Design and Launch of a Reentry Vehicle for Near Space Experimentation

March 9, 2009
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1.0 Abstract

The Wright State University High Altitude Balloon (WSU HIBAL) project is currently making progress toward developing both a more reliable and readily launchable system and a freefalling test vehicle for release from high altitude balloons. The team was previously limited in terms of launch readiness and flight capabilities. In order to improve reliability during the launching process and provide more launching opportunities, the current system and methods have been reevaluated and redesigned. To overcome the roadblocks while launching, a fabric tent-like enclosure was designed to shield the balloon from high ground wind speeds and other hazards during the filling process. Balloon filling procedures and payload connections have been individually tested and redesigned to reduce the risk of balloon loss during launches. This series of improvements will allow the WSU HIBAL team to launch under harsher conditions and greatly reduce complications for current and future teams.

The second venture of the current team was to design, build, and test an aerodynamically stable vehicle with a remotely or automatically deployable parachute to be released from a high altitude balloon. A cut-down mechanism was designed and installed to sever the connection between the re-entry vehicle and the balloon through both automatic and remote controls at the discretion of the operators. The ability to control the detachment from the balloon and deployment of the parachute will provide a system capable of simulating low-gravity through a stable and uninhibited freefall capable of landing in a safe manner. The proposed designs and modifications will greatly increase experimental capabilities and launching ability for the WSU HIBAL team.

2.0 Introduction

The WSU HIBAL team is an inter-disciplinary project providing a broad range of experimentation and design projects. Past projects have varied greatly, providing valuable experience for each year’s participants. Overall, much information about aerospace applications has been obtained from HIBAL experimentation. The HIBAL project is an important venture for the exploration of near space and is capable of doing it successfully and inexpensively. This has led to the establishment of industry collaboration on the project. In previous years, several companies such as CRG and ILC Dover have expressed an interest in the HIBAL team.

During the 2005-2006 school year, the primary efforts of the project were made in designing a payload and establishing communication systems, which laid the foundation for future experiments [5]. After the essential ground work had been developed, the 2006-2007 HIBAL team was able to focus on improving flight prediction, developing more reliable tracking methods, and creating a tube that would deploy in near-space using only 18 volts of power. This shape memory tube was donated by the aerospace company, ILC Dover [4]. The following year (2007-2008), the HIBAL team worked toward creating a three-dimensional, unfolding truss using shape memory materials from Cornerstone Research Group (CRG) [3].

The 2008-2009 HIBAL team, consisting of both mechanical and electrical engineers, focused on improving the launch and flight capabilities of the WSU HIBAL. For the mechanical portion of the project the main goals were to develop an improved launching system, build a release mechanism to sever the balloon from the payload, manufacture a stable command module with a low terminal velocity, and install a deployable parachute on the command module.

Certainly HIBAL near space experimentation is an important project at WSU and worth the effort involved. Many different design projects and experiments can emerge from ballooning at nearly 100,000 ft, and joint-ventures with industry can also be established. This project will continue to entice outside companies to collaborate with WSU in future research and promote this fine university as a respected name in near space research.
3.0 Design Criteria
The 2008-2009 WSU HIBAL team has two main goals to accomplish during the year. The first is that past teams have been very limited in launching ability. This year’s team must improve launching procedures to allow more launches under harsher conditions and with fewer complications. Some of the challenges to overcome were high ground wind speeds, uncertainty in the filling process, and component failure due to dynamic loading during balloon takeoff. These areas must be investigated and resolved to allow current and future teams to launch more frequently.

The second direction the team must work in is creating a payload that may be dropped from 100,000 ft and freefall in a stable fashion for 20 to 30 thousand ft before deploying a parachute and gliding back to ground. Such a system requires three major areas of development. The first is a method of releasing the payload from the balloon with automatic and remote control. The second is a parachute deployment system with redundant deployment. Both of these areas must be capable of working in harsh high altitude environments. Both systems must be designed for very cold (-50°C) temperatures and a low pressure environment and sufficiently tested in both areas before implemented in the payload system. The third area of development is the payload body itself. The package design must be reconsidered as a large body with high drag to slow the descent of the payload for safety reasons and provide a stable flight during freefall. The package must be able to house all of the necessary components internally yet remain consistent with the strict FAA regulations. How these goals were approached and resolved are discussed in the following sections of this paper. A simplified schematic of the final payload operation is shown in Figure 3.1.

![Figure 3.1 Freefall payload operation schematic](image-url)
4.0 Launch Readiness and Improvements

In previous years one of the major detriments to the Wright State High Altitude Balloon Team has been launch readiness and reliability. This has again proved to be a major issue for the 2008 – 2009 HIBAL team. In order improve the success of current and future teams several issues needed to be resolved.

4.1 Filling

In previous years, the HIBAL team relied on estimating the amount of helium in the balloon during the filling process by observing balloon diameter and measuring lift using a fishing scale. If the balloon had an insufficient helium volume to generate the required lift, the payload had to be untied and the filling nozzle reinserted into the balloon neck. This was often a very time-consuming iterative process.

In order to improve the filling procedure, an Omega FMA-1844 flow meter equipped with a totalizer was purchased shown in Figure 4.1. This equipment was obtained in order to remove much of the guesswork from the filling process. An attached flow totalizer records the total volume of helium entering the balloon (in liters) while the lower display monitors the instantaneous rate of helium flowing into the balloon. Connections were made to the helium tank regulator and filling nozzle for use in the field.

![Figure 4.1 Omega flow meter](image)

Before employing the flow meter during an actual launch, the totalizer values needed validation. A test was set up to check the actual helium volume with the volume values displayed by the totalizer. This was accomplished by filling a series of balloons with the flow meter and using the lift generated to find the actual volume of helium in the balloon. Multiple 36 inch balloons were filled to various volumes using the flow meter totalizer for measurement. An anchor was then tied to the balloon and measured as shown in Figure 4.2. This weight was then subtracted from the weight of the balloon, rope, and anchor before filling. The difference in weight was used to find the resulting lift produced by the volume of helium in the balloon as shown in equation 4.1.
Figure 4.2 Measuring balloon lift

\[ L = W_{\text{After filling}} - W_{\text{Before filling}} \]  

The value of lift was used in the following buoyancy relationship to find the actual volume and convert this value to liters

\[ V = \frac{L}{(\rho_{\text{air}} - \rho_{\text{He}})g} \]  

The densities for air and helium were found using the ideal gas law using room temperature and 1 atm pressure

\[ \rho = \frac{P}{RT} \]  

This volume was then compared with the volume readout from the flow meter totalizer and the process was repeated for each balloon.

In order to verify the results from the test previously described, a second method of finding volume was performed in combination. For each balloon the diameter was also found by wrapping a rope around the filled balloon and measuring the circumference. The diameter was obtained by modifying the circumference equation

\[ D = \frac{C}{\pi} \]  

The diameter was then used to find the volume by assuming the balloon shape as a sphere and using the equation for volume of a sphere

\[ V = \frac{4}{3} \pi \left( \frac{D}{2} \right)^3 \]  

While the second method of finding volume is less accurate than the first, it allows for a means of studying the effects of the balloon elasticity on the helium gas. A balloon’s elasticity increases the amount of internal pressure slightly as the elastic material becomes tighter near the elastic limit for very full balloons. This increased pressure raises the density of the enclosed gas by a small amount decreasing the buoyant effect of the lift gas. If the volume predicted from the lift values agrees with the actual measured volume within a reasonable amount of accuracy, then compression due to balloon elasticity on the helium can be assumed as negligible.
A comparison of the two methods shows an agreement between values suggesting that compression is negligible, and the volumes obtained from measuring lift are valid. The volume and lift of helium obtained from the lift measurements was then used in comparison with the totalizer output. The expected lift according to the totalizer output was obtained by modifying equation 4.2

\[ (4.6) \quad L = V(\rho_{\text{air}} - \rho_{\text{He}})g \]

After the first few rounds of testing, several of the data points were plotted and trendlines were added to fit the data. Figure 4.3 shows a plot of the actual lift generated at each volume compared with the theoretical lift for each volume of helium. As expected, lift increases linearly with volume with densities of air and helium held constant. However, the data for actual and expected lift do not overlap nor are the trendlines parallel. This leads to the conclusion that the flow meter was not reading the correct output causing balloons to be underfilled.

![Actual Lift vs. Expected Volume](image)

**Figure 4.3** Comparison of actual lift generated vs. the expected lift for the same volume

Following the previous conclusion, more balloons were filled in order to find a stronger relationship between the actual balloon volume and the expected volume output from the flow meter totalizer. All the data points obtained were plotted with the desired volume on the y-axis and the actual volume on the x-axis as shown in Figure 4.4.
Adding a trendline to the complete set of data gives the equation for a line modeling the trend for the difference in theoretical vs. flow meter volumes. Using this equation, a desired volume may be input and a required flow meter totalizer reading to achieve this volume will be output giving equation 4.7.

\[(4.7) \quad V_{Flow\;Meter} = 1.3946V_{Needed}\]

The relationship found from these experiments provides a means of compensating the flow meter totalizer to provide the correct amount of helium to the high altitude balloon. The efforts on this end have proven to be useful during HIBAL launches.

### 4.2 Flow Meter Results from October 18, 2008 Launch

A method for finding the volume of helium needed is necessary to make use of the flow meter during HIBAL launches. Too low of a volume will underfill the balloon causing a very slow ascent rate, and overfilling the balloon may cause premature rupture at altitudes lower than 90,000 ft.

A MATLAB program was written by a previous HIBAL team calculating the necessary volume and mass requirements in addition to predicting the balloon burst altitude and lift. The original program required inputs for system weight, balloon mass, ground temperature, and balloon burst diameter. This volume output from this program was converted to liters and used as the input for an older version of equation 4.7 during the October, 18 2008 HIBAL launch. This launch was the first test of the new balloon filling equipment and the process proved to still be insufficient. The launch resulted in a very slow ascent rate due to an underfilled balloon. Subsequently, both the flow meter and volume prediction program were investigated as possible sources of error.

The original volume calculator was used to predict helium filling requirements. The parameters input for the October 18 launch were 9lb for system weight, 1.5 kg for balloon mass, 8°C for ground surface temperature, and 35 ft for burst diameter of the balloon. The program yielded the following outputs:

- \(F_f = 50.9838\) N (lift force needed)
- \(V_{English} = 169.3775\) ft\(^3\) (volume of helium)
m = 0.8333 kg (mass of helium)

d = 10.6680 m (burst diameter of the balloon in meters)

P_k = 0.6888 kPa (atmospheric pressure that will burst balloon)

Converting the lift force to pounds provides a more useful number to compare to the payload weight.

F_f = 11.46 lbf

Converting the volume to liters provides the target volume needed to properly fill the balloon.

V = 4796.2 L

This volume was used in the first version of the flow meter calibration equation to find the reading needed to obtain the required volume.

\( V_{Flow \ Meter} = 1.398V\_{Needed} + 0.4675 \)

According to the above equation a flow meter output of 6705 L was required to obtain the necessary 4796 L. During the actual launch the balloon was filled to this value and released with the payload. The balloon provided sufficient lift to raise the entire system off the ground at an average ascent rate of 233 ft/min. This slow ascent rate caused the balloon to travel much further than predicted.

The actual system weight attached to the balloon from this launch was 7.874 lb. Because this weight was well under the estimated weight input to the Matlab file, the balloon should have had a much quicker ascent rate. More tests were performed on the flow meter to check the calibration equation, and the volume calculator was evaluated for errors.

### 4.3 Volume Calculator

A program was obtained called LIFTWIN 0.2 which automatically calculates volume, burst time, and ascent rate for various types of balloons. This program was not used to replace the previous program because it uses preloaded information for different balloon types. None of the preloaded balloons are used by the WSU HIBAL Team. Reference information provided with the program included suggested free lift values to obtain an ascent rate of 1000 ft/min based upon the writer’s experience. Free lift is the upward force provided by the buoyancy of the balloon in excess of the entire system weight. Free lift governs the ascent rate and required free lift increases with balloon ground diameter. This makes sense because increased volume means increased surface area and therefore higher drag.

The general launch diameter for the high altitude balloon is roughly seven ft corresponding to a required free lift value of 3.7 lb according to this reference. Assuming accurate flow meter compensation, the 4796 L volume the balloon was filled with theoretically provided 10.85 lb of lift. Adding the balloon weight (3.31 lb) to the system weight (7.87 lb) accounts for a total weight of 11.18 lb the balloon needed to lift. This introduces a situation where the balloon had insufficient lift to ascend, yet is near equilibrium. Observations from the October 18 launch showed that something similar to this happened. The balloon actually provided sufficient lift to ascend, but barely. The balloon was very near
equilibrium causing a very slow ascent rate. This means that the calibration equation provided more helium than expected and was not the cause of the underfilled balloon.

Therefore, the problem was in the required volume calculated by the original Matlab program. The program outputted a volume which would provide a lift sufficient to barely lift a 7.87 lb system weight even though an estimate of 9 lb was input into the program. Had the correct value been entered, an insufficient volume would have been output and the balloon would not have lifted the payload from the ground. It appears the program does not account for the weight of the balloon in the system weight. Volumes predictions for future launches should be based upon obtaining the free lift referenced in the LIFTWIN program information files instead of the Matlab program output.

