Concept Generation and Selection

EML 4551C – Senior Design – Fall 2011 Deliverable

Unmanned Aerial Vehicle

Team # 14

Ryan Jantzen[*], Antwon Blackmon[*], Walker Carr[*], Brian Roney[#], Eric Prast[#]
Alek Hoffman[#]

[*]*Department of Mechanical Engineering, Florida State University, Tallahassee, FL*
[#]*Department of Electrical and Computer Engineering, Florida State University, Tallahassee, FL*

Project Sponsor
Florida Center for Advanced Aero-Propulsion

Project Advisors

Dr. Rajan Kumar, PhD
Department of Mechanical Engineering

Dr. Michael P. Frank, PhD
Department of Electrical and Computer Engineering

Reviewed by Advisor: Dr. Rajan Kumar [ ]
Reviewed by Advisor: Dr. Michael P. Frank [ ]

Contents

Aircraft Configuration Design

Planform Concepts

The aircraft planform is a crucial part of the design of a successful unmanned aerial vehicle. The planform is the shape and layout of a fixed wing aircraft's fuselage and wing. In order to make an informed decision, we considered four different configuration layouts. These layouts include the conventional, canard, double boom, and flying wing planforms.

Figure 1: Conventional Configuration

The first concept considered was the conventional planform, as shown in figure 1. The conventional planform includes a traditional style aircraft with a fuselage, wing and empennage. This concept is both simple and stable but it is difficult to manufacture to be transportable and it has a larger wetted surface area which leads to a more drag.

Figure 2: Canard Configuration

The second concept considered was the canard planform, as shown in figure 2. The canard planform is configured with control surfaces towards the front of the aircraft. It is easier to construct than the conventional planform and has adequate maneuverability but has poor stability and requires a complex control surface analysis.

Figure 3: Twin Boom Configuration

The third concept considered was the double boom planform, as shown in figure 3. The double boom planform is similar to the conventional configuration but its main difference is that it has twin booms extending from the wing into the empennage. This benefit of this configuration is that it integrates well with the payload, it's easy to manufacture, and it is very transportable, meaning it can be designed to be broken down into several pieces for transporting to the airfield. The drawbacks from this configuration are that its heavy, it is difficult to balance the center of gravity, and there are only a few different tail configurations that can be used when working with a twin boom.

Figure 4: Flying Wing Configuration

The last concept considered is the flying wing planform, as shown in figure 4. The flying wing planform has no rear empennage and has a swept back wing that acts as both the wing and fuselage for this configuration. This allows the fuselage to act as a lifting body during flight. The drawbacks from this design are that it has poor stability and maneuverability, it is difficult to transport, and it requires a complex analysis for the flight dynamics.

Once a decision is made on the configuration of the planform of the aircraft, we can begin designing the fuselage. The fuselage influences the performance of the aircraft as well as the lateral and longitudinal stability. The primary function of the fuselage is to accommodate the payload such as the avionics and imagery subsystems. The fuselage must be designed so that the payloads are easy to access for maintenance while out in the field.

Wing Design

The next decision that must be made is the configuration of the wing for our aerial vehicle. When designing the wings, performance, stability, manufacturability, operational requirements and flight safety must all be taken into account. The wings must provide sufficient lift to the aircraft during all phases of flight while minimizing the drag and pitching moment. When we design the wings for our UAS, the first decision we must make is the vertical location of the wing with respect to our fuselage. We will then select the airfoil geometry for the wing that best fits with our mission profile. From there, we can decide on if our wing will need any high lift devices such as flaps to provide more lift than what the airfoil generates. Other parameters that must be decided during the wing design process include the aspect ratio, taper ratio, chord, span, twist angle, dihedral angle, sweep angle and incidence. Once all of these wing parameters are determined, we will be able to calculate the lift, drag and pitching moment of our design and determine if the configuration is adequate.

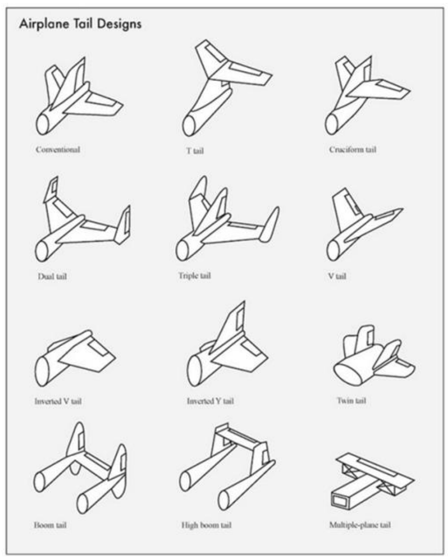

Figure 5: Empennage Configurations

Empennage Design

Once the wings have been designed for our aircraft, we will then begin designing the empennage. The empennage includes the horizontal and vertical tail surfaces. These not only provide lift to the aircraft but also longitudinal and lateral control. The design of both the horizontal and vertical tail sections will be designed to have both longitudinal and directional stability. There are many different empennage configurations that need to be considered once we select the planform layout, which are seen in Figure 5. The parameters that must be decided during the empennage design process include the horizontal location with respect to the fuselage, planform area, tail arm, airfoil selection, aspect ratio, taper ratio, chord, span, sweep angle, dihedral angle and incidence.

