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RF Environment Data Analysis for UAS Operations

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August 2022

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Acronyms

Acronym	Definition
CERTAIN	City Environment Range for Autonomous Integrated Navigation
C^2	Command & control
CRFS	Cambridge Radio Frequency Services
CSV	comma delimited file
DSSS	Direct-sequence spread spectrum
FCC	Federal Communications Commission
FCO	Frequency channel occupancy
FHSS	Frequency-hopping spread spectrum
ID	Identification
ISM	Industrial, scientific, and medical
ITU	International Telecommunication Union
LaRC	Langley Research Center
NASA	National Aeronautics and Space Administration
RF	Radio frequency
RFI	Radio frequency interference
SNR	Signal-to-noise ratio
SWS	System-Wide Safety
UAS	Uncrewed Aircraft System(s)
UAV	Uncrewed Aerial Vehicle

Abstract

As the usage of radio frequency spectrum and uncrewed aircraft systems continue to grow, the radio frequency environment and its implications to flight safety should be understood. This is important to ensure control and command links as well as data collection links maintain strong communications during flight. NASA System-Wide Safety (SWS) is currently developing standards of flight safety but lacks methods for establishing confidence in the availability of radio frequency space to make a go/no-go decision for drone flights. This study examines information about the radio modules used by SWS and how they interact with the RF environment though analysis of historical spectrum data. This review studies the potential effectiveness of observing the power spread and occupancy methods as they apply to the flight system radios. It has been determined that viewing the frequency and time when the environment is greater than a threshold which indicates potential interference levels may give insight into the patterns of spectrum usage.

1: Introduction

NASA's System-Wide Safety (SWS) project is driving an understanding of and developing processes to ensure safe flight for aviation systems. Within the aviation field, drone operations are becoming more prevalent. One of the challenges being faced by SWS is ensuring drones can operate safely and developing the systems and processes to establish safe flight. There are many complexities and system configurations that must be considered to support safe Uncrewed Aircraft System (UAS) operations. Figure 1 shows an overview of SWS Technical Challenge 2: Facilitating Emerging Drone Operations. The chart illustrates the In-Time Aviation Safety Management System Concept and identifies radio environment monitoring and forecasting as a key 3rd party safety service.

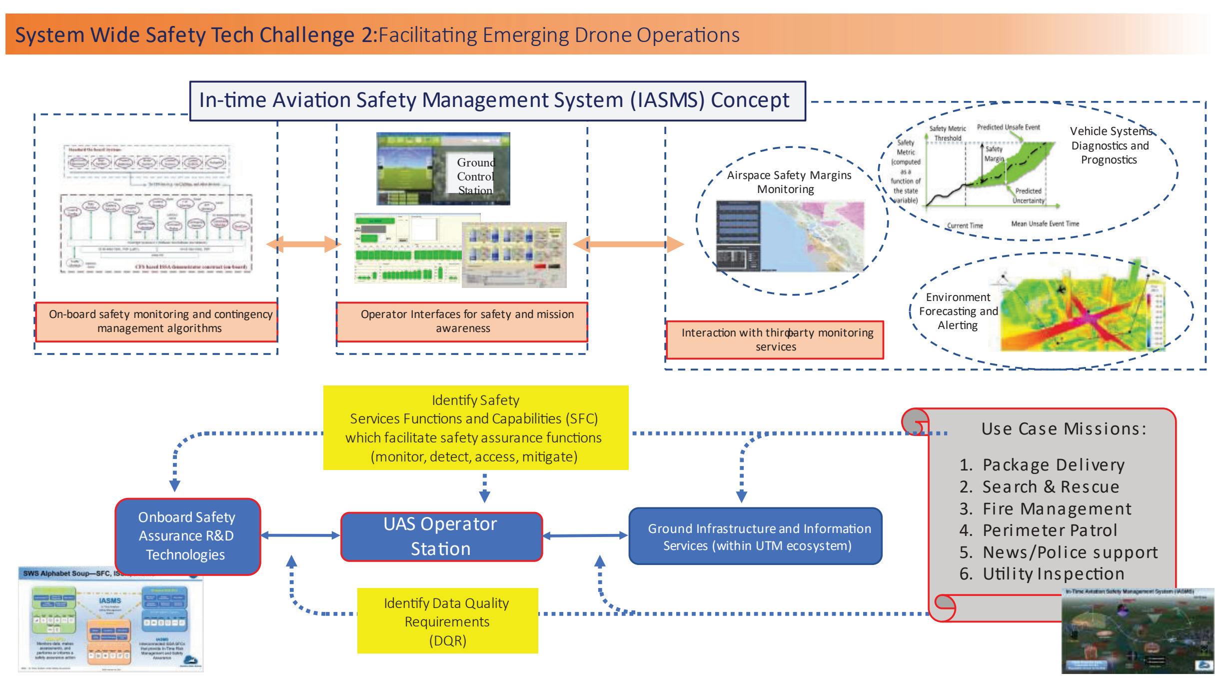

Figure 1. Emerging Drone Operations Challenge [1].

One of the important aspects of this mission is to understand the environment that vehicles will encounter during flight. This includes the radio frequency (RF) environment and possibilities of encountering radio frequency interference (RFI). Radio frequency interference happens when systems transmit on the same or adjacent center frequencies with overlapping spectral envelopes and cause disruption to signals in the system. The SWS drones rely on radio communications for the command & control (C^2) of the uncrewed aerial vehicles (UAVs), as well as for the transmission of health & data information. The flight system employs fault tolerance mechanisms that protect the vehicle and other properties in the case of complete loss of radio communications. However, the availability and integrity of the radio link is vital to safety-critical operations or those where the drone flies beyond the visual line of sight. The SWS drones use Industrial Scientific and Medical (ISM) unlicensed bands for communication. These bands are known to be crowded and unpredictable, so ensuring the integrity of the spectrum in unlicensed bands is unfeasible and unrealistic. However, the operations of SWS drones take place in a controlled geographical test area with shared, but manageable spectrum space. This allows the long-term monitoring of RF space to help develop an understanding of the occupancy of the spectrum environment to enable a level of comfort on the availability of enough radio channels to maintain a degree of communications between the drone and the controller on the ground. The SWS currently lacks methods for establishing confidence in the availability of RF space to make a go/no-go decision on drone flights. An understanding of the RF environment may help predict and prevent inference in drone systems.