A new Matlab program was written based upon the old code but changed to account for balloon weight and free lift requirements varying with diameter. The burst altitude calculations for the new program were left unchanged from the old program.

\[
F_{Lift\ Total} = W_{System} + W_{Balloon} + F_{Free\ Lift}
\]  

Equation 4.9 finds the total lift force required to achieve a sufficient ascent rate. Equations 4.3 and, 4.5 were then used to find the corresponding volume. Equation 4.7 was used to find the flow meter totalizer reading needed to achieve this quantity. The program initially takes inputs for balloon and system weights and calculates the balloon volume to lift the system off the ground. The program then checks the balloon diameter and chooses a corresponding free lift value and recalculates the volume requirements.

The new combination of flow meter and volume calculation has been tested during launch 3 to verify the improvements made to the filling system. The balloon was intentionally overfilled by approximately 300 L (on the compensation scale) resulting in an ascent rate of 1200 ft/min. While this is an acceptable ascent rate, filling the balloon to the value recommended by the program will allow for an ascent rate closer to 1000 ft/min. A copy of the new volume prediction program is included in Appendix A of this report.

4.4 Balloon Enclosure

In the past, the major factor preventing more HIBAL launches was high ground winds. Previously, the HIBAL team used their hands to stabilize the balloon during filling similar to Figure 4.5. The large surface area of the balloon was dramatically affected by winds causing it to be hard to control. As a result, a method to shield the balloon from high ground wind speeds was investigated in order to resolve this complication. Various fabric enclosures were researched as possible solutions. The enclosure needed to securely contain the balloon during filling without harming the latex material. Protecting the balloon from high ground winds would also eliminate the need for contact with the balloon by allowing for hands free filling. Such an improvement would eliminate the possibility of human oils coming in contact with the latex material. If human oils were to touch the balloon, they could cause the balloon to rupture prematurely by freezing on the surface and stressing the latex as it expands during ascent.
Another main criterion was that the balloon enclosure needed to be portable. Rip-stop nylon and pack cloth nylon had already been purchased the previous year for an enclosure. Tents, domes, and tubes were obvious options. One of the negative aspects of a tent or dome design was that the seam work would be more complicated than a tube design. This could make a tent or dome’s fabrication more expensive. A tube design would be simpler to construct because only rectangular pieces of material would need to be sewn at the edges. Overall, a tube design appeared to be the most cost effective and easy to set up and use during a launch.

For the tube shaped balloon enclosure, one of the main sources of inspiration came from Dr. David Rust from NOAA/National Severe Storms Laboratory in Norman, Oklahoma [12]. The balloon was filled inside the payload, and a break-away strap was pulled off of the side of the enclosure to release the balloon. Basically, the tube was actually a large sheet of fabric fastened together with Velcro at the edges. The balloon diameter was compressed by 20% inside the tube when completely filled. The compression had no negative effects on the balloon. However, it was decided that the HIBAL team’s balloon enclosure would not aim to significantly compress the balloon. Instead, it was calculated that the largest diameter balloon would be compressed by no more than 10%. This number was calculated based on the given amount of fabric available to work with. The design concept was based upon the maximum balloon size the HIBAL team is capable of using. A maximum balloon diameter of less than 10 ft was estimated. This diameter was based upon the resulting volume of helium needed to lift a system weight of 24 lbs suspended from the balloon. However, the balloon enclosure also needed to work for smaller, 6 ft diameter balloons. The following calculations were done in order to determine the exact dimensions of the balloon enclosure to be built. The first step taken was to determine the total volume of the largest balloon assumed as a sphere.

\[ V_{sphere} = \frac{4}{3} \pi r^3 = \frac{4}{3} \pi \times 5^3 = 523.599 \text{ ft}^3 \]

Then, the balloon was modeled as cylinder capped with two half spheres when compressed in the tubular enclosure. This approximation seemed to be an accurate representation for the largest balloon, slightly compressed. By equating the actual volume of a sphere with a 10 ft diameter and the balloon’s approximation, the required length of the enclosure was solved.

\[ V_{sphere} = 2V_{hemisphere} + V_{cylinder} \]
\( V_{\text{sphere}} = \frac{1}{2} \times \frac{4}{3} \pi \times 4.5^3 + \pi \times 4.5^2 l + \frac{1}{2} \times \frac{4}{3} \pi \times 4.5^3 = 523.599 \text{ ft}^3 \) \hfill (4.3)

\( l = 2.23 \text{ ft} \) \hfill (4.4)

\( l_{\text{total}} = l + \frac{1}{4} C + \frac{1}{4} C \) \hfill (4.5)

\( C = 2\pi r = 2\pi \times 4.5 \text{ inches} = 28.27 \text{ inches} \) \hfill (4.6)

\( l_{\text{total}} = 16.37 \text{ feet} \) \hfill (4.7)

A 5 ft by 40 yd piece of nylon pack cloth was available for use. Therefore, the most logical design was to make the enclosure with a 30 ft circumference and 20 ft length. A full set of dimensions for the balloon enclosure may be seen in Figure B.11 of Appendix B. This design would contain the largest balloon, allow for extra material for a synch cord at each end of the enclosure, and utilize the entire roll of nylon pack cloth. The synch cords’ purpose was to keep the balloon from coming out either end of the tube by tying off each open end. Additionally, weights were integrated into this design. The bottom of the cloth tube contained pockets in which weights were to be inserted. The purpose of the weights was to keep the balloon anchored to the ground during filling and before launching. It was decided that four 4 lb and four 8 lb bags of lead shot weights were to be used. The lead shot weights were able to mold to different shapes and did not have any sharp edges that could puncture the balloon.

![1/12 scale model](image-url)

**Figure 4.6** 1/12 scale model

A 1/12 scale model prototype was then made, as seen in Figure 4.6. Smaller balloons were put inside the scale model to make sure the balloon enclosure seemed feasible. It can be seen in the scale model that the balloon will leave the tube via the Velcro rip cord along the edge of the tube. Due to a lack of sewing equipment and expertise, fabrication was left to Sailor’s Tailor. One important point to note is that all seam work was done
such that all knots were on the outside of the enclosure. This was done in order to avoid any puncturing or harm to the balloon by the knots. The enclosure was fabricated before the first launch and test during this launch. The enclosure worked perfectly protecting the balloon from ground winds and allowing a free release when filled. The final product is shown in and a sequential image of the balloon being released may be seen in Figure 4.8.

![Figure 4.7 Balloon enclosure](image)

![Figure 4.8 Balloon release](image)

### 4.5 Connection Upgrades

**Payload System Failure Analysis**

Following the January 4, 2009 launch it became apparent that many of the connections used in the payload system needed to be replaced and a more thorough testing process should be implemented for every component used. Two unexpected connection failures occurred on the launch and components were analyzed following the launch and preventative measures were taken to avoid failures in the future. Efforts made to this end will improve launch readiness and reliability in future launches.

**Connection Failure #1**

There were two primary failures during the launch which should be avoided in the future. The first failure was in the connection between the balloon neck and ring as shown in Figure 4.9. This connection consists of a
swivel and several rings. The leftmost ring in the below figure allows the line attached to the parachute and payload to slip freely when the servo is released. The swivel allows the system to rotate freely during ascent to prevent tangling in the connection line.

![Figure 4.9 Balloon neck connection](image)

This system consisted of two split rings attached on either end of a swivel between two larger stainless steel rings. This system failed due to the balloon snapping on the connection during initial release from the bag. From observation, only the bottom (leftmost) ring in Figure 4.9 was left behind after losing the balloon leading to an initial theory that the split ring failed allowing the balloon to escape.

A more detailed analysis on the components was performed to better understand the failures which occurred. Tension tests were performed on both the stainless steel rings and split rings. The tension tests were performed by joining the split ring and hardened ring together and then pulling on both rings using a fishing scale on one end and a rope on the other. The setup was the same as the portion of the connection which failed. The force was slowly increased until failure occurred.

During the first test the split ring-stainless steel ring system failed at 14.5 lb. However, the split ring was not deformed and was not the cause of failure disproving the initial theory. It appears that the stainless steel ring has a split end that forms a gap deformation in the ring as shown in Figure 4.10. This gap allowed the split ring to slip through and break the connection. It is very probable this was the cause of failure during the launch.

![Figure 4.10 Split in stainless steel ring](image)

A similar test was performed on the split ring itself until failure. The maximum force observed before the split ring unraveled was 48 lb as shown in Figure 4.11. This supports the previous conclusion and efforts have been made to eliminate the gap problem with the hardened rings by brazing at the joint. Rings similar in size and weight but welded at the joint have also been obtained as replacements.
Once again, a tensile test was performed in a similar manner to test the new ring strength. A 100 lb was achieved without any signs of failure in the ring. It appears the improvement will be sufficient to prevent the same failure in the future. Despite the high failure force of the split rings these components will be replaced with stronger split rings with a 150 lb load rating. Such a change reduces the chances of failure in these connections. In addition, the split rings attached to the ball bearing swivels were replaced with the heavier split rings in order improve the strength of this connection.

**Connection Failure #2**

The second failure involved the loss of the second payload during balloon takeoff. Judging from launch day videos this failure occurred during a rapid ‘slingshot’-type load due to the rough nature of the launch. All future connections should be able to withstand this kind of loading without risk of breaking and every effort will be made to prevent such problems in future launches.

The original connection consisted of four 10 lb test fishing lines attaching at both ends by swivels to each payload. From observation, two of the connections failed due to the fishing line breaking. The other two connections appear to have failed due to the knot becoming undone. It is apparent that the fishing line was too brittle for this connection and the human error involved in tying strong knots needs to be removed.

10 lb test line was used due to a misinterpretation of the FAR 101 regulations limiting connections between payloads to 50 lb. The rule actually states that each connection must be able to break with a 50 lb force at some point in the connection. From this interpretation of the rule each of the four 10 lb test lines can be replaced with 50 lb lines.

The issue of tangling also needs to be discussed and resolved from this design in the same redesign step. The payload configuration from the launch placed the antenna between the two packages causing significant difficulty during the launch procedure. This problem must be resolved to allow the team to launch under high wind conditions.

In order to remove the error in knot tying and increase the strength of individual lines, heavy duty fishing leaders were obtained with a tested strength of 45 lb and a 2 ft length. Placing two leaders in line for each connection will allow for a four foot length. In order to prevent future tangling issues in this connection a spreader ring similar to the one used below the parachute will be placed as shown in Figure 4.12.
Several methods of softening dynamic loads have been investigated to help prevent stress on connections and lines in future launches. The first is a spring system attached in parallel with string lines as shown in Figure 4.13. The goal is to allow the spring to slow down the rate the force is applied to the payload system during take-off. The configuration allows for the spring to be placed in line with the rope in order to slow the rate of loading on the cord. However, most springs with a low enough stiffness to provide a sufficient spring rate cannot withstand sufficient static loads to be trusted with the connections. Therefore, the rope shown is tied to both ends of the spring as a continuous line. This prevents the spring from taking on the full static load while providing sufficient deceleration during perturbations in flight as shown in Figure 4.14. Should the spring fail for any reason, the connection is not compromised due to the unbroken rope connected in parallel with the spring. The best location for this system was between the parachute and balloon.
A method of easing dynamic loading on connections between payloads was also to be implemented. An elastic band was wrapped around the set of connections between payloads putting tension on the elastic and distributing tension more evenly across the six lines. The elastic bands should slow down the rate of loading on these connections helping to prevent failure in the 45lb fishing leader connections. 1” width polyester elastic bands have been purchased and sown into 3” diameter loops and wrapped around each set of steel leaders as shown in Figure 4.15.

![Figure 4.14 Spring system under loading](image)

**Figure 4.14** Spring system under loading

**Strength Testing and Proving Reliability**

In order to improve the reliability and prevent future failures, strength ratings will no longer be trusted and components will be individually pretested to a minimum of 50 lb static loads. In addition, system should be pretested with dynamic loads for quality assurance. System tests will be performed by lining up each component, with the exception of the balloon, as it would be during the actual launch to a pulley system as shown in Figure 4.16. The payload system is initially placed on the ground. While the weight is dropped, the dynamic loading caused by the weight snaps the payload upward simulating launch conditions. Failures and tangling issues are observed and resolved as needed during this testing process.
The pulley system consists of pulleys mounted on 2”x4” boards. The boards may be mounted to the campus bridge and spread apart enough to prevent the weight from contacting the payload during testing. The cord can be looped through the pulley system and the weight tied on one end while the other is attached to the payload system.

![Diagram of pulley system](image)

**Figure 4.16** System strength test

**Component Testing**

A number of components have been purchased to replace previous connections and strengthen existing connections. A number of components, both old and new, have been strength tested for failure prevention in future launches. Each component was tested with an increasing load until either failure or 100 lb was reached. Observations of the failure or component behavior during loading were noted. A list of components will be continuously updated for reference by future and current teams. The results so far can be seen in Table 4.1.

Most of the components tested satisfy the associated ratings while a few components do not appear to comply. The two connections likely to be weak points in future launches are the swivels and fishing leaders. The ball bearing swivels consistently fail in the split ring portion of the connection. The swivel strength was improved...
by using stronger split rings in place of the original. This improvement dramatically increased the loading capacity of the swivel.