Design Analysis

To help us with the design of our unmanned aerial vehicle, we will utilize several aircraft analysis programs for calculating the performance parameters to optimize our design. The first program we plan on using is XFOIL, which is used to calculate the pressure distribution and thus lift and drag characteristics over 2D airfoil geometries. XFOIL is a valuable program that will help us in the selection of an optimal airfoil for our design. XFOIL is used for generating polars for the coefficients of lift, drag and pitching moment. The next program we plan on using is XFLR5, which is a program that utilizes XFOIL for generating lift, drag and pitching moment data over 3D wing geometries. This will help us determine if the wings we have designed for our UAS meet our operational requirements. The final program we will use to help us with optimizing our design is the Aerospace Toolbox provided by MATLAB. MATLAB's Aerospace Toolbox allows you to simulate the 6 DOF flight dynamics of an aircraft by imputing the 3D CAD assembly as well as inertial measurements into a Simulink Blockset. The Simulink Blockset interfaces with a flight simulation program called Flightgear which allows you to test fly the plane before it's manufactured. This will allow us to estimate flight performance and determine if our design is flightworthy.

Material Selection Design

With our current design specifications we seek an airframe that is highly durable, light weight, and easy to manufacture with equipment available to us. With this in mind the most important material properties to consider are density, strength and toughness. Materials that possess a combination of low density and high strength and toughness will be the most useful for our applications. Having low density will decrease the overall mass of our system, allowing for less motor power and more air time. Because the wings experience both tension and compression, tension from the lift forces on the bottom of the wing and compression from the weight of the fuselage bearing down on the top, and that all control surfaces create bending moments on their fuselage connection points, materials that feature good strength properties are required. Toughness is necessary in all control and lift surfaces as failure in these areas will ruin the stability of the craft and cause it to crash. On the off chance that the plane is hit by something high impact resistance is also required. Below are charts displaying strength and toughness properties in relation to density and modulus of elasticity.

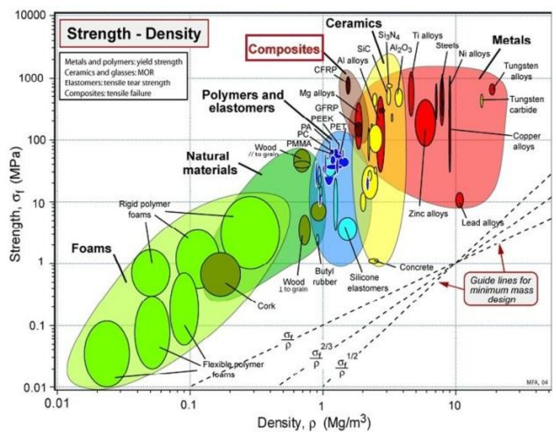

Figure 6: Strength versus density material chart

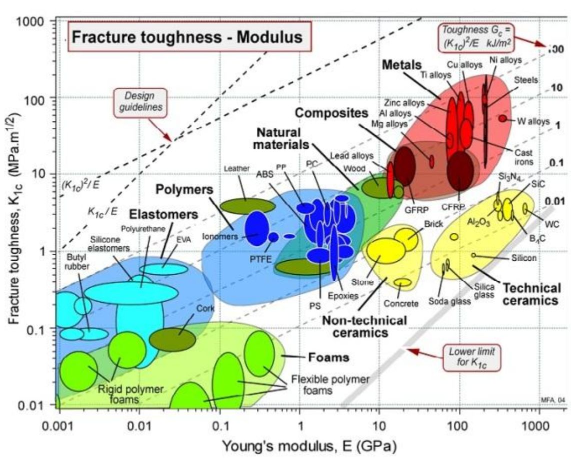

Figure 7: Fracture toughness versus Young’s modulus chart

It can be seen that, for their density, composites have exceptionally high strength, while different types of wood also have relatively high strength with very low density. Different types of foam are also of interest for their incredibly low density, where their lower strength can be offset by reinforcement with small amounts of other materials. All of these materials, foams, wood, and composites, can be easily procured by us or produced at facilities on campus. For these reasons we will attempt to utilize all three materials in our design.

