Report Submitted: 2018-07-03 at 08:30
Report Written by: J[redacted] Hong

[redacted] sUAS Crash into River – Preliminary Report

Overview

Date: 2018-06-30

Incident Time: 06:15

Location: Metal Trestle on White River – Arkansas

Type of Incident: In-Flight Power Failure

Injuries: None

Damage to Property: None

Damage to sUAS: Full loss of sUA, 64GB U3 SD MicroSD Card, Red Strobe Light

Total Cost of Damage: $1500

UAS Operation Details

RPIC: J[redacted] Hong
Certifications: 107 & Night Trained

VO: Y[redacted] A[redacted]
Certifications: Night Trained

sUAS Type: Phantom 4 Pro **FAA Registration Number:** [redacted] **DJI Serial #:** [redacted]
Total Hours on Airframe: Approx. 10 hours

Operation Type: Monitoring and Video

Planned Sorties: 10 **Conducted Sorties:** 4 **Batteries Consumed:** 3

Location of Flight Crew: On Trestle – Pier One Shaft Four during the crash

Witnesses: [redacted]

Sortie and battery order:

Sortie #	Battery #	Battery Start	Battery End	Other Details
1	Battery #3	99%	27%	N/A
2	Battery #1	99%	70%	Landed early because VO needed to assist with shooting elevations.
3	Battery #2	92%	22%	UAS was kept on for 10 minutes prior to launch - RPIC wanted to be ready to launch as soon as VO returned.
4	Battery #1	68%	26%	RPIC used partially depleted battery from Sortie #2 because he did not expect the last sortie to take over 10 minutes. Also, the Energen Drone Charger can only charge three batteries at a time so it was easier to deplete three than partially deplete two of four batteries that would otherwise be used.

Timeline of Events:

- 03:30* RPIC prepares aircraft –fasten propellers, check power, attach strobe anti-collision lighting, landing zone assessment.
- 04:10: VO Briefing and Parsons Night Training on visual illusions per the FAA's requirement
- 04:32: Sortie #1 (https://app.airdata.com/main?share=WAGLTk)
    - Encountered compass and IMU errors
    - Home Point was established mid-flight
- 05:09 Sortie #2 (https://app.airdata.com/main?share=pALdzD)
    - Encountered same problems as first one
    - VO needed to go shoot elevations halfway through – RPIC landed UAS
    - Landed at 70% Batt
- 05:42 Sortie #3 (https://app.airdata.com/main?share=nZnrxi)
        - RPIC turns on aircraft to ensure flight readiness when VO returns
- 06:05 Sortie #4 (https://app.airdata.com/main?share=uTjBfz)
- 06:15 sUAS drops into water
    - Less than a second prior, sUAS drifts to the south without RPIC input – NOTE
    - Flight screen displays no video transmission prior to crash
- 06:19 Rescue Mission Launched: Water recovery of strobe light
    - J. Hong, [redacted]
    - Boarded boat captained by [redacted]
- 06:26 – UAS water recovery mission called off
- 06:39 – J. Hong took screenshot of iPad screen

Preliminary Review:

Overview: sUAS had an in-flight power failure and crashed into the river.

Root Cause: Potentially Hardware/Software Error onboard sUAS

Potential Causes (Listed in no particular order)**:**

1. Battery: Unseated Battery by User Error – Unlikely
2. Battery: Short Circuit, Cell Failure, other unobserved damages – Somewhat possible
3. Aircraft Hardware: IMU, Compass (In Flight & On Ground Errors) – Unusual Error to Receive – Highly Possible
4. RF Interference: High RF Environment – Marine Radio, Site Radio, CB Radio, Cellular RF - Possible
5. Aircraft Software: Fatal In-Flight Software Crash – Highly Possible
6. Weather: High Humidity – Possible

Important Facts to Note:

Environmental Conditions

1. RPIC has never launched from the trestle before
2. Trestle was magnetic
3. The operating environment had lots of metal (trestle, highway, cranes, pump truck) and possible RF interference coming from cell phones, marine radio (tugboat), site radios, CB radios (from highway).
4. Visible condensation was building up on the sUAS while it was on the ground

