Development of an Adaptable Vent for Latex Weather Ballooning

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Abstract

Controlled venting of lift gas from a balloon while in flight allows one to slow the ascent, stop the ascent (AKA "float" the balloon), or even initiate a slow descent without going through the violence of "post-burst chaos." The ability to vent can allow balloon flights to reach altitude more quickly, loiter there as needed for experimental purposes, and/or take data during float or slow descent (which can be advantageous if payload sensors need to sample "clean air," rather than being in the wake of an ascending balloon). The stratospheric ballooning team at the University of Minnesota – Twin Cities has developed several vent devices over the years, some autonomous and others commandable by radio, but all were inordinately heavy and not particularly reliable nor efficient at allowing lift gas to escape, even when fully open. Inspired by an exceptionally lightweight, radio-commandable, but single-use (that is – intended to fly away with the balloon, rather than being recovered) vent built by ballooning collaborators at the University of Colorado Boulder, our team has developed a vent which has sensors so that it can operate autonomously, as well as a radio so that it can be commanded, either from a nearby payload or from the ground (if an uplink radio system is in place). Our mechanism is designed to be used with 1600 gram (wide-neck) Hwoyee weather balloons and has a relatively large vent opening so it is quite responsive, as long as venting is done before the balloon becomes too stretched out to provide the needed overpressure to efficiently expel lift gas. The mechanism construction is nearly all serviceable and the vent is reusable because it features a "waist line" cutter, which allows it to detach itself from the balloon (and subsequently be recovered). It also has a "main line" cutter for emergencies (since the vent would then fly away with the balloon, and not be recovered). In flight tests to date the vent has proven to be strong enough to hold a "full" (12 lb) stack, efficient enough to vent 6 lb of excess lift (needed to stop a "full" stack from ascending) at altitudes in excess of 70,000 feet, and capable of detaching from a balloon and being recovered (though admittedly we lost some vent mechanisms during testing). The autonomous logic allows us to program the vent to target specific ascent rates, including a near-zero ascent rate to "float" a balloon, and to call for terminations based on elapsed time, gps fences, and/or specific target altitudes on ascent or descent. We have flight-tested the ability to control the vent by XBee radio from a nearby payload. In the near future, we plan to integrate our radio system with the Iridium uplink system that will be used by the Nationwide Eclipse Ballooning Project (NEBP), making our vent commandable from the ground. Ultimately, we intend to use this vent to float balloons during eclipse ballooning missions in 2023 and 2024. Indeed, we already refer to it as the "e-vent" (AKA "eclipse vent").

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1. Introduction

The ability to vent lift gas from a latex weather balloon during flight allows one to reduce the ascent rate, potentially reaching "float" or even entering a "slow descent." This allows missions to reach altitude in less time and with less drift, float/loiter at a specific peak altitude and allow payload swing and rotation to dampen out, and/or provide a slow/gentle descent which may improve data quality for experiments that are adversely impacted by being in the wake of an ascending balloon. Venting to a float condition means that vertical oscillations due to the passage of meteorological gravity waves should be easier to detect. Natural reduction in payload swing and rotation in a floated balloon stack is beneficial for photography as well [1].

There have been presentations about latex weather balloon vent projects at AHAC (Academic High Altitude (Ballooning) Conference) events, including reports from Taylor University in 2011 [2], the University of Minnesota in 2014 [3], Montana State University in 2015 [4], and the University of Southern Indiana in 2015 [5]. These vent devices varied widely in weight and effectiveness, with the U of MN one (by our own admission) leaving much to be desired. All were academic/research projects – none of the vent devices made it as far as commercialization, as far as we know.

Starting in 2018, our team began collaborating with balloonists at the University of Colorado Boulder and also Embry-Riddle in Florida on a MURI (Multidisciplinary University Research Initiatives) project dubbed HYFLITS (Hypersonic Flight in the Turbulent Stratosphere) [6]. In that collaboration, Prof. Dale Lawrence and his students at the University of Colorado Boulder developed a reliable, exceptionally-light-weight vent which could reliably stop an ascending weather balloon carrying a ~2 lb payload at altitude (typically just above 110,000 ft) and coax it into slow descent, for data collection by suspended sensors as they penetrated "clean air." The sections that follow describe features of the HYFLITS vent, which inspired us to develop a version with additional functionality for use with larger-neck weather balloons carrying heavier stacks (so we need to vent much more lift gas than MURI flights) – with the intent of using it to float up-to-12 lb stacks during two upcoming solar eclipses.

2. Features of the HYFLITS Vent

The HYFITS vent, pictured in Fig. 1, is controlled by XBee radio from a nearby payload. The vent itself has neither a gps nor a pressure sensor with which to determine altitude and make autonomous decisions about when to open and close. As described in Ref. 6, the HYFLITS vent system attempts to follow a pre-defined ascent rate versus altitude trajectory, with the vent opening if the stack is ascending too quickly and closing if it is ascending too slowly for the altitude in question. The approach has been shown to be effective at reliably reaching a target altitude by compensating for modest differences in inflation, resulting in different initial ascent rates, as also for vertical winds encountered during ascent. The HYFLITS vent is intended to be a single-use device. Once a terminate condition is reached – typically a specific altitude on descent, after a "slow-descent" phase during which experiment data is collected – the vent is commanded to sever the main line connecting it to the payload(s) below after which the vent is carried away with the balloon and is neither tracked nor recovered (so a new vent must be constructed for every flight). The payload(s) descend by parachute, as is typical for most stratospheric ballooning missions.