The wing sections, tail, and fuselage will follow a similar fabrication method. The fuselage will be constructed by forming the composite cloth skin layers onto a mold. This mold can either be a male plug mold or a female shape mold and will be covered with no ply sheeting so that the skin doesn't stick to its surface. The first layer of composite sheet will be tightly wrapped to the mold and then be evenly painted with the proper amount of resin designated by the cloth's manufacturer. Each following layer is applied with a 90^{o} turn in respect to fiber direction and the appropriate amount of resin. This will provide greater strength in all directions of deformation. Once all layers are placed another layer of no ply sheeting will be applied and the entire mold and sheeting will be placed into a vacuum bag. The mold will be left in place for at least 6-9 hours, depending on the resin used, to dry.

The wing sections and tails will be formed by cutting a foam section of appropriate length, either by heated wire or a CNC machine, and then forming the outer skin layers to the foam core with the same process used on the fuselage. In this case a no ply sheet is only needed on the outside of the entire wing section, including the skin, because the composite layer must bond to the foam with the resin. Only an epoxy resin can be used because a polyester resin will dissolve the bonds of the internal foam structure.

The internal structure of the plane, including supports for the fuselage and mounting positions for the payload, will be constructed of sandwiched balsa wood and carbon fiber sheet. The balsa wood will consist of multiple layers placed so that their grain direction alternates by 90^{o} and then wrapped in carbon fiber and infused with resin.

Concept 1: Resin Impregnated Fiberglass and Blue Foam

This concept utilizes fiberglass reinforced plastics (FRP), consisting of woven fiberglass cloth sheets impregnated with an epoxy resin, and blue extruded polystyrene (EP) foam. The blue foam in use will feature a compressive strength of 25 psi and a density of 1.9 lb/ft^3. Blue EP foam is a standard in wing core construction and is relatively cheap and easy to procure. A drawback of using the blue EP foam is that when cut by heated wire droplets of the removed foam can create protrusions on the surface, rendering the core unusable.

Concept 2: Resin Impregnated Fiberglass and Spyder Foam

This concept will use the same fiberglass sheets and resin as Concept 1 but will use Spyder foam for the wing core material. Spyder foam features a cell structure aligned perpendicular to the wing surface creating a compressive strength of 60 psi while maintaining a density of only 2.2 lb/ft^3.[2] This foam costs more than the standard blue EP foam but is more than twice the strength, allowing for a smaller and shorter spar cross-section, less layers of fiberglass skin, and a much lower chance of failure. The cell structure of Spyder foam also allows for more resin movement into the foam, creating a better bond with the outer skin layers. When cut by heated wire Spyder foam also has none of the drawbacks featured by blue foam.

Concept 3: Resin Impregnated Carbon Fiber and Blue Foam

In this concept carbon fiber sheets will be used to create the skin of the craft in place of fiberglass sheets. The same blue foam used in Concept 1 will be used and the same type of epoxy resin can be used. A carbon fiber sheet that shares a similar weight to a fiber glass sheet features much higher toughness and higher tensile strength. This means that lift forces and impact energies on the fuselage can be supported with a smaller overall number of skin layers. Carbon fiber sheeting has a higher price than fiberglass sheets but less material is needed. The same sheets used in creating the fuselage support ribs can also be used for the skin which will reduce shipping costs and overall wasted material.

Concept 4: Resin Impregnated Carbon Fiber and Spyder Foam

This concept will be like that of Concept 3 but use Spyder foam for the wing core material instead of blue foam. This concept will be similar in weight to that of Concept 2 but will offer a much higher strength with an overall smaller amount of material. Of all designs this will be the most expensive but offer the highest durability and lowest possible chance of failure.

Concept 5: Hybrid Composite Skin

This concept will utilize both carbon fiber and fiberglass sheets in the construction of the planes outer layer. Fiberglass will be used as the primary material for the skin while carbon fiber will be used to reinforce critical sections of the plane, including the wings, tail, and nose cone. In any area where both materials are used carbon fiber will form the outer most layer so that its high toughness will be fully utilized.

Testing Process

Once the weight of the payload is known and the airfoil and wing length are chosen, material selection can begin. The different concepts listed will be tested by accurately measuring their weights using CAD models in either Pro-E or SolidWorks. The strength and failure evaluations will be tested by creating geometrically correct models in Comsol and samples of the skin and wing construction can be physically tested.

Propulsion System Design

Propulsion means to push forward or drive an object forward. A propulsion system is a machine that produces thrust to push an object forward. The thrust from the propulsion system must balance the drag of the plane when the plane is cruising. The thrust from the propulsion system must exceed the drag of the plane for plane to accelerate. The battery power will need to be last at least an hour. In choosing a motor we are looking at a few options. There are two main options an electric powered and a gas/glow motor.

