod Neck Mini) that also attaches live to an experiment pod. The EyePod-Mini is convenient for students to assemble the full payload, participate in a launch, and watch the data console live in their classroom. There is no need to recover payloads because of difficult terrain, urban location, near coastline water, or

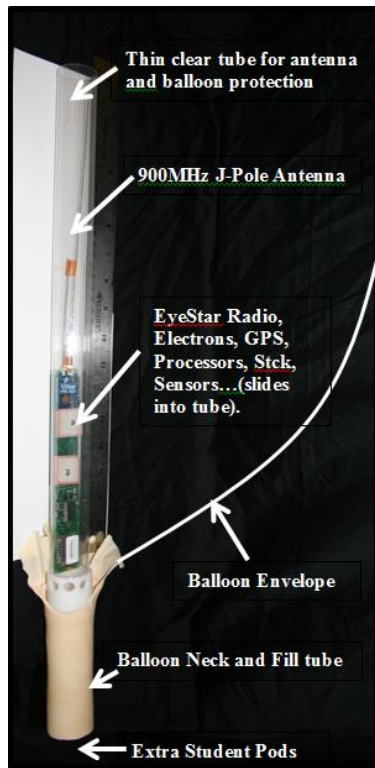


Fig. 1 EyePod All-in-One Neck Version located in the neck of Balloon.

In April 18, 2014 a successful student satellite (TSAT¹³) was launched on a Space-X rocket and used the EyePod and EyeStar new technology. In our recent six year ABET (Accreditation Board for Engineering and Technology) review the satellite/balloon efforts were identified as one of the three major department strengths. Over 350 balloons have now been successfully launched from Upland with over a 99% operational success and recovery rate. In addition, the previous two CCLI NSF grants at Taylor had many positive outcomes beyond what we expected in our original proposals. One positive outcome was the start-up of two successful companies for Ballooning (Stratostar Systems LLC and NearSpace Launch Inc., NSL) that ensure further stability and longevity of critical parts and service to a national STEM market.

remove cost/risk of chase). The Mini-Balloon also can be in contact with Globalstar as a low data rate while powered by a solar cell as an earth science probe (monitor ground conditions,(T, P, H, etc. or as a buoy if landing on water and operate remotely for months with student experiments). and finally 8) Fly a simple data logger attached to a SD card with a simple tracking device for chase and recovery.

Experience for the Balloon technology was developed over the past decade at Taylor University in Upland, IN for undergraduate student learning because of the measurable impact it had on STEM education and research for both Science and Gen. Ed. majors. The Balloon program advanced students learning to the point that a follow-on undergrad upper level CubeSat program began.

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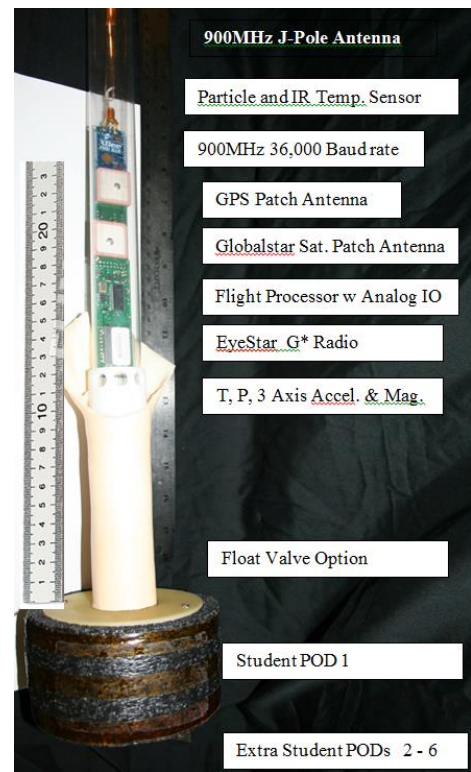


Fig. 2 Zoom of the electronics portion of the EyePod All-In-One system..

The All-in-one enabling technology -approach (EyePod, #3 in Table 1 implements the \$2B commercial Globalstar phone network of 40 plus Low Earth Orbit (LEO-Fig. 3) satellites to communicate with balloons. EyePod includes GPS, 2 GB SD-card storage, experiment digital and analog inputs, wireless pod-to-pod communication, battery, tether line attachments, and some calibrated sensors (T, P, 3 Axis Accelerometer and Magnetometer, light sensor, and PIN particle detector for Cosmic Rays). The EyePod is available in a “Hockey puck” version (Puck version) or in a narrow version that fits into the balloon neck (EyePod-Mini or neck Version). The Puck version is a cylinder 7cm long and 10cm in diameter. It includes a commercial FCC license.

