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ZS6STN Payload and Flight Analysis



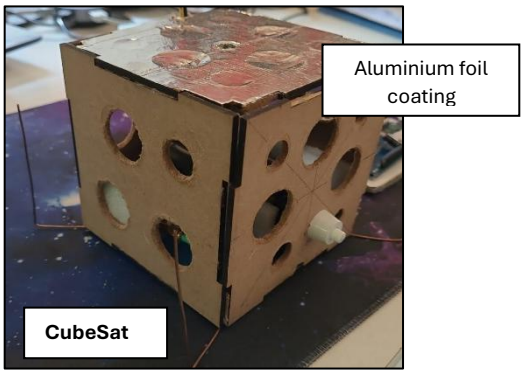
The objective of this report is to review the ZS6STN BACAR14 payload, evaluate the success of the payloads mission, to document the results obtained and the associated ideas for next time.

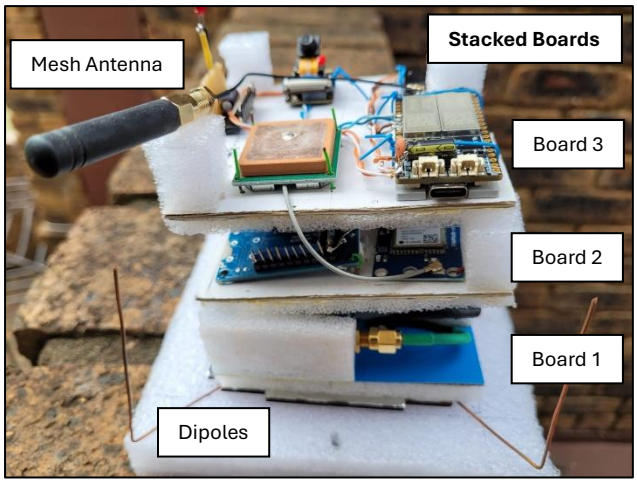
Payload Construction

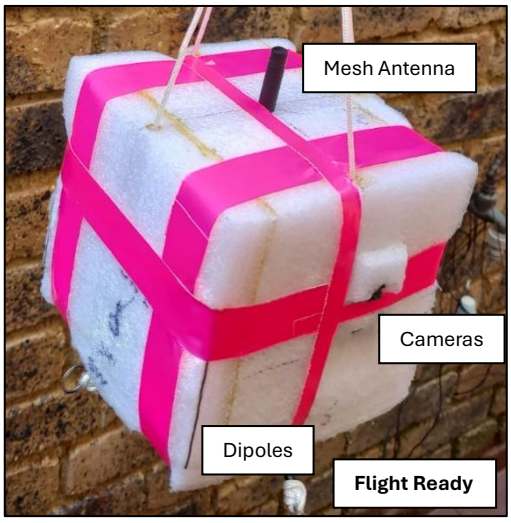
The ZS6STN payload had three physical boards stacked on top of one another within the 100mm*100mm cubesat. The cubesat was made from laser cut 3mm compressed board.

Multiple holes were cut in the cubesat sides to reduce weight. The insulation around the cubesat increased the overall dimensions to 120mm*120mm.

The circularly polarised U-shaped UHF cubesat antenna was integrated into bottom panel of the cubesat and fit nicely into the dimensions of the cubesat's insulation.







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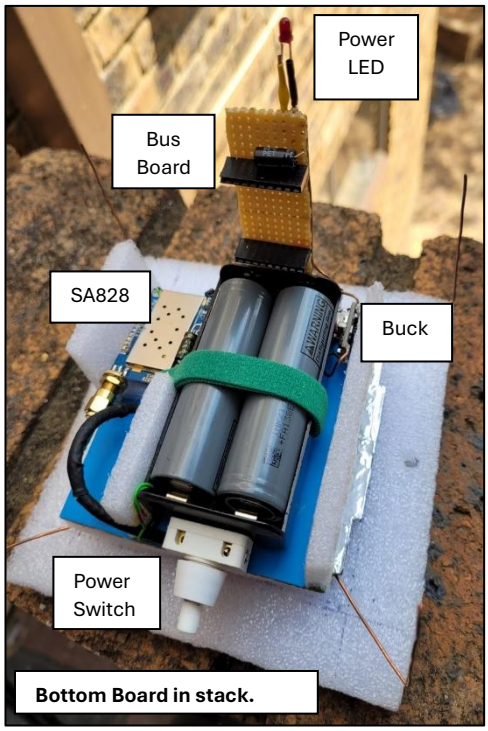
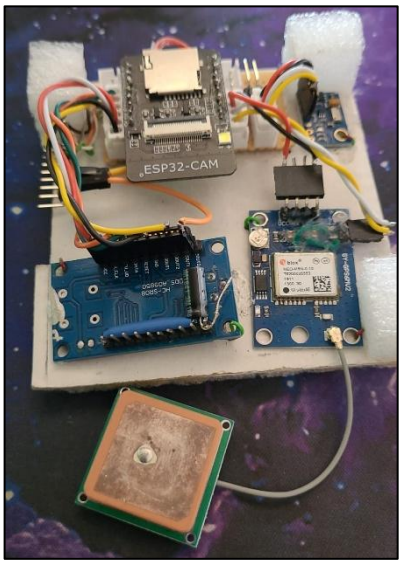
Board 1 – Bottom Board in the stack.