UAS Conditions

5. Multiple in-flight compass errors were experienced
6. Video transmission never blanked out in any of the sorties
7. Battery (Battery #1, Serial # 0DQAE[redacted]) was involved in the 2018-06-26 Fixed Object Strike and was cleared by RPIC after thorough inspection – however, no test flight was conducted, only a visual inspection, latch inspection, and a battery health check using the DJI Go 4 App.
8. sUAS moved a distance, up to a few feet, (need to use Lat/Long .000001 increments to determine the distance from the flight logs) prior the losing power and crashing – without pilot input.
9. Home point could not be determined while on the ground and GPS lock was established eventually while sUAS was in the air.
10. Top mounted strobe light attachment separated after the sUA crashed into the water – the attachment was mounted with the Scotch Extreme Fasters which mounted to a piece of packing tape that was mounted to the airframe.

Non-Contributing Factors:

- Pilot Fatigue
    - Saturday: 2 hr 32 min sleep
    - Friday: 3 hr 33 min sleep
    - Thursday: 5hr 36 min sleep + 1 hr nap
    - RPIC did not feel tired and does not believe that even with possible reduced decision-making ability that he could have caused the crash in the manner in which it occurred.
- Night/Dawn Flying
    - Risk factors increase because of visual perceptions, however, the crash occurred during daylight.

These non-contributing factors are noted to ensure report is as comprehensive as possible.

Preliminary Conclusions:

Based on the facts presented, it appears that the sUAS may have encountered a hardware and or software error and caused the UAS to drift without pilot input, cut power, and freefall into the river. The drift can be caused by the Inertial Measurement Unit (IMU) which consists of gyroscopes and accelerometers that keep the aircraft stable while in flight.

The preliminary investigation is unable to pinpoint the cause of the hardware/software error. Possible contributing factors include high RF interference that could have jammed or damaged the onboard electronics, high humidity, and or magnetic interference from the trestle.

Potential Cause #1 – Unseated Battery

Theory: J. Hong may not have fully seat battery in Phantom 4 Pro and latched only the top latch of the battery into the aircraft. This could cause a crash if the battery shifts from the forces of flight and disconnect. The result would be immediate loss of power and cause the action witnessed by the people on scene.

Oftentimes, new sUAS pilots do not insert the battery fully into the compartment. Pilot fatigue and complacency could also cause this to occur.

Relevant Facts:

7. Battery (Battery #1, Serial # 0DQAE[redacted]) was involved in the 2018-06-26 Fixed Object Strike and was cleared by RPIC after thorough inspection – however, no test flight was conducted, only a visual inspection, latch inspection, and a battery health check using the DJI Go 4 App.

If the battery was damaged externally during the crash, one or both of the latches could have weakened and caused the battery to become unseated. J. Hong did not notice any damages and any external damages would be inconsistent with the damages incurred during the 2018-06-26 Fixed Object Strike.

Theory Possibility: unlikely – The RPIC cannot prove that the battery did become unseated during the flight. However, given the facts, it appears unlikely that the in-flight power failure occurred from a loose battery. The sUA had operated for 10 minutes doing a variety of maneuvers, the last of which was very gentle. The battery most likely would not have been unseated during this maneuver.

Fact #8 does not line up with this theory: A sudden loss in power would not cause the sUAS to move up to a few feet south, without pilot input, while maintaining GPS lock and altitude.

SMS Best Practices to ensure unseated battery does not occur:

- When ensuring battery is seated:
    - Use both thumbs to push the battery into the compartment after seating the battery using the "one hand on drone, one hand pushing battery latch" method.
    - Do a tug check of the battery, then flip the drone over and do a visual inspection of the bottom latch.
    - Have another flight crew member double check the battery

Potential Cause #2: Battery Failure – Short Circuit, Cell Failure, Battery Protection Switched

Theory: Battery experienced a shutdown for one reason or another and caused the UAS to lose power and crash. Possible causes include short circuiting, simultaneous cell failure, or battery protection switched. At the time of this report, J. Hong is unfamiliar with the Phantom 4 Pro Smart Battery protection system.

