2019

AUVSI SUAS TECHNICAL PAPER

FLIGHT LABS UNSW

UNIVERSITY OF NEW SOUTH WALES

1. Systems Engineering Approach

1.1 Mission Requirement Analysis

The AUVSI SUAS competition is a complex mission requiring the completion of multiple different tasks with varying design requirements. There are two main mission objectives for the competition, the accurate drop of the UGV as well as the recognition of objects and people on the ground.

The UGV drop component of the competition requires both a cargo carrying and drop mechanism on board the aircraft in order to accurately drop the UGV. One of the main considerations for the UGV drop was whether the UGV would sit outside the airframe or be concealed within. Carrying the UGV outside of the airframe significantly reduces the aerodynamic efficiency but is much simpler than having the UGV stored in the aircraft. Another design consideration for the UGV drop was being able to consistently drop the UGV with a high accuracy. A quadcopter configuration is extremely favourable in comparison to a standard fixed-wing design for this task, due to its hovering abilities, but presents issues with flight time and range for electric propulsion.

The object and human recognition component of the competition requires a significant amount of image gathering and surveying to be able to accurately identify and classify the objects. One of the main considerations was the cruise speed of the aircraft and optimising this for surveying and image gathering applications. Flying at a higher speed in a fixed-wing aircraft would require surveying at a higher altitude to ensure no objects are missed, as well as a much higher resolution camera system compared to a quadcopter flying slower at a lower altitude. The inclusion of off-axis objects also requires the aircraft to have at least one camera which can survey at an angle instead of horizontal. This is also important in ensuring the aircraft can identify objects which are blocked by obstacles placed around the airfield and those placed beyond the flight boundary.

The aircraft must be able to complete the mission autonomously, and hence the autopilot used to control the aircraft must have those capabilities. Using a system that the team is both comfortable with and is reliable were important considerations for the autopilot system. Additionally, the system should be able to deal with sending and receiving the appropriate files and telemetry information to the ground station. The maximum flight time for the competition was set at 30 minutes to ensure all mission flight time could be used if required. For a 30-minute flight time, a fixed wing aircraft would easily complete the mission using electric propulsion while a quadcopter would require significant weight optimisation to extend the flight time. A quad-plane, which combines these two qualities, was also considered as a viable option to have VTOL characteristics while also maintaining a higher forward-flight efficiency.

1.2 Design Rationale

After determining the key mission requirements, the major design decisions for the aircraft were analysed and discussed. The first design decision considered was the airframe type, with a quad-plane design decided as the most suitable design. Flight Labs UNSW (FLU) has considerable experience with quad-planes, producing several airframes of this type in the past. This design also ensures the key mission outcomes can be achieved easily, by mixing quadcopter and fixed wing flight. The ability to hover ensures an accurate UGV drop, while being able to fly like a fixed-wing allows for the aircraft to fly for 30 minutes and easily survey a large area. The quadcopter motors can also be used to prevent stall and assist in slow-speed surveying where required. Using a quad-plane design, off-the-shelf frames are limited, and as such this led the team to fully design and manufacture the airframe using primarily foam and composites. This has given a much greater flexibility in the overall design and optimisation of the aircraft, leading to an airframe custom-built for the required competition tasks.

From previous experiences with traditional fixed-wing aircraft in a quad-plane configuration, it was decided the aircraft, named WREN, would be a flying wing design. A flying wing design is considerably easier to manufacture than a traditional fixed wing, due to the smaller number of parts, while also having a much higher structural integrity. This also makes it easier to design but sacrifices some aerodynamic stability due to the yaw instability tendencies of flying wings in general. For the UGV drop, it was considered that the UGV would remain outside of the airframe and dropped early in the mission, however using the flying wing design, it was decided that the UGV could be placed inside WREN. While this does introduce some complexity into the design and drop mechanism sequence, this allows for minimal aerodynamic impact during flight with the UGV attached.

As WREN must be transported from Australia to the USA for the competition, there were several space limitations for air travel, which imposed restrictions on dimensions for the aircraft. To circumvent this problem, detachable wings were designed for WREN, to ensure all parts fit within the space limitations. This also allows for different wings to be produced for different applications (i.e. long wings for gliding, shorter wings for agility), and be interchangeable quickly using latches at the joint of the wings to the body.

To be able to effectively control and autonomously fly a quad-plane, the open-source software ArduPilot was used as the primary flight control autopilot. As an open-source project, it is constantly evolving and has been developed over many years with extensive documentation and high reliability compared to a self-developed autopilot. This system is also extremely well known by many members of FLU, making it easy to implement and use with WREN. Most UAV applications use electric propulsion systems, and WREN is no different, with electric propulsion systems being cheaper and more reliable than petrol systems. As the system is configured as a quad-plane, electric propulsion can provide a 30+ minute flight time, a petrol propulsion system would be excessive and add considerable weight to the aircraft, requiring much more power from the VTOL motors.

2. System Design

2.1 Aircraft

2.1.1 Airframe & Structure

The airframe of WREN is a VTOL-capable, flying wing manufactured primarily out of composites. This design was pursued for a range of reasons, including ease of manufacturability, transport, favourable aerodynamic properties, STOVL capability, and ample cargo space for both electronics and the UGV or other payload.

