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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

The integration & evaluation of aerial Transportation in urban settings

Christopher Haruna

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Traffic Safety

SUPERVISOR :

Prof. dr. ir. Ansar-Ul-Haque YASAR

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De heer Roeland PAUL

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The integration & evaluation of aerial Transportation in urban settings.

"Testing the Impact of environmental RF signal radiation on UAV's" (Case of Hasselt and Diepenbeek)

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Abstract

With their flexibility, zero emission value, increasing payload capabilities and aerial speed, UAV's have the potential to feature as the next mode of transportation that could be well integrated in an urban setting without the concern for environmental disruption owing to carbon-based emissions. For passenger mobility, UAVs potentially hold the solution to the age long issue of traffic congestion in the urban fabric of transport, and when considering freight forwarding, UAVs could alleviate the huge challenge of the last mile. In today's world, RF signals are generated from almost every digital device, residential building and civil Infrastructure which possess smart capabilities. When flying UAVs in any urban location, it is important to know the impact of these generated RF signals on the specific UAV and how it could affect performance and the overall safety index of UAV operations. This research evaluates and tests the effects of these signals on a UAV operating on a 2.4ghz channel in urban areas and proposes solutions to mitigating the risks involved when operating UAV's. Using a DJI Tello drone, flight experiments will be performed in two different urban locations to test the impact of RF signals on drones. The experimental results will be used to determine if path planning which incorporates signal avoidance for UAV's is essential for optimal performance and safety, as well as justify how RF signals can impact adopting UAV's as an urban mobility solution.

Dedication

In your perspiration, I found Inspiration and your love taught me how to dream…

To my mother,

Margaret

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Highlights

- Comparison of Drone flight speeds between Hasselt having more population density and Diepenbeek having less population density.
- The outcome of varying UAV flight altitudes on flight speeds between high population environments and low population environments.
- The implication of reduced UAV performance in an environment.

Scientific unit Definitions

CCI- Co Channel Interference

UAV- Unmanned Aerial Vehicle

UAM- Unmanned Arial Mobility

UAS- Unmanned Aerial System

RF- Radio Frequency

IOT- Internet of Things

GNC-Guidance Navigation and Control

GPS- Global Positioning System

CME- Coronal Mass Ejections

SINR- Signal to Noise Ratio

EMF- Electro Magnetic fields

SD- Spectral Density

VTOL- Vertical Take off and Landing

IMU- Inertial Measurement Unit

GNSS- Global Navigation Satellite system

Chapter 1. Introduction

UAV's and the Potential to Sustainable Transportation

In the field of aviation and flights, flight safety remains the crucial focal point. Civil airplanes which are airborne, have a higher probability to experience technical issues or in some cases plane crashes in the face of hazardous atmospheric conditions. Efficient path planning could assist airplanes in avoiding severe weather conditions and ensuring the safety of passengers and commodities. In addition to safety, efficient path planning can also help reduce energy costs and assist in collision avoidance during flights.

As pointed out by Zhang et al. (2016), the use of an Algorithm in a simulated test flight improved the flight optimization of the test airplane while still operating within the requirements of aviation rules and safety. The Algorithm was also proven to be efficient with unmanned aircraft, whereby the unmanned aircraft successfully avoided restricted areas while utilizing an optimal path in Hazardous weather conditions, and finally arrived at its destination point.

As far as unmanned aerial mobility-UAM goes, unmanned aerial Vehicles- UAV's are currently emerging as a new kind of transportation option that is to be operated within national airspace. According to Yakushiji et al. (2020), based on wide advancement in technology, the operational feasibility of UAV's has been verified and a wide array of potential windows have been created for UAVs in medical and commercial applications, most specifically in the domain of commodity transportation and logistics-Unmanned Aerial Mobility.

However with all the potential possibilities that UAM could present, transport authorities did not perceive a situation where unmanned aircraft would become mainstream, so as asserted by the US government accountability office (2018), due to inadequate information there are lack of fixed policies and regulations that govern the operation of UAV's in airspace, which when compared to other transportation modes that have regulations in place, make UAM a mode of transportation with potentially undefined risk indexes and safety unknowns.

In the United States, the federal aviation administration stated the rising need to develop and establish policies standards and procedures that would regulate and enable future UAV operations within the national airspace. Since safety is an essential requirement in the operation of UAV's, this research will be adopting a safety-based approach in a bid to enlighten Public UAV policy making.

In the pursuit of sustainability, the world is also drifting towards the development of connected cities, smarter environments, intelligent transport and the internet of things- IOT. According to Angeliki Toli et al. (2020), the essential goal of every smart city is sustainability, hence urban sustainability pops out as one of the main themes. As far as the literature of smart cities are concerned, Evergreen (2018) also described smart cities as resilient and inclusive cities which are built collaboratively, incorporating different types of technology, mobility and data in order to achieve a better quality of life for all their residents. Hence it is not out of place to note that smart cities would include the adoption of UAM as a vital component of its design.

There is a wide range of commercial and civil applications for UAV's, there are a number of areas which UAV's have proven to hold a huge potential. In Europe, the (UAV safety issues for civil operations) USICO project, which is being sponsored by the EU commission aims to achieve commercial and civil UAV operations within European airspace.

Dai et al. (2019) stated that using geomagnetic fields for navigation has become mainstream in the field of navigation due to its passive and subtle advantages. In geomagnetic navigation technology, fetching the accurate measurement value of the geomagnetic field in the navigation area, is the fundamental theory of geomagnetic matching which is the crucial for determining the navigation accuracy. As a result of the special features of the magnetic field detection payload, the magnetic interference of the UAV platform will affect the magnetic field detecting equipment during the aeromagnetic measurement process. Therefore, it is necessary to measure and analyze the magnetic characteristics of the UAV body before the flight mission. Noise is processed to obtain high quality magnetic field data.

The UAV, Technology and Applications

The Scientific American Journal (2012) defines Unmanned Aerial Vehicles (UAV or Drone) as non-manned aircraft which are operated by wireless remote-control gear and its own program control device. It is ultimately made up of communication technology, sensor technology, intelligent control technology, information processing technology and power propulsion technology. Over the previous years, there has been a significant expansion in the types of UAV's which are currently available. Although current drone markets offer a wide range of systems, there is still no universal classification.

In the United States, the US military utilizes a tier system with specifications attributed to range and endurance, however in Europe, the size and payload of the drone is crucial in categorization.

	Advantage	Disadvantage	Visual
Fixed-Wing	• Long range • Endurance	• Horizontal take-off, requiring substantial space (or support, e.g., catapult) • Inferior maneuverability compared to VTOL (Vertical Take-Off and Landing)	 Source: Indra Company
Tilt-Wing	• Combination of fixed-wing and VTOL advantages	• Technologically complex • Expensive	 Source: sUAS News
Unmanned Helicopter	• VTOL • Maneuverability • High payloads possible	• Expensive • Comparably high maintenance requirements	 Source: Swiss UAV
Multicopter	• Inexpensive • Easy to launch • Low weight	• Limited payloads • Susceptible to wind due to low weight	 Source: Microdrones

Fig.1 UAV Build Types
Source: DHL Trend report-dhl.com

According to the table in figure 1 which highlights the various build types of UAV's, the multi-copter popularly known as the "Quadcopter drone", offers a lot of advantages in terms of low costs, low weight, VTOL which promotes high flexibility as well as 0% emission and reduced noise disturbance when flying within a habited space.

UAV's could be used for various applications based on their given build types, and a host of their applications are listed as follows;

- <u>Remote sensing</u>

Pipeline spotting, Powerline monitoring, Volcanic sampling, Mapping, Meteorology, Geology, Agriculture.

- Surveillance

Law enforcement, Traffic monitoring Coastal/Maritime patrol, Border Patrol

- Delivery

Firefighting, Crop dusting Package delivery

- Entertainment

Cinematography, Advertising

- Communications Relay

Internet, Cellular Phone.

- Disaster Response

Chemical sensing, Flood monitoring, Wild fire management

- Transport

Cargo Transport

- Search and Rescue

Amazon Prime Air and "The Last Mile" Challenge

According to Amazons plan; 'Amazon prime air' was slated as a delivery service that would be entirely made up of UAV fleets, the whole aim of the plan was to save time, produce zero emissions and also have the potential to efficiently achieve sustainability. However, in order for a drone to land a delivery, subscribers to the service need to have custom landing areas for these UAVs. Such landing areas have to be flat, free of livestock, people, traffic, and other objects which may pose as hazards.

In order for these requirements to be met, some assessments need to be carried out. However, 13 years after Amazon launched its prime delivery service in 2007, there's still been little change, when it comes to the challenges associated with the last mile delivery. Amazon have been working on a driven plan to achieve instant delivery, with the primary target of, utilizing 30 minutes for the last mile deliveries to doorsteps after clicking the "Order Now" button.

As presented by Walia (2020), a majority of delivery companies relying on a supply chain encounter common challenges during the last mile of every products journey.

As regards to high costs; from the first step of the products exiting the shipping container to the clearance from the truck's load, to the loading of smaller vans and in some cases cars or two wheelers for the final distribution of those products, it is important to note that the drivers performing the final lap of such distributions in a locality are restricted to a fraction of the millions of products that were shipped, hence the need for more drivers for the trucks and even more drivers for the smaller vehicle drivers that run the final distribution phase, especially in a case where the demand frequency is influenced by peak periods. Therefore, the high employment rates of these drivers to satisfy demand and supply of these products would come at very high costs to these shipping and forwarding companies. This has made Amazon to experiment with the idea of cutting out these excessive costs by using autonomous scout vehicles and more recently UAV's.

UAV's as a solution to the Last Mile Challenge

Amazon started testing their drone fleet since 2013, however the approval from the Federal Aviation Administration to operate a drone fleet for delivery was given in 2020, joining the list of companies, who are currently exploring the concept of adopting drones for the last mile solutions, such as Wing Aviation owned by Google's parent company, Alphabet, UPS flight forward, DHL Parcelcopter, Zipline and Flytrex (Euland, 2021). This concept is based on a supply chain that utilizes drones after the normal packaging process, however the boxes are specially customized to be carried by drones. These Drones takeoff from Drone ports within the facility up to altitudes of about 300 feet before embarking on last mile trips.

Similar to self-driving cars, UAV's consist of several sensors such as GPS, visual, thermal, sonar and IMU sensors which help it in navigating its surroundings and this forms the basis of what Amazon refers to as "sense, and avoid technologies" on UAV's. When the UAV reaches the delivery address, it starts scanning for safe landing areas which are devoid of obstacles, and this is done by the UAV determining a suitable landing area, based on data supplied by the client, a mapping system, or a special map that provides the UAV a reference data point. The map technology employs the use of either a machine-readable color-coded symbol for the Drone, or a QR code, that confirms the correct location supporting privacy.

Although, the Current weight limit for Parcels for UAV delivery is set at 2.3 kilograms, Amazon have claimed more than three-quarters of its Parcels weigh Less than the 2.3Kg weight limit. Hence various UAV models will be ideally designed for different environments, that are suited to the specific nature of different Cities.

Fig.2 Amazon Delivery UAV concept ***source****: euthespectrum.com*

Fig.3 Cargo UAV illustrating high payload potential ***source****: morethanshipping.com*

As illustrated in Fig.3, UAV's have been conceptualized for freight transportation. Based on the world shipping council reports (2014), container ships are responsible for a large fraction of transported goods in the world and more than four trillion dollars' worth of goods annually, however, it takes over a month for these goods to move, from Beijing to New York via the sea route. On land, Trucks are responsible for about seventy-one percent of all freight weight in the United States. The challenge dwells on the fact that there's a shortage of truck drivers in the U.S.

Problem Statement

When flying UAVs in an airspace, UAVs are subjected to signal interference from various sources within a city, the "smarter" and more connected the city, the higher the generated signals. These signal interferences from communication networks and other signal generating sources could present an unknown operational risk as well as a safety risk for UAV's.

Since some areas in a city could have high RF signal density generated from communication networks, not all areas should be deemed safe for UAV flight paths.

In this research, we will be investigating how certain areas in a city could increase the safety risk of UAV operations and there will be a methodical analysis of the safety considerations for operating the different UAV categories in airspace.

The analysis is aimed towards investigating how to protect the public from harm, while realizing the potential public benefit of UAV operations.

Research Questions

This research will be mainly considering the following research questions;

-*1 Can urban RF signals negatively impact the performance of UAV operations?*

-*2 Can urban RF signals negatively impact the use of UAV's as a mobility solution?*

-*3 Should path planning routes which avoid RF network areas for UAV's be a fixed operation policy for UAM"?*

Research Objective

This research's goal is to categorically study the impact of signal interference from RF signals within an environment on the performance of UAVs within airspace.

The findings of this research would determine if it is imperative to incorporate path planning that are signal aware for the operation of UAVs in a city as well as determine if dense communication network clouds within an environment could pose a safety risk for UAV operations.

In addition, the findings of this research would also determine if network congested areas in an environment could increase UAV crash risks and also as a pilot study to the model of using drones as a last mile solution.

Chapter 2. Literature Review

The UAV System

As much as UAV's offer various new possibilities whereby advanced technology can be utilized for traffic avoidance, communication with air traffic control and aircraft control, UAV's also have very different architectures as when compared with manned aircraft operations, there is basically a separator between the operator and the aircraft. UAVs essentially possess a sensor operator which regulates the UAV payload, to obtain environmental information, sometimes an operational controller is utilized to control the UAV activities. According to Boukoberine et al. (2019), the UAV platform is composed of;

1. an onboard flight control system based on processing units handling essential tasks, such as guidance, navigation and control (GNC) algorithms, in-flight data gathering and analysis, communication with the ground station, and mission planning;

2. a propulsion system including power supply sources, speed controller, converters, energy management system, motor, and propeller;

3. the required sensors to maintain an autonomous flight;

4. payload: equipment needed for the missions, such as actuators, cameras and

radar

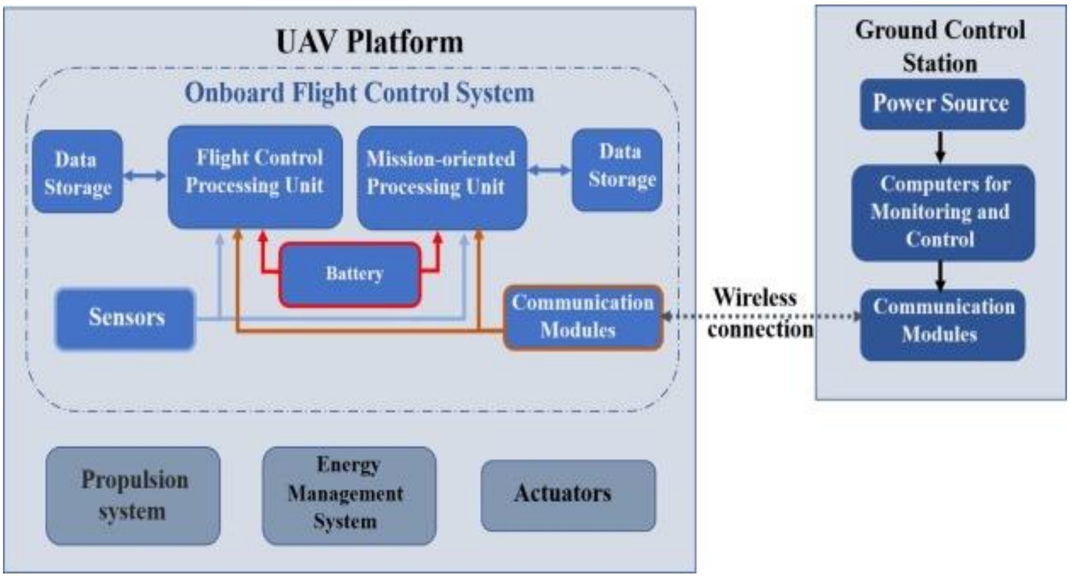


Fig.4 UAV control system Diagram

Source: Boukoberine et al (2019)

UAV Path Planning and Autonomy

Studies have identified several prevailing issues in path planning for UAVs, and amongst the multiple issues which were discovered, Zakria Qadir et al. (2021) found that; the most common challenge militating against the successful path planning for UAV's is the optimization of the system. The main goal in path planning is to achieve optimum computational costs, reduction of flight times and reduction of collision risks between UAV's which are mainly centered around mathematical constraints in solutions regarding the safe control for UAV's.

Guerrero et al. (2012) pointed out that the influence of the wind on the UAV behavior and onboard energy limitations are crucial parameters that must be taken into account, due to the fact that when flying UAV's either manually or semi-manually, there is the need to constantly compensate for perturbations due to weather elements. In these situations, areas such as UAV stabilization, optimal control, navigation, obstacle avoidance, wireless communications, computer vision, resource optimization, risk and operational cost minimization are fundamental issues which cannot be avoided.

According to Bijjahalli et al. (2020), navigation is the ability to determine location within a given environment and then map out a path which can lead from the current location to a desired destination. Navigating in the wilderness requires assistance from a map and using tools such as a compass GNSS or GPS to pinpoint an exact location and plot the best path to get around mountains, rivers, canyons and geophysical obstacles to reach a desired destination. Autonomous navigation does basically the same thing, without human assistance, it's the process of how vehicles determine their location, utilizing an array of sensors, usually GPS systems and built-in maps to move autonomously in an environment to reach a desired destination.

Run et al (2018) also add that an autonomous vehicle could mean any category of mobile machine, such as a car traveling down a road, a UAV on a return flight to its launch port, a satellite rocket moving across the solar system or a submarine exploring the ocean depths. Vehicle autonomous navigation in this case is the ability to make decisions and act on its own as regards to movement from one point to another.

A study Wang et al. (2020) revealed different levels of autonomy that range from level 1-5, with 1 being a semi-automated vehicle using partial human operated inputs by or a third-party, to 5 being a full out operation requiring no human or third-party input, due to the control of navigation algorithms on board the vehicle. These algorithms take over and autonomously keep the vehicle from falling into a ditch or running into obstacles.

According to Melo et al. (2021), full autonomous navigation, can be further divided into two different approaches;

- A heuristic approach, whereby autonomy is accomplished through a set of practical rules or behaviors. Although this doesn't guarantee an optimal result, it is good enough to achieve some immediate goal. The benefit of heuristics lies within the unnecessity for complete information about the environment to accomplish autonomy.
- An optimal approach, requires more knowledge of the environment that helps generate a plan and resulting actions from the maximization or minimization of an objective function.

