FAA/Skyward Memorandum of Agreement (MOA) Bimonthly Report

November 2021*

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*Redactions and corrections made by Verizon February 2024

1. Table of Contents

2. Revision History

Revision	Date	Description of Revision
1.0	11/1/2021	Initial report

3. Overview of Flight Campaigns

Flight campaign start date: August 2021
Flight campaign completion date: August 2021
Total quantity of flight hours: 10.3 hrs
Total quantity of flights: 12
Percentage of time with full C2 Link Connection: 99.961%
Percentage of time with full Cellular Network RF Environment: 97.30%
Uncrewed aircraft OEM: Censys Technologies
Uncrewed aircraft model: Sentaero VTOL FW LTE

Figure 3.1 Sentaero VTOL FW LTE

Daytona, FL Photo credit: Tanmay Naik of Censys Technologies

4. Overview of Analysis Method

4.1 Altitude

For statistical reporting, only those logs corresponding to aircraft altitude > 5m are considered in order to filter out ground-based logs. Total quantity of flight hours includes all logged time, which may include pre-flight, launch, mission execution and landing.

4.2 Full Connectivity

In order to accurately represent the impact of the RF environment and cellular connection availability on the performance of the C2 link, the concept of full connectivity is separated into two metrics: C2 link connection and cellular network RF environment. A degradation of the cellular network RF environment is expected to cause a degradation in the C2 link connectivity statistics.

Percentage of time with a “full C2 link connection” is defined as the amount of time that the UA is connected to the cellular network for command and control as represented by successful heartbeat messages logged at the same frequency as modem parameters, divided by the total quantity of opportunities to report heartbeats while the UA is in flight and using cellular for the C2 link.

Percentage of time with a “full cellular network RF environment” is defined as the amount of time that the onboard UE reports sufficient RF parameters such as RSRP and RSRQ, divided by the total quantity of opportunities to report the onboard UE RF parameters.

5. Operational Area and Environment

5.1 DOEFLT-124

Operation ID: DOEFLT-124
Operational area name: Volusia Daytona Beach Florida
Environment: Urbanized Area
Total quantity of flight hours: 10.08 hrs
Total quantity of flights: 10
Average altitude: 79m (50th Percentile)
Maximum altitude: 131m (99th percentile 121m)
Operational Risk Assessment (ORA): Moderate
Objective: Baseline Mobile Field/Area Survey

Figure 5.1.1 Flight routes in Volusia Daytona Beach, FL

5.2 DOEFLT-125

Operation ID: DOEFLT-125
Operational area name: Panama City Florida
Environment: Urbanized Area
Total quantity of flight hours: 0.219hrs
Total quantity of flights: 2
Average altitude: 104m (50th Percentile)
Maximum altitude: 125m (99th Percentile is 123m)
Operational Risk Assessment (ORA): Moderate
Objective: Baseline Local Infrastructure inspection, long linear inspection

Figure 5.2.1 Flight route in Panama City FL

6. UAS Configuration and Architecture

6.1 Reporting and Polling Frequency

An effort is made with the UAS OEM to gather data at the highest frequency possible from the subsystems on the UA and CS. Reporting and polling frequency is dependent on the UAS architecture and is therefore inconsistent amongst various UAS OEMs.

For the Sentaero VTOL FW LTE, recording frequency is approximately once every 3.58 seconds.

6.2 C2 Network Architecture

Round trip latency is measured (UA>Verizon Network [redacted] >CS>Verizon Network [redacted] >UA). Regardless of location of

flight, all C2 data traffic is going through the Verizon core network site [redacted]

[redacted]

6.3 UAS Performance

The Average Cruise Speed is reported in the UAS specifications sheet by the UAS OEM.

Average Cruise Speed: 73 kph

7. Operational Environments

Environmental definitions come from the Census Bureau Urban and Rural classification. For more information please visit https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural/2000-urban-rural.html.

Percentage of time flown in the following classifications:
Urbanized Area: 100%
Urban Cluster: 0%
Rural: 0%

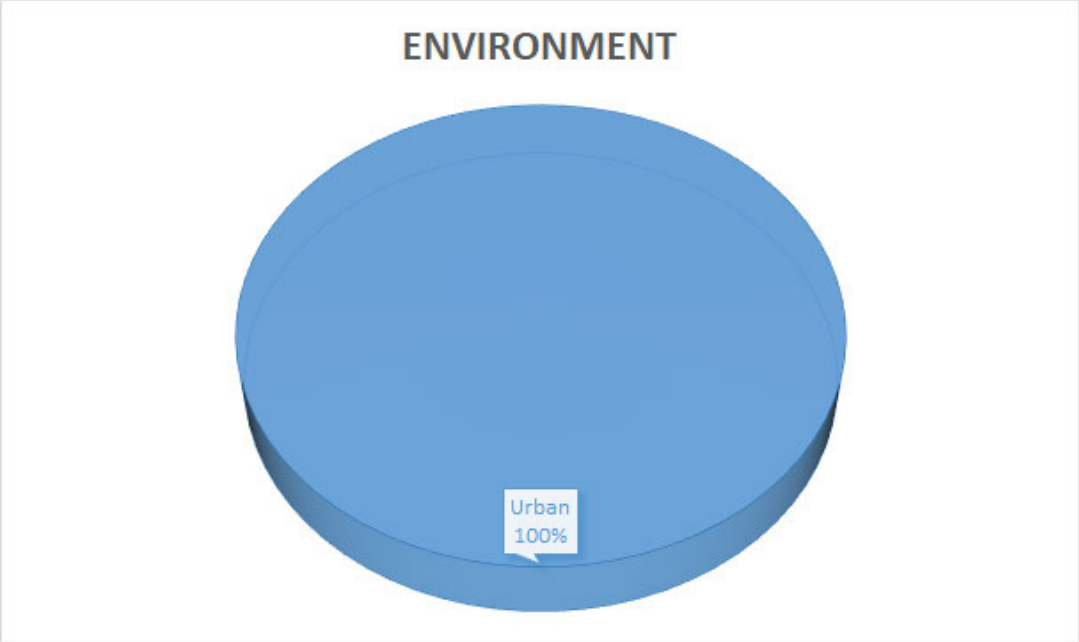

Figure 7.1 Environment Pie Chart

8. Cellular Metrics

8.1 Cellular Carriers and Bands

There were 3 bands utilized during the flight campaign. Band 13 was utilized most often. The cellular link was used for C2 for the entirety of the flight campaign. Each aircraft used one SIM card provided by Verizon.

Band	Name	Bandwidth (MHz)	Mode	Downlink Frequency (MHz)		
				Low	Middle	High
2	1900 PCS	60	FDD	1930	1960	1990
5*	850	25	FDD	869	881.5	894
13	700 c	10	FDD	746	751	756

Table 8.1.1 Band and Frequency

*This incident is covered under Section 9 Anomalies and Accidents.

