

Power Density Key to Drone/UAV Endurance

Drones and UAVs are fast becoming ubiquitous, but they still have limited endurance in long flights. This article reviews high power density, power-supply architectures, and other options for drones to help extend their flight time.

The drone and unmanned-aerial-vehicle (UAV) industries are in dire need of extended flight endurance. Most drones, powered solely via batteries, will likely experience flight times that only last for **approximately 15 minutes**. When drones are tasked to carry heavy payloads, their flight time will shorten even more.

Endurance and Flight Range

The company, 911 security,² helps us to understand endurance and flight range of a drone or UAV.

The endurance for either type is defined as the total length of flight time during flight. In general, for any electric fixed-wing UAV/drone aircraft or quadrotor, endurance will be directly related to the capacity of an on-board battery coupled with the amount of current the motor needs to draw to keep the aircraft flying. Because so many other aircraft parameters can determine the endurance of any aircraft, in this article, the endurance calculation (for simplicity) will be approximated by the equation:

Endurance (in hours) = battery capacity (Ah)/Current (amps)

This “endurance” in hours will greatly depend on the size, weight, and payload of the drone or UAV.

Range Capability

A drone or UAV range can be calculated by the amount of current that's produced by the onboard power supply, endurance, flight speed, and aerodynamic performance. The rough estimate range is:

Range (miles) = (kV) × (V) × (60) × (Pitch) × (Endurance in hours)/(12) × (5260)

Pitch is defined as rotation of the vehicle, fixed between the side-to-side axis (on an airplane wingtip-to-wingtip), also known as the lateral or transverse axis.

If we want a more accurate calculation of range, then we must use the added parameters of rotor/wing area, weight, and coefficient of lift in the airfoil.

UAV Power Sources

Electrical power systems are critical to a drone's or UAV's design and operation. Weight, operating temperature, and efficiency of the on-board power components have a major influence on performance parameters like flight duration, payload, operating ceiling, and range. Power density is a necessary power-supply feature as well.

The choices in selecting an electric power system will mostly hinge on the duration of the continuous and peak power requirements for the mission profile. Unlike many other UAV subsystems, the power system can support both the platform and the payload. Depending on the mission, the payload may require electrical power while in flight. This power demand may range from tens or hundreds of watts for sensors or communications, or it could be tens of kilowatts or even more for complex payloads.

[Thermal management](#) is a consideration, too, since much of the thermal load is frequently generated by electrical devices. The operation of hydraulic system components, and other actuators, may also be closely related to electrical system design requirements for peak versus average power.

Electrical power, typically in larger drones/UAVs, is often generated by a starter generator—a critical component for ensuring that the electrical system can meet the drone/UAV design objectives. A starter generator usually can be mounted right on the engine. The drive shaft will turn the rotor to produce electricity or, in addition, can be connected to the engine via mechanical means, e.g., a belt system.

If the electrical machine is solely used to generate power for the onboard systems, it may be called an alternator. A starter generator is capable of starting the internal combustion engine (ICE) itself. This system would be paired with an electronic engine starter, a power electronics component able to provide the commutation to the starter generator to rotate the internal combustion engine (ICE) shaft up to the desired cranking speed and torque.

Most starter generators can produce a three-phase ac voltage that varies with the RPM and load. The system next converts that ac to a dc voltage output via a power-management unit (PMU) or an intelligent power system (IPS). The PMU will use active rectification and regulation to supply the outputs of one or more dc voltages from the variable ac input.

Onboard, different systems will need different dc voltages. One example is the payload, which might use 12 V, while the avionics might only need to use 5 V.

A battery pack will usually be included to store energy to ensure a continuous supply of power over the required minimum operating time. This may also be used for power to start the engine as well, if necessary.

Types of Drone Energy Sources

Combustion-engine-powered drones will have the best performance characteristics across all parameters and capabilities. The most negative aspect of the combustion engine is their pollution contribution to Earth's air quality.

Solar systems also can be an option. These very eco-friendly solutions will have a reasonable flight time, but at higher cost than many other options.

If the cost vs. power system advantages looks doable, hydrogen fuel cells may offer an excellent alternative option to combustion engines because they enable a relatively long flight time, with low weight and very fast refueling time. This solution is obviously extremely eco-friendly.

Some Possible Solutions

Most solutions will tend to increase system complexity. The best options will probably be via fuel-cell (FC) and supercapacitor (SC) hybrids, and Li-ion battery power.

Hybrid systems can mitigate a power source's shortcomings by combining other kinds of power sources that can complement one power source's shortfall aspects as advantages. This enables designers to choose which disadvantages can best be tolerated. Power density is important here.

Combustion engines are quite robust, but make no mistake, they will add quite a bit of weight with a limited application. That's because they will mostly be deployed within fixed-wing aircraft types.

FCs and batteries will surely enable a longer flight time and a better extended range capability than some other solutions. The problem is that both options will have difficulty in supplying the peak current when needed by the aircraft. They also quickly drain down at an accelerated rate.

Hybrid systems will still provide solid advantages over most other systems. Since these mixed architectures use more than one power source, they acquire the specific advantages that each different power source has to offer.

A hybrid-system power-source advantage will best help lead to extended flight times for drones. This kind of system

must be comparable in weight and size to present existing drone power systems, while increasing the efficiency of the current power-system architectures and adhering to a high power density.

Such systems are far from perfect. They do tend to eliminate smaller issues like longer charging time, poor peak power in the supply, and more. The most common power source that can be used in hybrid systems is SCs. They tend to have advantages that overcome the disadvantages of most other available power-source options, with high energy density, short recharge period, and the tendency for a virtually infinite lifecycle.