A maze solving vehicle is an example of a heuristic approach, where this type of autonomous vehicle will proceed to wander up and down the hallways until it happens to reach the goal (Yilmaz et al. 2007). Since the vehicle doesn't maintain a map of the maze or have a downloaded maze memory to assist its movement in the maze in order to find its target. It can be said that it doesn't follow an optimal path.

A study from Baek et al. (2011), showed the heuristic approach in the simplest form of robotic vacuums such that, when it approaches an obstacle, for instance, a wall, it rotates to a new random angle and just keeps moving. As time increases, the chance that the entire floor is covered approaches 100%. therefore, in the end, the goal of having a clean floor is met, even if the vehicle doesn't take the optimal path to achieve it.

Also, Sahba et al. (2019) mention that in the absence of a heuristic methodology in autonomy, the optimized autonomous vehicles, use a process of continuously solving an optimization problem, where the vehicle builds a model of the environment, or it updates, a model which was an input, and then it figures out an optimal path to reach the goal.

It is important to mention that though optimized and heuristic approaches are good for different situations, Sahba et al. (2019) pointed out that optimal based strategies produce much better results than their heuristic-based counterparts, in the case of autonomous driving-where a vehicle has to navigate to a destination. Given the dynamic and chaotic setting encountered in traffic situations, relying on simple actions, is ideally not the best approach in achieving efficient autonomous trips. It is more efficient for the vehicle to have the ability to model the dynamic environment. Although both approaches can also be used to achieve a larger goal. Asides vehicles, UAV’s also apply these concepts in navigating air space and focus is on obstacle and collision avoidance.

When a UAV navigates through an environment that isn't perfectly known, it creates a plan. Polvara et al. (2017) emphasized the use of algorithms in building environmental models over time when exposed to a dynamic environment. This implies that the model must be frequently updated in the event of moving obstacles. Sensing and obstacle recognition is a first step for the environmental input in UAVs, given that they have to deal with unknown turbulences, bird flocks flying around, other human controlled planes and landing. Autonomous systems need to interact with the physical world and part of interaction is to collect data about the environment using sensors. This is a four step process, which entails;

- Sensing: The sensor data has to be interpreted into something that is more useful than just measured quantities.

- Perception: This is where other objects and obstacles are visualized when building a model, or mapping an environment, including the understanding of the state of the autonomous vehicle, its location and orientation. It is also entails the data interpretation, object tracking, model building and localization.

- Planning: With this information, the vehicle has everything it needs to plan a path from the current location to the goal, avoiding obstacles and other objects along the way.

- Action: Here the last step is to act on that plan. This consist of driving the motors and actuators in a way that prompts the vehicle to move in the most convenient path. Meaning that, the actuators impact the physical world after receiving data signals from the sensors, and the whole loop of sensing the environment, understanding its location in relation to landmarks of its environment continues.

Path planning in autonomous UAV, is very effective for battery optimization and the potential reduction of midair collisions. However, most of the literature that focused on path planning performed simulations and tests looking mainly at obstacle avoidance and the algorithms involved. Hence, the establishment between the energy consumption and interference has mostly been theoretically inclined.

Cellular Interference and Path planning

According to a simulation carried out by Debast et al. (2019), 3G and 4G cellular interference could increase the risk of harmful occurrences with UAV's and proposed that optimized routes for UAV's be created.

Debast et al. (2019) emphasized the need for path planning to be coverage aware by simulating trajectories with the least SINR in a virtual environment that utilized a 3D map of Flanders. Both cellular coverage and UAV movements were simulated. In the planning of Trajectories for UAV's, the desirable objective is the improvement of the SINR, but since UAV's have a limited energy capacity, the improvement of SINR is not usually dependent on very high trajectory lengths. Hence, the path length of the path planning methods is evaluated in the simulation by using the generated 3000 trajectories and averaging them. When normalized, the shortest path possible is used and it is usually a straight line. The results of the simulation showed the reduction in the probability of a wireless outage by a factor of 10, as well as the reduction in the duration of mean experienced outages by 60%, however, these were observed when the path length was increased by 7-8 %.

Jun and D'andrea (2003) proposed that UAV path planning should be based on a threat probability map. Using the Bellman Ford algorithm, they proposed an algorithm for the computation of the shortest path, having the advantage of a flexible iteration process when considering the choice of initial updates and estimates. This allows for a real time algorithm to be redistributed and implemented in a way that can handle changes in link length.

Bortoff (2000) proposed a two-step path-planning algorithm for UAVs using an algorithm which generates a stealthy path through a set of enemy radar sites of known location, and provides an intuitive way to trade-off stealth versus path length. In the first step, a suboptimal rough-cut path is generated using Voronoi polygons, while the second step, utilizes a set of nonlinear ordinary differential equations simulations, using the graph solution as an initial condition.

Electromagnetic Fields and the Environment

According to Balogh et al. (2009), the sun is responsible for a gravitational field that spreads out to all planets in the solar system. This gravitational field essentially shapes how they orbit, therefore solar activity directly influences the electromagnetic balance of the earth, as magnetism is also one part of a dual force in electromagnetism- electricity creates magnetic fields and magnetic fields, create electricity.

Webb et al. (2012) noted that plasma composed of electrically charged protons and electrons create a magnetic field as they move on the sun. This magnetic field then shapes the flow of particles, which become stuck in a dynamic feedback loop called a Dynamo, that is majorly responsible for sustaining the sun's magnetic field. Although this magnetic field stores high amounts of energy, there is a steady leakage of solar plasma from this field, into the solar system, which creates a semblance to a type of “rainy” weather in space.

Akasofu et al. (1972) noted that “solar winds” are not calm phenomena, since the sun's plasma churns and flows around itself, its magnetic field is non-uniform. This action creates magnetic bubbles that build-up extremely high amounts of energy. When these magnetic bubbles break apart like energy bombs or explosions, which explode outwards, they emit plasma and other dangerous particles into the solar system. On earth, this process is referred to as Solar storms, or solar flares, which are basically a tidal wave of high-energy radiations. Furthermore, Akasofu et al. (1972) pointed out these radiations move through the solar system at the speed of light. picking up protons in the solar wind, and accelerating them into a high speed, solar proton storm. The effect of these storms are commonly felt by electrical devices.

According to Webb et al. (2012), coronal mass ejections, which are a massive cluster of expelled plasma from the sun's atmosphere, are fired through the solar system at high speeds of nine million kilometers per hour. Although these emissions cause no initial damage on the Earth’s surface, despite being extremely destructive in space, with damaging effects on satellites and radio communications, the Earth's atmosphere protects the earth from the worst effects of a solar flare and absorbs these blasts in the atmosphere, before it reaches the Earth’s surface.

Webb et al. (2012), further pointed out the electrified plasma from a CME is deflected by the Earth's magnetic field diverting the energy storm to the North and South Poles, where energetic particles fall into the atmosphere causing an atmospheric glow-a horizon of colorful Aurora's that can be seen in the skies. Sometimes there are incidents of solar super storms, which have a rare occurrence of at least twice a century, the resulting implication of this natural phenomena, is a geomagnetic storm, which mainly occurs when the magnetic field of the CME is aligned to the Earth's in a way where, the two magnetic fields merge, and creates a cloud which stretches until it eventually explodes the energy stored towards Earth.

As pointed out by Molinski et al. (2000), a CMEs energy can induce currents in power grids. that either completely shut it down or destroy the transformer stations that keep grids running. This type of shutdown previously occurred in Quebec when a power grid failed after a strong solar storm in 1989.

In a study of Smart et al. (2006), during the Carrington event in 1859, the largest geomagnetic storms ever were observed on Earth. Massive aurora's occurred as far south as the Caribbean which were similar to bright sun spots on Earth, however, the technology at the time, mostly telegraph systems, failed all over the world, shocking their operators, and emitting sparks.

However, in the present day there are more complex technology devices and systems, which are sensitive to solar activities, such as UAV's. According to Astafyeva (2014), geomagnetic storms, super storms and heavy CME's were seen to have an adverse effect on GPS performance, which make GPS systems to record system losses and have very error prone readings.

From the aforementioned studies, it could also be deduced that magnetism and EMF radiated signals could create significant interference to UAV's, when using a UAV to make environmental flights or calibrations. It is also important to carefully watch out for geomagnetic storms and high solar activities, as they can adversely affect the performance of the UAV. According to Notsu, Maehara et al. (2015) calm stars are also likely to create CME, which might eventually affect the electromagnetic stability of the earth.

Communication-signals

Communication signals are Radio frequency-RF waves, which are waves that are part of the electromagnetic spectrum, but have longer wavelengths than Infra-red (Barclay, 2003).

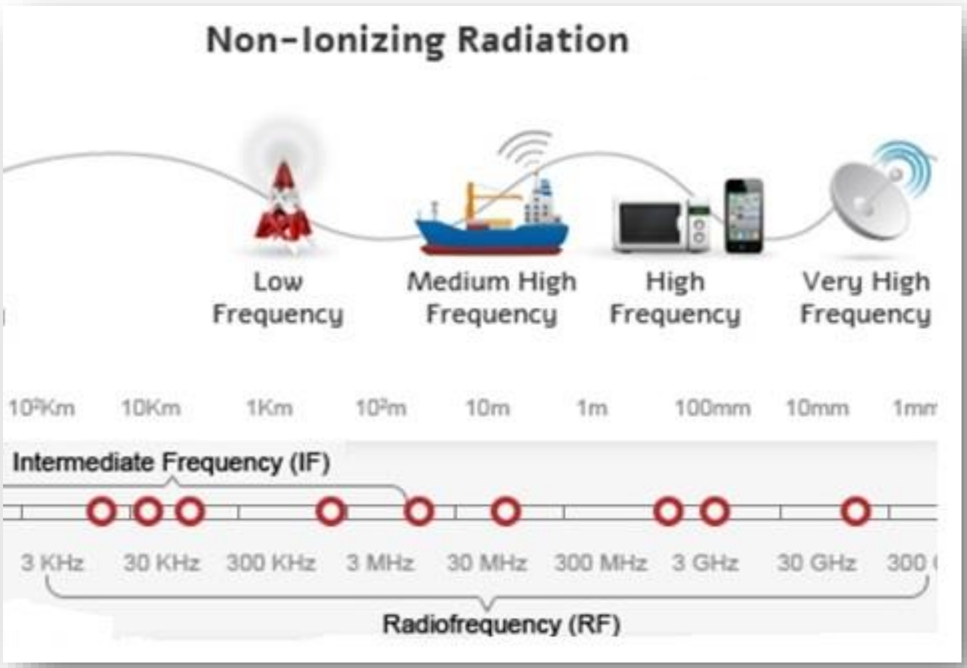


Fig.5 Signal frequencies Source : https://www.tnuda.org.il/en/radio-frequency

Fig.5 gives a clear illustration of the categorization of RF signals into levels and high frequency RF is mostly associated with mobile communication and internet data frequency.

Barclay (2003) further illustrated high frequency RF signals are most commonly used in telecommunications.

Band frequencies	**Band group ITU**	**Frequency range**	**Ranges of wave lengths**	**Examples of uses and characteristics Initial description - ITU**
VLF Very Low Frequency	4	3 - 30 kHz	10-100 Km	Navigation, time signals, submarine communication, wireless heart monitoring, geophysics
LF Low Frequency	5	30 - 300 kHz	1-10 Km	Navigation, time signals, long-wave AM transmission (Europe, part of Asia), Radio frequency identification (RFID), amateur radio
MF Medium Frequency	6	300 kHz - 3 MHz	100-1000 m	Medium wave AM transmission, amateur radio, earthquakes, avalanches
HF High Frequency	7	3 - 30 MHz	10-100m (short wave)	Short wave transmission, amateur and public radio, airways communication beyond the horizon, Radio frequency identification (RFID), beyond horizon radar, sky waves, mobile marine communication
VHF Very High Frequency	8	30 - 300 MHz	1-10 m	FM radio, TV transmission, earth-to-aircraft or aircraft to aircraft communication within the line of vision, mobile marine or ground communication, amateur radio, weather radio
UHF Ultra High Frequency	9	300 MHz - 3 GHz	100 mm – 1m	Classification according to principal generations of communications technologies:

				• Cellular, 800 – 3000 MHz (1)2nd generation (2)3rd generation (3) 3+ generation (4) 4th generation , LTE , etc • General, data transmission 3MHz-300GHz TV transmission, microwave ovens, microwave installations and communication, radio astronomy, cellular devices, wireless local area network (LAN), Bluetooth, global positioning system (GPS), two-way radio Family Radio Service (FRS) and General Mobile Radio Service (GMRS), amateur radio
SHF Super High Frequency	10	3 - 30 GHz	1 - 10 cm	• Radio astronomy, modern radars, communications satellites, TV transmission satellites, direct-broadcast satellite (DBS), amateur radio • Wireless local area network (LAN), Worldwide Interoperability for Microwave Access (Wi-Max), high-frequency 3+ GHz Wi-Fi, microwave installations and communication, modern communication technologies
EHF Extremely	11	30 - 300 GHz	1 - 10 mm	Radio astronomy, high-frequency microwave relay stations, distance sensing at microwave

High Frequency				frequency, amateur radio, directed energy weapons, millimeter wave scanner

Table 1. Frequency Table of different RF signals

Table 1 shows a frequency table of different RF signals, the 2.4 GHz Wifi channel falls under the UHF category, which is of the same frequency as cellular networks, GPS, and Bluetooth.

According to Chaube (2016), interference in Wi-Fi (802 11), is anything that corrupts or modifies the original signal. Interferences are usually sourced from non-Wi-Fi transmitters, multipath fading, co-channel, and adjacent channel Wi-Fi devices.

Chaube (2016) further stated that interference may occur between waves of an identical or harmonically related frequency, as well as multipath components, and this interference occurs at both layer 1 and layer 2. Layer one Interference comes from many common non 802 11 sources, such as microwaves, alarm systems, Bluetooth remote control devices, cordless phones, and sometimes weather radar. This type of interference, disrupts the physical carrier sense of Wi-Fi communications effectively disrupting the medium itself. However, 802 11 devices will not detect this as a transmission from another device trying to communicate with or contend for the medium, therefore, they will attempt to transmit and their transmissions will most likely collide with the noise. This causes the intended receiver to never receive the signal. Therefore, no acknowledgement can be sent to the transmitter without receiving one from the receiver. The original sender will wait until it receives an acknowledgement for a certain amount of time. This time is called the acknowledgement timeout threshold once it has expired. It will then try to gain access to the medium again by contending and trying to retransmit the signal.

A study of Villegas et al. (2007) point out that a good number of devices found on the same channel and within the same physical area will create undesirable, contention, domain sizes, and performance degradation. Traditionally this was called co-channel interference, however, it is not really interference in the same general way as noise interference, it is simply an increase in the contention for the medium that will slow down communications, but is not noise. Adjacent overlapping Channel Interference is interference more like the noise on layer 1. It happens in 2.4 gigahertz when devices are communicating on overlapping channels. They are not able to decode each other’s signals and treat those signals as if they are simply noise.

Co-channel interference occurs, whenever there are two basic service sets in close proximity on the same channel. This can be access points that have overlapping coverage or clients on the edge of two basic service sets overlapping (Mishra et al. (2005).

CCI occurs within a channel and not within a basic service set. The key is to reduce to a great extent the number of times the same channels are used on overlapping cells. Some people choose to disable 2.4 gigahertz on some of the access points throughout the environment to help accomplish this. Adjacent Channel Interference (ACI) is caused when channels are overlapped by design. Essentially, when non-overlapping channels cause side load interference or when 5 gigahertz channels and 2.4 gigahertz channels are five megahertz apart on the center frequency, and 20 or 22, megahertz wide depending upon the modulation techniques used. Therefore, it's a certainty that adjacent channels will overlap and cause interference in 2.4 gigahertz. However, in areas where neighboring wireless LANs can be seen, if they are using channels, 2 5 7 10 or 11 through 14 ACI may exist regardless of network settings. Chaube (2016).

Over the years, drone technology has developed and the costs of manufacturing drones with complex functions have been reduced, which is as a result of the growing popularity of light composite materials in the construction of vehicles and carriage devices as well as the advancement in satellite positioning technology (Austin, 2011). However, UAV's communicate and are controlled majorly by RF signals, exposure to these RF signals could cause a degree of noise during communication and control of UAV's.

EU Drone regulations

As of January 2021, all European citizens have been required to follow the same regulations in practice. This implies that, once a drone pilot has received a state authorization, he or she will be allowed to freely fly their drone in the European Union. The new framework will introduce three categories of operations; Open, Authorization and certification according to EASA (*European Union Aviation Safety Agency);*

Open: The open category, majorly covers low-risk operations. Though it will not require any authorization, it will be subject to strict limitations. Drone registration is necessary and a small test online is required.

Rules for the open category,

1. Your drone should always be in your visual periphery.

2. You cannot fly at night,

3. You can fly up 220 meters with drones in the A1 A2 and A3 class.

A 1 Class: Drones less than 900 grams. Examples are the mavic mini, spark, air, mavic Pro ***or DJI Tello.*** Basically toy drones fall under this category.

A2 Class: Drones more than 900 grams, but less than 4 kilos, like the Phantom and the mavic two Pro.

A3 are drones weighing more than four kilos but less than 25 kilos. Although these are the basic flying rules, UAV's still can't be flown everywhere, it's still important to find out if certain areas deemed safe enough to fly these drones, or if authorities have allowed their use in such places. Additionally, there's an app that assists in finding areas where a drone can be safely flown, drone spot app. Red spots on the map, indicate a "no fly zone". Red spots occur in mostly cities, and even toy drones are considered to encroach in such air spaces that are no fly zones.

If using the A2 and A3 drone class. It requires a bit more than just registering your drone online and taking quick online tests. Two theoretical tests demanded and one practical test need to be taken at a drone school, and it's strongly advised to have an insurance for all A classes.

In the eventuality of an accident or collision with a person or an object, an insurance is a prerequisite. You may be covered by your existing accident and damage Insurance, otherwise an addition of an extra drone liability cover is required.

Also, drone operators will have to acquire an authorization from the National Aviation Authority on the basis of a standardized risk assessment. Operations involving drones of more than 25 kilos or operated beyond visual line of sight, will typically fall under the specific category as a drone operator. One must perform a risk assessment and define mitigating measures or verify that they comply with a specific scenario defined by EASA and on these bases, an individual can obtain an authorization from the National Aviation Authority.

