White Paper

Drone Design Guide

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I. Abstract

The intent of this white paper is to address the state of multi-rotor drone technology sufficiently enough to perform a meaningful comparison of existing payload, battery capability, and flight hardware.

II. Commercial Drone Market Overview

A report titled “The Economic Impact of Unmanned Aircraft Systems Integration In the United States” published by the Association of Unmanned Vehicle Systems International, dated March 2013 is the definitive resource quoted by industry and the media, ref 1. To balance this industry report see ref. 2 for denigrating comments aimed at the Economic report. Taken together, the outlook for the growth of the commercial drone market is indeed good.

One very important variable is the pace at which the FAA rulemaking body is incorporating the commercial drone capabilities into the national airspace. The FAA has missed one congressional deadline by almost a year already and the FAA has not entirely come to grips with this new industry. Only a handful of companies can legally operate commercially as they have been granted an FAA exemption. The commercial drone exemptions are in the agricultural, industrial inspections, and Hollywood movie categories with many more exemptions under review.

There are a number of companies building and selling production quality drones of various sizes that come in a ready-to-fly state out of the box. Most of these drones are purchased by hobbyists since the commercial high end drone market has not flurished due to the slow pace of the FAA rule makers.

From a design perspective, the drone market is served by a variety of commercial vendors providing every structural, mechanical, electrical, motor, and sensor component necessary to build a flyable drone. Additionally, there are several periodicals dedicated to armatures and experts bent on building and flying one-of-a-kind drones for specific applications.

III. Drone Basics

For analysis purposes it is necessary to become familiar with the multi-rotor drone components requiring power while in flight. As an aside, single rotor drones are inherently unstable while in flight and very difficult to master as an operator. The multi-rotor drones have onboard flight computers, gyros, and accelerometers that make them stable in flight and easy to master as an operator.

Thrust components – A set of rotors driven by brushless DC motors is the primary means for creating lift and motion. The brushless DC motors are cable coupled to a control board with electronic components reacting to flight control signals from the primary flight computer.

Flight Computer - The flight computer provides the interface between the airborne drone and the operator. The flight computer varies in complexity and at a minimum contains the electronics necessary to maintain stable flight. The flight computer may also contain interfaces for GPS, telemetry circuitry to relay health and status, video downlink circuitry, and additional capability for operating payload sensors.

RF Link – Integral to the drone is an RF receiver in communication with a hand held transmitter for controlling drone flight. The drone may in turn have an internal transmitter for down linking information back to the operator.

Power Source – The preferred battery is by far the Lithium Polymer (Li-Po) type. There are inherent safety concerns with charging these batteries. One concern is overcharging may cause the battery to burst into flames, once damaged even normal charging may cause them to burst into flames, and disposal is a concern as well. The tradeoff in the positive direction is cost and ability to deliver adequate power on demand. There is a one page sheet on battery terminology at the end of this paper, look for in flight white colored drone with a GoPro camera mounted on the bottom.

Mechanical Structure - A variety of vendors sell arms, rotors of varying lengths, main body structure for accepting arms and electrical components, antenna attachment points are integral, as well as gyro stabilized platforms for mounting camera equipment. If you can visual it you can build it.

Payload – Drone payloads are sensors and cameras that communicate with the flight computer for operation and data relay. Some of the payloads have their own battery systems while others my rely on the drone power plant.

See the last few pages of this paper for “Anatomy of a Drone” and the multirotor “Skyhook with Mantis arms” for specifics.

IV. Quadcopter Power Plant

This section addresses a theoretical commercially viable quadcopter that is needed to support itself and a small payload that weighs in combination something on the order of 2.5 lbs. Hobbyist drones are much smaller and much lighter and can operate on batteries providing as little as 380 mAh at 7.4v and above. Hobbyist drones are addressed later in this paper but are not the focus of the comparison.

The quadcopter needs power to operate the propeller motors for lift and maneuvering as well as for running the electronics and flight controls. Since the power for lift and maneuvering is by an order of magnitude greater than that required for the other systems the analysis will focus on the motors.