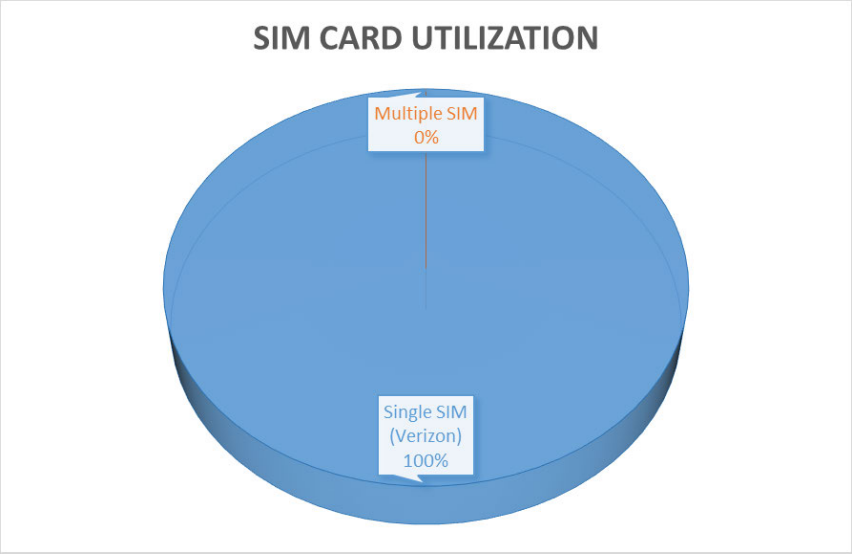

Figure 8.1.1 SIM Card Utilization Chart

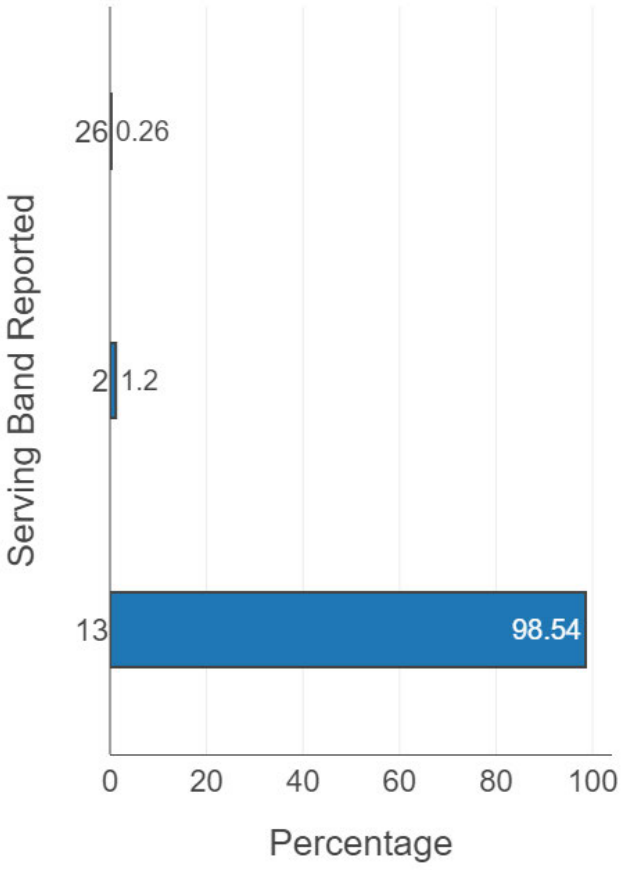

Figure 8.1.2 Band Utilization Chart

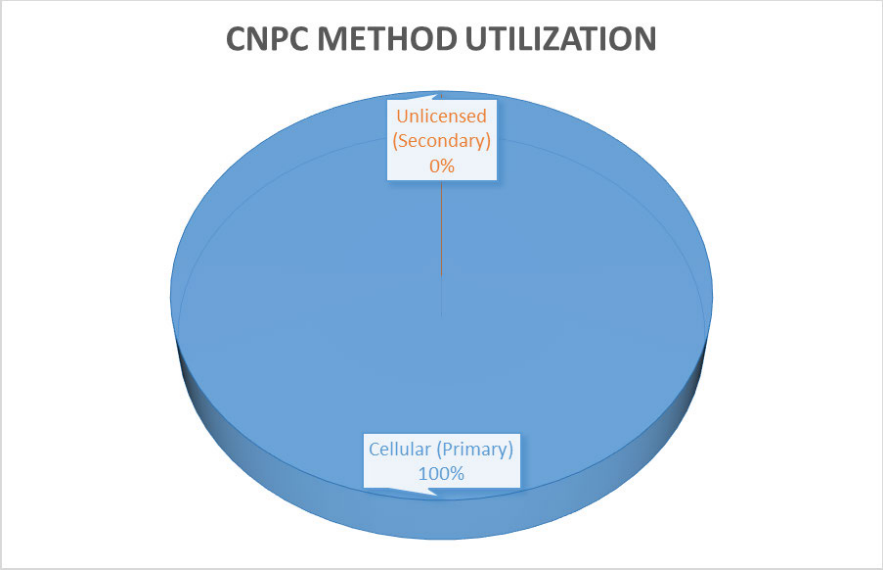

Figure 8.1.3 CNPC Method Utilization

8.2 Altitude

Altitude reporting mechanism: Barometric altitude. Calibrated at the takeoff location.
Maximum altitude: 131m
Average altitude: 79m (50th Percentile)
Percentage of flight time at or below 122m altitude: 99.72%

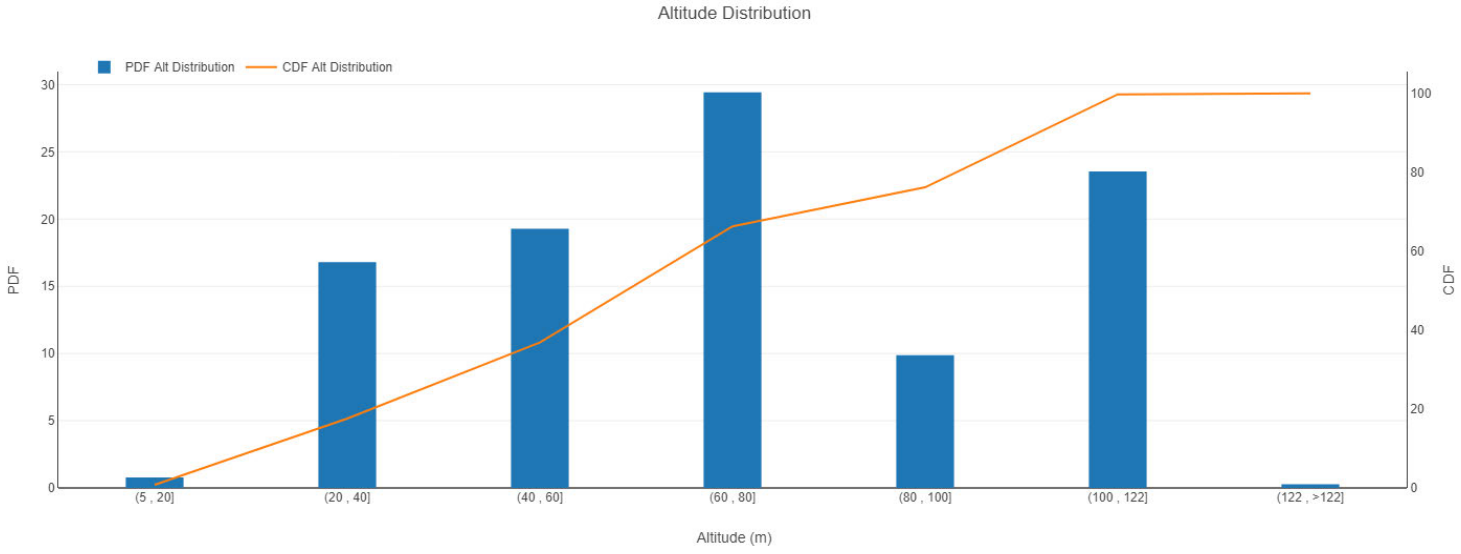

Figure 8.2.1 Operational Altitude Distribution Chart

Metric	Altitude (m)

5th Percentile	39
50th percentile	79
99th Percentile	121
Max	131

Table 8.2.2 Operational Altitude Distribution Table

8.3 Distance

The “distance between the CS and UA” is defined as the calculated linear distance. This parameter is commonly of interest when analyzing UAS data due to the use of line of sight radios connecting the CS and UA. In this case the UA is connected to the CS via the cellular network, therefore the “distance between the CS and UA” does not depict the traveled distance of the communication link. See Section 6.2 for a description of the network architecture and the traveled distance of the communication link.

Average distance between UA and CS: 411m
Maximum distance between UA and CS: 6271m
The CS was stationary at all times and the take-off and landing location is in close proximity to the CS.