However, after a careful review of the UAV regulations that apply in Europe, EASA have not considered interference as potential transient obstacles, and did not consider a framework for the avoidance of transient obstacles.

Chapter 3. Methodology

The Methodology of this research consists of an experimental design to test the impact of RF signals on a UAV.

Currently there are a number of UAVs in use with various specifications, so to get a more precise evaluation of a UAV, regardless of the specifications and properties, performance will be examined solely on the primary function of flight speed with relation to altitude.

Experimental Design

This research will measure the effect and impacts of RF signals in two different environments on the flight speed of UAV's at lower altitudes and higher altitudes between July and August 2021.

Velghea et al. (2019), concluded that the amount of RF radiation in an environment was dependent on the population density, hence an area with a high population density will have a higher RF reading than an area with a low population density.

Citypopulation.de estimates the Population density of Diepenbeek in 2021 at 465 Km^2, while the Population density of Hasselt in 2021 is estimated at 773.9 Km^2.

In controlled conditions, test flights are carried out with a UAV over the two selected geographical locations- Kapermolen, Hasselt and Diepenbeek. These locations represent a higher population density that would radiate a high RF density, and a lower population density that would radiate a lower RF power density. The flight logs can be analyzed for data on;

-Altitude

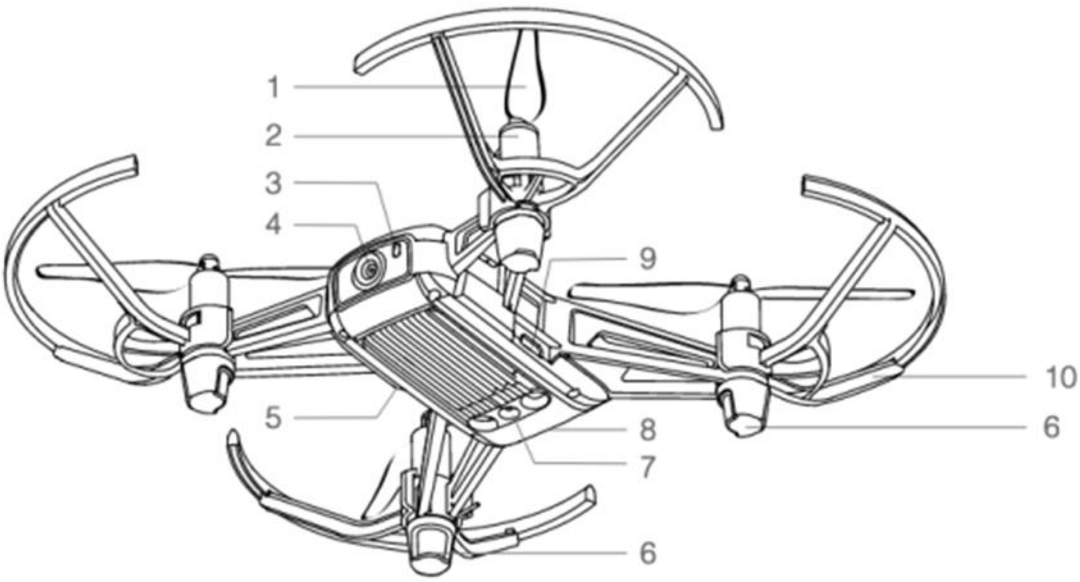
-Speed

Using a UAV air data Application dashboard; The average maximum height in meters and average maximum speed in Km/h of the drone is given for the duration of each flight, since each flight generates a unique dataset.

Equipment- UAV Type and Technical Specifications

For this study, a drone was employed.

DJI (Ryze) Tello



1. Propellers
2. Motors
3. Aircraft Status Indicator
4. Camera
5. Power Button
6. Antennas
7. Vision Positioning System
8. Flight Battery
9. Micro USB Port
10. Propeller Guards

Fig.6 DJI (Ryze) Tello Component descriptions
Source: Ryze Sheet ryzerobotics.ccom

Aircraft (Model: TLW004)

- Weight (including Propeller Guards) 87 g
- Max Speed 17.8 mph (28.8 kph)
- Max Flight Time 13 minutes (0 wind at a consistent 9mph (15 kph))
- Operating Temperature Range 32° to 104° F (0° to 40° C)

- Operating Frequency Range 2.4 to 2.4835 GHz
- Transmitter (EIRP)
- 20 dBm (FCC)
- 19 dBm (CE)
- 19 dBm (SRRC)
- Flight Battery
- Capacity 1100 mAh
- Voltage 3.8 V
- Battery Type LiPo
- Energy 4.18 Wh
- Net Weight 25±2 g
- Max Charging Power 10 W

The Dji Tello is classified as a toy drone, however the drone possess a very effective vision positioning system, that makes the drone to have optimal stability while airborne, in the absence of strong wind gusts, the drone is very stable during hover states, which ensures that any movement it attains while hovering is as a result of a directional control input.

Experimental Procedure

For this study, distance and altitude are measured in meters while speed is measured in Kilometers per hour.

The drone is flown from a random start point at maximum speed on a clear linear path free of obstacles, to a distance of 50 meters and back to the start point. This process is repeated to and fro again for a duration of least 1 minute, before landing.

The data is obtained after each flight to get readings on the average maximum speed of each flight cycle. Data on Altitude's, will be separated into two groups as categorical data, hence altitudes from 1 – 9.99 meters are categorized as a lower altitude and altitudes from 10 meters above are categorized as a higher altitude. Since the maximum height limit for the experiment is pegged at 26 meters due to the DJi Tello altitude limit. The altitudes of the experimental flights that are categorized into High and Low would determine if there would be a significant impact on the speed of the drone upon a categorical comparison when analyzed comparatively.

Nine flights were conducted on high altitude, and nine flights on low altitude in both locations, bringing the total flights carried out to 36 flights.

Flight Locations

Fig 7: Diepenbeek position Map (Lower RF location) *Source: Google Maps*

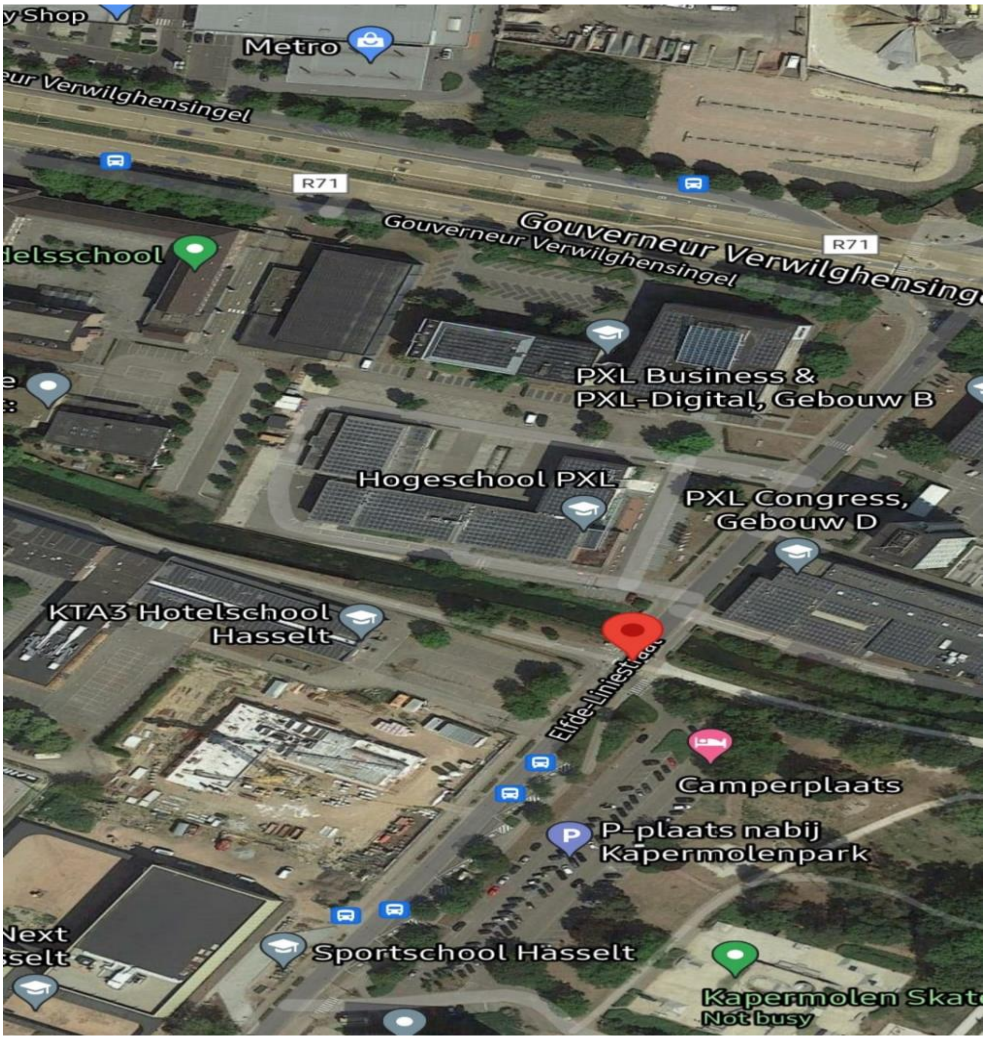


Fig 8: Kapermolen position Map (Higher RF location)
Source: Google Maps

All experimental flights carried out in the two locations, were carried out in controlled situations. The weather conditions were favorable for flights, the wind speed was relatively stable during the day and the KP index which indicated geomagnetic activity and solar flares did not exceed 3, which was stable enough to not interfere with the flight dynamics of the drone (See Appendix 9).

To avoid bias, an equal number of flights between the two locations were flown in a single day, however the testing days were spread out between the months of July and August.

Chapter 4. Analysis, Results and Findings

Flight Speed Datasets

After the flight experiments were completed, the following datasets were obtained from Kapermolen, Hasselt and Diepenbeek.

Location 1 Diepenbeek (Low RF Location)

Higher Altitudes in Meters	*Speed in Km/h*	*Lower Altitudes in Meters*	*Speed in Km/h*
19.8	**8.77**	4.6	10.67
12.7	**27.34**	5.1	10.68
25.6	**10.32**	2.8	8.90
12.0	**8.57**	1.8	11.24
12.0	**8.63**	3.1	11.79
10.5	**10.34**	1.3	8.64
10.6	**8.20**	3.1	5.35
11.5	**7.57**	6.1	12.4
11	**8.2**	3.2	5.32

Table 2: Speed and Altitude table in Diepenbeek

Location 2 Kapermolen, Hasselt (High RF Location)

Higher Altitudes in Meters	*Speed in Km/h*	*Lower Altitudes in Meters*	*Speed in Km/h*
10.5	**7.99**	1.8	6.65
19.5	**7.65**	2.5	9.71
14.4	**9.64**	2.1	8.66
16.2	**11.30**	5.4	6.70
16.5	**10.32**	2.4	8.11
14.4	**9.8**	3.9	9.8
14.5	**10.1**	0.4	3.9
10.5	**9.2**	7.5	7.92
16.2	**11.30**	1	3.8

Table 3: Speed and Altitude table in Kapermolen, Hasselt

The following Flight speed datasets were recorded on both locations via the Airdata platform. (See Appendix 8).

Although a trend was observed from the raw data, between the two locations and the two altitudes, the experiment was carried out on different days.

Analysis and Interpretation

In the boxplot analysis carried out on the flight datasets, a clearer visualization of the speed distributions in different altitudes was observed. Fig 9, shows the speeds of the UAV in Diepenbeek to attain top speeds on lower altitudes, interestingly in high altitudes at Diepenbeek a greater percentile of flights would go faster as compared to lower altitudes, where the speed ranges are almost similar hence having a common average. In Kapermolen lower altitudes showed lower speeds while at higher altitudes there is a considerable difference in speed, specifically the boxplot shows a much less variation at higher altitudes at Kapermolen, which indicates a more consistent prediction.

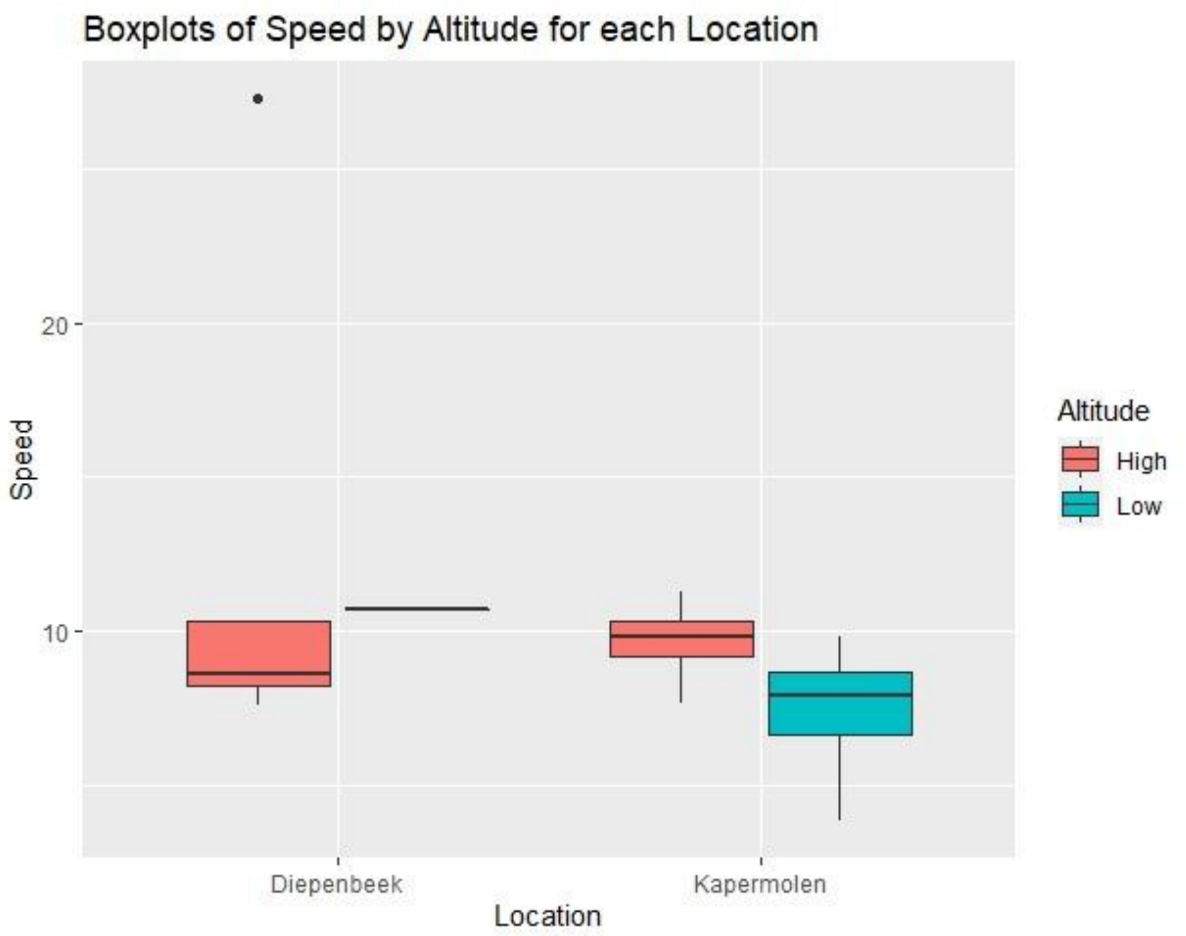


Fig 10: Boxplot representing speeds and altitude for each location *source: Rplot*

The exploratory analysis for speeds at high altitudes in both locations as depicted by Fig 10 showed there is a much less variation in speeds at high altitudes when compared to speeds at lower altitudes, and this consistency in speeds should make predictions more dependable than the more variable speeds on lower altitude, the speeds are also consistently higher at higher altitudes, hence the boxplot explains the trend which was observed in the raw dataset, whereby there is a more consistent speed outcome at higher altitudes.

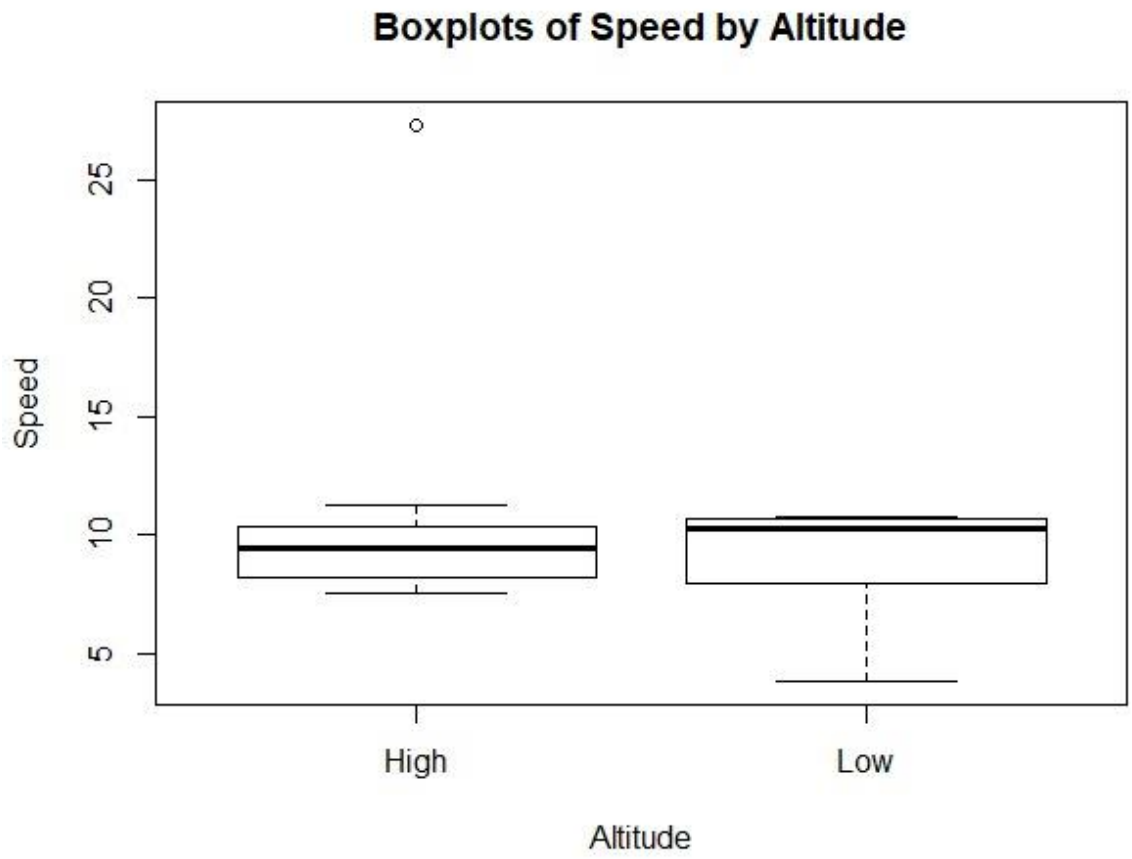


Fig 11: Boxplot representing Speeds by Location
Source: R plot

As depicted by the boxplot of Fig. 11, there is more speed variation at Diepenbeek when compared to Kapermolen, when observing the median, the median at Diepenbeek is significantly higher than the median at Kapermolen, which indicates a factor causing speed reduction at Kapermolen, which in this case happens to be the RF factor between both locations.

