Developing a Zero-Pressure Flight System

Timothy Basta[1], Scott Miller[2], Jamesen Motley[3], Nichole Murray[4], Randal Larimer[5], Berk Knighton[6]
Montana State University, Bozeman, MT, 59717

The purpose of this system is to allow researchers to fly latex burst balloons at specified altitudes for extended periods of time. This is accomplished by venting a known volume of Helium through a valve to allow the balloon to reach neutral buoyancy at a desired altitude. This valve system has real-time control, allowing users to modify their float altitude at any time during the flight. The valve system is also equipped with an integrated flight termination system, allowing users to terminate the flight at any time by compromising the balloon canopy. This enables a balloon flight to be terminated without cutting away the valve system.

I. Introduction

THE typical method of zero-pressure ballooning involves purchasing a balloon manufactured to contain a specific volume of a low-density gas. These balloons are designed to float at a certain altitude based on the volumetric capacity of the balloon and the payload weight. As the balloon ascends, the contained gas expands until it fills the entire volume allowed by the balloon. Any additional expansion causes the excess gas to be expelled from a hole in the bottom of the balloon, which is left open. In this manner, a typical zero-pressure balloon is able to reach neutral buoyancy by displacing enough air to allow it to float at static equilibrium with respect to gravity. These balloons, however, are out of the financial reach of many smaller universities and ballooning groups. Most university ballooning groups use latex weather balloons, which typically burst during their ascent. These balloons are normally filled with a volume of low-density gas to provide enough lift to carry the payload at an acceptable rise rate. As the balloon ascends and its internal volume increases, the latex skin of the balloon stretches to accommodate the increase in volume. The balloon eventually reaches a critical volume, and the skin ruptures, terminating the flight. Weather balloons are inexpensive, and relatively easy to fly, but only provide an experiment platform that is either ascending or descending. To enhance the flight dynamics of a typical latex weather balloon, we have developed a remotely operated valve, which allows for gas to be vented from the balloon, affecting its altitude during flight. The following sections detail the operation of the valve, and present flight data demonstrating its effectiveness.

[1]Undergraduate, Mechanical Engineering, BOREALIS, Montana State University
[2]Undergraduate, Computer Engineering, BOREALIS, Montana State University
[3]Undergraduate, Mechanical Engineering, BOREALIS, Montana State University
[4]Undergraduate, Mechanical Engineering, BOREALIS, Montana State University
[5]Montana Space Grant Consortium Deputy Director, BOREALIS, Montana State University
[6]Montana Space Grant Consortium Flight Director, BOREALIS, Montana State University

II. Description

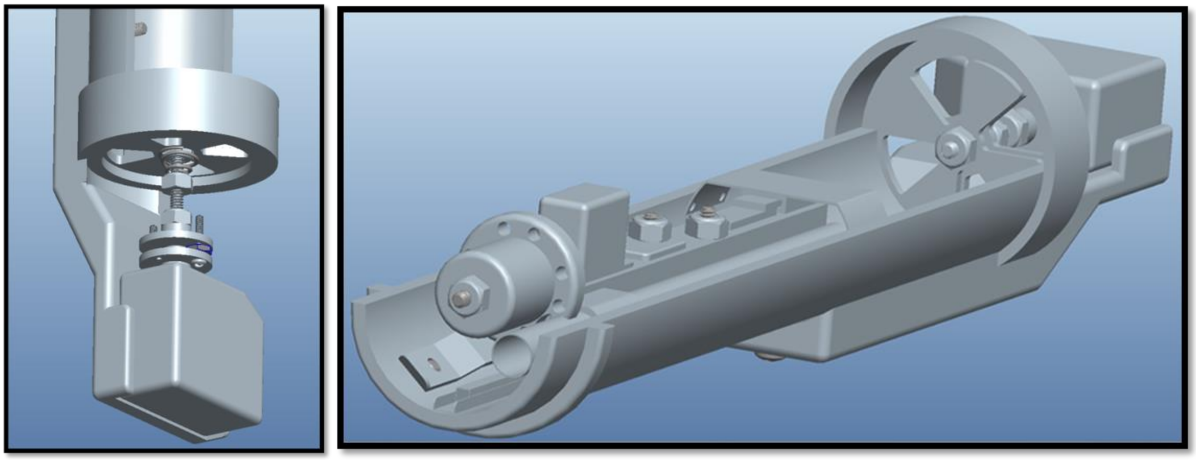

Figure 1. Zero-Pressure Valve System 3-D Model. Shown with Main Tube halved, to display internal components.