Relevant Facts: See "Additional Relevant Facts" for *Potential Cause #1.*

Theory Possibility: Somewhat Possible. Typically, a faulty battery will show signs of rapid power loss, not a sudden shutdown. A sudden shutdown of the battery would be consistent with the cutting out of the motors which caused the sUA to freefall into the river.

Fact #7 does not line up with this theory: A sudden loss in power would not cause the sUAS to move up to a few feet south, without pilot input, while maintaining GPS lock and altitude. However, if the battery was faulty and caused a spike in the voltage/amperage, then the onboard electronics could have been fried and caused the resulting crash. Preliminary investigation does not cover this scenario in depth.

SMS Best Practices to ensure unseated battery does not occur:

- Ensure battery is healthy by using:
    - Using DJI Go 4 app to check battery and cell health prior to every flight
    - Use AirData to monitor battery performance after each operation – check for cell voltage and amperage deviations that are inconsistent with the stick inputs.
    - Visually check each battery prior to every operation
    - Note any shortened flight times and determine the reason (altitude, wind, etc.)
- If a crash does occur:
    - Inspect the battery thoroughly
    - Carefully charge
    - Use DJI Go 4 App to confirm battery cell voltages
    - Conduct a test flight from 100% - 20% battery at an altitude of no more than 3' AGL

Potential Cause #3 – Hardware Errors: IMU (Inertial Measurement Unit) and Compass Error

Theory: Hardware failures caused the sUAS to shut down and freefall into the river. The facts and the sequence of events could support this theory.

Relevant Facts:

2. Trestle was magnetic
5. Multiple in-flight compass errors were experienced
8. sUAS moved a distance, up to a few feet, (need to use Lat/Long .000001 increments to determine the distance from the flight logs) prior the losing power and crashing – without pilot input
9. Home point could not be determined while on the ground and GPS lock was established eventually while sUAS was in the air.

Theory Possibility: Highly Possible – The failure of the IMU could be a cause of the drift of the aircraft prior to the crash. No errors were indicated by the telemetry data, but this could be a possibility.

The magnetic trestle caused many compass errors for the sUAS which included in-flight compass errors. This is rare in most environments. However, the RPIC has never launched from a magnetic surface before and cannot conclusively say that the trestle was the issue. The aircraft behaved normally during the pre-operation maintenance check conducted in the White River Field Office on 2018-06-28 at 14:28 p.m. which lasted a total of 15 seconds.

Test: Follow Up: Ask [redacted] Field Engineer) to test GPS from the same iPad and his cell phone while standing on the trestle – see if the GPS on the electronics works.

- Reason: Home Point not acquired for any of the flights from the trestle. If these work without issue, then something could have been happening with the sUAS.

SMS Best Practices:

- Change locations if launching from a magnetic surface
    - Use a VO at the vantage point and use good communication to ensure obstacles are avoided
- Hand Launch/Hand Catch the sUAS to avoid contact with magnetic surface
        - Required PPE would include the addition of gloves for the crew member hand launching and hand catching the sUA.

Potential Cause #4 – RF Interference: High RF Environment – Marine Radio, Site Radio, CB Radio, Cellular RF

Theory: Radio frequency interference could have jammed the UAS and caused it to crash.

Relevant Facts:

1. RPIC has never launched from the trestle before
2. Trestle was magnetic
3. The operating environment had lots of metal (trestle, highway, cranes, pump truck) and possible RF interference coming from cell phones, marine radio (tugboat), site radios, CB radios (from highway).
5. Multiple in-flight compass errors were experienced
9. Home point could not be determined while on the ground and GPS lock was established eventually while sUAS was in the air.

Theory Possibility: Possible – The Phantom 4 Pro operates on 2.400-2.483 GHz. To determine if RF interference was an issue, the investigation can turn to documenting each of the radio frequencies used on site.

However, the sUAS did not lose video transmission or control response until the incident occurred. This means that either RF did not play an important role in the crash or that there was a very powerful transmission that caused the crash to occur. The most likely culprit for that powerful transmission would be the marine radio. This can be checked by speaking with the Tug Boat Captain to see if any transmissions were made during that time period. Even with that data, the results may be inconclusive. A SME indicated that sUAS due to marine radio interference has been documented before.