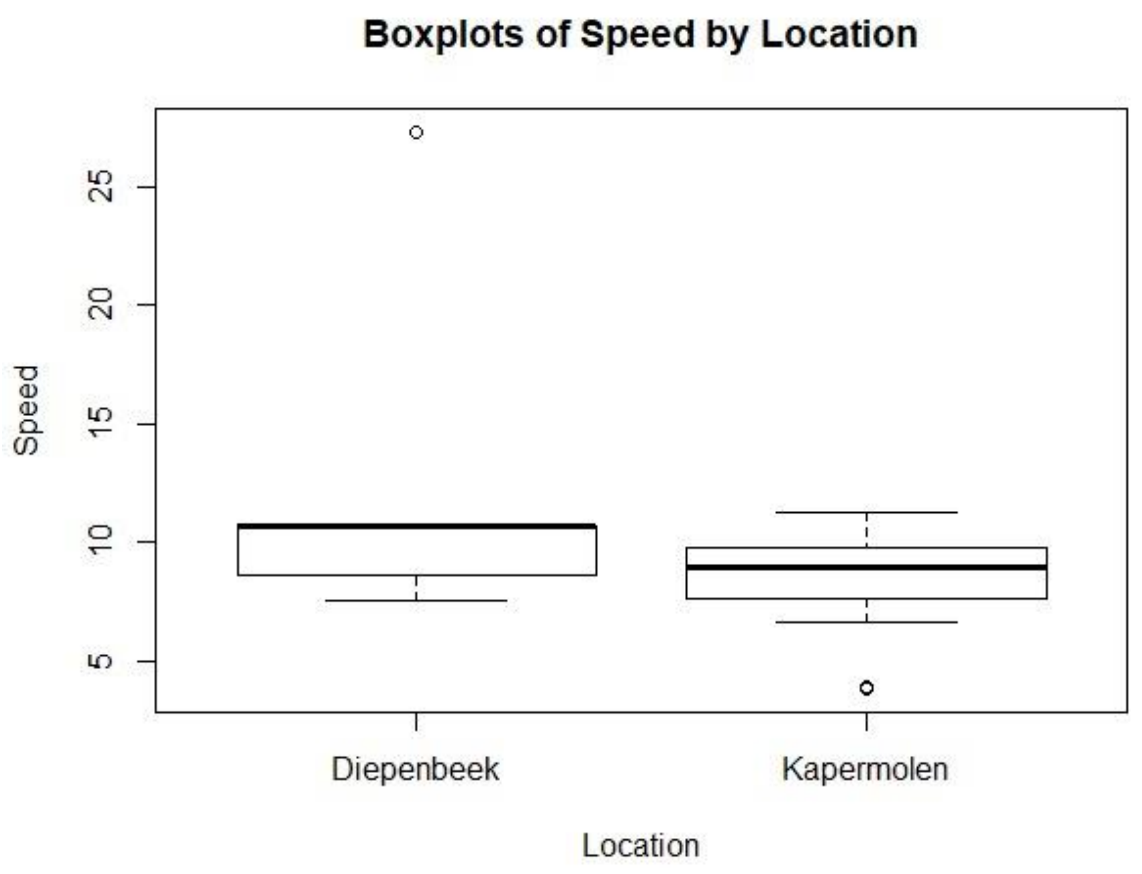


Fig 12: Boxplot representing Speeds by Location
Source: R plot

Given the clear understanding of the datasets between both locations and both altitude categories by using the boxplots for exploratory analysis. A T test is carried out to compare the two groups of speed results;

Group 1: Low-altitude speeds Kapermolen, Hasselt and Low- altitudes speeds Diepenbeek,

Group 2: High-altitude speeds Kapermolen, Hasselt and High-altitude speeds Diepenbeek

This is to compare if the means of the speeds, are statistically significant. For the First T- Test

The hypothesis is stated below;

H_o ; There is no significant difference between mean speeds of High Altitude in High RF and High altitude in Low RF locations;

H_1 ; There is significant difference between mean speeds of High Altitude in High RF and High altitude in Low RF locations;

test 1, t test for comparing speed in high Altitude in High RF Vs High altitude in Low FR#

t = -0.55665, df = 8.6689, p-value = 0.5918

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval:

-6.014745 3.650301

With the result of the P Values from the T test, *H1* can be rejected, as there is no significant difference with the mean speeds of the High altitudes in Diepenbeek and Kapermolen, Hasselt.

For the second T-test,

Ho ; There is no significant difference between mean speeds of low altitudes in High RF and Low altitudes in Low RF locations;

H_1 ; There is significant difference between mean speeds of Low Altitude in High RF and Low altitude in Low RF locations;

test 2, t test for comparing speed in low altitude in high RF Vs low altitude in Low RF#

t = -1.9122, df = 15.573, p-value = 0.07443

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval:

-4.6303358 0.2436691

sample estimates:

mean of x mean of y

7.250000 9.443333

With the results of the P values from the Second T-test, we can reject H_1, as there is no significant difference with the mean speeds between the Low Altitudes of the two locations.

Conclusions and Recommendations

It is statistically observed that locations with high RF readings have no significant impact on the speed of UAV's flown in the 2.4GHz channel, when compared to the location with low RF readings, in the case of Hasselt and Diepenbeek.

Although there is a speed difference between the two locations, which points to the explanation that RF signals can impact UAV speeds, which can basically decrease the flight efficiency of a UAV. The analysis has indicated that RF signals have no significant impact on the operation speeds of UAV's flown in the 2.4Ghz channel in the case of Diepenbeek and Hasselt.

This points to the conclusion that RF levels between Hasselt and Diepenbeek, are not strong enough to cause a significant difference in UAV mean speeds between the locations.

From the experimental observation, RF radiations are transient obstacles that can reduce UAV speeds, it is recommended for UAV's to have algorithms which consider transient obstacles in flight, I recommend putting sensors on UAV's that can perceive Transient obstacles such as RF signals and path planning algorithms that can avoid these Transient obstacles by height variation actions in the UAV trajectory.

Using UAV's as a solution to the last mile challenge in a city with a high population density, could give rise to lower speeds, compared to using UAV's in a low population density environment, however the mean speeds based on the statistical results, did not have a significant difference in the case of Hasselt and Diepenbeek. Therefore, the operational efficiency of a UAV between locations like Hasselt and Diepenbeek could have differences in UAV speeds that are not too spread apart, especially if the UAV's are flown on a 2.4GHz channel.

While carrying out the experiment it was also noted that the UAV drifted sideways a lot more during mid flights in the high RF zone, while in the low RF zone, the UAV was more stable and less drifting was observed.

It is important to note that Geomagnetic activities are important to note in order to have proper flight readings as the UAV could get unresponsive in the presence of Solar flares and geomagnetic storms. Motors with induction principles are prone to these geomagnetic activities and UAV'S with quadcopter designs are easily affected.

Future Research

It is recommended for future research to be carried out on Drones using LTE networks, so as to accurately measure the impact of RF signals on LTE, since LTE connections for UAV's have a longer range and stronger connection when compared to WiFi connection.

I recommend the usage of drones that have a higher altitude for tests beyond 30 Meters, as a difference in speeds were recorded, however the Dji Tello was not capable of going beyond 26meters without the risk of a fly away.

I recommend further tests to be carried out in locations with a larger difference in population densities and specific RF readings to get more accurate readings from the UAV, to have a specific measure of RF impacts to the UAV speeds.

I recommend further studies to be carried out on the impact of RF signals on the RSSI (Received Signal Strength Indication) on drones as there was an unexplained drift in the high RF location which was not observed in the low RF location.

The impact of RF signals on UAV's with enabled GPS systems would also be useful since most LTE connected drones are GPS enabled.

It is also recommended to research the relationship between RF interference and battery power consumption of the UAV's.

Limitations

In the early stages of the research, the researcher suffered a spell of Covid-19 which limited the progress of the experiment.

Conducting the experiment was highly dependent on favorable weather in Diepenbeek and Hasselt, it was often too hot which affected the performance of the drone when making a hover ascension (constant overheating warnings), it was also mostly windy on most days which created air resistance when flying towards head wind and this affected the results. Rainy days also militated against the possibility of flying a drone. Therefore, stable flights largely depended on the elements being favorable. Within the period of July and August in Belgium favorable weather for flying was not readily available for repeated flight procedures over certain areas especially in Diepenbeek and Hasselt.

More flight logs from other drone’s specifications in different fields and environments would have also helped the study to have more robust data, however due to flight logs being very sensitive pieces of information, they were not readily released by drone tech companies.

Using the DJI Ryze tello which is categorized as a “Toy” drone offered a lot of limitations when conducting the flight experiments, such as duration on a single battery charge; the battery charge duration for a Ryze tello drone is fixed at 13minutes, however if attaching the propeller guards which are extra weights, the flight time is reduced to 10/9 minutes, limiting the number of flight experiments the researcher could make between two locations in a day.

The flight data analyzers on the Airdata platform usually gave incomplete flight logs due to the DAT files not being compatible with the system, so data about total distance covered, battery health and rudder information was usually not available.

The Tello drone uses its own Wifi network for communication which gave the drone a very limited operation ranges, and a single channel on 2.4Ghz, did not permit the researcher to test the robustness of the 2.4 Ghz channel. The lack of a GPS feature on the drone also reduced the test range of other variables as stability of the drone depends on just the optical sensors.

Solar flare incidents occurred which the UAV flight log recorder was not able to get proper readings during the days with Solar flare warnings or Geomagnetic storms.

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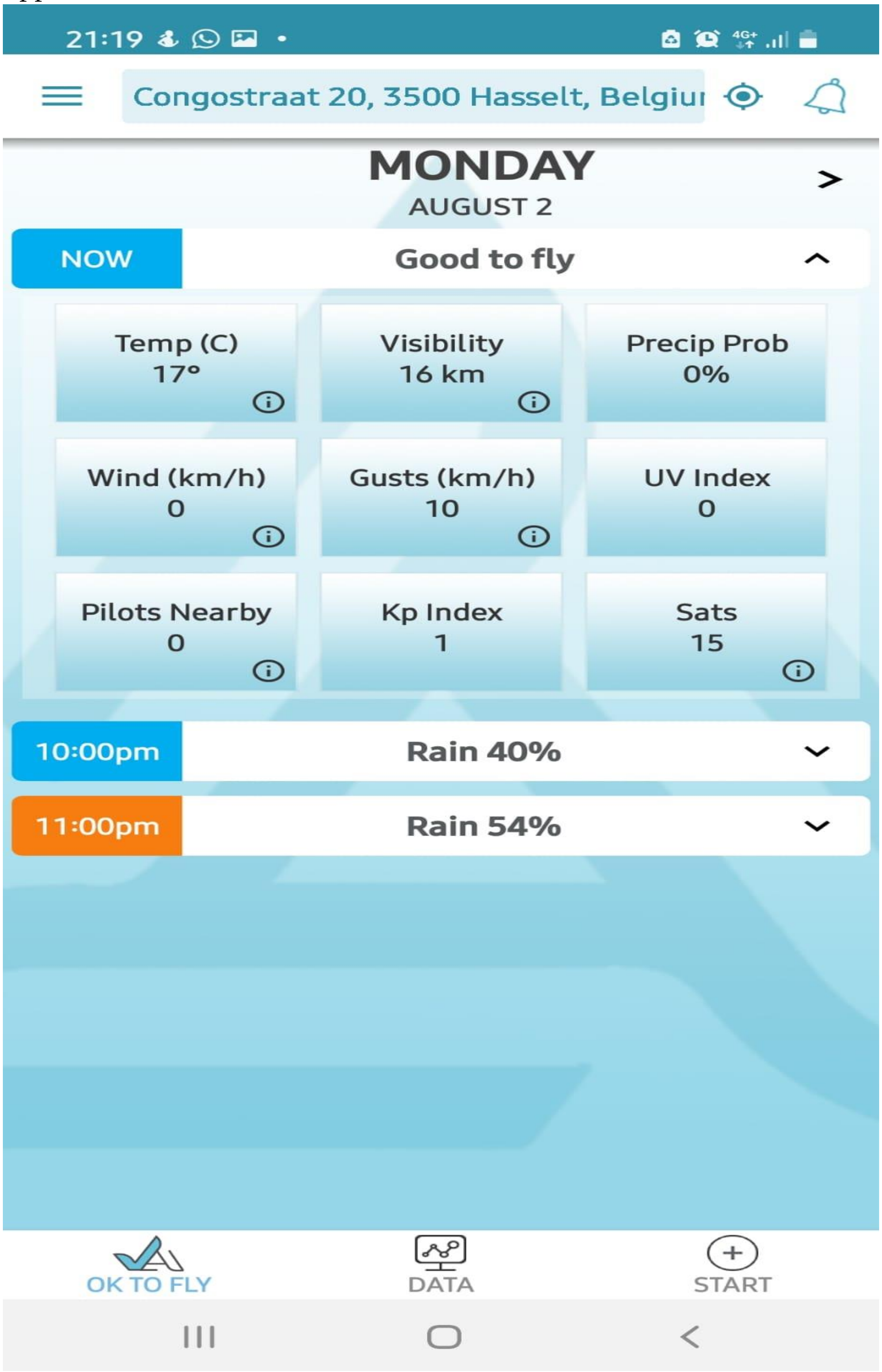
Appendices

UAV Weather Data Logs

Appendix 1

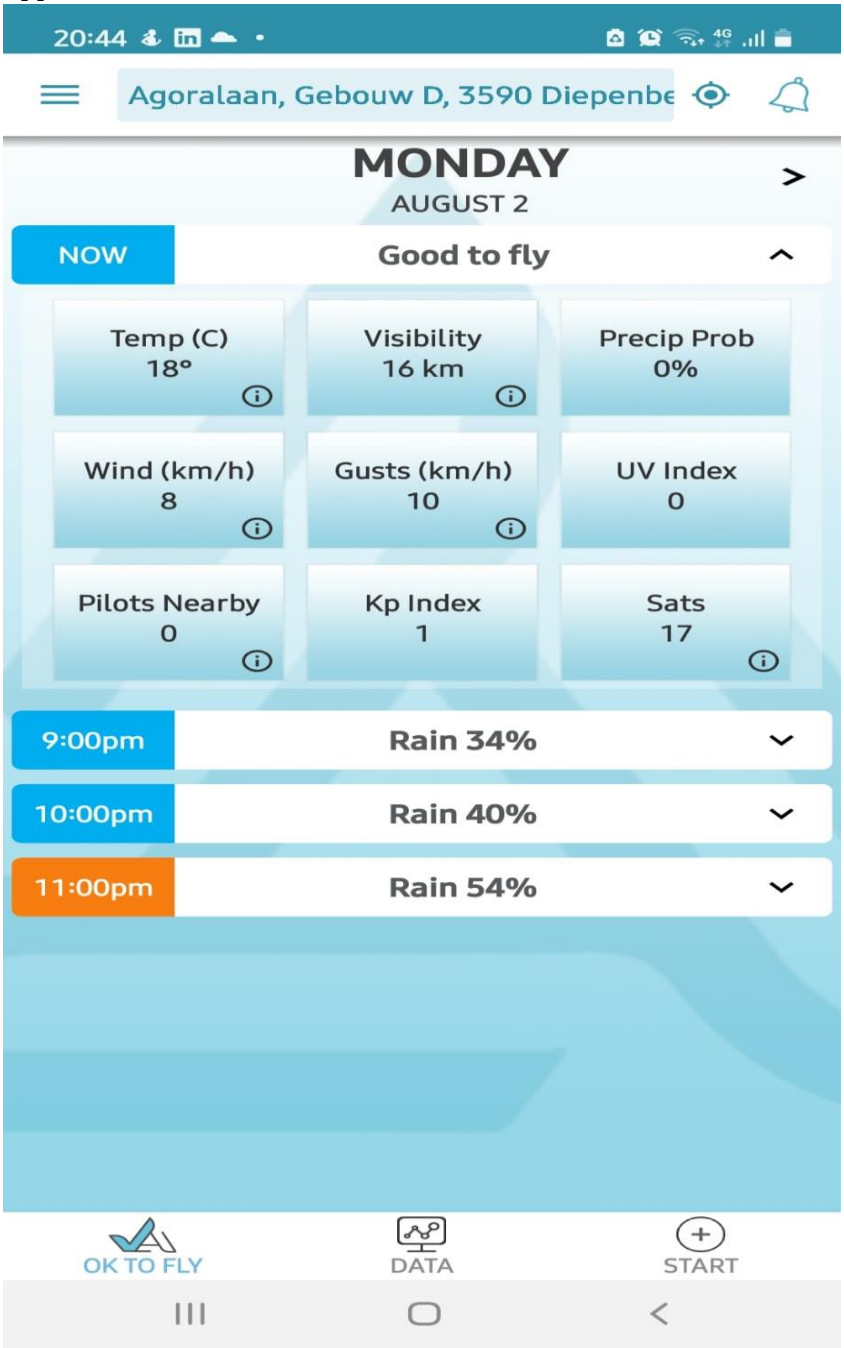
Appendix 2


21:19
Congostraat 20, 3500 Hasselt, Belgiu
MONDAY
AUGUST 2
NOW
Good to fly
Temp (C)
17°
Visibility
16 km
Precip Prob
0%
Wind (km/h)
0
Gusts (km/h)
10
UV Index
0
Pilots Nearby
0
Kp Index
1
Sats
15
10:00pm
Rain 40%
11:00pm
Rain 54%
OK TO FLY
DATA
START