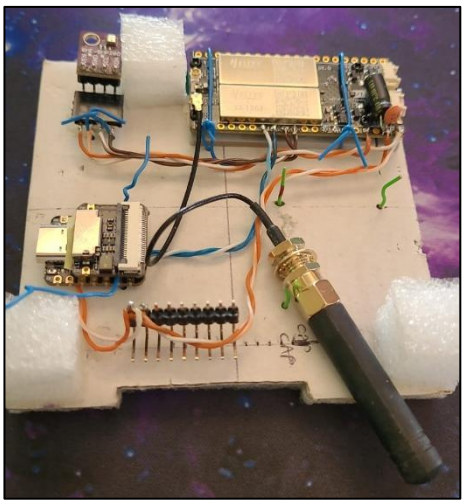
a. The Board contained a piece of strip board that formed the bus board into which all boards plugged to enable routing of power and required connections to all boards in the stack, with an LED so that you could see when the power was on or off.
b. The board also contained the SA828 UHF transmitter module, a INA226 power monitoring sensor beneath the battery holder, a buck converter, a power switch and two 21700 Lithium batteries configured in series in a two-battery holder. The board also contained a USB-C port and a micro switch enabling switching between power over the USB-C port, or via the batteries and buck converter, for ease of testing during development.

2. Board 2 – Middle Board in the stack.



a. Board positioned in the middle of the cubesat three board stack.
b. The board contained an ESP32-Cam module with OV5640 auto-focus camera and SDcard, an AD9850 DDS sinewave generator, a GY63 temperature and pressure sensor and a GY-GPS6MV2 module containing a ublox Neo-M8N GPS communicating with ESP32-CAM over I2C bus.
c. This board also communicated with the INA226 on board 1 over the I2C bus and its ceramic GPS antenna was mounted on board 3.

3. Board 3 – Top Board in the stack.



a. Board positioned at the Top of the cubesat three board stack.
b. Board contained a Xiao ESP32-S3 Sense module with OV5640 fixed focus camera, a BME280 temperature, pressure and humidity sensor and a T096 Heltec meshtastic node with integrated UC6580 GNSS receiver and antenna.
c. The meshtastic 868MHz antenna was mounted through the top panel of the cubesat.

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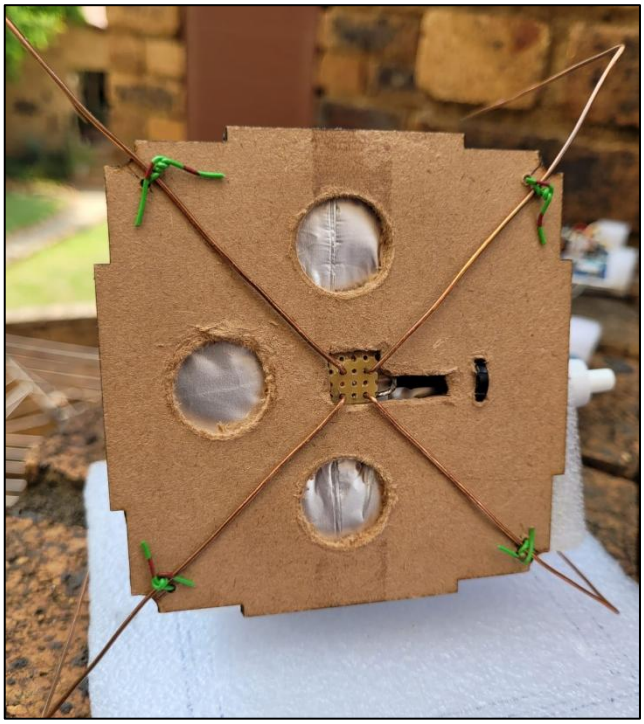
EMI/RF interference.

During testing it was discovered that when the UHF was transmitting, the meshtastic node was unable to receive or respond to text commands. This was successfully resolved by coating the top of the top panel of the cubesat with aluminium foil to form a ground plane and EMI/RF shield for the meshtastic 868MHz antenna.



To enhance the EMI/RF shielding, the bottom of each of the boards 1 to 3, and the top of the bottom panel in which the antenna was integrated, was coated with aluminium foil.

Whether this was necessary or helped/hindered is unknown, although during testing and the preflight period whilst switched on and still on the ground, everything was working well.

Ground monitoring station.