The skin of the primary fuselage section is composed of monocoque 2x2 twill weave carbon fibre reinforced polymer (CFRP). This was selected due to the omnidirectional strength properties of the material, allowing the skin to support a significant portion of the in-flight loads and minimised the need for a bulky internal structure. The CFRP skin is vacuum laid on milled XPS foam that has been hollowed out to allow for the accurate placement of structural components and electronics after the skin has cured.

The forward section of the primary fuselage section joins to a nose section, which is comprised of a foam core and fibreglass skin. The nose section is completely removable and stores all the flight electronics, except for a GPS receiver in the rear of the airframe and the telemetry radios housed in the wingtips. A fibreglass skin was selected because it is radio transparent and lightweight yet is still rigid enough to maintain structural integrity under most flight conditions. The nose section is manufactured in a similar manner to the main fuselage. By having a detachable nose section, the geometry and layout can be changed quickly and easily without affecting the larger primary fuselage.

The internal structural components within the carbon-fibre skin consist of two 28 mm diameter, 1 mm wall-thickness carbon fibre tubes, moving outwards from the centre of the fuselage, and following the wing sweep back to the outboard wings. A central strut exists between the two tubes to aid in moment transfers between the internal structure and the skin, which enhances the overall rigidity of the airframe. The outboard wings were developed as separate components from the primary fuselage section, which contains the central fuselage and inboard wing sections as one part. The primary motivation for this was transportation purposes as the airframe has a total wingspan of 2.2m, making it extremely difficult to transport this from Australia to the USA in one part. As a result, the wings were designed as separable and constructed from foam core CFRP, with a 26mm carbon fibre tube structural member running along the ¼ chord length.

The structural member in the outboard wing extends into the structural carbon tube in the fuselage section, allowing for the wings to be easily added and removed by telescoping the carbon tubes. A latch mechanism was designed to connect the outboard wing sections into the main fuselage in a quick and secure manner. An additional benefit of this design is modularity, where different sets of wings can be manufactured for different applications, including modification of wing aspect ratio and winglet design. The four vertical lift motors are integrated into the main fuselage section using carbon fibre tubes attached at the edge of the inboard wing section. This ensures both adequate cable management between motors and on-board ESCs, and easy removal for maintenance and transport.

2.1.2 Aerodynamics

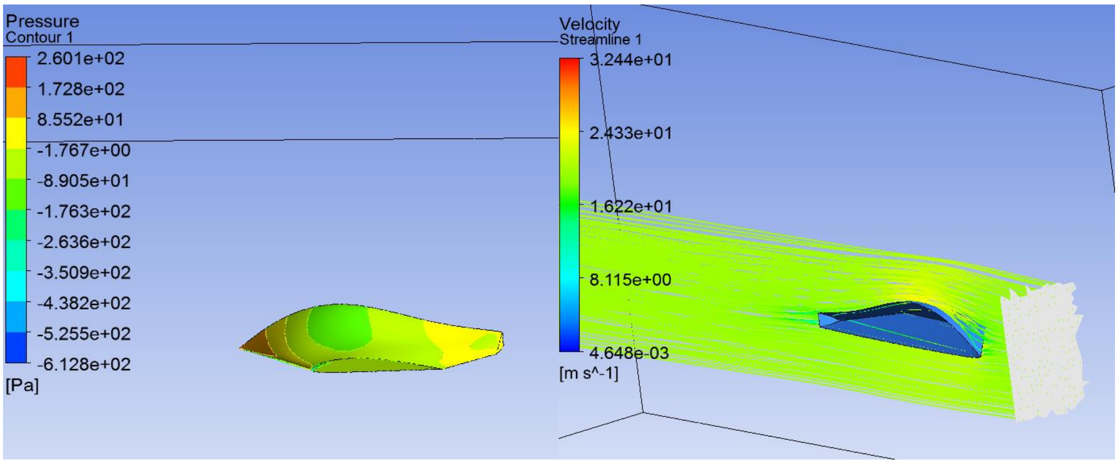
The aerodynamic profile of WREN was developed to maximise the performance of the aircraft in a quad-plane configuration. A cruising speed of 70-80 km/h in forward flight configuration was chosen according the requirements of the computer vision system, while using weight estimations based on previous projects and quad-plane designs, a minimum lifting force of 79 N was determined to be enough for the aircraft. A factor of safety of 1.5 was used to design the air foil and area requirements.

The S7055-il air foil was selected to complement the scale of WREN and optimise the aircraft characteristics for low Reynolds number conditions, below 500,000. This air foil was chosen due to preferable lift and drag characteristics at low angles of attack around 5 or 6 degrees and has a maximum lift-to-drag ratio at 5.25 degrees. This is expected to be the maximum angle of attack in forward flight, as the aircraft has VTOL capabilities and hence does not need to be optimised for take-off and landing.

The WREN is configured as a flying wing which blends into the main fuselage body. A thirty-degree wing sweep was determined to be enough in improving the yaw stability of the airframe, while the performance of the aircraft was further aided by tapering the air foil towards the tip and using winglets. A range of further modelling is expected to be undertaken to determine the optimal winglet type, and whether they can serve additional purposes as landing struts. The planform of the wings and blended fuselage was then developed around accommodating the payload and propulsion systems, whilst minimising manufacturing complications.