2: Assessment Goals

One way of understanding the RF environment is to study environment data from the past. NASA Langley Research Center (LaRC) hosts a network of Cambridge Radio Frequency Services (CRFS) RFeye[1] nodes designed for spectrum monitoring. The goal of this study is to gain an understanding of the interactions between the drone systems currently in use by SWS and the RF environment using historical data collected by the RFeye spectrum monitoring nodes. Proposed methods of analysis that are being investigated as possible measurements of safety include the spread of the power data over frequency and time and RF channel occupancy.

3. Radio Information

In order to directly correlate collected data to the UAS being used by SWS, information about the radios is needed to perform an accurate analysis. Several radios are used in the system, which include operating frequencies in the 900 MHz and 2.4 GHz Industrial Scientific and Medical (ISM) unlicensed bands.

3.1: 900 MHz Band Radios

There are two radios that may be integrated into drone system that operate in the 900 MHz band. These are the Harris Aerial RFD900x[2] Radio Modem and the uAvionix microLink[3]. Both radios use frequency hopping spread spectrum (FHSS) techniques. FHSS radios constantly switch the operation frequency within the ISM band. FHSS is a method that decreases the chances of interference occurrence because it stays on one frequency for a short time period. Both radios

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[1] NOTE: Specific vendor and manufacturer names are explicitly mentioned only to accurately describe the test hardware. The use of vendor and manufacturer names does not imply an endorsement by the U.S. Government nor does it imply that the specified equipment is the best available https://www.crfs.com/receivers/

[2] https://www.harrisaerial.com/product/rfd900x-radio-telemetry-modem/

[3] https://uavionix.com/products/microlink/

have channel bandwidths of less than 250 kHz to meet the FCC regulation which states "the system shall use at least 50 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 20 second period," [2].

Information about these radios was collected from respective data sheets and supporting documents from the FCC Report Database. This database includes information about the system from FCC certification filings accessible via the FCC ID, such as the number of channels, channel separation, channel center frequencies, channel bandwidth, transmit power, and receiver sensitivity. This data is summarized in Table 1.

	RFD900x	**microLink**
FCC ID	2adle-900x	2AFFTC2XISM
Number of Channels	102	99
Channel Separation	250 kHz	250 kHz
Channel Bandwidth	240 kHz	200 kHz
Starting Central Frequency	902.25 MHz	902.75 MHz
End Central Frequency	927.75 MHz	927.25 MHz
Transmit Power	0 to 30dBm in 1dBm steps	30dBm
Receiver Sensitivity	>121 dBm at low data rates	-118 dBm

Table 1. Radio Information [3].

The channel information is specifically useful for data analysis. Both radios use the same channel separation of 250 kHz which allows the two to share many of the same center frequencies. The difference between the two radios is that the RFD900x starts at 902.25 MHz and ends at 927.75 MHz and excludes the 915.00 MHz channel, while the microLink starts at 902.75 MHz and ends at 927.25 MHz, including the 915.00 MHz and all other channels in between. This leaves the RFD900x with 102 channels and the microLink with 99 channels, totaling 103 center frequencies between the two. The transmit power of the RFD900x may be modified by the user in 1dBm steps up to 30dBm. During SWS testing, the RFD900 is set to transmit at 30dBm.

The frequency hopping systems works by pseudo-randomly choosing 50 hopping channels out of the total number of channels. This decreases the chances of interference and jamming because the pseudo-random nature of these 50 channels allows the radio to use different portions of the frequency band. The radio will jump between these 50 channels and then restart the cycle of choosing another pseudo-random 50 channels across the spectrum to use [3].

3.2: 2.4 GHz Band Radios

Information about the UAS radios that operate in the 2.4 GHz ISM band was also collected using the respective data sheets and supporting documents. The transmitter in this band is the Futaba T18MZ[4] and the receiver is the Futaba R7008SB[5]. These radios have different operating modes including FASSTest, FASST, and S-FHSS [3]. This project utilizes the FASSTest mode which incorporates 23 channels starting at 2405.376 MHz and ending at 2472.960 MHz [3]. These radios use a direct sequence spread spectrum (DSSS) technique. In DSSS modulation, the signal is encoded and decoded with a key that is shared between the transmitter and receiver. The receiver

[4] https://futabausa.com/product/18mz/
[5] https://futabausa.com/product/r7008sb/

knows what the signal should look like and will only gather information from a signal that follows the expected pattern. This means that the signal does not necessarily have to be higher in power than other signals. The power of a DSSS signal could be within the power level of the noise or other signals and still have the potential to be detected by the receiver.

4: CRFS Nodes

NASA Langley Research Center has five CRFS RFeye nodes deployed across the campus, seen in Figure 2. The purpose of these nodes is to collect data about the RF environment for spectrum monitoring purposes. The model is the RFeye Node 100-8 and covers a frequency range from 9kHz to 8GHz with an instantaneous bandwidth of 100 MHz. The nodes can be configured to run different types of scans to produce data for specific needs. Data scan options include sweep, occupancy, I/Q, possible signal, geolocation, mask event, messages, node location, and node health data. The CRFS system includes a user interface website, RFeye Mission Manager[6], that is used to monitor the nodes, set up scans, and retrieve or view collected data [4]. LaRC also hosts a computer terminal which allows greater use and flexibility of the CRFS system.

Figure 2. Map of Nodes at LaRC.

It is noted that times listed in Mission Manager are listed in the local time of the nodes. When the data is exported, the times are converted to UTC. This means that during Eastern Standard Time there is a five-hour difference and during Eastern Daylight Time there is a four-hour difference in the data in Mission Manager compared to the exported data files.