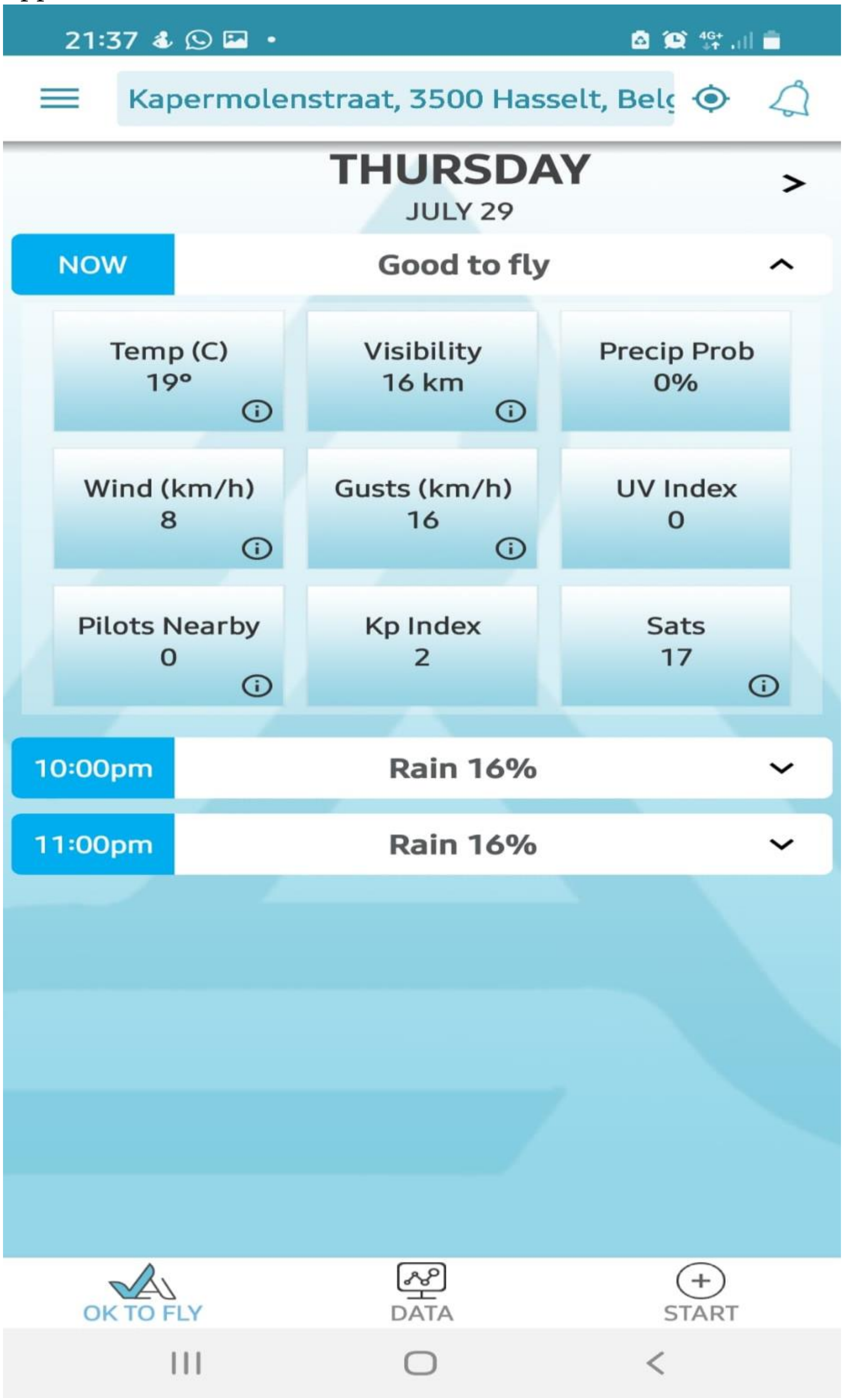
Appendix 3

18:59
Kapermolenstraat 18, 3500 Hasselt, E
MONDAY
AUGUST 2
NOW
Good to fly
Temp (C)
19°
Visibility
16 km
Precip Prob
0%
Wind (km/h)
8
Gusts (km/h)
11
UV Index
1
Pilots Nearby
0
Kp Index
1
Sats
20
7:00pm
Rain 34%
8:00pm
Rain 34%
9:00pm
Rain 34%
10:00pm
Rain 40%
11:00pm
Rain 54%
OK TO FLY
DATA
START

Appendix 4


20:44
Agoralaan, Gebouw D, 3590 Diepenbe
MONDAY
AUGUST 2
NOW
Good to fly
Temp (C)
18°
Visibility
16 km
Precip Prob
0%
Wind (km/h)
8
Gusts (km/h)
10
UV Index
0
Pilots Nearby
0
Kp Index
1
Sats
17
9:00pm
Rain 34%
10:00pm
Rain 40%
11:00pm
Rain 54%
OK TO FLY
DATA
START

Appendix 5


21:37
Kapermolenstraat, 3500 Hasselt, Bel
THURSDAY
JULY 29
NOW
Good to fly
Temp (C)
19°
Visibility
16 km
Precip Prob
0%
Wind (km/h)
8
Gusts (km/h)
16
UV Index
0
Pilots Nearby
0
Kp Index
2
Sats
17
10:00pm
Rain 16%
11:00pm
Rain 16%
OK TO FLY
DATA
START

Appendix 6

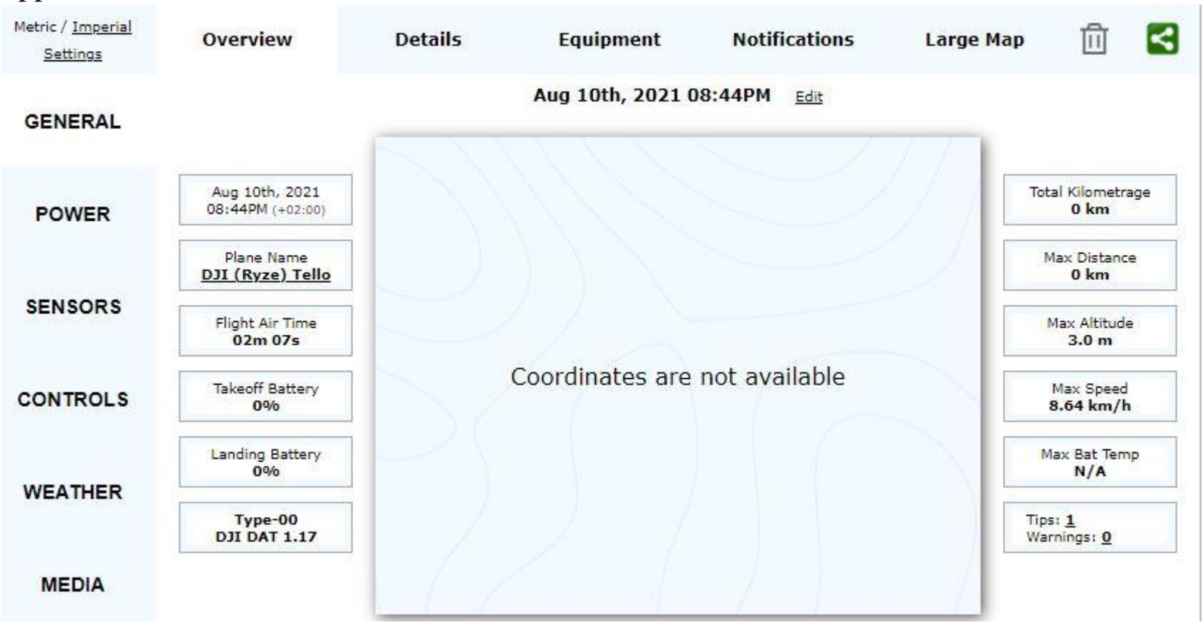
22:12
Willekensmolenstraat 61, 3500 Hasse
WEDNESDAY
JULY 28
NOW
Good to fly
Temp (C)
17°
Visibility
16 km
Precip Prob
0%
Wind (km/h)
11
Gusts (km/h)
16
UV Index
0
Pilots Nearby
0
Kp Index
3
Sats
19
11:00pm
Rain 29%
OK TO FLY
DATA
START

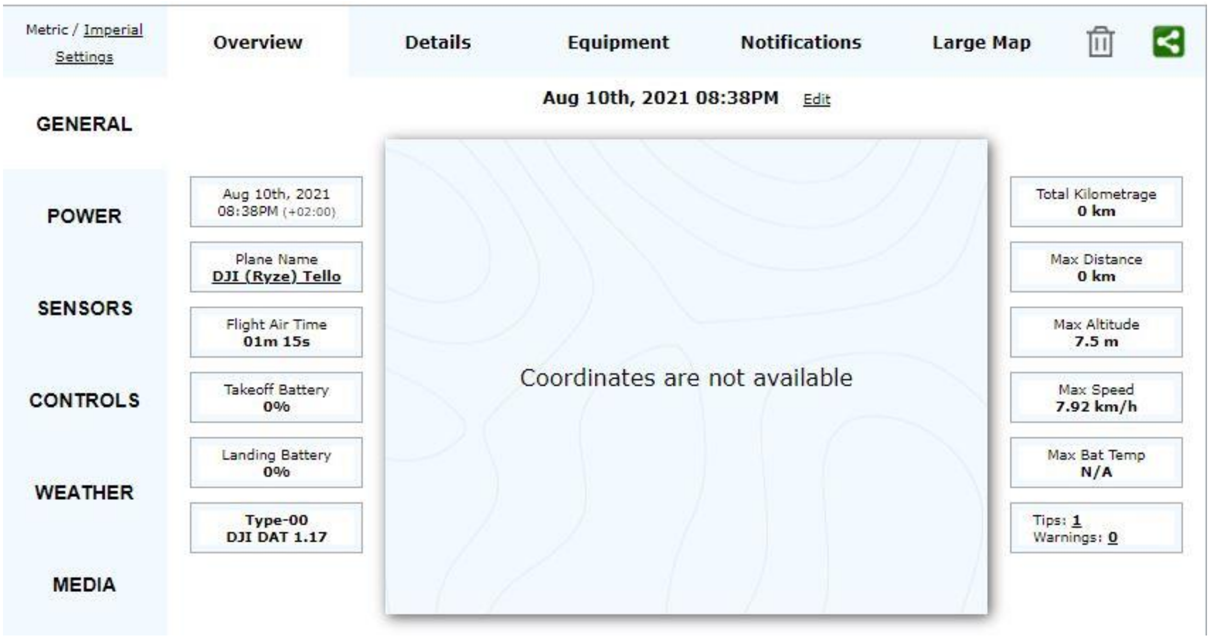
Appendix 7

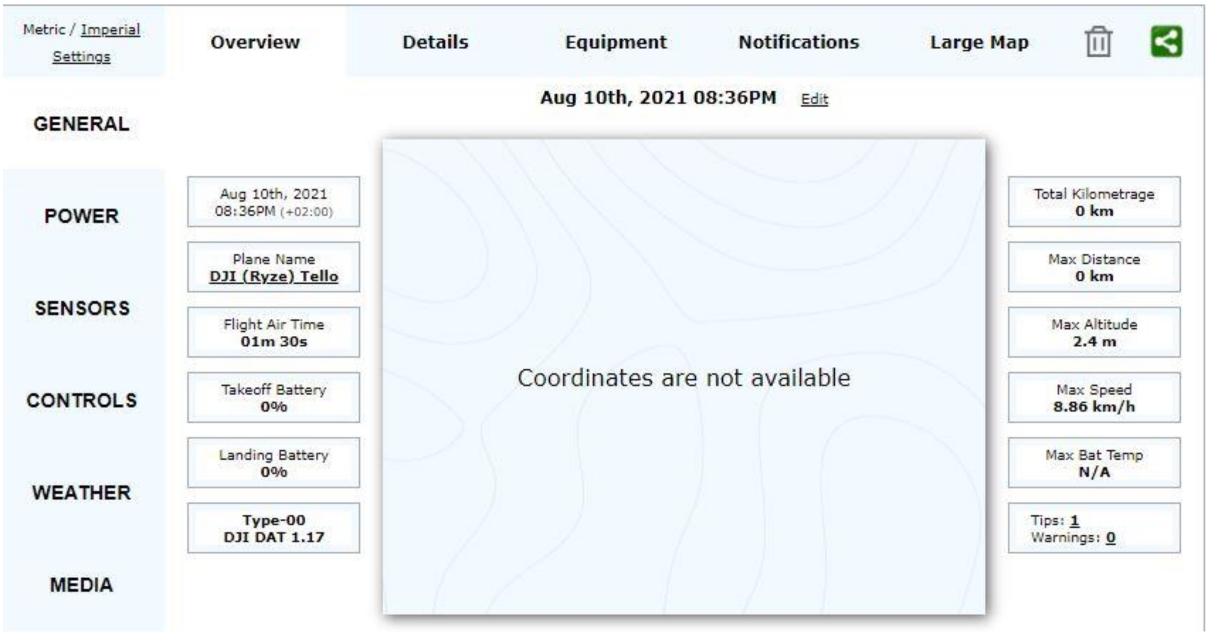
20:23
Agoralaan Gebouw D, Lokaal D22, Ag
THURSDAY
JULY 29
NOW
Good to fly
Temp (C)
20°
Visibility
16 km
Precip Prob
0%
Wind (km/h)
11
Gusts (km/h)
26
UV Index
0
Pilots Nearby
0
Kp Index
2
Sats
19
9:00pm
Rain 16%
10:00pm
Rain 16%
11:00pm
Rain 16%
OK TO FLY
DATA
START

