Techniques for Payload Stabilization for Improved Photography During Stratospheric Balloon Flights

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Payload-box rotation and swing are perennial challenges to achieving high-quality photography (typically videography) during weather-balloon flights to "near-space" (AKA the stratosphere). Continuous camera motion can lead to blurred still photos, nearly-impossible-to-watch video footage, and precludes time-exposure photography required for most astronomical imaging even though altitudes are reached where the daytime sky appears black. Apparently-random payload rotation, persisting even at altitude, can often exceed servo rotation rates and frustrate attempts to do active camera pointing. Here we discuss mostly-passive payload stabilization strategies we, and our collaborators, have used to mitigate and dampen both swing and rotation of suspended payloads on high-altitude balloon missions, primarily on ascent. In particular, we stress the importance of avoiding single "main" lines and of firmly coupling the payload stack to, as opposed to intentionally trying to decouple (rotationally) from, the neck of the balloon. We discuss consequences these strategies have on stack weight and also on the location of the parachute, sometimes displacing it from its normal location hanging between the neck of the balloon and the payload stack. We expect these payload stabilization techniques will be of particular interest to balloonists planning to photograph the total solar eclipse of August 2017.

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I. Introduction

STRATOSPHERIC weather-balloon missions, also known as high-altitude balloon flights, involve hanging one or more payloads (typically containing science experiments) from the neck of a lighter-than-air balloon with cords and lifting them into "near-space" (the stratosphere) where environmental conditions, and the view, are similar to outer space. Balloon payloads, whether lofted alone or as part of a multi-payload "stack," invariably experience pendulum motion and rotation about their suspension-line axis while in flight. This motion interferes with certain types of experiments and data collection, such as taking stabilized video footage. Even during relatively-turbulence-free (no-jet-stream) ascents, rotation rates can easily reach up to one rotation per second, resulting in video footage that is so unsteady it is literally hard to watch. "Post-burst chaos" – turbulence induced by falling at high speed after the balloon bursts or is cut away – can cause even more violent payload motion, as can passing through the jet-stream and/or experiencing clear-air turbulence on ascent. Aside: If you use sensors polled at 1 Hz to check for rotation you may be fooled by aliasing effects. Typically video footage is the final arbiter as to whether or not payloads are actually rotating or swinging, and how much.

Rotation and pendulum swinging of the payload train is associated primarily with wind. Although balloon flights "go with the wind," vertical ascent through the atmosphere leads to a relative velocity with respect to local air even in still conditions. Streamlines of this induced airflow are disturbed by the presence of the expanding balloon above, the parachute (typically hanging closed during the ascent, but irregular in shape), and the payloads themselves. Different cross-wind speeds at different altitudes can lead to wind shear on the payload train, causing tipping followed by gravitationally-driven and air-resistance-damped pendulum motion. Rotation, which can appear to be quite random, arises in large part from torques induced by air-drag applied to asymmetric payloads. In the stratosphere air density is low, and wind speeds are usually low, allowing balloons to ascend quite vertically with little pendulum motion of the stack. Yet video from balloon flights suggests that irregular payload rotation can persist even at altitudes of 100,000 ft where there is very little air. Although weather balloons are usually quite featureless, close examination of up-looking video from near-space missions suggests that balloons themselves do not rotate much at altitude – observed rotation is primarily in the suspended payload(s).

In this paper we report on our experiences using passive means to lessen payload rotation in particular, in hopes of improving video quality – especially for out-looking video. Studies exist, such as Ref. 1, in which active mechanisms were tried to stabilize balloon payloads. However such active mechanisms are inherently complicated and heavy, and different solutions may be needed for low-vs-high altitudes, so we limited our investigation to passive-stabilization devices.

II. Air Scoops

We have had reasonable success in damping both pendulum motion and rotation, especially at relatively low altitudes where there is sufficient air, using air-scoops mounted on booms which extend horizontally (or horizontally and slightly downward) from balloon payloads. We have used a 2-scoop version of an original 3-scoop design by Rick Brennan, K0BR, a local ham radio operator with whom we collaborate. Figures 1 and 2 show Rick Brennan's design; Figure 3 is our 2-scoop implementation of the same type of device. The scoops are 12 inches in diameter, made of lightweight foam-core, and mounted using carbon fiber hollow rods. Rick Brennan's version, where the scoops hang down somewhat and are farther from a vertical axis through the payload boxes, was more effective at damping both pendulum motion and rotation than our shorter "dumbbell" variant. See Ref. 2 to read more about Rick Brennan's flight experience with this design.