[6] https://www.crfs.com/product/software/rfeye-mission/

4.1: Historical Data

This study uses historical data collected by RFeye Node 200343 from 900 MHz to 930 MHz. The data collected for these historical collections is sweep data. A scan that collects sweep data can be configured to collect power or field strength data, using a processing method of collecting the peak, mean, or root mean square of the measured sweep values. The historical data in this study represents the peak power data in dBm over a series of seven months. The node was configured to complete a scan every 15 minutes from 900 MHz to 930 MHz with a resolution bandwidth chosen by the software. The resolution bandwidth was automatically set to 15293 Hz.

RFeye offers the ability to export each scan into comma delimited files (CSV) for post processing, and multiple scans can be grouped and exported together. The historical data was exported on a monthly basis. Each of the files consist of columns with information about the scan. A MATLAB script was written to process the data from these files, including the column titles and collecting the needed information into MATLAB variables. Three primary variables were collected: a frequency vector, a time vector, and a power matrix. The frequency row vector produced was the same for all seven months and contained 3934 evenly spaced frequency points between 900 MHz and 930 MHz, based on the resolution bandwidth. The time column vector varied from month to month and contained all time points where a scan was completed. The power matrix contains a measured power value in dBm for every frequency sample. For example, the time vector for the month of December contains 10009 datetime points as a column vector so the power matrix for December is a 10009-by-3934 matrix. The number of data points in time collected and the days they represent for each month is shown in Table 2.

Month	# of Time Points	Days Represented
November 2021	3759	Nov 19 - 30
December 2021	10009	Dec 01 - 31
January 2022	9606	Jan 01 - 31
February 2022	505	Feb 01-02
March 2022	0	N/A
April 2022	3356	Apr 04 - 30
May 2022	3491	Apr 30 – May 31

Table 2. Historical Data Information.

5: Analysis

5.1: Data Processing

The first step of analyzing the historical data is to understand how it was collected and what it is representing. The data must be understood before analysis methods or calculations can be performed.

5.1.1: Time Intervals

It can be seen in the collected data, shown in Table 2, there is a discontinuity in the dataset. The data begins on November 19th, 2021 and ends on May 31st, 2022. Data collection ceased on February 2nd, 2022, and no data was collected again until April 4th, 2022. Through discussion, it was discovered that the break in the data collection was caused by a software malfunction within the CRFS system. When data began collecting again on April 4th, 2022, it collected less data points than previous months. The months of April and May present less points in time than compared to November, December, and January. This indicates a higher point density in the early months of observation before the known software malfunction occured. Because of these differences, and uncertainties about when the CRFS software will be fully functional, the data in December and January was determined to be the most reliable, until new data can be accurately collected.

The scan rate was set to 15 minutes when the scans were initiated. The data was expected to have one point in time every 15 minutes, but this is not what is observed. Instead of one point every 15 minutes, the points are spread across uneven time intervals. The time intervals range from no change in time (with an accuracy of seconds) to some being with a minute or two of each other while others are 5 to 15 minutes apart. There tends to be several points within about two minutes of each other before a larger jump occurs and the size of these clusters is inconsistent.

A sample of data collected on December 8th, 2022 demonstrates the unevenly spaced time intervals, as seen in Figure *3*. This screen capture shows that there are points listed at the same time and inconsistent time intervals are seen throughout. By examining the time points and plots generated by Mission Manager of the scans, it can be determined that the RFeye nodes likely complete a scan within milliseconds. This can further be examined by viewing charts of the collected power data at each time in Mission Manager. On 12-08-2021 there are two points listed as being scanned at 12:29:06 PM EST. When observing the power charts at these two listings, each one showcases a different environment, seen in Figure 4 and Figure 5. The first scan demonstrates more activity across the spectrum while the second scan is primarily noise with a large, wide signal in the 922 MHz to 927 MHz range. These differences demonstrate that the environment can change within milliseconds. Because the environment is observed to change within milliseconds and the RFeye Node was able to capture both environment scans, it can be concluded that the RFeye scans are taken within milliseconds.

TIMESTAMP ▲	NODE
Dec 8, 2021, 01:01:06 PM	rfeye200343
Dec 8, 2021, 01:00:06 PM	rfeye200343
Dec 8, 2021, 12:59:06 PM	rfeye200343
Dec 8, 2021, 12:46:06 PM	rfeye200343
Dec 8, 2021, 12:44:07 PM	rfeye200343
Dec 8, 2021, 12:44:06 PM	rfeye200343
Dec 8, 2021, 12:31:05 PM	rfeye200343
Dec 8, 2021, 12:29:06 PM	rfeye200343
Dec 8, 2021, 12:29:06 PM	rfeye200343

Figure 3. Time Intervals of Collected Data.

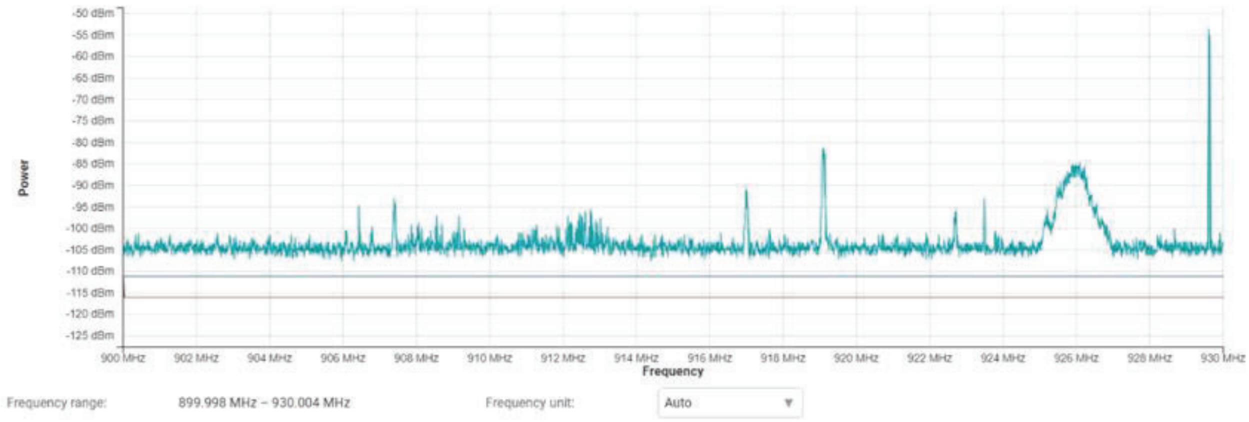

Figure 4. 12-08-2021 12:29:06 PM Scan 1.