The use of carbon tubes for the VTOL motors, which transfer the lifting force of these motors to the airframe influenced a few aspects of the aerodynamic analysis. The planform was adjusted to improve the structure and rigidity of the airframe against the moment caused by the quad arms under the quad rotor configuration. Meanwhile, the aerodynamic effects of these arms are minimised using circular tubes as well as an H configuration, which reduces the frontal area of flow disturbed by the VTOL motors and tubes in forward flight. The frontal surface area and drag associated with the motors and carbon tubes is further minimised by blended fairings at all mounting points.

A Computational Fluid Dynamics aerodynamic analysis was conducted to validate the blended fuselage and airframe prior to full-scale manufacturing and flight testing. The computation was run on a wingless body model at a flight angle of 0 degrees with a cruise speed of 70 km/h. While this analysis was not conducted at the optimum angle of attack, the analysis showed that the cruise angle of attack would be around 3 degrees. The results showed no flow separation over the body with a relatively low efficiency for the lift-to-drag ratio of approximately 5, which was expected from a wingless aircraft. The large hump on the top surface created a low-pressure region aiding in the lift of the body.



The sharp leading edge will inevitably create separation earlier than a more common smooth leading edge seen on most subsonic crafts. Since the craft employs a vertical take-off and landing the angles of attack is not expected to exceed 5 degrees, and hence this issue is unlikely to affect the aerodynamics of the aircraft. Additionally, the hump on the top surface aids in flow attachment (or reattachment where flow separation occurs) reducing the negative effects of a sharp leading edge of the body.

Initial flight testing of the airframe has been conducted to further verify the stability of the design under power of the quad motors. Several hover and quadcopter flight tests have been successful, with the airframe withstanding all forces extremely well, including several hard landings. Resistive forces from the airframe during vertical take-off under quad power was also anticipated, however did not affect the flight stability of WREN once the aircraft was out of ground-effect.

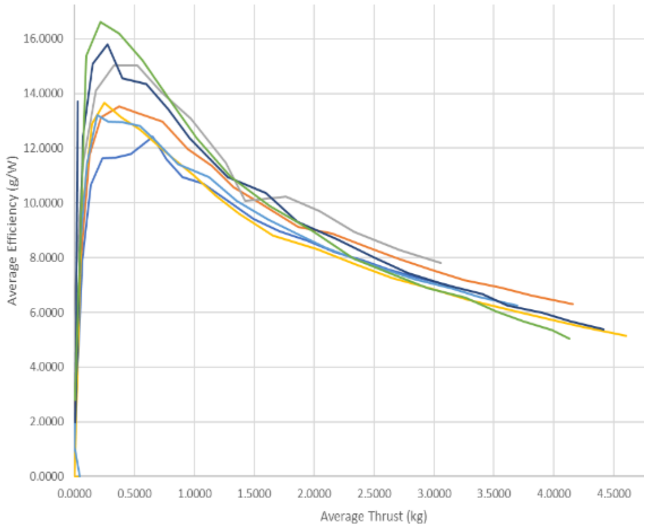
2.1.3 Propulsion

The propulsion system is divided into two sections, the VTOL and forward flight (FF) systems, which both employ brushless DC electric motors and propellers. The VTOL system consists of 4 motors in a standard H-frame quadcopter configuration, and the forward flight system uses one motor at the rear of the aircraft with a propeller in pusher configuration. Both systems are powered by a set of 6-cell lithium polymer batteries.

The use of an aircraft in a quad-plane configuration with VTOL motors was chosen for a variety of reasons, including that the aircraft can more reliably autonomously take off and land, and be more versatile and flexible in the areas that it can access. The design also reduces the need for specific runway directions and wind considerations (under most operating conditions), and almost eliminates the risk of stalling at slow forward flight speeds due to the autopilot activating the VTOL motors to provide additional lift. This also allows for the aircraft to take off at a weight heavier than the forward flight maximum take-off weight, increasing the potential payload or flight time with additional batteries. The ability to hover at any given point in the mission allows for extremely accurate dropping of payloads, while also allowing the aircraft to perform high agility manoeuvres and stabilise flight controls.

A petrol internal combustion engine (ICE) was considered for the forward flight motor, as petrol has a higher energy density than lithium polymer batteries. However, the extra weight of an ICE and the need to carry both petrol and lithium batteries meant that the benefits of the ICE were only expected to be reached for extended flight times or range using the forward flight motor. Given that the maximum mission time is limited to 30 minutes, an all-electric approach provides enough flight time with a comfortable safety margin, is inherently safer and is considerably simpler than an ICE. The FF motor is rear mounted in a pusher configuration for weight distribution. In this configuration, the FF motor also minimises the turbulence from the propeller affecting the VTOL propulsion system. The lifting body fuselage also generates more lift by having the FF motor mounted at the rear instead of at the nose of the aircraft.