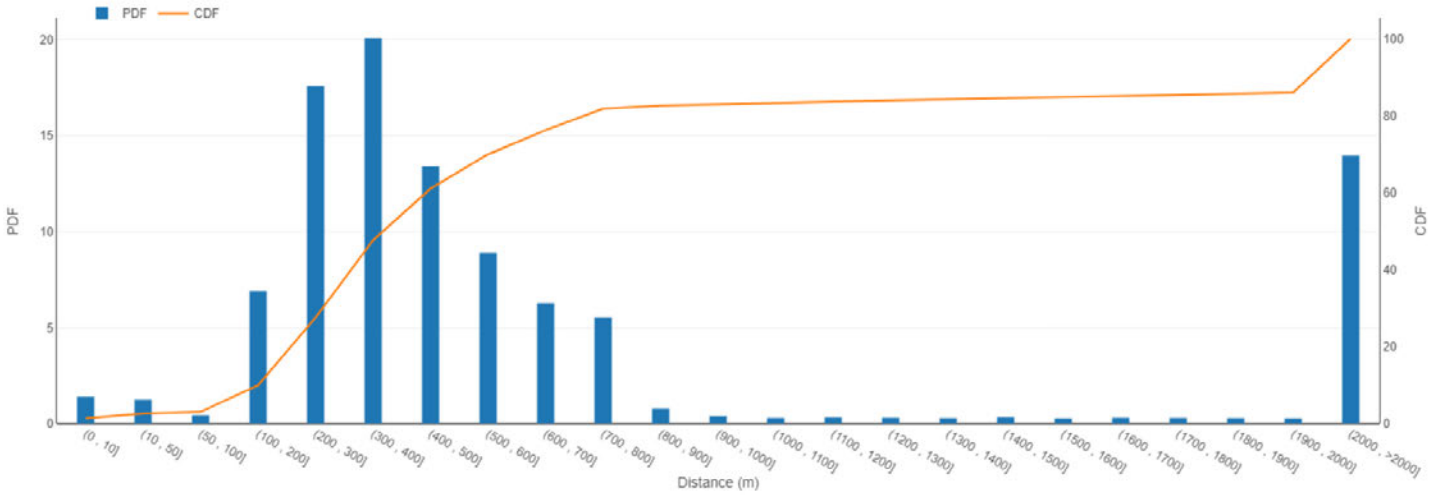

Figure 8.3.1 CS to UA Distance Distribution Graph

Metric	Linear distance between UA & CS (m)
5th Percentile	148
50th percentile	411
95th Percentile	5,072
Max	6,271

Table 8.3.1 CS to UA Distance Table

8.4 Control Mode

Percentage of time in automatic control mode (barometric altitude > 5m): 96.94%

Remainder of flight time the UA was in a combination of semi-manual and other modes. (https://ardupilot.org/plane/docs/quadplane-flight-modes.html)

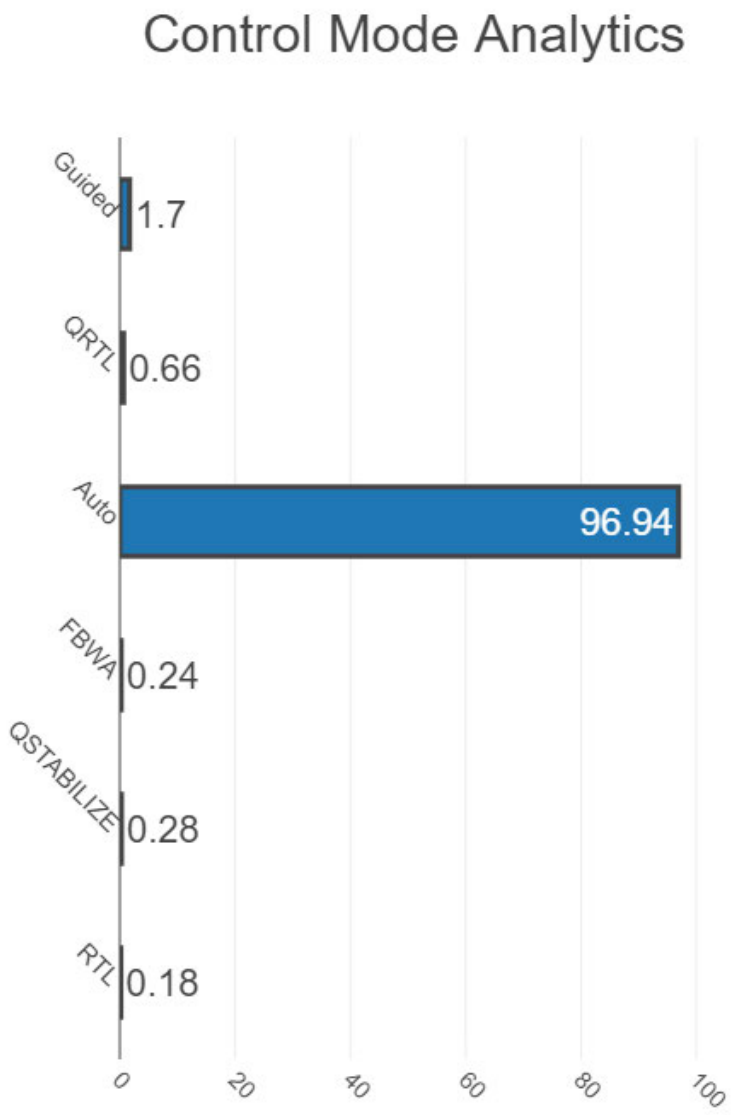

Figure 8.4.1 UA Control Mode Graph

8.5 Latency

Latency 99.9th percentile: 561ms

95th percentile: 307ms
Maximum latency: 758ms

Refer to Section 6.2 C2 Network Architecture for a description of the latency measurement.