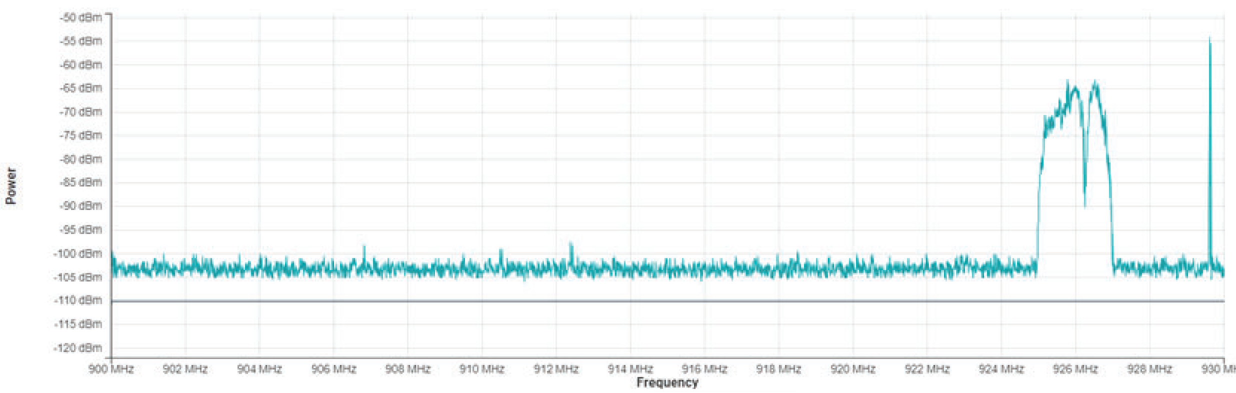

Figure 5. 12-08-2021 12:29:06 PM Scan 2.

5.1.2: Initial Signal Observations

The data collected from the CRFS node is grouped in separate CSV files for analysis. The scans are grouped together and downloaded in a period specified by the user. For this study, scans were grouped monthly. When the data from each CSV file was read into the MATLAB processing script a surface plot could be created with the frequency, time, and power as the x, y, and z axes respectively. This was the first visualization of grouped scans, shown in Figure 6, and aided in the first understandings of the RF environment around this node and at LaRC. This visualization is of the unprocessed file and does not incorporate applications to the SWS radios. While some power spikes can be seen throughout the data, it is noted that there are a couple of signals that remains consistently visible. The first signal is transmitted from the NextNav system, a geolocation device hosted on LaRC[7]. The NextNav operates between 922 MHz and 927 MHz with the highest

[7] https://nextnav.com/

power signal observed between 925 MHz to 927 MHz. The NextNav device is always powered on and typically displays power levels greater than other measured frequencies in the historical data, meaning it can be consistently observed throughout the data. Similarly, there is a signal that operates around 929.6 MHz which also exhibits a relatively strong signal and is present throughout the data. The source of this signal is unknown; however, it is outside of the spectrum range of operation of the 900 MHz radios, meaning an interference threat to the SWS hardware is not of concern.

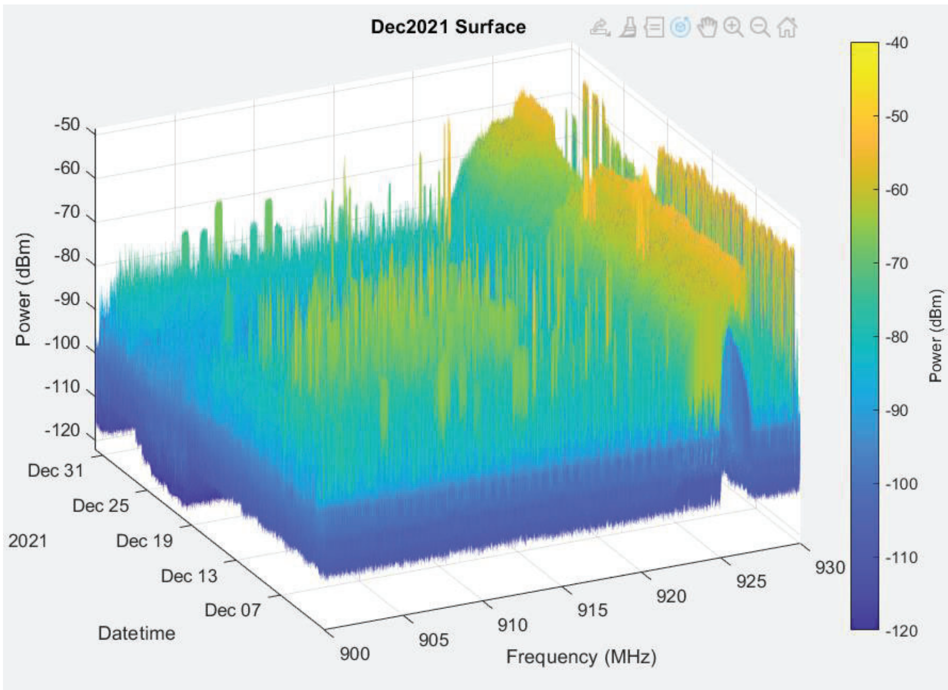

Figure 6. Surface Plot Dec 2021.

The processing script read in one file at a time, and each month that was input was saved to a MATLAB Data file and stored in the open directory. The data files were all loaded into an analysis script, and the information was combined into similar variables containing the data for all files. This allows the data from across the months to be combined and analyzed at the same time. This is useful in determining methods of analysis and to look for patterns over long periods of time. After this data is imported, the time and power matrix contained a number of rows equal to the sum of each month's time vector length. The frequency vector and power matrix remained at 3934 columns because the frequency samples remain the same between files.