The local (at the BACAR launch site) ground station consisted of:

- A laptop powered from a 12v battery through a small 500w 12v to 220v inverter.
- A handy talky directly coupled to the audio input of the laptop.
- The laptop was running RXSSTV to receive and decode the UHF SSTV images.
- The laptop was running a browser based online morse decoder to receive and decode the CW telemetry.
- A separate handy talky to audibly receive the UHF/VHF SSTV images.
- A Meshtastic V3 with mini-integrated antenna to send and receive messages to and from the T096 meshtastic node on the payload coupled to the laptop for power via USB cable.
- A cell phone running the Robot36 App to decode the UHF/VHF SSTV images and running the Meshtastic App to send and receive Meshtastic messages.

Distant stations were asked to monitor, receive, decode and publish their interactions with the various payloads and the SSTV and telemetry received on WhatsApp.



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Pre-Launch ground testing on switch on



Once each of the payloads had been connected together in the planned flight order in the payload train, the instruction was given to switch-on and test all payloads. The payloads were on and remained on the ground for ≈ 45 minutes whilst the balloon was inflated.

At switch on, the ZS6STN payload initialised and successfully started running its routines as planned.

Board 2 was successfully running its loop, transmitting on 433.400MHz its CW telemetry for about 20 seconds, followed by a 30 second gap before sending SSTV in Robot36 format for 36 seconds before sleeping for 60 seconds. The SSTV images alternated between live camera images and fixed images. Every 10th image was sent in Martin1 SSTV format.

Board 3 was successfully running its loop, receiving text and commands sent from the ground station meshtastic V3 node via the cell phone, which was received and responded to via the T096 and Xiao S3 on board 2 of the payload.

Once it was proven that the payload was awake and working my personal testing stopped as I then went to help with the inflation of the balloon.



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Post-flight data analysis.

Board 3 – Xiao ES32 S3 Sense with camera, Meshtastic Node and BME280

The Xiao S3 on board 2 was taking its images in a continuous loop, overlaying its images correctly and saving them to the SDcard. This continued throughout the flight as evidenced from the images saved on the SDcard.

Whilst on the ground, the T096 GNSS had lock and was reading the BME280 correctly as evidenced from the overlaid GPS coordinates, altitude, temperature and humidity readings, as well as the saved data recorded on the SDcard.

The Xiao wrote a data record to the SDcard every time it saved an image. The rate of taking and saving images was much faster than the GPS update rate received over the UART from the T096, with the last GPS data being repeatedly used until the next GPS update was received. *This was a design decision but here lies an opportunity – use the data and then clear the variables until new valid data is received so that a true GPS data update pattern can be determined*.



Timestamp	Latitude	Longitude	Altitude	Speed	Heading	Temperatu	Humidity	Pressure	BaroAlt
516	-26.764902	29.281485				0	0	0	0
516	-26.764902	29.281485				0	0	0	0
516	-26.764902	29.281485	1578	0	537000	0	0	0	0
516	-26.764902	29.281485	1578	0	537000	17.03	47.89	850.77	1450.17
516	-26.764902	29.281485	1578	0	537000	17.03	47.89	850.77	1450.17
516	-26.764902	29.281485	1578	0	537000	17.03	47.89	850.77	1450.17
516	-26.764902	29.281485	1578	0	537000	17.46	48.23	850.69	1450.95
516	-26.764902	29.281485	1578	0	537000	17.46	48.23	850.69	1450.95
516	-26.764902	29.281485	1578	0	537000	17.46	48.23	850.69	1450.95
516	-26.764902	29.281485	1578	0	537000	18.17	47.7	850.76	1450.26
516	-26.764902	29.281485	1578	0	537000	18.17	47.7	850.76	1450.26
520	-26.758293	29.275246	1611	2	0	18.17	47.7	850.76	1450.26
520	-26.758293	29.275246	1611	2	0	18.17	47.7	850.76	1450.26
520	-26.758293	29.275246	1611	2	0	18.84	47.41	850.75	1450.35
520	-26.758293	29.275246	1611	2	0	18.84	47.41	850.75	1450.35
520	-26.758293	29.275246	1611	2	0	18.84	47.41	850.75	1450.35
520	-26.758293	29.275246	1611	2	0	19.67	47.51	850.73	1450.58