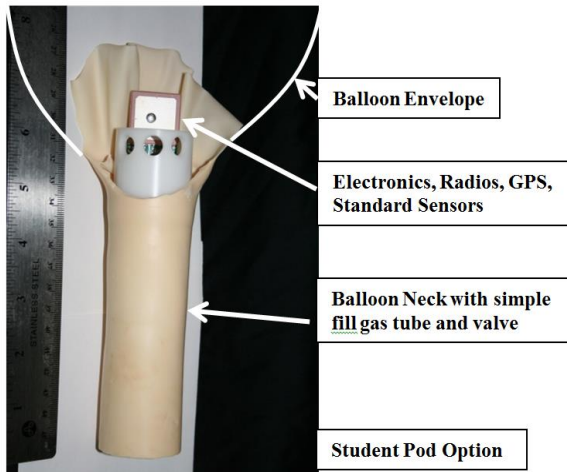


Fig. 3 The EyeStar- Mini module

The General EyePod Command Module that is located in the neck of the balloon is shown in Figure 3.

Innovative EyePod-Mini All-in-One design located in the neck of balloon. The Command Pod was developed for balloons and satellites (EyePod and EyeStar^{1,3}) and was demonstrated for global coverage and data transfer on TSAT. The neck EyePod-Mini version for balloons greatly reduces costs, improves launch success and data communication success, and reduces drag for better wind and turbulence measurements.

Figure 2 shows a zoom of the electronics portion of the EyePod-Mini All-In-One system. The electronics board slides part way down into the rigid clear tube which is used for easy fill of lifting gas and attaches to the innovate student pods. Several student pods can be attached to the EyePod-Mini with multiple experiments in each Pod. A single small student Pod is shown at the bottom in Figure 2.

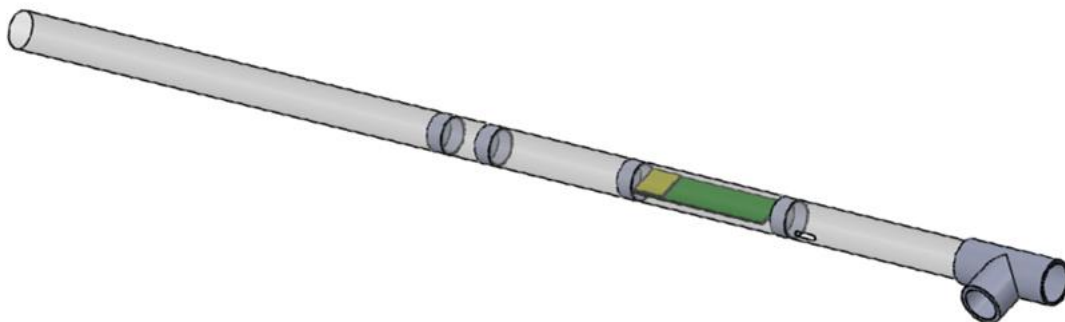


Fig. 4 CAD rendering of EyePod-Mini unit showing water bulkheads and T for filling balloon.

A simplified EyePod-Mini neck version is shown in Figure 3 and is used for urban, coastal, and rugged terrain regions where it is not economical to recover the payload. All data and GPS is streamed in real-time to the GlobalStar network for open internet storage and for mapping and sensor plots.

A CAD 3-D rendering is shown in Figure 5 and the orthographic view is shown in Figure 5. The clear

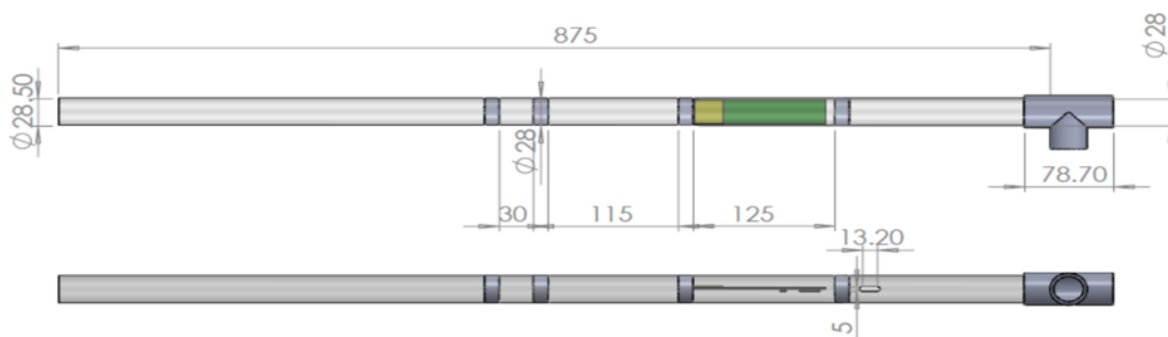


Fig. 5 CAD orthographic views of EyePod-Mini unit showing some dimensions in mm.

plastic tube is lightweight and suitable for flight. The bulkheads are used for securing internal assemblies and for water tightness. When the tube is inside of the balloon it better protects the light weight 900 MHz J-pole antenna and reduces payload drag. The clear plastic tube is used to give students visibility of the communication, GPS, and processor system. The tube has also been used successfully to measure the internal lifting gas temperature to better predict heat transfer rates and resulting lift. The top end of the tube is usually fitted with a small bumper cushion to prevent a sharp edge rupturing the latex balloon surface.

