

Stratospheric Thermal Balloon Wake Investigation



Mara Blish, Rachel Hedden, Juliana White, Amanda Grove, Erick Agrimson
Department of Mathematics and Physics, St. Catherine University, St. Paul, MN 55105

James Flaten and Spencer McDonald
Department of Aerospace Engineering and Mechanics, University of Minnesota, Minneapolis, MN 55455

Abstract

We present data characterizing the thermal wake that trails below ascending high-altitude balloons (AKA weather balloons) as they ascend into the stratosphere. This wake, which is warmer than the ambient air during the day but colder during night flights, is reported to be significant within 25 feet of the base of the balloon (see Ref 1). We have built and flown a "wake boom" that hangs below latex weather balloons with a 1-D array of temperature sensors that extends horizontally from directly beneath the balloon to outside of the predicted width of the thermal wake. We present analysis of the temperature profiles collected utilizing this apparatus.

High Altitude Ballooning

High-altitude balloons used at St. Catherine University are typically flown around 100,000 ft. This places the balloon in the stratosphere, which is considered to be in "near-space" conditions. High-altitude ballooning is used for furthering research concerning the atmosphere as a way to test equipment used in outer space and also as a recreational hobby. The balloon is filled with enough helium to lift student-built experiment payloads up into the stratosphere (figure 1 and 2a).

All payloads are equipped with one or more tracking devices so that the balloon can be tracked during flight and found after landing (figure 2b). Some systems commonly used in high altitude ballooning are: Automatic Packet Reporting System (APRS – ham radio), StratoStar (900MHz radio GPS tracking), Geiger counters, accelerometers, cameras, temperature and relative humidity sensors, and pressure sensors just to name a few. Some of these systems can be flown on their own, while others have to be placed within a payload box.

Photo of the Atmosphere



Figure 1. Photo of the horizon taken from a balloon flight. At this altitude you can see some of the layers of the atmosphere, as well as the blackness of space.

Wake Boom Set Up

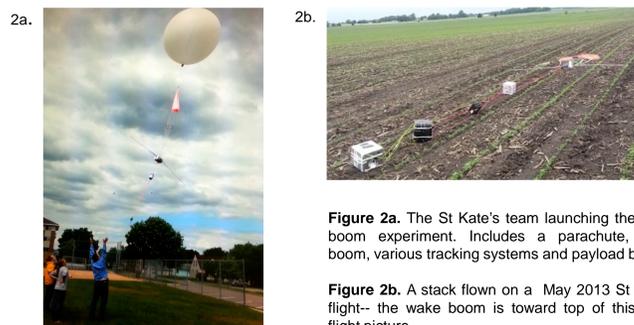


Figure 2a. The St. Kate's team launching the wake boom experiment. Includes a parachute, wake boom, various tracking systems and payload boxes.

Figure 2b. A stack flown on a May 2013 St. Kate's flight-- the wake boom is toward top of this post-flight picture.

Our thermal wake boom was comprised of two main components.

A) Carbon fiber rods — the rods allow for attachment of temperature sensors. Data sensors are attached to the rods at selected locations in attempt to resolve the spatial extent of the wake. HOBO temperature sensors used were cylindrical sensors (5.1 X 33mm).

B) Payload box — the box holds all of the instrumentation used to collect the temperature data. We have used HOBO data loggers, but we have also explored the use of Arduino Uno loggers this fall. Pink foam insulation is the primary structural element — this is covered by white duct tape. Attachment points are also setup as to allow connection to other payloads.

The wake data collection device is typically located 2.5 meters or less from the neck of the balloon, which is well within the theoretical extent of the wake predicted by reference 1.

Data Collected

Data typically show a variation of typically no more than +/- 1.5 degrees Fahrenheit for data collected in the troposphere and for data collected post balloon burst. The temperature difference created by the thermal wake is more substantial for the daytime wake as compared to the nighttime wake.

