Helium Valve for Dynamic Balloon Flight Control

Introduction

A high altitude latex weather balloon, the standard for university balloon groups, ascends at a near constant velocity and expands as the ambient pressure decreases. The balloon then bursts once the stretching of the walls exceeds the tensile strength of the balloon. As a result, the maximum duration of flight and the maximum distance over which to conduct experiments are limited, and the flight path is effectively fixed as soon as the balloon is launched. One alternative is to use zero pressure balloons, which do not expand and therefore hover at a maximum altitude at which the balloon payload is neutrally buoyant. However, these balloons are often too expensive for university groups.

This ongoing project seeks to develop a balloon valve capable of releasing a specified amount of helium midflight to dynamically alter the flight trajectory. The valve could theoretically control the ascent rate and burst altitude of the balloon. The valve could also make the balloon neutrally buoyant near a specified altitude for several hours up to the lifetime of the balloon, allowing extended duration and distance over which to perform experiments.

Launch Requirements

To date, two valve prototypes have been flown. Both balloons were launched from Clear Spring, MD, about $150\,km$ west of the Chesapeake Bay with winds to the east. To avoid substantially extending the balloon flight and drifting into the water, the valve operation programs have focused on causing the minimum measurable difference in balloon ascent rate as the criterion for success.

Additionally, the valve has flown resting directly inside the balloon neck above the parachute to avoid the additional mass of tubing required to place it elsewhere on the payload string (see Fig. 1). However, one resultant concern was whether the valve would compromise the parachute upon descent. As such, the mass had to be as small as possible.

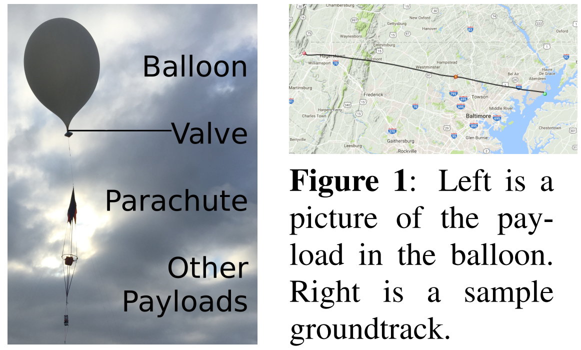

Figure 1: Left is a picture of the payload in the balloon. Right is a sample groundtrack.

Methods - 2015 Valve

To achieve the desired flow rate, a custom aluminum valve was constructed using a $10\,mm$ linear actuator, with 12 radial vents sized to utilize the full actuator range of motion (see Fig. 2). In total, the vents provide half the total cross sectional area of the $12.7\,mm$ diameter tube used for balloon inflation. The aluminum valve was connected with $30\,cm$ of tubing to an aluminum disc in the balloon neck that stretched and sealed the balloon, as well as to the inflation port. The payload was installed in the balloon neck and then inflated through the tubing. The payload also recorded the ambient pressure inside and outside the balloon, and the GPS location. The valve opened for $60\,s$ at $18\,km$, and flew in a $1600\,g$ balloon in November 2015.

Figure 2: Valve assembly with valve structure, plug with O-ring, and $10\,mm$ actuator. The top was glued to short tubing attached to the balloon disc, while the bottom fastened to an actuator mount.

Results 2015

The measure of success for the payload was whether opening the valve made a significant difference in the balloon ascent rate. First, altitude was graphed versus time, producing a nearly linear ascent plot (see Fig. 3). The ascent rate appears constant, then appears to decrease when the valve is opened, and then recovers after the valve is closed. A linear regression indicates slopes of $6.15\,m/s$ before opening and $5.84\,m/s$ after closing (Fig. 3, dashed lines), with an average ascent velocity of $6.10\,m/s$. However, a closer analysis of several subintervals on both sides shows that the ascent velocity was consistently increasing over the period before the valve was opened. The velocity shortly before opening had reached $6.35\,m/s$ (Fig. 3, Interval A), while the velocity just after closing was $6.31\,m/s$ (Fig. 3, Interval B), before abruptly falling $500\,s$ after the valve closed.

Comparing the descent rate, a representative launch from one month prior to the first valve launch had an average velocity during the last $2400\,m$ of $8.0\,m/s$ (according to tracking data), while with the valve above the parachute, the balloon had an average descent velocity of $9.1\,m/s$ (according to payload GPS—tracking data indicates $9.3\,m/s$, but is less accurate).

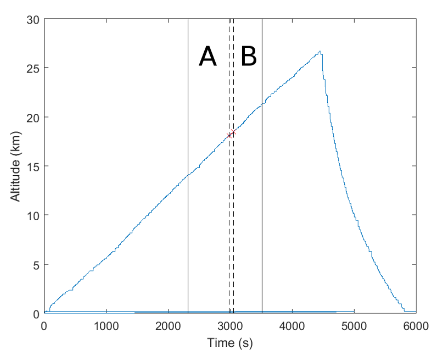

Figure 3: Altitude versus time during first launch. The dashed lines are when the valve opened and closed. Interval A is from the first solid line to the first dashed line. Interval B is from the second dashed line to the second solid line.