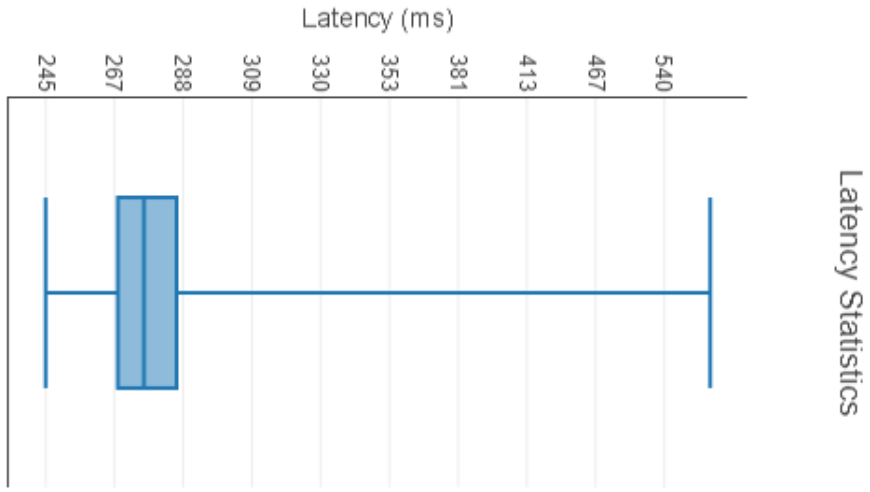

Figure 8.5.1 Latency Box and Whisker Plot

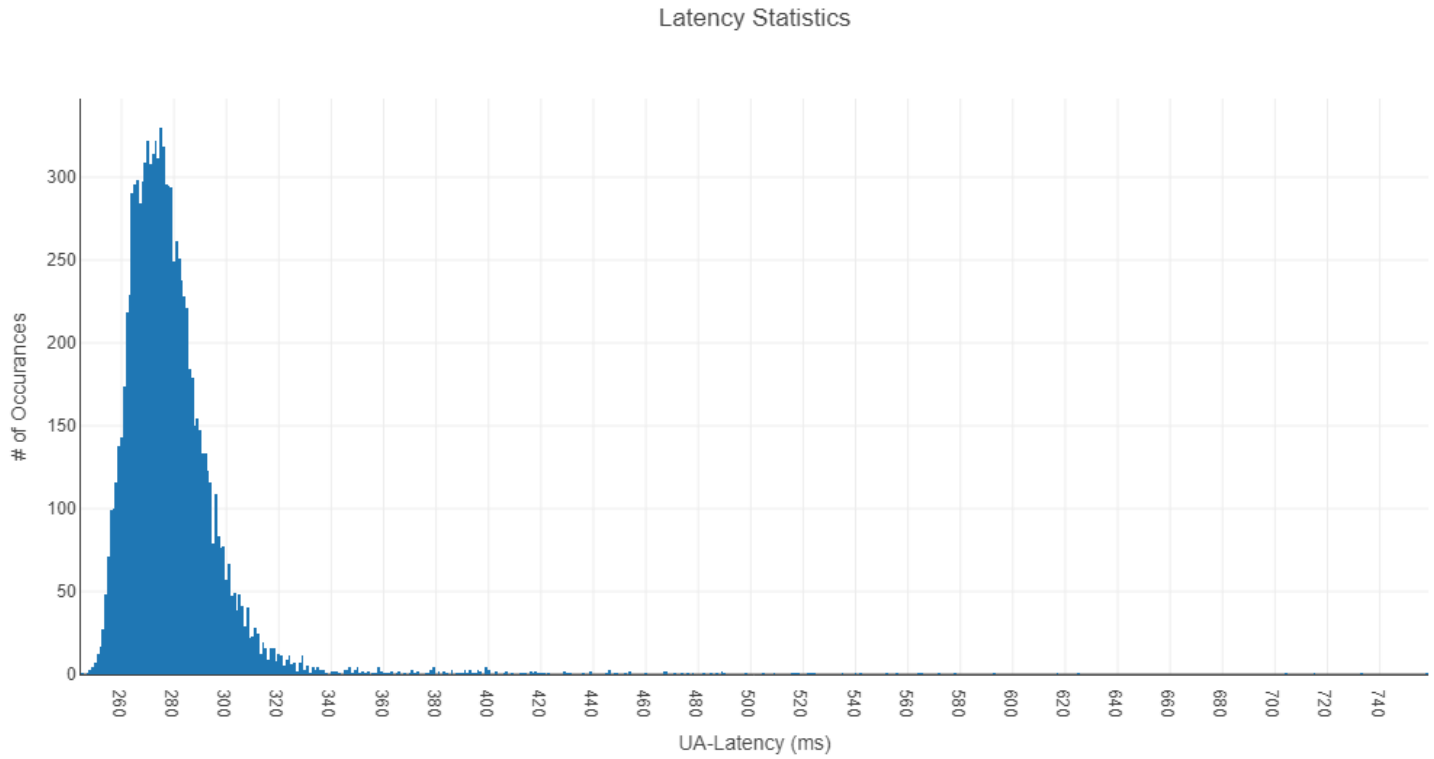

Figure 8.5.2 Latency Graph

Metric	Latency (ms)
5th Percentile	259
50th percentile	276
99.9th Percentile	561
Max	758

Table 8.5.1 Latency Table

Aircraft (Autopilot)	Lost link trigger setup timer
Censys (Pixhawk)	10s

Table 8.5.2 Lost Link Declaration Duration

8.6 Signal Parameters

Minimum RSRP: -99dBm
Minimum RSRQ: -20dB

RSRP and RSRQ charts are not separated per band.

RSRP value reporting range is defined from -140 dBm to -44 dBm with 1 dB resolution per 3GPP standards. For more information please see section 9.1.4 RSRP measurement report mapping at this link: https://www.etsi.org/deliver/etsi_ts/136100_136199/136133/08.15.00_60/ts_136133v081500p.pdf

RSRQ value reporting range is defined from -19.5 dB to -3 with 0.5 dB resolution per 3GPP standards. For more information please see section 9.1.7 RSRQ measurement report mapping at this link: https://www.etsi.org/deliver/etsi_ts/136100_136199/136133/08.15.00_60/ts_136133v081500p.pdf

SINR and SNR are not standardized 3GPP parameters and measurement and logging can vary from OEM to OEM. In order to accurately present a comparison of different UAS configurations, SINR and SNR are not analyzed.

In all campaigns in this report SINR or SNR was recorded but not analyzed.