5.2: Apply Channels

It was earlier established that both the RFD900x and microLink radios use channels and that many of the center frequencies are shared. All the channel center frequencies used by the two radios can be described by a vector that starts at 902.25 MHz and ends at 927.75 MHz with regularly spaced elements of 0.25 MHz separation. This yields a vector that holds the center frequencies of 103 total center frequencies. To relate the data collected by the CRFS node to the radios, the data was condensed into these frequency channels. This allows the user to understand the data in terms of how it will be applied to the hardware, the radio receivers in this case.

The frequency band produced by the CRFS nodes in the historical data is 3934 elements long. Condensing the data means taking the frequency vector from being 3934 elements to 103, to represent the 103 center frequencies of the radios. Similarly, the power matrix can also be condensed to represent the 103 center frequencies while the time vector remains unchanged. The bandwidth can easily be swapped between the two radios. This process is done by collecting the location of frequencies that fall within the channel and representing them as one point as the value of the center frequency for that channel.

Different operations can be considered for condensing the power data. These analysis methods are done to each row (which represent a point in time) within the columns of the frequency channel. This results in a matrix which has the same number of rows as before the operation (because the number of time points does not change) and 103 columns (one for each channel). The general process of condensing the data within one of the channels is shown in Figure 7. The power data may be operated on as needed. Operations that were used throughout this study include finding the mean, maximum, and power spectral density of the power data with each being stored a variable, as seen in Figure *8*. When using power samples in other analysis methods or calculations, it was specified which operation would be utilized.

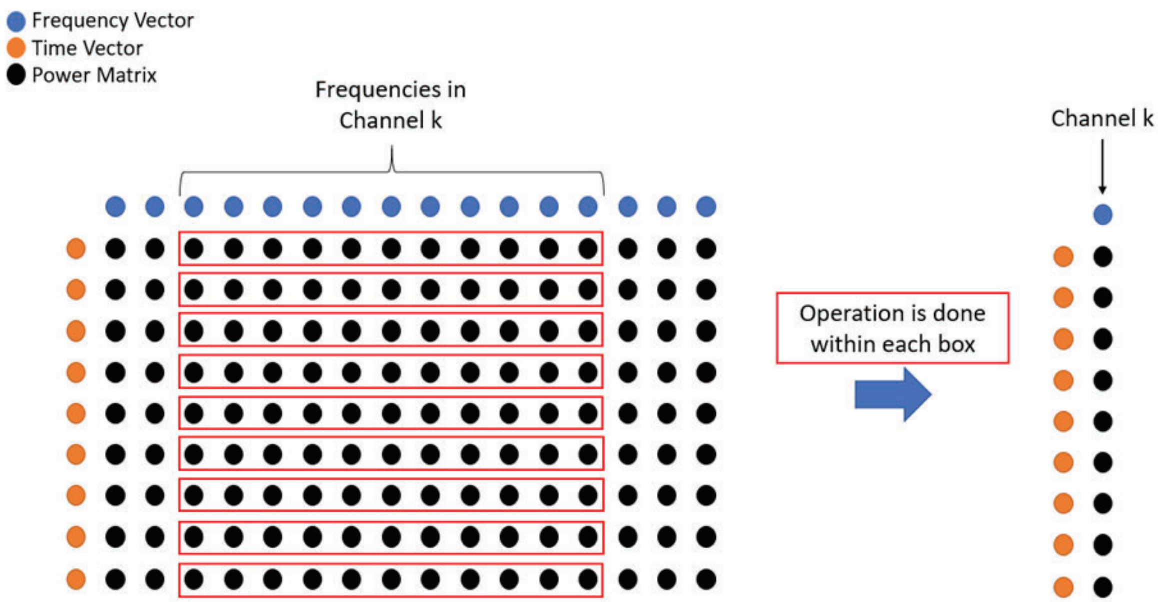

Figure 7. Condensing Data within Channels

```
%% Split Data into Channels

for k=1:length(channels)

    [~,columns]=find(f_MHz >= channels(k)-halfbandwidth & f_MHz<channels(k)+halfbandwidth);
    pwrk = pwr(:,columns);
    pwr_mean = [pwr_mean,mean(pwrk,2)];
    pwr_max = [pwr_max,max(pwrk,[],2)];
    pwr_sd = [pwr_sd,10*log10(sum(10.^(pwrk/10),2)/0.2)];

end
```

Figure 8. Condensing the Data and Power Calculations.

Condensing the data into channels allows it to be analyzed as it applies to the hardware being used. This gives it direct application and leads to an easier understanding of the outcome.

5.3: Flight Observations

The scan for any collected time can be viewed in Mission Manager just as it was for Figure 4 and Figure 5. Viewing a time when a flight was in progress is useful in understanding the power observed by the RFeye node while the radio is operational. A scan captured on 01-06-2022 at 11:29:31 AM EST during ARAGOG flight F049 observed six of the channels being used by the on-board radio, as shown in Figure 9. The power in these channels ranges from -91.5 dBm to -69.5 dBm with most of the points in these channels being above -85 dBm.

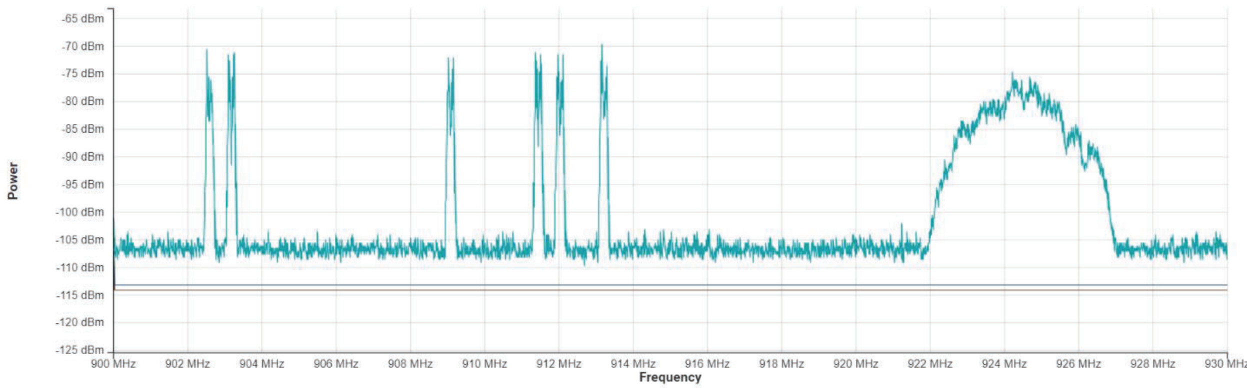

Figure 9. Data Collection During Flight.