A plethora of different power sources are available on the market, with batteries, solar power, FCs, combustion engines, etc., and many of them can be applied to drones.

Probably, the most suitable type of battery can be determined by comparing the power density, energy density, weight, volume, lifecycle, cost, safety, and maintenance (just to name a few criteria) of the different options. But beware, each of these criteria will affect different aspects of the drone—power density will impact acceleration capability, energy density will determine the range, lifecycle determines how often the battery needs to be replaced, weight and volume will affect the range of the system, and finally, cost affects availability.

Drone and UAV Power Density

Batteries

Despite all of the advantages of battery characteristics, they're still unable to adapt to long UAV missions when used as a unique power source. That's due to their low power density.

Many researchers have selected supercapacitors as the power-supply system of choice because of their very high power density. The hybridization system is a key solution to enhance flight distance. However, selecting a suitable energy system is quite complicated because of the many considerations of both power sources' characteristics and mission types.

Fuel-Cell Systems

Fuel-cell systems can be a good solution due to their high power density and rapid refueling. Especially when it comes to [direct methanol fuel cell \(DMFC\)](#) and [alkaline fuel cell \(AFC\)](#) power, no commercial products can be found due to their very low power density. Thus, an industrial system will be needed. Recent research efforts have determined the outstanding performance of DMFC with a very high power density of 181 mW/cm² at 80°C, under a very low air pressure of 0.05 atm.

[Proton exchange membrane fuel cells \(PEMFCs\)](#) have been employed in various applications worldwide. In particular, they're used to power UAVs because of their advances

in high efficiency, improved power density, and low operating temperature.

Recent advances in compressed hydrogen-powered PEMFC have seen power densities of up to 1.4 kW/kg in the 100-kW range and only 250 W/kg for a 1-kW commercial model. In this case, it would be a better advantage to use liquid fuel when fuel storage and delivery are considered more critical than battery power density.

In such a design architecture, the fuel-cell system powers an electric motor that, in turn, drives a propeller. The main disadvantage of the application of fuel cells is their low power density, which will restrict the overall performance of the UAV. To rectify that, a fuel cell will normally be combined with a battery as the overall hybrid system to power UAVs.

The specific power density of a PEMFC system is about 700-1000 W/kg right now. The main disadvantage in the application of fuel cells is low power density; this will restrict the performance of a UAV.

Because of low power density, batteries will only provide enough power for short-flight-time missions of UAVs. They also have a much longer recharge time than their flight duration.

Spark Ignition Engine

Another possible choice offering the advantages of high power density and efficiency is the spark ignition (SI) engine. It's still used to power UAVs, especially with two-stroke engines. Problem: pollution, pollution, pollution.

Typically, a brushless electric DC motor (BLDC) is used to power the drone propellers¹ due to its advantages in high efficiency, good power density, good torque characteristics, reliability, and long lifetime.

A BLDC motor, along with microcontroller (MCU), that will decode the speed reference signal coming from a central controller may be an option. The MCU measures the motor's back-EMF and current signals, then sends the proper control signals for the power stage. The second main component is the power stage composed of a gate driver and power MOSFETs. The power stage will amplify the control signals from the MCU to the motor.

One design, for example, minimizes board space with a highly integrated step-down buck converter, compact N-channel power MOSFETs for high power density, and a small-footprint JTAG connector. The total board space of the reference design is 2.2 × 1.0 in.

The Last Drone Standing

The U.S. Department of Commerce issued a challenge to drone manufacturers. The purpose was to compete in a First Responder Unmanned Aircraft System (UAS) Endurance Challenge. This competition would find the best drone technology to help extend the flight time for drones that carry heavy payloads.

Existing technology in modern-day drones frequently can't provide adequate support to first responders. The equipment package necessary is too heavy for drones to carry for very long.

Overall, 43 teams entered the competition in which the participants would design, build, and flight test a UAS for 90 minutes. The UAS was to carry a 10-lb communications device that would provide broadband coverage in an area lacking adequate communications bandwidth, for as long as the system could function properly to transfer critical data files to the first responders.

The big challenges were weight restrictions, vertical take-off and landing (VTOL), a navigation system, and an appropriate fuel system. And all of this must ensure cost-effectiveness.

The top prize went to Team [Advanced Aircraft Company \(AAC\)](#), a veteran-owned company making American-made drones, whose entry was a six-rotor drone with propellers on each of the six arms. Power was provided by a hybrid-electric propulsion system that significantly improved en-



The AAC HAMR UAV has an advanced aerodynamic design that minimizes drag and maximizes mission performance (Credit: Advanced Aircraft Company)

ergy density over batteries, enabling longer flight times.

Their flight time in this challenge was 112 minutes and 17 seconds. The UAS weighed 29.93 pounds (13.58 kilograms), the lightest one in the competition (*see figure*).

Hybrid-Electric Generators

A hybrid-electric generator combines traditional fuel and electricity to increase flight endurance as well as provide the ability to carry heavier payloads.

A California-based aerospace startup, [LaunchPoint Electric Propulsion Solutions, Inc.](#), developed a new hybrid-electric generator system combining traditional fuel and electricity that will increase flight endurance and enable drones to carry heavier payloads.

Summary

Over the last few years, electric motors (EMs) have seen improvements in power density as well as efficiency. Power densities of 5.2 kW/kg have been achieved in 160-kW motors. In fact, NASA is expecting an EM in the 1-MW power class with a power density of 13 to 16 kW/kg.

References

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