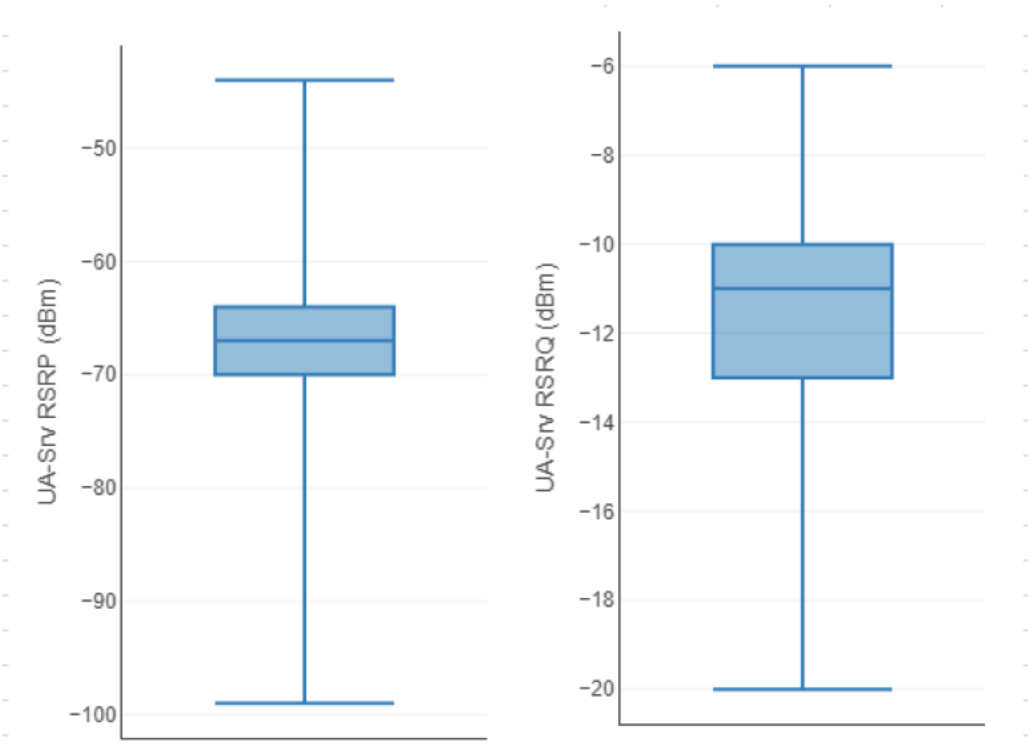

Figure 8.6.1 RSRP & RSRQ Box and Whisker Plots

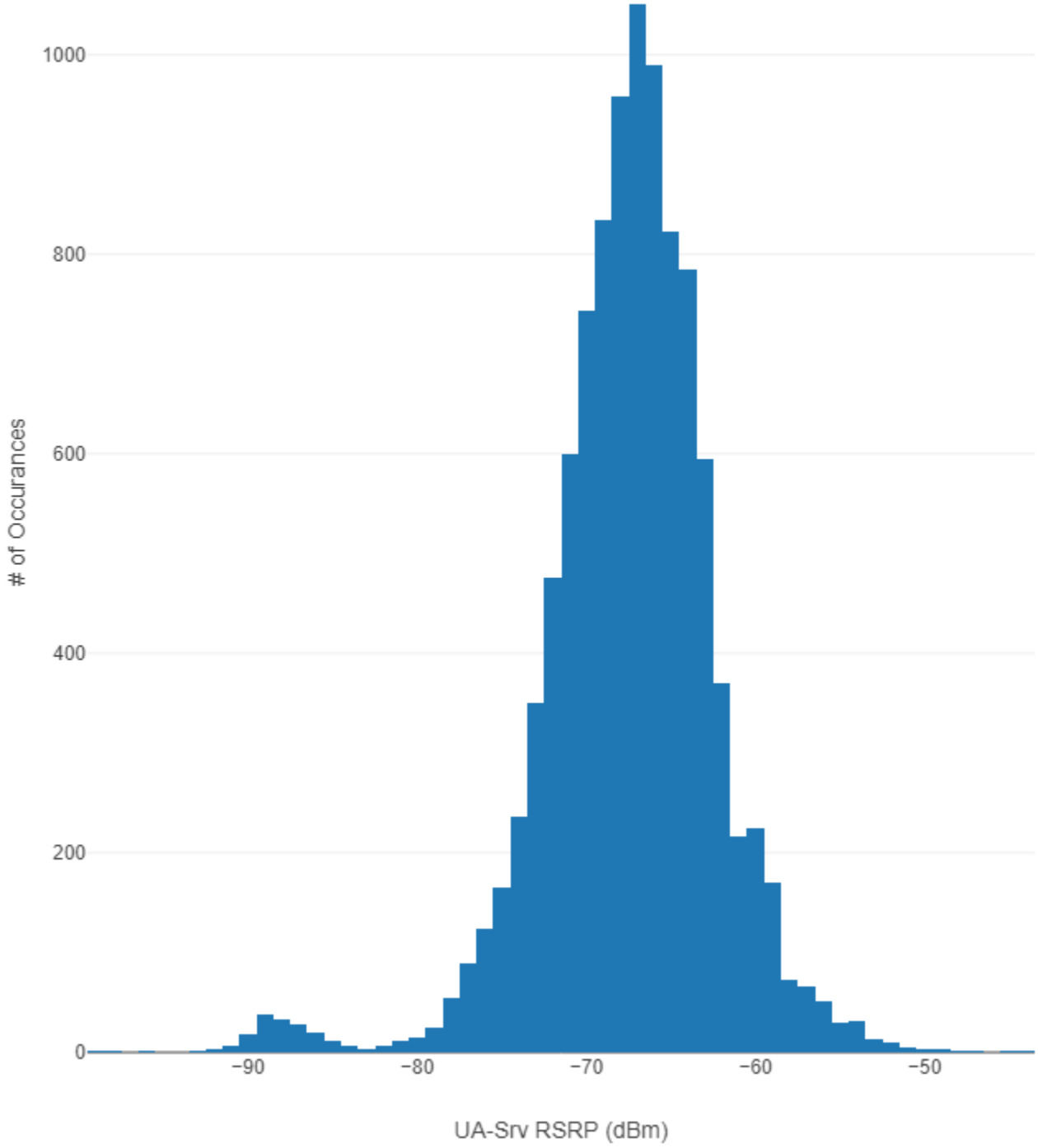

Figure 8.6.2 RSRP vs. # of Occurrences Graph

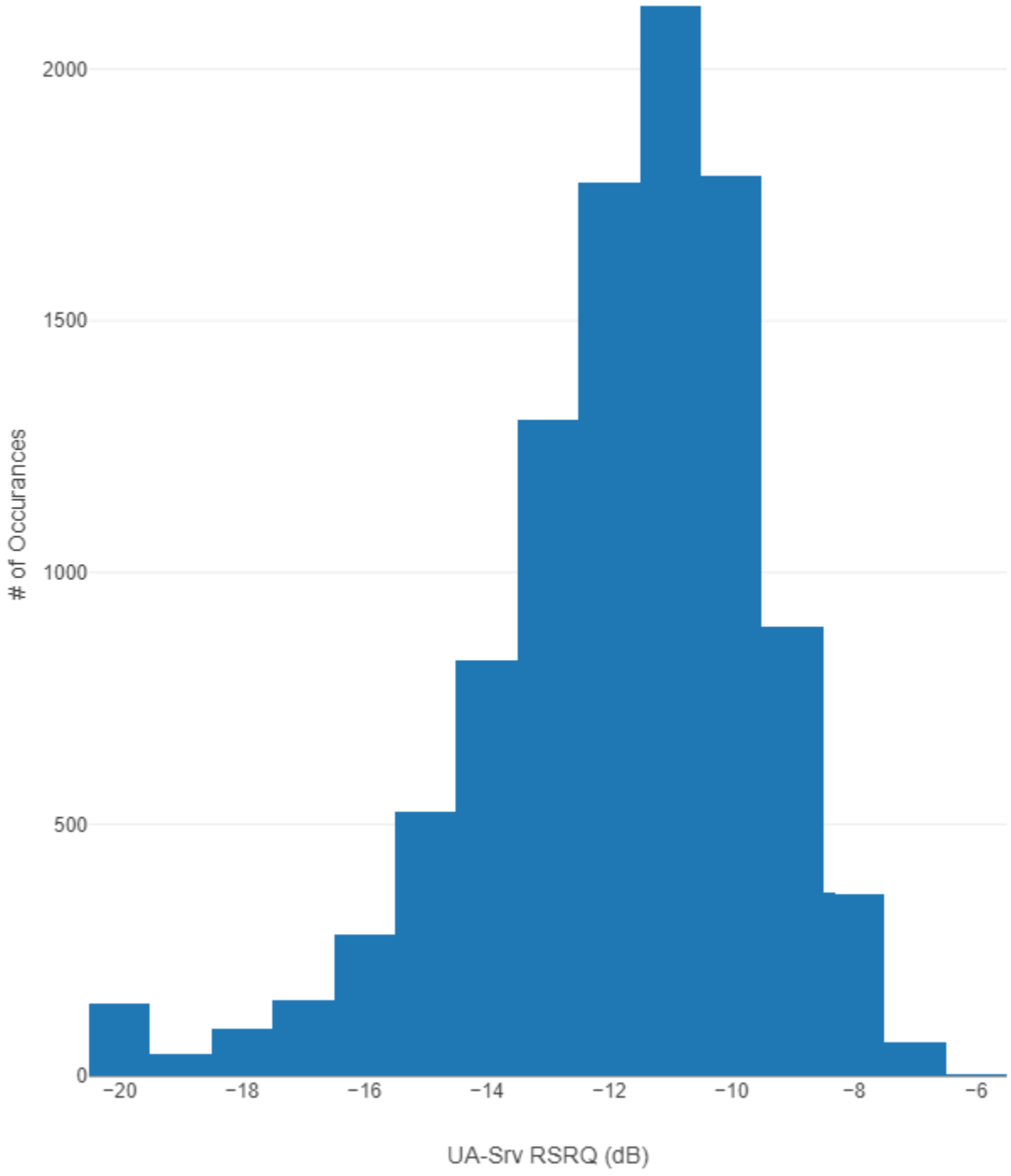

Figure 8.6.3 RSRQ vs. # of Occurrences Graph

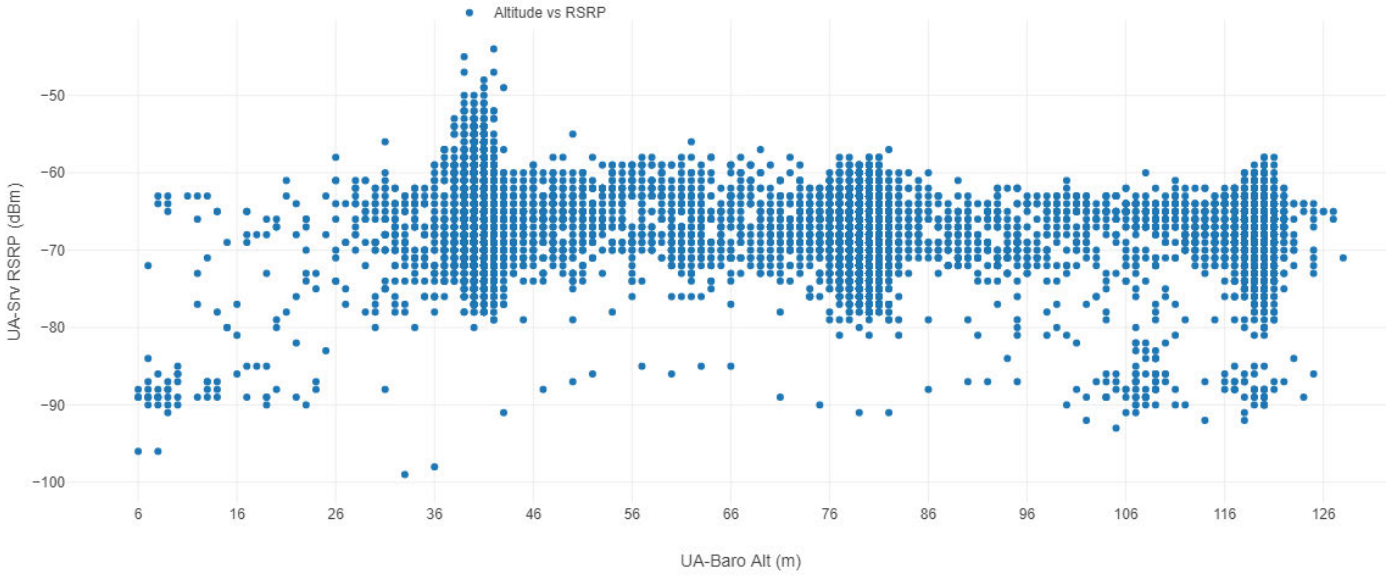

Figure 8.6.4 RSRP vs Altitude Scatter plot

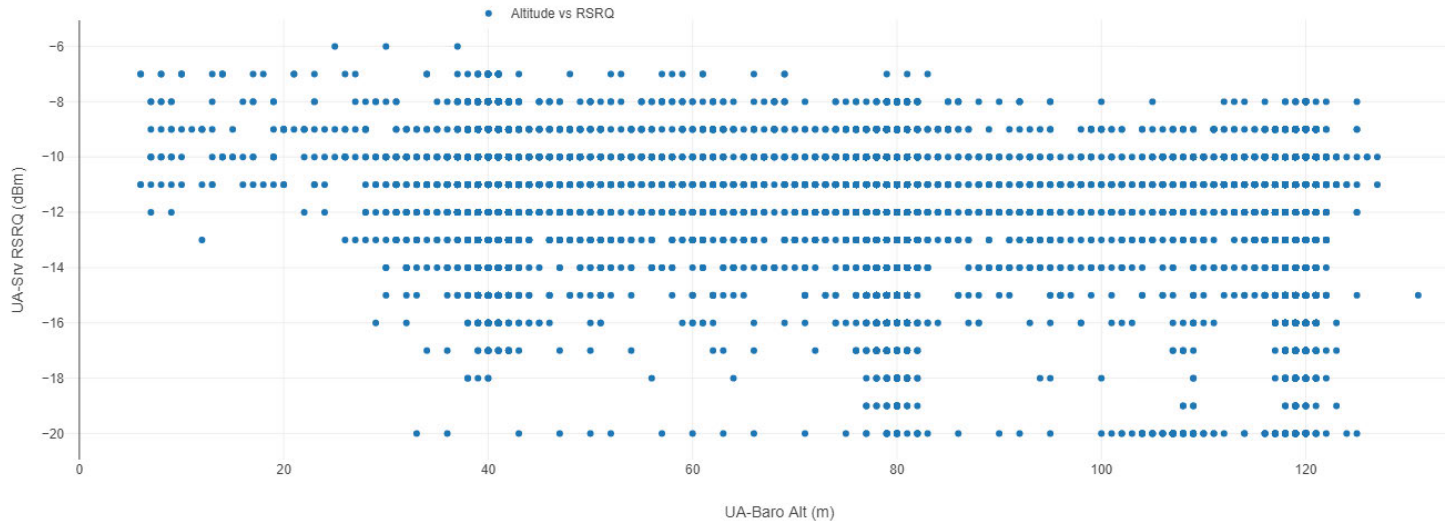

Figure 8.6.5 RSRQ vs Altitude Scatter plot

Metric	RSRP (dBm)	RSRQ (dB)
MIN	-99	-20
5th percentile	-75	-16
50th percentile	-67	-11
95th percentile	-60	-9

99th percentile	-56	-8

Table 8.6.1 RSRP & RSRQ Table

8.7 Cellular Network Handovers

Quantity of observed handovers: 516
Total quantity of flight hours: 10.3 hrs
Total distance flown: 664.34 km

In cellular network systems a handover is defined as the process of transferring a data session from one cell to another cell. Handover logic may consider signal strength, channel utilization, channel capacity, cell density and other parameters when determining which channel to transfer the session to. The objective of the handover logic is to prevent interruptions to the session that could result in a dropped call or termination of the connection.

A cellular site may have multiple different cells with different bands and frequencies representing different sectors of the cell site. Due to the complex nature of handover trigger settings and cell selection algorithms, as well as the varying cell site design possibilities, a comparison of the quantity of handovers per mile of flight between different locations or UAS would not be a valid comparison. While handover failures may occur due to signal interference, cell availability and other causes, the UE is unable to record instances of unsuccessful handover attempts due to limitations of device logging capabilities.

8.8 Interference

Local Verizon Network Performance team members were notified of flight operations prior to and during the flight campaigns referenced in this report. The Network team members were instructed to provide reporting on any observed abnormalities, such as interference KPI's, in the area of flight operations.

There were no reports of such abnormalities presented during the flight campaigns referenced in this report.

In one of the flight operations it was reported that the UA connected to Band 5. Band 5 is restricted for aeronautical use. Please see section 9.2 for more information.

9. Anomalies and Accidents

9.1 8/17/2021 RTL Root Cause Analysis

9.1.1 Overview

On 8/17/2021 during a flight in the Panama Beach FL area, the UAS invoked RTL after a few minutes of flight. The flight landed safely as planned and there were no other mishaps reported. The flight service provider was able to retrieve both UA and CS log files.

