Project HoloCube

Findings from BACAR-14 “Skybridge”

Payload 100 mm Pepper’s Ghost holographic cube · **Flight** BACAR-14, October 2026 · **This report covers** power-on to landing, T+0 to T+2:45
Report date 22 October 2026



Figure 1. T+0:02, still on the ground at the launch site — and already the first problem. This is the view out through the 64 mm aperture: a gazebo leg, a banner and someone standing beside the cube. The aperture was meant to be looking down at the Earth. The overlay carries the elapsed-time clock, frame index, ESP32 die temperature and SD free space that the rest of this report is built on.

In short

HoloCube flew on BACAR-14, recorded cleanly the whole way through the flight, and came home with a complete dataset and no hologram.

Three things were wrong with the optical train as built: the camera faced the sky instead of the ground, the 64 mm aperture admitted far more light than the pyramid needed, and the pyramid itself was mounted the wrong way round. Any one of those would have been enough on its own. The footage then adds two more problems on top — the exposure was saturated for most of the ascent, and from about T+1:30 the optic fogged over with condensation.

The flight was still worth making. The enclosure, the power and the thermal design all did their jobs: the electronics never dropped below 32.2 °C in an environment of roughly –50 to –60 °C, capture ran essentially lossless for the whole flight, and the battery was still going long after landing. What this flight produced is a short, specific list of fixes rather than a picture — and every one of them is cheap.

What the cube was meant to do

A Pepper’s Ghost pyramid makes a picture look like a solid object floating in mid-air: a transparent face reflects an image placed in front of it, and the viewer sees that reflection hanging in space behind the glass. HoloCube’s idea was to do this with no screen at all and use the Earth itself as the light source. An aperture in the floor of a 100 mm cube lets the view of the ground in; the camera, tilted 18° inside the sealed cube, looks at the near face

of an 85 mm acrylic pyramid and should see the Earth floating inside it. Flown at 25–35 km, that would have been a hologram of the Earth, made by the Earth.

What we got wrong in the build

These three are known faults in the payload as it flew, not deductions from the footage. They are listed first because they outrank everything else in this report: with any one of them present, the illusion could not have formed no matter what the weather or the exposure did.

1. The camera was looking the wrong way

The design calls for the aperture to look **down**, at the Earth. As built and flown it faced the **sky**. The footage bears this out from the first minute: in Figure 1, on the ground, the view through the aperture takes in a gazebo leg and a banner rather than the dirt beneath the cube, and through the ascent the disc fills with sky and cloud rather than terrain below. With the camera facing up there was no nadir image for the pyramid to work with — and nothing to meter against but open sky and the sun.

2. The aperture was far too big

64 mm of open sky is enormously more light than the pyramid needs. Rather than illuminating the faces it simply saturated the sensor, which is the direct cause of the white-out measured in the next section. The aperture wants to be a good deal smaller — sized to admit only as much light as the illusion needs, not as much as the hole can pass.

3. The pyramid was mounted the wrong way round

In the orientation flown, the faces cannot form the reflection the Pepper's Ghost effect depends on. Reversed, they present the geometry the illusion actually needs. This one is independent of everything else: with the camera pointed correctly, the aperture stopped down and the optics bone dry, the pyramid as flown still would not have produced a floating image.

> **So the honest verdict on the optical experiment is that it was never run.** It did not fail at altitude — it could not have worked at sea level either. Everything in the next section sits on top of that, not instead of it. The value of this flight is that it proved the airframe and produced an unambiguous fix list.

What the footage adds

Saturation

The OV2640's automatic exposure was asked to meter a scene that is almost entirely dark cube interior with one small, very bright disc of sky in it. It exposed for the dark. Across the flight the median frame had **57 % of its pixels clipped to pure white**; two thirds of samples were more than half clipped, and five of the fifty-nine sampled frames were 100 % white with nothing in them at all. Only 12 % came in under 5 % clipping.

A smaller aperture fixes most of this on its own. Locking the exposure fixes the rest.

