Flame in Freefall
An Exploration Using PocketLab One[1]

Materials: Smartphone, PocketLab One, App (free), Box, Candle, Packing Material, Dark Spray Paint

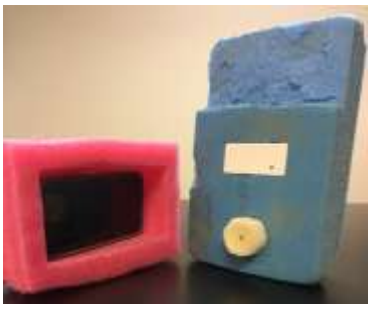
Background and Purpose:
Flames are ordinarily teardrop in shape due to localized upward convection currents set up by the flame acting as a source of thermal energy. These convection currents exist due to a buoyant force acting on the warmer gas surrounding the flame. This buoyant force is in the opposite direction of Earth's gravitational field.

In freefall, or a microgravity environment, the gravitational field is not discernable. Therefore no buoyant force exists and the teardrop shape of the flame due to convection currents should change to a spherical shape as the thermal energy from the flame radiates symmetrically outward from the flame source.[2,3]

Preparation: *A recommendation is to have students design their own or improve this apparatus!*[4]
Construction of the apparatus is inexpensive and fairly straight-forward as can be seen in the photographs. We used scrap materials found in the lab.

1. The container was painted satin black on the inside to limit incoming light and reflections from the flame.
2. We used painted aluminum foil to line the lid (to help prevent the plastic lid from melting).
3. Snug cutouts in the foam held components in place in the correct orientations. The foam for the phone included an additional piece so the phone would be at an angle and not parallel to the foam's surface. This helped put the flame in the field of view and was intended to reduce glare/reflection from the back wall of the box.
4. A detail that is less obvious is that one end of the base foam (blue) has mass inserts beneath the candle so that the entire container is balanced when the phone is in position. This reduced the likelihood of tumbling/rotation during freefall.






Slot to accommodate masses.

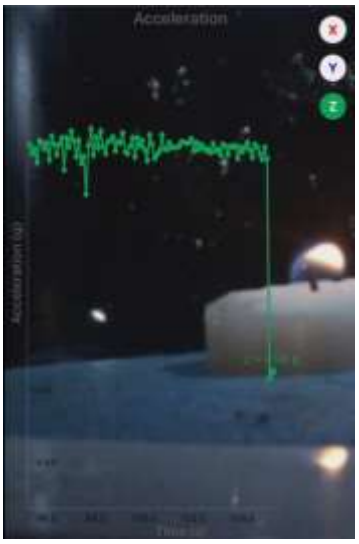
Credit for the original idea leading to this design goes to Daniel Walsh @TheLiteralWalsh.[3]

Collecting Data:
We used a PocketLab One sensor in order to capture video and data simultaneously. Once the sensor was paired to the phone, we activated the camera and verified it was recording in the preferred orientation.

We collected acceleration data in all three directions. We then deselected the x- and y-direction acceleration data prior to saving the data to clean up the final video file.[5]


Ladder height was ~22m

Teardrop shape while at 1g



Flame shifts to sphere at ~0g

Additional Notes:

- We were fortunate with the video footage. Since the standard frame rate is only 30fps, multiple trials may be necessary to capture good footage of a spherical shaped flame in a single frame of recorded video. It may be possible to increase the frame rate of the phone camera.[6]
- We learned much by performing pilot runs off of a building fire escape:
    - Make sure the phone has adequate charge. Saving files while the phone powers down could yield a loss of data.
    - Early on, we recorded the time it took for the flame to extinguish with the lid closed (~2 minutes for our system). This gave us an idea of the maximum allowable prep/climb time after the system is closed, which came in handy for the firefighter scaling the extension ladder!
    - In one case, we ended up with the flame video and plot recorded perpendicular to one another. While still informative, this is a less desirable way to present the data.
    - Successfully catching the box in a bedsheet requires practice!

- Opting to remove x- and y-directional accelerations may clean up end video but could bypass a valuable teaching moment ("Why are x- and y-direction accelerations always around 0g?").
- Presenting this challenge as "only one trial" for some courses/contexts may be appropriate. Volunteers giving up their time is analogous to reserving use of a facility--there may be little or no opportunity for a "do over" (astronomers know this!).
- Shown to the right, one can see the effect of air resistance yielding an upward curve following the stark drop in the plot during the box's "freefall." Contact with the bedsheet below began just prior to the final data point displayed.

References:

1. The PocketLab One and corresponding app is required for this application http://thepocketlab.com/
2. ScienceCasts: Strange Flames on the International Space Station https://www.youtube.com/watch?v=BxxqCLxxY3M
3. ThePhysicsGirl: Fire in Freefall https://www.youtube.com/watch?v=VAA_dNq_-8c&t=226s
4. Next Generation Science Standards: Engineering Design https://www.nextgenscience.org/sites/default/files/Appendix%20I%20-%20Engineering%20Design%20in%20NGSS%20-%20FINAL_V2.pdf
5. For access to video of this activity, browse to https://twitter.com/SteveMaier_/status/916334687014047747
6. Increasing the frame rate of your phone's video: https://www.cnet.com/how-to/how-to-enable-60-fps-video-recording-on-iphone-6-and-6-plus/

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- Alva Fire Department for volunteering their time, despite having completed three previous calls prior to our 8:30AM experiment
- The PocketLab for their support and tips along the way