After the UA-invoked RTL event the route was flown a second time. During the second flight the RPIC indicated that C2 link performance was degraded and the RPIC initiated a manual RTL.

Aircraft Serial Number: CTC04210042
Aircraft FAA registration number: FA3AWEYKKH
Aircraft Variant: Sentaero v2 VTOL

There were not any reports of the aircraft exhibiting physical issues during any time in flight and hence this investigation is focused on the UAS communication link and its components.

9.1.2 Investigation

UA and CS both were connected to the Verizon 4G LTE network as required by the program. As per the log files obtained for this flight, the UA and CS were connected to the following bands:

Component	[redacted]	PCI	EARFCN	Band
CS		193, 357	2050	4
UA		2, 195, 195	950, 5230, 8850*	2, 13, 26* (actually 5)

Table 9.2.1.2 Basic RF Parameters of UA and CS

*The UA reported a connection to Band 26 per the modem logs. Verizon does not own Band 26. Based on the cell ID reported, it was confirmed that the UA was connected to Band 5 but it was reported as Band 26.

Analysis related to the connection to Band 5 is detailed in Section 9.2.

9.1.3 Sequence of Events

The UA initiated take off around 195209 (format: hhmmss) while it was connected to Band 26 (later determined to be Band 5). Approximately around 195347 (98 seconds later) the UA transitioned to Band 2 and continued flying until it invoked RTL at 195922, after around 7 minutes into the flight.

The UA was preprogrammed to invoke RTL after 10 seconds of missed heartbeat messages between the CS and UA. Based on the data, it can be confirmed that the system worked as expected because the time difference between the last heartbeat record and RTL invocation time is 10 seconds. Timelines are provided in the table below.

For reference, heartbeat messages are sent 10 times per second between the UA and CS. Each heartbeat message is recorded in the autopilot log file. The combined log file aggregates data from the autopilot, modem and other logs, and follows the modem recording frequency of one recording approximately every 4 seconds.

Comment	Time stamp
last heartbeat	195912
1st heartbeat loss reported in the combined log file	195916
RTL invoked	195922

Table 9.1.3.1 UA Timestamp vs. comments

[redacted]

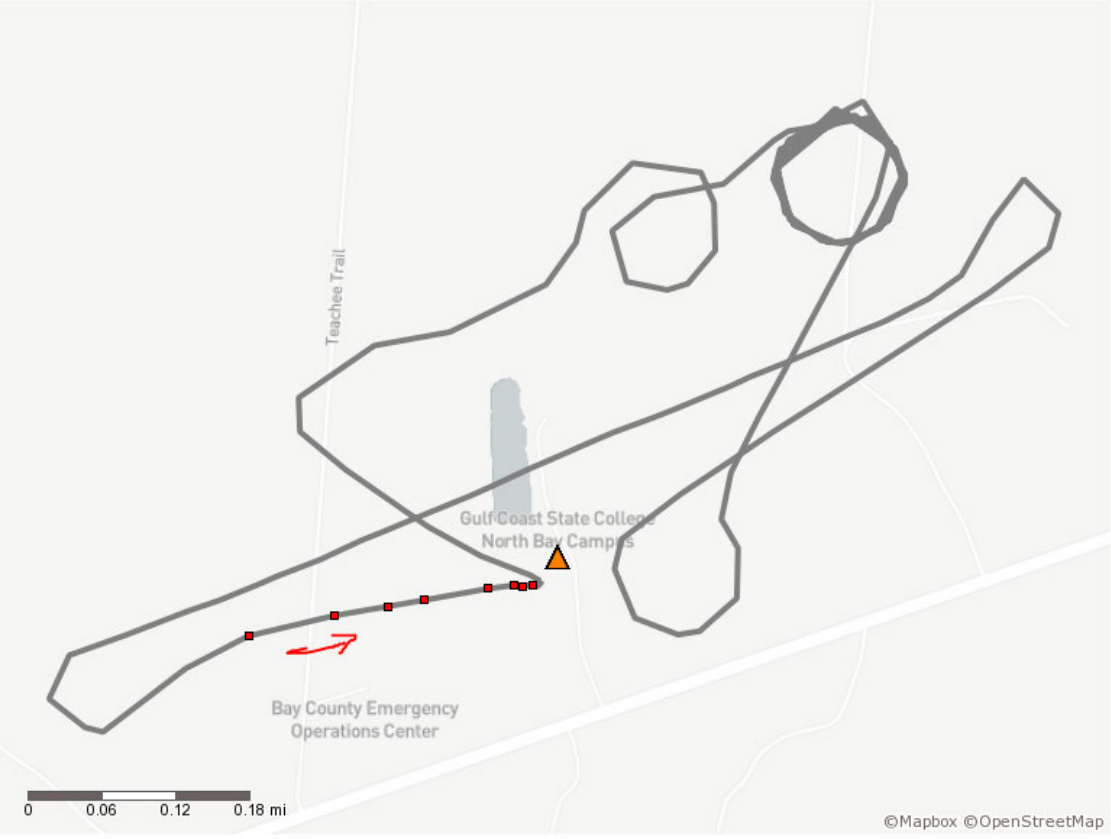

Figure 9.1.3.2 Flight route with mode=RTL plot (red dots) Triangle icon is GCS location

The following image shows overall UA RF reporting during this flight as per the combined log file. RF parameters of UA and CS are studied further.