Once the configuration was decided for WREN, much of the design effort in creating the propulsion systems was focused on selecting and testing the necessary components. The most important consideration in this process was selecting motor-propeller combination. For each motor-propeller combination, the necessary thrust per motor was calculated, and a variety of motors and propellers were selected to test from a range of manufacturers. All the combinations of motors and propellers were tested using a simple thrust stand, and using the data shown in the graph below, the final combination of motor and propeller was based primarily on their efficiency vs thrust performance, their maximum thrust output, and their weight.



Design Metric	Expected	Actual/Tested
Weight	7-8 kg	8 kg
Dimensions	2.2 m x 1.1 m x 0.25 m	2.2 m x 1.1 m x 0.25 m
Max. Quad Speed	4-6 km/hr	To be tested
Max. FF Speed	100 km/hr	To be tested
Cruise Speed	70-80 km/hr	To be tested
Flight Time	30+ minutes	To be tested

2.2 Autopilot

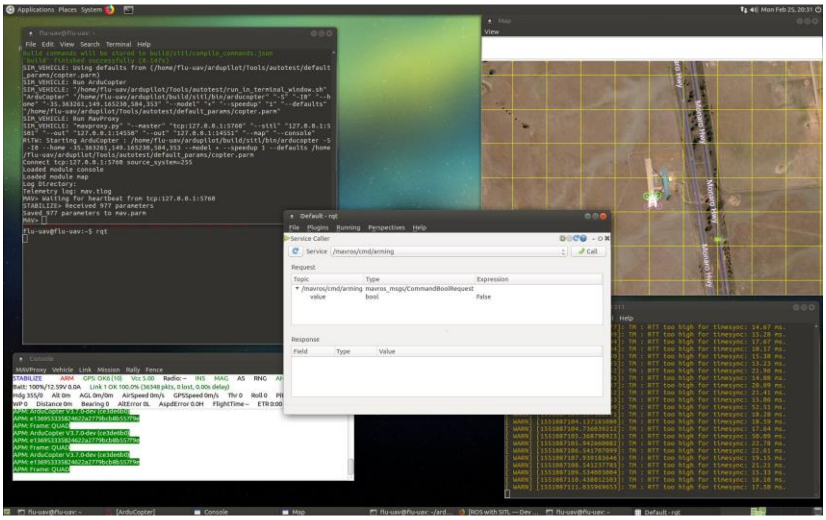
The aircraft will be utilising the CubePilot flight controller and the Up Core Plus as a companion computer to control the aircraft. The autopilot system is based on two open source systems adapted to handle high level and low-level control of the aircraft. For the low-level control, which is handled by the flight controller, the system relies on a popular industry standard open source software suite, ArduPilot, using the ArduPlane firmware. For the high-level control, which is handled by the ground station and companion computer (CC), the system uses the Robotics Operating System (ROS), MAVProxy and MAVROS (MAVLink package for ROS). This allows the companion computer to send high level commands through the MAVLink protocol to the flight controller.

The table below maps the competition tasks to the capabilities of the autopilot system:

Competition Tasks	Capabilities of Autopilot system

Autonomy	The system can receive waypoints and search locations and develop a flight plan with includes autonomous take-off and landing. The system will optimise for the fastest time to complete the mission and maximising points. The system also allows for a user confirmation before dropping the UGV autonomously.
UGV Drop	Once receiving confirmation from the user to drop the UGV, the command will trigger the winch system. The winch will optimise its drop speed to bring down the ugv as quick as possible and come to a stop 5 inch above the ground and release it. The winch will wait for the UGV to confirm it has been released and being to collect the tether. Once completed the UAV will complete the rest of the mission
30 Minute Flight (maximum)	The system will calculate the return time home at each stage of the mission to determine if it's still possible to complete the mission. If the time to fully complete the mission > remaining time, the UAV will return home and end the mission.
Image Recognition (objects on ground)	The system will develop a surveying plan at the start of the mission when provided waypoint boundaries. It will first plan a high-level survey of the ground to collect points of interest. Once it completes this section of the mission it will then develop a more refined survey plan at a slower speed and height to recapture the points of interest and determine what they are.
Static object avoidance	For static object avoidance, the waypoints and exclusion diameter will be added to the mission's exclusion zone. The aircraft will develop its paths around the exclusion points/obstacles.

The ground station will be running on Windows to run the Mission Planner ground station application and a POSIX-compatible environment to run the team's custom autonomous flight planning software. Mission Planner will be used as a configuration unity and visual notifier of what is happening with the aircraft. It will provide us with WREN's current location, current stage of the mission and vital flight telemetry. The custom autonomous flight planning software will provide us with what's currently being processed by the aircraft, the status of the companion computer and text input for manual override of the flight plan.



2.3 Obstacle Avoidance

Our algorithm adopts the method utilised in the ArduPilot fencing algorithm. It requires 3 inputs, the radius of the area, the latitude and the longitude. There is also a global variable to set a distance for a soft fence to avoid an additional area around the obstacle.

When the flight planner is running it will first upload the geofence and obstacles to the mission and apply the soft boundaries. Then it will take the waypoints and develop a path avoiding the obstacles by creating a response vector to avoid coming near the obstacle. The response vector is a combination of vectors which include max left, max right, max up and max down to keep it away from the obstacle whilst staying within mission bounds and path.