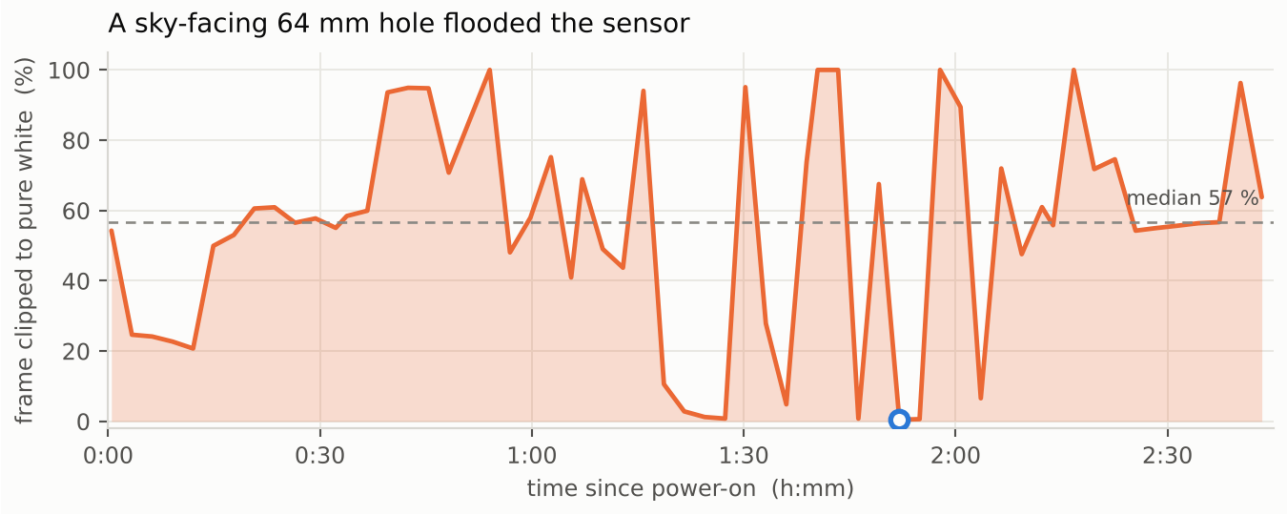

Figure 2. Share of each frame clipped to pure white, power-on to landing. The blue ring marks the best-exposed frame of the whole flight, at T+1:52 — the same frame shown fogged in Figure 3.

Condensation

At T+1:22 the aperture is clear: terrain and a shadow band are visible across the disc. Thirty minutes later the same disc is a dense field of spherical droplets and the view through it is gone.