Table 4.1 Component Testing

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight (lb)</th>
<th>Rating (lb)</th>
<th>Tested (lb)</th>
<th>Fail?</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>12” titanium shock leader</td>
<td>0.003</td>
<td>50</td>
<td>50</td>
<td>No</td>
<td>Significant elastic stretch</td>
</tr>
<tr>
<td>Cabela's stainless steel split rings</td>
<td>0.001</td>
<td>none</td>
<td>20</td>
<td>Yes</td>
<td>Ring unravels</td>
</tr>
<tr>
<td>Carabiner (Colored)</td>
<td>0.038</td>
<td>75</td>
<td>100</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Carabiner (Silver)</td>
<td>0.044</td>
<td>150</td>
<td>90</td>
<td>No</td>
<td>Line breaks</td>
</tr>
<tr>
<td>Eagle Claw heavy duty leaders</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Picture hangers</td>
<td>&gt; .001</td>
<td>unknown</td>
<td>40</td>
<td>Yes</td>
<td>Loop splits under static load</td>
</tr>
<tr>
<td>Quick link connections</td>
<td>0.016</td>
<td>220</td>
<td>90</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Sampo ball-bearing swivels</td>
<td>0.006</td>
<td>50</td>
<td>30</td>
<td>Yes</td>
<td>Split ring unravels</td>
</tr>
<tr>
<td>Sampo swivels with SPRO rings</td>
<td>0.006</td>
<td>unknown</td>
<td>100</td>
<td>No</td>
<td>Strength greatly improved</td>
</tr>
<tr>
<td>Small decorative carabiner</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Deforms at 120 lb</td>
</tr>
<tr>
<td>Solid aluminum from Sling Rings</td>
<td>0.03</td>
<td>150</td>
<td>100</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>SPRO power split ring</td>
<td>0.004</td>
<td>150</td>
<td>100</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Steel curtain ring 1-1/2”</td>
<td>0.024</td>
<td>Unknown</td>
<td>110</td>
<td>No</td>
<td>No deformation or gap</td>
</tr>
<tr>
<td>Steel ring 1-1/2” (split end)</td>
<td>0.026</td>
<td>Unknown</td>
<td>14.5</td>
<td>Yes</td>
<td>Split widens significantly</td>
</tr>
<tr>
<td>Steel ring 1-1/2”(welded end)</td>
<td>0.046</td>
<td>202</td>
<td>90</td>
<td>No</td>
<td>No deformation or gap</td>
</tr>
<tr>
<td>Steel ring 2” (welded end)</td>
<td>0.064</td>
<td>202</td>
<td>90</td>
<td>No</td>
<td>No deformation or gap</td>
</tr>
<tr>
<td>Superelastic Nickel-Titanium Wire</td>
<td></td>
<td>55</td>
<td></td>
<td>Yes</td>
<td>Breaks when tied</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Breaks at 30lb at knot</td>
</tr>
<tr>
<td>Yellow kite string</td>
<td></td>
<td>unknown</td>
<td>20</td>
<td>Yes</td>
<td>Breaks</td>
</tr>
</tbody>
</table>

Shock absorbing methods will improve the strength of these connections, but higher quality leaders were also investigated. 55 lb test nickel-titanium alloy fishing leader line was purchased for its elastic properties. However, the line was single strand and easily fatigued during bending. The line was difficult to tie without breaking and when successfully tied only held 30 lb before the stress from the knots broke the cord. It was decided the cheaper leaders were more practical for this application.

With the newly acquired components a new configuration for connecting the balloon to the release line was devised with greatly improved strength. Two of the ‘quick link’ components will be used on either end of the swivel with a two inch welded ring on one end of the chain as shown in Figure 4.17.
Using the two inch ring will allow the release line to slip through the connection with less risk of tangling while the swivel will help prevent the connections from twisting together as the payload is twisted in the wind. A similar connection should be placed below the parachute to prevent parachute twisting during descent. Images of new components and component failure can be seen in Figure 4.18 through Figure 4.20 below.

**Figure 4.17** Balloon connection chain

**Figure 4.18** 'Quick link' connection (left) carabiners and welded rings (right)

**Figure 4.19** Swivel and leader failure

**Figure 4.20** Picture hanger failure (left) tied nickel-titanium leader (right)
The rigging upgrades described have been tested on multiple launch simulations and one actual launch. The improvements have proved to be strong enough to withstand dynamic loads much more violent than an actual launch, yet weak enough to not violate the FAR 101. These improvements have also allowed a new method of launching using the balloon enclosure. The balloon is now released directly from the enclosure without assistance from an ascent cord reducing complication and error during the launching process as shown in Figure 4.8.

5.0 Payload Cutdown

5.1 Servo Release Mechanism

After researching different ideas for a release mechanism, it decided that the primary mode of release for the balloon was to be a servo release mechanism. The backup release was to be the nichrome wire cut-down, as seen in Figure 5.1. The servo release mechanism design was inspired by a similar device used by a team at the University of North Dakota [13]. The servo release mechanism consisted of an HS-645MG Hitec servo, a servo tester, a foam enclosure to insulate the servo, the servo circuit, 8 AA batteries for power, a ham radio to receive the release signal, a DTMF-8 board to trigger the release, a wood block with a hinge, and a looped cord. The release mechanism operated in the following manner. A cord connecting the entire release system to the balloon was attached to the servo release mechanism via a looped cord (Figure 5.1). When the servo top was triggered to rotate, the top piece of wood will be pulled upward by the looped cord. The top piece of wood is attached to the bottom piece of the wood by a hinge, so the looped cord can freely slide off of the top piece of wood. The entire release mechanism will be detached from the ring that is connected to the balloon. The balloon will then be separated from the rest of the payload-parachute system. If this system failed, then the nichrome wire would be initiated.

The following description is a detailed account of how the servo release mechanism (Figure 5.2) was built. To start, a high torque servo with metal gears was selected for our release application. Metal gears are stronger than plastic gears and will jam less easily. A high torque servo was chosen over high speed servos because the servo’s functionality in this application was dependent on torque, not speed. The wooden block was made using 4.5 by 0.5 by 1 in pieces of balsa wood. The wooden pieces were shaped using a knife and sand paper. A loose hinge was chosen to connect the pieces of wood, in order to allow for as little resistance as possible. The loose
hinge connection and all of the wooden pieces were coated in epoxy. The epoxy served a dual purpose in its application. First, it enabled the looped cord to slide off of the top wooden piece more easily, with less friction than wood alone. Also, it served as a strong connection for the bolts in the hinge. Balsa wood is soft, so simply screwing the bolts into the balsa wood would create a connection that could easily fail. Instead, holes were made for the bolts, and the holes were then coated in epoxy. The bolts were screwed into place, and the parts on the hinge that directly touched the wood were also coated in epoxy. In order to connect the balsa wood to the top of the box, holes were drilled into the balsa wood, and even smaller holes were drilled into these larger holes. Then, the bottom wood piece was bolted into the top of the box without affecting the looped cord. Washers were also put in, so there would be no pull-out of the Styrofoam.

![Figure 5.2 Servo release mechanism](image)

The battery selection for the servo’s power supply was rigorously tested. Below is Table 5.1 with the basic requirements for the servo’s operation.

<table>
<thead>
<tr>
<th>Table 5.1 Servo specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operating Voltage Range</strong></td>
</tr>
<tr>
<td><strong>Operating Temperature Range</strong></td>
</tr>
<tr>
<td><strong>Idle Current</strong></td>
</tr>
<tr>
<td><strong>Running Current</strong></td>
</tr>
<tr>
<td><strong>Pulse Time</strong></td>
</tr>
</tbody>
</table>

After analyzing these specifications, some testing was needed in order to ensure a properly working servo. It should be noted that the servo tester’s pulse time range of 1ms – 2ms was less than the servo’s pulse time range. As opposed to rotating the complete 120°, the servo only rotated 100° when connected to the servo tester. The servo tester was needed though because it was a portable device that served the same function as a frequency generator. Fortunately, 100° was a sufficient amount of rotation for the servo top to allow the wood piece to open.
Due to the current, voltage, and temperature limitations, the servo and two different kinds of batteries were thoroughly cold tested. A picture of the experiment setup is shown in Figure 5.3. During the first night of testing, six lbs of dry ice was placed inside a Styrofoam cooler. The goal was to cool the cooler to -50°C, in order to simulate the temperatures at 100,000 ft. However, the lowest temperature recorded inside the cooler by the thermocouple was -25°C. An insufficient amount of dry ice was used, but the experiment was still continued. The two different types of batteries that were tested were the small 12v23A battery and 8 AA batteries. For each test, the given battery or batteries were connected to the servo and wooden piece, servo tester, servo circuit, DTMF-8, and ham radio. For each test, all of the parts were placed in the cooler for about an hour, in order to cool the components and simulate the temperatures and time of an actual launch. For both tests, an 8 pound weight was hung from the wooden piece that was connected to the servo. This was done to ensure that the servo would have enough torque to rotate the 100°, even if its performance was decreased due to cold temperatures.

Prior to testing, there were some complications with the 12v23A battery holder. The battery holder was entirely conductive and only appeared to operate in one direction. Consequently, a make-shift battery holder was used by clamping the leads to the battery with a strong clip and electrical tape.

After all components had been inside the box for an hour, the DTMF-8 board was programmed to trigger the release. By opening the box to do this, the temperature inside the box rose slightly to -15°C. Several conclusions arose from each test. When the 12V23A battery was used, the battery died before the release was even triggered. The original voltage of the battery was 11.48 v, and the voltage after being in the cooler for a while was 2.5 v. It could be concluded that this battery would not be a reliable option to power the servo because the cold temperatures had such an undesirable effect on the voltage. When the pack of 8 AA batteries was used, the servo did work. Unfortunately, the servo top did not provide 100° of motion. The speed of the servo was the same, but the servo did not rotate enough for the top piece of wood to open.
On the next night of testing, the pack of 8 AA batteries was tested again with the remaining dry ice. The cooler was set up in the same configuration and got down to about -15 to -20°C. All components were connected in the same configuration. This time, the servo worked perfectly and provided the 100° of rotation. Two hypothesizes were suggested to explain this malfunction. First, there may have been a cut-off temperature for the servo and the box did not reach that temperature on the second night of testing. Second, the servo tester may not have been set at the correct end of the operating range (1ms or 2ms). Regardless, it was decided that another test at a colder temperature would need to be done. The possibility of insulating the servo with foam was also proposed, in order to increase the temperature of the servo.

The foam enclosure (Figure 5.4) was made with 1.75 in thick pieces of Styrofoam. The pieces were then sewn together using thread. Afterwards, the foam enclosure was connected to a piece of cardboard with epoxy. Connecting the enclosure to a piece of cardboard instead of the Styrofoam lid itself enabled portability. The enclosure could be used on difference payloads. To use the foam enclosure, the servo was placed inside the foam enclosure and bolted through the cardboard and Styrofoam, in order to be connected to the lid of the payload.

The next night, the servo was put to the test again. The experiment was set up in a slightly different configuration than before. This time, only the servo (with the wooden block) was put into the -40° C cooler. Only the servo was put in the cooler, in order to try to isolate which components would and would not perform at cold temperatures. After about an hour and a half of being in the cooler, the servo was again tested with an 8 lb weight and the same pack of 8 AA batteries. This time, the servo released perfectly. The servo top rotated the expected 100°. This confirmed that the servo would perform at low temperatures, and perhaps another electronic was the weak link.

Next, the whole system was put in the cooler for an extended period of time. The experiment was configured in the same way as Figure 5.3 shows. Once again, the servo worked perfectly with the same 8 AA batteries. Afterwards, it was decided that the servo should be cold tested using the foam enclosure. The servo was placed in the foam enclosure and both were placed in the cooler. Additionally, a hand warmer was also placed inside the foam enclosure. Initially, the temperature inside the foam enclosure was 40° C. In the past, hand warmers
have been a standard for the payload since they help to raise the initial temperature inside the payload. Due to the fact that the servo and foam enclosure will actually be placed on the outside of the payload, hand warmers are a simple precaution that will be helpful. After leaving the foam enclosure and servo in the cooler for about an hour and a half, the temperature inside the foam enclosure was -1° C, and the servo was tested again with success. It rotated 100°.

The 8 AA batteries worked for all of these tests, but it was decided that the smaller, lighter 12v23A battery should also be tested. In a similar test, the 12v23A battery was cooled to about 3° C and tested with the servo and all of the other electronic components. The battery was not able to supply enough current to the servo, so the servo top was not able to rotate. At the upper atmosphere, the servo will probably see temperatures lower than 3° C. Therefore, it was decided that the 12v23A battery was not a reliable way to power the servo.

5.2 Nichrome Wire Release

![Nichrome wire cold testing](image)

The nichrome wire release (Figure 5.5) was going to be the back-up release mechanism. The electrical engineers built a circuit to power the nichrome wire. Gauges 28-33 sized nichrome wire were cold tested in the same manner that the servo was tested in. All of the gauges were able to sever the cord. After deliberation, it was decided that the current circuit was not going to be used anymore. The circuit contained a large capacitor, and the HIBAL team collectively agreed that this would not be safe. If the circuit were to malfunction, the capacitor could potentially land on the ground while still being charged. Consequently, a new circuit is still being built. Once this new circuit is completed, it will need to be thoroughly tested.

6.0 Parachute Deployment

After researching parachute deployment methods in the model rocketry field it was determined that any design should be based on an air tight cylindrical tube. Expanding gas provides the pressure to push the parachute out of the tube. Low power model rockets which fly up to 1,000 ft use a black powder charge that is built into the end of the motor to deploy a parachute. As a result, two different sizes of low power model rocket motors, as shown in Figure 6.1, were purchased for experimentation purposes.
A ‘C’ sized motor was cut such that only the black powder deployment portion was remaining as shown in Figure 6.2. The charge was ignited by a small piece of nichrome and batteries. Unfortunately, portions of the propellant remained which caused a good deal of fire and sparks before the charge ignited. The ejection charge seemed rather weak and it was concluded that while it may be sufficient for a short and small 1.5” diameter rocket it would not create enough pressure in the HIBAL application.