The tube system is very modular depending on the students and class creativity in meeting their requirements. There are several basic modules that can be assembled in various configurations. The available modules include: 1) the Globalstar beacon assembly with processor, 2 Gbyte memory card, and GPS, 2) the 900 MHz communication system with J-Pole antenna and GPS, 3) the APRS Ham 2m transmitter with GPS, 5) A battery pack, 6) the fill and interface unit, and 7) an experiment module. Usually two communication systems are flown and high speed continuous processor data is also stored on the 2GB memory stick for later analysis.

Students and other researchers can pick and play with mixing the EyePod-Mini with conventional parachute and pods with tethers or can choose options such as the Hydro-Parachute (HydroChute) system and/or with the auxiliary small balloon.

III. The Secondary Balloon and HydroChute Design Options

For most urban launches it is desirable to launch from an open area like a park in low wind environments with small balloons (<300g) with sufficient lift for >1000 ft/min ascent velocity. Special permission is required if you launch within 5 miles of an airport. In A launch we did in Albuquerque, NM we were within 5 miles of the international airport and we were easily able to get approval but had to call the airport when we launched. We have also launched larger balloons (1000g) at the County Fair in Indianapolis and at Science Central in Fort Wayne without any problems. Smaller balloons are much easier to launch, lower costs, lighter, and do not have the perceived risk associated with them for a universities or K-12 schools to readily support as an educational outreach.

The basic concept for the urban launch is shown in figure 6 with several options. The design for simplicity implements a 1 inch clear tube structure that is inserted into the neck of the main balloon for

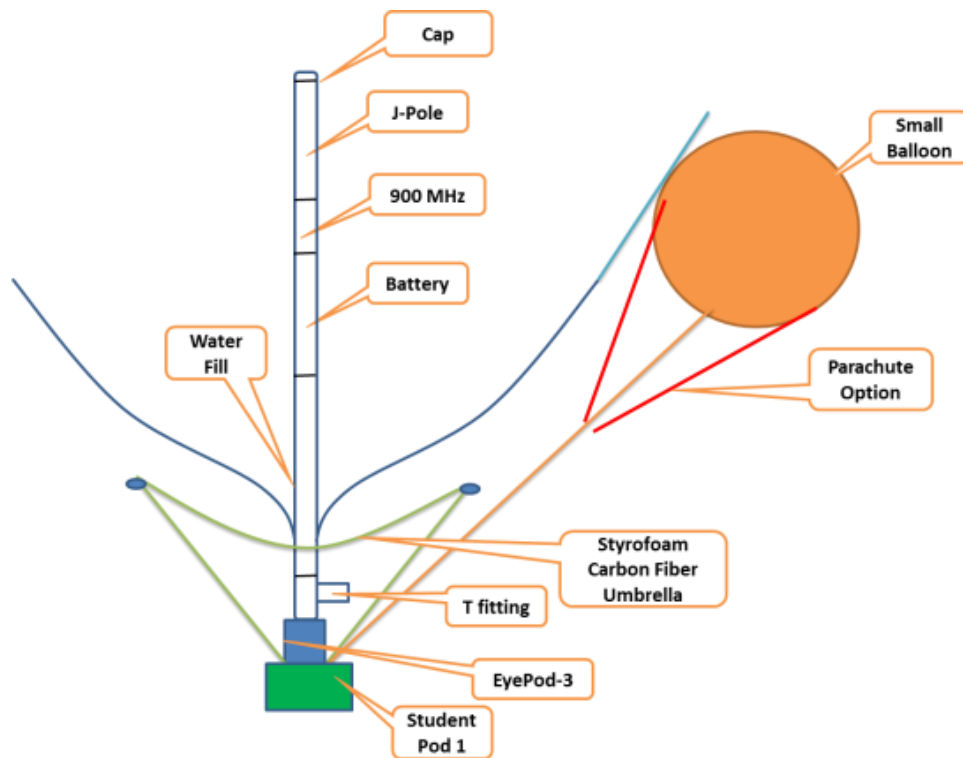


Fig. 6 HydroChute concept design for urban launches using 200 g balloons

protection of the 900 Mhz antenna, improved measurements, and better aerodynamic flow.