For quadcopter designs, a 2:1 thrust-to-weight ratio is the goal. That is, at 100% throttle, you want your combined propeller thrust to be capable of lifting two times the weight of the loaded craft.

In order to determine the amount of power the motors need to generate the required thrust a data sheet with motor and matched propellers is available.

Quadcopter Performance gives a good data sheet example:

	A	B	C	D	E	F	G	H	I	J	K
1	Motor	ESC	Prop		50%	60%	70%	80%	90%	100%	
2											
3	Tower Pro 2410-09	Turnigy 10A	EPP1045	Watts	28.4	29.3	54.5	72.9	92.2	95.2	
4			.2 oz	RPM	3940	4480	5030	5490	5890	5910	
5				Thrust in grams	230	300	390	475	555	560	
6				Thrust in ounces	8.11	10.58	13.76	16.75	19.58	19.75	
7											
8	Tower Pro 2410-09	Turnigy 10A	GWS9050 x 3blade	Watts	26	33.6	46.4	62.5	81.5	81.5	
9			.35 oz	RPM	4435	4930	5540	6129	6725	6725	
10				Thrust in grams	195	245	320	400	485	485	
11				Thrust in ounces	6.88	8.64	11.29	14.11	17.11	17.11	
12											
13	Tower Pro 2410-09	Turnigy 10A	Two-EPP1045	Watts	32	46.4	64.4	84.5	107.4	111.5	
14			perpendicular	RPM	3420	3910	4358	4759	5090	5115	
15			.4 oz	Thrust in grams	225	300	385	455	530	530	
16				Thrust in ounces	7.94	10.58	13.58	16.05	18.7	18.7	
17											
18	Tower Pro 2410-09	Turnigy 10A	Two-EPP1045	Watts	31.4	43.8	61.5	81.6	104.3	106.9	
19			parallel	RPM	3505	4020	4520	4929	5282	5300	
20			.4 oz	Thrust in grams	225	305	385	470	545	545	
21				Thrust in ounces	7.94	10.76	13.58	16.58	19.22	19.22	
22											
23	Tower Pro 2410-09	Turnigy 10A	Modified EPP1045	Watts	27.3	35.6	50.4	66.9	87.4	87.2	
24			cut down to 9x45	RPM	4240	4780	5400	5935	6477	6459	
25			.2 oz	Thrust in grams	200	255	335	415	500	500	
26				Thrust in ounces	7.05	8.99	11.82	14.64	17.64	17.64	
27											
28	Tower Pro 2410-09	Turnigy 10A	EPP1045	Watts			102			178.6	
29	very brief run at 100%	**14.8V**	.2 oz	RPM			6018			7114	
30	for obvious reasons			Thrust in grams			550			800	
31				Thrust in ounces			19.4			28.22	
32											
33	Tower Pro 2410-08	Turnigy 10A	EPP1045	Watts	34	50.3	67.5	88.3	111.4	117.4	
34	motor REALLY hot		.2 oz	RPM	4200	4770	5293	5721	6118	6188	
35	on 90-100% runs			Thrust in grams	260	345	430	510	575	595	
36				Thrust in ounces	9.17	12.17	15.17	17.99	20.28	20.99	

From the fact that Amps= Power (Watts) / Volts we can calculate the current draw for a particular set of motors.

Looking at the data for the first entry on the motor performance data sheet we will use the 50% thrust values as a hovering base line so we have margin to accommodate our 2:1 thrust to weight design ratio for lifting and maneuvering.

Therefore it looks like the absolute maximum hovering weight 4 rotor motors in combination can support is approximately 920 thrust grams, where each motor supports 230 thrust grams. However, watts contain units of kg therefore we have 0.92 thrust kg which equates to a medium weight drone weighing in at a little under 2.5 lbs.

From the data sheet the 4 motors x 28.4 watts each equates to 114 watts of total consumption while hoovering, which means the current will peak at 7.7 amps for a 14.8 volt battery.

