Laki2

The UCF Robotics Club is competing in the 2019 AUVSI SUAS competition for the first time with their octorotor vehicle Laki-2. The intention of the team was to develop a vehicle capable of effectively completing all competition elements. This Technical Design Paper describes the approach taken by the team to develop the system. The paper highlights the key aspects of the mechanical, aerodynamic, electrical, and software designs as well as the fundamental engineering considerations behind them.

Competition Rules | SUAS 2019 by the AUVSI Seafarer Chapter

http://www.auvsi-suas.org

This document contains the rules for the 17th Annual Student Unmanned Aerial Systems Competition (SUAS) by the Association for Unmanned Vehicle Systems International (AUVSI) Seafarer Chapter.

Competition Purpose. The AUVSI SUAS Competition is designed to foster interest in Unmanned Aerial Systems (UAS), stimulate interest in UAS technologies and careers, and to engage students in a challenging UAS mission. The competition requires students to design, integrate, report on, and demonstrate a UAS capable of autonomous flight and navigation, remote sensing via onboard payload sensors, and execution of a specific set of tasks. The competition has been held annually since 2002.

Statement of Liability. The Seafarer Chapter of AUVSI and the host organization, their employees and agents, as well as the SUAS committee, are in no way liable for any injury or damage caused by any entry, or by the disqualification of an entry. The Seafarer Chapter and AUVSI at large are not responsible for ensuring SUAS teams operate their UAS systems within the Federal Aviation Administration (FAA) rules and regulations.

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Overview

The competition has three major elements: the Technical Design Paper, the Flight Readiness Review Presentation, and the Mission Demonstration. The paper details a team's UAS design. The presentation details the team's testing and preparedness for the competition. The demonstration simulates a mission in which the UAS and team is evaluated. The mission consists of autonomous flight, obstacle avoidance, object detection, and air drop.

SUAS 2019 Mission. A package delivery company has tasked an Unmanned Aerial System (UAS) to deliver a package to a customer. The UAS must avoid obstacles like buildings, identify potential drop locations, drop the package to a safe location, and then move the package to the customer's location.

Competition Location. The competition will be held in June 12th to 15th at Webster Field, St. Inigoes, Maryland of the Naval Air Station (NAS) in Patuxent River, Maryland.

Google Groups. All communication will use the AUVSI SUAS mailing list on Google Groups. All team members and advisors must join in order to receive important announcements and ask questions.

Rules Subject to Change. The judges try to provide the best possible rules and competition experience. Sometimes errors are made and situations change. The judges reserve the right to make changes at any time to the rules, point allocations, and prizes.

Spirit of Competition. The judges expect teams to compete in a fair and professional manner. Cheating will not be tolerated. Teams caught cheating will be disqualified, and the school will be banned from competing for 4 years.

Ranks and Awards. There are three major graded elements of the competition: the mission demonstration, the technical design paper, and the flight readiness review presentation. There

are also awards for which teams earn prize money.

Schedule & Deliverables

This section describes the major elements of the competition, the schedule of events and deliverable due dates, and details for deliverable submission.

Google Calendar. The competition hosts an AUVSI SUAS Calendar containing the competition events and deliverable due dates. All dates listed here will also be in the calendar. The calendar's events will be updated with details as they become available. It is the team's responsibility to monitor the calendar and comply with all deadlines and dates.

Deliverable Submission. All non-mission deliverables will be submitted via Google Forms. Each team will need a single Google account which has access to Google Drive (to host file deliverables) and YouTube (to host video deliverables). Teams are responsible for ensuring all links are accessible by the judges (publicly viewable) for the duration of the competition.

Document Format. All documents must be submitted as a PDF. The filename and first page of the document must include the university and team name. All documents must have at least 10pt font and 1 inch margins. Documents must be uploaded to Google Drive, and teams will provide a publicly accessible link.

Video Format. All videos must be at least 1080p resolution with at least 24 frames per second. The video name must include the university and team name. Videos must be uploaded to YouTube, and teams will provide a publicly accessible link.

Lateness. Teams are given these deadlines months ahead of time. Failure to meet a deadline will result in either losing points for the graded element or disqualification from the competition. The judges will evaluate extenuating circumstances for exemption and deadline extension.

The following subsections describe the individual deliverables and events.

Draft Rules, Comment Period, Final Rules

(2018-09-14) Draft Rules Released. The judges will release a draft of the rules in order to get feedback from the teams. The rules will be posted to the competition website.

(2018-09-15 to 2018-09-28) Comment Period. During this period, teams must read the rules and should submit questions and comments to the Google Groups. The judges may respond to the comments and adapt the rules.

(2018-10-04) Final Rules Posted. The final rules will be posted to the competition website. The judges reserve the right to change the rules after this date if necessary.

Kickoff & Registration

(2018-10-05 1pm) Competition Kickoff Meeting. The judges will hold a conference call to discuss the final rules, answer last-minute questions, and otherwise prepare for the competition year. This meeting is purely for the benefit of the team and is not mandatory.

(2018-10-14 to 2018-10-29) Registration Period. During this period, the team captain can submit the following Google Form to register a team. The team captain must also send a registration fee and it must be delivered prior to the end of this period. Registration is first-come, first-served: the first 75 valid form submissions that also provide the registration fees will be accepted. The registration fee is $1,000 USD. The registration fee is non refundable once a team is officially accepted into the competition. The registration fee will only be refunded to teams which are not accepted to the competition. The registration fee must be sent as a check or money order in USD. The fee must be payable to “AUVSI Seafarer Chapter”. The registration fee must be sent to the address in the Mailing Address Appendix.

Registration Form: goo.gl/forms/TkLtiXsMfd8uN9Pu

Personnel Registration & Base Access Documents

(2019-03-04) Personnel Registration. The team captain will electronically submit a form for each member of the development team and the advisor.

Personnel Registration Form: goo.gl/forms/lwHdcmDdjcS0VcRP

(2019-03-04) Base Access Documents. The competition is held on a US Naval Air Station. Each person attending competition, from competitors to guests, will be required to fill out a form and provide documentation in order to be vetted for base access. Failure to obtain passports or visas in time for the submission deadline will not be cause for any extension. International teams should obtain passports and visas as soon as possible. See the appendix sections for Base Access Form & Documents and Foreign National Form & Documents. These forms must be mailed and received by the provided date. See the Mailing Address appendix.

Fact Sheet & Technical Design Paper

(2019-04-14) Fact Sheet. The teams will submit a Google Form detailing specific facts about the UAS the team is designing. The details specified in this form must not change after this point without written approval from the judges.

Fact Sheet Form: goo.gl/forms/YH4b2X1pPPeEGfr

(2019-04-14) Technical Design Paper. The Technical Design section describes this deliverable. It is a paper detailing the technical design and plan for evaluation of the UAS designed by the team.

Technical Design Form: goo.gl/forms/6AgUVopJGwzDgvph

Proof of Flight, Safety Pilot Log, Flight Readiness Review

(2019-05-14) Proof of Flight. Teams must provide proof via video that the UAS can be flown safely. Teams must provide a video showing a manual flight including the safety pilot, UAS takeoff, 5 minutes of UAS flight where the UAS gets at least 1000ft from the safety pilot, and UAS landing. Teams must provide a second video showing the UAS in autonomous mode, transition to manual mode, and manual landing. Teams must provide this video for each potential pair of safety pilot and aircraft instance (primary, backup, etc) that might be used at competition.