Electric powered model aircrafts have gained popularity, mainly because the electric motors are more quiet, clean and often easier to start and operate than the combustion motors. People who use these types of motors tend to try and make their planes as light as possible to obtain a reasonable flight time or wing loading. The coreless motor has the rotor coils not wrapped around an iron core but just fastened into shape with glue, which makes the rotor much lighter and faster to accelerate and thus suitable for servos. Since the coreless motors don't have iron cores they have much less iron losses, which make them more efficient than cored motors. However, the coreless motors will not stand continuous high RPM and/or loads without falling apart. That's why they are generally rather small, with low speed and low power. A DC motor converts the electric current into Torque and the voltage into rotations per minute (RPM). There are two main types of electric motors; brushed and brushless.

Brushed motors need some maintenance, since both the brushes and the commutator will wear after a while due to the friction. Most quality motors allow brush replacement. The commutator itself also needs cleaning as it gathers deposits of carbon and gunk due to the graphite powder from the brushes. It may be cleaned by a very light polishing action with scotch rite or with a so-called commutator stick. Brushes are usually made of three different compounds: Graphite, Copper and Silver. Brushes made of silver are normally used in competitive racing as they have low resistance, but they produce the highest commutator wear and also have medium brush wear and lubrication. Silver brushes produce sludge that only can be removed by lathing the commutator. Copper brushes don't produce sludge and work best at high rpm. These brushes produce medium commutator wear and have high brush wear and low lubrication. Graphite brushes produce low commutator wear, have low brush wear and high lubrication but have high resistance, which means that they are not suitable for racing. Sparks that occur between the brushes and the commutator can cause radio interference. In order to prevent radio interference it is recommended the use of ceramic capacitors soldered between each motor terminal and the motor case. For extra security against interference, a third capacitor should also be fitted between the motor terminals.

Brushless motors are little more expensive but they have higher efficiency typically between 80 to 90%. Since they have no brushes, there is less friction and virtually no parts to wear, apart from the bearings. Unlike the DC brushed motor, the stator of the brushless motor has coils while the rotor consists normally of permanent magnets. The stator of a conventional (in runner) brushless motor is part of its outer case, while the rotor rotates inside it. The metal case acts as a heat-sink, radiating the heat generated by the stator coils, thereby keeping the permanent magnets at lower temperature.

Brushless motors are 3-phase AC synchronous motors. Three alternated voltages are applied to the stator's coils sequentially (by phase shift) creating a rotating magnetic field which is followed by the rotor. It's required an electronic speed controller specially designed for the brushless motors, which converts the battery's DC voltage into three pulsed voltage lines that are 120^o out of phase. The brushless motor's max rpm is dependent on the 3-phase's frequency and on the number of poles. Increasing the number of poles will decrease the max rpm but increase the torque. A recent type of brushless motor is the so-called "out runner". These motors have the rotor "outside" as part of a rotating outer case while the stator is located inside the rotor. This arrangement gives much higher torque than the conventional brushless motors, which means that the "out runners" are able to drive larger and more efficient propellers without the need of gearboxes.

Glow engines are actually internal combustion engines that form the heart of any gas or nitro powered RC plane. Most nitro R/C models use a 2- or 4-stroke glow engine, sized specifically for that model. Typically, they range in displacement from .049 cu. in. to 1.2 cu. in. (80cc to 20cc) — a variety that satisfies virtually any model's power requirements. Glow engines cannot be operated with the same gasoline you'd get at a filling station pump. They require a special fuel, called "glow fuel." It contains methanol as the base, with varying amounts of nitro methane to increase the energy that the fuel can provide. Oil, pre-mixed into the fuel, lubricates and protects your tiny engine as it pounds out amazing power.

There are two primary kinds of glow engines; two-stroke and four-stroke. Two-Stroke simply means that the engine "fires" (ignites the fuel in its combustion chamber) with every revolution of the piston. Generally, they're a good place for new nitro modelers to start. Two-strokes are easier to operate, less vulnerable to problems if misused, and deliver more power for their size and weight. Four-Stroke engines fire once with every two revolutions of the piston. They consume less fuel, sound more realistic, and provide more torque but cost more, are harder to adjust and require more maintenance. Most glow engines have a simple ignition system that uses a glow plug rather than a spark plug so there's no coil. The glow plug is heated by a battery-operated glow starter; meanwhile, the modeler uses a recoil starter, Electric 12V Starter or Starter Box to turn over the engine. When fuel enters the combustion chamber, it's ignited by the heated glow plug and the engine starts. At this instance the engine begins gaining the momentum to continue running after all the starter accessories are removed. The engine's carburetor supplies the fuel and air needed for combustion. A rotating throttle arm controls the amount of fuel and air that enters the combustion chamber. The high-speed needle valve controls the mix or proportions of fuel vs. air at mid- to high-speeds. The idle mixture screw is similar to the high-speed needle valve, except that it controls the mix of fuel and air when the engine is only idling. When you've adjusted the high-speed and idle mixtures properly, your engine should operate smooth and steady throughout its range of speeds. True gas engines have a lower power to weight ratio than glow engines.