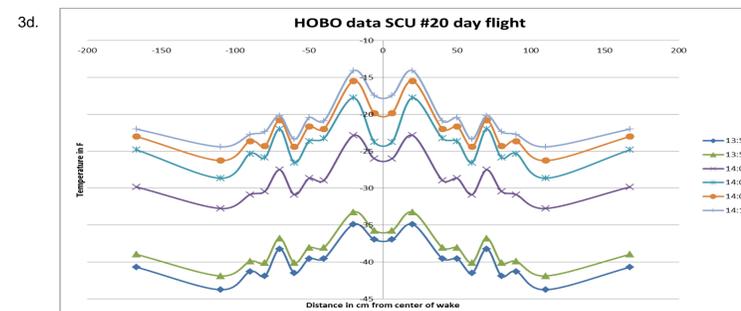
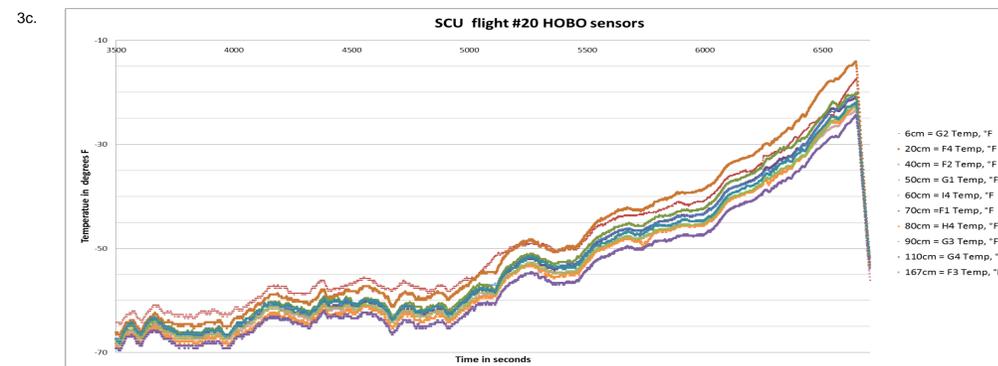
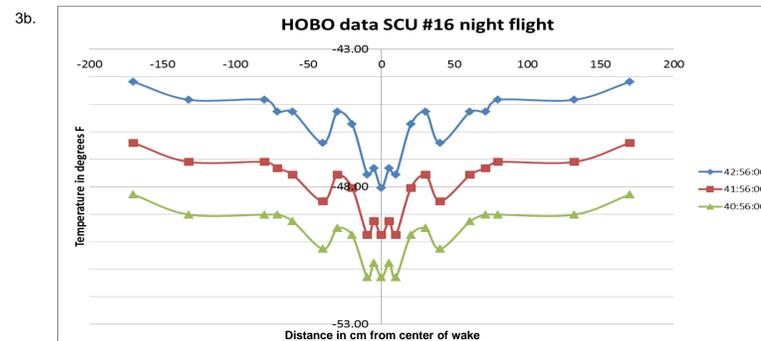
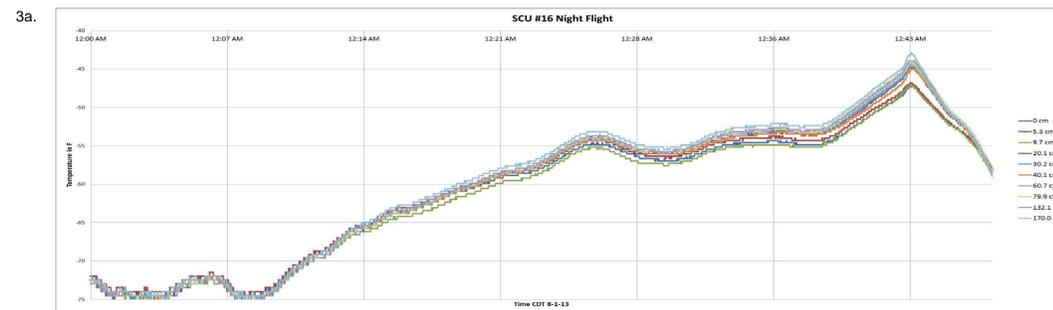


Figure 3a. Graph showing HOBOTemperature sensor values vs. time for a nighttime flight conducted on 8-1-2013 – the data encompasses a latter portion of ascent plus a portion of descent data.