Proof of Flight Form: goo.gl/forms/ESr0c2kB8EeESk4F

(2019-05-14) Safety Pilot Log. Safety is critically important for the competition, and vital to safety is the safety pilot's ability to control the aircraft in an emergency. To this end, teams must submit a safety pilot log detailing the manual flights conducted by the safety pilot on the UAS in competition configuration. The pilot must perform and log at least 3 hours of manual flight, 10 takeoffs, and 10 landings. The team must provide multiple logs, each meeting this specification, for each pair of pilot and aircraft instance (primary, backup, etc) that might be used at competition.

Safety Pilot Log Form: goo.gl/forms/cosrRRKPRCK3mvSt

(2019-05-14) Flight Readiness Review. The Flight Readiness Review section describes this deliverable. It is a video presentation detailing the result of testing and the team's preparedness for competition.

Flight Readiness Review Form: goo.gl/forms/u3QEOoJBfcfVgKyW

Team Promotional Video

(2019-05-31) Team Promotional Video . Each team is required to submit a promotional video for their team. The video must be no longer than 2 minutes, show the full team, show the UAS in flight, and briefly describe the design. The team can add additional content to the video as

desired.

Team Promotional Video Form: goo.gl/forms/j0SPFmFB7zNp4Y5o

Competition: Check-in, Mission, Awards Banquet

(2019-06-12 3pm - 6pm) Career Fair. After teams have checked in, the students may participate in a career fair hosted by the competition sponsors. Students can use this time to meet potential employers and learn about the companies and their technologies.

(2019-06-12 4pm - 6pm) Check-In. The teams will check-in to receive base access badges, fill out forms, and complete other logistical tasks. The team captain and at least 50% of the team competitors must be present. Check-in will close to new teams 30 minutes prior to end. Teams which fail to check-in may be disqualified. Unexpected delays must be communicated to the judges as soon as possible. The team captain will need to provide a signed waiver for all attendees. At this time, the team will be provided the interoperability connection details.

Waiver:

http://www.auvsi-suas.org/static/competitions/2019/auvsi_suas-2019-risk_and_liability_waiver.pdf

(2019-06-12 6pm - 7pm) Dinner. The competition will provide a buffet dinner, which teams will be welcome to once they have checked in. Limited dietary restrictions will be accommodated at this meal.

(2019-06-12 6pm - 8pm) Orientation. This is a meeting covering all of the logistics for the week. Teams must be present to receive last-minute updates.

(2019-06-13 6am - 7am) Base Entry. Teams must arrive at the base gate and make it onto the base by 8am. Teams with foreign national students or guests must arrive at the gate no later than 7am. People who aren’t on base by 8am might not be allowed entry at a later time.

(2019-06-13 7am) Safety Inspections. The UAS and the ground station will be inspected for

safety and competition compliance. Inspection will include at least a physical inspection, fail-safe and flight termination check, and maximum weight check. Teams will be evaluated in their flight order. If a team fails inspection or is not present, they will be put in the back of the queue for an additional attempt. Failing safety inspection may change the team's mission demonstration order. Each aircraft instance must be safety inspected.

(2019-06-13 7am) Individual Team Photos. After a team has passed safety inspection, the entire team will pose for a photograph in front of the competition banner. These photos will be posted to the web with the rest of the competition photos.

(2019-06-13 7am) Interop Testing. Teams will be given the opportunity to test their system's connection with the Interoperability System using the same mission credentials and a representative set of hardware. Teams should begin testing immediately after the team photo. Note that teams which are called to the flight line will need to use an in-pit timeout to extend this testing time.

(2019-06-13 12pm - 7pm) Mission Demonstrations. Mission demonstrations will be started once a critical mass of teams have passed safety inspections and taken their photo. Teams will be given at least 5 minutes notice of transportation to flight line. The team and the equipment will be transported via flatbed trailer to the flight line, after which the setup time will start. Depending on base logistics, the Group Photo may be moved to this time so all teams must be present.

(2019-06-14 6am - 7am) Base Entry. Same as Thursday.

(2019-06-14 7am - 7pm) Mission Demonstrations. Same as Thursday.

(2019-06-15 6am - 7am) Base Entry. Same as Thursday.

(2019-06-15 7am - 4pm) Mission Demonstrations. Same as Thursday.

(2019-06-15) Group Photo. The teams and judges will get together for a competition photo. It

will most likely happen after the last flight. Teams and their UAS must be present. Note the Group Photo may be moved to Thursday.

(2019-06-15 6pm-10pm) Awards Banquet. The awards banquet includes dinner, a keynote speaker, and the presentation of awards. The recommended attire is business casual. Teams must attend to collect their awards and prize money.

Requirements

This section describes the requirements that the team and UAS must meet. Teams which fail to comply with these requirements may be disqualified.

Team Composition

Single Team per School. Each school may only register a single team.

Development Team. The development team must consist of undergraduate or high school students which attend school full-time for at least one semester during the academic year. The team may have at most 1 graduate student participate during the academic year.

Competition Team. The team of students which attends the competition, participates in the Flight Readiness Review (FRR), and participates in Mission Demonstration must be at most a 10 person subset of the development team. The competition will provide food, t-shirts, and other resources for these 10 students. Extra resources may be available for purchase.

Team Captain. One member of the competition team will fill the role of team captain during the competition year. This student will be the primary point of contact for the judges. All questions, comments, statements, and deliverables must be submitted by the team captain. The judges must be immediately notified of any team captain change.

Advisor. Each team must have a school faculty member/advisor or official point of contact (POC) from the team’s school. Teams whose entire team is age 18 years or above are not

required to have the advisor or school official travel with the team, otherwise at least two adults shall travel with the team and shall take full responsibility for the students. The advisor will also be admitted to all competition events, and will be provided food and a t-shirt. The advisor will be permitted to observe the team at the flight line, but is forbidden from communicating or otherwise assisting the team during setup, mission, or tear down.

Safety Pilot. The safety pilot used during the year, for whom a safety pilot log is required, can be a student, the advisor, or non-student. At competition, you may use the same safety pilot or request a competition volunteer act as safety pilot. The safety pilot will count as 1 of the 10 members of the competition team, regardless of whether it's the advisor or competition volunteer. If the pilot is not a member of the development team then the pilot is limited to safety related functions and communication, and may not advise or participate in other roles.

Competition Guests. Each team will be allowed to bring up to 10 additional guests to competition. If desired, these guests may be development team members, but they cannot assist with the mission demonstration. These guests will need to purchase tickets for access to on-site food and the awards banquet. There are a limited number of food and banquet tickets which will be distributed first-come-first-served. The team is required to provide the base access details for these guests by the specified deadline.

Unmanned Aerial System

General Restrictions. The team may only fly a single aircraft during the mission. The aircraft must be capable of heavier-than-air flight, and be free flying without any encumbrances like tethers. The max takeoff weight is 55lbs.