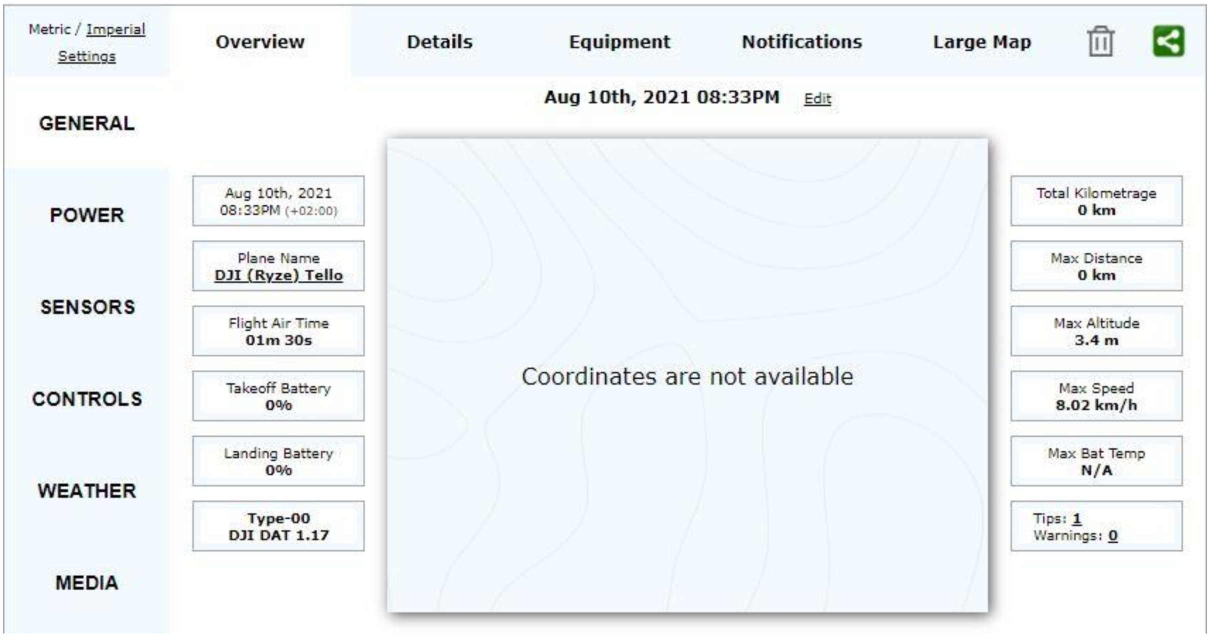
UAV Flight Data Logs

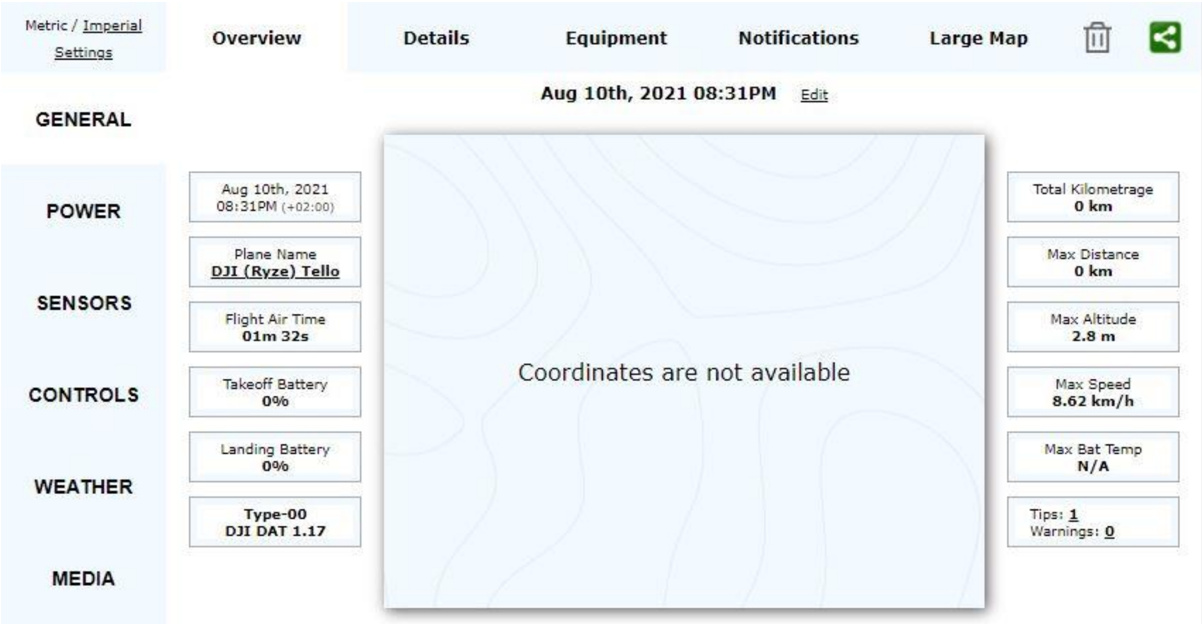
Appendix 8

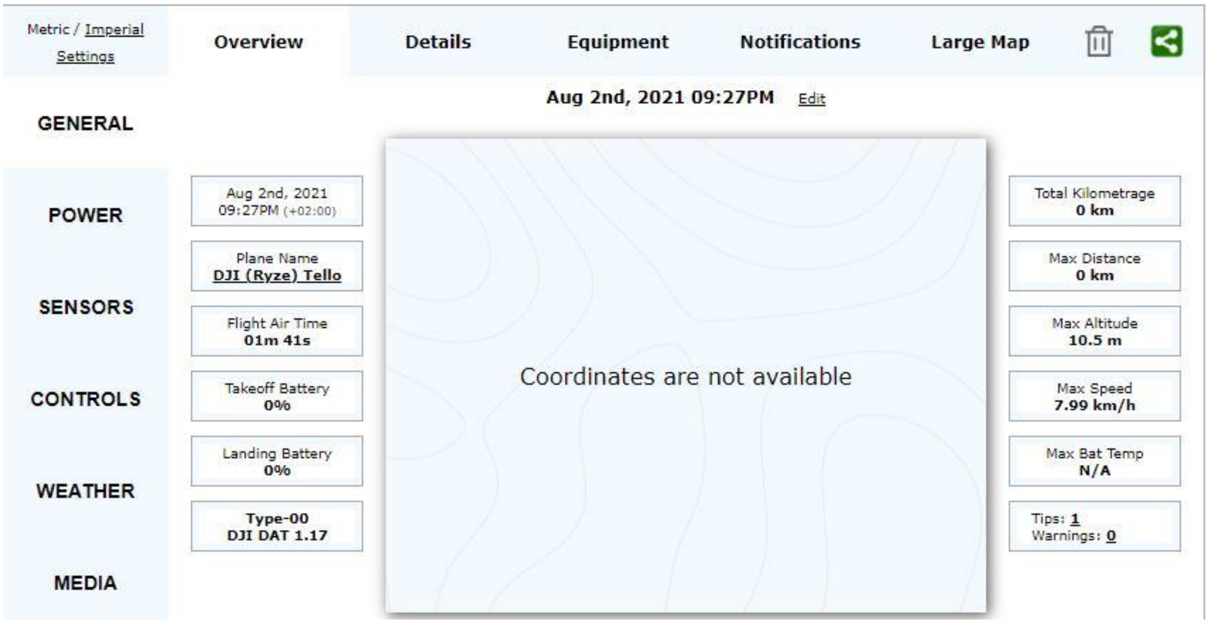


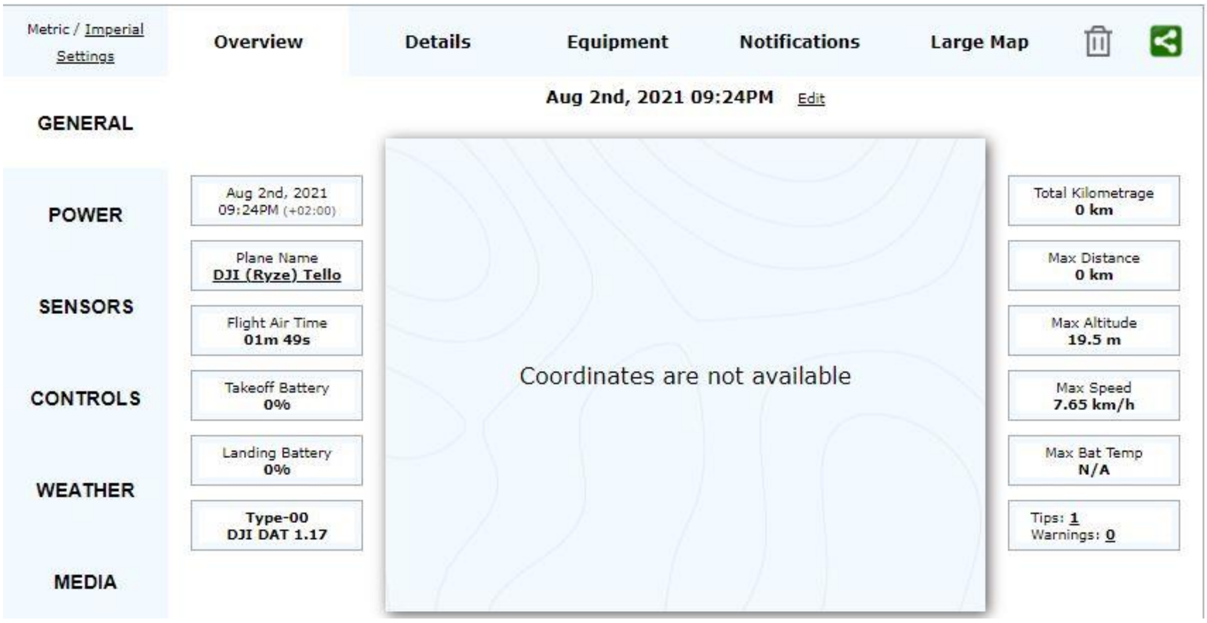


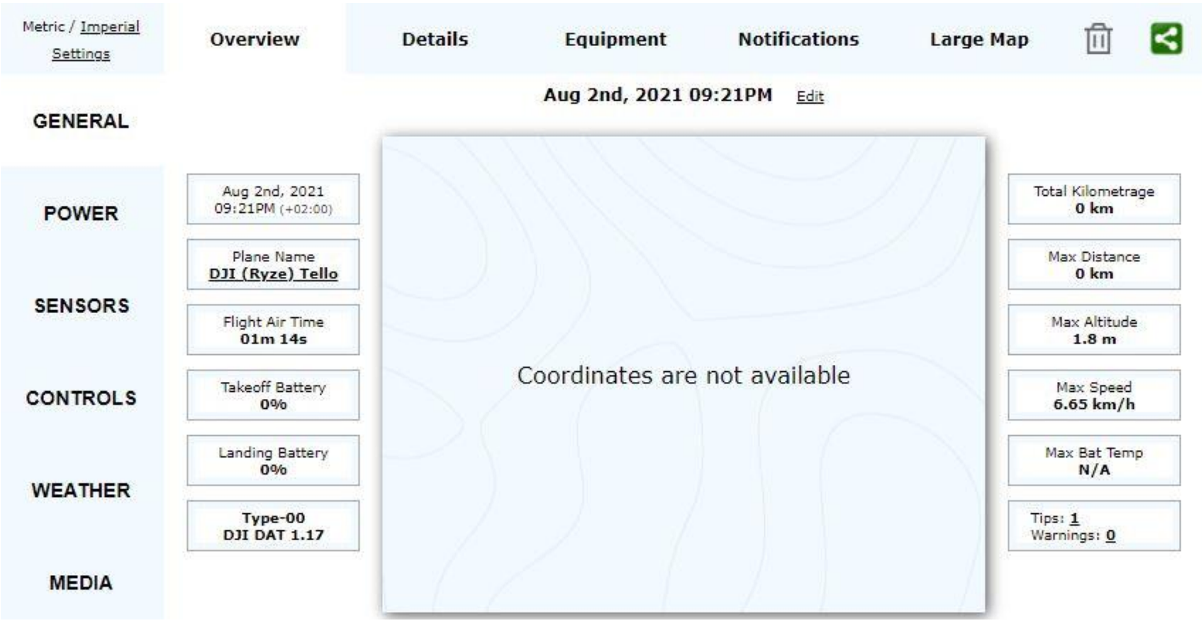

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 10th, 2021 08:36PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 10th, 2021 08:36PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 30s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 2.4 m
Max Speed 8.86 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

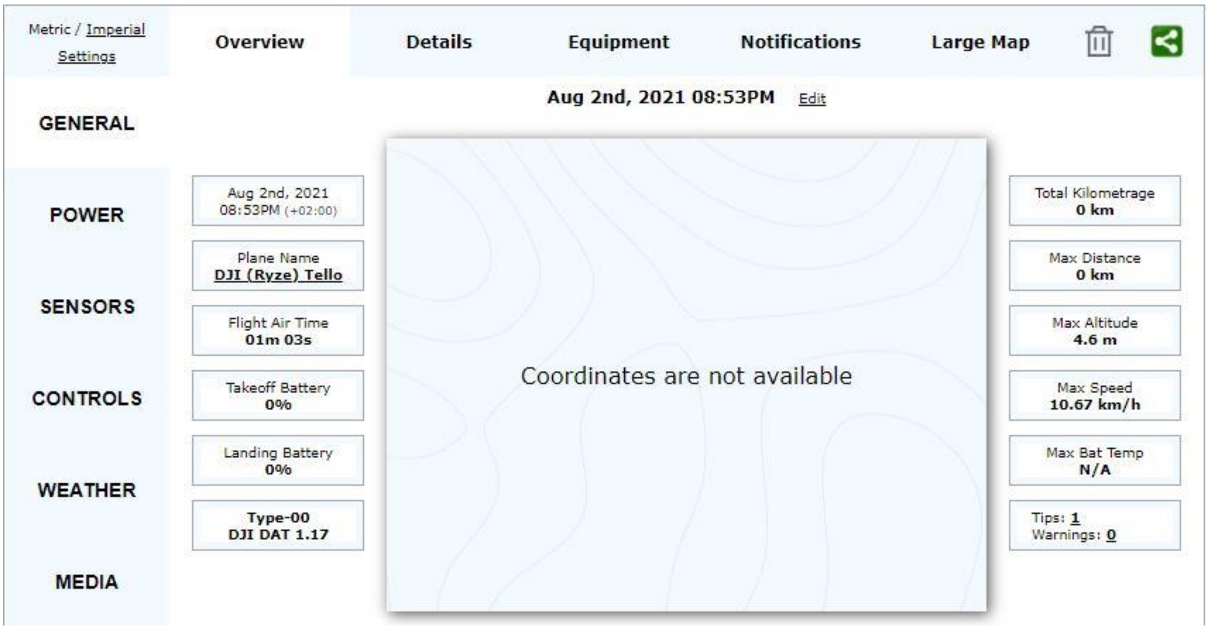

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 10th, 2021 08:33PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 10th, 2021 08:33PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 30s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 3.4 m
Max Speed 8.02 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0


Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 10th, 2021 08:31PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 10th, 2021 08:31PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 32s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 2.8 m
Max Speed 8.62 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

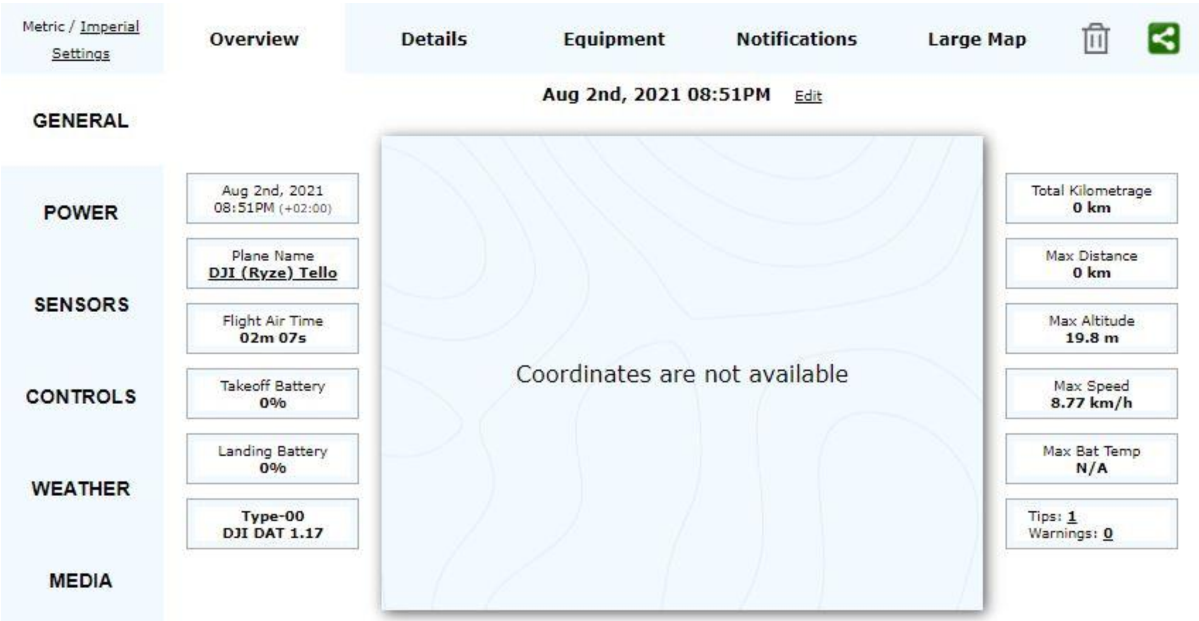

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 2nd, 2021 09:27PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 2nd, 2021 09:27PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 41s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 10.5 m
Max Speed 7.99 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0


Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 2nd, 2021 09:24PM Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 2nd, 2021 09:24PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 49s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 19.5 m
Max Speed 7.65 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

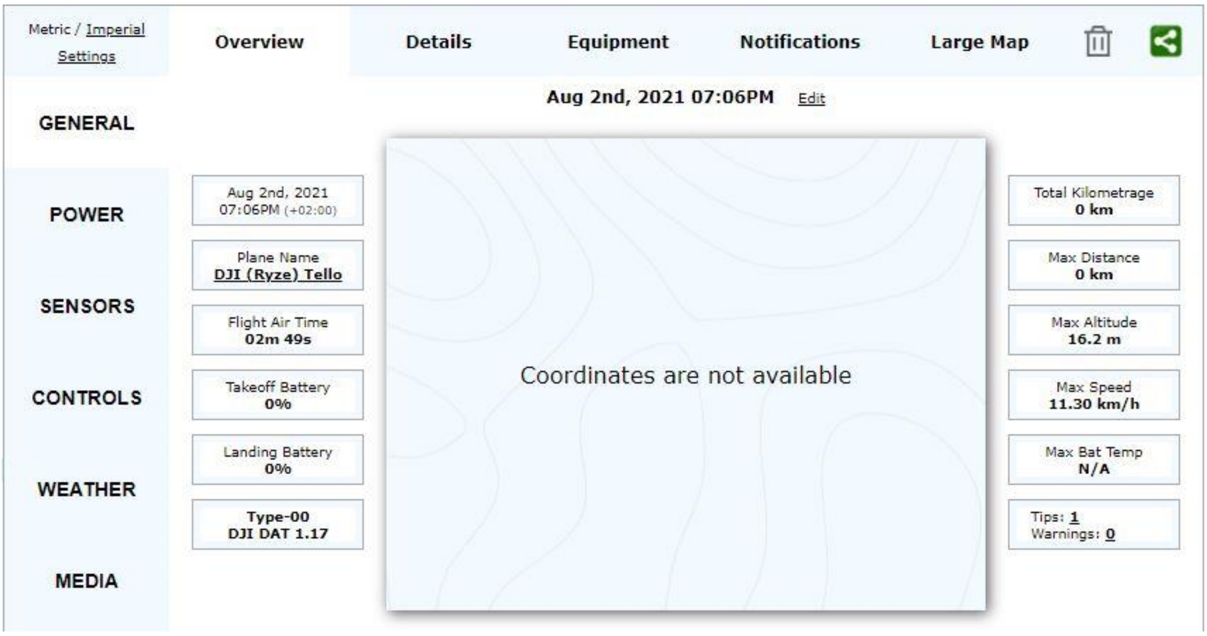

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 2nd, 2021 09:21PM Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 2nd, 2021 09:21PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 14s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 1.8 m
Max Speed 6.65 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