In an attempt to generate large amounts of expansion gases, the rocket engine was applied in a unique manner. The propellant portion cut off in the previous experiment was secured with epoxy into the bottom of a 1.75” diameter cardboard tube such that when the motor was ignited by nichrome and batteries the thrust would shoot inside the tube. A circular piece of cardboard was loaded into the tube to protect the dummy parachute from the hot gases. This method generated enough pressure to deploy the dummy parachute, but it severely burnt the dummy parachute and the cardboard tube as shown in Figure 6.3. The experiment setup is shown in Figure 6.4 below.
At this point it became evident that a different approach outside of rocket motors needed to be investigated. High powered model rockets which reach altitudes of 10,000 to 50,000 ft became the new source of design inspiration. These rockets use a small quantity of black powder held in a fixture to deploy the parachute. Therefore, various means of obtaining black powder were investigated including making it. After extensive communication with WSU’s environmental health and safety services the team was granted permission to purchase pre-made black powder.

In altitudes above 20,000 ft black powder begins to have a hard time fully burning. This is due to the fact that in a vacuum there is a lack of air molecules to transfer heat energy from molecule to molecule. “With a lack of air as a heat transfer medium, there is no way to continue the combustion and maintain the needed ignition temperature [1].” In addition, as the gases produced during the initial ignition of the black powder expand, they cool and quickly rush away from the point of ignition. This can create a self-extinguishing effect by lowering the temperature below the ignition temperature, and the hot gases rush away before igniting the next particle [1]. As a result, it is well known the best way around these effects is to self contain the black powder in an air tight container.

After purchasing black powder a 4” diameter 48” long tube was used to make the first deployment device. The length was kept long so that it could be cut to an appropriate length later. A ½” thick piece of plywood with a 1/4” x 3/4” x 2-1/2” steel U-bolt and two charge holders were epoxied to the bottom of the tube as shown in Figure 6.5. The charge holders consisted of a 1” x 3/4” PVC female bushing, 3/4” PVC male plug, 3/4” x 1/2” PVC female bushing, and a 1/2” PVC male plug. The female portion was epoxied into a hole in the plywood so that the male part could hold the black powder and be threaded and unthreaded into the deployment tube for multiple uses. Two different sizes of charge holders were used so that the backup...
would be larger than the primary. A larger charge would provide a larger deployment force in case the primary charge was too weak to deploy the parachute. The male charge holders were modified such that a 5/32” hole was drilled in the bottom so that an electric match could be epoxied into it for igniting the black powder. Charges were prepared by filling them with black powder and using paper towel as wadding to pack the powder. Then the top was covered with epoxy to make the fixture air tight. After building was complete, multiple tests were carried out.

![Figure 6.5 First deployment tube](image)

To evaluate the performance of this design several ground tests were conducted using the two different sizes of charge holders. The smaller held 3 grams while the larger held 4 grams of black powder. First, a piece of cloth was used as a dummy parachute to eliminate the possibility of destroying the real parachute. Both sizes of charges successfully deployed the dummy parachute quite well. However, the larger charge did push the dummy parachute out further. No visible burn marks were found on the dummy parachute so the real parachute was loaded and tied off to a tubular nylon shock cord connecting the tube to the 72” parachute via a U-bolt. The charges were remade and loaded back into the female bushings. Both of these tests were also successful. While the small charge ejected the parachute approximately 3’ into the air, the larger charge ejected it 5’ and caused the shock cord to pull tight lifting the entire tube into the air. Ground testing proved this design would perform its intended function, but it still needed to be proven in a vacuum.

A 3 and 4 gram charge were carefully prepared the same way as was used in ground tests. Both were ignited in the vacuum chamber with a pressure of 6.3kPa which is equivalent to an altitude of approximately 61,350 ft. In both tests the charge ignited and blew the epoxy top off while scattering over half of the unburned powder as shown in Figure 6.6. To evaluate the tests against a control, one more charge was prepared and placed in the vacuum, but the pressure was not lowered. This charge also ignited and blew the epoxy top off while scattering the same amount of unburned powder. It became clear that as the powder ignited inside the sealed charge holder the pressure grew too quickly to contain the black powder long enough to fully burn. Therefore a better way of containing the black powder to allow expansion during ignition was researched.
Figure 6.6 Unburned black powder

The team made the decision to stay within the FAR regulations and make the re-entry payload 6 pounds. This decision was made based on the fact that an application needs to be submitted to the FAA and permission granted a month in advance of a launch. Impossibility in predicting Ohio winter weather a month in advance became the deciding factor to not exceed 6 pounds. With a lighter payload a smaller 60” parachute was needed and therefore a smaller 3” diameter tube. A new deployment tube was quickly constructed out of a 3” diameter tube and was cut to 22” length. Focusing on making the overall design light the plywood plug was cut from 3/8” thick plywood and the steel U-bolt was replaced with aluminum. The smaller diameter tube also helped save weight. Two of the smaller 3 gram capacity PVC charge holders were used this time due to the size limitations of the 3” diameter. Below, in Table 6.1, the two designs are compared in terms of weight for the components that differed. The total weight savings is 0.467 lb.

Table 6.1 Weight comparison of two deployment tube designs

<table>
<thead>
<tr>
<th>Item</th>
<th>Design 1</th>
<th>Weight (lb)</th>
<th>Design 2</th>
<th>Item</th>
<th>Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4” diameter tube 22” long</td>
<td>0.621</td>
<td></td>
<td>3” diameter tube 22” long</td>
<td>0.264</td>
<td></td>
</tr>
<tr>
<td>Steel U-bolt and 4 nuts</td>
<td>0.0840</td>
<td></td>
<td>Aluminum U-bolts and 4 nuts</td>
<td>0.0260</td>
<td></td>
</tr>
<tr>
<td>1/2” thick 4” diameter plywood plug</td>
<td>0.0861</td>
<td></td>
<td>3/8” thick 3” diameter plywood plug</td>
<td>0.0546</td>
<td></td>
</tr>
<tr>
<td>1” x 3/4” PVC female bushing</td>
<td>0.0263</td>
<td></td>
<td>3/4” x 1/2” PVC female bushing x 2</td>
<td>0.0300</td>
<td></td>
</tr>
<tr>
<td>3/4” x 1/2” PVC female bushing</td>
<td>0.0150</td>
<td></td>
<td>1/2” PVC male plug x 2</td>
<td>0.0360</td>
<td></td>
</tr>
<tr>
<td>3/4” PVC male plug</td>
<td>0.0280</td>
<td></td>
<td>Total 0.411</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2” PVC male plug</td>
<td>0.0180</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.878</strong></td>
<td></td>
<td><strong>Total</strong> 0.411</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After building the new deployment tube several tests were in order all using 3 grams of black powder. Using a piece of cloth as a dummy parachute, the tube was loaded into the vacuum chamber with 6.3kPa pressure. The dummy parachute easily deployed and there was once again a good deal of unburned powder.
To simulate the deployment against potential eddy currents discovered in the CFD analysis, the tube was loaded with the dummy parachute once again. This time the deployment tube was aimed head on into a powerful fan. Using a wind velocity meter the wind speed was measured at 17mph and the dummy parachute easily deployed into the wind. Next, the deployment tube was placed in the vacuum chamber with 6.3kPa pressure and it was loaded with the real parachute and several pieces of fire retardant paper to protect the parachute. The parachute failed to deploy so the same setup was loaded into the vacuum chamber again and the test was reran. Again, the parachute did not deploy. This was probably because the real parachute did not create as good of a seal inside the tube to allow the pressure to build underneath it and push it out. Then the dummy parachute was loaded in the tube first followed by the real parachute. Once again the parachute failed to deploy in the 6.3kPa pressure vacuum probably due to too much friction along the inside of the tube. At this point a new approach was needed.

To increase the burn rate and explosiveness of the black powder it was ground into a fine powder using a mortar and pestle. Figure 6.7 compares the original black powder to the finely ground black powder. The real parachute was loaded into the tube along with fire retardant paper. After loading the tube in the vacuum of 6.3kPa the 3 grams of fine powder was ignited causing the parachute to deploy. However, the cardboard tube blew out and the parachute sustained some burning. The same design was quickly rebuilt using a slightly thicker walled cardboard tube and the helical seam on the tube was reinforced with epoxy and duct tape as shown in Figure 6.8. This tube weighs 0.370 pounds, but this design still offers a 0.361 pound advantage over the large 4” diameter tube. Two pieces of fire retardant Nomex cloth were attached to the tubular nylon shock cord to replace the fire retardant paper and better protect the parachute. Two 3 gram charges were prepared using the fine powder. Each test was conducted in the vacuum of 6.3kPa pressure and both resulted in the male charge holder shattering. The parachute failed to deploy both times. At this point it became clear that the PVC charge holder needed to be reconsidered.

A new, air tight, charge holder was needed that would allow the black powder to expand as it ignites without releasing expanding gases until most of the black powder has burned [7]. As a result, ½” I.D., 5/8” O.D.,
1/6” thick wall latex surgical tubing was purchased. This material was chosen under the presumption that it would allow the hot gases to expand until most of the powder burned. Several tests were prepared in which the electric match was loaded into the surgical tubing and each end was zip tied after loading the black powder to make it air tight as shown in Figure 6.9. Each test consisted of 4-5 grams of finely crushed black powder in a 2.5”-3” long piece of the surgical tubing. Two tests were conducted with the surgical tubing in the vacuum chamber without the deployment tube. Both tests resulted in over half the powder burning and the video that was recorded showed the surgical tubing blowing up like a balloon before rupturing as shown in Figure 6.10. This was a good indication that the surgical tubing was performing as intended. However, after performing two more experiments with the surgical tubing charge loaded in the deployment tube, it was discovered that the charges failed to produce enough expansion gases to deploy the parachute. Out of curiosity, a ground test was conducted which successfully deployed the parachute. The failure of this method presumably lies in the failure of zip ties to make an air tight seal and the wall thickness of the surgical tubing was of insufficient wall thickness. A thicker wall would have allowed the charge to be contained longer allowing more complete combustion. Due to the difficulty and cost of obtaining thicker walled surgical tubing, a new charge holder was researched.

An aluminum charge holder was researched and machined based off the design and testing in the literature [8]. Nate Herrmann machined two 1” O.D., ¾” I.D. aluminum charge holders one being 2” long and the other 2.25” long for additional black powder capacity. A 5/32” hole was drilled in the bottoms for the insertion of the electric match. Several charges were prepared like that shown in Figure 6.11 with the PVC male plug acting as a wire grommet to seal the deployment tube. A piece of paper towel was wadded up and pressed inside the aluminum canister to pack the black powder. Five pieces of electrical tape cover the

Figure 6.9 Surgical tubing based deployment charge configuration

Figure 6.10 Before and after ignition in vacuum of surgical tubing charge
top with one longer piece wrapped around the circumference. This contains the black powder long enough to achieve complete combustion. Two initial vacuum chamber tests with 3-4 grams of black powder without the deployment tube were very violent and resulted in 100% burn. A test with the deployment tube and the same black powder loading resulted in the cardboard tube blowing out. The entire tube jumped and hit the top of the vacuum chamber which kept the parachute from coming out. After rebuilding the tube, making it one inch shorter to save weight and reinforcing it with Guerilla tape, another test was run with 1.75 grams of black powder. This test successfully deployed the parachute without damaging the tube. A 1.80 gram and 2.25 gram charge were prepared and loaded into the deployment tube to be sent up on a HIBAL launch. For launch testing purposes the parachute was wrapped in a rubber band to prevent it from opening. The system was mounted to the bottom payload and sent up on the February 24, 2009 launch as shown in Figure 6.12. Unfortunately, the electrical circuit did not trigger the electric matches to ignite the black powder. However, after the launch recovery the deployment tube was loaded in the vacuum chamber and successfully deployed the parachute when batteries were used to trigger the electric match. This design will be the final revision, but still needs validated on the next HIBAL launch. Future teams may work towards reducing the weight by utilizing more aluminum connections and lighter weight composite tube materials.

![Figure 6.11 Aluminum charge holder configuration](image1.jpg)

![Figure 6.12 Launch test configuration of deployment tube](image2.jpg)
7.0 Payload Design

Dropping a payload system from a high altitude balloon requires more than just the means to release the package and deploying a parachute; the payload itself also needed to be redesigned to fall in a safe and stable fashion. To this end, several constraints were taken into account.

First, the new payload should be able to house all electronics, experiments, antennas, radar reflectors and other components inside the body. Because the new payload was designed to freely fall everything must be contained in a single package. Certain components such as the ground-plane antenna and radar reflector must be located inside the payload body. This requires the payload body to be large with each component inside carefully placed for balance, aerodynamics, and prevent interference between communications devices.

The payload should also have a higher amount of drag for safety reasons. A high drag will result in a slower terminal velocity which will in turn put less stress on a parachute cable as it deploys. Also, if the parachute fails, the slower terminal velocity will reduce the amount of damage caused to property or the payload itself when it lands.

Stability was also an important factor in the vehicle design. If the new payload tumbles through the air as it falls, parachute deployment could be a difficult task. The cord could easily become wrapped around the body as the folded parachute is ejected. An unstable freefall could also jeopardize any experiments contained inside the payload body. Several common aerodynamic shapes were considered as inspiration for payload design. These included model rockets, nose cones, and NASA reentry vehicles as shown in Figure 7.1.

![Figure 7.1 Reentry vehicle geometry concepts](image)

The designs were compared based upon the criteria described previously. While missiles provide a large amount of stability due to the pressure drag being located near the tail end of the body, they are also very aerodynamic and this shape would not produce much drag. Nose cones are also very aerodynamic and have a less stable flight. It quickly became obvious that a shape with a blunter nose would be necessary for the new payload reentry vehicle to have a slower descent rate.