3. Desired Additional Vent Functionality

Motivated by the HYFLITS vent design, our team set out to build a similar vent but with additional functionality. In particular, we wanted a vent that could be recovered for reuse. This required a

Figure 1: Photo of a HYFLITS single-use, radio-commandable vent, which only weighs about 4 oz. For a photo of this vent somewhat disassembled, with parts labeled, see Ref. 6.

mechanism whereby the vent could disconnect itself from the balloon above it, not just from the payload(s) below it, though we maintained the latter as an "emergency" cut capability. We also wanted a vent with a larger opening, to take advantage of the wide necks of the Hwoyee weather balloons. (The HYFLITS vent was designed to fit into the narrower necks of Kaymont weather balloons, though it can be used with wide-neck Hwoyee balloons as well.) Our vent has both gps and a (back-up) pressure sensor, so it can be programmed to operate fully autonomously. It also has an XBee radio with which it can be commanded from a nearby payload which, in turn, could potentially relay commands from the ground. We elected to use more-conventional batteries than HYFLITS vent (we use 9 volt Energizer "Ultimate Lithium" batteries) and we also selected a servo with a feedback line and added three indicator LEDs, to give users more feedback about what the vent as actually doing (as opposed to just logging what it was told to do). We made a custom pcb for the vent avionics that used only through-hole soldering, for ease of construction, and limited the use of epoxy so that our vent mechanism was fairly serviceable.

Early development of our vent, hereafter called the "e-vent" (which stands for "eclipse vent," because of our intent to use it during eclipse balloon flights in 2023 and 2024), was led by Jacob Meyer. Ref. 7 is a poster summarizing Jacob's progress on the e-vent as of his graduation in the spring of 2021, with Fig. 2 from that reference showing his final e-vent design. Jacob was able to successfully vent 1600 gram Hwoyee weather balloons carrying ~2 lb payloads up to 110,000 ft, and after his graduation we managed to vent two balloons at 120,000 ft with Jacob's vent design. Those 1600 gram balloons are much less expensive than the 3000 gram Kaymont balloons used by our MURI collaborators, and also require less helium for inflation. Jacob developed a custom pcb for e-vent avionics, implemented two cut resistor circuits using H-drivers (different from the

Figure 2: Photo, from Ref. 7, of Jacob Meyer's e-vent (final iteration). Avionics are inside insulated tubing (on the right) and the waist-line cut resistor is visible (in the foreground, on the left). Small permanent magnets (on the left, at the bottom) were used to strengthen the flapper seal when closed.

HYFLITS vent's FET resistor cutter), and tried various flapper/servo configurations. Jacob even included, for a time, small permanent magnets to help improve the flapper seal when closed.

4. E-vent Mechanism

The e-vent mechanism (e-vent avionics is discussed in the next section) has undergone various modifications since Jacob Meyer's version which, in turn, was based on the HYFLITS vent design. The current e-vent mechanism is pictured in Fig. 3. It consists of a clear "ultra thin wall" PETG tube [8] that is 3" in diameter and 8" long, the top and bottom of which are reinforced with caps (red on top [8]) and clear on the bottom [8]), the centers of which are removed (so they serve as reinforcement rings, not caps) to allow for gas flow. Both caps are tied/taped in place. String/tape is used in favor of epoxy elsewhere in the design as well, so the device can be disassembled for servicing.

An internal two-layer "flapper" seals the tube at the bottom, and is raised and lowered with a servo mounted through a hole cut into the side of the tube. We tried both internal and external flappers and settled on one that opens inward, following the lead of the HYFLITS vent, because the flapper is less susceptible to tangling on external rigging. Also, the slight overpressure of the balloon tends to hold the flapper closed, rather than trying to force it open. The bottom layer of the flapper, which makes the seal, is made of EPDM foam [9]. The top layer of the flapper is hard plastic - the cut-out from the upper cap - which sticks to the foam and can be pulled or pushed by the servo rod above (see Fig. 4). The push rod needs to be bent, and the servo arm oriented, so that the servo can push the flapper fully closed but also pull the flapper as far up as possible, for efficient venting. The servo is epoxied to the wall with Shoe Goo to maintain a seal, then also taped in place. The flapper seal is visually tight, but probably not completely leak tight. Our

Figure 3: Photo of e-vent mechanism, with main-line lasso (and emergency cut resistor) in the foreground and servo (to be plugged into the avionics) on the left. Electrical tape is used to hold strengthening rings in place, top and bottom, and strapping tape is used to hold a tube (in the foreground) for the main line. The use of removable tape for construction makes the vent mechanism more serviceable.