The propeller is the part of an RC vessel that pushes air (or water) behind it by spinning quickly, causing the craft to move forward. The propeller gets the energy to do this from the engine to which it is connected. Engines come in two basic forms: electric or internal-combustion, which is also known as a glow engine in the RC world. Because they are less expensive and easier to maintain, beginners are advised to choose an electric RC craft. They are also much less noisy than glow engines, so you can use them in a wider variety of areas, rather than just private fields and RC air fields.

Most simple RC airplanes use a single two-blade propeller attached to the nose of the craft. Most RC boats use one propeller as well, but a special type that is suitable for use underwater. RC blimps typically use two small propellers, one on each side of the bottom portion of the blimp (gondola). These propellers can vary speed and direction to precisely control movement, or even hover. Hydrofoams also use two propellers, but they have three blades instead of two, and have a ring connecting the blades going around the circumference of the tips. The fastest and most expensive form of RC craft is jets. They use a multi-bladed propeller, called an impeller, that spins at very high revolutions per minute (RPM) and generate significant thrust.

Power Supply System Design

The power supply system of the aircraft is the system that will supply the electrical energy to all the electrical loads present in the aircraft. This system will consist of an electrical storage device (batteries), a voltage regulation system, the conductors carrying the current to the loads, and a device for recharging the electrical storage device. The requirements for these basic components are drawn from attributes that are universally beneficial for an aircrafts' composition. These requirements are low weight, small size, low heat emission, and the ability to store and deliver the required electrical energy necessary for flight. The target flight time for mission completion is forty minutes. This required flight time provides a foothold for generating a power supply conceptual design. However, due to the fact that the various aircraft components that will be powered through this system have not yet been picked, the battery specifics and voltage regulator specifics cannot be determined at this stage in the design process.

Another important aspect of the power supply system design process is its' close relationship with the propulsion system of the aircraft. The propulsion plant of the aircraft could be powered either by gasoline or by electricity. If the propulsion is handled by a gasoline engine, the power supply system will not have to supply the amount of power required for an electrical propulsion plant. The design of the propulsion plant will affect the power system in the selection of the batteries and the voltage regulation components. Without knowing the aircrafts' definite propulsion plant, the design of the power supply system can only be cursory and based on the comparison of the available battery types.

The electrical storage device is the most important part of the power supply system. There are a wide variety of batteries on the market specifically designed for applications such as Remote Control airplanes and cars. The different batteries are distinguished by their chemical composition and three major types have achieved popularity in the RC community. The three popular types of batteries and their traits are shown below in figure 8.

Battery Composition	**Abbreviation**	**Specific Energy**	**Energy Density**	**Charge/Discharge efficiency**	**Specific Power**
Nickel–cadmium	NiCad	40–60 W·h/kg	50–150 W·h/L	80%	150 W/kg
Nickel–metal hydride	NiMH	60–120 W·h/kg	140–300 W·h/L	66%	250–1000 W/kg
Lithium-ion polymer	LiPo	130–200 W·h/kg	300 W·h/L	99.80%	7100 W/kg

Figure 8: Battery Characteristics

Based on these battery characteristics, three different designs can be generated based on the three types of batteries. By analyzing the requirements of the power supply system and applying the requirements to these three battery types, a decision can be made on which battery type is best suited for the aircraft.

Power Supply System Design Concepts

Nickel Cadmium (NiCad) batteries are referred to as old technology, and are not as common in the RC world as they once were. As can be seen from figure 1, the charge/discharge efficiency of the NiCad battery is much higher than the NiMH batteries, but there are many reasons the NiCad batteries are used less frequently than the other types. NiCad batteries must be fully discharged after each use; otherwise they will develop what is called "memory" or an inability to discharge fully during use. The capacity per weight, which can be seen from the specific power, is lower than the two other batteries, which makes it a poor contender for use in an aircraft. The Cadmium that is used in the manufacture of the battery is also harmful to the environment, and was the purpose behind the development of the nickel metal hydride battery. The benefits of using the NiCad battery are the inexpensive cost of the battery, the absence of safety issues dealing with an aircraft crash, and the NiCad's ability to discharge high current with no damage to the battery.