The Zero-Pressure Valve is a system designed to allow the user to modify the flight of a traditional burst balloon. The balloon is filled with the same quantity of gas as it would be on a normal flight, but rather than sealing the bottom of the balloon, it is secured to the top of the valve system. The rest of the payload chain is then secured to the strap on the bottom of the valve, and the command capsule is linked to the valve system via CAT5 cable. The Command Capsule contains a satellite modem, and an Arduino microcontroller, which provides remote operation of the valve system. In addition to providing position reports throughout the flight, the satellite modem also allows the ground crew to uplink commands during the flight. These commands are received by the modem and sent via RS232 line to the Arduino, which in turn controls the valve and flight termination systems. The Zero-Pressure Valve system is depicted in Figure 1. This high conductance valve is constructed from two circular gates, which can be rotated open or closed using the attached servomotor. With the gate in the open position, the triangular openings in each of the two circular layers align, which allows the internal pressure of the balloon to force the low-density gas through the opening. This decreases the amount of air displaced by the balloon, and the resultant buoyant force lifting the payload. After a quantity of gas has been expelled, the valve is closed, and the balloon rises until it reaches a state of equilibrium between the buoyant force of the displaced air, and the weight force of the balloon and payload. After this has been accomplished, the balloon reaches a state of float. This process can be repeated at any time during the flight to adjust the float altitude.

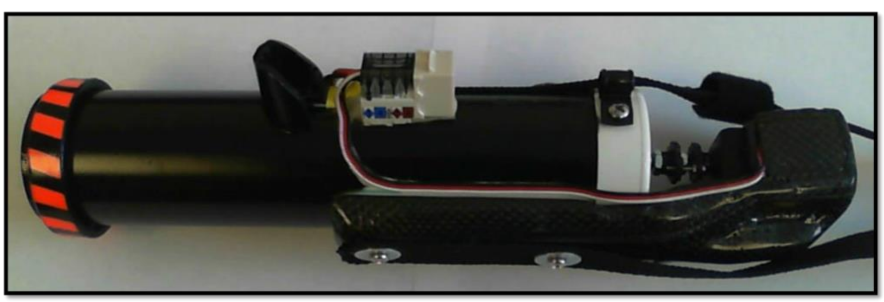

Figure 2. Zero-Pressure Valve System shown without balloon (Left) and with balloon (Right)

III. The Latest flight

On April 19, 2014, the Zero-Pressure Valve was flown with a 2000 g. balloon and a 12 lb payload. It was launched from the Wheatland County Airport in Harlowton Montana shortly before 8:30 am. The Vertical Velocity and Altitude Profiles are shown in Figures 3 and 4, respectively. The different rise rates of the payload through the troposphere and stratosphere and the effects of the vertical winds are easily seen in figure 3. After the Balloon reached an altitude of 72,800 ft, the vent command was sent to the valve system via the onboard Satellite Modem. The balloon was allowed to vent for about 10 minutes. At this point, the rise rate had dropped below 5 ft/s, and the close vent command was sent. The balloon continued to slowly rise, with its ascent rate slowly decreasing, until it reached neutral buoyancy at 84,000 ft. For the next 15 minutes, the payload floated between 83739 ft and 84017 ft. At 10:53 am, the flight termination command was sent. Immediately after the termination command was sent, the payload began to descend very quickly. The parachute slowed its descent, and the payload landed safely in eastern Montana. The Payload was recovered with all experiments and tracking systems intact, and with minimal damage to the payload containers.