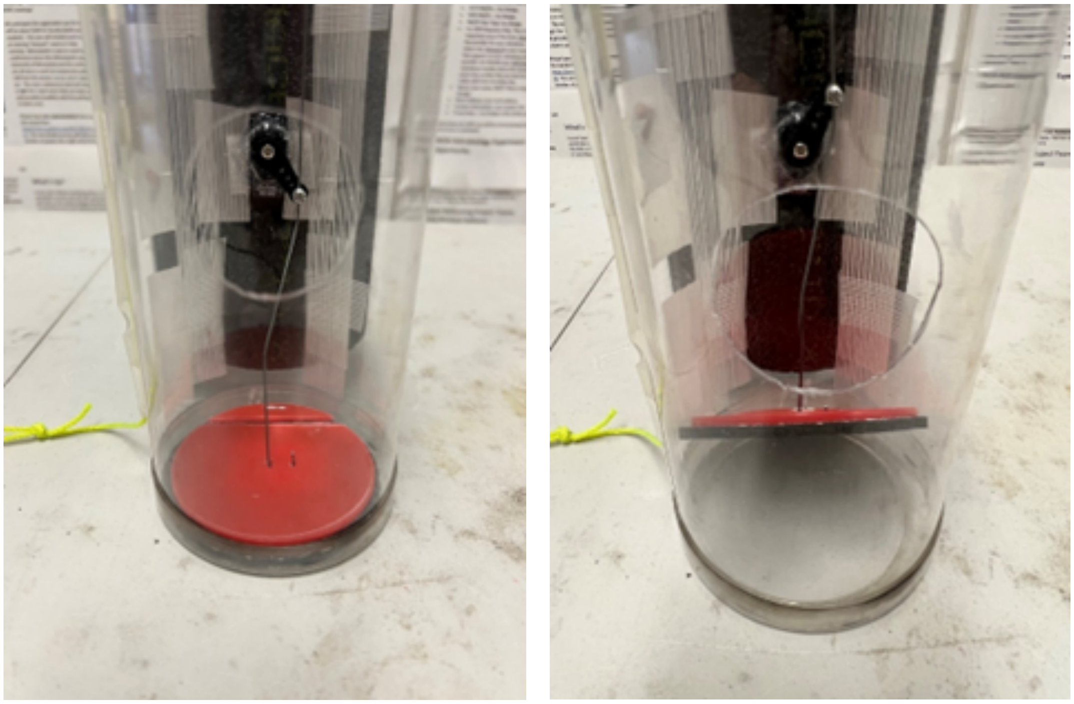

Figure 4: E-vent flapper and servo closed (left) and open (right), with access hatch (to be sealed before flight) in the foreground.

experiences suggest that it is not necessary to apply vacuum grease to the foam seal. Like the HYFLITS vent, the EPDM foam runs out to the edge of the tube but the hard plastic layer does not, forming a foam hinge which remains flexible even at the low temperatures encountered on stratospheric balloon flights. An access hatch is cut into the tube across from the servo (visible in Fig. 4) through which the servo arm can be attached and through which the balloon can be filled with the e-vent in place (see Fig. 5). The hatch is taped closed after filling, just prior to release (see Fig. 6).

Two ¼” wide rings of EPDM foam run around the e-vent tube near the top, separated by ¼”. The “main line” from which the payload stack is suspended (the pink braided mason twine visible in Fig. 3) forms a lasso that encircles the tube between the two foam rings, then runs through a polyethylene tube taped (with strapping tape) to the side of the e-vent. A notch or gap in the polyethylene tubing allows an “emergency cut” resistor to touch the main line part way down the body of the e-vent.

The e-vent is designed to be used with a wide-neck Hwoyee 1600 gram weather balloon. The balloon neck is draped over the two foam rings on the top of the e-vent tube, then tied in place with a “waist line” - braided mason twine, pulled very tight (pink line in Fig. 5; yellow line in Fig. 7, where extra wraps were added). A second cut resistor - the “waist line” cut - is visible toward the bottom in Fig. 7. When this resistor gets hot and cuts one wrap, the waist line will unwrap and stack tension will pull the balloon neck off the e-vent. The e-vent will then return to the ground still tied to the stack below, and can be recovered. If the waist line cut fails, for any reason, the e-vent logic can call for an “emergency (main line) cut,” in which case the stack drops off, so the e-vent flies away with the balloon and is not recovered. The HYFLITS vent only has a main-line resistor cutter - it is intended for single use and not expected to be recovered.

Our NEPB collaborators at Montana State University fill balloons through a spring-loaded one-way valve “quick-disconnect” [10]. We added such a value to one e-vent – it is visible in Fig. 7. Although we like the automatic sealing nature of the device, the spring is so stiff that one has to push quite hard to engage it - so hard, in fact, that the thin wall of the e-vent can buckle and the epoxy used to install the valve can crack. If we switch over to using a quick-disconnect regularly, we will probably need to strengthen the e-vent wall where it is mounted. But the hole for the hatch is not going away, since that is how we gain access to the servo arm.