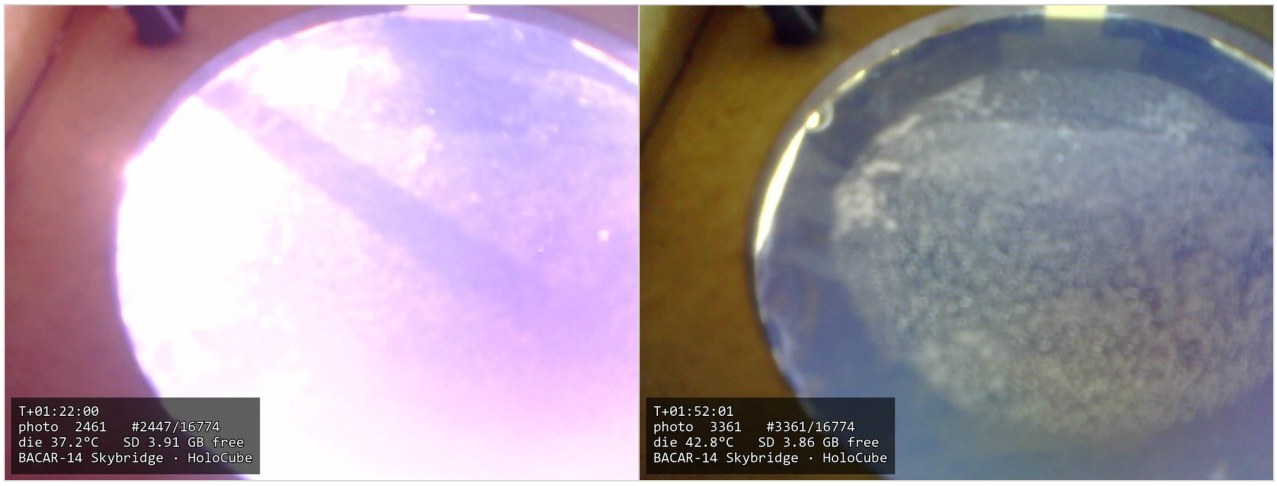

Figure 3. Left: T+1:22, optics clear, scene visible but heavily overexposed. Right: T+1:52, the best-exposed frame of the flight — and by now the optic is beaded over. There is no frame in this flight that is both clear and correctly exposed.

The cube was sealed at ground level with ordinary humid air inside. As the window cooled, that moisture condensed and froze on it. The temperature record supports this: the beading appears as the die temperature falls through its first minimum, it is worst at the coldest part of the flight, and it clears into streaks once the cube warms back past about 60 °C on the way down. The footage cannot prove which surface the droplets sit on — the aperture window or the pyramid face — but condensation on the inside of the window fits what the thermometer did.

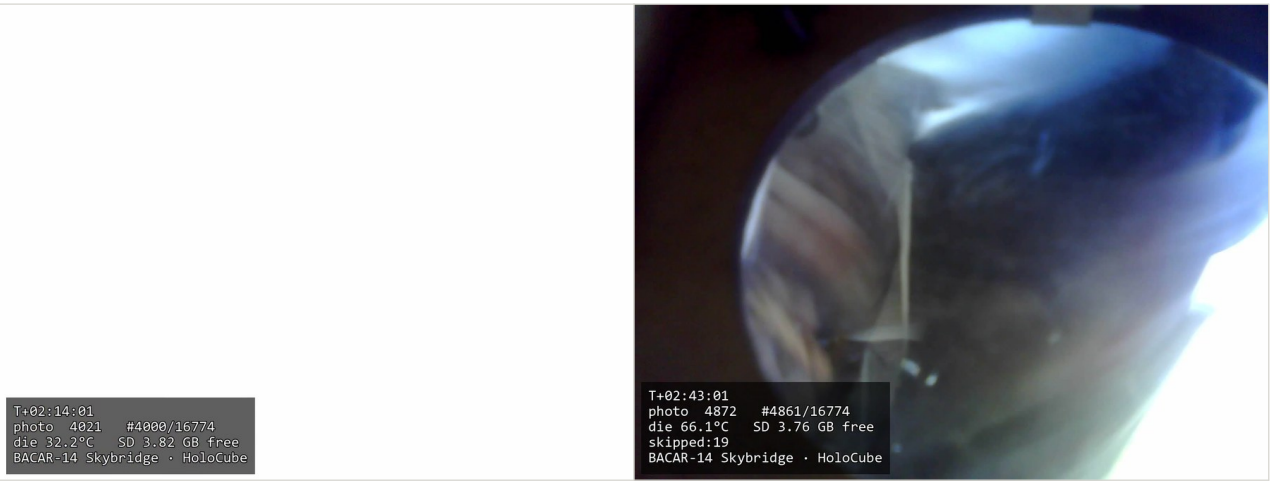

Figure 4. Left: T+2:14, the coldest moment of the flight (32.2 °C) — the frame is 100 % white, with nothing in it but the overlay. Right: T+2:43 at 66.1 °C, the beading has melted to smears and the optic is readable again — by which time the payload was at or near the ground.

What worked

The thermal design is the subsystem that earned its place, and it did so with margin. The LiPo and the chemical hand warmer held the electronics at 32.2 °C at the coldest moment of the flight. There was no brownout, no cold-related fault and no SD corruption.