Figure 3b. Graph of time slices (and their mirror image) through the temperature data showing the profile of the nighttime wake. Note the "cold" region (at least 2 degrees Fahrenheit colder) that exists for sensors inside of 50cm. This region is predicted in reference 2-- the surrounding temperature is nearly isothermal while the balloon continues to cool adiabatically. The air streaming past the balloon absorbs the energy loss of the balloon gas and creates a cool region.

Figure 3c. Graph showing HOBOTemperature sensors values vs. time for a daytime flight conducted on 10-26-2013 – the data encompasses a latter portion of ascent plus a portion of descent data.

Figure 3d. Graph of time slices (and their mirror image) through the temperature data showing the profile of the daytime wake. Note the "warm" region (at least 5 degrees Fahrenheit warmer) that exists for sensors inside of 50cm. This region is predicted in reference 2-- the energy absorbed is assumed to be proportional to the balloon surface being hit by solar radiation.

Standard Atmosphere

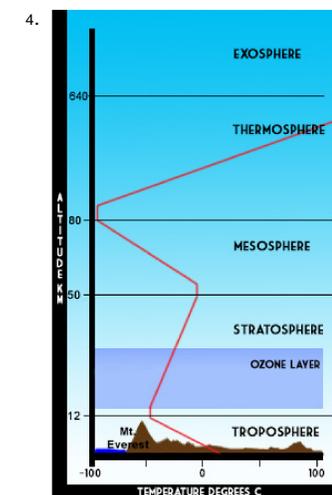


Figure 4. This graph is a representation of the atmospheric levels of Earth. The troposphere is the lowest layer of the atmosphere. It reaches up to 7 km at the poles to as far as 18 km at the equator. The higher you climb in the troposphere the lower the temperature gets. The tropopause is the boundary between the troposphere and the stratosphere; in this region, the temperature is relatively stable. Once the balloon reaches the stratosphere, the temperature begins to rise again, which is a characteristic we look for in our data to tell when we have reached the stratosphere. The stratosphere extends to around 50 km. Located in the stratosphere is the ozone layer at around 20-30 km.

Challenges making wake measurement

- Offset of sensors – calibration at one temperature is not a fixed parameter; drift occurs for each sensor within certain temperature ranges.
- Color sensitivity is a huge factor. Black, silver, and white temperature sensors can have a variance of over 10 degrees Fahrenheit.
- Some temperature measurements occur outside of manufacturers specifications (HOBO sensors are within operating conditions down to -40 degrees F).
- The wake boom (and other payloads) sometimes swings like a pendulum outside the wake during ascent.
- Rotation of the wake boom with respect to the balloon (and therefore the wake) suggests a warm (sun side) and cold side on daytime flights (see Reference 2).

Future Steps

- More thorough cross-calibration of the temperature sensors and the use of other types of temperature sensors.
- Build and fly a two-dimensional X-shaped wake boom to investigate a potential warm side of the wake (sun side of the balloon).
- Use upward-oriented video of the balloon to assist in determining the size of the balloon and characterize the orientation of the wake boom with respect to the sun side of the wake.
- Higher data logging rates to investigate pendulum motion effect.

References

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- Tiefenau, H. and Gebbeken, A. *Influence of meteorological balloons on Temperature Measurements with Radiosondes: Nighttime Cooling and Daylight Heating*, J. Atmos. and Oceanic Tech. 6 (36-42), 1989.
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