Nickel metal hydride (NiMH) batteries were developed to replace the NiCad batteries, and have several benefits over NiCad. NiMH batteries are not required to be fully discharged each use, and do not develop a memory over time. The capacity per weight is much higher than the NiCad battery, and it is available at a price not much higher than the NiCad. This battery is also easy to charge and discharge as compared to the LiPo battery and like the NiCad, does not have any inherent safety issues.

Lithium ion polymer batteries are the newest battery to be developed and brought to market. This battery's capacity per weight is many times the capacity of the NiMH and NiCad batteries. The composition of the battery cells also results in the LiPo battery being around half the weight of a NiCad or NiMH battery. Because LiPo batteries can achieve twice the capacity of the other batteries with half the weight, they are ideal for using in an aircraft. However, there are issues that have prevented the LiPo battery from dominating the RC market. The biggest negative factor in using LiPo batteries is the fire hazard inherent in using these batteries. If a LiPo cell is incorrectly charged or physically damaged, it may burst into flame, and severely damage the aircraft and its components.

From the analysis of the three types of batteries, it is clear that the design of the aircraft power supply system could be completed using either the NiMH battery or the LiPo battery. Using either of these two batteries, as well as allowing for the two different types of propulsion plants possible for the aircraft, four different designs can be generated. The designs are shown below in figure 9, and include each battery with each type of power plant.