To improve descent data collection and prevent chaotic free fall after burst in stratosphere it is advantageous to fly a secondary small balloon. After the main balloon burst the partially inflated smaller balloon with its partial lift and larger diameter in the stratosphere slows down the descent through the exponential atmosphere resulting in a descent rate profile similar to the ascent profile. The violent free

fall period is eliminated resulting in good stability and collection sensor data for comparison with ascent. The parachute can be wrapped around the secondary balloon or can be flown as a drag parachute.

If expecting a water landing the HydroChute option is available and attaches to the EyePod-Mini structure with a quick disconnect. The HydroChute is fixed in shape and is made of foam board material, fiberglass, and aluminum facesheet. The purpose of the HydroChute is to 1) act as a backup parachute if the secondary balloon also burst, 2) helps float the payload in an upright position if landing in water or upright if landing as a ground probe in a remote area, 3) acts as a radar reflector for flight for added safety, 4) forms the base structure for solar cells to keep the transmitter and sensors powered when floating or as a ground probe, 5) acts as the structure for mounting sensors and cameras to collect experiment data, and 6) is a platform that is fixed to the balloon for less rotation and pendulum motion relative to the cable tethered pods.



Fig. 7 Secondary balloon nighttime astronomy launch and resulting landing configuration with just the secondary still inflated. Note the stretch marks on the secondary balloon after it returned from high altitude flight. The balloon was actually successfully flown on another flight.

When the secondary balloon is mounted at the bottom of the 1 inch tube structure the assembly becomes much more streamlined and robust (see figure 7). The aerodynamic shape results in less drag and turbulent eddies. Because the two balloons are connected together the rotations can work against each other and there is less pendulum motion. With only limited data sampling at this time better stability enhances data collection and wind measurements.

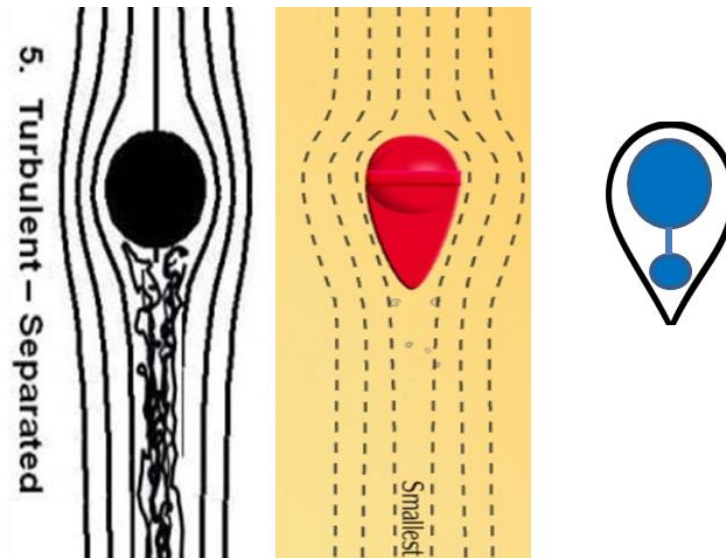


Fig. 8 Aerodynamic Secondary Balloon, HydroChute, and Tube structure for more aerodynamic shape, data collection, and symmetry

A CAD SolidWorks flight sequence for the HydroChute is shown in Figure 9.