Downsides of this approach include the following: (a) it adds weight (5 oz per ball plus 1 oz per 1-m-long carbon fiber rod), (b) it is most effective at low altitudes, (c) it basically only works for one payload at a time – we put a single dumbbell on the top payload in a multi-payload stack and it had very little effect, (d) it may reduce ascent rate due to additional drag, though this is probably not a large effect – we have not tried to characterize this, and (e) the structure is fragile, to save weight – the carbon fiber rods break nearly every time we fly this design, either during post-burst chaos or upon striking the ground.

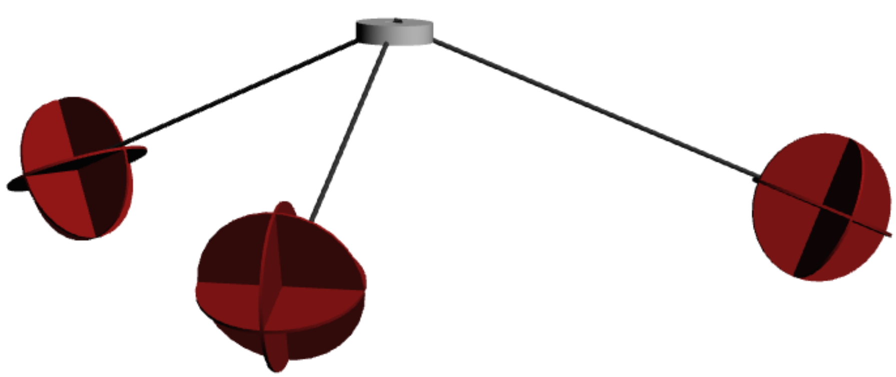

Fig. 1. Rick Brennan's 3-D CAD model for a 3-scoop stabilization device. Construction details available upon request. Scoops are made of foam-core that is laser-cut and assembled into ball shapes. Rods are 1-m-long carbon fiber tubes.

Fig. 2. Photo of Rick Brennan's built device which was flown, attached by a single line, at the bottom of a payload stack. The central part of the structure contained a video camera. Good stabilization was achieved, but only this bottom payload was stabilized.

Fig. 3. U of MN student Victor Portillo prepares to release a single-payload balloon (parachute and 300-gram balloon are above, out of sight) with a 2-scoop "dumbbell" stabilizer. These two balls were attached to the ends of a single 1-m-long carbon fiber tube, so the device is significantly smaller than Rick Brennan's.

III. Strong Coupling to the Balloon Neck

Motivated by the observation mentioned earlier that weather balloons stop rotating at altitude, we set out to increase the coupling between our payload trains and the balloon neck. The key to doing this is to get rid of the single line typically attaching the balloon neck to the parachute hanging below, attaching instead multiple tie-points to the balloon neck that are spread horizontally to increase moment arm.

Figures 4 shows how this was done for a 1600-gram balloon (reconstructed for an exhibit, after being flown), with 4 lines 8 inches apart running from the balloon neck down to the payload train below and another 4 lines running down to booms attached to the lid of the top box. These lines held up the ends of the 3-m-long (1.5 m on each side) boom arms and also increased the coupling between the payloads and the balloon. The parachute in this case was laid inside a "parachute basket" attached to the neck of the balloon and to which the lines were tied. This set-up proved to be very effective at damping rotation at altitude – watch the background (not the mascot!) in the following video. https://www.youtube.com/watch?v=hxApfU8DqUs. Figure 5 shows a similar much-smaller installation with a single payload box, before the 300-gram balloon was attached to the pvc tube and the parachute was laid in the basket (both near the top of the photo). This too worked well at altitude, but inadvertently accentuated pendulum oscillation about an axis parallel to the 1-D boom structure, unlike the larger 2-D version.