Traditional space reentry vehicles have blunt ends for the purpose of creating a larger drag coefficient. This is mostly for reducing heat loads during atmospheric reentry. This same concept may be applied to the new payload system for the purposes of creating a lower terminal velocity. One common reentry vehicle geometry is the sphere-cone which consists of a spherical section with a conic frustum mounted to the back end. Sphere-cone shapes have been used and proven to be aerodynamically stable.

The new payload will be based upon a sphere-cone design because this geometry is simple, inexpensive to construct, and exhibits all of the qualities needed for the payload design. Styrofoam hemispheres were obtained
from Plasteel Corporation as shown in Figure 7.2, and the frustum tail could be manufactured in-house or custom made by Scenic Solutions near Dayton, Ohio. However, before the payload can be constructed a more thorough analysis on the geometry must be performed in order to find the best angle to use for the frustum tail.

![Figure 7.2 Hemisphere obtained for payload construction](image)

**CFD Analysis of the Effects of Frustum Geometry on Payload Freefall**

Once the tear-drop shape was chosen as the most promising payload geometry, the effects of the frustum dimensions needed to be analyzed to find the most desirable shape. The primary desired effects include freefall stability, increased drag, smaller wake region, and low weight. Freefall stability was desired in order to provide better video from any mounted cameras and prevent complications during parachute deployment. The parachute may have difficulty deploying if the payload falls upside down or tumbles through the air. High drag was desirable in order to reduce terminal velocity for safety reasons. If the parachute fails to deploy for any reason, a slower falling payload will be less likely to hurt a person, property, or the payload itself.

The wake region has a high amount of interest because larger wakes can cause complication in parachute deployment. As the payload falls, some air will want to flow around a conic region trailing the frustum while some air will be forced to fill in this region following the payload. This creates turbulent wake currents which can potentially weaken a parachute’s momentum during deployment or obstruct its exit from the rear of the payload.

Finally, due to strict FAA regulations for high altitude balloons the entire payload is limited to 6 lb. The shorter the frustum section is on the payload the lighter this component will be. The goal of this analysis was to find the best frustum shape based upon these requirements.

**Creating the Meshed Model**

In order to find all of the needed information, six two dimensional models were created in Solid Works as shown in Figure 7.4. The first three models show the sphere mounted on the bottom of a frustum with half angles of 15°, 25°, and 35°. The last three models show the same set of payloads tilted at 10° simulating wobble during descent. Each case was drawn inside a larger rectangle and the object converted to a surface. This left a payload cutout in final surface. The resulting surface represents the body of air flowing around the payload while the cutout represents a solid body in that mass of air. The surface was made sufficiently larger than the payload in order to prevent boundary layers formed by the edges from interfering with air flow behavior around the payload cutout. Each model was saved as an IGES file and loaded into Gambit for meshing.
In Gambit, each model was prepared with a fine mesh near the payload body and a looser mesh further away near the model boundaries. The mesh variation was done by meshing the payload body edges with a 20mm mesh size and then meshing the outside wall of the surface with a 100mm mesh size. The surface was then meshed with a triangular 100 mm mesh causing cell sizes to be small near the payload and increasing in size further away as shown in Figure 7.5. This mesh variation was added in order to speed up computation time yet obtain accurate results near the payload edges. Boundary conditions were also set in Gambit. The inlet was defined as a velocity inlet and the outlet was defined as a mass flow outlet. The left and right walls as well as the payload edges were defined and the continuum was set as a fluid. The resulting mesh was exported in two dimensional format.
Air Properties and Pre-Simulation Setup

In order to obtain a good understanding of how the payload shape will behave during descent it must be modeled in an environment reflecting the actual freefall conditions. Because the balloon rises to nearly 100,000 ft, the payload will see a wide range of atmospheric conditions. Therefore, the most significant case must be selected for the CFD analysis. Most of the properties desired for the payload shape are related to assisting in parachute deployment performance. Freefall conditions were then found for air at 60,000 ft due to this being the altitude set for parachute deployment.

<table>
<thead>
<tr>
<th>Table 7.1 Air properties at 60,000 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, $\rho$ (kg/m$^3$)</td>
</tr>
<tr>
<td>Pressure (Pa)</td>
</tr>
<tr>
<td>Viscosity, $\mu$ (kg/m*s)</td>
</tr>
</tbody>
</table>

Air properties for this altitude were obtained as shown in Table 8.1 and used to find an estimate for the terminal velocity using equation 8.1.

$$V_t = \sqrt{\frac{2mg}{\rho A C_D}}$$

Because the drag coefficient was unknown for the payload shape was unknown, the drag coefficient was roughly estimated to be a little higher than the coefficient for a sphere [6]. The value chosen was 0.5. The area was assumed for a 2 foot circle. A Matlab program was written to calculate the terminal velocity for a 6lb
payload using this equation and properties. A terminal velocity of 55.8 m/s was found as an estimate. This number seems a little high but is sufficient because the analysis is based upon a comparison of the different geometries under the same conditions.

**Fluent 2D Simulation**

The meshed models were then loaded into Fluent for a 2D analysis. The initial round of testing used a velocity inlet on the bottom edge of the mesh and an outflow for the top edge of the mesh. All other edges, including the payload cutout, were set to wall boundaries. The 55.8 m/s terminal velocity was loaded into the velocity inlet and the operating pressure was set to 6910 Pa, the atmospheric pressure at 60,000 ft. The flow was modeled as inviscid and the solver set to second-order upwind approximation. The mesh was then initialized to the inlet conditions and allowed to iterate until a sufficient level of convergence was obtained. Convergence was observed by plotting the residuals and increasing the iterations until the residual magnitudes dropped below 1e-04. This same process was applied to all three payload geometries.

Several properties were then plotted using contour and velocity plots in Fluent. The most interesting of these was the static pressure as shown in Figure 7.6. As expected, a high pressure area formed in the front of the payload and a slightly lower pressure area behind. However, most of the static pressure in this contour plot is negative. At first, it was assumed this was due to the plot showing gage pressure. In order to resolve this, the operating conditions were set to 0 Pa to force the contour plot to show absolute pressure. This did not resolve the problem because the contour plot was already showing the absolute pressure distribution. Several more settings were changed in order to find a solution to this problem.

![Figure 7.6 Static pressure for first round of CFD simulation](image)

Eventually, it was found that using an outflow boundary condition caused the model to be poorly defined. Velocity inlets do not require any pressure information and the outflow condition makes assumptions based on the rest of the model. Pressure was never defined so the outflow boundary assumed the inlet was at 0 Pa and chose a negative pressure to allow for a pressure drop across the flow field. The problem was corrected by changing the outflow boundary condition to a pressure outlet set at 6.91 kPa. This change forced the atmospheric pressure to be the desired value producing results like those shown in Figure 7.7.
From the static pressure plots shown in Figure 7.7 the pressure distributions on each case were compared. All three payload geometries create a high pressure region in the front of the spherical nose as the air presses against this face. Each case produced a similar frontal pressure distribution.

However, the pressure trailing each payload is different for each case. For the 15° payload (top left) the region trailing the payload tail was very near the atmospheric pressure causing a lower pressure differential between the front and back ends of the payload. Fluent was used to sum the pressure forces along the edges of the payload in order to find the pressure drag. The 15° payload had a total pressure drag of 21.6 N as a consequence of the small pressure change.

![Figure 7.7 Comparison of static pressure distributions](image)

The 25° payload (top right) had a slightly lower pressure following the tail end as evidenced by the light green region. This caused a higher pressure differential and consequently a higher drag. After summing the pressure forces on each side of the payload, the total drag force was found to be 31.48 N. As can be expected, the 25° payload experiences a higher drag than the 15° payload.

Finally, the 35° payload (bottom) showed a darker green region trailing behind the body. This represents a very low pressure region relative to the front end of the payload. This caused a higher pressure difference from the
front to the back of the payload which results in a higher pressure drag. Summing the pressure forces along each edge of the payload produced a 68.1 N drag force.

The pressure drag force information obtained from this analysis was used to find the drag coefficient using equation (8.2).

\[
(8.2) \quad C_d = \frac{2F_d}{\rho V^2 A}
\]

The drag coefficient was then applied to equation (8.1) and replacing air density with ground level air density. This resulted in estimated terminal velocities of 43.8 mph, 36.3 mph, and 24.74 mph for the 15°, 25°, and 35° half-angle geometries respectively.

Next, a study was performed using vector plots of the air velocity for each of the three shapes. Velocity vectors in Fluent show both direction and magnitude of the airflow which was useful for observing turbulent wake behavior trailing each payload geometry. The vector plot for velocity magnitude was produced and plotted for all three shapes as shown in Figure 7.8 and compared.

Both the magnitude and the behavior of air velocity change significantly between the different payload geometries. In each case, eddy currents are shown forming along both corners of the payload tail edge. This happens because of the low pressure region formed by the turbulent wake. As the airflow over the payload surface separates from the surface during sharp boundary layer transformations, a low pressure region is formed. Air further up the streamline is forced to change direction and fill in the low pressure area causing the resulting backflow. The air changes direction in such a way that the air actually flows against the back edge of the payload. The turbulent wake behavior is important to observe because it could significantly affect the performance of the parachute deployment system. The air trailing the payload actually opposes the parachute as it is ejected from the rear of the payload body. If the parachute cord is not long enough to trail behind this turbulent region the performance of the deployed chute could be deterred as well. The purpose of this study is to properly size the parachute cord and deployment charge and assist in choosing the best frustum geometry for the payload tail.

As seen in Figure 7.8 the turbulent wake trailing the 15° payload (top left) is relatively small and weak. This shape is very streamlined and flow separation does not occur until reaching the back edge. The resulting low pressure region is very small and weak resulting in a small turbulent wake. Parachute deployment for this geometry would not have very strict requirements. For the 25° payload (top right), flow separation was observed before reaching the end of the conic section. The early flow separation causes a larger turbulent wake with longer eddy currents. A parachute deployment system for this geometry would require a much longer cord and a more powerful deployment charge to exit the turbulent region. Finally, the 35° system shows flow separation at the cone-sphere connection caused by the sharp surface change at the junction. A parachute deployment system would have the most difficulty for this geometry based upon the reasons stated previously for the other geometries.
Weighing the pros and cons based on the studies so far, a few conclusions can be made about the different payload tail shapes. The 15º frustum causes the payload to be very streamlined with a low amount of pressure drag. This will cause a higher terminal velocity which is not desired for this design. However, the turbulent wake is very small and would provide better conditions for parachute deployment. The 35º frustum creates a large pressure drag resulting in a lower terminal velocity. The lower terminal velocity is desirable for the payload design. However, the turbulent wake is very large and the least desirable for parachute deployment. Both ends of the spectrum have advantages and disadvantages. Recent developments on the parachute deployment system have proved to be very successful and tests deploying against strong winds have proved the turbulent wake may not be an issue on an actual flight. The longer cone will also require more material. Consequently, the payload would be heavier. For these reasons, a tail geometry between 25º and 35º exhibits the best combination of desirable qualities for the payload design.
A stability analysis using Fluent was originally planned. However, due to time constraints this portion of the analysis was not performed and the geometry using the 25° half-angle was chosen for the final payload shape. The frustum was ordered and fits together with the hemisphere as shown in Figure 7.9.

**Figure 7.9** Final payload shape

### 8.0 Launch Summaries

The 2008-2009 HIBAL team has had multiple opportunities to launch and test equipment or experiments. The following is a summary of each launch this team has participated in.

#### 8.1 Launch 1: October 18, 2008

On October 18, 2008 the 2008-2009 WSU HIBAL team launched their first balloon. Launch goals included obtaining voltage data on a solar array prepared by an advisor as seen in Figure 8.1, collecting temperature and telemetry data, testing a capacitor based nichrome cut-down device, utilizing the new balloon enclosure, and to give this year’s team experience.

**Figure 8.1** Solar Array

The two days leading up to the first launch, the ME team tracked the weather, performed flight predictions, selected the parachute and balloon size based on the payload weight, determined the required volume of helium using a previous team’s MATLAB program, obtained launch permission from potential launch sites, gave Dayton Approach a courtesy call, and faxed them a final flight prediction. Last minute preparations took place the morning of the launch from 7:00 A.M. to 9:30 A.M. This included packing and loading all
equipment based on a check list from previous teams and performing a flight prediction using the latest atmospheric weather data. Shortly after leaving the team turned around and went back to the lab when it was realized the balloons and batteries were forgotten. Finally, after an hour and forty-five minute drive to the selected launch site, Portland, Indiana, the team quickly unloaded equipment, checked the ground for possible balloon puncturing debris, and unfolded the newly fabricated balloon enclosure as shown in Figure 8.2. While the EE team prepared the payload electronics the ME team spread out a 1500 gram balloon, connected the flow meter and helium filling equipment, and began filling the balloon. Once the balloon began filling the enclosure contained the balloon well enough which enabled students to focus on preparing for the launch. The ME team took note from the advisors of how to prepare the rigging, parachute, and tie off the balloon. By 2:00 P.M. the balloon was off the ground and immediately there was concern over the accent rate and the heading of the balloon among experienced advisors.

![Figure 8.2 Balloon Enclosure](image)

After packing up the equipment, the team began to track the balloon for recovery purposes. Based upon the morning upper atmosphere data the balloon was expected to land a few miles east of I-75 near Sidney, Ohio. After half an hour it became apparent that the balloon was not following the prediction and it was climbing very slowly. The decision was made to call off recovery efforts and drive back to WSU. Team members tracked the balloon online until 7:00 P.M. when the balloon landed in the Daniel Boon National Forest, Kentucky after reaching a maximum altitude of 86,400 ft. Nick Baine, a graduate student, volunteered to fly his personal airplane to the last known location to attempt a recovery. Fortunately, recovery efforts were successful thanks to the cooperation of the land owner whose tree the balloon landed in.