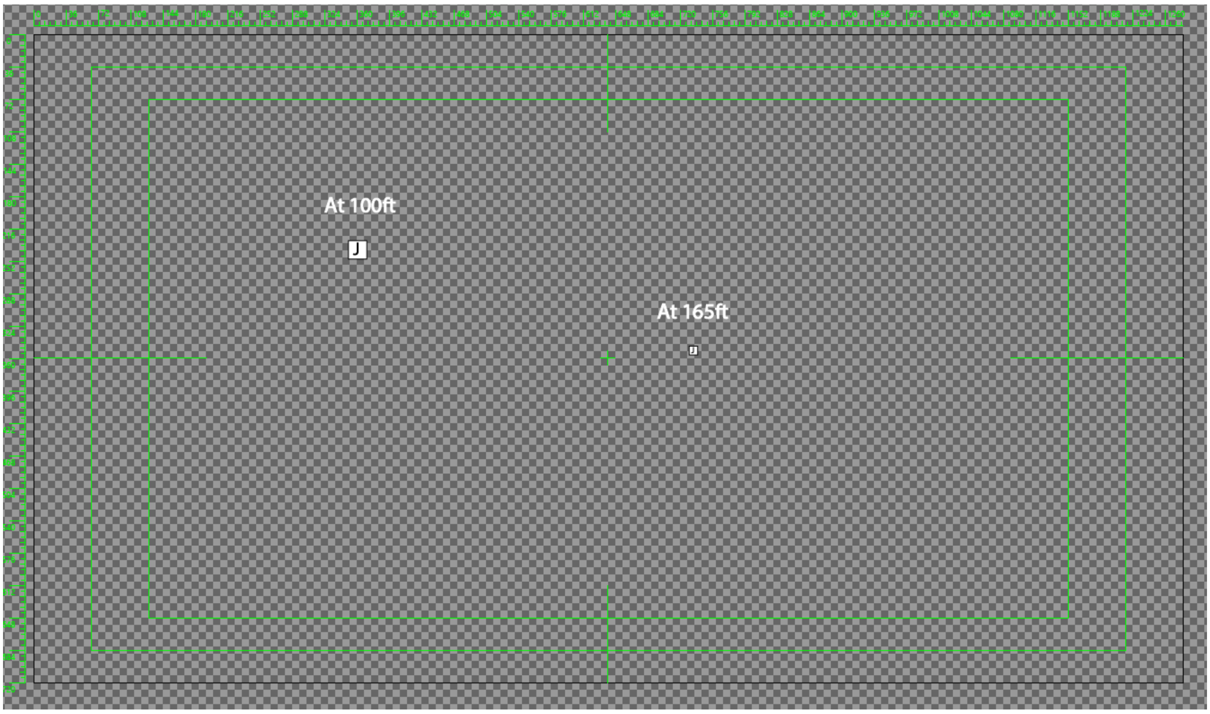
2.4 Imaging System

The Imaging System will use two UP HD machine vision cameras. It has removable lenses so the team can adjust the focal length when need be, auto white balance, auto exposure and auto focusing. One is situated pointing directly underneath the aircraft to be used to image any important objects in detail. The other will be pointed between 25-45 degrees ahead to spot any potential interesting objects to fly over and image any out of bounds objects. There are 3 major constraints the team has put on the camera section:

1. Must be lightweight (under 400g for 2)
2. Images can be processed on board
3. Have a small footprint

The current specifications of the cameras are as followed: 1280 by 720 resolution, a focal length of 12mm and a view angle of 26.2 degrees.

For surveying, the team has taken a two-stage process, by first collecting points of interest at 165 ft and a final detailed detection at 100 ft. At 165 ft, the cameras will be covering 16049 square foot of land and the object is 0.02% of the image which is enough to recognise the general shape of the object. At 100ft, the camera will be covering 6167 square foot of land and the object makes up 0.05% of the image which is enough to see characters and details of the object. The figure below shows a general comparison of a simple object at these heights. At these heights the imaging system can process multiple objects in a single pass through thus reducing time spent surveying.



2.5 Object Detection, Classification, Localisation

The autonomous processing is done by passing the camera feed into a Neural Network trained to find coloured shapes and people (named interesting objects). This extracts the interesting objects from the image and the GPS location of the object is determined relative to the drone. This is done on the first, faster flyover of the objects. A further selection of tasks are then applied to the image to determine more information about it on the second, slower flyover, which are described below:

- Optical character recognition and subsequent orientation detection
- Shape type recognition through edge detection and counting
- Colour classification through colour type boundaries
- Person pose detection
- Environment description