Extract from SDcard saved

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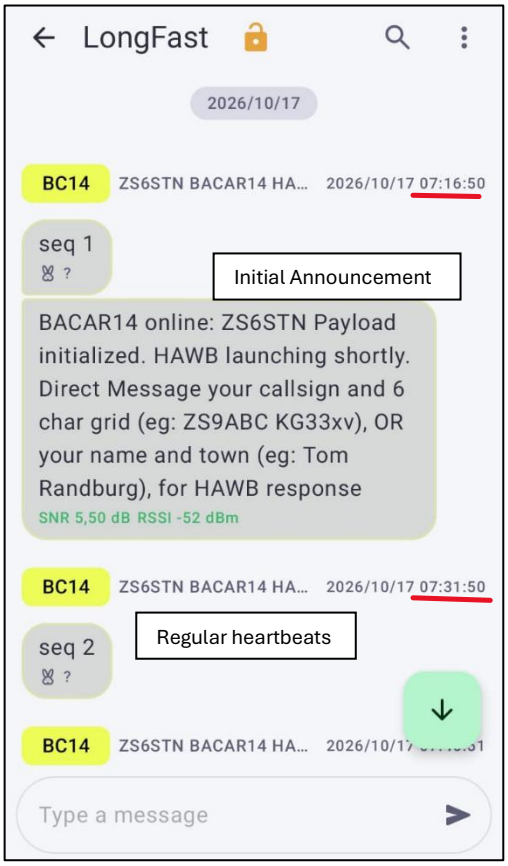
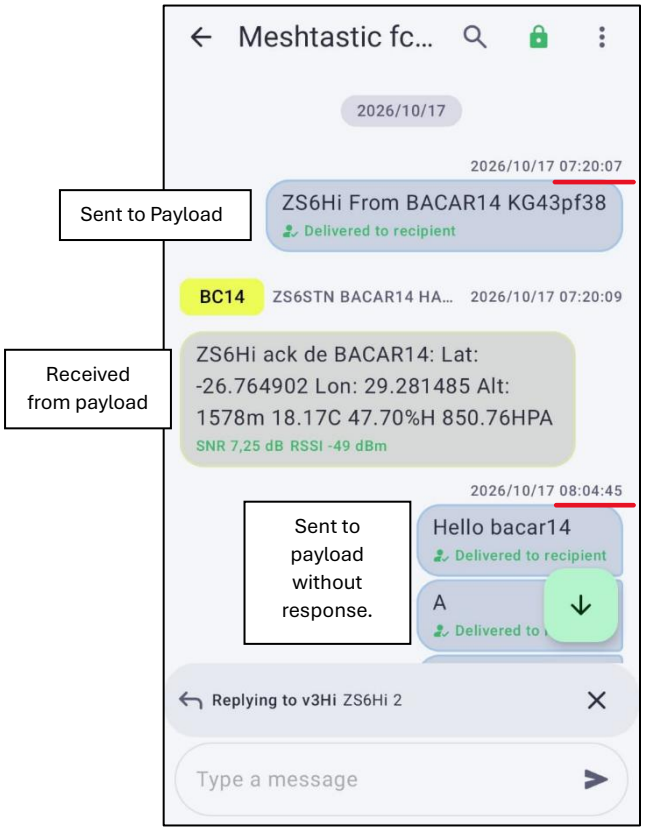
The Meshtastic node correctly announced itself on initialisation and sent its heartbeat regularly as planned throughout the flight. Meshtastic times shown are in CAT.



Whilst on the ground the node was correctly responding to texts received from the Heltec V3 ground station as evidenced from the sent and received messages recorded on the V3. The payloads reply also shows that the GPS was locked and the telemetry fully operational pre-launch.

The message sent to the payload at 08h04 CAT post-launch, “Hello bacar14”, whilst recorded as successfully delivered was not responded to.





The only messages recorded as being received by the Xiao are shown hereunder. The messages at 0516 and 0520 UTC were received pre-launch and were recorded and responded to. The message at 1014 UTC was a subsequent test executed back at base after recovery.

Timestamp	FromNode	Channel	Message
1014	0xBD4FA9F	0	A
516	0xBD4FA9F	0	ZS6Hi From BACAR14 KG43pf38
520	0x433F17E	0	ZR1WT KG43PF38

No Meshtastic messages were recorded on the SDcard whilst airborne.

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ZS6STN Payload and Flight Analysis

The suspicion is that the GNSS onboard the T096 locked up on launch due to the CoCom limits being exceeded and thereafter the T096 refused to provide any data to the Xiao over its UART port. This is supported by the fact that the GPS data, including the time, altitude and BME data coming from the mesh node remained constant post-launch, the Xiao just kept regurgitating the last known data set whilst it continued to take and save new images to the SDcard. No new data was forthcoming from the T096 mesh node UART.

Whilst retaining the last known good coordinates was by design, perhaps its better to only report and record confirmed data. I will have to give this one some thought. I also did not set the GNSS into flight mode as it was controlled by the Meshtastic firmware and according to various AI sources this GNSS automatically adapts, but perhaps this was a mistake.

If the supposition is correct that no data was being provided to the Xiao over the UART port, this explains why no messages were recorded as received by the Xiao during flight and the Xiao did not respond to any messages by replying with the latest GPS and sensor data. The messaging and response were reliant on the T096 providing GNSS, Message and BME data to the Xiao over the UART port. The T096 did transmit its Meshtastic heartbeat throughout the flight.

Another variable that could have impacted is the transmission range of the V3 and T096 modules when using their mini antennas, and/or perhaps the additional EMI/RF interference generated by the payload train causing de-sensing as was experienced during testing on the bench, however, if either of these did impact, then GNSS/BME data would still have been received and stored on the SDcard, which was not the case.