The EE team extracted temperature data, telemetry data, and the solar array voltage data as shown plotted in Figure 8.3, 8.4 and 8.5 respectively. Temperature and accelerometer data were collected for nearly 4.5 hours from the time power was applied to the system until the memory was filled to capacity as can be deduced from the time axis of the plots below. Unfortunately, due to the under inflation of the balloon and winds which were drastically different than forecasted, data from liftoff to touchdown was not collected because of the long duration of the flight. As a result, points of interest such as the balloon burst and landing impact dynamics along with a complete internal temperature profile were not recorded [9]. It is interesting to note that the temperature in the payload did not go below 15F and it appears the solar array provides a good deal of power. However, the weight of the solar array will limit its usefulness in future launches. The accelerometer data is really rather meaningless since it did not capture the balloon rupture or landing. During the first half hour of data collected the payload was still on the ground which explains the jitteriness.
of the plots during this time frame. The temperature is shown ramping up during this time due to the addition of hand warmers which were added to keep the electronics warm. Perturbations in the temperature during the first half hour are attributed to taking the lid off while the accelerometer and voltage data were affected by moving the orientation of the box around during flight preparation.
Much was learned from getting this first launch off. As a whole the launch was considered a success due to its recovery and the experience everyone gained. The nichrome cut-down capacitor charging circuit was never turned on and therefore this test was not successful. However, the EE team determined that the relay for the nichrome was fired by the onboard basic stamp computer. It also became apparent that the filling process and volume prediction software needed to be re-evaluated. In addition, the need for a cut-down device and a new check list were stressed after this launch.

8.2 Launch 2: January 4, 2009

The second launch began on January 4th, 2009 at Portland, Indiana. The HIBAL team attempted to have the second launch on December 20, 2008 and then January 3, 2009, but both of those dates resulted in cancelled launches due to poor weather conditions. The initial weather conditions on January 4th were slightly foggy and drizzly, but the surface winds were calm. Additionally, the upper atmosphere winds were low, so the balloon was not expected to travel far. Based on the morning’s weather data, the balloon was projected to land about 10 miles northeast of Sidney, Ohio. This was based upon a cut-down altitude of 60,000 ft.

A two payload system was built for use in this launch. For the mechanical engineers, the main experiments were the servo release and the nichrome wire release. The servo release was going to be tested on the top box at 60,000 ft. When the GPS and APRS data showed that the balloon was at 60,000 ft the signal for the servo to release the payload system from the balloon was to be sent. The nichrome wire was also to be tested with a light dummy load attached to the bottom payload.
Unfortunately, as the morning went on, the surface winds increased and the fog never lifted. The weather conditions were still drizzly, so it was challenging to keep the electronics completely dry. As the team was securing connections between the payloads, parachute, and balloon, the team discovered there were not many swivels. Therefore, the connection shown in was used as the balloon’s connection to the rest of the system. This connection contained trusted components the team assumed would work sufficiently.

![Figure 8.6 Balloon connection](image)

The launch was originally scheduled to occur at 11:30 am, but the system wasn’t ready for launching until 1:30 pm due to multiple complications. For instance, the basic stamp triggered the servo release without any apparent cause during preparation. It is still undetermined as to why this malfunction occurred. Unfortunately, this issue could not be fixed at the launch site so the basic stamp’s release trigger was disabled. Basically, this meant that there would be no automatic, back-up altimeter release.

When the electrical components were returned to a workable state the system was ready for a launch. The ascent cord was looped through the bottom ring the connection shown in Figure 8.6. After the 3000 gram balloon was filled to 12,700 liters of helium, the balloon enclosure was opened. The ascent cord was anchored to the ground by two people holding the balloon in place for the last few adjustments. As the enclosure opened, the balloon lifted up, rotated, and supplied a quick shock to the payload connections. Part of the reason the rotation happened was due to the fact the nozzle of the balloon rotated upward to a horizontal position while filling. When the bag was opened, the balloon pivoted about the ascent cord attached near the nozzle of the balloon. Because the nozzle was located higher than normal, the balloon was able to gain a higher angular velocity during release. The ground winds had also become stronger which aided in the dynamic load supplied by the balloon. Ultimately, this force was too much for the balloon’s connections to withstand. The balloon quickly broke free from the rest of the system and ascended upward. The rest of the system fell a short distance to the ground.

The general consensus was to fill another balloon and re-launch. As the next balloon was filling, the failed connection failure was analyzed in order to determine which component failed. Initially, the team believed a key ring broke releasing the balloon. However, this was not the case as discovered later and discussed in the Connection Upgrades section of the report.
Meanwhile, as the second balloon was filled, part of the team went to a nearby hardware store to purchase more swivels while the electrical engineering team examined the electronics inside the payloads. The battery pack supplying the APRS and basic stamp had shorted out and melted part of the housing.

By 3:30 pm, the system was ready for a second attempt. This time, one person held the neck of the balloon while the bag was opened in order to prevent the snap observed during the first attempt. By this time, the surface winds had increased significantly to blowing the balloon out of control. The team tried to let the balloon go up slowly using the ascent cord so none of the connections would experience impact loads similar to what was seen during the first attempt. However, when the ascent cord was released, the balloon was blown in the horizontal direction causing the bottom payload to make contact one of the team member’s parked car. This caused the bottom payload to bounce and snap the connections to the rest of the system. Consequently, the top payload, parachute, and balloon ascended very quickly. The nichrome, located on the bottom payload was no longer able to be tested in flight. The strobe light, also located on the bottom payload, did not go up in this flight. After the system had ascended into the air, the team realized the battery for the smoke detector was not plugged in resulting in another method of tracking that could not be utilized.

Four 10 lb fishing lines were used to connect the top and bottom payloads. This was done in order to comply with a FAR 101 rule that states connections between payloads must be able to break with 50 lb of force or less. Fishing line was used due to a misinterpretation that the total load carrying capacity of the connections cannot exceed 50 lb. Instead, the rule simply states that each individual line connecting payloads must be able to break under a 50 lb force. Future connections will be designed using this interpretation.

After the launch, the team packed up and began to chase the payload. Initially, the APRS transmitted location and altitude data. Unfortunately, when the balloon reached 4,000 ft, the APRS and GPS stopped sending position data and all communication with the balloon was lost. A short time after the APRS and GPS stopped transmitting, a cut-down signal was sent to the DTMF-8 board via the manual controls to trigger the servo release. It is still unknown as to whether or not this cut-down signal was received.
Several search efforts were made including two aerial searches on the 5th and 24th of January based on several potential landing sites. County sheriffs’ offices were also contacted following the week of the launch. Finally, on February 9th the payload was recovered outside of Wapakoneta, Ohio. It was apparent that the cut-down signal had worked, as the balloon landed about 6 miles from the cut-down flight prediction for January 4th. The parachute was also found to be missing from the payload. Based upon the location of the system during the cut-down and the location of the landing site, the parachute must have stayed on during much of the descent. While it is still unclear as to exactly how the parachute became detached, there are several theories. One possibility is that during the release, the force of the parachute opening snapped the split ring. Another possibility is that the parachute was ripped off after it was on the ground.

It is still undetermined as to why the balloon lost signal at 4,000 ft. One of the possible theories was that the antenna was not powerful enough. The antenna was never tested before the launch, so this is a possibility. Another theory was that the moisture from the light rain caused electronics to malfunction.

8.3 Launch 3: February 24, 2009
The third launch took place on February 24th, 2009 from Wright State University’s Lake Campus in Celina, Ohio. For this launch two payloads were being used in the standard configuration (Figure 8.8), providing a total system weight of 12 lbs. Once again, the servo release mechanism was going to be tested. Additionally, a dummy parachute below the bottom payload was also going to be deployed. The heat sink test, a video camera watching the balloon/release, and a video camera watching the parachute deployment were also employed on this launch. The heat sink test was an endeavor pursued by the electrical engineering team to measure temperatures on a heat sink at high altitudes with a dummy heat load.

![Image](image.jpg)

**Figure 8.8** Third launch system configuration

In the morning the surface winds were rather low (less than 8kts). From the morning wind data for a 75,000 ft cut-down, the balloon was projected to land near South Vienna, Ohio. As launch time approached, the APRS stopped transmitting valid information. It was later discovered that a wire on the connector connecting the GPS unit to the APRS unit had become unsoldered. After this was fixed the launch was underway. Around 4 pm, the balloon was released. During previous launches the balloon was released slowly with an ascent cord. This time,
the balloon was released without an ascent cord, in what has been called a “rip and go” procedure that the HIBAL team had been working toward. For this launch, many system components had been replaced with shock absorbing components during the extensive ground tests. For this launch, the “rip and go” release method worked flawlessly as all of the upgraded connections remained intact.

The balloon ascended at approximately 1,200 ft/min in an E SE direction. The balloon appeared to be traveling more east than the morning winds had predicted. Around 50,000 ft the APRS stopped transmitting data. It is believed that a wire had broken at this time in the flight. The release trigger was sent shortly after losing communication with the payload for safety reasons. The parachute deployment was also initiated immediately following the release.

A short time later, a team member tracking the payload picked up a signal from the short range tracking beacon near Marysville, Ohio. It is believed that the payload may have been descending at this point. The HIBAL team headed toward Marysville and picked up the signal from the tracking beacon. The payload was found about 20 miles west of Marysville 3/8 of a mile off the road in a field. After examining the payloads, it was discovered that the servo had worked, the heat sink would sufficiently cool the circuit for the video transmitter, and both video cameras had recorded the entire flight. Unfortunately, the dummy parachute had not deployed due to a battery malfunction as a result of cold temperatures. In future launches, temperature management will be a higher priority.

Temperature sensors had been placed at various locations inside the bottom payload. Figure 8.9 is a plot of these temperatures and battery voltages with respect to time, during the ascent and descent. This plot was obtained from Bruce Rahn [10].

![Figure 8.9 Temperature data during flight](image-url)
After watching the videos from the payloads, other important information was also discovered. The payloads did not actually release when the servo release was triggered. The looped cord could be seen as it came free, however, the balloon still remained attached to the payloads. Initially, it was thought that the cord may have become tangled, prohibiting release. At about 75,000 ft, the balloon neck tore from the rest of the balloon, causing the payloads to fall to the ground.

The theory that a tangled cord prevented the release of the balloon was tested after the launch. However, the system was not able to tangle due to the swivel. It was discovered that a spring put in line with the orange cord, similar to Figure 4.14, could have caused the failure. During post launch testing, it was found that the spring did not slide through the balloon connection ring easily. If the spring was located on the side of the orange cord that needed to go through the balloon connection ring, it typically became stuck. During the actual launch, the spring was located very close to the neck of the balloon. While it is thought that the spring was on the correct side of the orange cord, it could have shifted to the other side during takeoff or during a rough portion of the flight.

In conclusion, this launch was an overall success with a few failures. The upgraded payload rigging was proven to hold up to an actual launch. The flow meter and balloon enclosure proved to be valuable during the launch delays and balloon takeoff. The system was released without the assistance of the ascent cord proving the functionality of a ‘rip and go’ system. Multiple videos were obtained of the entire flight and temperature data was taken in the bottom payload. Post-launch analysis of the failures has provided valuable insight in how to improve the system as a whole and prevent similar failures in the future. Overall, this launch has helped prove WSU HIBALs capability of launching under broader weather conditions and more frequently as needed.

9.0 Conclusions and Future Work

The HIBAL team has had several setbacks and advances throughout the course of this year’s project. Overall there have been many significant contributions to the project in multiple areas. One of these has been in creating a system to pave the way for more frequent and reliable launches for current and future teams. A balloon enclosure has been designed and constructed to allow for ‘hands-free’ balloon filling. A flow meter has been accurately calibrated and the volume calculation process has been corrected using a better required volume calculation method. This system has been tested and verified on the third launch proving that a large amount of uncertainty and complication has been removed from the filling process.

The rigging for the standard payload configuration has been significantly upgraded to comply with FAR 101 regulations and withstand balloon takeoff dynamics. Many new components were tested and the strengths have been documented for future teams. The combination of rigging upgrades, balloon enclosure, and flow meter have allowed the launching process to move towards a ‘rip and go’ system. This means that the enclosure may be ripped open and balloon allowed to be released without assistance.

Several additions to payloads have been developed as well. A release system has been built and tested in flight. A parachute deployment system has been developed, ground tested, vacuum tested and ready for a flight test. Finally, a new payload shape for freefall has been researched, analyzed and developed.