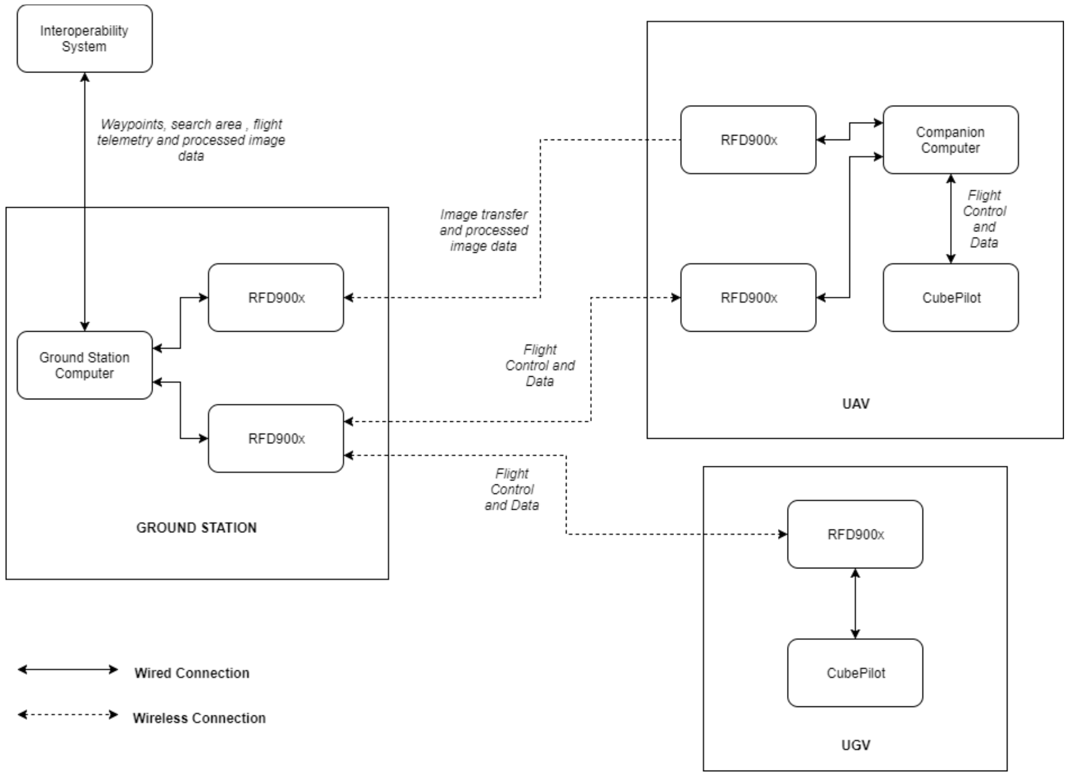
Following all this data extracted from the image, a database collation system asynchronously stores all the data in a data-structure to create the ODLC files required for the competition, and subsequently sent to the judges via the ground station.

2.6 Communications

The communication between the multiple different systems on the ground and in the air is an important aspect of the design of WREN. The table below shows each of the communication interfaces, the applicable hardware and specifications, as well as the data that is sent through this interface. Following that, a simple block diagram showing the communication system for WREN is shown below.

Interface	**Hardware**	**Specifications**	**Data Sent**
Interoperability to Ground Station	Ethernet Cable	-	Flight Telemetry, Waypoints, search area, out of bounds object and processed image data.
Ground Station to Companion Computer	RFD900x	Frequency Range: 902 -	Flight telemetry, flight plan, geofences, no fly zone objects, and drop confirmation which is

(UAV) for telemetry		928 MHz (USA)	packaged using the MAVLink Protocol
Ground Station to Companion Computer (UAV) for image transfer	RFD900x	Frequency Range: 902 - 928 MHz (USA)	Raw, processed images and data will be sent to the ground station via FTP
Companion Computer (UAV) to CubePilot (UAV)	Serial Cable	-	Flight telemetry, flight plan, geofences, no fly zone objects, and drop confirmation which is packaged using the MAVLink Protocol
RC Transmitter to CubePilot (UAV)	FrSky Taranis x9D FrSky x8R	Frequency: 2.4GHz	User input converted to SBUS signals for throttle, pitch, yaw, roll and flight modes.
Ground Station to CubePilot (UGV)	RFD900x	Frequency Range: 902 - 928 MHz (USA)	Flight telemetry, flight plan, geofences, no fly zone objects, and drop confirmation which is packaged using the MAVLink Protocol



2.7 Airdrop

The airdrop system is comprised of two parts, the payload (or UGV) and the winch mechanism. The winch mechanism is housed inside of the cargo bay of the UAV, separated from the UGV using a system of pulleys to ensure the UGV falls from the correct position in the UAV. This reduces the likelihood of the wire tangling during both descent and retrieval processes, making the system easy to reload when on the ground. This was also required due to the space limitations inside of the cargo bay and being unable to mount all the required winch components directly above the UGV.

An Arduino Uno will be used to control both the servos opening of the cargo bay doors, as well as controlling the descent of the UGV during the airdrop. The Arduino will also command the retrieval of the winch cable after it has been detached from the UGV. To allow for integration with our flight control system, the Arduino waits for a HIGH servo signal from the CubePilot before beginning the drop sequence. This prevents the drop from being unintentionally started, as this command can only come from the autopilot in AUTO mode, or the monitoring

Ground Station. A brushless motor is also used, controlled by the Arduino, which controls the speed of descent for the UGV and holds the UGV in place when not in descent using motor braking through the ESC. The ESC connected to the motor is running BLHeli32, which allows for a full range of programming of the ESC, including braking.