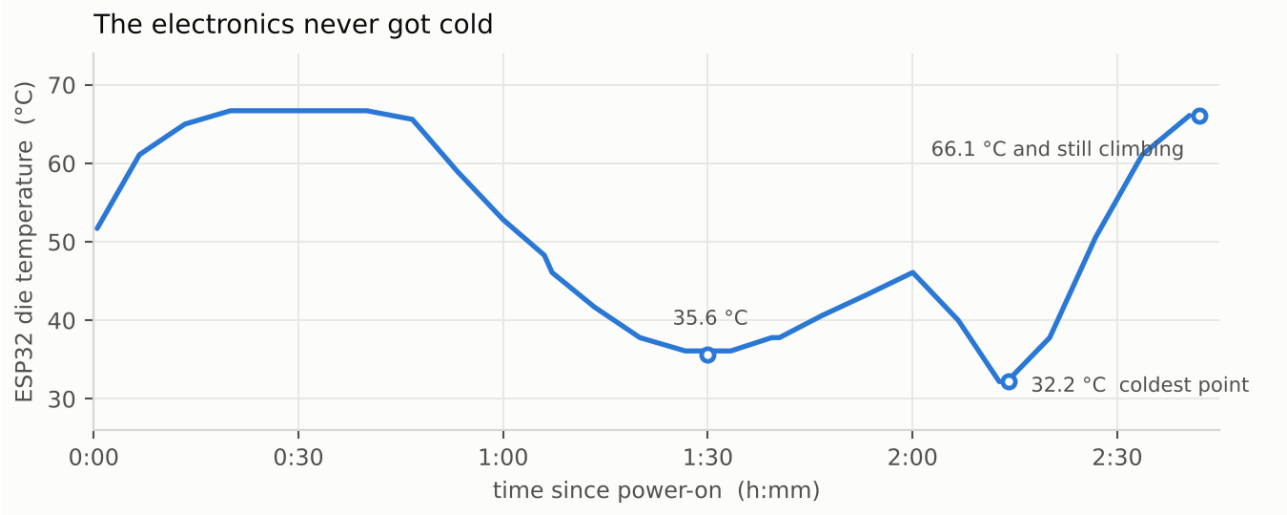

Figure 5. ESP32 die temperature from power-on to landing. The two minima and the sharp recovery after them are the clearest evidence of the flight profile in this dataset. The chip's own heat and the hand warmer mean the die lags ambient by some tens of minutes, so these minima sit later than the real tropopause crossings.

Recording was effectively lossless through the flight. The firmware attempted a frame every two seconds and wrote almost all of them: just five skipped frames by T+2:30. Storage was never remotely a constraint — 0.28 GB written during the whole flight, from a card with 4.04 GB free. (Losses did climb steadily once the payload was down and the cube was sitting in the sun; that is a ground-phase problem and is not covered here.)

Battery life was outstanding and deserves its own line. A single 3.7 V LiPo did not merely cover the flight — it was still powering the camera and writing frames at T+17:04, better than six times the flight duration, and it stopped with the card still three quarters empty. Endurance is not a constraint on this design and does not need to be designed around next year.

The flight in numbers

Window covered	power-on to landing, T+0 to ~T+2:45
Frames in that window	~4,930, one every 2 s
Frames skipped	5, to T+2:30 — effectively lossless
Image size	1600 × 1200, OV2640 on the ESP32-CAM
Die temperature	32.2 °C minimum, 66.7 °C maximum
SD written in flight	0.28 GB, from 4.04 GB free
Battery	one 3.7 V LiPo, still recording at T+17:04
Frames clipped to white	57 % of the median frame; 5 samples wholly white

Flight timeline

Times are from the burned-in T+ clock, counted from power-on at the launch site.

T+0:02	On the ground, pre-launch. A gazebo leg and a banner visible through the aperture — the camera is not looking down.
T+1:22	Optics still clear — terrain and cloud visible through the disc — but badly overexposed.
T+1:30	First temperature minimum, 35.6 °C. First wisps of condensation on the optic.
T+1:52	Best-exposed frame of the entire flight (0.5 % clipped). The optic is by now a solid field of droplets.
T+2:14	Coldest point, 32.2 °C. The frame is 100 % pure white.
T+2:43	66.1 °C and climbing fast; the beading has melted into smears.
~T+2:45	The record turns violently light/dark — landing, with the cube rolling or being dragged. The flight record ends here.