The next step is to assemble the new payload shape and integrate the necessary components inside the payload body. The shape should be drop tested from a significant height to allow for a full system test before being sent on an actual flight.
10.0 Gantt Chart
## 11.0 Budget Breakdown

### Launch Expenses

<table>
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<tr>
<th>Item</th>
<th>Price</th>
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</thead>
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<tr>
<td>Balloons 1.5 kg</td>
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**Total/Launch** $209.00

**Total for 4 Launches** $836.00

**Total Launch Expenses** $2,146.00

### Project Expenses

#### Flow Meter & Calibration

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**Total Flow Meter & Calibration** $1,055.00

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**Total Cost** $753.58

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**Total** $192.78
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Total $220.00

Release Mechanism

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<td>HS-645MG Ultra Torque Servo</td>
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<td>Servo Tester</td>
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<td>Relays</td>
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<td>$10.00</td>
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<td>Dry Ice (per pound)</td>
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Total $195.90

Total Project Expenses $2,417.26

Project Expenses

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<tr>
<th>Item</th>
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<td>Balloon Enclosure</td>
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<td>Parachute Deployment</td>
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<td>Payload Design</td>
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<td>Total Launch Expenses</td>
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<td>Miscellaneous Project Expenses</td>
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Total $4,763.26
## 12.0 Project Expense Report

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<tr>
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<td>Batteries Plus</td>
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<td>$9.99</td>
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<tr>
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<td>Jo-Ann Fabric</td>
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13.0 References


Appendix

A. Programs Used in Design Process

A.1 Volume Prediction Program
Written in Matlab

% Balloon filling calculations
% Caleb Barnes 2008
% Adapted from hab_Vol_gas_burst_press created by Brandon Kirby 2006

clear all; clc; close all;

disp('-----------------------------------Inputs-----------------------------------')

% Input launch conditions and initial conversions
Ta = input('nInput ground surface temperature (C): ');
Ffe = input('nInput system weight (lb) (everything except balloon): ');
Mb = input('nInput mass of balloon (kg): ');
disp('
Input burst diameter of balloon (ft): ');
disp('1500g balloon: 27ft');
burst_de = input('3000g balloon: 35ft 
');

Wb = 2.20462262*Mb; %Convert mass to lb
Ffe = Ffe + Wb; %Add weight of balloon to system weight
Ff = Ffe*(1/.224809); %Convert payload weight to Newtons;

% Find the density of helium and air at ground temp and pres
rohe = (101.4*10^3)/((2.0769*10^3)*(273+Ta)); %kg/m^3
roa = (101.4*10^3)/((.2870*10^3)*(273+Ta)); %kg/m

% Calculate balloon volume (assuming elastic effects negligible)
% This section calculates volume to obtain equilibrium
V = Ff/(roa-rohe)*9.81; %in m^3
Venglish = V*35.3147; %Convert to ft^3
Vliters = V*1000; %Convert to Liters
ground_d = 2*(3/(4*pi)*Venglish)^(1/3); %ground diameter in inches

('-----------------------------------Outputs-----------------------------------')
% Compensate for lift required to obtain 1000 ft/min ascent rate
% Based on reference sheet provided by Hank Riley, N1LTV with LIFTWIN v1.02
% This information included at the end of the program
if (ground_d < 3.5)
    Ffe = Ffe + 0.7;
elsif ((ground_d > 3.5) & (ground_d < 4.5))
    Ffe = Ffe + 1.2; FL = 1.2;
elsif ((ground_d > 4.5) & (ground_d < 5.5))
    Ffe = Ffe + 1.9; FL = 1.9;
elsif ((ground_d > 5.5) & (ground_d < 6.5))
    Ffe = Ffe + 2.7; FL = 2.7;
elsif ((ground_d > 6.5) & (ground_d < 7.5))
    Ffe = Ffe + 3.7; FL = 3.7;


60
elseif (ground_d > 7.5)
    Ffe = Ffe + 4.8; FL = 4.8;
end

% Recalculate volume with compensated free lift
Ff = Ffe*(1/224809);
V = Ff/((roa-rohe)*9.81);
Venglish = V*35.3147;
Vliters = V*1000;
Vfm = 1.398*(Vliters) + 0.4675; %Compensated for flow meter reading
ground_d = 2*(3/(4*pi)*Venglish)^(1/3);

% Display results
fprintf ('%nFinal lift force needed: %6.2f lb', Ffe)
fprintf ('%nFree lift required for balloon size: %4.1f lb', FL)
fprintf ('%nVolume required: %6.2f L, or %6.2f ft^3', Vliters, Venglish)
fprintf ('%nBalloon ground diameter:  %3.2f ft', ground_d)
fprintf ('%nCompensated flow meter reading: %6.0f L', Vfm)

% Find the balloon burst altitude
m = V*rohe; %Mass of helium inside balloon in kg
burst_d = burst_de*0.3048; %Convert bd to meters
r = burst_d/2; %Radius of balloon at burst
Talt = 253; %K %°20C Approximate temperature at max altitude
Vb = (4/3)*pi*(r^3); %Balloon burst volume in m^3
P = m*(2.0769*10^3)*Talt/Vb; %Pa
Pk = P/1000; %kPa

%altitude data pulled from http://www.sablesys.com/baro-altitude.html
if P<7.24 & P>4.49, %60K to 70K
    ah = 70000;
al = 60000;
Ph = 4.49;
Pl = 7.24;
    Altitude = (ah - al)*((Pk - Pl)/(Ph - Pl)) + al; %ft
end
if P<4.49 & P>2.8, %70K to 80K
    ah = 80000;
al = 70000;
Ph = 2.8;
Pl = 4.49;
    Altitude = (ah - al)*((Pk - Pl)/(Ph - Pl)) + al; %ft
end
if P<2.8 & P>1.76, %80K to 90K
    ah = 90000;
al = 80000;
Ph = 1.76;
Pl = 2.8;
    Altitude = (ah - al)*((Pk - Pl)/(Ph - Pl)) + al; %ft
end
if P<1.76 & P>1.12, %90K to 100K
    ah = 100000;
al = 90000;
Ph = 1.12;
Pl = 1.76;
Altitude = (ah - al)*((Pk - Pl)/(Ph - Pl)) + al; %ft
end
if Pk<1.12,\nfprintf(\nBurst beyond 100,000ft\n')\nend
if Pk>7.24,\nfprintf(\nBurst below 60,000ft\n')\nend
fprintf(\nFinal altitude is approximately %6.0f ft\n',Altitude)

%Information from the file freelift.txt provided with Hank Riley's LIFTWIN

% There is a somewhat popular notion that one pound of freelift
% provides an acceptable ascent rate for a small amateur radio
% equipped balloon.
%
% This is a good approximation if the balloon is close to 4 ft
% in diameter at release, but most of the payloads now with GPS
% onboard and one or more radios will need a bigger release diameter
% to obtain the necessary lift.
%
% Here is a small table of values obtained by using LIFTWIN that
% shows the dependence on release diameter for the proper value
% of freelift required to achieve an ascent rate of 1000 ft/minute.
%
% Release diameter            Freelift for 1000 ft/minute
%
% 3 ft                              .7 pounds
% 4                                  1.2
% 5                                  1.9
% 6                                  2.7
% 7                                  3.7
% 8                                  4.8
%
% Hank Riley, N1LTV
% 04/24/00
A.2 Volume Prediction for Flow Meter Testing
Written in Matlab

% Balloon filling calculations
% Caleb Barnes 2008
% Adapted from hab_Vol_gas_burst_press created by Brandon Kirby

clear all; clc; close all;

% Input launch conditions and initial conversions
Ta = input('nInput ground surface temperature (C): ');
Ffe = input('nInput desired lift (lb): ');

Ff = Ffe*(1/.224809); % Convert payload weight to Newtons;

% Find the density of helium and air at ground temp and press
rohe = (101.4*10^3)/((2.0769*10^3)*(273+Ta)); % kg/m^3
roa = (101.4*10^3)/((.2870*10^3)*(273+Ta)); % kg/m^3

% Calculate balloon volume (assuming elastic effects negligible)
% This section calculates volume to obtain equilibrium
V = Ff/((roa-rohe)*9.81); % in m^3
Venglish = V*35.3147; % Convert to ft^3
Vliters = V*1000; % Convert to Liters
Vfm = 1.398*(Vliters) + 0.4675; % Compensated for flow meter reading
ground_d = 2*(3/(4*pi)*Venglish)^(1/3); % ground diameter in inches

% Display results
fprintf ('nFinal lift force needed: %6.2f lb', Ff)
fprintf ('nFree lift required for balloon size: %4.1f lb', FL)
fprintf ('nVolume required: %6.2f L, or %6.2f ft^3', Vliters, Venglish)
fprintf ('nBalloon ground diameter: %3.2f ft', ground_d)
fprintf ('nCompensated flow meter reading: %6.0f L', Vfm)
A.3 Cone Dimension Finder
Written in Fortran 77

PROGRAM CONE_DIM
INTEGER n, i
REAL PI, HEIGHT, HYP, H1, H2, HYP1, HYP2, BASE, ANGLE, TOP, W, L
REAL B(50), D(50)

WRITE(*,*) 'INPUT CONE HALF-ANGLE: '
READ(*,*) ANGLE
WRITE(*,*) ''
PI = 3.14159
ANGLE = ANGLE*PI/180.0
BASE = 4.0
TOP = 3.3333333/2.0
W = 0.75

H1 = BASE/TAN(ANGLE)
H2 = TOP/TAN(ANGLE)
HYP1 = BASE/SIN(ANGLE)
HYP2 = TOP/SIN(ANGLE)

HEIGHT = H1 - H2
HYP = HYP1 - HYP2

WRITE(*,*) 'Frustrum height is: ', HEIGHT
WRITE(*,*) ''
WRITE(*,*) 'Hypotenuse length is: ', HYP
WRITE(*,*) ''

n = 0
L = H1 + W

DO WHILE (L .GT. H2)
  n = n + 1
  L = L - W
  D(n) = REAL(n-1)*W
  B(n) = 2.0*L*TAN(ANGLE)
ENDDO
WRITE(*,*) 'Layer Height Diameter'

DO i = 1,n
  WRITE(*,10) i, D(i), B(i)
10   FORMAT(2x,I2,8x,F5.2,6x,F5.3)
ENDDO

END
A.4 Terminal Velocity Estimation Program
Written in Matlab

% Finding Terminal Velocity

% Program designed to roughly estimate the terminal velocity
% of the payload during freefall at several altitudes
clear all; close all; clc
format compact

m = 6*0.45359237; % lb to kg
g = 9.81; % m/s^2
R = 0.2870; % kJ/kg*K
d = 2*0.3048; % m
A = pi*d^2/4; % m^2

Height = [90000 80000 70000 60000]; % ft
Pres = .1*[16.2 26.3 42.9 70.8]; % kPa
Temp = [210 210 210 210]; % C
Cd = .5; %estimate between bullet and sphere Cd values
disp('-------------------------------------------------------------------')
for i = 1:4
    rho(i) = Pres(i)/(R*Temp(i)); % kg/m^3
    Vt(i) = sqrt(2*m*g/(rho(i)*A*Cd)); % m/s
    Vt_e(i) = Vt(i)*2.2369; % mph
    disp('Altitude')
    disp(Height(i))
    disp('Air density in kg/m^3')
    disp(rho(i))
    disp('Terminal velocity in m/s')
    disp(Vt(i))
    disp('Terminal velocity in mph')
    disp(Vt_e(i))
end % for i
B. Various Design Schematics and Images

Figure B.1 Antenna placement concepts for launch 4
Figure B.2 Frustum dimensions (1) for construction

Figure B.3 Frustum dimensions (2) for construction
Figure B.4 Frustum dimensions (3) for construction

Figure B.5 Criss-cross mounting used in launch 3
Figure B.6 Schematic showing the basic layout of the top payload for Launch 4

Figure B.7 Schematic showing the basic layout of the bottom payload for launch 4
Figure B.8 Vacuum chamber used in multiple experiments

Figure B.9 FORTIS II wind machine used in parachute deployment wind testing and considered for payload wind tunnel testing
Figure B.10 Material scrapped from payloads before launch 3 in an effort to reduce weight

Figure B.11 Schematic showing dimensions of balloon enclosure given to Sailor's Taylor for fabrication
C. Launch Preparation Documents

WSU HIBAL
Launch Go/No-Go Conditions
Last Updated 2/4/2009

- Visibility must be greater than 5 miles
- Dry conditions (no rain, mist, or high humidity)
- Temperature must not be excessively cold (less than 20° F)
- Ground wind speeds must be below 20 mph bursts
- Experienced advisor must be present at all launches
- Equipment must be thoroughly tested and inspected by advisors
- Balloon must not be projected to land in or travel through/near restricted air space
- Payload must not be projected to land more than 90 miles from Dayton
- Payload must be ready Wednesday before launch
Mechanical Team Launch Procedure Checklist
Last updated 2/4/2009

- 1 week before launch
  - Prelaunch simulation – test rigging using dynamic simulator and strengthen connections accordingly

- 2 Days before launch
  - Begin flight prediction and weather checking
  - Notify potential launch location of pending launch
  - Begin packing equipment
  - Run helium filling calculations and print the output

- 1 Day before launch
  - Finish packing equipment
  - Run final flight predictions
  - Fax flight prediction information to Dayton approach
  - Notify Dayton approach of fax

- Day of launch – At home base
  - Load equipment in vehicles – check off items as they go into the vehicle

- Day of launch – Setting up the enclosure
  - Check launch area for sharp objects/rocks and large items
  - Spread tarp on ground
  - Spread balloon enclosure centered on top of tarp
  - Place bean bag weights into enclosure pockets
  - Check enclosure for debris
  - Use gloves to spread balloon on top of balloon enclosure
  - Check balloon for defects

- Day of Launch – Filling the balloon
  - Unload two helium tanks from the truck (used tanks first)
  - Attach the regulator/filling line to helium tank
  - Close all valves on filling line
  - Open the tank valve
  - Set regulator pressure to 25 psi
  - Bleed a little helium to make sure the pressure is correct
  - Connect battery to flow meter and zero the totalizer
  - Connect filling line to filler nozzle
  - Connect filler nozzle to balloon neck by folding outward the balloon neck material and stretching over the nozzle end
  - Clamp balloon neck to nozzle using PVC fixture and clamp
  - Zero the totalizer again and begin filling by opening the regulator valve and ball valve next to the flow meter
  - Monitor the totalizer and keep the team notified on balloon filling status
  - After the balloon has been filled with around 500L close the bag over the balloon
  - Check the nozzle position frequently to make sure the clamp does not puncture the balloon and keep the nozzle from working its way upward
When the balloon reaches the desired volume shut off the regulator valve and the ball valve located near the flow meter.