5. E-vent Avionics

The e-vent avionics box houses all the electronic components, including the custom pcb, Teensy microcontroller, sensors (ublox M8N gps module, GY-63 MS5611 pressure sensor, thermistor for temperature), two 9-volt batteries (one for the microcontroller and the resistor cutters; one for a heater), and three LED indicator lights. The pcb is custom-designed to use only through-hole soldering. The servo - already mentioned as part of the vent mechanism - sticks through a hole in the back of the avionics box and is plugged into the microcontroller. Fig. 8 shows a populated e-vent pcb (on a removeable sled) for a Teensy 3.5 microcontroller, and a newer (unpopulated) pcb designed for a Teensy 4.1 microcontroller.

The avionics for the HYFLITS vent is encased within a cylinder of pipe insulation. After using that approach for a while, we switched to a foamcore box with avionics mounted on removable “sleds.” Though less insulating, this design (coupled with a mesh heater wrapped around the batteries, that only turns on when the batteries get below freezing) gave users much better access to the avionics while assembling the avionics. This change was made after the tight pipe insulation mounting approach caused an electrical short moments before liftoff on one flight, effectively

Figure 5: Inflation of a 1600 gram Hwoyee weather balloon with an e-vent installed. The avionics are in a (thin) foam-core box, rather than in a (thick) foam-insulation tubing.

Figure 6: Inflated balloon with e-vent attached (closed flapper, sealed hatch), ready for release. Moments after this photo was taken of a final lift check, the balloon slipped off the e-vent and was lost, leading to a change in how we wrap the “waist” line around the foam ridges on the e-vent (see Fig. 7).

Figure 7: Modified “waist-line” attachment of the e-vent to the neck of a 1600 gram Hwoyee weather balloon. The balloon may be inflated through a spring-loaded quick-disconnect nozzle (in the foreground - only installed on this one e-vent (so far)) or else through the access hatch (see previous Fig. 5).

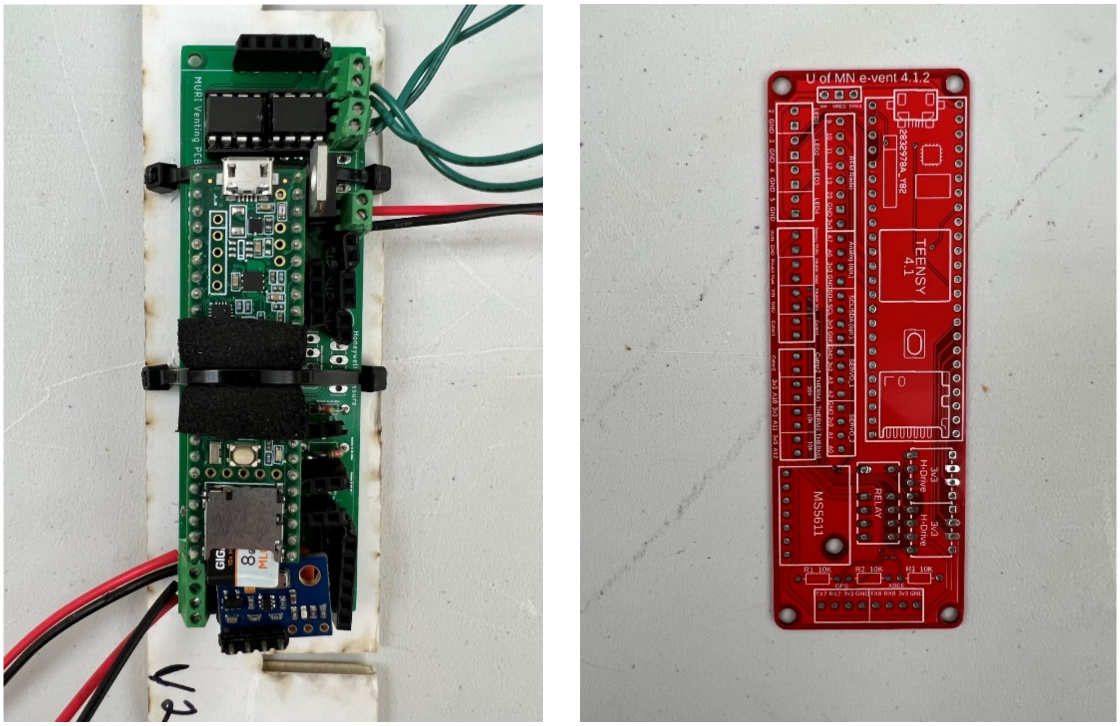

Figure 8: Custom pcb for e-vent avionics using a Teensy 3.5 microcontroller, on the left, and a Teensy 4.1 microcontroller, on the right. The latter also has a header for an RFM69 radio, in case XBee3 radios become unavailable.

scrubbing the entire e-vent system. Fig. 9 shows the avionics sleds inside an avionics box (without the cover) and Fig. 10 shows how the avionics box seats on, and is taped to, the side of the vent mechanism tube.

Three downward-facing indicator LEDs are attached at the bottom of the avionics box, so as to be visible to an uplooking camera while in flight. The LEDs flash in various patterns to indicate the state of the logic and the performance of sensors - SD logging yes/no; gps lock yes/no; etc. The flashing patterns, if captured in video footage, can complement SD card logs (or even replace them, if the SD record happens to be lost or become corrupted). Typically, a particular flashing sequence indicates what the software is attempting to do like "open the flapper" or "call for a cut." Post-flight examination of such video footage allows us to determine exactly when in the flight the particular function was executed.