As for the UGV, it is simply a repurposed RC buggy that has been stripped of all unnecessary components and refitted with the required components for the competition. A CubePilot Mini has been attached to the UGV to allow for autonomous steering control, as well as sensing when the UGV has touched the ground. The CubePilot will also release the latch once it is confirmed the UGV is on the ground, allowing for the winch cable to be retrieved. This will be controlled by a servo permanently connected to the UGV and will allow for a hook to be held in place to attach the winch cable to the UGV.

As the CubePilot software is programmable, like the CubePilot used in the UAV, the UGV will be able to autonomously navigate from the drop position to the specified waypoint, as per the rules of the competition. The payload fixing device is attached at an angle towards the rear of the UGV, allowing for an optimal force distribution over the small UGV, as well as allowing it to easily fit inside the cargo bay. The size of the fixing device can be tailored for different sized and shaped payloads, with the largest payload dimensions being 350x250x100mm, with a tapered restriction along the length to conform to the shape of the UAV

As the UAV is designed as a quad-plane, this gives the UAV the flexibility to accurately hold both altitude and ground position constant during the drop. As such, using the accurate GPS location of the UAV in conjunction with the GPS position of the UGV, the position of the UAV can be adjusted to ensure the UGV lands as close to the chosen position as possible. In this case, a slower drop will be more accurate as the UAV has more time to react to changes in the position of the UGV and adjust the position accordingly.

2.8 Cyber Security

Security threats are an important consideration for commercialised UAVs, for this competition it has been considered in both our own UAV and UGV. It is also important for the ground station to be protected from any attacks or alterations of data. The table below identifies the cyber security threats considered and the possible solutions that can be implemented to protect the UAV, UGV and ground station systems from any attacks.

Threats	**Solutions**
Spoofing Telemetry Stream	• 128-bit stream encryption • ID locked radio • Cryptographic key shared by the base station and UAV
Telemetry Packet Sniffing	• Detection of unexpected packet sniffing software on the telemetry stream via open source software such as 'Antisniff'. • Data Encryption - any data compromises will be unable to be read, and any attempts to modify or send compromised information will be flagged on the system as unexpected.
GPS interference, lack of encryption or authentication	• Spectrum monitoring analysing surrounding area for signal and GPS jammers
Base station malware	• Packet sniffer for continuous data analysis • Limit network bandwidth and IP and MAC Address limitations • Response time analysis of network traffic for comparison between allowed and unauthorised traffic • Denial of service attack prevention software, securing the base station from overloaded network traffic

3. Safety, Risks & Mitigations

3.1 Developmental Risks & Mitigations

Workshop Safety

UNSW Sydney has multiple design and fabrication workspaces, all of which have strict safety guidelines that are enforced by the staff that run the workspaces. To gain access to this space, all team members have been trained on general workplace safety, the safe use of hand-tools and the minimum appropriate PPE to be worn, including enclosed shoes, safety glasses, hair/loose clothing tied back. All workshops are equipped with emergency exits, fire extinguishers, first aid kits, spill kits, etc. in the case of any emergency that may occur, and all staff are trained in first aid and responding to emergencies should they occur. University campus security is contactable immediately on any phone (cell or in-line) to deal with any kind of emergency that may occur as well, if for some reason the staff member is incapacitated.

Flight Labs UNSW has appointed a team member to take on the role of safety officer, who oversees ensuring all tasks are performed safely, minimising risks to all members in the team and any other non-members involved in the process. The safety officer oversees ensuring all documents for risk assessments and safe work procedures have been read and signed by team members, these documents are managed through UNSW intranet on safesys.unsw.edu.au. The table below summarises the main risks in the aircraft development and manufacturing processes, aligned with the existing UNSW Sydney safety documentation.

Risk Type	**Mitigation Procedures**	**Likelihood**	**Potential Consequence**	**Overall Risk**
Cuts & bruises	General workshop safety is enforced; cutting is done away from the body, clamped when required. First aid kits are available in all workshops in the event of a cut.	Unlikely	Minor	Low
Fumes from: -Laser Cutter -3D Printing -Resin Layups -Fibreglass / Carbon Fibre	Fumes from laser cutters are handled with a built-in extraction system with a filter. Cutting and sanding machines are handled with extraction systems around the shop. When laying moulds with resin; respirators are used, and layups are only performed in well-ventilated areas. The same ventilated area and respirator rules apply for when cutting and sanding of fibreglass or carbon fibre is done. If a large amount is to be done, then this job is outsourced for safety and a better finished product	Unlikely	Moderate	Medium
Chemical spills and burns (mainly during layups)	During layups, the epoxy resin (and fibres from carbon) can cause irritation to skin. PPE including safety goggles, gloves and respirator is worn Washing hands after handling epoxy resin is also very important.	Unlikely	Minor	Low
Electrocution	All tool cables are tested and tagged Wiring is checked prior to power being switched on for craft or tools.	Unlikely	Moderate	Medium

Burns and fires	Fire extinguishers and smoke detectors are in all workshops in the event of a fire, with fire services being automatically notified. Burns to skin can be immediately treated with available sinks in the workshops and further treatment can be checked at the nearby hospital if required.	Unlikely	Moderate	Moderate
Temporary or permanent hearing damage	When using tools that generate loud noise or if exposed to noise for an extended period it is important to protect ears with ear plugs. When using loud tools warning others in the workshop about the level of noise is important.	Unlikely	Minor	Low

3.2 Mission Risks & Mitigations

Testing

Testing is conducted in such a way as to reduce the risk of damage or injury in the case of designing and operating new sections or features of the system. In cases where it is possible, software is tested on the ground, and mechanical and electrical systems are tested on smaller scale test aircraft that have been set up for exactly that purpose. Once the systems are working correctly, they are added to the main airframe and the system is tested as a complete package.