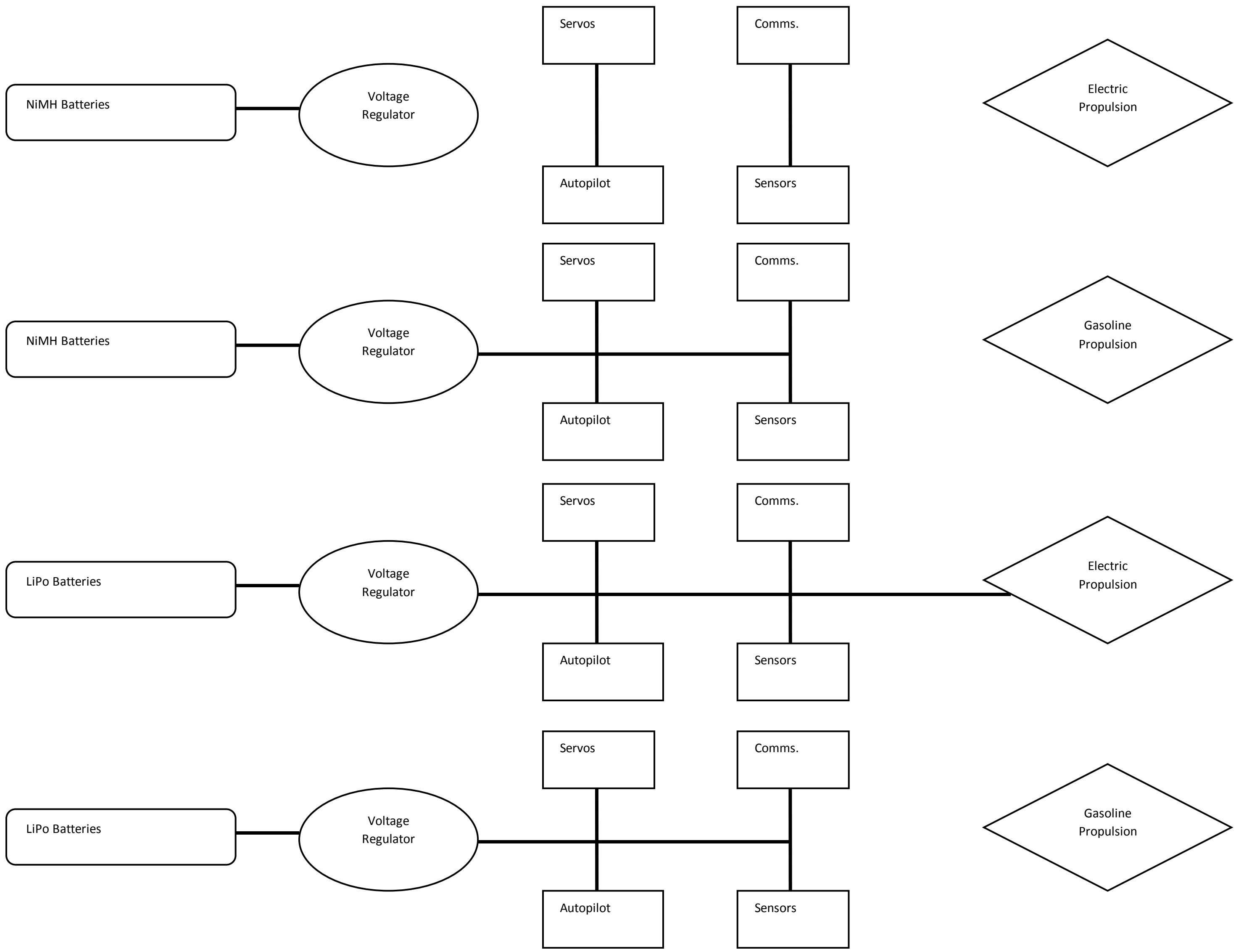

Figure 9: Power Supply System Design Concepts

Autopilot System Design

Autopilot Requirements

The UAS must complete waypoint navigation and search an area for given targets and then return back to base. The UAS must complete these objectives without being controlled by any person. The autopilot system will allow the UAS to complete these objectives with this requirement.

The ideal autopilot for this project will have a few system elements that will be vital in selecting the one best suited for the mission. Since most autopilots are not designed to search a given area, the source code of the autopilot must be easily modifiable so that this capability can be added to the system. The ideal autopilot will also use a small amount of power throughout the entire flight. It would be very helpful if the autopilot could also interface with most sensors, allowing the team to mix and match sensors for the mission. Lastly, the autopilot board needs to have some way to be able to control the camera system gimbal.

Autopilot System Concepts

The first system considered is the Ardupilot Mega autopilot system. The ideal batter for this system is a 7.4V 2s pack with a peak amperage of 1A. This board has a built in switching power supply to accommodate the 5V bus used for outputs. The weight is approximately 45g and the dimensions are 40mm x 69mm. The positives for this system are that it has a built in kill switch that is needed for if the autopilot malfunctions and the UAS needs to be flown manually. Also, the software for the autopilot interface runs in windows, making it very portable. The negatives to this board are that it lacks the extra ports for the camera system gimbal, meaning the gimbal would have to be controlled using some other system. Also, there is no source code directly given with the software, so modifying it to be able to handle the search area will be difficult.

The second system is the Piccolo SL autopilot system. The input voltage ranges between 5-30V, and has an average power usage of 4W. The weight of the system is 100g, and the dimensions are130 x 59 x 19 mm. A positive to this board is that it has been tested at running over 100 degrees Fahrenheit, which is one requirement for the system to complete the mission. Another positive is that it has over ten I/O ports, allowing for many other parts of the system to be controlled besides the servos. This would be helpful for the camera system gimbal. Some negatives to this board is that the developer kit is sold separate from the actual autopilot board, so the cost to integrate the search area could would be more expensive, and the source code included in the developer kit is not made to easily be modified. This is a major disadvantage for trying to implement the search area.

The third system considered is the Paparazzi Tiny v2.11 autopilot system. The input voltage ranges from 5-18V with a maximum amperage of 2.5A. This system also has a built in switching power supply for supporting the 5V bus on the board. The weight is 24g and the dimensions are 70.8 mm x 40 mm. Some positives for the Paparazzi board is that it has a built in kill switch, it has two extra ports to control the camera system gimbal, the entire source code is downloadable of their website, and it interfaces with most sensors. Although the website does have a list of preferred sensors. Some negatives is that the board is not pre-built, the website just lists the parts used to build the board, and the interface software only runs on Linux platforms, making it less portable than most other autopilots.

Majors Sensors: GPS and IMU

The GPS is the Global Positioning System sensor used to track the location of the sensor. This is vital in navigating the waypoints and completing the search area task. The GPS uses satellites to track its position on the earth. The IMU is the Inertial Measurement Unit, which uses three orthogonal accelerometers and a gyroscope to measure the linear acceleration and orientation of the system. This is important to keep the UAS upright and to tell the autopilot the speed at which it is traveling.

GPS Sensor Concepts

The first GPS sensor is the u-Blox LEA series sensor. This GPS is recommended for most UAV projects due to its simplicity and easy interface. The sensor has a 4Hz update rate and the average power consumption is 47mA at 3.0 V. The second GPS sensor is the NAVILOCK NL-507ETTL. This GPS sensor has 16 channels for transmission, making it very reliable in always getting a reading from it. It has a 1Hz default update rate, but it can be pushed up to 4Hz and the average power is 47mA at 3.3V. The third GPS sensor is the SPK GS406. This sensor has a power usage of 75mA at 3.3V. This device only has a 2Hz update rate.