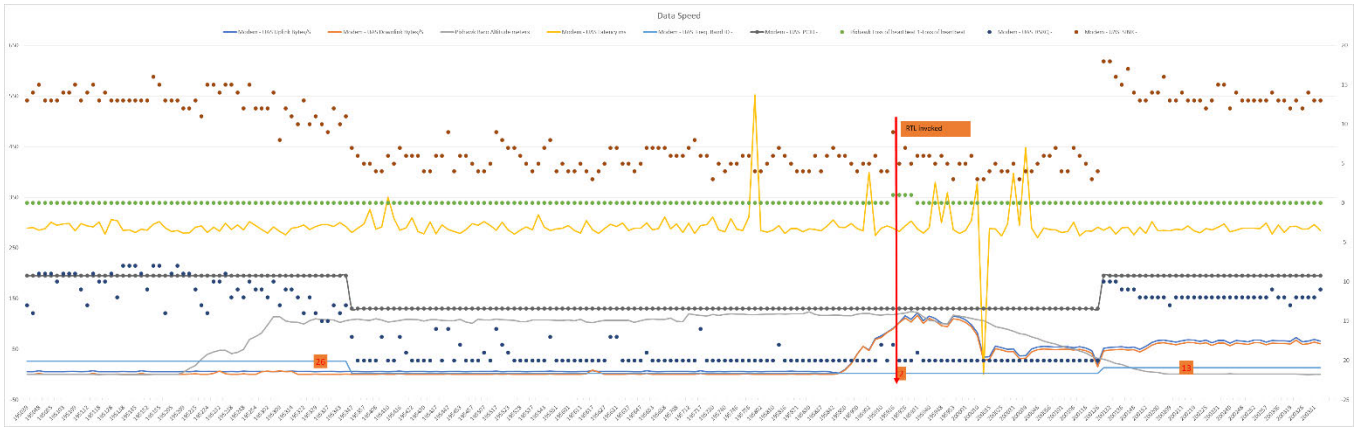

Figure 9.1.3.3 UA RF reporting based on combined log file

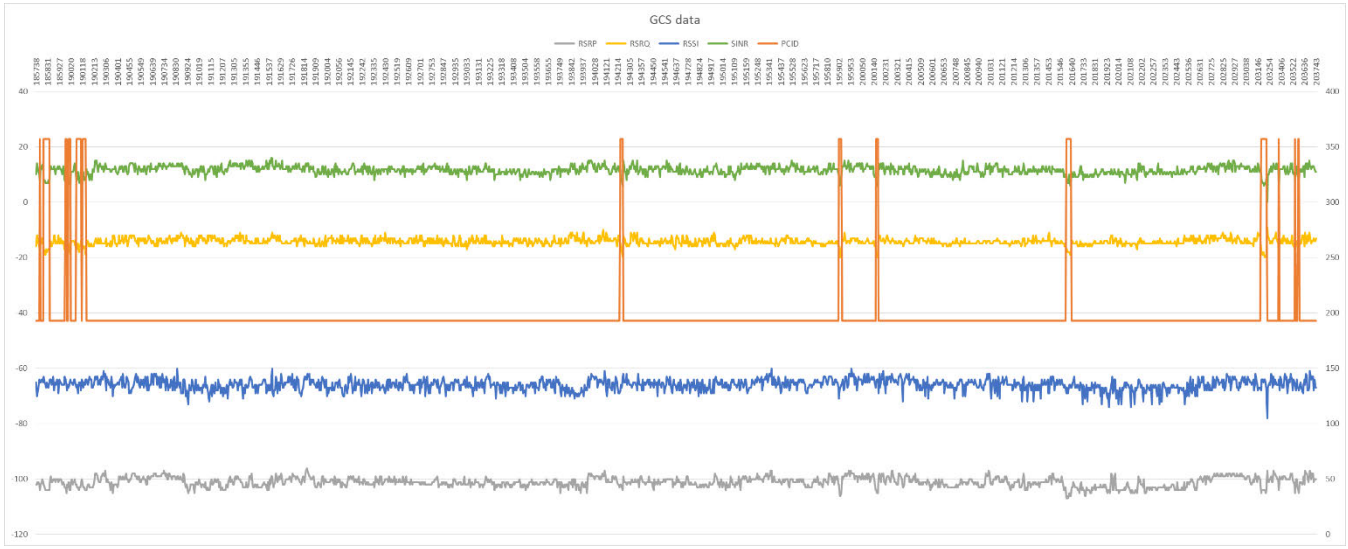

Figure 9.1.3.4 GCS RF reporting (GCS log file)

The UA was initially connected to Band 5 then later transitioned to Band 2 and then to Band 13. Data suggests that the UA encountered a similar RF environment immediately before the RTL event while connected to Band 2 as it did for the last few minutes of flight in Band 2. However, it is observed that the quality of the signal (RSRQ) is around -20dB during its time on Band 2. The following image shows cell, signal strength and signal quality immediately preceding the RTL invocation time.

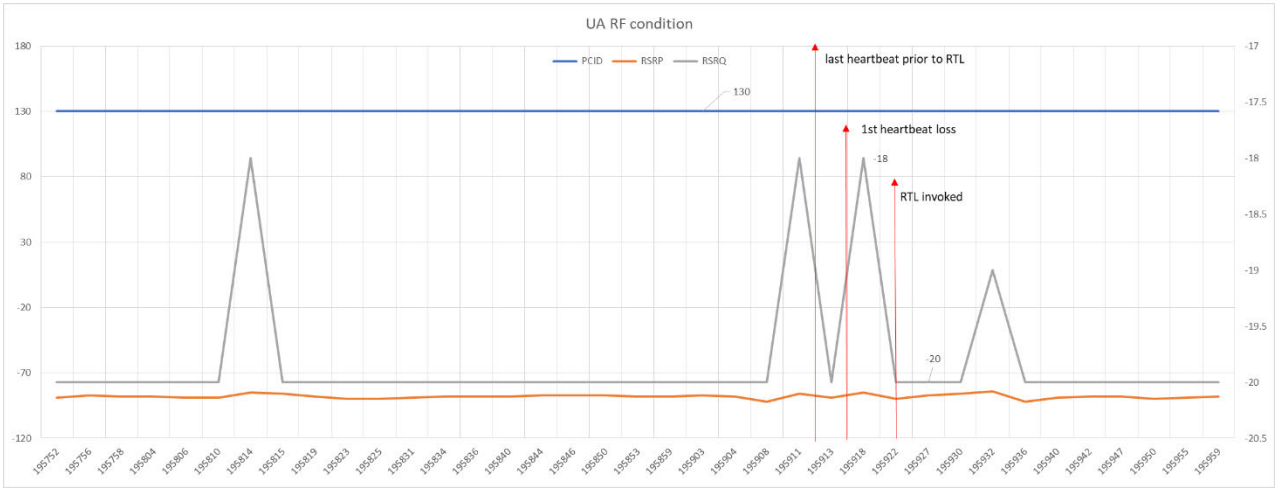

Figure 9.1.3.5 UA RF reporting immediately before RTL

The CS log file was studied and it was observed that the CS was bouncing between two Physical Cell IDs (PCI), PCI 193 and PCI 357, on numerous occasions. The CS was stationary on the ground. Bouncing between different cells is unusual for a stationary UE and occurrences of this type of behavior are the result of the network configuration. Idle mode cell reselection (the transitioning of cells while the UE is not in active data session) and connected mode cell handover are controlled by the network and the modem adheres to the parameters communicated by the network. It was also observed that the CS had changed cells right before the RTL event.