Another possibility, although unlikely, is someone had a RF jammer and jammed the sUA. This however, may not explain the drift of the sUA prior to the crash.

SMS Best Practices:

- Determine all frequencies used on site and consult someone with RF knowledge to determine if RF interference will be a major issue
- Use a RF analyzer to analyze the RF in the area – this method is regarded as highly inaccurate by sUAS subject matter experts, including those at the [redacted]
- Use DJI Go 4 app's video frequency selector to determine the best channel within the 2.4/5.8 band to use.

Potential Cause #5 – Aircraft Software: Fatal In-Flight Software Crash

Theory: Some type of software error caused a systematic shutdown of the sUAS.

Relevant Facts:

5. Multiple in-flight compass errors were experienced
8. sUAS moved a distance, up to a few feet, (need to use Lat/Long .000001 increments to determine the distance from the flight logs) prior the losing power and crashing – without pilot input
9. Home point could not be determined while on the ground and GPS lock was established eventually while sUAS was in the air.

Theory Possibility: Highly Possible – The sUAS shut down without any warning from the software indicating that a problem was occurring. Throughout the flight, there were also many errors that could be attributed to other factors but could also be what crashed the UAS. The manufacturer is best able to determine if any bugs in the software could cause a system shutdown.

SMS Best Practices:

- Keep software up to date unless if there is trustworthy literature that advises against it.

Potential Cause #6 – Weather Related: High Humidity

Theory: High humidity may have compromised the electronics on the aircraft and caused a series of hardware and or software errors leading to crash. Condensation inside the sUAS could cause short circuits or other errors.

Relevant Facts:

4. Visible condensation was building up on the sUAS while it was on the ground

All batteries were stored inside the Phantom 4 Pro case when not in use. The case is not humidity proof and is not sealed.

Theory Possibility: Possible – The effects of water damage to electronics however is somewhat unpredictable and cannot be proven because the sUAS was not recovered and it was immersed in water. Previous flights in high humidity have been conducted on the project site without sUAS incidents. The humidity percentage was listed as 94% on Kittyhawk and 95% on AirData. Perhaps multiple exposures to high humidity could have led to the fatal error.

SMS Best Practices:

- Keep sUAS in vehicle for as long as possible prior to launch.
- Air out the sUAS in front of fan after every operation
- Keep multiple silica gel packets in vehicle
- Inspect circuit boards visible from the side every week

Other Best Practices:

- Multiple Memory Cards: If RPIC had swapped out memory cards after every sortie, most of the data would have been preserved. Perhaps purchasing multiple 32 GB memory cards would be provide the best combination of capacity and cost.
    - RPIC did not switch cards because the other 64 and 16 GB cards had slightly lower read/write speed although they would have accomplished the task just as well.
    - Minimum of three 32 GB microSD cards would be a good start
- Immediate download of SD Card prior to next sortie
    - RPIC had time and the equipment on site to download the data from the microSD Card but did not do so because he did not think about it and it would have been a long trek to the vehicle and back, especially for back to back operations. The computer would be exposed to high humidity if not kept in the vehicle.
- Drone Recovery System: Have a small device with a bobber and fishing line that can deploy when a sUAS gets submerged. Then the recovery team could pull the sUAS out of the water and salvage the memory card.
- Risk mitigation strategies:
    - If flying near magnetic structures, RPIC should change location and have VO stand at the vantage point.
        - Good communication method must be established prior.
        - For this particular mission, RPIC did not change location because the spot provided an excellent vantage point of the sUAS operation.
    - Use zooming camera lens for gathering close-up shots of subject when there is high interference near the surface
        - If zooming lenses are not an option, RPIC must accept the limitation and fly from further away.
- Batteries:
    - Launching each sortie with a fresh battery could be a best practice. Some sUAS pilots will not fly two sorties on one battery because there is a rumor that fresh batteries will last longer. There may be data on this topic but it is not covered in the scope of this report.

