PET: A Novel Payload Heating Method
GSBC Most Innovative Component

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A novel payload heating method was investigated using a transparent polyethylene terephthalate (PET) container as part of the 2015 Global Space Balloon Challenge. The PET container maintained the payload temperature above the minimum operating temperatures of the electronic components, and demonstrated the benefit of utilising the freely available solar irradiance for heating. This heating method has the potential to significantly reduce payload mass and size, and consequently increase the maximum altitude and endurance of high-altitude balloon flights.

1. Introduction

Many electronic components in high-altitude balloon (HAB) payloads have minimum operating temperatures. Maintaining the temperature above these minimum levels is an important design consideration as the atmospheric temperature decreases with altitude, at least in the troposphere.

This is particularly important for batteries that power other electronic components as their discharge rates decrease at lower temperatures. Therefore, over-rated batteries are often selected, at the expense of increasing the payload mass, to ensure that sufficient voltage is supplied throughout the flight.

Consequently, payload containers have been traditionally made from bulky insulating materials such as styrofoam to reduce heat loss to the atmosphere and, along with handwarmers, maintain the internal payload temperature. However, styrofoam payload containers reflect back a major source of heat during much of the flight — the sun. Solar irradiance is a source of energy that can be utilised to heat payload containers and maintain the temperature of the components and batteries above their minimum operating temperatures.

Therefore, the primary motivation for launching a HAB and participating in the 2015 Global Space Balloon Challenge (GSBC) was to investigate the performance of a cheap, transparent polyethylene terephthalate (PET) payload container as a novel method to heat payloads by harnessing the freely available solar irradiance, and compare its performance to traditional styrofoam containers.

This report begins by briefly describing the PET container design in §2, before a comparison between styrofoam and PET is discussed in §3. The results of preliminary tests and actual flight performance of the PET container are presented in §4 and §5, respectively. A brief discussion on design improvements proceeds in §6, before conclusions on the novel payload heating method are drawn in §7.

2. PET Container Design

The PET container design was based on the 'bottle-in-bottle' concept by Bruninga (2015) but developed further by using only a *single* insulating layer instead of multiple layers. A 10cm-diameter by 20cm-long cylindrical PET container with screw-top lid was purchased off-the-shelf. Due to the manufacturing processes typical of injection moulding, the container bottom was removed and replaced with a flat, transparent acrylic sheet to allow unobstructed and undistorted viewing for a bottom-facing camera. The PET container is shown in Figure A1 in the appendix.

3. Comparison of PET with Styrofoam

Heat Transfer: Firstly, convection is restricted in closed payload containers regardless of the material used. Styrofoam is less conductive than PET and minimises radiative heat transfer to its surroundings but, as mentioned in §1, also blocks solar irradiance into the container. The transparency of PET, on the other hand, allows virtually uninhibited radiative heat transfer to the payload components.

Weight: While the density of PET is approximately thirty to fifty times that of styrofoam, the thickness of PET containers is typically one to two orders of magnitude smaller than traditional styrofoam containers. Additionally, a larger styrofoam thickness is required to produce the same rigidity and structural integrity as that provided by PET. Consequently, our PET container weighed 42g and was ten times less than our styrofoam container used in the 2014 GSBC with a weight of 400g.

Safety: Styrofoam can absorb substantial amounts of energy from impacts during landing. PET also offers this protection to the internal payload components, provided that it is allowed to deform on impact.

Recyclability: Styrofoam is generally more difficult to recycle than PET. Styrofoam can be recycled through specialised methods but the process requires high volumes for financial viability, and its low density impedes transporting large quantities by weight. Consequently, recycling typically takes place in major cities by specialist recyclers. On the other hand, PET is a widely recycled plastic in most municipalities, at least in Australia. That being said, both styrofoam and PET containers can be re-used many times if they are constructed well.

Availability & Cost: Both PET and styrofoam are easily purchased and free from excess packaging. However, as both are manufactured in standardised shapes and sizes, construction and assembly is often necessary for custom HAB containers.

Design Opportunities: The transparency of PET and its availability in various standard shapes allows for container designs that would not otherwise be possible with styrofoam. For example, the screw-top lid of our container allowed easy twist-access to the electronic components, and its transparency allowed the installation of an LED display that monitored the status of the electronic components.

4. Preliminary Tests

Preliminary tests of the PET container were performed at sea level using a thermocouple. It was found that once the container was closed with its lid, the temperature inside rose rapidly until reaching a steady-state that was about 15°C higher than the external air. The thermocouple probe hole allowed pressure equilibrium with the atmosphere, but did not permit significant airflow into or out of the container. Thus, heat transfer to and from the container was predominantly due to radiation and conduction.