Flight Testing Location Legalities

During testing WREN, a trip with the team needed to be taken out to a more rural area where it was legal to fly much further ranges out and higher altitudes in order to protect the public and any other planes/helicopters that may have their flight path over. This is all in accordance with CASA, who govern aviation laws in Australia.

Safety Controls

A full pre-flight checklist has been developed which focuses on the safety of the aircraft, crew and pilots and general members of the public. This is achieved through checks on the airframe, tooling, electrical systems, system calibration, communication systems, environment and software systems. Multiple safety controls are implemented into the design in the case of an emergency where immediate landing might be necessary such as pre-planned emergency landing areas, return to home procedures programmed into the craft and complete flight termination should the plane cease communication with the ground station for an extended amount of time.

Autonomous Flight

During autonomous flight, the safety pilot will be ready to take manual control should anything go wrong during operation, they will be trained for this prior to the competition. All flight details will be relayed continuously to the ground station during flight to monitor all information associated with the current flight, including system health, current task, speed and position.

Risk Type	**Mitigation Procedures**	**Likelihood**	**Potential Consequence**	**Overall Risk**
Public Liability Insurance	Public Liability Insurance has been obtained through the University of New South Wales student organization ARC. Test flights will occur at MAAA affiliated flying fields that have insurance cover.	Rare	Minor	Low

Aircraft Operation Laws	Airframe operations will be carried out at designated Model Aeronautical Association of Australia flying fields, under the auspices of local flying clubs and with the required flying accreditations.	Rare	Minor	Low
Range Safety	Field tests will be conducted following the MAAA Manual of Procedures.	Rare	Minor	Low
Injury from Motors / Propellers	Motors to be disarmed before approaching aircraft. Motors not to be armed if personnel are within 3 meters of the airframe.	Unlikely	Minor	Low
Flight Batteries	Lithium Polymer (LiPo) flight batteries will be stored in padded, decommissioned ammunition tins (non-airtight) for transport and charging. LiPo Flight Batteries will be brightly coloured to be distinguished in the case of a crash. All testing flights will have a fire extinguisher on hand in case of a LiPo explosion	Unlikely	Moderate	Medium
Avionics Power Failure	In the case of the battery running out of charge the main propeller will lose power but the aileron servos will still have power to safely land the craft to then properly recharge the batteries.	Unlikely	Minor	Low
Autopilot Failure or Lockup	This will be handled by the flight termination system. with the option to manually trigger flight termination if required. Or automatically return to home/return to land. In accordance with the rules, the craft will terminate flight after 3 minutes of communication loss. The UGV will terminate after 30 seconds of communication loss (or after leaving boundary area).			
Manned Air Traffic	Test Flights will occur at MAAA affiliated flying fields. Long Distance tests (>1000ft) will occur over private property, well away from known manned flight paths. Radio watch will be maintained on the Aviation Frequencies. Test Flight altitude will not exceed 400 ft AGL.	Rare	Minor	Low
Recovering Downed Aircraft	It is likely that a downed aircraft will be in a remote location to the Ground Control Station and Operations Base. Risks to be mitigated by: Stationing observers along planned flight path to maintain visual contact as much as possible. No single person to enter range alone, pairs at minimum, with means of communication to Ground Station. Maps of area to be carried by ground teams when in the field. Fire precautions to be taken in the case of a LiPo battery leak/explosion.	Unlikely	Minor	Low

Issues with Software	Software simulations to be run before implementation on aircraft to verify correct operation and monitor performance and behaviour. New software releases to be tested on test craft before installing on competition plane.	Unlikely	Minor	Low
Electrical Connections	Our team comprises of engineering students with a high proficiency in circuit design and construction. All circuits will be designed to eliminate the chance of potential overloads. Any connections made, such as any soldering work, will be checked for proper and permanent contact. Pre-flight Checks will involve electrical system checks.	Unlikely	Minor	Low
Payload Drop	The UGV will be dropped only when the safety pilot has been notified and given the all clear during competition and in training. Testing of the drop will be done in a cordoned off area where possibility of hitting people or animals can be completely mitigated	Rare	Minor	Low
Fatigued Persons Operating Airframe	Implementing logbook operations with the qualified pilots and flight crew. Have minimum sleep requirements in the 24 hours preceding to operation of the craft, especially for the competition.	Unlikely	Minor	Low
Inebriated or otherwise Inhibited Persons Operating Airframe	Blanket ban on any alcohol in the preceding 24 hours before operating the Airframe. Any other inhibiting substance such as prescription medication must be disclosed to the mission controller and the decision to let the pilot control the aircraft rests with the mission controller alone.	Unlikely	Minor	Low

4. References

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