We have not thoroughly explored the necessity of actively heating the batteries while in flight and we use "Ultimate Lithium" Energizer 9-volt batteries which, though expensive, do quite well even when cold. A flexible heater mesh is wrapped around the two 9-volt batteries and a thermistor is used to monitor the battery core temperature (without touching the mesh heater). A relay is used to activate the heater when the battery core temperature falls below freezing, which usually happens at least when the device is passing through the tropopause on ascent. The e-vent uses separate batteries for the heater and for the microcontroller system, with the resistor cutters being powered by the microcontroller battery. This to guard against the whole system going down if the heater happens to run so long that it drains its battery, though experience suggests that does not occur during a typical flight with a modest float duration. Additional ground testing in a thermal/vac and/or flight testing may reveal that the e-vent can be operated on a single 9-volt battery, or possibly even a rechargeable battery, though ground testing to date suggests that the 3.7 volt battery packs used by other payloads in the NEBP program can run the vent avionics, including the servo, but cannot source enough current for the cut resistors. Although the mesh heater is wrapped around the batteries, not the servo nor the microcontroller, the servo in particular almost certainly benefits from being inside of an avionics box that is not allowed to get too cold.

6. E-vent Coding - Autonomous Logic

The flight logic (AKA "venting logic") of the e-vent is naturally centered around the ascent rate, because that is what the vent can potentially decrease. For example, to "float" a balloon one must vent until the ascent rate equals zero, though one must be careful not to overshoot because once the balloon starts to descend that cannot be stopped using just a vent device. The ascent rate is determined by calculating the difference in altitude between known moments in time. Altitude data is collected primarily from the gps, unless the gps clearly is not working or the gps altitude is deemed unrealistic. The e-vent is programmed to recognize, and disregard, bad gps altitude data and default to a pressure-derived altitude estimate as needed. Both versions of altitude data are logged, along with their respective calculated ascent rates, for potential use by the venting logic. A record is kept of its ascent rate in the form of a running average, to avoid being misled by noise in the data.

The running average ascent rate is then compared to the different possible "ascent (and descent) states" listed in Table 1 every two seconds. A proposed state is suggested as a possibility for the next state of the e-vent. When enough successive state proposals agree - say ten - the state is considered to be valid and the e-vent reacts accordingly, based on the new state. How the e-vent reacts depends on whether or not the current state conforms with the pre-programmed flight plan. In the event of an unexpected state being reached, such as the e-vent drifting outside of a gps fence,

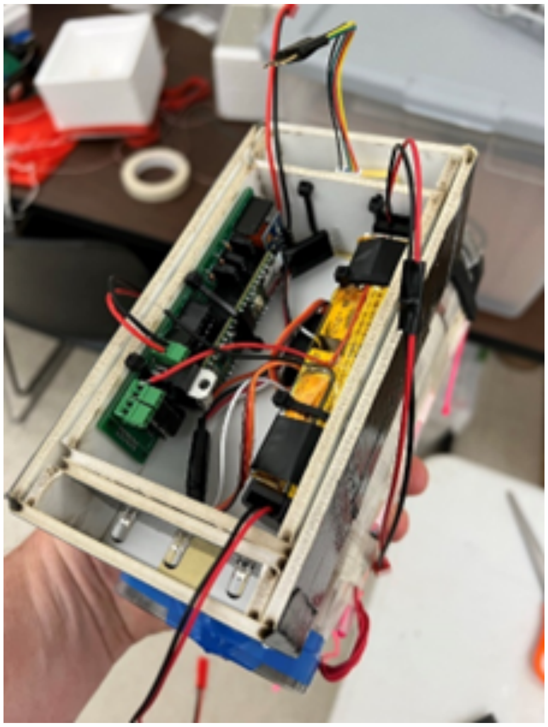

Figure 9: Photo of e-vent avionics foam-core box, with lid off, showing the Teensy/pcb (left), 9-volt batteries (right), gps (top), indicator LEDs (bottom), all on removeable sleds. The servo sticks through the hole in the back of the box. A thermistor monitors the internal temperature so that the heater mesh (wrapped around the batteries) only turns on when the box temperature gets too low. Not installed in this photo – the XBee radio, also on a removeable sled.

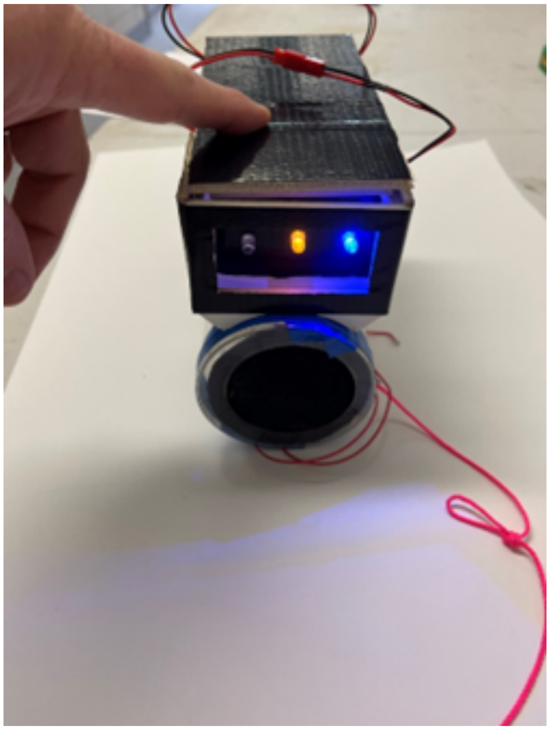

Figure 10: Avionics box on e-vent mechanism (not yet strapped down), as seen from below. The flapper is closed and the three LED indicator lights are visible.