Post-landing, when the power was cycled on the payload, the T096 GNSS obtained lock very rapidly as recorded on the SDcard. I only left it on for a few seconds at that time as I did not want it to overwrite the flight data. *Another improvement opportunity, append new data records at switch-on if data already exists rather than overwriting existing data records.*

Timestamp	Latitude	Longitude	Altitude	Speed	Heading	Temperatu	Humidity	Pressure	BaroAlt
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1014	-25.79497	27.892122	1403						0
1014	-25.79497	27.892122	1403						0

GNSS lock at 1014 UTC after power cycled back at base.

One unexplained anomaly is that the Xiao data records indicate that the T096 stopped sending new data from ≈ 0536 UTC onwards (0736 CAT), even though the launch only took place ≈ 0759 CAT. Was the payload train moved into its pre-launch position at 0736 CAT, possibly causing a problem or the GNSS to lose lock? The GNSS usually obtains lock very rapidly, so this scenario is unlikely. Perhaps the recorded times are out of sync, and the CoCom limits were triggered during launch, which seems to be the most likely. Whatever the cause, the T096 GNSS and BME data remained constant throughout the flight and only refreshed once the power was cycled at 1014 UTC back at base camp.

Timestamp	Latitude	Longitude	Altitude	Speed	Heading	Temperatu	Humidity	Pressure	BaroAlt
536	-26.758188	29.275175	1600	0	0	28.76	49.5	850.82	1449.71
536	-26.758188	29.275175	1600	0	0	29.2	49.86	850.68	1451.02
536	-26.758188	29.275175	1600	0	0	29.2	49.86	850.68	1451.02
536	-26.758188	29.275175	1600	0	0	29.2	49.86	850.68	1451.02
536	-26.758188	29.275175	1600	0	0	29.2	49.86	850.68	1451.02

GNSS data and time as well as BME data does not change from ≈ 0536 UTC onwards.

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Board 2 –ESP32-Cam, M8N GPS, INA226 Power and GY63 Sensors

The second GPS on board 2 of the ZS6STN payload, the M8N, unfortunately did not provide any GPS coordinates from switch-on and during flight, it only began delivering coordinates once the payload had landed at 0750 UTC (0950 CAT). I cannot account for why the GPS did not obtain lock pre-launch unless it was due to the orientation of its antenna being side on to the sky whilst waiting on the ground in the payload train, or perhaps it needed a smack which it got on landing. *Something to remember to check before flight next time assuming I re-use the M8N as its heavy and has let me down on two BACAR flights to date, even though it was programmed to use flight mode this time around*.

Date	Time	GPSlatitud	GPSlongitu	GPSaltitud	GPSspeed(	GPSheadin	BMEtemper	BMEpressu	BMEaltitud	BMEhumidi	V_Normal(\	I_Normal(r	P_Normal(r	Shunt_Norr	Load_Norm	V_TX(V)	I_TX(mA)	P_TX(mW)	Shunt_TX(n	Lo
																7.75	7.6	691.35	5252.08	69.21
																7.74	7.6	678.65	5155.94	67.93
																7.75	7.6	691.47	5250.55	69.22
17102026	750	26.799840	29.213404	1602	0	302	37.74	848.53	1643.99	0	7.7	422.55	3253.17	42.3	7.74	7.6	695.01	5279.54	69.57	
17102026	753	26.799870	29.213399	1617	2	145	40.01	848.53	1659.89	0	7.69	430.91	3315.74	43.14	7.74	0	0	0	0	
17102026	755	26.799777	29.213241	1617	2	231	41.82	848.57	1665.2	0	7.69	419.07	3224.18	41.95	7.73	7.59	680.3	5162.05	68.1	
17102026	755	26.799777	29.213241	1617	2	231	42.77	848.6	1670.5	0	7.7	432.56	3327.94	43.3	7.74	7.6	707.82	5378.72	70.86	
17102026	800	26.798799	29.211348	1588	3	303	43.52	848.84	1675.8	0	7.7	400.15	3080.75	40.06	7.74	7.58	710.88	5387.88	71.16	
17102026	800	26.798799	29.211348	1588	3	303	44.4	848.47	1681.1	0	7.68	441.53	3392.03	44.2	7.72	7.54	701.11	5285.64	70.19	
17102026	800	26.798799	29.211348	1588	3	303	45.56	848.63	1686.4	0	7.68	450.68	3459.17	45.11	7.72	7.56	701.17	5299.38	70.19	
17102026	800	26.798799	29.211348	1588	3	303	45.85	848.83	1686.4	0	7.67	443.24	3401.18	44.37	7.72	7.55	706.91	5339.05	70.76	
17102026	810	26.799350	29.209531	1605	4	323	46.61	848.46	1691.7	0	7.67	429.14	3291.32	42.96	7.71	7.62	446.9	3405.76	44.74	
17102026	810	26.799350	29.209531	1605	4	323	47.42	848.31	1697	0	7.63	432.56	3300.48	43.3	7.67	7.63	445.01	3393.55	44.55	
17102026	815	26.799398	29.209539	1610	0	292	48.04	848.51	1702.3	0	7.63	432.25	3298.95	43.27	7.68	7.62	457.52	3488.16	45.8	
17102026	817	26.799109	29.209433	1609	25	358	48.63	848.41	1702.3	0	7.63	435.85	3324.89	43.63	7.67	7.51	693.66	5209.35	69.44	
17102026	821	26.780199	29.228914	1623	65	85	49.51	846.61	1730.64	0	7.64	433.84	3312.68	43.43	7.68	0	0	0	0	
17102026	825	26.782374	29.268146	1614	67	15	50.51	848.45	1712.9	0	7.64	433.84	3312.68	43.43	7.68	0	0	0	0	
17102026	828	26.759013	29.273687	1599	45	14	51.17	849.37	1706.64	0	7.64	433.84	3312.68	43.43	7.68	7.64	433.84	3312.68	43.43	
17102026	830	26.758255	29.275217	1607	2	304	52.16	849.4	1711.9	0	7.64	433.84	3312.68	43.43	7.68	7.64	433.84	3312.68	43.43	

