Solar Ballooning: A Low-Cost Alternative to Helium Balloons for Small Spacecraft Testing

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Introduction
Helium-filled latex weather balloons have been utilized for many years to carry small satellite prototypes into the stratosphere to allow testing in a “near space” environment. A variety of environmental factors similar to the space environment can be found in this region, such as a rarified atmosphere, increased thermal stress, increased solar radiation, the necessity of remote command and control, tracking, and telemetering of data. UND’s CubeSat development project [1, 2] is gaining operational experience and data from balloon testing.

While this method of flight testing has been well proven, a recent increase in the price of helium has driven the cost of such test programs to much higher levels.

This project explores an alternative technology to provide the flight mechanism: solar-powered hot-air balloons (“solar balloons”) [3]. Such a balloon contains ordinary air that is heated by the balloon envelope, which is heated by solar radiation. The heated air expands, and the lower density causes a buoyancy force which lifts the balloon.

Solar balloon envelopes can be constructed of easily available materials, and launched at a cost orders of magnitude less than using commercial latex weather balloons and helium. Trade-offs are also considered.

Lift Mechanism
Rather than using a lighter-than-air lift gas such as helium, solar balloons use air that has been heated to a higher than ambient temperature and is thus less dense. This differing density creates a net difference in buoyancy creating a lifting force. This temperature difference is maintained by the conduction of heat from the balloon envelope to the air in contact with the envelope material. The envelope is heated by sunlight striking its surface. It is dark in color to maximize this effect. As long as adequate sunlight continues to fall on the envelope, the temperature differential is maintained and lift is produced.

Envelope Construction
Balloon envelopes are typically constructed from some form of polyethylene plastic sheeting. Some groups [4] have used clear plastic sheeting rendered opaque by the application of a dark pigment powder.

The two test balloons launched by UND were constructed from plastic sheeting obtained by cutting open 33 gallon capacity black garbage bags. These bags were then assembled into larger sheets using paper-backed adhesive tape (“masking tape”), which was finally folded and attached into a tetrahedral-shaped envelope. One corner of the tetrahedron was cut away to form the filling nozzle, and duct-tape reinforcement and lift straps were added. The tetrahedral shape is simple to build from flat sheets, and is stable in flight.

Educational Benefits
From participation in the ballooning activities, students can learn about aerospace mission design [5, 6] and operations. They can also gain an appreciation for the complexity and need for reliability of mission-critical cyber-physical systems. Prior work [7, 8, 9] has demonstrated the efficacy of aerospace projects for providing both discipline-specific skill education and ancillary skills to students from numerous disciplines.

Lift Capability vs. Helium
The lift provided by a solar balloon depends upon the difference in temperature between the air inside and outside the envelope. This difference depends upon a number of factors, such as the amount of incoming solar radiation, cooling from contact with outside air, thermal radiation from the ground, the volume of the trapped warm air, and other factors.

In general, solar balloons tend to produce less lifting force than a helium-filled balloon of equal volume. Thus, for a given payload mass, a larger envelope will need to be used for a solar balloon than a helium balloon.

Other groups have also reported that solar balloons do not attain as great a maximum altitude as helium balloons (lower vs. upper stratosphere).

Weather Constraints
Solar balloons have more stringent launch weather requirements than their helium counterparts.

To develop maximal lift, solar balloons require strong sunlight and a cloudless environment. Though surface winds can play havoc with any balloon handling and launch operation, the additional cooling produced by winds blowing over the surface of a solar balloon still moored to the ground will cause a loss of lift due to a lowering of the temperature of the inside air.

While these requirements do mean a decrease in the total number of suitable launch days for a given location for a solar balloon, they do make it easier to follow Federal regulations regarding balloon operations, especially in terms of visibility and cloud cover. In unsuitable weather, a solar balloon simply won’t work.

References
5. Nordlie, J.; Feng, F. In Blending research and teaching through high-altitude balloon projects; Proceedings of the 2nd Annual Academic High Altitude Conference, 2011.
7. Straub, J.; Whalen, D. An Assessment of Educational Benefits from the OpenOrbiter Space Program. Education Sciences 2013, 3, 259-278.

UN Test Flights
The University of North Dakota has flown two solar balloons to test concepts and gather preliminary data.

On July 21, 2013, a solar balloon made from 16 bags of 0.7 mil thickness was flown to prove the concept. The envelope was approximately 10 feet in diameter when inflated. This balloon carried no payload and was not recovered.

On December 9, 2013, a balloon made from 36 bags of 0.5 mil thickness was launched to prove cold-weather capability and carried a passive radar reflector to allow tracking. The envelope was approximately 16 feet in diameter when inflated, and proved no more difficult to launch in cold weather (-9°F) than the earlier test balloon. This balloon ascended to approximately 36,000 feet AGL at 90 minutes after launch, at which time it was still ascending when radar contact was lost.

Conclusions & Future Work
Though their lifting performance is lower, the test balloons cost nearly two orders of magnitude less to construct and launch than similar-sized helium balloons.

Future flights will be conducted carrying prototypes of small spacecraft hardware, tracking systems, and in-situ measurement equipment.

The use of a release tether system to invert the envelope and deflate it, allowing recovery of the entire system will also be explored.