the flight may be terminated early to limit time in the air and to minimize drift, so as to increase the likelihood of a successful recovery. Table 2 and Table 3 list the adjustable parameters in the vent code and the values that are logged, respectively.

In the case of a "standard" vent-to-float-then-terminate flight plan, the venting logic may look something like this:

> The balloon ascends continuously, monitoring its ascent rate, and possibly doing some short "pre-vent" flapper motions to ensure the servo does not freeze up.

> The balloon reaches a target altitude and opens the flapper for the "main" vent.

> The ascent rate decreases until the running average ascent rate reaches a target ascent rate such as "less than 0.50 m/s".

> The flapper is closed and a "float timer" is started, to limit the duration of the float state.

> At the end of the float, the flapper is opened (and left open) and the "waist line" cutter is activated (multiple times, if need be) to attempt to release the balloon and terminate the flight.

> If the previous step fails, as evidenced by the e-vent not going into "descent" or "fast descent," the e-vent may activate the "emergency cutter" to sever the main line and try to at least get the stack back, though not the e-vent itself.

> If the e-vent fails to stop the balloon's ascent, the logic may call for a termination before the balloon reaches burst altitude (with the flapper closed, once the e-vent gives up on trying to vent, to preserve upward ascent toward burst if all cut attempts fail).

> If the e-vent drifts outside of pre-selected gps boundaries on ascent, the logic may call for an early termination. However, if the e-vent is in "fast descent" or "descent" (presumably under parachute), the logic typically will let the stack continue to fall to the ground without calling for any terminations, even if it happens to overfly a gps boundary, so as not to lose the vent device.

> If the mission takes too long, possibly because the stack has somehow become caught at altitude, a master timer will trigger a termination.

7. Radio Control Options

Although the e-vent has the sensors and code/logic needed to operate autonomously, radio control has recently been added to the e-vent hardware and code for potential use by participants in the Nationwide Eclipse Ballooning Project (NEBP) with their Iridium uplink capability. The end goal of the radio control is to act as a back-up to the autonomous logic on the e-vent, or the other way around (with uplink commands taking precedence). Since parameters for autonomous venting are pre-coded prior to every flight based on what we want the e-vent to do under various circumstances, it will be valuable to be able to command the e-vent from the ground as well, in case the flight does not proceed exactly as anticipated, potentially fooling the onboard logic.

The e-vent has successfully received radio commands and transmitted acknowledgement messages on several flights, culminating in one flight commanded almost exclusively by radio (from a nearby payload, so still technically autonomous, but in a different way - we have not yet implemented uplink from the ground through Iridium). In that recent flight the e-vent received a radio command to begin venting helium at 80,000 ft ASL, and successfully proceeded to float the balloon then terminate it about 25 minutes later (see altitude vs time plot in Fig. 11). Interestingly enough, earlier in that same flight the payload sending radio commands to the e-vent temporarily malfunctioned and the e-vent correctly identified the lack of radio communication and switched back to its autonomous flight plan for a short time. When the radio link was reestablished, the e-vent returned to radio-controlled operations, demonstrating its versatility.

Table 1: List of possible ascent/descent states

State Name	Ascent	Slow Ascent	Float	Slow descent	Descent	Fast descent
“Ascent” Rate (AR) (all in m/s)	AR >= 1.9	1.9 < AR >= 0.50	0.50 < AR >= -0.50	-0.50 <= AR > -1.9	-1.9 <= AR > -10	-10 >= AR

Table 2: List of adjustable parameters in the e-vent code.

Start timer altitude (ft ASL)	Target ascent rate (m/s)	Pre-vent 1 altitude (ft ASL)	Pre-vent 1 duration (sec)	Pre-vent 2 altitude (ft ASL)	Pre-vent 2 duration (sec)
gps fence (N & S lat, E & W long) (dec. degr.)	Target float altitude (ft ASL)	Float duration timer (min)	Master duration timer (min)	Target descent rate (if trying to achieve slow descent) (m/s)	Target terminate altitude (presumably after a slow descent phase) (ft ASL)

Table 3: List of values being logged by the e-vent once every two seconds.