IMU Sensor Concepts

The first IMU sensor to be considered is the Booz IMU v1.2. It has a 16 bit ADC and does 200,000 samples per second. This IMU was built primarily for the Paparazzi autopilot but has been recently modified to interface with most autopilots now. The second IMU is the YAI v1.0. This is very similar to the Booz IMU because it has a 16 bit ADC and does 200,000 samples per second but this IMU was built to better interface with the lower cost sensors. The third IMU sensor to be considered is the Aspirin IMU. This is a next generation flat IMU, where most IMUs are built up from the board. It uses a three-axis accelerometer, gyroscope, and magnetometer. The magnetometer helps with the GPS calculation by measuring the magnetic fields of the Earth to find where the sensor is on the planet.

Imagery System Design

Our goal is to design an intelligent imagery system capable of accurately determining the target location from an aerial position. The system will need to locate the targets background color, shape, orientation, alphanumeric, and alphanumeric color. Some of the function requirements for this task are the following:

- Accurately determine target characteristics from 500-750 ft
- Lightweight design to be mounted on the airframe
- Low power consumption
- Transmit images or video back to the ground-station
- 120 degree or greater Field of View

Imagery

The two main possibilities to capture, send, and process images are to either use still-image camera pictures or implement a real-time video display. Both choices have immediate advantages as well as disadvantages to the unmanned aerial system.

A still picture camera requires far less transmission data than a constant data feed. Pictures with a still camera are usually captured at a much higher resolution than a video camera. Also the camera will require far less transmission power to send less data. In contrast, a still-picture camera is required to take many pictures to capture the target. The user will need to implement multiple cameras or apply a gimbal system to change the cameras viewing angle. Still images will not be updated as quickly as a live video feed and could possible cause a delay in changing the camera position. In this case, the target could easily be missed. Target acquisition will most likely take longer than normal opposed to a constant data feed. Camera systems such as a DSLR provide a higher resolution than most video cameras but are heavy to mount to the airframe and expensive.

Implementing a live video stream allows the user to constantly update their position for an immediate target acquisition. This technique shortens the amount of time required to find a target as well as makes shorting images much easier. These video systems are similar to security cameras or machine vision cameras. They provide a lightweight design that is easily mounted to a gimbal. Unfortunately, constant data feeds require much more power than a still image system, and must be transmitted at a higher frequency, most likely in the gigahertz range to maintain a 6-8 Mbit/sec bit rate. Live camera video requires a clean signal for operation as well as real time image stabilization.

Communications

Data Link Transmission

In order to transmit the captured images or video feed a specific data link must be created between the ground-station and the aerial vehicle. The UAS will fly along GPS waypoints during its mission and need to wirelessly transmit data back down to the ground-station at a maximum distance of up to 2-3 miles. Achieving this goal will require a carefully designed system to broadcast at VHF to UHF range depending on whether the data sent will be through a video feed or as digital stills.

There will also be two other separate data links from the UAS to the ground-station. The first being the Autopilot data sent to ground-station such as position, angle of attack, airspeed, altitude, etc. This communication link will need to be operated at a different frequency far away from the Imagery system. For safety reasons, the UAS must also have a data link that provides a manual engine override of the Autopilot during any time. It could be advantageous to use an Autopilot with additional servos can broadcast the manual control on the same frequency.

Data Link Reception

Signals sent from the UAS will be received by the ground-station through its flight. The data transmissions will be digitally sent through the on-board transmitter using a spread spectrum either CDMA, FDMA, or COFDM. These transmissions must be received by either one or multiple antennas. There are many different antenna configurations, such as a Patch Antenna. These low profile radio antennas can either be mounted or freestanding. Simple designs using air dielectric mediums and metal sheets covered in a plastic radome are easily constructed. Determining the size of the antenna in relation to the lowest radiating frequency can be done by:

$$L = \frac{\lambda 2}{\mathrm{d}} = \frac{\lambda_\circ}{2\sqrt{\varepsilon_r}} \quad , \quad f = \frac{c}{\lambda} = \frac{c}{2L} = \frac{c_o}{2L\sqrt{\varepsilon_r}}$$

$$\varepsilon_r(\omega) = \frac{\varepsilon(\omega)}{\varepsilon_0}, \qquad c_0 = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}.$$

Using these equations one can calculate the required dimensions of a square Patch Antenna. The power requirements are directly related to the broadcasted frequency. Although the power requirements of the ground-station as less constraints than that of the payload. The flight ground-station equipment may be as large as necessary to accommodate all the communication equipment. Separate dedicated antennas may be chosen to handle Autopilot MCU data opposed to the Imagery system.

The on-board plane antenna must be an omnidirectional while the ground antenna system could easily be directional. Unfortunately, using a directional ground-station antenna will require the user to angle the antenna in the direction plane to receive the maximum reception during flight.