Initial Conclusions

The first valve had no statistically significant impact on the balloon flight dynamics. At first look, it appeared to have a small impact, but a more thorough analysis revealed that the difference in ascent velocity was negligible. This is likely because it was assumed that the elasticity of the balloon would create a positive pressure difference inside that would force helium out the valve. However, graphs of pressure show almost no difference between pressure inside and outside the balloon, disproving this assumption. Though all payloads were recovered intact, the descent velocity was substantially higher than usual.

Modifications - 2016 Valve

The effect on the parachute was likely due to the weight as well as the area footprint of the payload on the parachute, so the new valve was made much more compact, with no tubing between the disc and valve. The aluminum disc was remade out of acetal resin (see Fig. 4). With the valve concept now proven safe, higher resolution Honeywell SSC pressure sensors were purchased, and the GPS receiver location was altered to reduce noise.

A fan was also added to force a pressure difference inside the balloon. An experiment with an inflated $300\,g$ balloon took $90\,s$ with the fan on until the balloon skin wrinkled, so the valve was set to open for $90\,s$ at $20\,km$, knowing that the fan would be much less effective at higher altitudes. The balloon was filled through the valve stem before installing the plug with O-ring and actuator this time. The valve flew in a $3000\,g$ balloon in September 2016.

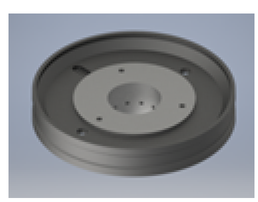

Figure 4: The new aluminum valve is bolted into the acetal resin disc, and sealed with an O-ring.

Results 2016

With the improved GPS setup, it was also possible to measure the ascent velocity while the valve was open. The velocities were $6.50\,m/s$ before opening, $5.47\,m/s$ while open, and

$5.89\,m/s$ after closing. Looking at subintervals, one finds that again the velocity increases with altitude, except this time the balloon decelerated before opening, and then reaccelerated well after closing. The lowest velocity was measured before and after the valve was opened instead of the highest velocity. In an interval similar to Interval A, the velocity was $5.84\,m/s$, while the velocity was $5.59\,m/s$ in the equivalent of Interval B (see Fig. 5).

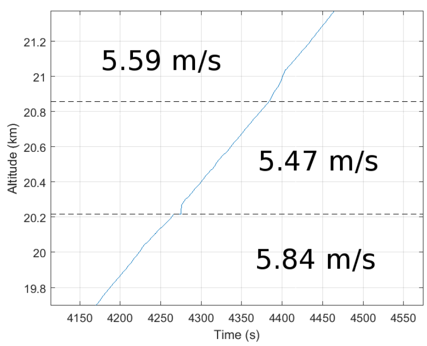

Figure 5: Altitude versus time during the second launch: a close up of when the valve was opened and closed (dashed lines).

As for the descent velocity, the payload GPS unit failed on descent. By pressure altitude, the descent velocity was $6.0\,m/s$, but this sensor was likely covered by the balloon during descent. According to tracking data, the descent velocity was $7.8\,m/s$, indicating the new design did have less impact on the parachute.

Conclusions

Neither launch can confirm definitively that the valve succeeded at its objective of changing the ascent velocity, but both suggest that the valve did cause some sort of change. In the second launch, the ascent rate is measurably smaller while the valve is open, though not afterwards, suggesting that the balloon might recover partially after the valve is closed. The GPS data for this launch is remarkably smooth, and the bump that looks like noise near the lower dashed line in Fig. 5 is the only bump of that size in the entire data set. The altitude graph at that time for the first launch is similarly noisier than at all other times. Given these promising but statistically doubtful results, the valve needs to be tested open for a much longer interval during a Spring 2017 launch when the winds will reverse, decreasing the risk of such an attempt at a longer duration flight. This would show that the valve actually performs as expected in flight beyond differences attributable to other factors.

Future Work

The valve first needs to be tested for a longer duration to see if new oddities arise. To make the valve a precise flight control system will then require vacuum chamber experiments to measure its flow rate, which will then need to be corroborated against several flight tests in the real flight configuration. The payload never flies without an additional payload string, so the safety of those payloads is essential, though this limits the pace at which new valve test programs can be attempted.

The payload should also attempt to measure other aspects of balloon performance, such as elasticity and deformation upon release. The more precise pressure sensors did identify a slight difference in pressure inside the balloon at high altitudes, hinting at some elastic pressure. The three temperature sensors also indicated that the environment inside the balloon was even more stable than inside the insulated electronics box, so significant weight and complexity could be eliminated by placing all electronics inside the balloon.

A lab mistake during an inflation test also suggests that by running the fan in reverse, the valve can induce a balloon burst. This possibility will also be investigated, as a neutrally buoyant system would require a means of flight termination. Finally, a soap bubble test for leakage was conducted during the second launch. This revealed that air was actually being pulled into the balloon due to the low temperature of the expanding helium, rather than helium leaking out, so a more secure inflation procedure is also under development. Thus, the payload focus is still on making a safe and effective valve, as a nearly complete first step to a dynamic flight control system.