Time since e-vent was launched (sec)	Time since e-vent was turned on (sec)	Time since e-vent was turned on (msec)	Current hour of day as reported from the gps	Current minute of the hour, as reported from the gps	Current second of the minute, as reported from the gps	Temperature of batteries (F)
Pressure, as read from pressure sensor	Estimated altitude from pressure sensor data	Suggested gps bounds state (in/out of gps fence)	Current ‘valid’ decision if the e-vent is within gps bounds	Latitude in dec. degr., as reported by gps	Longitude in dec. degr., as reported by gps	Altitude in ft ASL, as reported by gps
Number of Satellites gps has a lock on	Ascent rate currently used for running average (m/s)	Running average of ascent rate (m/s)	Ascent rate calculated from gps altitude data	Ascent rate calculated from pressure-based altitude data	State of the heater (on/off)	State of the flapper (open/closed)
Analog read of the current servo position (degrees)	State of the resistor cutters (off/on, and which resistor cutter is burning)	Ascent state being suggested (Table 1)	Current ‘valid’ ascent state (Table 1)	Reason for the flapper to be open/closed (autonomous or radio controlled)		

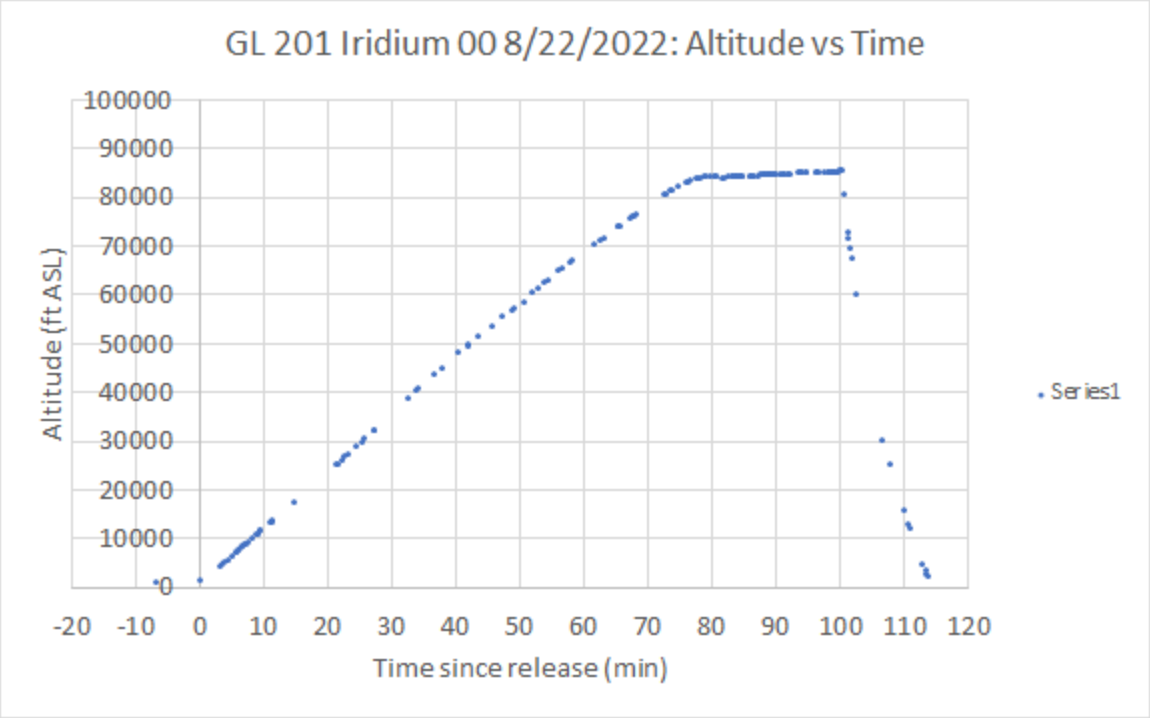

Figure 11: Altitude vs Time plot for a balloon floated about about 85,000 ft ASL.
The parachute tangled on this flight, so it descended much faster than intended.

In recent flight tests, we have been able to confirm the e-vent's ability to receive and transmit radio messages and respond appropriately to radio commands. So far, these radio communications have all been from a sensor suite in a nearby payload. The end goal is to be able to communicate with the e-vent from the ground using an Iridium modem and an XBee radio relay. The Montana Space Grant already does this with other hardware planned for use in the NEBP "engineering side" (AKA "video streaming side"). They fly an Iridium tracker flying on the same stack and use the Iridium satellite network to send commands to it, which can be relayed to other payloads such as a cut-down (and, ultimately, an e-vent) by short-range XBee radio.

The current short-range communication is established using a pair of XBee radio modules, one on the e-vent and one on a nearby PTERODACTYL flight computer (see Ref. 11 to learn more about the PTERODACTYL). Table 4 gives a list of commands the e-vent can currently receive and acknowledge. Along with listening for these commands, and responding to them, the e-vent also transmits information about its general state once a minute. Such transmissions are picked up by the PTERODACTYL and added to its radio/data log.

8. Flight Results

The e-vent continues to be actively tested, both on the ground and in flight, in preparation for eclipse use (and general use), with improvements being made after almost every flight (so far). We have flown e-vent devices both in "parasite" mode (not attached to the neck of a balloon, but logging data and in view of a camera), and also in "vent" mode (where they can actually vent lift gas from a weather balloon). Ref. 7 includes plots of altitude vs time and also altitude vs ascent/descent rate for the final vented flights conducted by Jacob Meyer in the spring of 2021.