Single Design & Backup Instances. The team must use exactly one design throughout the competition. Teams are locked into a specific design upon submission of the Technical Design Paper. The team may use backup instances of that design during development. The team must

use exactly one instance during the Mission Demonstration.

AMA Safety Code. The aircraft must comply with the AMA Model Aircraft Safety Code except that autonomous operation is authorized at competition, and both free flight and control line are not applicable.

Return to Land & Flight Termination. The UAS must have either autonomous return to home (RTH) or return to land (RTL), and autonomous flight termination. These must be configured with the location specified in the Mission Flight Boundary Appendix. Both must be activatable by the safety pilot and the ground station. After 30 seconds of communications loss, the aircraft must automatically RTH or RTL. After 3 minutes of communication loss, the aircraft must terminate flight. For fixed wing aircraft, flight termination must be: throttle closed, full up elevator, full right rudder, full right or left aileron, and full flaps down (if equipped). For non fixed wing aircraft, throttle must be closed and all actuators off. The termination system must be designed to touch ground within 500ft over ground of the termination point.

Fuel & Batteries. Exotic fuels or batteries will not be allowed. Any option deemed by the judges as high risk will be denied. All batteries must be brightly colored for identification in a crash, and it is preferred if they are wrapped in bright colored tape.

Fasteners . All fasteners must have either safety wire, loctite (fluid), or nylon nuts.

No Unauthorized Air Drop. No pieces may depart from the aircraft while in flight, except for the components involved in air drop while attempting that task. Foreign object debris (FOD), like nuts and bolts, must be cleared from the operating area before mission flight time stops.

Autonomous Flight. The UAS must have autonomous flight capabilities to compete. The UAS must fly autonomously for at least 3 minutes to receive any mission demonstration points.

Unmanned Ground Vehicle

General Restrictions. The team may use a single Unmanned Ground Vehicle (UGV) at the

competition as part of the air drop task. The entire drop payload can weigh up to 48oz. The UGV drive speed may be up to 10 miles per hour.

Drive Termination. The UGV must terminate driving after 30 seconds of communication loss or after driving out of the boundary specified in the Air Drop Location & Boundary Appendix. Drive termination must also be activatable by the safety pilot or the ground station.

Fuel & Batteries. Exotic fuels or batteries will not be allowed. Any option deemed by the judges as high risk will be denied. All batteries must be brightly colored for identification in a crash, and it is preferred if they are wrapped in bright colored tape.

Autonomous Driving. The UGV may only drive autonomously.

Ground Station

Ground Station Display. Teams must have a display, always viewable by the mission judges, which shows the a map showing the flight boundaries, the UAS position, and all other competition elements. This display must also indicate the UAS speed in KIAS or ground speed in knots, and MSL altitude in feet. Teams will not be able to fly without this display.

Safety Materials. Teams must have available personal protective equipment (PPE) (tools, gloves, eye protection, hearing protection, etc.), safety risk mitigation (training, checklists, radios, etc.) and equipment to support rapid response to accidents (first aid kit, fire extinguisher, etc.) as needed.

One Motor Vehicle & One Trailer. Teams may use up to one motor vehicle and one trailer at the flight line. The judges will provide a tent, table, and set of chairs. Additional equipment may be brought by the team. These vehicles cannot assist UAS takeoff or recovery.

No Objects Taller than 15ft. No antenna masts, balloons, or other objects taller than 15ft will be permitted.

No Ground-Based Sensors. No ground based sensors can be used.

Radio Frequency (RF)

No RF Management. The judges will not provide any RF spectrum management. This means that any device can be used in any of the allowed bands at any time. This includes both the flight line and the pits. Teams are encouraged to use hardwired connections when possible. As relevant, teams should use encryption, directional antennas, and RF filters. Each team should expect other teams to be using similar equipment (e.g. same autopilot), and teams must ensure they don't allow invalid connections (e.g. connecting to another team's autopilot). Where possible, teams should use frequency hopping or dynamic channel selection. The judges reserve the right to institute RF management if necessary, but teams may not rely on or expect such.

Allowed Bands. All RF communications must comply with FCC regulations. 72MHz is allowed for RC control but is highly discouraged. 433MHz is allowed but must use frequency hopping spread spectrum. 462.7Hz is allowed, but the judges will also be using this frequency for handheld radios. 900MHz is allowed. 1.08, 1.12, 1.16, 1.2, 1.24, 1.28, 1.32, and 1.36 GHz are allowed but must use frequency hopping spread spectrum. 1.2GHz to 1.3GHz may only be used for analog or digital video systems. 2.4GHz, 5GHz, and cellular connections are allowed.

Intentional Interference. Teams found intentionally jamming or interfering with another team's communications will be considered cheating.

Weather & Airfield

The judges will temporarily suspend the competition if conditions are deemed unsafe. Teams must be able to secure equipment against sudden weather like winds and rain.

Winds. The aircraft must be able to operate in 15 knot winds with gusts to 20 knots, including takeoff and landing. There are two accessible runways that are 90 degrees apart. Teams may launch in any safe direction from the grass.

Temperature. The system must be able to operate in temperatures up to 110 degrees Fahrenheit peak, and 100 degrees Fahrenheit sustained.

Precipitation & Visibility. Teams will not have to operate during precipitation, but they must be prepared to quickly secure their equipment from sudden precipitation. Fog conditions are acceptable if there is at least 2 miles of visibility.

Provisions. The judges will provide the team a tent for shade, a folding table, chairs, and a single electrical power extension cord from a mobile generator.

Electrical Power. The electrical power provided will be 115 VAC, 60 Hz, rated up to 15 amperes. This may not be enough for many ground stations, and teams should consider bringing additional generators and UPS battery backups. There is a possibility the mobile generator may run out of gas at any time during the competition and not be refilled and restarted for some undetermined period of time. Teams must be capable of operating without competition provided electrical power for up to 10 minutes.

Airfield Notes. Airfield coordinates are 38°09'01.5"N, 76°25'29.7"W. Airfield elevation is 22 feet MSL. Airfield magnetic deviation is 11 degrees west. The runway is a paved asphalt surface, roughly 100 feet wide, with no height obstacles. Grass areas within the takeoff/landing area will not be prepared but will be available for use.

Interoperability System

The Interoperability System is a network and web server that teams should interact with during the mission. This system provides mission details and receives mission deliverables. The system provides automatic evaluation for scoring, and is available to teams for testing.

Code Repository & Documentation

Code Repository. The entire Interoperability System is open source so teams can develop and

test against the system. The AUVSI SUAS Interop Github Repository contains all code and documentation. The system will evolve over the year as features are added and bugs are fixed, so teams should watch the repository to receive notifications.

Documentation. All documentation for the Interoperability System can be found linked off the code repository website. This documentation contains instructions for setting up the system, configuring it, integrating with it, and testing with it.

Interaction with System

This section provides a high-level overview of the interaction with the Interoperability System. Teams should refer to the documentation website for details.