SME References:

[redacted] – [redacted] DEM UAS Coordinator – Pilot

[redacted] – Electrical Engineer

[redacted] – Systems Engineer

[redacted] Vice Presidents

[redacted] – Electrical Engineer

Additions to the original report 1:

Memo: GNSS Location not established for Ground Control Station (GCS)

RE: 2018-06-30 sUAS Crash - Preliminary Report

During the entirety of the sUAS operation on June 30th, 2018, the location of the ground control station was not able to be established with the iPad. When the RPIC clicked the icon for set home location as transmitter location, the DJI GO 4 app displayed that it could not complete the action. The home location could only be established by the sUAS.

J. Hong wondered if the iPad GPS was the cause of the transmitter home point error and asked [redacted] go back on Tuesday, July 3rd, 2018 and conduct an isolated retest the initial observation.

[redacted] conducted the test using his cell phone and the iPad. When he walked onto the trestle and used the iPad, the iPad could not determine his location. When he used his cell phone, he was able to acquire a GPS location both on airplane mode and with 4G LTE active. The only difference between the two was that airplane mode only displayed a blue dot and not the base map.

On Thursday, July 5th, 2018, [redacted] tested out the iPad from the field office located at [redacted], AR. He observed that the GPS was able to locate his position without wi-fi or 4G LTE.

Based on these facts, it is reasonable to conclude that the trestle was the cause of GNSS interference for both the sUAS and the iPad. It is however, not possible based on this conclusion alone to determine if the interference could have caused the sUAS to crash.

This memo is to be amended to the initial report. It supplements the original information with additional details and includes follow-up testing of the noted observations.

Memo Submitted on 2018-07-05 by J[redacted] Hong

Additions to the original report 2:

Memo: Strobe assembly detachment from sUAS

RE: 2018-06-30 sUAS Crash - Preliminary Report

The strobe (anti-collision light) assembly consisted of the following:

- 1x piece of clear packing tape – 3M Heavy Duty (attached to airframe)
- 2x Scotch Extreme Fasteners (attached on strobe and on clear packing tape)
- 1x STROBON Cree Standalone White LED
- 1x Clear/Diffused White Plastic Cap from Bug Repellent & Sunscreen bottle
- 1x piece of string

The strobe assembly was created to allow for better visibility of the sUAS during the day while also meeting the nighttime operation requirements per the Parsons Daylight Operations Waiver. The diffuser cap radiated the light 360° and was secured to the strobe light through friction and a security string. The string was tied in on either side of the base of the cap and then placed between the strobe light's fastener and the airframe's fastener. The design allowed the cap to be secured to the airframe when the RPIC was turning on or off the A/C lighting and in case it came loose from the light. The string prevented the cap from contacting the propellers and or falling to the ground.

After the sUAS had the in-flight power failure and fell into the river, the strobe light assembly floated to the surface. The RPIC, VO, and deckhand went out and recovered the strobe light assembly. The RPIC noted the following:

- The entire strobe light assembly (excluding the packing tape) detached from the airframe and floated to the surface.
- The STROBON Cree Standalone White LED was wedged tightly into the Diffuser Cap.
    - This means that the strobe light separated from the extreme fastener that was mounted to the airframe
- The extreme fastener that was mounted to the airframe was held by the security string.

J. Hong finds noteworthy that the extreme fastener separated from the packing tape and airframe. Both adhesive units were applied directly to the mounting surfaces. Water causing the separation of the units within 20 seconds of water contact seems unlikely. High humidity could be a contributing factor but without further testing, it is unknown why the extreme fastener separated so easily from the airframe.

This memo is to be amended to the initial report. It supplements the original information with additional details about the noted observations.

Memo Submitted on 2018-07-05 by J[redacted] Hong

Additions to the original report 3:

Memo: Variation between AirData and DJI Flight Log Home Locations

RE: 2018-06-30 sUAS Crash - Preliminary Report

There is a difference between the AirData flight Log and DJI Flight Log Home Locations.

After reviewing the AirData log, I noticed that the DJI Log did not start until 53 seconds into the flight where it recorded the home point. This is interesting because the DJI Flight Log and the AirData telemetry all comes from the same source.

I had not noticed this issue prior to this incident and will ask [redacted] or [redacted] to send me the screen recording of the other flights of the day and see if the same issue occurred.

Memo Submitted on 2018-07-03 by J[redacted] Hong