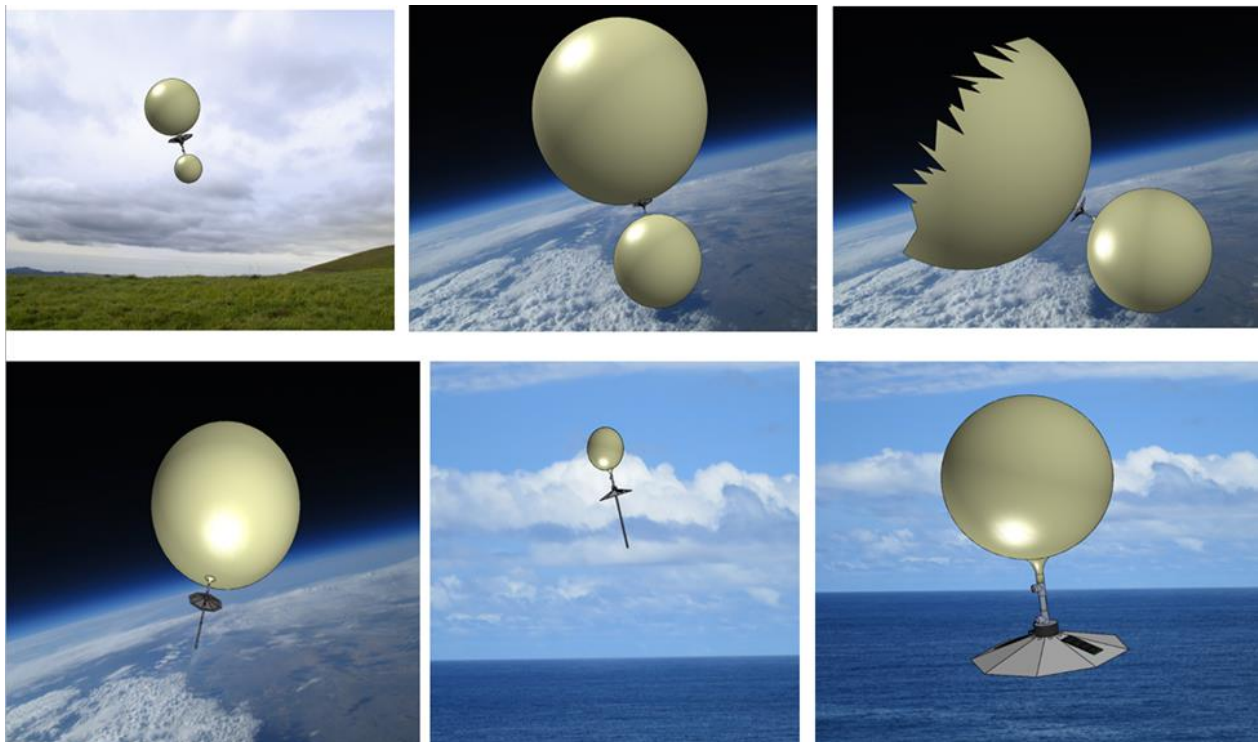


Fig. 9 CAD simulation showing launch, High altitude, Burst, Secondary balloon decent, Water approach, and hydro landing

Initial Testing of the HydroChute was done with a 71cm diameter prototype. As shown in Figure 10 it was dropped from a bridge at a height of 11 meters in our Euler science building. A 12 m scale in one meter increments was attached from the bridge and extended to the floor. Various configurations were tested with and without the secondary balloon and with the parachute having various size top holes for stability. The terminal velocity with a secondary balloon was found to be about 2 m/s and the terminal velocity of just the HydroChute was about 3 m/s.

After these aerodynamic tests the HydroChute's buoyancy was tested. To do this we brought the prototype used in the aerodynamic balloon test down from Euler to Taylor Lake. There the balloon was dropped and slowly went into the water, allowing the payload and HydroChute to adjust and actually float! The underwater part of the tube was designed with some holes to flood certain sections for ballast weight. The water tight sections contained the LiPoly battery packs and the 900 Mhz transceiver. Because of water filling and the battery weight the bottom tube acts as an anchor which seats the HydroChute and allows it to float along the surface of



Fig. 10 Measuring the performance and terminal velocity of the HydroChute and Secondary Balloon options.

the water due mainly to the Styrofoam chute which has been flipped around from takeoff (see Figure 11).

The result was extremely encouraging as the buoyancy and Center of Gravity worked perfectly and the payload, sensors, and Globalstar EyePod stayed protected and operational above the chute.

The next test was to see if the Secondary Balloon would work as a sail that guided the chute on water to shore where it could be picked up. To do this, we tossed the HydroChute assembly into the lake from the far end and returned about a half an hour later to see if it would blow to the other side of the lake without any added help other than nature and the balloon as a sail. We returned with a long hook

attached to a pole, expecting to have to recover it from the reeds, and that was *if* it survived floating all the way across the lake without sinking. However, when we arrived with our pole we discovered that not only had the chute remained buoyant for its entire journey across the lake, but the sail also worked well at driving it up onto the shore of the lake opposite where it was launched from, so no pole was needed. This test proved the first HydroChute prototype to be operational for a water landing.