Network Connection. At setup time, teams will receive a single ethernet cable with which to connect to the Interoperability System. This connection will provide DHCP and a single static IP address. The IP addresses will be on the subnet 10.10.130.XXX with subnet mask 255.255.255.0. Teams will typically connect this to the WAN port of their router, which will provide a separate subnet for the team's systems. Teams will then connect to the system using the IP address (DHCP or static), username, and password that is provided at Check-In and Orientation. Teams may then use this connection until the end of the mission clock.

Mission Download. Teams must download mission details from the Interoperability System.

UAS Telemetry Upload. Certain tasks require teams to upload valid UAS telemetry at an average of at least 1Hz while the UAS is airborne. Telemetry must not be duplicated, interpolated, or extrapolated beyond what is generated by the autopilot. Teams may upload telemetry faster. Data dropouts will count against the team.

Object Upload. Teams can submit objects via the Interoperability System to earn more points. The Interoperability Specification defines an object, with details like the set of valid background

colors for a standard object.

Mission Demonstration (60%)

This section describes the mission demonstration that will be conducted by the team at competition. It is for this mission that teams must design a UAS. It is worth 60% of the entire competition.

Points and Penalties. There are a series of components for which teams can receive points. Each subsection below contains a component and it’s worth as a percentage of mission demonstration points. Penalties are also described in the subsections below. Penalties are defined as a percentage of achievable component points. Unlike points, penalties do not have a bound. This means time spent out of bounds can cost the team all points for mission demonstration. If penalties are greater than points, the team will receive a zero for demonstration. Teams cannot score points while generating a penalty.

Mission Details and Deliverables. The mission flight boundaries are given in the rules in the Mission Flight Boundary Appendix. The air drop location and boundaries are given in the rules in the Air Drop Location & Boundary Appendix. The interoperability connection details will be provided at competition check-in. At setup time and during the mission, teams may retrieve all other mission details via the Interoperability System. All deliverables will be submitted to the judges via the Interoperability System.

Lead, GCS, and Safety Judge. The GCS judge will be located in the team’s tents and will watch the Ground Control Station screens. The safety judge will stand with the team’s safety pilot. The lead judge will be with the team’s mission lead.

Order of Team Demonstration. The judges will score all deliverables due before the mission demonstration and produce an initial ranking. This ranking will be the order in which teams get a

chance to perform mission demonstration. Teams will not be notified of this initial ranking. The judges will attempt to fly as many teams as possible.

Order of Tasking. Teams must successfully takeoff and go above 100ft MSL within the first 10 minutes of the mission clock, or the demonstration will be terminated. Upon every takeoff, teams must immediately fly the waypoint path before attempting other tasks, thereby simulating the trip to the operation area. Teams are allowed to attempt other tasks while flying the waypoints, so long as such doesn't require a change in flight path. After the waypoints, teams may decide the order of all other tasks.

Termination and Disqualification. Breaking the rules, risking safety, and accumulating too many penalties may cause mission termination and may cause disqualification.

Timeline (10%)

UAS must be able to fly missions in a restricted time scenario. This involves setting up the UAS, flying the mission, and tearing down within provided time limits.

Setup Time. Teams will be provided at least 20 minutes for setup. The last 5 minutes of the setup time must include the pre-mission brief. This brief must include a summary of planned tasks, roles and responsibilities, and other information judges should know. Once the other teams have stopped occupying the airspace and the setup time has elapsed, the judges will start the mission time regardless of team readiness.

Mission Time (80%). Teams will be provided 40 minutes to complete the mission. This is broken down into two periods: flight time and post-processing time. Flight time is when the team occupies the runway or airspace. Post-processing time starts once the UAS has landed, the UAS has cleared the runway, and the team relinquishes the airspace. Post-processing time ends when the team has stopped processing imagery, stopped uploading data through interoperability, and has returned the interoperability network cord to the judges. Flight time and

post processing time are limited to 30 minutes and 10 minutes respectively. The ratio of mission time points a team is awarded will be $max\ (\ 0\ ,\ 60\ -\ 5\ max\ (\ 0\ ,\ X\ 20\ )\ )\ /\ 60$,whereXisthe

? ? Y

team’s flight time in minutes and Y is their post-processing time in minutes.

Mission Time Penalty. The team will receive a penalty equal to 3% of timeline points for every second of flight time or post processing time over their respective limits.

Timeout (20%). Teams are allowed one timeout to stop the mission clock, and it will cost them these timeline points. A timeout can only be taken at the flight line, after the mission clock starts, and before the UAS first completes the waypoints. The timeout will last at least 10 minutes.

Teardown Time. Teams will be provided 10 minutes to remove all of their equipment from the flight line tent area.

Autonomous Flight (20%)

UAS which can fly autonomously are cheaper to operate, which means organizations can leverage more UAS at the same cost, which means better performance and more missions. Autonomy also keeps the UAS airborne during connectivity loss, a very likely occurrence in real world environments.

Autonomous Flight (40%). The team receives points if the UAS flies autonomously for at least 3 minutes. Teams will lose 10% of autonomous flight points for each safety pilot takeover into manual flight. Manual takeoff and manual landing will each count as a takeover. Hand launch with autonomous climbout counts as autonomous takeoff. The team is responsible for telling the mission judge (in the tent) and the safety judge (next to safety pilot) whenever the autopilot transitions between modes.

Waypoint Capture (10%). The teams will be given a sequence of waypoints that should be flown during the mission. The waypoint path may be up to 4 miles in length. Teams may attempt

the waypoints multiple times, and the highest scoring sequence will be used. Teams will be graded on whether they can fly the entire waypoint sequence and get within 100ft of each waypoint. Teams will be evaluated by a human observer at the autopilot station.

Waypoint Accuracy (50%). Teams will be graded on how close they can get to the waypoints in a sequence. Teams may attempt the waypoints multiple times, and the highest scoring sequence will be used. Each waypoint will be weighted equally, and the ratio of points received per waypoint will be $max\ (\ 0\ ,\ (\ 100\ ft - distance\ )\ /\ 100\ ft\ )$. To receive points for waypoint accuracy,

teams must upload valid telemetry to the Interoperability System at an average of 1Hz while airborne.

Out of Bounds Penalty. Teams are given a flight boundary in the Mission Flight Boundary Appendix. Every time the UAS goes out of these bounds, or if the UAS goes below 100ft MSL or above 750ft MSL, the team will receive a penalty equal to 10% of autonomous flight points. For every boundary violation that risks safety, like by flying over the pits or the flight line tents, the team will receive an additional penalty equal to 10% of autonomous flight points. Teams will be evaluated by human observers.

Things Falling Off Aircraft Penalty (TFOA). If parts fall off the UAS during flight, teams will receive a TFOA penalty equal to 25% of autonomous flight points.

Crash Penalty. If the UAS crashes during flight, teams will receive a crash penalty equal to 35% of autonomous flight points.

Obstacle Avoidance (20%)

UAS must integrate with the national airspace in order to perform missions. Part of this integration means avoiding obstacles. The UAS should have obstacle avoidance capabilities.

Telemetry Prerequisite. To receive points for obstacle avoidance, teams must upload valid

telemetry to the Interoperability System at an average of 1Hz while airborne.

Stationary Obstacle Avoidance. Through the Interoperability System, the teams will be given a set of stationary obstacles. Each stationary obstacle will be a cylinder, with height axis perpendicular to the ground, and bottom face on ground. The cylinders will have a radius between 30ft and 300ft, and height between 30ft and 750ft. There can be up to 30 stationary obstacles. The ratio of points received for will be (*obstacles avoided* / *total obstacles*).

3

Object Detection, Classification, Localization (20%)

UAS should be able to search for objects. Teams will have to detect, classify, and localize two types of objects: standard and emergent. A standard object will be an colored alphanumeric (uppercase letter or number) painted onto a colored shape. The standard object will be at least 1 foot wide with 1 inch thick lettering. One of the standard objects will be located outside the flight boundary. The emergent object is a person engaged in an activity of interest. There may be up to 20 objects. Each object will be weighted equally. Teams must submit objects via the Interoperability System. Teams may additionally provide objects via the Object File Format over USB drive, which will be used only in the event of an unplanned failure of the judging system.

Search Area & Off-Axis . Teams will be given a search grid which will contain all but one of the objects, and will be given the position of a standard object located outside of the flight boundaries. The off-axis object will be up to 250ft beyond the flight boundary. Teams must not fly over the off-axis object if it is out of bounds. Objects may be placed under obstacles.

Object Matching. During scoring, submitted objects are matched with real objects to determine points scored. The judges will use the matching that maximizes the points for the team. Matching is performed separately for manually and autonomously submitted objects.

Imagery. To receive credit for an object, teams must submit a cropped image such that the object fills 25%+ of the image. Judges will decide whether the image is sufficient to resolve the object.

Characteristics (20%). Each object has a set of characteristics, and teams are awarded points for ratio of correct characteristics: *correct characteristics* / *total characteristics*. For standard objects there are 5 characteristics: shape, shape color, alphanumeric, alphanumeric color, and alphanumeric orientation. The interoperability specification provides an enumeration of possible standard object characteristics. For emergent objects there is one characteristic: a description of the person in need of rescue and the surrounding scene.

Geolocation (30%). Teams are awarded points for accurately providing the GPS location of objects. The ratio of points a team is awarded is $max\ (\ 0\ ,\ (\ 150\ ft\ -\ distance\ )\ /\ 150\ ft\ )$ where *distance*

is the geodesic distance between the submitted GPS location and the object's true GPS location.

Actionable (30%). Objects which are submitted during the team's first flight will be considered actionable. For the Object File Format, teams will submit an additional USB drive prior to the aircraft landing. Objects submitted as actionable via the Object File Format must not be present in the end of mission submission, as they will be considered an additional object and may incur an extra object penalty. For interoperability, objects which were created and last edited during the first flight will be considered actionable.

Autonomy (20%). Teams may submit objects manually and autonomously. Submission is autonomous if no human assistance is needed from image capture to object submission, and otherwise processing is considered manual. A match gets additional points if it is autonomous. If a team submits a manual and autonomous object that is matched to the same real object, the higher scoring object will be counted, and the lower scoring object won't count as an extra

object.

Extra Object Penalty. Each submitted object which isn't matched with a real object will be penalized at 5% of object detection, classification, and localization points. An object will not match a real object if such a match would yield no point value, or if another submitted object has been matched with the real object to yield more points.

Air Drop (20%)

UAS should be able to air drop an object to a specified position. The safety judge must be notified before the UAS attempts the air drop. The aircraft must not fly below the minimum altitude in order to deliver. Teams may only perform the drop once.

Payload. Teams should design an Unmanned Ground Vehicle (UGV) that can be air dropped to a specified location. The UGV must carry a standard 8oz water bottle (example) that will be provided by the judges at setup time. Upon landing, the UGV should be capable of driving to another location with the water bottle. See the Unmanned Ground Vehicle Requirements.

Drop Accuracy (50%). Teams are given the GPS coordinates of the drop location. To receive points, the UGV and water bottle must land gently and without damage. The percentage of points awarded for a drop is 100% for within 5ft distance, 50% for within 25ft distance, 25% for within 75ft distance, and 0% for beyond 75ft distance, where *distance* is the distance between the actual and the desired drop location.

Drive to Location (50%). Teams are given the GPS coordinates of a destination. Upon landing, the UGV should drive to this location with the water bottle and stop. Teams are awarded points if the UGV stops within 10ft of the specified location without going out of bounds.

Operational Excellence (10%)

Operational excellence will be graded by the judges as a subjective measure of team

performance. This will evaluate things like operation professionalism, communication between members, reaction to system failures, attention to safety, and more.

Technical Design Paper (20%)

Each team must submit a technical design paper that describes the design of their entry and the rationale behind their design choices. The purpose of the paper is to show the team's overall coordination and systems engineering process, design tradeoffs, final design solution, with a plan to collect analytical evidence and bench/flight test data proving it will safely fly and perform planned mission tasks. The paper must address the mission tasks the team is capable of achieving during flight.

The paper must be typed on 8.5" by 11" paper, single spaced, with at least 1" margins and a 10-point font, and use either Times New Roman or Arial font. Each page must have a footer containing the school, team name, and the page number. The paper must not exceed 15 pages including the title and references page. The following subsections contain the sections a team's paper must have, and the relative weighting of those sections.

Systems Engineering Approach (20%)

This section of the paper describes the systems engineering approach to UAS design.

Mission Requirement Analysis. Teams need to analyze the tasks to determine what requirements are placed on the UAS, what are the design tradeoffs for those requirements, and which systems need to be built to complete these tasks.

Design Rationale. This section should start with the environmental factors (e.g. team qualifications, budget, etc.) and mission requirements (e.g. tasks, point system, etc.), and describe the flow of decisions which led to the final design. For example, how the object task influences camera choice which influences aircraft choice which influences autopilot choice. It

should describe the tradeoffs of design options and the rationale for the final solution. For example, for a fixed-wing aircraft what are the high-level tradeoffs between a high-wing and low-wing design.

System Design (50%)

This section of the paper describes the design of the UAS system. For each system, the paper should describe what was chosen or built, why it was chosen, and what implications it has for task performance. This section should also describe tests which were conducted on each component and provide data on performance. If a team elects not to include certain elements (e.g. air drop), it should be so stated in the appropriate section.

Aircraft. This section should describe the design and fabrication of the airframe and surfaces, along with a discussion of the aircraft's aerodynamics and propulsion system. It should include a labelled diagram of the airframe and a table containing all relevant metrics.

Autopilot. This section should identify the autopilot used by the UAS and describe its capabilities and how they map to the competition tasks. It should also provide a description and picture of the associated ground control station (GCS).

Obstacle Avoidance. This section should describe the algorithm(s) used to update the flight plan so as to avoid nearby obstacles.

Imaging System. This section should identify the camera used by the UAS and describe its capabilities. It should provide a detailed analysis to demonstrate that the chosen camera can resolve objects of the size required by the competition.

Object Detection, Classification, Localization. This section should provide a description of how both manual and automatic processing is performed (e.g. algorithms).

Communications. This section should describe the hardware used for communication between the aircraft and ground station, and between systems on the ground. It should list the

frequencies used and for each, identify the type of data that is sent. This section should include a block diagram of the communications system.

Air Drop . This section should describe the payload and mechanism used to drop the payload. Furthermore, it should describe the approach used to determine optimal drop time.

Cyber Security. This section should define potential cyber security threats and describe how the team addressed them in their ground station and aircraft design to protect their aircraft, payload, and data.

Safety, Risks, & Mitigations (20%)

Safety is a top priority for the SUAS competition. This section describes the potential safety risks and the steps taken to mitigate them.

Developmental Risks & Mitigations. This section should describe any safety risks posed by the development process, and what was done to mitigate them.

Mission Risks & Mitigations. This section should describe any safety risks posed by the competition mission, autonomous flight, and testing, and what was done to mitigate them.

Writing Style (10%)

The SUAS competition values clear and concise communication. Teams will be judged on their quality of writing.

Clarity. The paper should be easily understandable to engineers from various fields (i.e. mechanical engineering, computer science, electrical engineering, etc). It should clearly define all terms and symbols, label all accompanying illustrations, and ensure that all points are expressed as clearly as possible.

Accuracy & Precision. Data and facts presented in the paper should be free from errors. All assumptions relevant to data analysis should be clearly stated and challenged for legitimacy.

Experimental or analytical data should be accompanied by error bars or confidence bounds.

Logic. The paper as a whole should make sense and not contain any contradictions. The conclusions should be supported by logical analysis. The flow of decisions should be clear.

Relevance, Depth, Suitability. The included data and analysis should be carefully selected to provide detailed insight into the UAS without being irrelevant to the competition. The writing style should be appropriate for the intended audience.

Flight Readiness Review (20%)

The flight readiness review is a presentation where teams demonstrate that their system is mature enough to compete. This readiness must be demonstrated with data. Judges will review this presentation to determine whether teams are ready enough to attend competition, and they may decide to disqualify unprepared teams.

The flight readiness review will be a video presentation submitted prior to attending competition. The video must be no longer than 15 minutes. The following sections contains the sections a team’s presentation must have, and the relative weighting of those sections.

Experience, Roles, Responsibilities (5%)

At the start of the presentation, each member of the competition team must introduce themselves and provide the following information.

Experience. Team members should state their class year at their university, the number of years they’ve been on the team, and their degree of experience with UAS technologies.

Roles and Responsibilities. Team members should identify their role and their responsibilities on the development and competition team, and what they will do on the flight line.

System Overview & Planned Tasks (15%)

Teams must provide an overview of their system and identify the tasks they are planning to attempt.

System Overview. This section should contain a *brief* overview of the mechanical, electrical and software systems of the UAS. Note that the overview need not be very detailed, as the specifics of the system will already have been discussed in the technical design paper.

Planned Tasks & Expected Performance. In this section, teams should classify each of the mission tasks into one of two categories: attempting and not attempting. Furthermore, teams should indicate how confident they are about successfully completing each of these tasks.

Developmental Testing (50%)

Testing is vital to proving the readiness of a team's UAS for completing the mission. In this section, teams must detail the testing they conducted on individual components of the UAS to ensure they work according to specification. Data must be presented and described how it demonstrates readiness.

Types of Developmental Testing. This section should describe the types of testing conducted by the team (i.e unit testing, simulations, etc) and the rationale behind choosing to conduct each type of test.

Autonomous Flights. This section should identify the number of autonomous flights conducted by the team and the average amount of time spent in manual mode per flight. It should also discuss the process of tuning the aircraft for autonomous takeoff, flight, and landing.

Waypoint Accuracy. This section should contain a description of the testing conducted on waypoints and provide statistics such as number of waypoints attempted, the number of waypoints hit, and the average waypoint miss error.

Obstacle Avoidance Performance. This section should describe the types of tests conducted to verify obstacle avoidance. In particular, it should include statistics on the number of obstacles

tested against, and the number of obstacles avoided.

Imaging Performance. This section should contain an overview of the tests conducted on the imagery system and provide statistics such as the average resolution of the objects in the images. It should also discuss the team's strategy for ensuring the best image quality.

Detection & Classification Performance. This section should contain an overview of the testing conducted on the autonomous detection and classification algorithms, the data the testing was conducted on, and the results of the testing.

Localization Performance. This section should contain a description of the testing conducted on the localization algorithms, the number of objects on which localization was tested, and the average localization error identified.

Air Drop Performance. This section should contain a description of the testing conducted on the air drop task and provide statistics such as number of times air drops attempted, the number of times the payload has survived the landing, and the average distance from the target the payload has landed.

Mission Testing (30%)

This section describes the full mission testing with the competition UAS and the competition team which will operate it.

Full Mission Tests. This section should describe in detail the mission tests conducted by the team and use the results to provide evidence that the system is capable of completing the planned tasks. It should discuss whether the testing that was conducted provided sufficient coverage, any flaws that it exposed in the system, and the subsequent corrective actions that were taken.

Estimated Score from Full Mission Tests. Teams should grade their full mission tests based on the rubric provided in the Mission Demonstration section. They should provide the scores

from each full mission test, the average across all tests, and their expected performance.

Awards & Prize Money

This section describes the awards and prize money given to teams at the competition.

Overall Ranking

Trophies will be awarded to the teams which ranked first, second, and third. Plaques will be awarded to the teams which ranked fourth and fifth. The overall ranking will be worth prize money: the higher a team ranks the more prize money the team will receive.

Best In Class

There are three awards for best in class: best in technical design, best in flight readiness review, and best in mission. For each best in class award received, the team will receive a plaque and prize money.

Completed Tasks

Each team which completes eligible tasks will receive prize money. Tasks include autonomous flight, obstacle avoidance, object detection / classification / localization, and air drop. A task attempt is eligible if the team receives some points for the task.

Special Awards

A single team will be selected for each special award. For each special award received, the team will receive a plaque and prize money. The special awards are Dawn Jaeger Tenacity Award, Dr. Arthur Reyes Safety Award, JustJoe Sportsmanship Award, and Cyber Security Award.

Appendix

The Appendix contains additional reference material the teams will need at some point during the developmental year. Similar to the rules, these details are subject to change.

Mailing Address

```
U.S. Postal Service:
```

```
AUVSI Seafarer Chapter
```

```
Post Office (P.O.) Box 141
```

```
California, MD 20619
```

301 - 862 - 1246

```
UPS or FEDEX:
```

AECOM

```
46591 Expedition Drive, Suite 100
```

```
Lexington Park, Maryland 20653
```

```
ATTN: Mr. Tim Piester
```

301 - 862 - 1246

Base Access Form & Documentation

Each competition attendee must fill out the following form. Foreign Nationals must their use Passport as the ID. A photocopy of IDs must be sent with form. The same ID must be presented at check-in. These forms, ID photocopies, and other sensitive data must not be sent electronically; we will only accept them via mail. See the Mailing Address appendix.

Base Access Form:

http://www.auvsi-suas.org/static/competitions/2019/auvsi_suas-2019-base_access_form.pdf

? Block 25: Leave blank, to be filled in by judges

? Block 26, 27, 28: Leave blank, not required for this event

? Block 30: Must return passes to competition director by end of event

? Block 31: Must be signed

Foreign National Form & Documentation

Any team which will have foreign nationals attend competition must mail an additional letter to gain base access. The team must send a letter on university letterhead that is signed by a responsible university official. See the Mailing Address appendix for the address. The letter must contain at least:

? Purpose of visit: ? UNCLASSIFED ?, Students from this (name of University or College) will

participate in the Association for Unmanned Vehicle Systems International (AUVSI)

Student UAS (SUAS) Competition to be held at Webster Field, St. Inigoes, Maryland.

Student teams will inspect and check their airplane and system, and will fly the vehicle

around a prescribed course at Webster Field under the guidance and supervision of

Navy Government personnel and other AUVSI officials and volunteers.

? Confirmation that the visitation is strictly limited to the dates and times of the SUAS

competition held at Webster Field, MD.

? For each foreign national, provide: Full Legal Name, Place of Birth (POB), Date of Birth

(DOB), Country of Citizenship, Country of Residence, Title/position (Team Lead, Team

Member, Faculty Advisor, Guest, Sponsor, etc.), Passport / Visa / Resident Alien “Green

Card” number and expiration date. A photocopy of the passport or green card must also

be included.

? Include University address, and phone and fax numbers.

? A responsible University official (a Dean, Department Head, or Senior Faculty official),

other than persons listed on the request, shall sign the letter. The official name and

position, and the date, must be typed on the letter, along with the official’s written

signature and date.

Sample Mission Map

White Triangle: Pit Area Tents

Red Start: Flight Line Tents

Red Outline: No-Fly Zone Boundary

Yellow Pins: Boundary Judge Stations

Blue Outline: Waypoint Sequence

Green Outline: Search Area

Blue Circle: Off-Axis Object

White Pin: Last Known Position (LKP) of Emergent Target

DROP Pin: Air Drop Location

Mission Flight Boundary

The following are a series of GPS points which form a polygon that is the mission flight boundary. The UAS must remaining within this polygon and within the altitude restrictions.

N38-08-46.57

W076-25-41.39

N38-09-05.85 W076-25-43.26

N38-09-06.80 W076-25-53.28

N38-09-02.14 W076-26-07.30

N38-08-51.24 W076-25-56.43

N38-08-40.80 W076-25-58.61

N38-08-35.72 W076-26-05.16

N38-08-25.67 W076-25-57.49

N38-08-26.59 W076-25-33.65

N38-08-37.54 W076-25-16.34

N38-08-50.45 W076-25-23.56

N38-08-46.07 W076-25-35.95

The following must be the configured lost comms RTH/RTL and flight termination point.

N38-08-41.20

W076-25-45.90

Air Drop Location & Boundary

The following is the air drop location.

N38-08-45.10

W076-25-35.00

The following are a series of GPS points which form a polygon that is the driving boundary for the UGV. The UGV must remaining within this polygon.

N38-08-46.20

W076-25-36.00

N38-08-46.90 W076-25-34.20

N38-08-44.10 W076-25-33.90

N38-08-43.50 W076-25-35.80

The following is the driving destination for the UGV.

N38-08-46.20 W076-25-35.10

Object File Format

The Object File Format is a folder containing object detection files. Each object submitted by the team gets 2 files in the folder, both of which start with a number unique to the object, where one has the extension “json”, and the other has either the extension “jpg” or “png”. The “json” extension file must contain a JSON formatted object data conforming to the POST /api/odlcs data segment. A “jpg” extension file must be a JPEG image, and a “png” extension file must be a PNG image. The team will copy this folder to a USB drive provided by the judges. If the team is attempting actionable objects, the team will be provided 2 USB drives.

Example folder structure for 2 objects:

```
? myteam/
? 1.json
? 1.jpg
? 2.json
? 2.png
```

Example JSON file:

```
{
?"type"?: ?"standard"?,
?"latitude"?: ?38.1478?,
?"longitude"?: ?-76.4275?,
?"orientation"?: ?"n"?,
?"shape"?: ?"star"?,
?"background_color"?: ?"orange"?,
?"alphanumeric"?: ?"C"?,
?"alphanumeric_color"?: ?"black"
}
```

The judges will ignore object detection files which are not proper JSON or do not conform to the specification. The judges will ignore object images which are not in either JPEG or PNG format.

Technical Report

Mission and Design

Table 1: Mission Demonstration Analysis			
Mission Element	Beneficial Abilities	Required Hardware	Tradeoffs
Waypoint Navigation (20%)	- High Maneuverability - Long Range - Flight Autonomy	- Flight Computer - Flight Controller - Large Battery Capacity	- Lower Speed
AirDrop (20%)	- Hovering Capabilities - Mobile UGV	- UGV - Descent Retarding Mechanism	- Reduced Range (Non-Fixed Wing) - Increased Weight
ODLC (20%)	- Actionable Submission - Autonomous Submission - Accurate Vehicle Localization - Accurate Vehicle Attitude Determination	- Camera System - Flight Computer - Image downlink - Onboard Processing - Gimbal	- Increased Weight
Obstacle Avoidance (20%)	- High Maneuverability	- Flight Computer - Flight Controller	- Lower Speed
Timeline (10%)	- High Speed - Fast Setup and Removal	- N/A	- Lower Maneuverability - Increased Mechanical Complexity

Component Set	Number of Arms		
	4	6	8
	Mass Estimate (kg)		
Base Weight w/o UGV	14.1	14.8	15.4
Base Weight w/ UGV	15.4	16.1	16.7

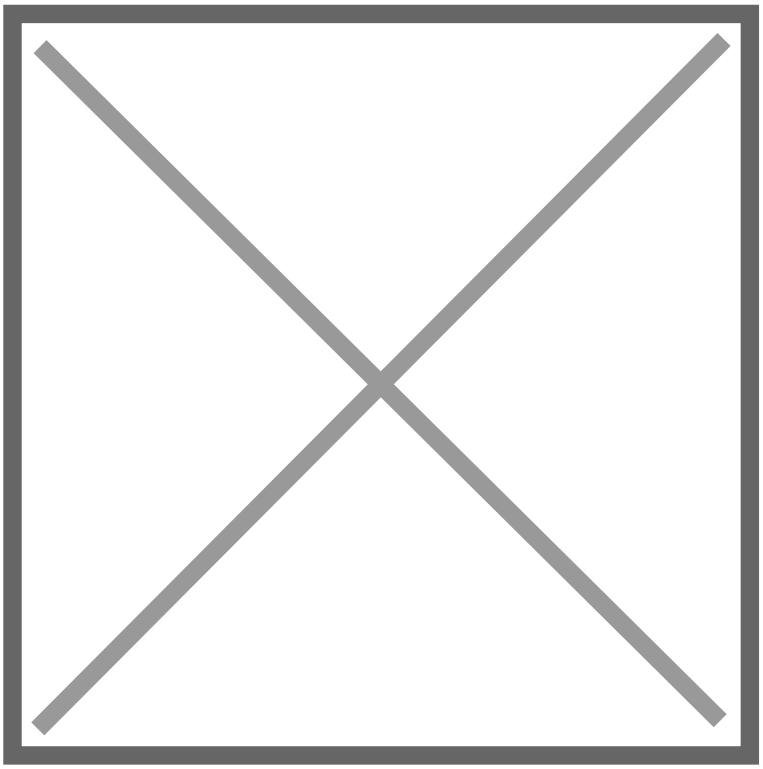
Motor Propeller	4004	4006	4008	5008	5010	5012	5015	6008	6012	6015	8110	8115	8120
15 x 5.5		NH											
16 x 6		NH	NH	NH									
17 x 6		NH	OP	NH	NH	NH		NH	NH	NH			
18 x 6.5		OP	OP	NM	80%	80%	NM	NM	NM	NH			
18.5 x 6.7		OP		OP	60%	60%	75%	NM	NM	NH			
19 x 6				OP	65%	65%	75%	NM	NM	NM			
19.5 x 7				OP	55%	55%	55%	OP	70%	NM			
20 x 6				OP	60%	60%	60%	OP	75%	NM	NH		
21 x 6				OC	OC	OC	OC	OC	60%	70%	NH		
21 x 12									OC	OC	NH		