The power levels of observable flights in the data seem to remain around similar power levels when flying in Langley's City Environment Range for Autonomous Integrated Navigation (CERTAIN) range, a designated UAS flight testing range at LaRC. The peaks of the channels are typically between -80 dBm and -65 dB, as captured by node 200343. However, both radios transmit at a power of 30dBm meaning that the power observed by the node will depend on the distance from the transmitter and is different than what is received/transmitted by the on-board radio.

5.4: Power Spread

One of the proposed methods to investigate safety was to understand the spread of the power data. This could provide insight into the typical measurements and produce information about common signals and environment conditions. This could potentially allow observations to be made on the day of flight comparing the current environment to the typical power variations. A possible flight safety tool could be to compare the current power levels to the sigma values to determine if the environment is safe to fly in. To achieve this measurement, the standard deviations and average power were calculated monthly for the months of December and January. A probability histogram can be useful to visualize the average power and standard deviations. The spread of the data will vary depending on the strength of signals present. A channel that does not typically have much activity, i.e., the 907.75 MHz channel, will look different than a channel that has a consistently strong signal, i.e., 926.50 MHz in the NextNav signal band (See Figure 10). This plot can be examined for any of the channels and can be used to understand the spread of data in specific channels. It is difficult, however, to view the spread of all the channels at once to observe the whole spectrum, as it could be overwhelming to a person making flight decisions when looking across 103 channels. Another problem with this approach is that measurements are valid for the time and place of collection, meaning that a prediction of the "normal" environment is difficult to establish as it is always changing. This is especially true for the ISM bands which are open to any user and application, making the usage of ISM bands inconsistent and unpredictable.

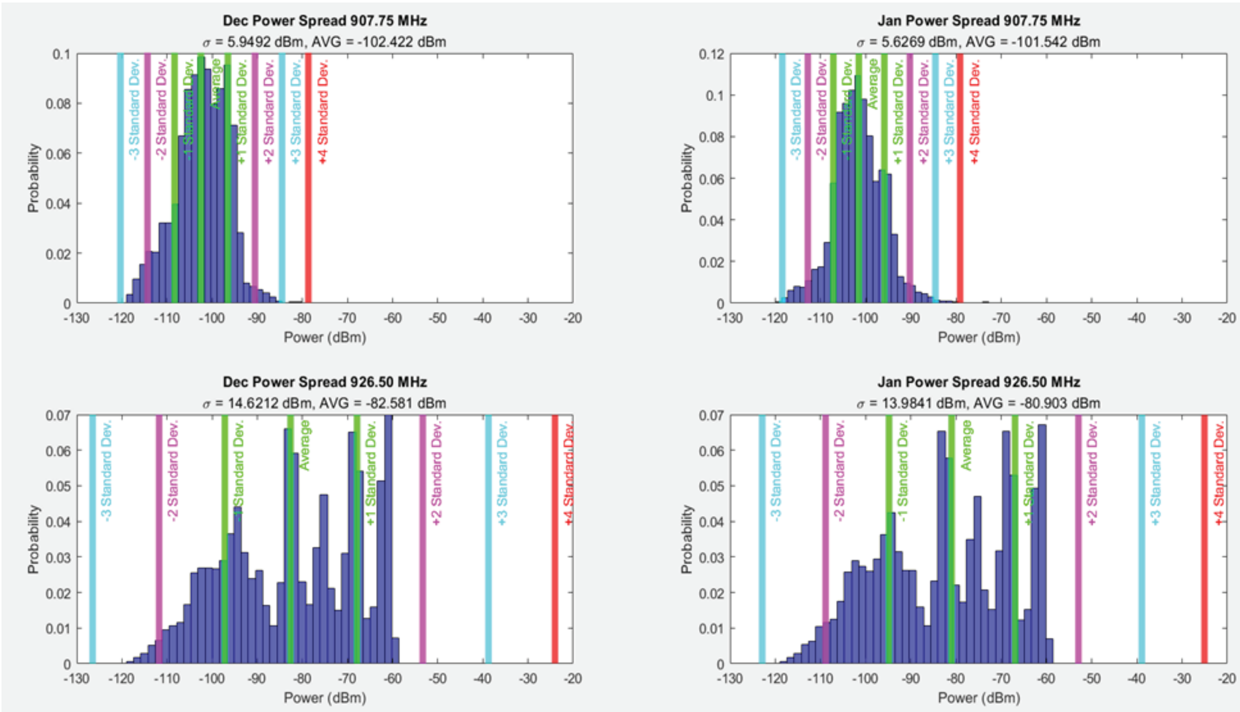

Figure 10. Power Spread of 907.75 MHz and 926.50 MHz.

Understanding the typical environment and power spread can potentially help make decisions to determine what entails irregular or dangerous environmental conditions. A greater understanding of how these statistics impact the flight radios needs to be established to determine if this could be a useful go/no-go indicator.

5.5: Occupancy

Occupancy is an indication of how much a frequency band is being used. This measurement is calculated over a specified period of time and is represented as a percentage of channel usage. The International Telecommunication Union (ITU) has created a report with recommendations on how to measure occupancy [5]. To calculate frequency channel occupancy, a power threshold must be determined. The threshold is used to determine how much time or how many samples are above the occupancy threshold. This threshold should be set to a level low enough to be able to identify signals from the radio being used and high enough to avoid noise and unnecessary signals. Once a threshold is established, there are two methods of determining occupancy. The first method is found by dividing the amount of time spent over the threshold by the integration time [5]. The second method involves dividing the number of points over the threshold by the total number of points and can be used if a constant revisit time can be assumed. The revisit time is how long it takes the measurement device to visit all the channels and return to the first [5]. The ITU definition of the two frequency channel occupancy methods is shown in Figure 11 [5].