To investigate further increases in the temperature difference between the container interior and surroundings, various darkly-coloured materials, such as cardboard and foamboard, were placed inside. It was found that many of the materials contained moisture that evaporated in the closed container, and then recondensed on the container wall. This reduced the temperature difference, ostensibly due to the reflection of radiation and, hence, reduction of solar irradiance entering the container, as well as absorption of energy by the condensate. When it was wiped away and contained closed again, the temperature difference was found to be higher than without the darkly-coloured materials.

5. PET Container Performance

The internal container and external atmospheric temperatures, as well as the altitude, during the HAB flight are plotted against time in Figure A2. While the external temperature reached a chilling minimum of -60°C at 17 km altitude, the internal container temperature only attained a minimum of -12°C which was above the minimum operating temperatures of the electronic components. This demonstrated the ability of the PET container to harness the freely available solar irradiance during the flight and sufficiently maintain the payload temperature with a single insulating layer.

Examination of the side-facing camera photos post-recovery revealed water condensation on the container walls that later froze to ice. This was due to the retention of moisture in the darkly-coloured foamboard and air, as well as the electronic components. The condensate and ice, as demonstrated by the preliminary tests in §4, would have lowered the minimum temperature by reducing solar irradiance into the container and absorbing thermal energy. Therefore, it is reasonable to assume that an even higher minimum temperature would have been achieved if the condensate and ice were not present, and improved the heating offered by the PET container.

6. Future Improvements

Some improvements to the PET container design that may be considered in the future to increase the internal container temperature include:

- reducing the container size to decrease the volume of air being heated;
- using darkly-coloured electronic components to maximise radiative heat absorption;
- insulating the top of the container near the lid to reduce heat loss via conduction;
- using reflective materials on the lid bottom to reflect radiation back to the electronic components.

Prohibiting the condensation of water and formation of ice on the container walls would also improve the efficacy of the heating and increase the internal temperature. The inclusion of water-retaining materials such as silica gel balls or pre-drying electronic components are possible methods of reducing water condensation.

7. Conclusion

As part of the 2015 GSBC, a novel payload heating method was investigated using a transparent PET container to harness the freely available solar irradiance, in place of traditional bulky insulating materials such as styrofoam. The results demonstrated the PET container successfully maintained the internal payload temperature above the minimum operating temperatures of the electronic components. While the safety provided by and cost of PET containers are comparable to that of styrofoam, substantial savings in payload weight and size, as well as improved material recyclability, can be gained.

REFERENCES

Bruninga, B. 2015. Naval academy balloon missions. *http://www.aprs.org/balloons.html*.

APPENDIX

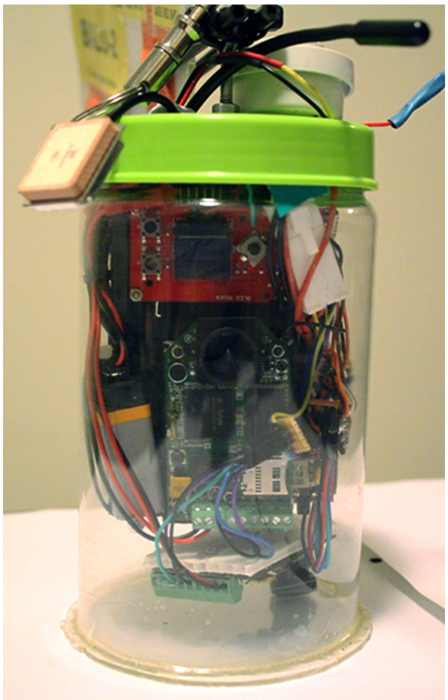

Figure A1. PET payload container with electronic components.