M8N GPS data and time data only recorded from 0750 UTC.

The ESP32-Cam, DDS and SA828 worked well, taking pics and sending CW and SSTV as programmed. The GY63 sensor temperature, pressure and calculated altitude data is also present in every SDcard record, however, whilst the INA226 measured voltage was always recorded, the measured current and power is missing in some records.











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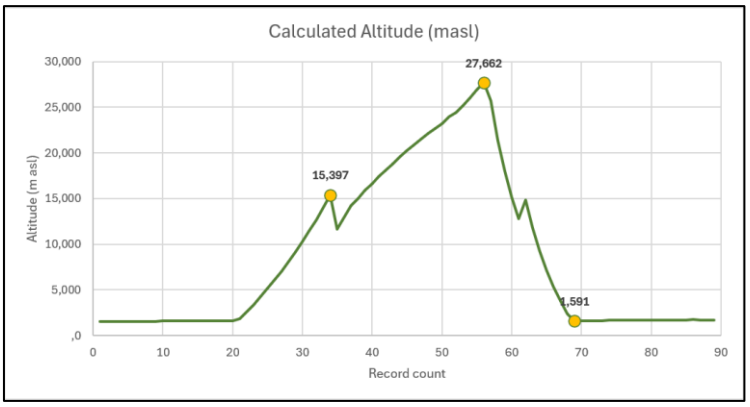
Data Graphs

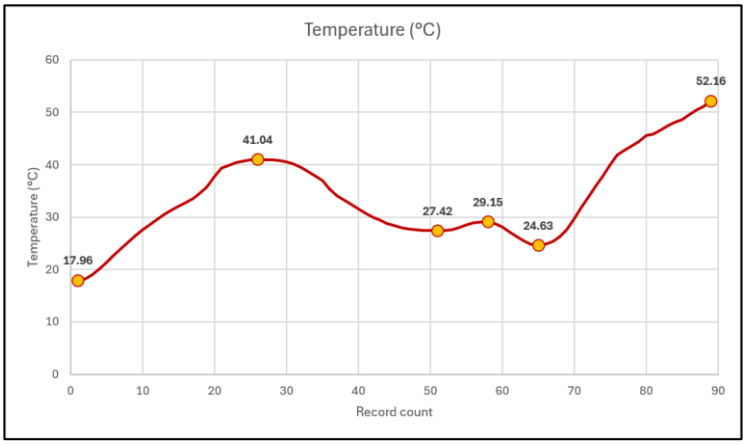
The GY63 sensor was in the middle of the cubesat and measured internal temperature, pressure and calculated altitude.

The altitude graph shows launch at record 20, maximum altitude at record 56 and landing at record 69.

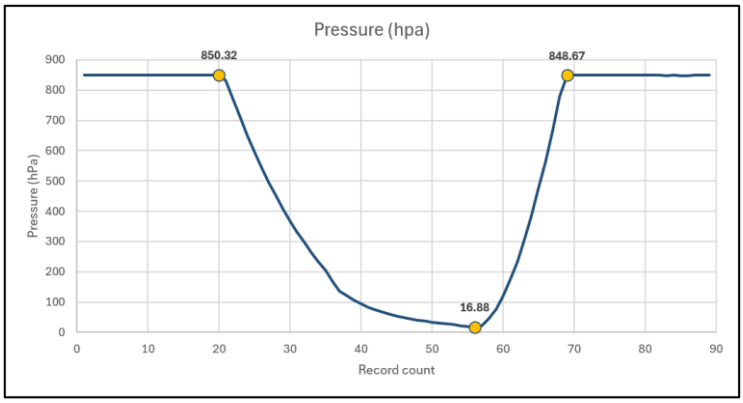
Why there is a glitch in the data between 12 and 15km is unknown.



The temperature graph shows the internal temperature increasing on the ground from switch-on prior to launch (corroborated by the BME280 on board 3), decreasing during flight as the outside temperature decreased, and increasing once it had landed and been bundled into the recovery vehicle.