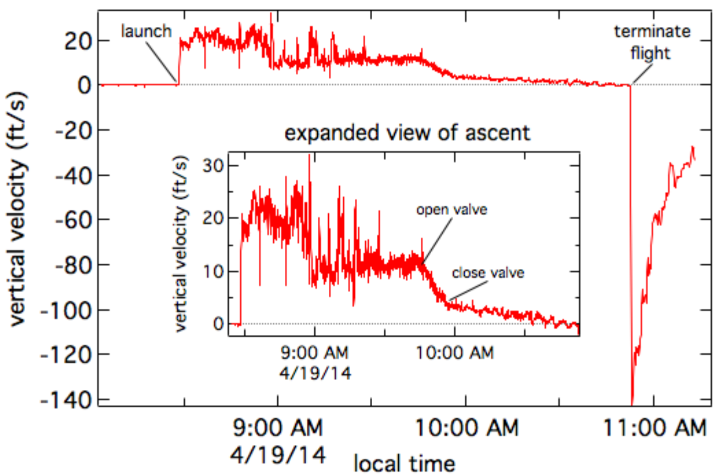

Figure 3. Vertical velocity profile for the BOREALIS 4/19/2014 Flight

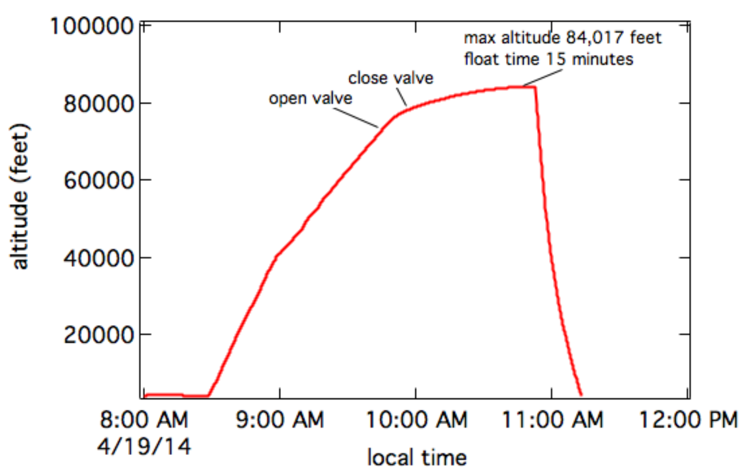

Figure 4. Altitude vs. Time profile for the BOREALIS 4/19/2014 Flight

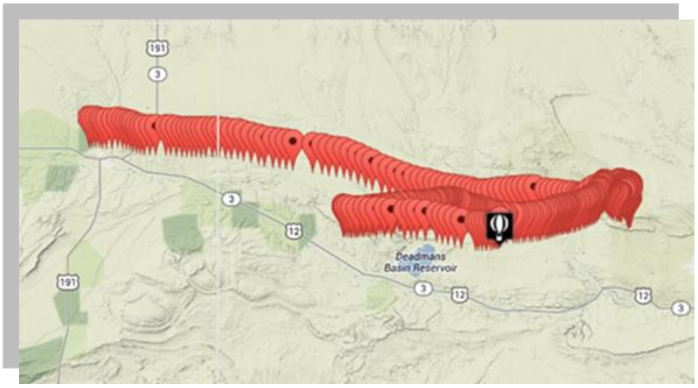

Figure 5. Position Reports for 4/19/2014 Flight

IV. Results

The satellite modem was successful in providing position and velocity reports throughout the entire flight and the valve system properly responded to all of the commands uplinked via the modem. The shape of the flight track, Figure 5, is due to the opposing directions of the wind at different altitudes and the vent command was intentionally timed to have the balloon float in the easterly winds. This decreased the overall downrange distance of the flight. The balloon reached and maintained a state of buoyant equilibrium with the atmosphere for 15 minutes, demonstrating the efficacy of the valve system to provide a zero-pressure flight using a latex weather balloon. The flight termination system was activated successfully, and terminated the flight within 30 seconds of the termination command being sent.

V. Conclusions

There have only been two test flights of the Zero-Pressure Valve to date, but they have both been successful. The flight on April 19, 2014 was proof that the valve system used in conjunction with our satellite modem can provide neutrally buoyant flights, as well as in-flight control of altitude. Future flights will include a high sensitivity pressure sensor to provide greater insight for our flow rate calculations. A prediction chart will also be developed that will detail vent times and altitudes in order to achieve float at specified altitudes. The mechanics of the Zero-Pressure Valve will also be simplified, making it easier and less expensive to produce.