Method 1

$$FCO = \frac{T_O}{T_I}$$

T_O : time when measured level in this channel is above the threshold

T_I : integration time

Method 2

$$FCO = \frac{N_O}{N}$$

Assumes constant revisit time.

N_O : number of measurement samples on the channel concerned with levels above threshold

N : total number of measurement samples taken on the channel concerned during the integration time

Figure 11. ITU FCO Definition [5].

Because the data is unevenly spaced over time, the revisit time is inconsistent, meaning the second method is not an option for the historical data. The first listed method was then examined. An integration time, T_I, of one hour was examined in the historical data, meaning all points within one hour were analyzed to determine how many were over the threshold. To determine the time measured above the threshold, a duration would have to be set for each point. Because it has been established that each scan happens in milliseconds, the duration of each point would have to be milliseconds long. This means that a very small percentage of the hour is observed, which results in an inaccurate occupancy measurement. The ITU describes that it can be difficult to create an occupancy that produces useful and necessary information when multiple systems may occupy the same frequencies and when frequency agile radio systems, including frequency hopping, are involved [5]. The inconsistent time intervals and small observation times violate the assumptions of occupancy estimations making it impractical to calculate using the historical data.

5.6: Threshold Observations

Although an accurate occupancy measurement as defined by the ITU cannot be established using the historical data, viewing points that cross the threshold can provide insight into the patterns of the environment. The threshold used can be easily changed, based on the needs of the hardware and a determined level of power at which interference may occur. Based on power levels shown in Figure 9 and observed power levels of related flights, most peaks observed by Node 200343 from the radio signals are greater than -80 dBm when flown in the CERTAIN range. This value is used as an arbitrary threshold that allows the system to maintain 15 to 25 dB of signal to noise ratio (SNR) (See Figure 12). This threshold can be used to observe the flight radio signals or potential interference sources. The value of the threshold should be reevaluated based on empirical observations of interference.

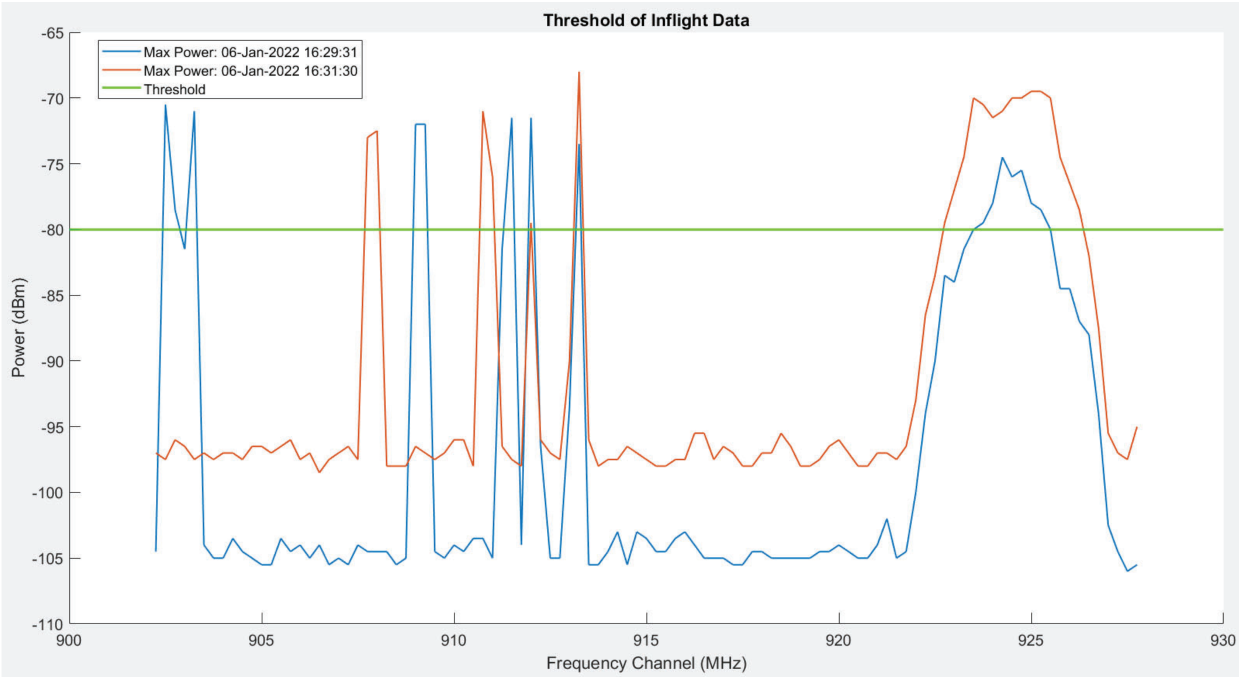

Figure 12. Flight Observation Threshold.

Although Figure 12 is useful for determining an arbitrary threshold, viewing where in the spectrum and when a power level occurs above the threshold can give decision makers insight into the usage of the spectrum. This gives an understanding of when the spectrum is occupied in the 103 channels. Points that exceed the defined threshold can be viewed at the time and frequency they occurred, as shown in Figure 13.