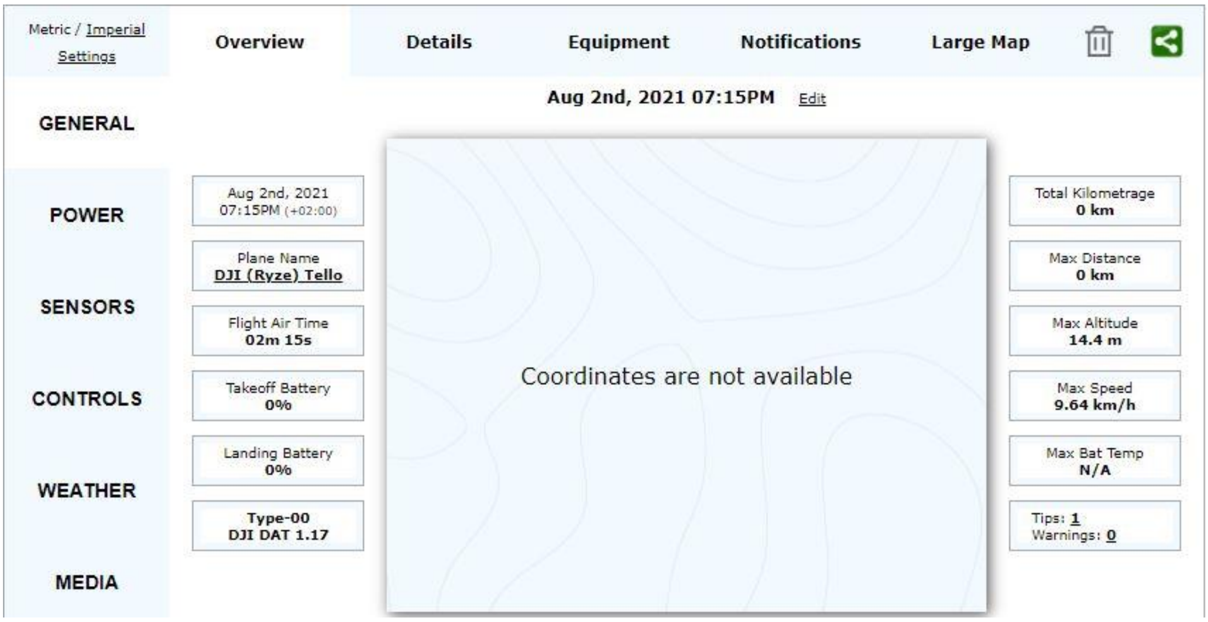


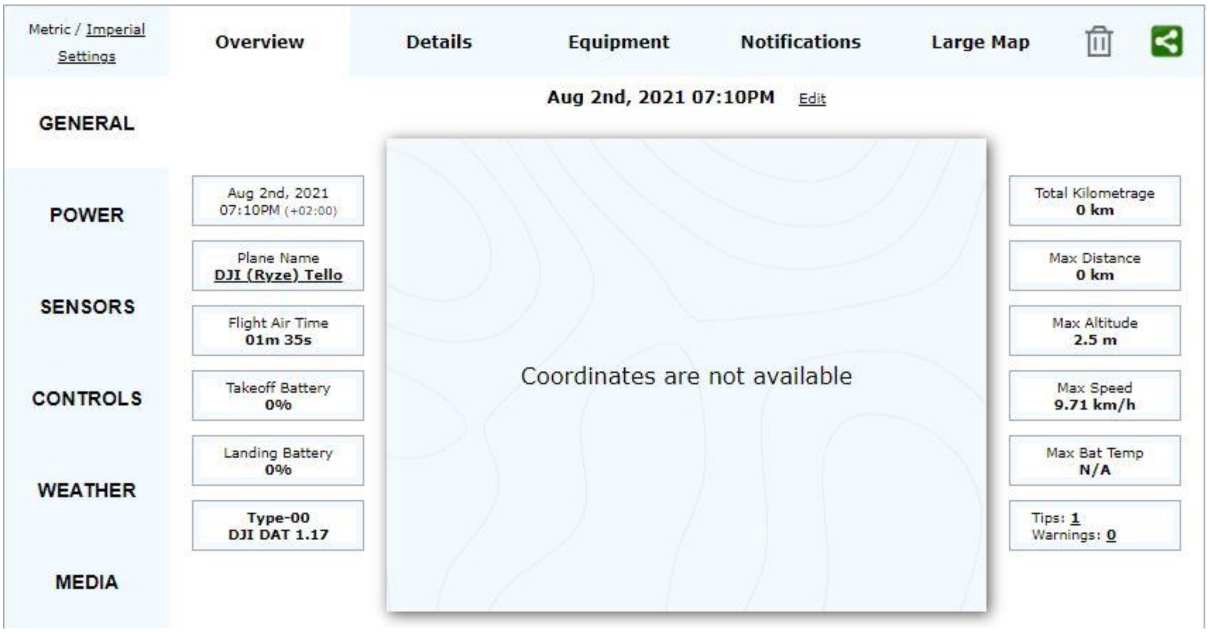
Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 2nd, 2021 08:53PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 2nd, 2021 08:53PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 03s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 4.6 m
Max Speed 10.67 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

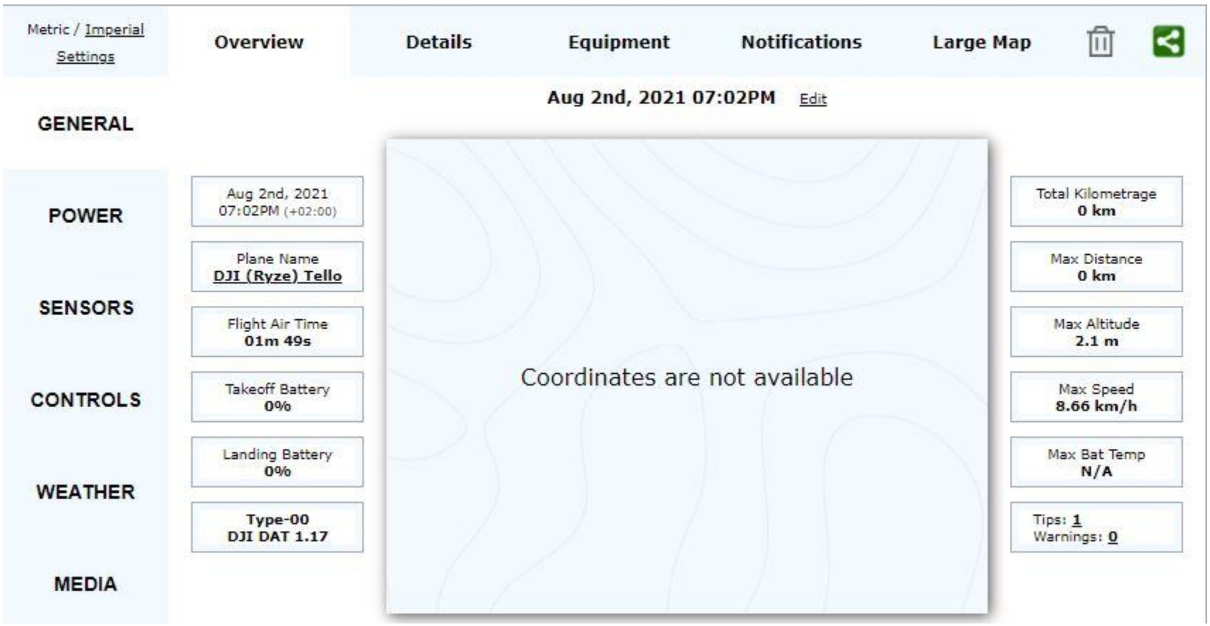


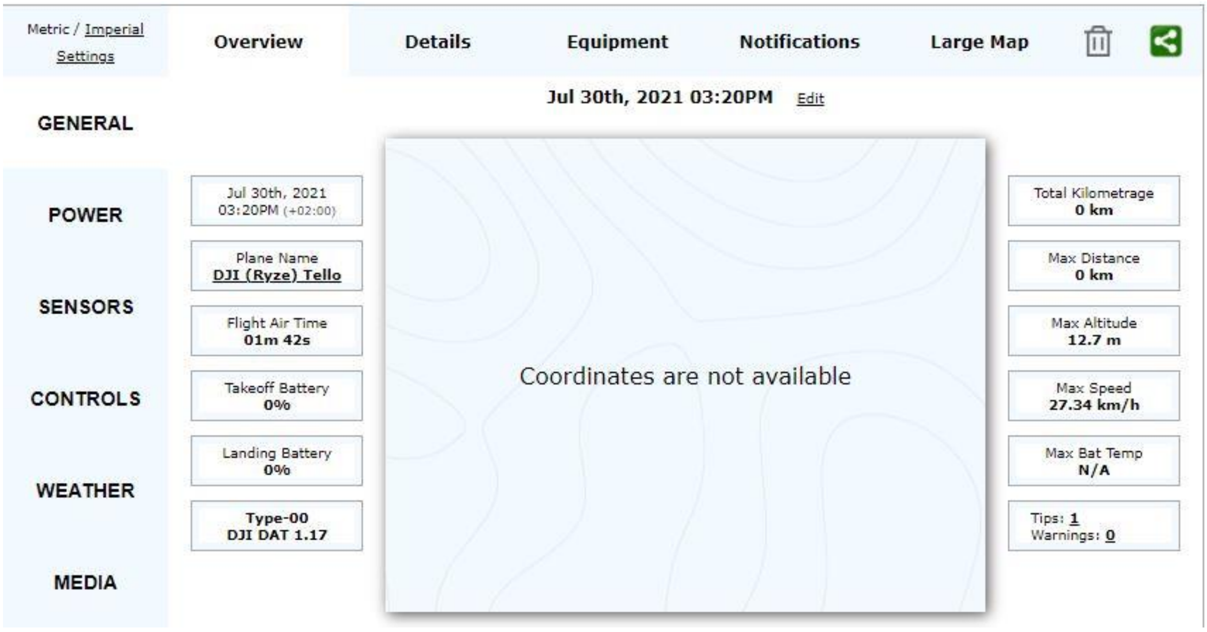
Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 2nd, 2021 08:51PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 2nd, 2021 08:51PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 02m 07s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 19.8 m
Max Speed 8.77 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

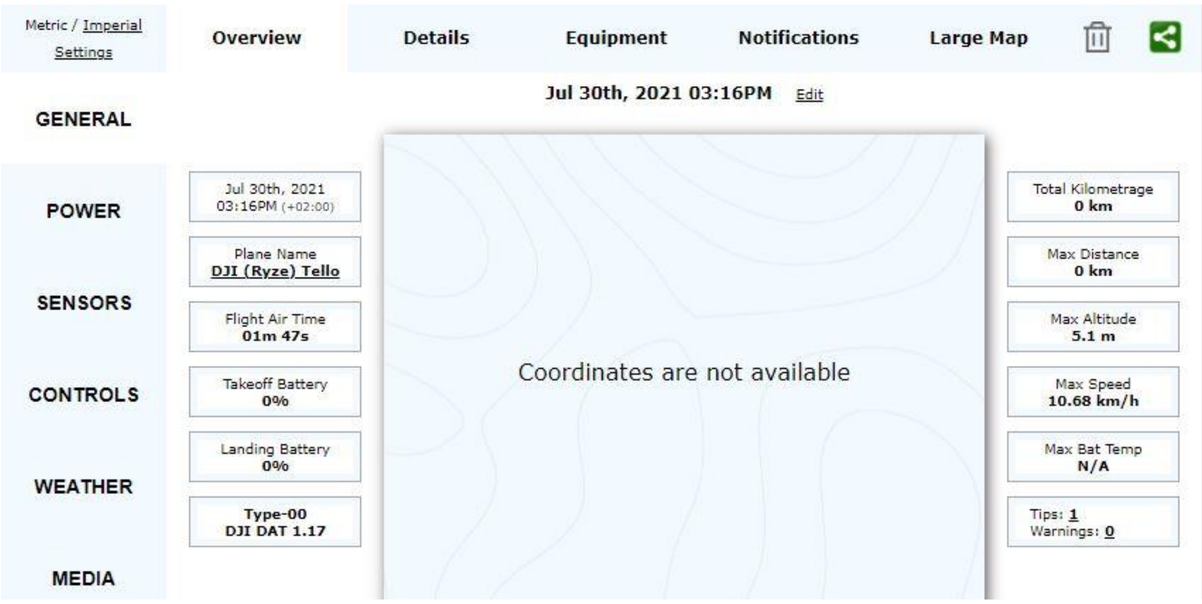

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 2nd, 2021 07:06PM Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 2nd, 2021 07:06PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 02m 49s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 16.2 m
Max Speed 11.30 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

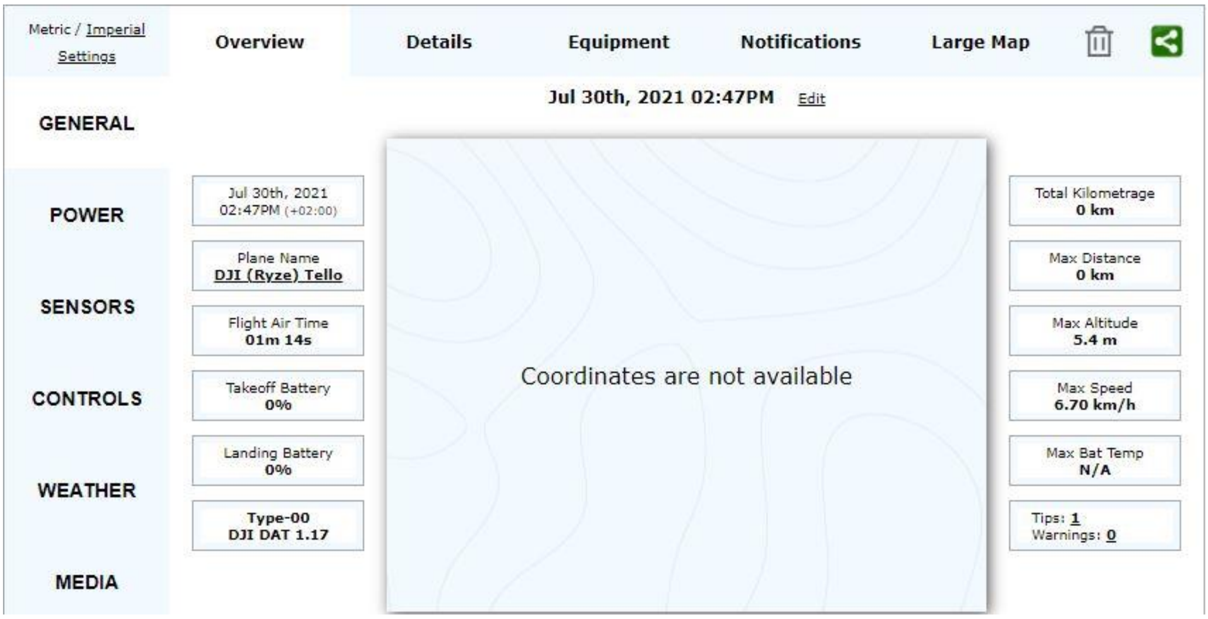

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 2nd, 2021 07:15PM Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 2nd, 2021 07:15PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 02m 15s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 14.4 m
Max Speed 9.64 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

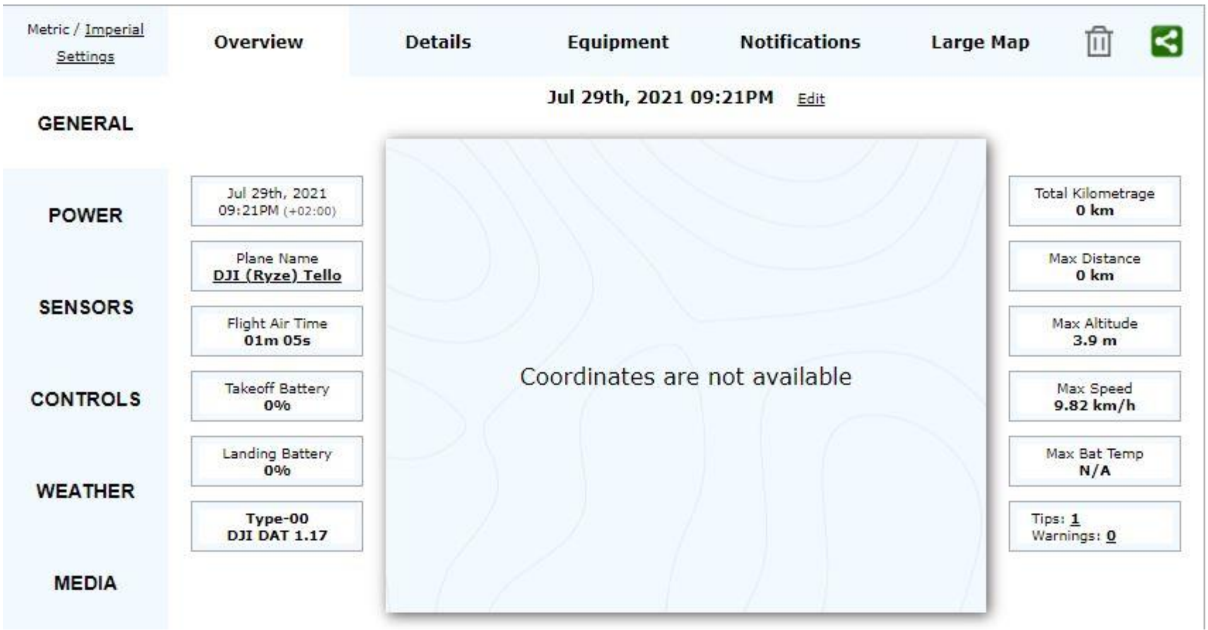

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 2nd, 2021 07:10PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 2nd, 2021 07:10PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 35s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 2.5 m
Max Speed 9.71 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

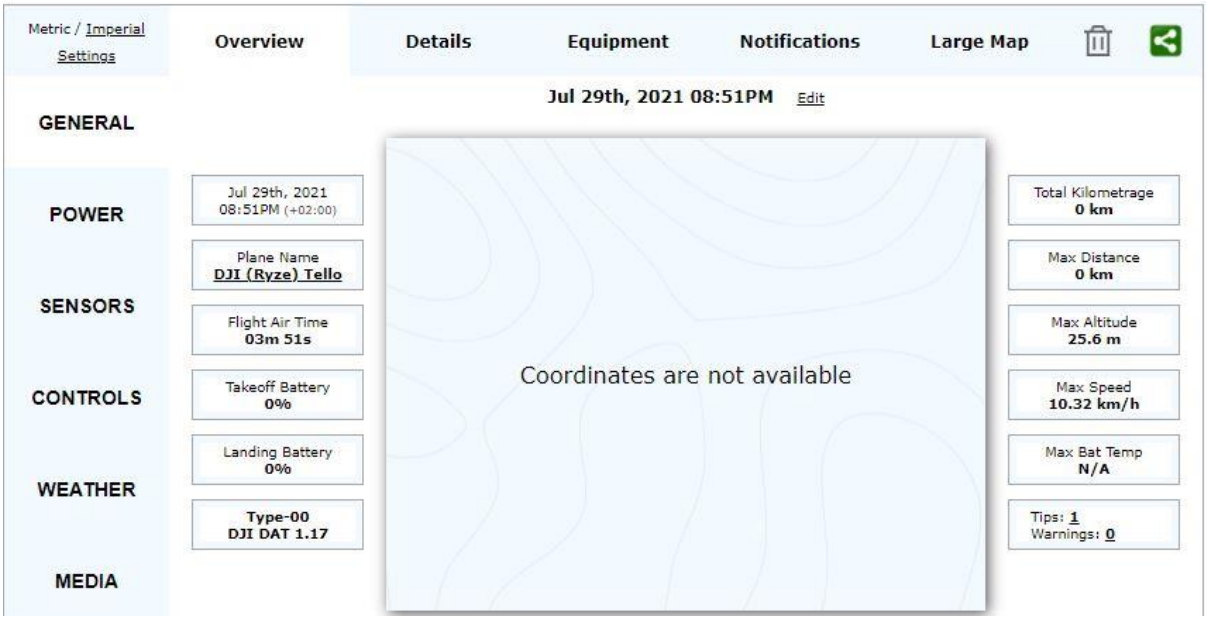

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Aug 2nd, 2021 07:02PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Aug 2nd, 2021 07:02PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 49s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 2.1 m
Max Speed 8.66 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