- **Tying off the balloon**
  - Create the balloon neck connection system
    - This consists of two quicklink connectors one Sampo ball bearing swivel and one welded steel ring and a 1’ section of yellow cord
    - (A picture of this setup should be placed here)
    - The split rings on the swivels MUST be replaced with the SPRO split rings
  - Pinch off the upper portion of the balloon neck and remove from nozzle. Hold firmly as letting go now will waste a lot of helium
  - Fold neck in half lengthwise (fold is parallel to neck length) and wrap the middle in black duct tape
  - Tie the yellow cord from the connection mentioned above to on top of the duct tape
  - Fold the neck over the tied portion of cord and tape over the same section
  - Tie the remaining portion of the cord over the neck again

- **Connecting the system**
  - Cut the orange cord to length and tie one end using perfection loop
    - (show picture of perfection loop)
  - Connect the looped end to release mechanism arm
  - Run the other end through the welded steel ring attached to the balloon neck and then tie to the top of the parachute
  - Connect the parachute to the top spreader ring using a carabiner
  - Wrap the elastic bands around each section of connection lines on the spreader rings
  - Clip the snaps to the D-rings on the top package harness
  - Connect the lower spreader ring to the top and bottom package by connecting the clips to the D-rings. The section with springs should be at the very bottom
  - Check for tangling or misconnected links
  - The system should now be ready for take-off

- **Releasing the balloon**
  - Run the ascent cord through the welded steel ring and fasten to two sturdy people
  - One person should be place to remove the rip strip from the bag while two more pull the enclosure panels away from the balloon
  - A fourth person should be placed at the neck of the balloon to prevent a rapid jerk to the system (this person needs to be carefully covered preventing contact with the balloon)
  - Raise the balloon slowly with the ascent cord and do one final inspection/check
  - Release the balloon by letting go of the free end of the ascent cord
HIBAL FLIGHT PREPARATORY CHECKLIST

Preflight Planning

Three Weeks Prior

___Determine Launch Captain

___Payload(s) Weight Estimate

___Balloon and Spare of Required Size on Hand

___Required Helium volume calculated

___Helium Tank Quantity Sufficient (two fills single launch, three fills for double launch)???????

___Gas Cylinder Transport Arranged

Two Weeks Prior

___Flight Computer Program tested for proper functioning. Check flight prediction software by running
cite selection and flight path (most current) to make sure flight paths and landing cites match.

___APRS Programmed and Tested

___DTMF-8 Programmed and Tested

___Launch Team & Chase Team Personnel Totals

___Check flight prediction software: run site selection and flight path (most current) to make sure flight
paths and landing sites match
**WEEK OF**

- Completed Payload(s) weighed
  - Payload and parachute weight: _________ lbs

- Calculate Helium Volume Needed
  - Desired lift: \(1.2 \times (\text{#1 balloon}) - \text{payload} = \) _________ lbs

- Determine & Mark Helium Cylinders Needed for Mission Fill

- Possible Launch Site(s) Confirmed

- Launch Team & Chase Team Personnel Totals & vehicle arrangements

- Gas Cylinder Transport Arrangements Confirmed

- All Batteries Charged / Sufficient Disposable Batteries on Hand

- Airport Contacted (on Thursday) (if launch site is an airport)

- Ground Test All Systems (conduct ground flight)

<table>
<thead>
<tr>
<th>Flight Computer</th>
<th>Flight Computer Operating as Intended</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Altitude Triggers Operate Properly</td>
</tr>
<tr>
<td>Gas Fill Team</td>
<td>Balloon Available</td>
</tr>
<tr>
<td></td>
<td>Fill Valve Ready</td>
</tr>
<tr>
<td></td>
<td>Equipment Ready</td>
</tr>
<tr>
<td>Imaging/Cameras</td>
<td>Camera(s) Functioning</td>
</tr>
<tr>
<td></td>
<td>Memory Available</td>
</tr>
<tr>
<td></td>
<td>Batteries Charged</td>
</tr>
<tr>
<td></td>
<td>Flight Crew Available</td>
</tr>
<tr>
<td>Communications</td>
<td>Air to Ground Communications Operate Properly</td>
</tr>
<tr>
<td></td>
<td>Radios &amp; GPS Functioning</td>
</tr>
<tr>
<td></td>
<td>APRS Programmed Correctly &amp; Operating Properly</td>
</tr>
<tr>
<td></td>
<td>Audio Beacon Functioning</td>
</tr>
<tr>
<td></td>
<td>Fox Hunting Beacon Functioning</td>
</tr>
</tbody>
</table>
**PAYLOAD**

- DTMF Systems Operate Properly
- Laptop Functioning & Power System Ready
- Batteries Charged
- All Flight Boxes in Good Condition
- Experiment in Working Order
- Experiment Data Collection Working
- Experiment Controls Operation as Intended

**WITHIN 24 HOURS OF LAUNCH**

- Weather Checks Completed
- Flight Prediction Okay
- Airport Approval Confirmed (if launch site is an airport)
- NOTAM faxed to FAA ATC Facility (Dayton Approach). Call to make sure fax was received. Initial fax must be sent at least 6 hours before launch. On fax sheet, change Rowdy Raider and the cell phone number and the landing location. (fax from Flight Prediction Package)
- Call FAA ATC Facility to Confirm Receipt of NOTAM Fax

**Launch Day**

- Run flight path again in morning. If path has changed, send a new fax to (NOTAM) to FAA ATC Facility (Dayton Approach). Call to make sure fax was received.
- Call Dayton Approach when balloon is released.
- Call Dayton Approach when balloon is recovered.
PARTS CHECKLIST

- Ground cloth/tarp and stakes
- Balloon enclosure and Velcro break-away strap
- Lead shot weights for balloon enclosure (4 big and 4 small)
- Weights for ground cloth (water jugs)
- Table
- Handling gloves (latex gloves)
- Helium (in secure transport structure)
  - Take 3 tanks for 1500 gram balloon
  - Take 4 tanks for 3000 gram balloon
- Helium regulator
- Balloon hose and filler assembly
- Filler assembly hose clamp
- Quick clamp (for balloon filling)
- Flow meter
- Scientific scale (not fish scale)
- Fish scale/counterweight
- Bucket to fill with sand
- Balloons (this means more than 1!)
- Party balloons
- Aluminum foil (for party balloons)
- Servo
- Servo tester
- Foam enclosure for servo
- Gauge 32 nichrome wire
- Nichrome wire circuit
- Parachute
- Kite string cut to length???????????
- Yellow cord
- Orange nylon cord
- Red cord for ascent control
- Payload harness
- Water bottle with soapy water
- Carabineers
- Barnes Balloon Attachment Connector/Ring
- Radar reflector
- Handheld GPS tracker
- Notebook and pen
- Mobile HAM (with car battery)
- directional antennae
- ham radios used with directional antennae
- AA batteries for directional antenna radios
- Cigarette lighter plug
- FRS Walkie-Talkies (for foxhunting)
- AAA batteries for walkie-talkies
- Smoke detector
- Cigarette lighter plug
- Spreader Ring
- Swivels (at least 3)
- Quick link connectors (at least 4)
- 4 black shock absorbing bands
- Fishing leaders
- Extra snaps
- Extra springs
- Extra jones plugs
- Extra split rings
- Extra welded rings
- Balloon connection
- **Laptop**
  - Power cable
  - Floppy drive
  - CD-ROM drive
  - Drive cable
  - HAM→PC cable
  - USB flash drive

- **Communication module**
  - GPS receiver
  - GPS antenna
  - Battery pack (for GPS)
  - Handheld HAM radio with battery pack
  - HAM antenna
  - Screamer circuit
  - 9V battery for screamer
  - “SOS” foxhunting beacon
  - Camera
  - Box lid
  - Nylon bag
  - Bag label card – harmless radio device; contact info
  - hand warmers
  - carabineers to attach to bottom of command module

- **Experiment module**
  - _Data logger power cord__________________________
  - _DVR remote__________________________
  - _DVR batteries__________________________
  - ____________________________________
  - ____________________________________
  - ____________________________________
  - ____________________________________
  - ____________________________________
  - ____________________________________
  - ____________________________________

- **Tool kit**
  - Multimeter
  - Screwdrivers
  - Pliers
  - Wire cutters
  - Wire
  - Electrical tape
  - Duct tape (black)
  - Gorilla tape
  - 2 large adjustable crescent wrenches
  - Measuring tape


- Soldering iron
- Solder
- Solder wick
- Spare AA batteries
- Battery charger
- Spare 9V batteries
- Zip ties
- Kite string
- Pocketknife
- Scissors
- Extra battery terminal leads
- Stop watch
- Tackle box
- Allen Wrenches
- Extra carabiners

□ Documents
  - Tax exempt form
  - Phone numbers (launch cite and area approaches)
  - Directions to launch site (enough for all drivers)
  - Directions from launch site to landing site (enough for all drivers)
**In-Box**

- Thermal load
- Servo unit
- Camera
- APRS
- Basic stamp
- DVR
- Beacon/Screamer
- Data logger

** Power on as close to launch as possible
Launch Preparation Procedure

1. AT LAUNCH SITE
   a. Spread ground cloth with no sharp objects located underneath (weight down corners)
   b. Attach regulator to cylinder #1
   c. Make sure regulator output closed
   d. Note Initial pressure of cylinder #1: ______________psi
   e. Put on handling gloves
   f. Place balloon on ground cloth, inspect for damages
   g. Tape lift gauge loop to filler assembly
   h. Place balloon nozzle over filler assembly
   i. Clamp or tape balloon nozzle onto filler assembly
   j. One person should be holding the balloon nozzle, one person operating the regulator, others guarding the balloon with “big hands”
   k. Begin inflation (use regulator to begin slowly and increase fill rate as balloon takes shape)
   l. When appropriate, connect fish scale to loop
   m. Attach lift gauge to weight on the ground (to prevent accidental release)
   n. When cylinder #1 reaches ~100 psi close regulator output
   o. Record cylinder #1 pressure: ______________ psi
   p. Shut off in-line valve
   q. Shut off cylinder #1 valve
   r. Move regulator to cylinder #2
   s. Open cylinder #2 valve
   t. Record cylinder #2 initial pressure: ______________ psi
   u. Open regulator
   v. Open in-line valve, continue inflation
   w. Carefully let go of balloon nozzle while someone holds fish scale
   x. Take several readings and roughly average in your head
   y. When desired lift achieved, close in-line valve and regulator
   z. Record final pressure of cylinder #2: ______________ psi
   aa. Close cylinder
bb. Pinch off balloon nozzle
cc. Twist balloon nozzle
dd. Tie balloon nozzle with kite string (CAUTION: not too tight or it will tear through) at the top of the nozzle, make this string have an extra 2-3 feet in length to attach to the weight on the ground
ee. Wrap tape around the tied section
ff. Tape and tie load loop on balloon nozzle about mid length down the nozzle by wrapping and tying the string and then wrapping that with a small piece of tape; this string should have an extra 4–5 feet in length that will attach to the parachute; wrap this section with tape
gg. Fold nozzle material at the load loop section
hh. Tie again
ii. Duct tape balloon nozzle

2. CHECK CONNECTIONS
   a. Flight GPS antenna to GPS unit (before power-up)
   b. Flight GPS to flight HAM radio (Kenwood TH-D7)
   c. Batteries to GPS unit
   d. Flight HAM radio to HAM antenna
   e. HAM radio battery pack
   f. Camera batteries
   g. Camera timer circuit
   h. Camera timer circuit switch
   i. Screamer speaker
   j. Screamer circuit
   k. Screamer battery
   l. Screamer switch
   m. HOBO thermocouple

3. PREPARE LAPTOP/MOBILE HAM RADIO
   a. Power on laptop
   b. Power on HAM radio
   c. Connect to mobile HAM radio
   d. Set HAM frequency to 144.390 MHz
   e. Check TNC mode
   f. Check APRS mode
g. Load Xastir

4. **CHECK SETTINGS**
   a. Power on HAM radio  
   b. Set frequency to 144.390 MHz  
   c. Check TNC mode  
   d. Check Beacon mode  
   e. Lock keypad *(hold F for >1s)*  
   f. Confirm receiving signals in Xastir  
   g. Move communication module around, checking that Xastir updates location

5. **HOBO LAUNCH**
   a. Close Xastir *(serial port is needed to launch HOBO)*  
   b. Connect HOBO cable  
   c. Launch HOBO logger  
   d. Delete log file in Xastir log folder  
   e. Reopen Xastir  
   f. Reconfirm data reception  
   g. Start trace on call sign  
   h. Confirm that coordinates are reasonable by comparing with handheld GPS

6. **CHECK EXPERIMENT MODULE OPERATION**
   a. ____________________________  
   b. ____________________________  
   c. ____________________________  
   d. ____________________________  
   e. ____________________________  
   f. ____________________________

7. **CAMERA**
   a. Turn on camera  
   b. Turn on timer  
   c. Confirm pictures are being taken  
   d. Make sure the display is off

8. **Switch on screamer circuit**

9. **Final check of APRS packet reception**

10. **Begin APRS packet logging**

11. **Connect Radar reflector to hoop**
12. Connect parachute to balloon  (redundant strings)
13. Connect parachute to hoop
14. Connect hoop to communications module
15. Connect communications module to experiment module

16. **LAUNCH**

17. Call ATC to confirm launch
18. Recovery Team Heads for Predicted Landing site.

**CONTACT SHEET AND DIRECTIONS**

Contact Names and Phone Numbers: