AEROCARDS

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1. Introduction

1.1. Mission Requirements

Our team plans to compete in four competition events (**BOLD** indicates differences between objectives and thresholds):

- Autonomous Flight Task (Primary)
  - Thresholds:
    - Achieve controlled takeoff, flight, and landing
    - Navigate waypoints with 50 ft. accuracy at waypoints and 100 ft. accuracy along flight path
    - Display no-fly zone, current position, air speed, and altitude on ground station
  - Objectives:
    - Achieve controlled **autonomous** takeoff, flight, and landing
    - Navigate waypoints with 50 ft. accuracy at waypoints and 100 ft. accuracy along flight path **while in autonomous mode**
    - Display no-fly zone, current position, air speed, altitude, **and waypoints** on ground station
- Search Area Task (Primary)
  - Standard Target Characteristics:
    - Shape
    - Background Color
    - Letter Orientation (N, S, E, W, etc.)
    - Alphanumeric (Upper or Lower)

        - Letter/Number Color
        - Coordinates
    - Thresholds:
        - Determine location with 150 ft accuracy
        - Determine at least 2 characteristics
        - Detect QRC Code Target
    - Objectives:
        - Determine location with 75 ft accuracy
        - Determine all 5 characteristics
        - Decode QRC message
        - Give judge USB drive with .jpeg files for each target
        - Complete search while in autonomous mode
        - Decipher secret message from targets
- Off-Axis Standard Target Task (Secondary)
    - Description: Locate target of given coordinates outside search area without leaving the search area
    - Thresholds:
        - Determine at least 2 target characteristics
    - Objectives:
        - Determine all 5 target characteristics
        - Give judge USB with .jpeg file for target
        - Have autonomous tracking of target
- Emergent Target Task (Secondary)
    - Description: Set a new waypoint and search area in flight and find humanoid target

    - Thresholds:
        - Give judge USB with .jpeg of target
    - Objectives:
        - Add waypoint in flight
        - Complete search while in autonomous mode
        - Give judge USB with .jpeg file of target, coordinates accurate to 75 ft., and description of target's activity

1.2. Systems Engineering Approach

- The team was split into 5 major groups corresponding to each major subsystem in our UAS:
    - Airframe Design (general system design and specific frame)
    - Power System (motors, propellers, electronic speed controllers, battery)
    - Imagery System (camera, gimball, FPV, additional battery)
    - Flight Computer/Accessories (flight control board, GPS module)
    - Data Link/Ground Station (RC Tx/Rx, telemetry, ground station for flight info and video feed)
- Within these groups, individual members researched each part and developed a plan which resulted in the most efficient, cost-effective system possible
- On many occasions maximum quality had to be sacrificed for cost effectiveness, creating a constant balancing act for each part of the system

- All findings were reported first to the leaders of the 5 main groups, then discussed as a whole club to reach a consensus
- Our biggest limiting factors were our own naivety, as most of the club is brand new to the field, and the budget given to the club by the school
- Our system used our research to select what we believe to be the best options within this year's budget.

2. System Description and Part Selection

2.1. Airframe Design

2.1.1. Fixed Wing vs. Multi-rotor Aircraft

2.1.1.1. The team's first discussion was the choice of fixed wing or multi-rotor aircraft designs. Fixed wing designs have the ability to travel longer distances with less power consumption but lack stability and hovering capabilities to capture clear imagery. Multi-rotor designs are inherently more stable and have hovering and maneuvering capabilities well suited for the imagery system; however, their design shape/weight and greater number of motors results in a larger draw on the battery, meaning shorter average flight times.

2.1.1.2. After weighing the pros and cons of each design type, the team decided that the added stability and maneuverability of the multi-rotor design was the best option for our aircraft.

2.1.2. Quadcopter vs. Hexacopter

2.1.2.1. In general, for multi-rotor systems, the greater the number of motors, the more stable the system. Thus, the hexacopter design would provide the greatest stability and maneuverability, but will also drain the battery the fastest. The quadcopter design leaves more room for stability error, but lasts longer on the same battery power.

2.1.2.2. Because of the extended flight time necessitated by the mission requirements, the team chose the quadcopter design for the best balance between stability and current draw on the battery.

2.1.3. Frame Material

2.1.3.1. The main materials used for multi-rotor frames are plastic, aluminum, and carbon fiber. All three materials are relatively light. Plastic is cheap and light but lacks durability and strength to handle large payloads. Aluminum is stronger than plastic and is still light and inexpensive, but is still heavier and weaker than carbon fiber. Carbon fiber is a high quality frame material option and is extremely lightweight relative to its strength. Its only major downside is the cost, which is not astronomical but still well exceeds that of plastic and aluminum.

2.1.3.2. After researching and discussing each material thoroughly, the team decided that a carbon fiber frame was worth the added expense in exchange for its high strength and minimal weight.

2.1.4. Our research led us to select a multi-rotor design, specifically a quadcopter, with carbon fiber as the primary frame material. After conducting further searches with these criteria, the team settled on the Tarot 650 quadcopter frame. This frame’s primary features are its carbon fiber make, its high-end motor mounts, and its power distribution board (PDB). The

PDB allows the team to solder the battery and ESCs directly to the frame, eliminating troublesome wiring connections.

2.2. Power System

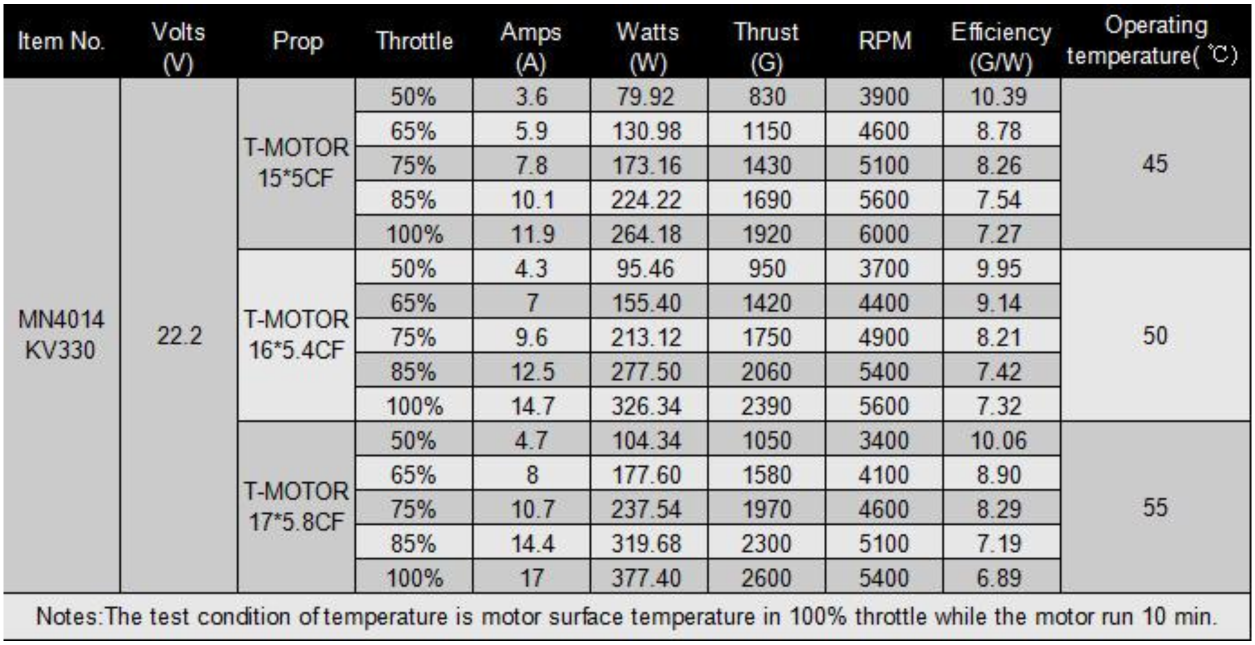
2.2.1. The power system is the greatest ‘balancing act’ of the entire system. Each individual part relies on the other so selection was a long, meticulous process to ensure there was proper power to lift the payload and keep it aloft for the lengthy mission flight time.

2.2.2. Propellers

2.2.2.1. The team used the propellers as a starting point in the power system. There are two major measurements associated with propellers: length and pitch. The chosen frame accommodates a maximum propeller length of 15 inches. The highest efficiency when lifting a heavy payload is achieved by using a long propeller of medium pitch with a relatively slower more powerful motor. Thus, we opted to use the maximum length of 15inches as our propeller length. After examining motor/propeller combo efficiency charts, a pitch of 5.5 was determined to be the best fit for our system (see 2.2.3 for more details). As for the propeller material, the team decided on carbon fiber for its strength and minimal weight. The rigidity of the propeller is extremely important, giving carbon fiber props a distinct advantage over flimsier plastic ones.

2.2.3. Motors

2.2.3.1. After deciding on a 15 inch propeller, the team analyzed motor efficiency charts to determine the optimum motor/propeller combination. Ideally, this combination would provide the necessary thrust at 60% throttle with a safe motor temperature. The chart below shows the data for the motors the team chose:



Item No.	Volts (V)	Prop	Throttle	Amps (A)	Watts (W)	Thrust (G)	RPM	Efficiency (G/W)	Operating temperature(℃)
MN4014 KV330	22.2	T-MOTOR 15*5CF	50%	3.6	79.92	830	3900	10.39	45
			65%	5.9	130.98	1150	4600	8.78	
			75%	7.8	173.16	1430	5100	8.26	
			85%	10.1	224.22	1690	5600	7.54	
			100%	11.9	264.18	1920	6000	7.27	
		T-MOTOR 16*5.4CF	50%	4.3	95.46	950	3700	9.95	50
			65%	7	155.40	1420	4400	9.14	
			75%	9.6	213.12	1750	4900	8.21	
			85%	12.5	277.50	2060	5400	7.42	
			100%	14.7	326.34	2390	5600	7.32	
		T-MOTOR 17*5.8CF	50%	4.7	104.34	1050	3400	10.06	55
			65%	8	177.60	1580	4100	8.90	
			75%	10.7	237.54	1970	4600	8.29	
			85%	14.4	319.68	2300	5100	7.19	
			100%	17	377.40	2600	5400	6.89	

Notes:The test condition of temperature is motor surface temperature in 100% throttle while the motor run 10 min.

The motor chosen has a speed rating of 330 kv, relatively slow but provides the correct power to give the necessary thrust. Our system weight is about 4 kg (4000g), requiring each motor to produce 1000 g of thrust. Using the 15*5.5 propeller, this motor provides the necessary thrust at a throttle % near 60 while remaining at a safe operating temperature (45 degrees C).

2.2.4. Battery

2.2.4.1. As seen in the above, each motor will draw between 5 and 6 A, with a total current draw of 20-24 A. Our battery needed to be the correct voltage (22.2 V) and be able to provide 20-24 A continuously for 20-40 minutes. After extensive research and comparisons, the team reached the conclusion that a 12,000 mah (12 Ah) 10 C 6s (22.2 V) lipo battery served our needs. To ensure it was capable of outputting the correct current (20-24 A), the team multiplied the capacity (12 Ah) by the discharge rate (10 C) to arrive at a continuous max current rating of 120 A, well above what we need. To determine if this battery met adequate flight time requirements, we divided the capacity (12 Ah) by the expected current draw (20-24 A) then multiplying by 60. This resulted in a calculated 30-36 minutes of flight time, within our necessary range.

2.2.5. ESCs

2.2.5.1. To determine the correct current rating for the ESCs, we used the ‘120% rule.’ This required that we take the maxmum possible current draw of our motor and multiply it by 120%. This ensures that the ESC will be able to handle any current draw the motor may pull, even if it is above the listed max values. Thus we multiplied 11.9 by 1.2, resulting in a 15 A ESC as the recommended value. This seemed a little low to us, so we researched similar motors and found the maximum current draw to be about 33 A which results in a 40 A recommended ESC. In an effort to stay on the safe side, we opted for the 40A ESC in case of incorrect current values our motors.

2.3. Imagery System

2.3.1. Camera

2.3.1.1. Our camera selection proved to be quite simple. The camera needed to provide high resolution images/video and be less susceptible to vibrations. One team member already owned a Go Pro Hero 3+ Silver camera, which fit these requirements well and greatly helped us to remain within our budget by eliminating the purchase of a new camera.

2.3.2. Gimball

2.3.2.1. Based on the mission requirements, the team determined that the yaw axis of a 3-axis gimball was unnecessary for our tasks as it is primarily used when taking professional videos showing broad landscapes. We decided that a 2-axis gimball that fit our camera was the best option to look for. Through some research, the team selected a 2-axis Go Pro compatible gimball that was specifically designed to mount to our chosen frame.

2.3.3. FPV Transmitter/Receiver

2.3.3.1. In choosing the video transmitter and receiver, the team's biggest consideration was to avoid the frequency of the RC Tx/Rx (2.4 GHz). This was solved by searching for 5.8 GHz systems. The selection of the 32 channel set was made to allow for frequency hopping to minimize interference from other aircraft on that frequency.

2.3.4. Battery

2.3.4.1. The FPV transmitter requires an 11.1 V input voltage and therefore cannot be powered by the 22.2 V battery used for the power system. Thus, the team selected a very small, lightweight 500 mah (.5 Ah) 3s 11.1 V 25C lipo battery. This will provide the necessary power for more than the duration of the flight time.

2.4. Flight Computer and Accessories

2.4.1. Flight Control Board

2.4.1.1. After conducting research on popular flight control systems, the team selected the Pixhawk flight controller. This is an open source flight controller allowing for personal edits to the program codes. Another major factor in our decision was its corresponding ground control software, Mission Planner. This is considered by most to be one of the best, most well organized ground control software programs. This flight control board allows for conventional inputs along with SBUS capabilities (necessary to pair with our Futaba RC tx/Rx), as well as a multitude of ports for external accessories such as GPS, telemetry, etc.

2.4.2. GPS Module

2.4.2.1. After choosing the Pixhawk as our flight control board, the team also decided upon getting the companion external GPS module, also made by 3DR. This is a good quality GPS system that greatly aids the system in establishing autonomous flight and navigation.

2.5. Data Link and Ground Station

2.5.1. Radio Control Transmitter/Receiver

2.5.1.1. One of our members already owned a Futaba 14 channel 2.4 GHz RC transmitter. This fit all of the specifications needed to control the parts we chose to complete the mission tasks. It also has frequency hopping capabilities to minimize interference due to other teams using that particular frequency at the same time. This transmitter is paired with a Futaba receiver on board the quadcopter, connected to the flight control board using an SBUS cable.

2.5.2. Telemetry

2.5.2.1. After choosing the Pixhawk flight control board, the team chose the companion 3DR telemetry set to use for flight data communication between the flight control board and the ground station software. This Tx/Rx pair runs at a frequency of 915 MHz and does not have frequency hopping capabilities.

2.5.3. Ground Station

2.5.3.1. Flight Data

2.5.3.1.1. A laptop running the Mission planner software (companion software to Pixhawk and Ardupilot flight control boards) will be used to obtain flight data (i.e. altitude, coordinates, speed, etc.) via the telemetry kit and to program autonomous flight paths.

2.5.3.2. Imagery

2.5.3.2.1. An LCD screen will be wired to the FPV receiver to view video feed form the Go Pro camera to locate standard, QRC, and off-axis targets, as well as the emergent target.

3. Risks and Mitigation Methods

3.1. After careful review of the FAA guidelines, all applicable regulations and restrictions were taken into consideration during the planning and construction of our system.

3.2. The Pixhawk flight controller and Mission Planner ground station software provide fail-safe mode options such as hover or return-to-launch when communication is lost, as well as automatic descent when battery voltage drops to a critical level.

   3.3. All soldering and other potentially hazardous steps in the construction process were carried out in accordance with proper safety guidelines, using personal protective equipment and following sound procedures.

4. Testing
   4.1. Due to unexpected delays in the construction process; namely, parts acquisition, test were unable to be completed prior to the submission of this journal. Static and flight tests are planned for the next weeks to ensure balance of the systems within the copter as well as adequate preparation for each mission task.