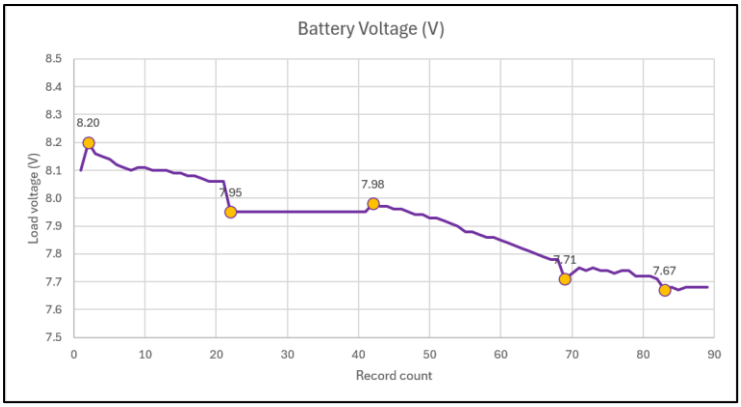


The pressure graph shows a similar albeit inverse pattern to the altitude graph, with pressure decreasing as the balloon ascended, reaching its lowest point at close to 16.9 hpa at maximum altitude and then increasing again as the balloon returned to earth.



The voltage of the two 21700 lithium batteries in series was tracked throughout the flight. The initial voltage reported was 8.2v, and the final voltage reported was 7.67v.

This implies the flight consumed ≈ 40% of the available battery capacity with ≈ 55% remaining post payload recovery.



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Thoughts for BACAR15

- **GPS Devices**
  - Find a better GPS for High Altitude Weather Balloon flights and make sure that any GPS is indeed in Flight mode. Ditch the M8N.
- **Command and Control**
  - Consider using a Meshtastic device for onboard command and control that does not have a built in GPS, such as the V3, as this will prevent CoCom limits triggering GPS/ UART lock-up and the loss of command-and-control functionality.
- **BACAR Launch**
  - Consider slowly feeding the payload train into the sky hand over hand along the entire train rather than just releasing the balloon when reaching the first payload in the train. May reduce violence of launch and triggering CoCom limits.



- **Data Recording**
  - Ensure data recording algorithms do not overwrite existing data records after a power down and subsequent switch on.
  - Possibly use a real-time clock as a fallback, as using GPS for time stamps when GPS fails means data loses its time accuracy.

Date	Time	GPSlatitude	GPSlongitude	GPSaltitud	GPSspeed(	GPSheadin	BMEtempei	BMEpressu	BMEaltitud	BMEhumidi	V_Normal(\	I_Normal(m	P_Normal(r	Shunt_Norr	Load_Norm	V_TX(V)	I_TX(mA)	P_TX(mW)	Shunt_TX(n	Load_TX(V)	Battery%
							27.52	848.67	1590.99	0	7.67	417.36	3201.29	41.78	7.71	7.56	697.51	5270.39	69.82	7.63	100
							29.64	848.56	1601.59	0	7.69	424.13	3260.8	42.46	7.73	7.58	689.27	5226.14	69	7.65	100
							31.86	848.62	1612.19	0	7.71	420.41	3239.44	42.08	7.75	7.6	691.35	5252.08	69.21	7.67	100
							33.93	848.57	1622.79	0	7.7	421.57	3247.07	42.2	7.74	7.6	678.65	5155.94	67.93	7.66	100
							35.87	848.57	1633.39	0	7.71	418.27	3222.66	41.87	7.75	7.6	691.47	5250.55	69.22	7.66	100
17102026	750	26.799840S	29.213404E	1602	0	302	37.74	848.53	1643.99	0	7.7	422.55	3253.17	42.3	7.74	7.6	695.01	5279.54	69.57	7.67	100
17102026	753	26.799870S	29.213399E	1617	2	145	40.01	848.53	1659.89	0	7.69	430.91	3315.74	43.14	7.74	0	0	0	0	0	0
17102026	755	26.799777S	29.213241E	1617	2	231	41.82	848.57	1665.2	0	7.69	419.07	3224.18	41.95	7.73	7.59	680.3	5162.05	68.1	7.66	100
17102026	755	26.799777S	29.213241E	1617	2	231	42.77	848.6	1670.5	0	7.7	432.56	3327.94	43.3	7.74	7.6	707.82	5378.72	70.86	7.67	100
17102026	800	26.798799S	29.211348E	1588	3	303	43.52	848.84	1675.8	0	7.7	400.15	3080.75	40.06	7.74	7.58	710.88	5387.88	71.16	7.65	100
17102026	800	26.798799S	29.211348E	1588	3	303	44.4	848.47	1681.1	0	7.68	441.53	3392.03	44.2	7.72	7.54	701.11	5285.64	70.19	7.61	100
17102026	800	26.798799S	29.211348E	1588	3	303	45.56	848.63	1686.4	0	7.68	450.68	3459.17	45.11	7.72	7.56	701.17	5299.38	70.19	7.63	100
17102026	800	26.798799S	29.211348E	1588	3	303	45.85	848.83	1686.4	0	7.67	443.24	3401.18	44.37	7.72	7.55	706.91	5339.05	70.76	7.62	100
17102026	810	26.799350S	29.209531E	1605	4	323	46.61	848.46	1691.7	0	7.67	429.14	3291.32	42.96	7.71	7.62	446.9	3405.76	44.74	7.66	100
17102026	810	26.799350S	29.209531E	1605	4	323	47.42	848.31	1697	0	7.63	432.56	3300.48	43.3	7.67	7.63	445.01	3393.55	44.55	7.67	100