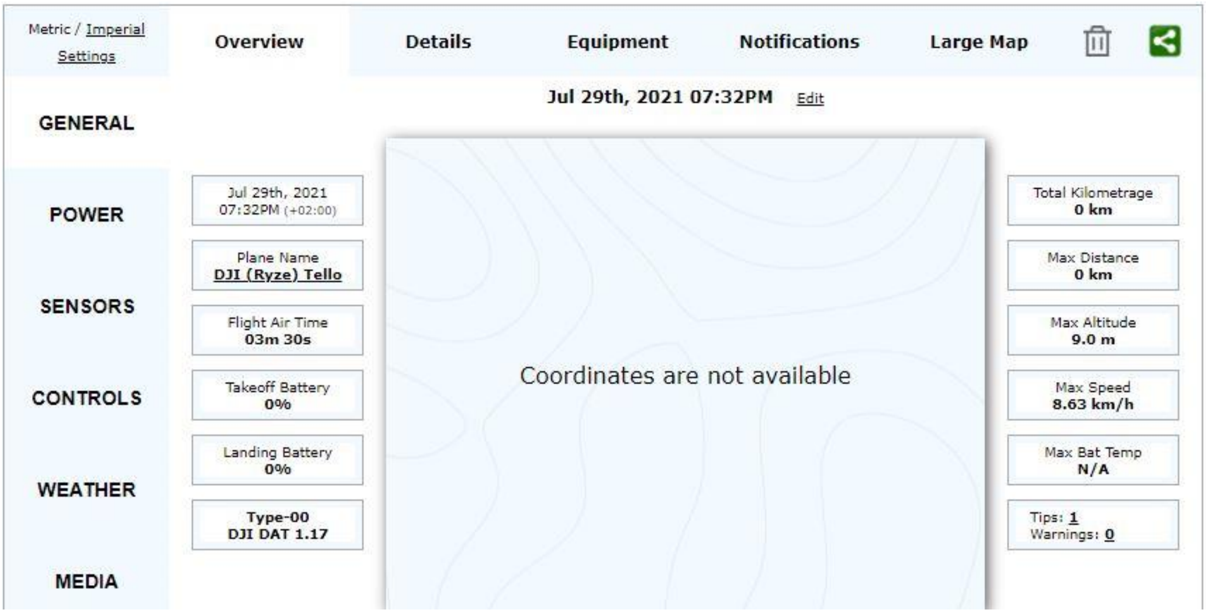

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Jul 30th, 2021 03:20PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Jul 30th, 2021 03:20PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 42s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 12.7 m
Max Speed 27.34 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0


Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Jul 30th, 2021 03:16PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Jul 30th, 2021 03:16PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 47s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 5.1 m
Max Speed 10.68 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0


Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Jul 30th, 2021 02:47PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Jul 30th, 2021 02:47PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 14s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 5.4 m
Max Speed 6.70 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

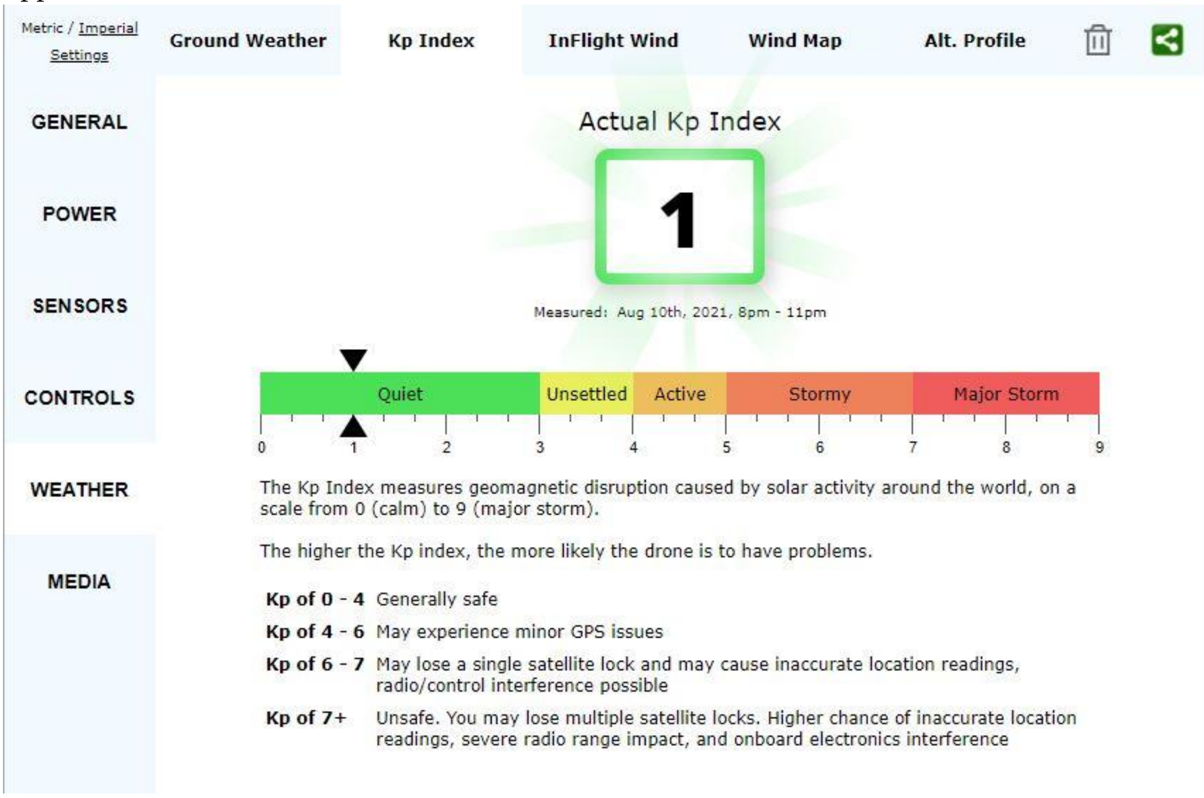

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Jul 29th, 2021 09:21PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Jul 29th, 2021 09:21PM (+02:00)
Plane Name DJI (Ryze) Tello
Flight Air Time 01m 05s
Takeoff Battery 0%
Landing Battery 0%
Type-00 DJI DAT 1.17
Coordinates are not available
Total Kilometrage 0 km
Max Distance 0 km
Max Altitude 3.9 m
Max Speed 9.82 km/h
Max Bat Temp N/A
Tips: 1
Warnings: 0

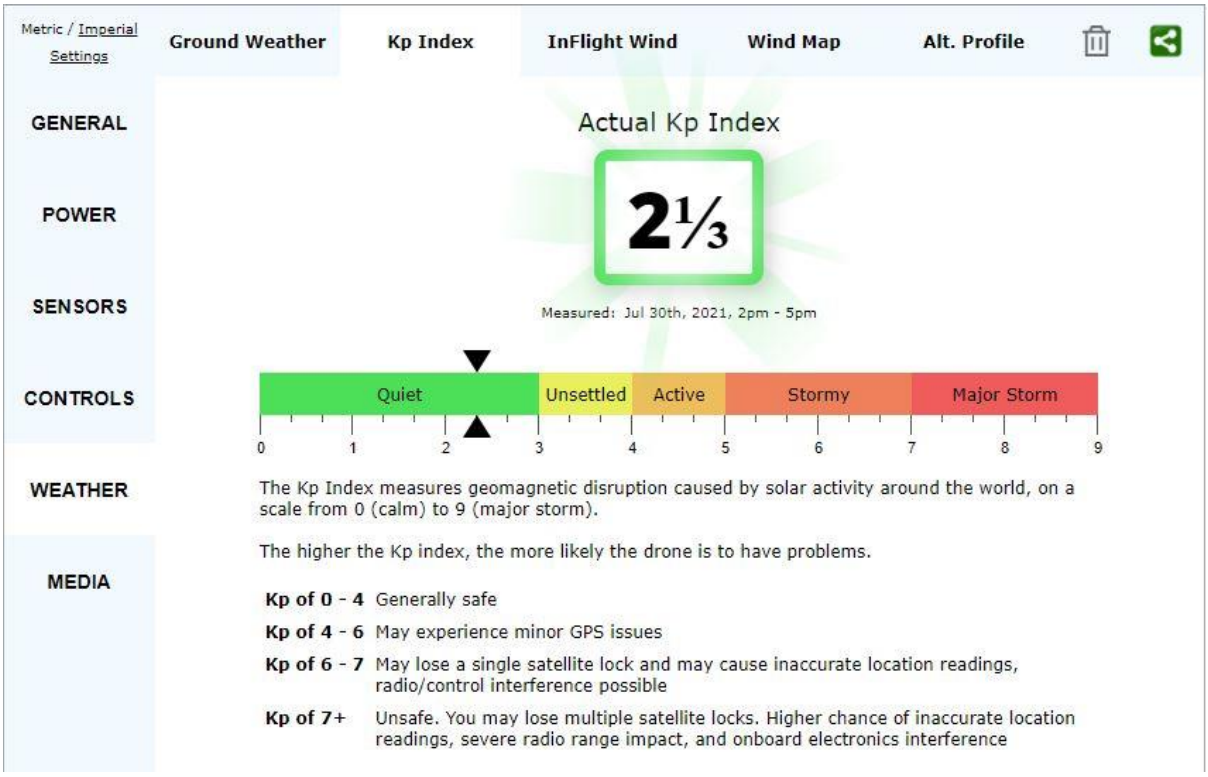

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Jul 29th, 2021 08:51PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Jul 29th, 2021
08:51PM (+02:00)
Plane Name
DJI (Ryze) Tello
Flight Air Time
03m 51s
Takeoff Battery
0%
Landing Battery
0%
Type-00
DJI DAT 1.17
Coordinates are not available
Total Kilometrage
0 km
Max Distance
0 km
Max Altitude
25.6 m
Max Speed
10.32 km/h
Max Bat Temp
N/A
Tips: 1
Warnings: 0

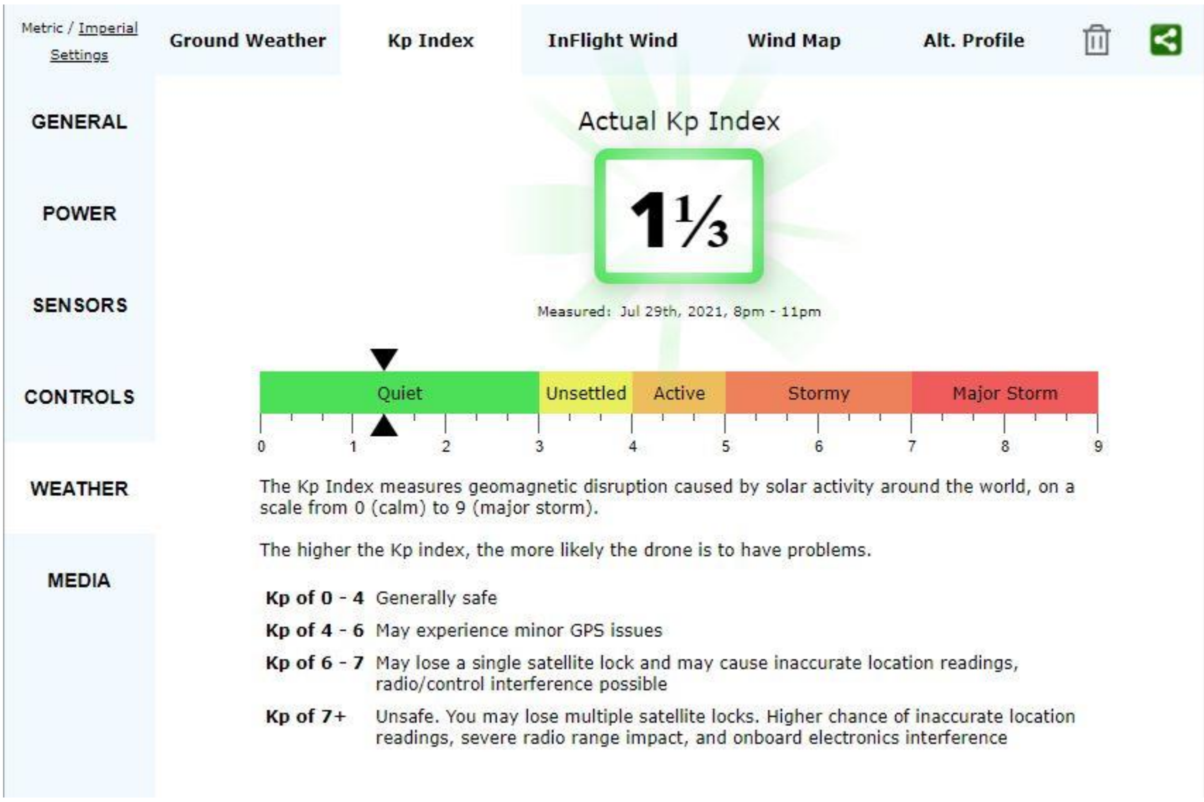

Metric / Imperial
Settings
Overview
Details
Equipment
Notifications
Large Map
Jul 29th, 2021 07:32PM
Edit
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Jul 29th, 2021
07:32PM (+02:00)
Plane Name
DJI (Ryze) Tello
Flight Air Time
03m 30s
Takeoff Battery
0%
Landing Battery
0%
Type-00
DJI DAT 1.17
Coordinates are not available
Total Kilometrage
0 km
Max Distance
0 km
Max Altitude
9.0 m
Max Speed
8.63 km/h
Max Bat Temp
N/A
Tips: 1
Warnings: 0

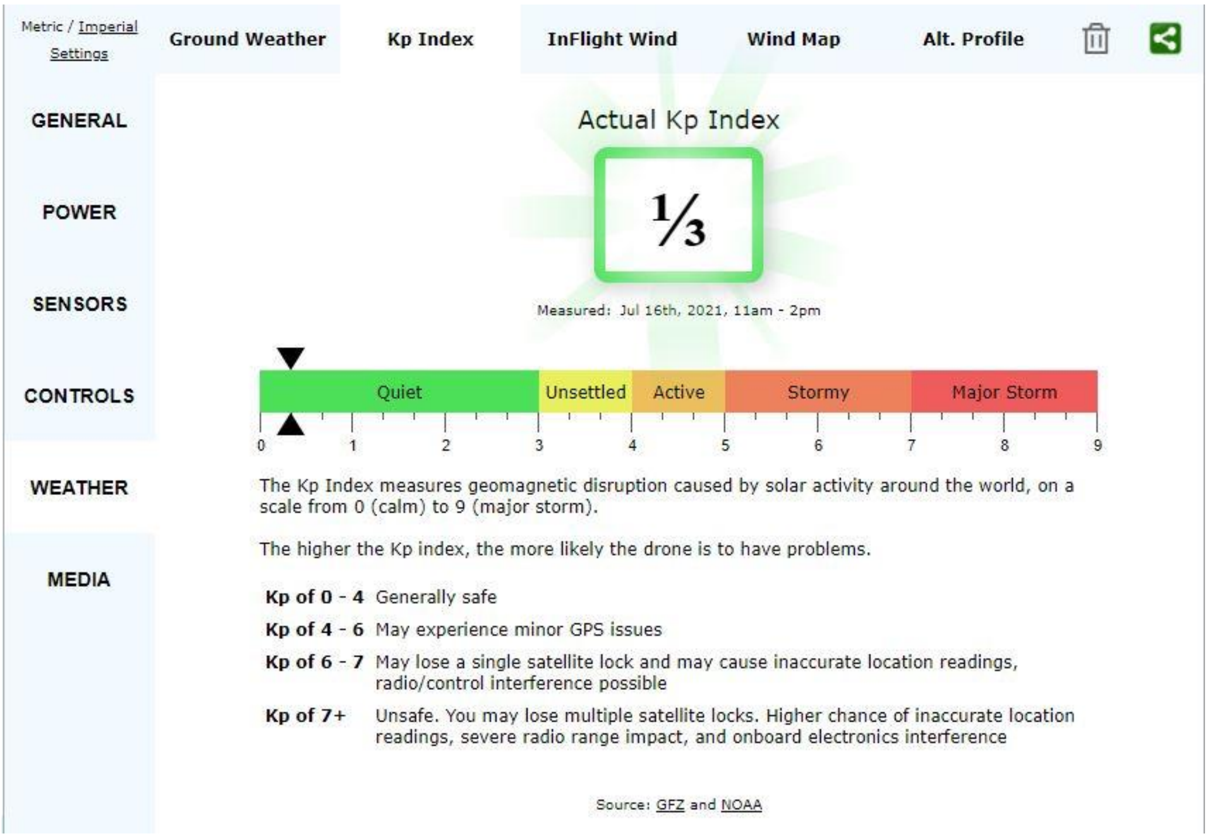
Electromagnetic readings- Solar activity

Appendix 9






Metric / Imperial
Settings
Ground Weather
Kp Index
InFlight Wind
Wind Map
Alt. Profile
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Actual Kp Index
1⅓
Measured: Jul 29th, 2021, 8pm - 11pm
Quiet
Unsettled
Active
Stormy
Major Storm
0 1 2 3 4 5 6 7 8 9
The Kp Index measures geomagnetic disruption caused by solar activity around the world, on a scale from 0 (calm) to 9 (major storm).
The higher the Kp index, the more likely the drone is to have problems.
Kp of 0 - 4 Generally safe
Kp of 4 - 6 May experience minor GPS issues
Kp of 6 - 7 May lose a single satellite lock and may cause inaccurate location readings, radio/control interference possible
Kp of 7+ Unsafe. You may lose multiple satellite locks. Higher chance of inaccurate location readings, severe radio range impact, and onboard electronics interference


Metric / Imperial
Settings
Ground Weather
Kp Index
InFlight Wind
Wind Map
Alt. Profile
GENERAL
POWER
SENSORS
CONTROLS
WEATHER
MEDIA
Actual Kp Index
⅓
Measured: Jul 16th, 2021, 11am - 2pm
Quiet
Unsettled
Active
Stormy
Major Storm
0 1 2 3 4 5 6 7 8 9
The Kp Index measures geomagnetic disruption caused by solar activity around the world, on a scale from 0 (calm) to 9 (major storm).
The higher the Kp index, the more likely the drone is to have problems.
Kp of 0 - 4 Generally safe
Kp of 4 - 6 May experience minor GPS issues
Kp of 6 - 7 May lose a single satellite lock and may cause inaccurate location readings, radio/control interference possible
Kp of 7+ Unsafe. You may lose multiple satellite locks. Higher chance of inaccurate location readings, severe radio range impact, and onboard electronics interference
Source: GFZ and NOAA