Downsides of this approach include the following: (a) it adds the weight of the booms and the basket, (b) it interferes with the normal parachute placement so users run the risk that the parachute will either tangle in the additional lines or possibly not pop out of the basket on descent (we speak from experience on that second point – hint: make sure the floor of the basket is *highly perforated* (i.e. almost absent) so that air can flow through it easily to dislodge the parachute – despite ground tests in which parachutes always come out easily, we have had two parachutes that failed to come out of their baskets at all during actual flights), and (c) it potentially exacerbates pendulum motion about an axis parallel to the boom axis in the case of the1-D rather than the 2-D boom structure.

Fig. 4. A 1600-gram balloon is inflated indoors for an exhibit. Notice the parachute basket and the 8 widely-space load lines extending down to the (white) payload below and to the ends of the 3-m-long booms on the lid of the payload below. The "Goldy Gophernaut" video footage (see YouTube link in main text) came from the black box suspended below the white payload.

Fig. 5. Preparing a 1-D anti-rotation boom for use with a single-payload, 300-gram balloon flight. The parachute will lay in the parachute basket, made from two embroidery hoops (AKA spreader rings). The pvc tube around which the parachute basket is built, will be partially inserted into the balloon neck. The central line holds the load – 2 outer lines prevent relative rotation.

IV. Stabilization Rules of Thumb

Here is a list of recommendations (not all tested by us, yet) to minimize and mitigate rotation and pendulum oscillation during high-altitude balloon flights.

- Avoid using single rigging lines *ever* – provide a restoring moment by using multiple, spaced, parallel lines running between payload stack components and starting at the balloon neck itself – we recommend 4 lines, though many ballooning groups we know use just 2 lines.
- Use booms, possibly tipped with tennis balls, to increase the moment of inertia – this slows rotation to servo-compensatable speeds, and also makes it more predictable.
- Use cylindrical payloads to reduce the ability of wind to apply forces and torques to the payloads that can foster rotation and/or pendulum motion.

- Keep payload spacing modest – no more than 6 to 8 times the spacing between support lines – longer lines tend to twist around one another, compromising their restoring moment effectiveness.
- Fly the heaviest payload(s) at the bottom of the stack – light payloads near the bottom can get tossed around and even strike payloads above or become separated and fall free from the stack.
- When doing predictions, actively void hitting the jet stream – clear-air turbulence, on the other hand, is harder to predict and to intentionally avoid.
- Attach air scoops to payloads that you are most concerned about rotating and, if possible, place them at or near the bottom of the stack so they are influenced less by weights below.
- Couple payloads strongly to the balloon neck using multiple, widely-separated lines – the use of single main lines, or even swivels to decouple rotationally from the balloon, allows for excessive payload rotation.
- Use a parachute basket to keep the parachute above multiple support lines and avoid tangling – admittedly this concept needs more testing to ensure reliable parachute deployment.
- If you are able, vent balloons to bring them to a "float" state in the stratosphere – this gives them even more time to reach a low-or-zero rotational or swinging state.

Air scoops work best at low altitudes and balloon-neck-coupling works best at high altitudes, when the balloon motion itself settles down. Thus we believe that using air scoops *and* neck-coupling on a single stack could help reduce rotation throughout an entire ascent. We have not yet tested this hypothesis on a flight.

We are not optimistic about mitigation of rotation, swinging, and even tumbling upon descent, focusing, as do most balloonists, on collecting stabilized data on ascent. Taylor University has reported at AHAC conferences [e.g. Ref. 3] on being able to reduce post-burst chaos somewhat by placing an underinflated balloon inside their parachute which expands with altitude and holds the parachute somewhat open. This prevents the parachute, which is normally stretched vertically during the ascent, from snapping open when the balloon bursts and tension is relieved. It also allows air to flow more easily around the balloon during the early part of the descent. Such a balloon system is said to reduce post-burst chaos significantly but, again, we have not tested that ourselves yet.

V. Conclusion

Pendulum motion of payload stacks and individual payload rotation can both be significantly reduced on stratospheric balloon missions using simple, passive mechanisms, at least during “calm” parts of the ascent. Our main recommendation, in addition to using multiple, parallel, short, widely-space lines between payloads, is to affix air scoops at the end of booms to individual payloads for low-altitude rotation damping and pendulum damping and *also* to couple the top of the stack to the neck of the balloon as strongly as possible with multiple, widely-spaced lines, to prevent relative rotation. This will ensure that the payload train will stop rotating once the balloon stops rotating as it rises above the tropopause and into the usually-calm stratosphere.

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