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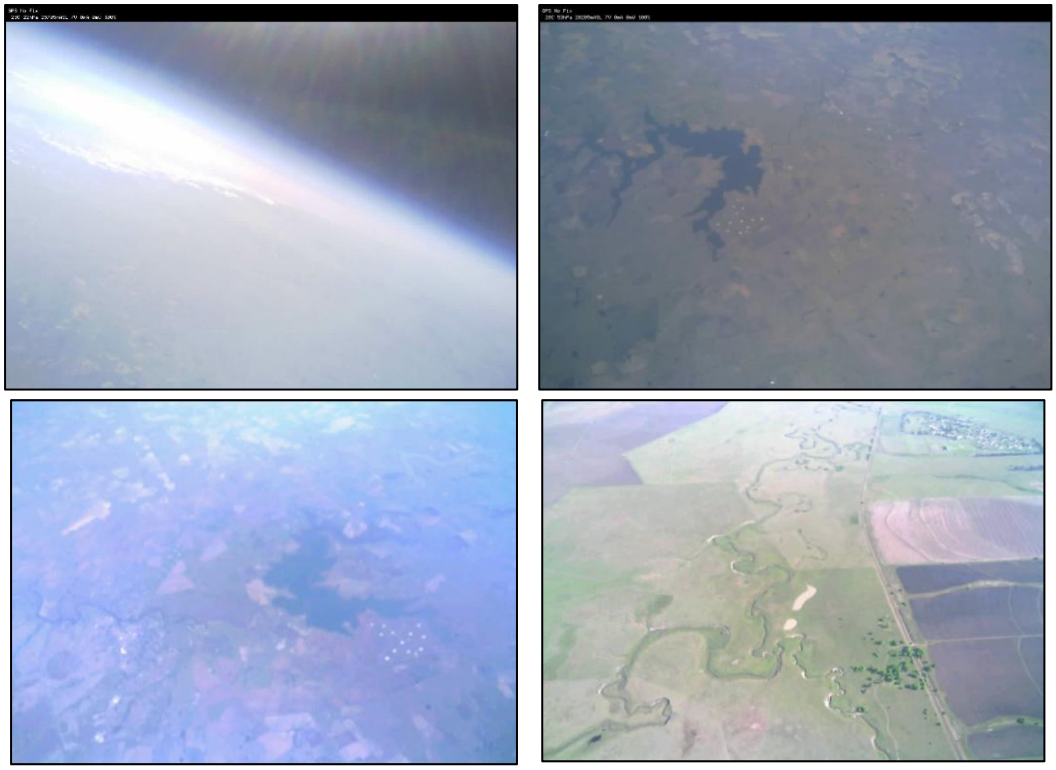
ZS6STN Payload and Flight Analysis

- **Camera imaging**
  - Cameras were aimed 45° downwards from the horizontal, which makes images more susceptible to haze as evident in many of the high-altitude ground images. Consider pointing cameras almost straight down to minimise image haze.
  - Consider the use of a camera lens shroud to minimise glare.



- **Power management**
  - The two 21700 lithium batteries in series, and the buck converter supplying 5v to the payload worked well. There was more than enough power for the flight with a healthy reserve, even with all the tech onboard the cubesat.
  - The Meshtastic node was not transmitting as often as it should have, but even allowing for this there is enough power for a longer flight.
  - As the two 21700 batteries weigh ≈ 240g, perhaps downgrading to two 18650's will save weight and still provide sufficient power.
  - The internal temperature never fell into dangerous territory to affect the lithium batteries.

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ZS6STN Payload and Flight Analysis

Conclusion

This was the first flight of the circularly polarised UHF antenna system, the twin 21700 lithium battery power pack, the Xiao S3 and the Meshtastic node, and even though the ZS6STN payload did not function 100% as planned, a lot was learnt and a lot of data obtained.

BACAR14 was an exciting and extremely enjoyable event. The number of very interesting payloads and the enthusiasm from all was contagious, motivating, and encouraging further experimentation, learning and improvement.

A big thank you to Christo, Gert and all in the Secunda ARC for managing the event, all the payload builders and flyers for their energy and enthusiasm, and especially to the farmer, wife and son team who let us use their land, came along to spend time with us, setup a breakfast station, cooked us boerewors hotdogs and gave us coffee all at their own cost. This was absolutely unexpected and simply amazing, making the day that much more special.



See you in 2027 at BACAR15. 73 de ZS6Hi

Some of the other interesting payloads.