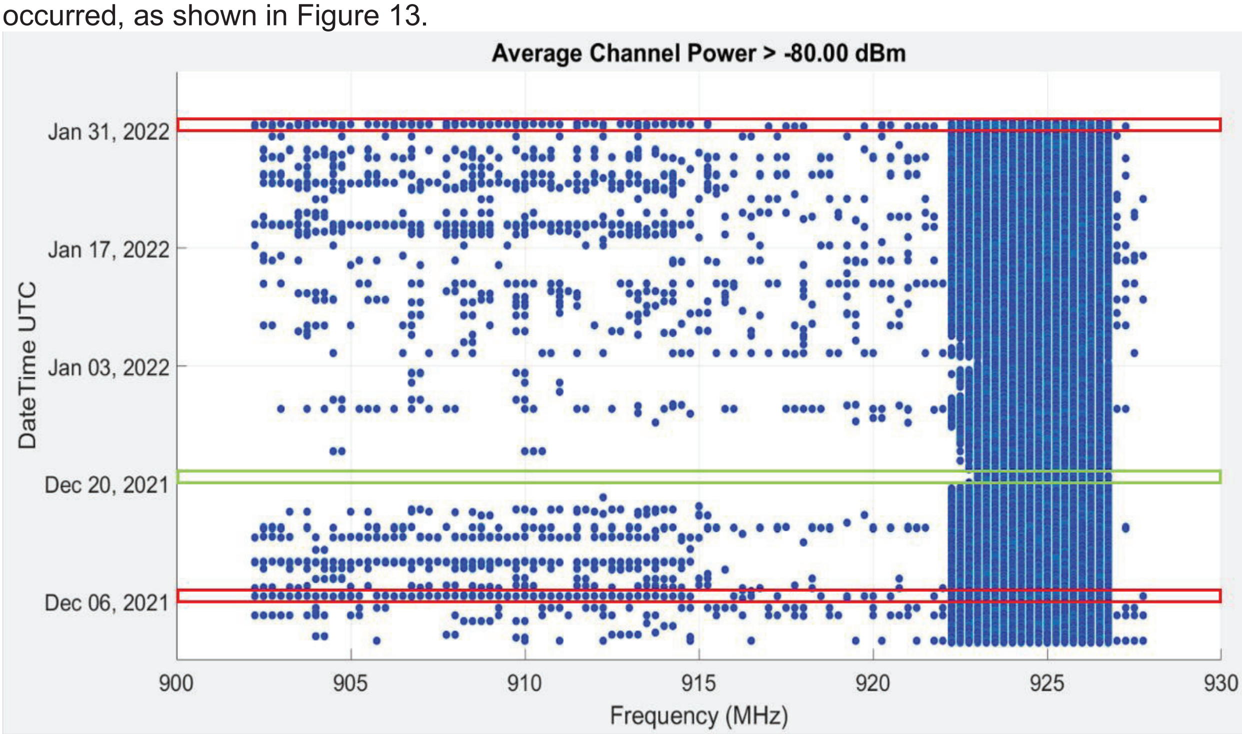

Figure 13. Data Points Over Threshold.

Viewing the times and frequencies where the power levels cross the threshold can show a lot about the environment. The NextNav signal can be observed as crossing the threshold for most of the collected data. This means that the NextNav is a source of potential interference during UAS flights. Frequencies across the spectrum, excluding the NextNav band, tend to become more active at similar times, as seen by the horizontal line pattern in Figure 13. These lines indicate days of high occupancy and may be used to determine if a day is suitable for flight. For example, the days of 12-06-2021 and 01-31-2022 show high occupancy while 12-20-2021 is clear and may indicate a good day to fly (See Figure 13). Some of the occupied times can be matched to recorded drone flights, while others are unknown sources of potential interference. This chart may be used to determine patterns of usage across the 900MHz spectrum for defining the flight environment.

6: Summary/Conclusions

Understanding the RF environment and how it may interact with a flight system is crucial in determining a standard of flight safety. CRFS RFeye historical data and information about the UAS system has been analyzed to gain an understanding of the RF environment at NASA LaRC. The historical data from the studied RFeye node gave useful insight into the RF environment, how the data is collected, and how it may be used to develop a process of determining flight safety. It was discovered during this study that the historical data provides time intervals inconsistent with the RFeye scan settings and that a software issue caused data collection to cease for a period of about two months. Data collected after the software was running again has been questioned as to whether it was accurately collected because of ongoing issues with the software. Although there are currently issues with the data collection systems, the historical data can still be used to create a process of understanding flight environments and how they apply to the hardware being used. Learning about the radios being used gives insight into what kind of analysis methods may be used. For analysis in the 900 MHz band, it was useful to condense the data to match the channels used by the flight radios. This allowed for simpler processes to be established that still represent the environment. It was found that a statistical analysis of the data would need more consideration as to how the power spread applies to the hardware and that an occupancy measurement cannot be created from this data. The most useful chart found in this study is the scatter plot which showcases points in time and frequency when the power exceeds a set threshold. This chart showcases when the spectrum may be occupied and in what channels. This information may be useful in determining usage patterns and understanding how the environment is occupied across the spectrum. Future analysis of this type of chart may be considered by conducting susceptibility testing with the radios to determine a more accurate threshold and creating a similar plot for smaller periods of time that may be easier to interpret usage patterns over time. Creating an understanding of the RF environment will create a path for improved flight safety of drone operations within SWS and at LaRC.

7. Next Steps

There is currently ongoing communication between NASA and CRFS to improve and solve data collection methods involving the CRFS software and RFeye nodes. Improving this system will allow more confidence in the collection methods and data accuracy. The CRFS system has the capability to perform occupancy scans following the ITU recommendations. CRFS occupancy scans invoke sweep scans but keep track of the time signals that are active above the specified threshold [4]. The frequency range, channel width, and integration time are parameters specified by the user and it may be useful to set these parameters to match the operations of the radios. The occupancy scan capabilities could provide even more insight into the RF environment by determining the amount of time each channel is occupied. This could possibly result in improved observation times. Empirical observations may be used to determine if an occupancy percentage threshold can be used as an indication of dangerous flight conditions. Occupancy data could also be collected to create a chart like Figure 13, where an occupancy percentage threshold may be used instead of a power threshold if that is determined to be helpful.

Another step that could be taken to further this project is to understand how the 2.4 GHz radios interact with the RF environment. Because the 2.4 GHz radios use a DSSS modulation technique, the signal power levels may be within the power levels of other transmitters. More research is needed to understand helpful analysis methods and interference risks with the 2.4 GHz radios.

Finally, the CRFS system may be used for geolocation services. This is done by collecting data from multiple nodes at the same time which will allow a more comprehensive view of the environment at NASA LaRC. Geolocation can provide insights into potentially dangerous areas to fly and collect more precise data for across the LaRC campus by expanding to the areas that can be monitored by the network of RFeye nodes. This will allow a larger observation area making it possible to monitor the space in which flights will take place, and increase the confidence of safety determinations.

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