Viable Option. (%) Amount of total battery capacity required to fly 4 miles carrying UGV payload	NH: No Hovering	OC: Over Current	OP: Over Power
	NM: No Maneuverability	Blank Box: Not Feasible	

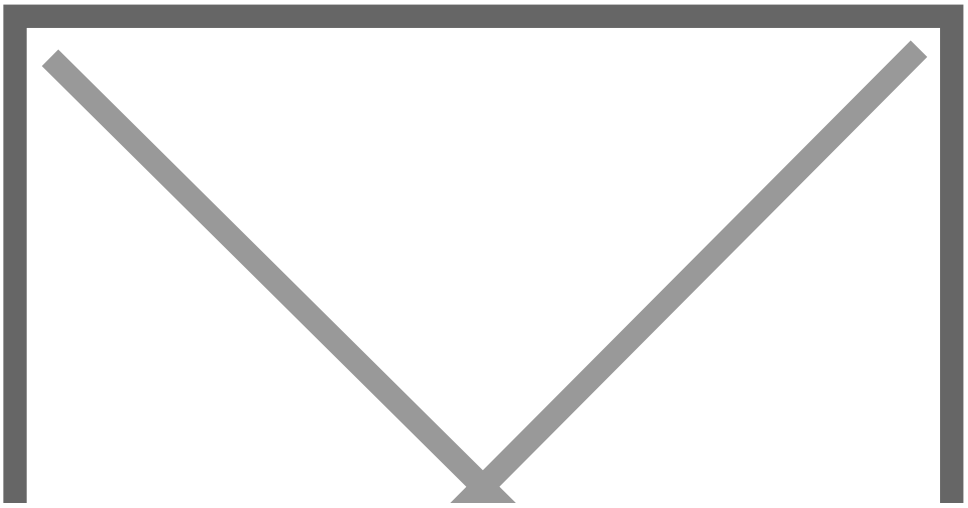
Motor Propeller	4004	4006	4008	5008	5010	5012	5015	6008	6012	6015	8110	8115	8120
16 x 6		OP	NM	NM	NM	NM	NH						
17 x 6		OP	95%	70%	70%	70%	NM	NM	NM				
18 x 6.5		OP	OP	60%	55%	55%	60%	65%	75%	NM	NM	NH	
18.5 x 6.7		OP	OP	OP	55%	55%	55%	60%	60%	80%	NM	NH	
19 x 6				OP	60%	60%	60%	65%	65%	80%	NM	NH	
19.5 x 7				OP	55%	55%	55%	OP	55%	60%	NM	NH	
20 x 6				OP	60%	60%	60%	65%	60%	65%	NM	NH	
21 x 6					OP	OC	65%	OP	60%	65%	NM	NH	
21 x 12					OP	OC	OC	OC	OC	OC	NM	NH	

Viable Option. (%) Amount of total battery capacity required to fly 4 miles carrying UGV payload	NH: No Hovering	OC: Over Current	OP: Over Power
	NM: No Maneuverability	Blank Box: Not Feasible	

Carbon Fiber	1335	66724
Aluminum 6061-T6	89	25536
Titanium 6M-4V	191	25419



in a matter of



minutes.

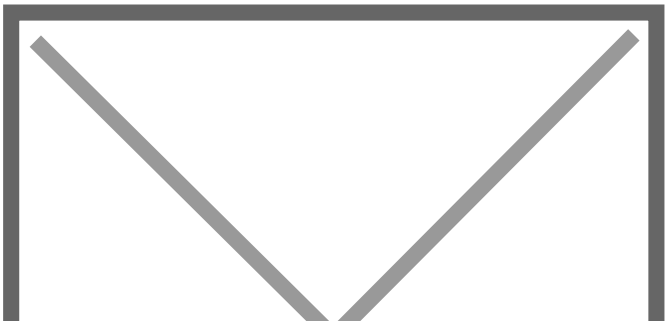


Table aa: Aircraft Properties				
Item	Relevant Properties		Item	Relevant Properties
1. Chassis Plates	22” Effective Diameter x 0.172” Thickness		6. Vehicle Maximum Thrust	339 N (76.2 lb)
2. Chassis Structure	22” Effective Diameter x __” Height		7. Vehicle Cruising Speed	25 km/h (15.5 mph)
3. Arms	0.997” Outer Diameter, 0.880” Inner Diameter, 23.0” Length		8. Vehicle Max Speed	27 km/h (16.8 mph)
4. Propeller	19.5” Diameter x 7 Pitch		8. Climb Rate	10 m/s (32.8 ft/s)
5. Motor	300 Kv, 200g, 36A Max, 62 mOhm		9. Vehicle Design Range	4 miles (6.4 km) carrying UGV + 2 miles (3.2 km) additional without UGV
10. Vehicle All Up Weight	16.4 kg		15. Flight Time	15 Minutes Forward Flight 35 Minutes Hovering Flight
11. UGV Weight	0.68 kg		7. Assembly Time	15 minutes
14. Batteries	6S, 20P, 4050 mAh		6. Disassembly Time	6 minutes

Acronyms and Terminology

AMA - Academy of Model Aeronautics

BLDC - Brushless Direct Current

cc - Cubic Centimeter

CFD - Computational Fluid Dynamics

COTS - Consumer Off-The-Shelf

EECP SD - Electrical Engineering and Computer Engineering Senior Design

EKF - Extended Kalman Filter

ESC - Electronic Speed Controller

FEA - Finite Element Analysis

GPS - Global Positioning System

IMU - Inertial Measurement Unit

Kt - Motor Torque Constant

Kv - Motor Velocity Constant

LiPo - Lithium Polymer

LRU - Line Replaceable Unit

MAE SD - Mechanical and Aerospace Engineering Senior Design

mAh - milli-Amp Hours

MC - Experiments Monte Carlo Experiments

NCR - Nickel Cobalt Rechargeable

NiCd - Nickel Cadmium

NIMH - Nickel Metal hydride

PRM - Probabilistic Road Mapping

PWM - Pulse Width Modulation

ROI - Region of Interest

ROS - Robot Operating System

RPM - Rotations Per Minute

RRT - Rapidly-exploring Random Tree

UAS - Unmanned Aerial System

UGV - Unmanned Ground Vehicle