Zero Pressure Balloons for use in Undergraduate Studies

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The HABET group at Iowa State University has been building and launching engineering payloads for years, to give students the ability to learn about the engineering involved in creating and launching payloads to near space conditions. This includes launching long duration zero pressure balloon payloads, in pursuit of this goal we have design and build our own zero pressure balloons. This year we explored new gore patterns, and looked at our fabrication methods in order to streamline and improve them. Originally we based our gore pattern on a standard hot air balloon gore, this year however we explored a tetrahedral gore pattern. The Tetrahedral gore pattern offered a simple and easily constructed design, which would allow for a potential increase in the number of zero pressure flights ISU HABET could conduct in a year.

Nomenclature

ρ_a	Ambient air density
ρ_f	Density of the balloon film
ρ_g	Lifting gas density
A	Surface area of the balloon
m_b	Mass of the balloon
m_p	Payload mass
t	Thickness of the balloon film
V	Balloon volume
HABET	High Altitude Balloon Experiments in Technology

I. Introduction

The HABET group has continued its work on Zero Pressure balloons. This has led to a new project where a tetrahedron balloon will be built from the ground up. The tetrahedron is designed to float close 100,000 ft for 24 hours.

II. Design

Previous attempts by the HABET team to construct a zero pressure balloon have been hampered by complexity of the balloon design itself. The complexity of the shape of the balloon caused construction difficulties which lead to less than desired performance. This new design attempts to minimize design complexity at the expense of overall balloon efficiency.

A. Comparison

The HABET team has previously attempted to build a natural shape balloon and a cylindrical balloon with a spherical top cap. The cylindrical design presented problems in adequately sealing the spherical top portion of the balloon and lead to premature venting and the balloon failed to reach the designed float altitude.

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The natural shape design presented problems with the complexity of both determining and building the gore shape.

After reviewing the previous problems, the HABET team decided to pursue a tetrahedral balloon. The tetrahedral balloon is a regular tetrahedron with the payload suspended from a single corner. Due to the lack of rotational symmetry the tetrahedron looks like a poor shape for a balloon. However, it has a flat top and an acute angle at the base, both features approximate the natural shape.[1]

The tetrahedral balloon is very easy to construct due to the simple shape. However, this simple shape causes an increase in the surface area of the balloon and therefore a tetrahedron of equal volume will have a lower payload capacity than a natural shape balloon. The HABET team deemed this an acceptable compromise for the payload mass in question as it did not require an appreciable increase in lift gas.

B. Governing Equations

A simplified analysis was carried out to determine the size of the balloon from the mission objectives (payload mass and float altitude). First the volume of lift gas needed to be in equilibrium with the payload mass at the desired float altitude was computed as in equation 1.

$$V = \frac{m_p}{\rho_a - \rho_g} \tag{1}$$

The edge length of a regular tetrahedron with that volume was then computed as in equation 2.

$$a = \sqrt{2}\sqrt[3]{3V} \tag{2}$$

The surface area of that tetrahedron was then compute as in equation 3.

$$A = \sqrt{3}a^2 \tag{3}$$

The surface area of the balloon was then used to estimate the mass of the balloon as in equation 4.

$$m_b = At\rho_f \tag{4}$$

This estimate of the balloons mass was then combined with the payload mass and the process was repeated until the length of the balloon converged.

III. Build

The HABET team constructed the balloon over several days. The construction team was composed entirely of first year team members. The first phase, constructing the large sheet, required about 3 hours. The second phase, cutting and sealing into the final shape required about 7 hours. There was a noticeable improvement in working efficiency at the end of the project and it is believed construction time could be reduced drastically with the experience gained from this first construction.

A. Resources

The construction of the balloon required considerable resources but is still believed to be less than the cost of purchasing a commercial balloon. The equipment used included a tape measure, rolling cutter, rolling heat sealer and paper weights. In addition, a large clean space is required to construct the initial large plastic sheet. A single roll of 3 mil thick painters plastic is the only consumable resource required.

B. Procedure

The first step in constructing the balloon was connecting several lengths of plastic into a larger plastic sheet, 36 by 120 feet. The individual gores were then cut from this larger sheet. By constructing a larger sheet first, the team was able to cut a trapezoid and a equilateral triangle and utilize folds to reduce the number of edge seals to four. After cutting the trapezoid and triangle, the trapezoid was folded into shape and the edges were sealed into the tetrahedral shape. Plastic tape was then applied along the edges of the balloon and from the base to the apex. The tape provides a backup seal should the heat sealed edge have a leak and carries the majority of the payload mass.

The plastic was sealed with a rolling heat sealer. Several experiments were performed to determine the ideal sealing temperature setting and speed. The original sealer had a textured surface that was causing problems with the thin plastic. It was found that a smooth surface provided a more uniform seal by minimizing the amount of holes created in the plastic.

The sealing procedure used by the team involved several steps. The edges of the plastic were first pulled taught and then aligned. Weights were used to hold the edges in alignment while the heat sealed was rolled along the edge. Short strokes with overlap were used to minimize any chance of error and to reduce operator fatigue.

IV. Flight

The new balloon has not yet been flown at the time this paper was submitted. The team hopes to fly the balloon in the near future. Flight predictions have shown the balloon drifting west into Nebraska or Wyoming which is fairly unusual for our launch site.

A. Goals

The goals used in designing this balloon were:

- 1 kg payload
- 100,000+ feet float altitude
- 60,000+ feet overnight float altitude
- 24+ hour flight time

B. Data

Data collected from the balloon flight consists of ambient temperature and GPS flight track. This information will be used to extract the performance of the balloon and to evaluate our predictive models. The ambient temperature is a major component of the equilibrium altitude of the balloon and is needed to determine if a sinking balloon is the result of cooling temperatures or gas escaping the envelope.

V. Conclusion

The construction of this balloon has proved to be much easier than the previous attempts due to the simplified shape. The largest challenges to construction were the impressive size of the balloon requiring the team to use the entire atrium of Howe Hall and the inconsistent sealing operation. The team thinks that these problems can be mitigated for future constructions and the final product can be improved further.

The flight performance of the balloon will be analysed after the first successful launch. Major points of evaluation will be the performance of the balloon sizing method and the extended performance of the balloon envelope itself. If the balloon can be recovered, it will be analysed to attempt to determine the cause of failure.

Further results will be posted at http://sites.google.com/site/cyhabet/

References

[1]Yajima, N., *Scientific Ballooning: Technology and Applications of Exploration Balloons Floating in the Stratosphere and the Atmospheres of Other Planets*, Lecture Notes in Physics Series, Springer London, Limited, 2009.