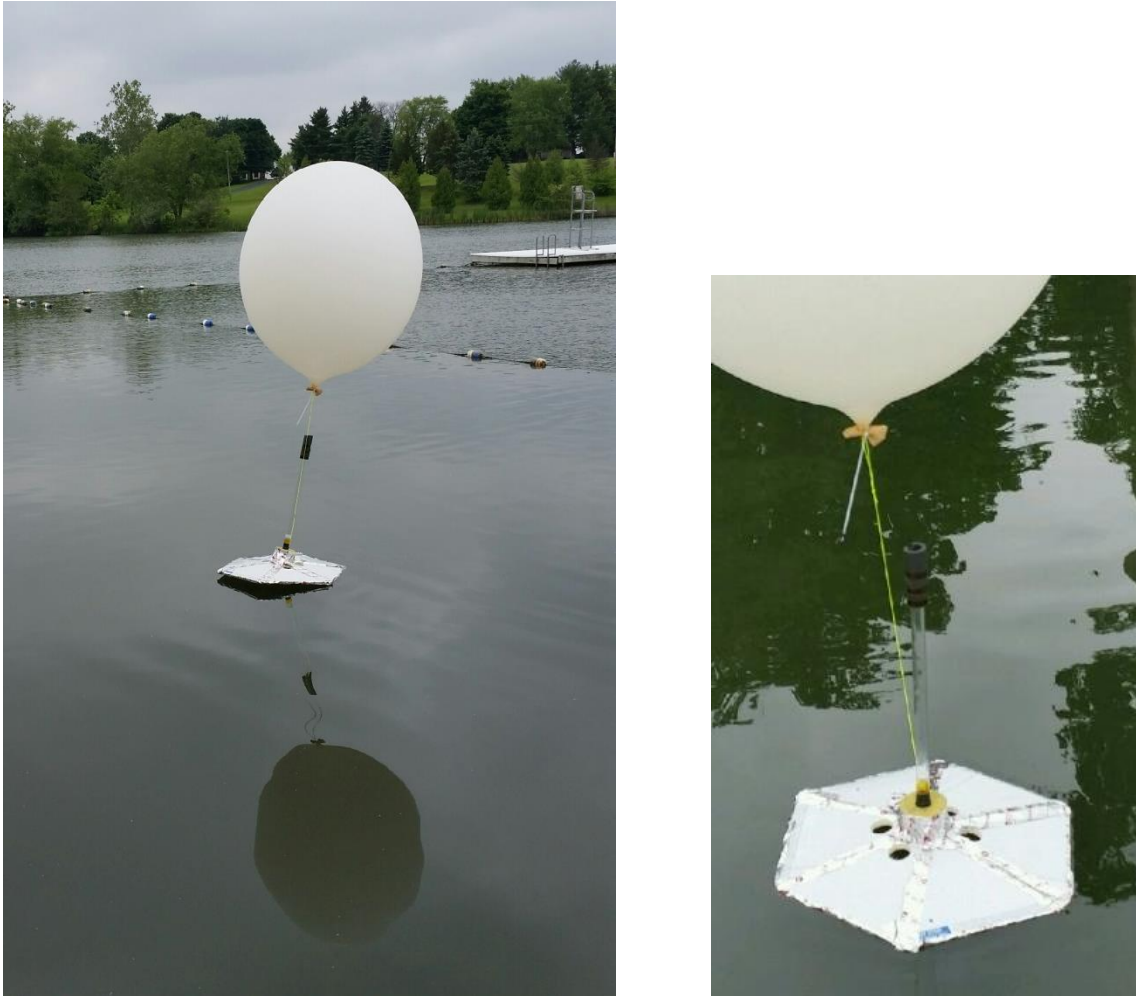


Fig. 11 The left picture shows the HydroChute with balloon as a sail. It successfully made it across the lake on its first maiden voyage. The right close-up picture shows the HydroChute floating above water with the payload and Globalstar link. The Clear shaft above can house the 900 MHz unit or a APRS Ham radio link. The four holes in the HydroChute are for parachute aerodynamic stability and for improving external temperature measurements with the higher flow.

IV. Data and Tracking Ground Segment Data Management Plan

The Data and Tracking Ground Segment Data Management is already operational for balloon and satellite data and has unlimited bandwidth (Figure 12). No balloon ground station with tracking antenna is required with the EyePod Puck or Neck Versions. Another advantage of the common Globalstar communication network is the standardized Structured Query Language (SQL) database with common and time ordered GPS and sensors data for single and constellations of balloons. As many institutions begin to use the Globalstar modem and server (EyePod) a unique and common open data set will be available for constellation study, for STEM learning, and for research data mining.

Launch-for-Hire customers can also watch their data streaming live on the internet while the flight is in progress and can also watch the balloon footprint on a map (see Figure 13). This so called Dashboard capability on the console is useful for live data but it can also be used for post flight data plotting.

Students

particularly like watching the real-time display of their instrument performance and compare it with the other sensors. Student data analysis and reports can begin immediately after the flight and before the payload is recovered.

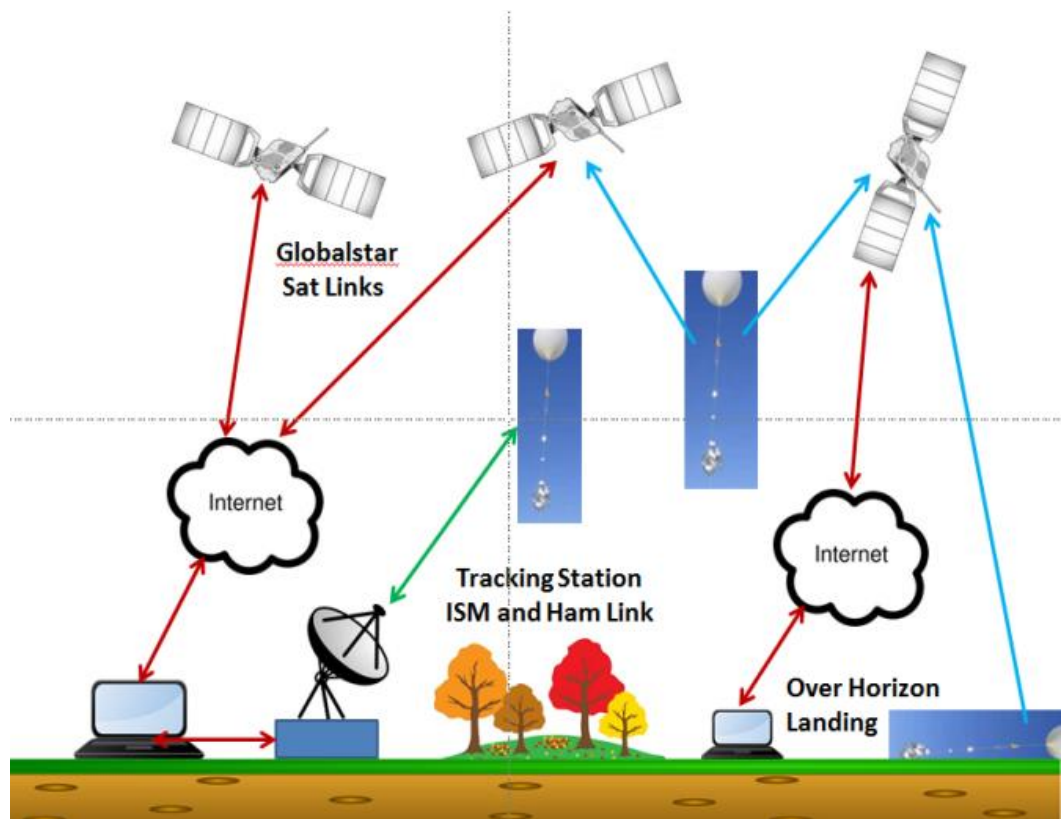


Fig.12 New paradigm in ground tracking using the commercial Globalstar communication network (No over horizon problem). No ground station is required with data available on internet server. Coverage is global for international and long duration flights and for multi-balloon/constellation flights and common database.

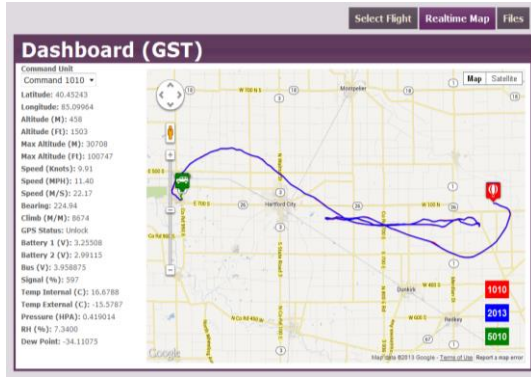


Fig 13 Shows one example of one Dashboard window available for real time tracking of a balloon flight. Other windows can be used for graphing data as it becomes available.

In Figure 14 a block diagram shows how the data flows from multiple balloons to LEO satellites, through the Globalstar network of satellites and gateways to the NSL server. The data from multiple space platforms are then parsed into separate files with time, GPS, and spacecraft data for a specific customer to be downloaded or pushed to the customer server. A number of encryption and security measures are available.

One of the powerful capabilities of the EyePod data system is that all Globalstar data comes through a single Common Time Ordered Data Base (see right side box in Figure. 14) with common GPS data and EyeStar sensor data.

The NSL server is redundant and backed up on the cloud as well. The data base can be open source so students and researches can compare their data to other common sensors flown at different time and locations. For example, STEM flight data temperature profiles would be available for inter-compared with temperatures at other solar zenith angles, other seasons, and other locations.

Balloon-Satellite-Globalstar-Server Data Network

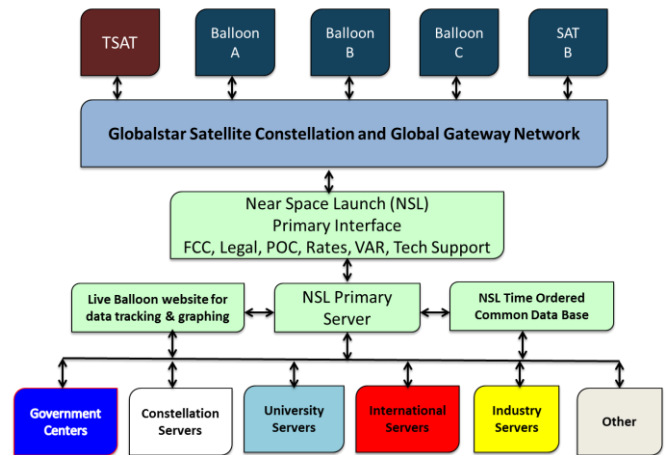


Fig 14 Block diagram of how data flows from various Balloon and Satellite systems through the NSL primary server and then to servers or log-on file data transfers to other institutions



Fig. 15 The EyePod all-in-one data system was recently tested (Dec. 13, 2014 at Highland High in Albuquerque, NM with a suite of exciting instruments. Photo courtesy of Albuquerque Journal, Saturday December 13, 2014.

V. Summary

The EyePod All-In-One data system was tested (Dec. 13, 2014 at Highland High in Albuquerque, NM (Figure 15). This school has a high percentage of minority students. The launch engaged over a thousand students and a few classes developed student Pods that were launched (enthusiastically with some mascots and flags as well). Students participated with the launch, tracking, and data collection. A teacher went on the chase that recovered the payload in the desert over a mountain range away and returned it back to the students with many stories. This picture (Figure 15) and a story appeared on the front page of the Albuquerque Journal Metro section the next day. The school plans to implement more launches as they analyze the interesting EyePod data and their experiments. (This launch was partly supported by the AFRL for a Pilot Study program for High Schools and others.) The EyePod-Mini now extends the use of balloon systems more economically and geographically to more students and researchers.

VI. Acknowledgments

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VII. References

- [1] Dailey, Jeff, and Hank Voss, EyePod-3: An all-in-one Global Data & Tracking Module, 5th Annual Academic High Altitude Conference (AHAC), North Dakota, 2014
- [2] Voss, H. D., Jeff Dailey, and Steve J. Snyder, High-Altitude Balloon Launches and Hands-On Sensors for Effective Student Learning in Astronomy and STEM, Voss, Earth and Space Science: Making Connections in Education and Public Outreach, ASP Conference Series, Vol. CS-443, p340, ©2011, Editor Jenson: ISBN 978-1-58381-766-7.
- [3] Voss, Hank and Don Takehara, Strengthening Balloon Programs: University and Business Collaborations, Research, Outreach, and Internal Support, 5th Annual Academic High Altitude Conference (AHAC), North Dakota, 2014
- [4] Dailey, Jeffrey F., "Over-The-Horizon Global High Altitude Balloon Communications System," Proceedings of the 4th Academic High Altitude Conference, Taylor University, June 26-28, 2013.
- [5] Augustine, Norman R., et. al., *Rising Above the Gathering Storm, Revisited*, The National Academies Press, Washington, D.C., pp. 4-5.
- [6] Voss, Hank D. and Dailey, Jeff, "Express Launch: A New Capability for NearSpace," *Proceedings of the 4th Academic High Altitude Conference*, Taylor University, June 26-28, 2013.
- [7] Takehara, Donald, Dailey, Jeffrey, Gavin, Susan, Snyder, Steven, and Smith, Bethany, "High Altitude Ballooning in High School Science Classes," *Proceedings of the 3rd Academic High Altitude Conference*, 2012.
- [8] Takehara, Donald, Medows, Pamela, Gavin, Susan, Dailey, Jeffrey, Snyder, Steven, Smith, Bethany, and Tomasik, Rachel, "High Altitude Ballooning into Undergraduate STEM Curriculum: Preparing for Widespread Implementation." *Proceedings of the 3rd Academic High Altitude Conference*, 2012.
- [9] Voss, Hank D. and Dailey, Jeff, "High-Altitude Balloon Curriculum and Hands-On Sensors for Effective Student Learning in Astronomy and STEM," *Proceedings of the 3rd Academic High Altitude Conference*, 2012.
- [10] Voss, Hank D., Ramm, Natalie A., and Dailey, Jeff, "Understanding High-Altitude Balloon Flight Fundamentals," *Proceedings of the 3rd Academic High Altitude Conference*, 2012.
- [11] Dailey, Jeffrey F., "Extended flight time of latex balloons through the use of a buoyancy control system," *Proceedings of the 2nd Academic High Altitude Conference*, 2011.
- [12] Yajima, N., Izutsu, N., Imamura, T., and Abe, T., *Scientific Ballooning*, Springer, ISBN 978-0-387-0972715, 2009, pages 213
- [13] Voss, H. D. and J. F. Dailey et al., TSAT First Results and Globalstar Coverage Link, Cubesat Workshop, AIAA 26th Small Satellite Conference, Logan, Utah, August TSAT
- [14] Global Space Balloon Challenge, <https://www.balloonchallenge.org/>
- [15] Globalstar SPOT Tracking Device Product (<http://www.findmespot.com/en/>)
- [16] HOBO Data Loggers, (<http://www.onsetcomp.com/products>)