One caveat. Altitudes and the burst time are inferences, not measurements. This dataset contains no GPS and no pressure — only elapsed time, die temperature, SD free space and a skipped-frame counter. The ascent–burst–descent–landing reading rests on the two temperature minima and the rapid warming after T+2:14.

What this flight does not tell us

- **Whether the Pepper's Ghost effect forms at altitude.** Untested — the optical train was mis-built in three independent ways before weather or exposure entered into it.
- **Burst altitude and time, ascent and descent rates, landing position.** None of it is in this dataset. Pairing the T+ clock with the club's tracker log would recover all of it, and would let the temperature curve be plotted against real altitude.
- **Which surface the condensation formed on** — the aperture window or the pyramid face.
- **How much light the pyramid actually needs.** Every frame was saturated, so the footage gives no reading on this at all. The right aperture size will have to be found on the bench — try a few sizes against a bright target and keep the smallest one that still gives a clear image in the faces.

For next year

1. **Point the camera down.** The aperture must look at the nadir. This is the single change that turns the payload from a sky camera back into the instrument it was designed to be, and nothing else on this list matters until it is done.
2. **Turn the pyramid around.** Flown reversed, the faces present the reflecting geometry the illusion depends on. Worth mocking up on the bench first and confirming by eye before it goes anywhere near a balloon.
3. **Shrink the aperture.** Size the hole to the light the pyramid needs rather than to the view. A much smaller opening both kills the white-out and gives a cleaner, better-defined disc for the faces to work with — and a smaller hole is easier to seal and double-glaze.
4. **Lock the exposure.** Auto-exposure cannot be trusted with a small bright disc on a large dark field. Fix the OV2640's exposure and gain to a value set on the bench, or bracket — cycle two or three fixed exposures frame to frame so at least one in each set is usable. Firmware only, costs nothing.
5. **Deal with the moisture.** Purge the cube with dry air before sealing and put a desiccant sachet inside. A double-glazed aperture with a sealed gap would keep the inner surface nearer the interior temperature, which is where the fogging starts.
6. **Bench-test the whole optical chain cold.** Seal the cube, put it in a freezer with the camera running, and look at the frames. All three build faults and both footage problems would have shown up in an afternoon on the bench.
7. **Log altitude on the payload.** A BMP280 or similar costs almost nothing and needs no GPS lock, and would turn next year's temperature and exposure curves into real atmospheric profiles.
8. **Leave the thermal and power design alone.** Both did their jobs without complaint. The endurance result in particular is better than this payload needs.

Appendix — how these numbers were produced

The measurements come from the contents of the `timelapse_out` folder: sixteen rendered timelapse videos and the surviving source frames in the last overlay directory. The original JPEGs lived on the E: drive and were not available, so frame measurements were taken from the rendered video. Everything plotted here is restricted to the flight window, power-on to landing at roughly T+2:45; the recording itself continued for a further fourteen hours on the ground and is not analysed in this report.

- **Brightness and clipping** — sampled via `ffmpeg signalstats` and measured pixel-wise in Python with the overlay band excluded, so the clipping percentages describe the image only.
- **Telemetry** — the burned-in overlay was OCR'd across sampled frames to recover elapsed time, frame index, die temperature, SD free space and the skipped counter.
- **The time axis** — built from the attempt clock: T+ = 2 s × (frames saved + frames skipped). Checked against the OCR'd T+ values at a dozen points and against the end of the recording; it agrees to within about a minute over seventeen hours.
- **Derived data** — the CSVs behind every chart, the charts themselves and the extracted frames used as figures were written to `timelapse_out/_claude_analysis/`.

The three build faults in section three are known facts about the payload as it flew, supplied by the builder. Figures and percentages are measurements from the footage. The flight-phase reading — ascent, burst, descent, landing — and the explanation offered for the condensation are interpretations of those measurements, and are marked as such in the text.