Table 4: List of current radio commands. These may need to be distilled down to fewer commands since the Iridium system only supports 8 uplink commands, and several are already spoken for.

Command	Action	When to send
JIGGLE	When the e-vent receives this command it changes the state of the flapper (open or close), waits ~2 seconds, then returns the flapper to its original state.	When the ascent rate data is received
RATE	When the e-vent receives this command it transmits its current ascent rate based on gps (or pressure).	Every 5 minutes
PRE-VENT	When the e-vent receives this command it goes through its pre-vent function where it opens the flapper for a set amount of time (usually quite short) then closes it again.	At the pre-selected pre-vent altitude
FLOAT	When the e-vent receives this command it goes through the float function where it opens the flapper until the average ascent rate is low enough to be considered floating (less than 0.5 m/s).	At the pre-selected float altitude

Those flights had lightweight payloads and were vented into “slow descent” (as opposed to into “float”) at altitudes above 100,000 ft ASL. The pre-coded termination condition was reaching a particular altitude on descent – namely, 80,000 ft ASL.

More-recent flight tests, during the summer of 2022, used the e-vent with “full” (12 lb) stacks – the maximum weight for “exempt” ballooning according to FAR Part 101. These were more challenging because the extra stack weight meant the static tension on the e-vent connection to the balloon neck was much higher, especially while the stack was being held down after inflation but before release, sometimes in windy conditions. Indeed, on one occasion a fully-inflated balloon slipped off the e-vent prior to release. This has only happened once, so we don’t think it is a fundamental issue with the design; but after that experience we began wrapping the “waist” line both above and below the foam strip on the e-vent tube (yellow string in Fig. 7) to increase frictional resistance to premature tension-induced separation.

The amount of excess lifting gas increases with stack weight, so to stop a “full” stack from ascending requires venting up to about 6 lb of lift gas – much more than is vented in a light-stack MURI flight. Also, the balloon stretches more before release when carrying heavier payloads, so it will naturally burst at a lower altitude – about 100,000 ft ASL for 12-lb stacks with 1600 gram Hwoyee balloons, as opposed to above 120,000 ft ASL for 2-lb MURI stacks with those same balloons. That said, we have practiced venting to achieve float at more-modest altitudes – just above 70,000 ft ASL on one recent flight, and just above 80,000 ft ASL on a second recent flight. An altitude vs time graph for the latter flight, where float was maintained for about 25 minutes before a termination timer released the e-vent from the balloon, is shown in Fig. 11. On the other hand, the link in Ref. 12 shows a video of a successful termination from a still-ascending vented flight that reached 97,000 ft ASL without slowing the ascent rate very much. In that latter case we did not have the e-vent open long enough to actually stop the ascent, so it basically just became a cut-down test.

In addition to testing venting efficiency, which decreases with increasing balloon stretch and can become completely ineffective if you get too close to burst (see Ref. 6 for more details), flight tests have been used to check gps reliability and logic robustness in the face of gps noise and potential gps failure, with pressure-based altitude estimates used by the logic as a back-up if gps altitude is unavailable.

Most flight testing has been done with the e-vent operating autonomously, attempting to follow a pre-selected flight plan by making decisions based on its own gps and pressure sensors. However, the e-vent has an XBee radio through which we have instructed it to open and close (sometimes only for very short periods, mostly as evidence that it can be done). Only one flight, so far, has had the e-vent fully commanded by radio from a flight computer in a nearby payload, with e-vent onboard sensors and logic serving as a backup. Going forward, we intend to test radio command functionality more thoroughly, and eventually incorporate uplink from the ground to onboard payloads (which can relay commands to the vent), to give us real-time control of the e-vent in flight. However, we maintain that having the e-vent be able to operate autonomously is important, in case the radio link trying to command the vent from the ground fails.

9. Epilogue

Motivated by the successful single-use HYFLITS vent, our ballooning team has enjoyed the challenge of developing an autonomous/radio-commandable vent for use with wide-neck 1600 gram Hwoyee weather balloons for potential use by NEBP teams during the solar eclipses in 2023 and 2024. Multiple students have contributed to building, testing, and improving the physical mechanism, the avionics to run it, and the coding logic to allow it to operate both autonomously and by radio control. Supply chain challenges forced us to switch from Teensy 3.5 to Teensy 4.1 microcontrollers recently. The updated avionics pcb is ready to accommodate a RFM69 radio module, if XBee3 radio modules become unavailable. Recent flights have demonstrated that the e-vent is capable of venting 6 lb of lift gas, to bring a 12 lb stack into float at both 72,000 ft ASL (one flight) and 85,000 ft ASL (on a different flight) - altitudes that should serve eclipse balloonists well. The "waist-line" resistive cutter is capable of detaching the e-vent from the neck of the balloon, allowing it to fall with the payload stack and be recovered. The e-vent was intentionally designed to be serviceable, since it can get damaged upon landing or recovery. In the near future we expect to extend radio command capability from an XBee module in a nearby (autonomous) payload to genuine uplink from the ground, using the Iridium system already adopted by the NEBP.

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