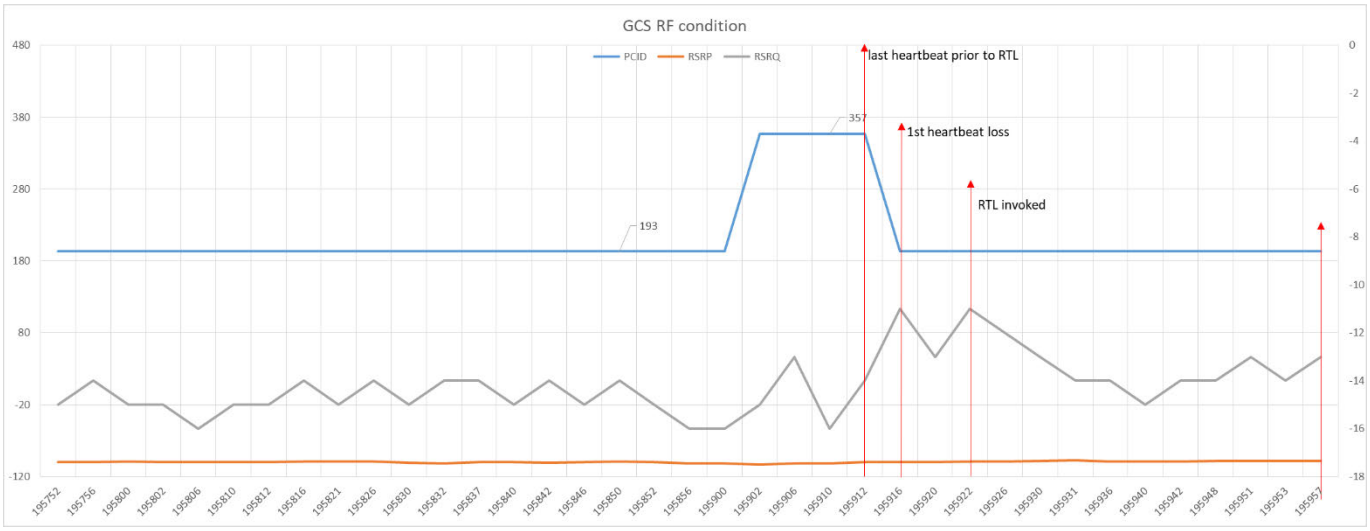

Figure 9.1.3.6 GCS RF reporting immediately before RTL

9.1.4 Root Cause

No abnormal change in RF condition during flight was reported by the UA. The CS, on the other hand, reported a change in cells right before the RTL event. It is possible the CS had communication issues that resulted in missed heartbeat messages that lasted more than 10 seconds, resulting in RTL as per the system settings. The frequent change in cells reported by CS also suggests a clear lack of dominant server in the area where CS was located.

9.2 Band 5 Root Cause Corrective Action Report

9.2.1 Review of ALO Certification Status

During the course of the RTL investigation identified in Section 9.1, we reviewed the modem logs and the cell ID, which indicated that the UA was connected to Verizon Band 5 for a total duration of 94 seconds.

Airborne LTE Operations (ALO) certified modems are prohibited from supporting Band 5 so we directed Censys to inquire into the details of the ALO certification status of the modem used during the flight. Censys indicated that they contacted Microhard, the company that supplied them the modem; and it was found that the modem used in the UA was not an ALO certified modem according to Microhard's records. This contradicts what was entered in the UAS Configuration file and contrary to Skyward's contract with Censys.

On September 3, 2021 Censys provided Skyward the following IMEI and ALO certification status as communicated by Microhard about the modems used during the flight:

Serial no.	ALO certification (Y/N)	IMEI	Description
012-1368737	N	#867698040837265	UA - #CTC0421042
012-1331850	Y	#867698040841275	GS - #CTC0421042

Table 9.2.1.1 ALO certification status by modem per Censys records

9.2.2 Conclusion

Microhard recommended that we replace the non-ALO certified modem with an ALO certified modem with the latest version of the modem firmware from their publicly available services site and repeat the test. Microhard assured Skyward that the new firmware would not have an impact on performance of the modem, but would apply any updates to prevent connection to Band 5.

Skyward forwarded the recommendation to use an ALO-certified modem with updated firmware to Censys and has requested that an additional ground test be run. Skyward is awaiting the results of this ground test. In the meantime, Skyward has requested that all partners flying with the Microhard ALO certified modem immediately apply the firmware update before commencing with flight operations.

Our investigation determined that poor quality control and communications between Verizon, Censys and Microhard were the root cause of the anomaly. Censys operates under contract with Skyward to fly and collect data for the MOA. They were reminded that it is contrary to FCC regulations and Verizon policy to use Band 5 while in the air. They assured us that going forward they will confirm all UA have ALO-certified modems with updated firmware.

We are unaware of any interference caused by this incident, nor are there any required reports to the FCC or other government agencies.

10. References

10.1 Operational Risk Assessment (ORA)

The following ORA was used to document preparation for both the Volusia Daytona Beach, FL and Panama City, FL flight operations.

Verizon - Skyward - Corporate

Volusia_Daytona_Beach_FL

Risk Assessment

Last Updated On Aug 06, 2021 16:43 PM UTC by Bri O'Neill

20 LOW	1 MODERATE	21 RISKS IDENTIFIED	MODERATE FINAL RISK 21 of 21 Completed
		13 RISKS MITIGATED	

Notes

Crew

1.1	Is the pilot certified and qualified for this mission?	Yes	LOW
	Mitigation: they have flown these systems or similar systems in these locations before		LOW
1.2	Has the pilot recently flown a similar mission?	Yes	LOW
1.3	Is the pilot qualified to fly this aircraft?	Yes	LOW
1.4	Is any crew member affected by fatigue or other factors that could impact performance?	No	LOW
1.5	Have all crew members been briefed on the operation?	Yes	LOW

Aircraft

2.1	Has the aircraft been inspected and determined to be airworthy?	Yes	LOW
2.2	Have Return-to-Home and Maximum Altitude values been checked?	Yes	LOW

	Mitigation: part of pre-flight checklist		LOW
2.3	Is the GPS signal within minimum required parameters?	Yes	LOW
	Mitigation: part of pre-flight checklist		LOW

Weather

3.1	Are cloud cover and ceiling within acceptable limits?	Yes	LOW
	Mitigation: part of pre-flight checklist		LOW
3.2	Is temperature within acceptable limits?	Yes	LOW
	Mitigation: part of pre-flight checklist		LOW
3.3	Is visibility within acceptable limits?	Yes	LOW
	Mitigation: part of pre-flight checklist. no night waiver in Volusia. checking on Panama City.		LOW
3.4	Are wind conditions within acceptable limits?	Yes	LOW
	Mitigation: part of pre-flight checklist		LOW
3.5	Is precipitation forecast during the scheduled operation?	No	LOW
	Mitigation: part of pre-flight checklist, will not fly if rain is forecast		LOW
3.6	Will the operation finish after civil twilight?	No	LOW

	Mitigation:		LOW
	unless we get night waiver		

Location

4.1	Is the operation authorized in the airspace?	Yes	LOW
4.2	Are there populated areas near the operation such as parks, schools, or stadiums?	No	LOW
	Mitigation:		LOW
	well clear of populated areas, no flights over people		
4.3	Are there heliports or congested air traffic near the operation?	No	LOW
	Mitigation:		LOW
	banner planes on beach but will be limited during weekdays during flights. No air traffic in Panama City.		
4.4	Is there uneven terrain or significant elevation change in the area of operation?	No	LOW
	Mitigation:		LOW
	pretty much flat (Florida)		
4.5	Are there hazards or obstructions in the area of operation?	Yes	MODERATE
	Mitigation:		MODERATE
	trees under 100 ft in Panama City waypoint file setup will disallow descending near trees		
4.6	Are people other than the crew present in the area of operation?	No	LOW
4.7	Have takeoff and landing area(s) been surveyed?	Yes	LOW

11. Acronyms & Abbreviations

Acronym or Abbreviation	Definition
ALO	Airborne LTE Operations
C2	Command and Control
CNPC	Control Non-Payload Communications
COTS	Commercial Off The Shelf
CS	Control Station
EKF	Extended Kalman Filter
FW	Fixed Wing
GCS	Ground Control Station
KPH	Kilometers Per Hour
LTE	Long Term Evolution (4G)
MPN-GW	Mobile Private Network Gateway
OEM	Original Equipment Manufacturer
ORA	Operational Risk Assessment
PCI	Physical Cell ID
P-GW	Packet Gateway
PNW	Pacific Northwest
RC	Remote Control
RF	Radio Frequency
RPIC	Remote Pilot in Command
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RTL	Return to Launch
SIM	Subscriber Identity Module
SINR	Signal to Interference Plus Noise Ratio
SNR	Signal to Noise Ratio

UA	Uncrewed Aircraft
UAS	Uncrewed Aerial System
UAV	Uncrewed Aerial Vehicle
UE	User Equipment
VTOL	Vertical Takeoff and Landing