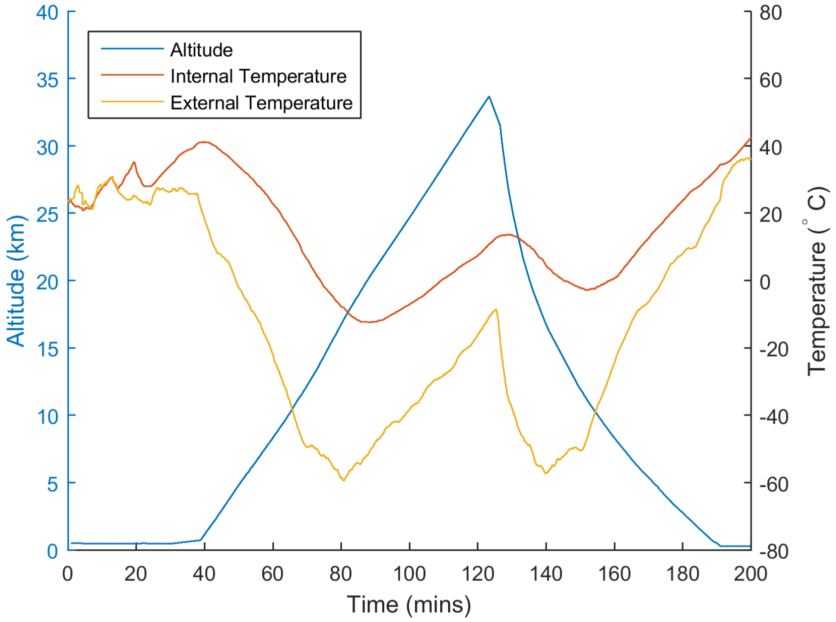

Figure A2. Internal container temperature, external atmospheric temperature and altitude during HAB flight.

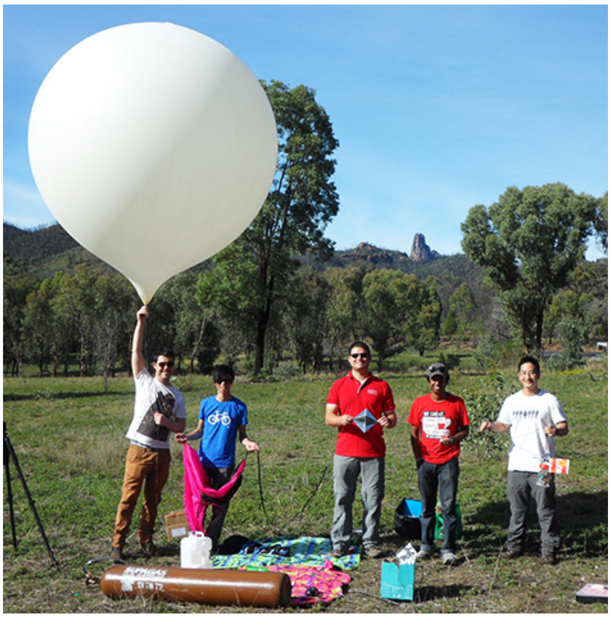

FIGURE A3. Team photo on launch day.

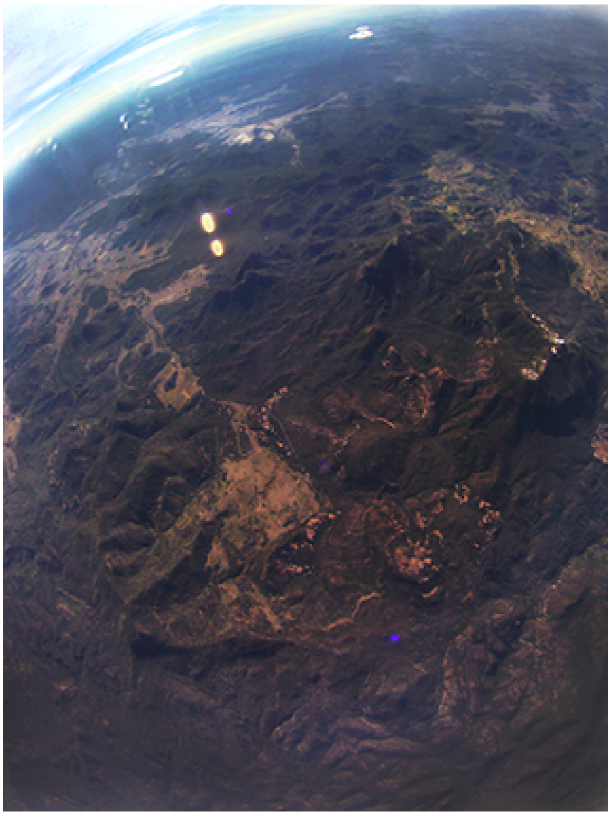

FIGURE A4. Photo of Warrumbungle National Park, Australia during flight.

Josh Yen
@josh_yen

Another successful high-altitude balloon launch by @UNSW postgrads from the #Warrumbungles for the #GSBChallenge!!

RETWEETS
2

6:19 PM - 12 Apr 2015

FIGURE A5. Tweet from team member on launch day.

AAO Astronomy
@AAOastro

.@ACSERUNSW PhD students launch balloon from Warrumbungles, nr Siding Spring Observatory newsroom.unsw.edu.au/news/science-t … ^AJH

RETWEETS
4

FAVORITES
8

2:54 PM - 16 Apr 2015

FIGURE A6. Tweet from Australian Astronomical Observatory on the launch.