Here the 14.8 V is provided by a LiPo battery made by a Korean company called

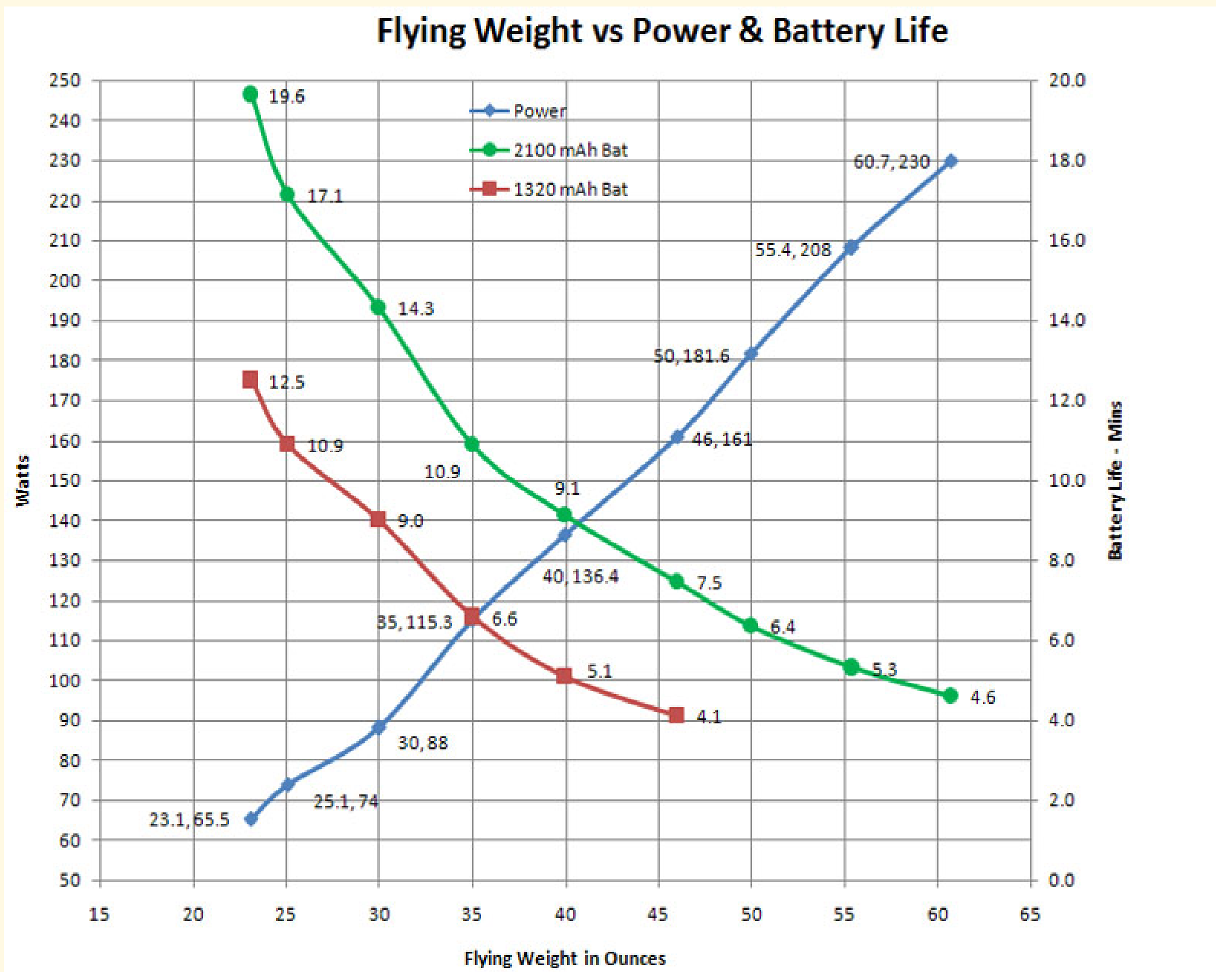
Topgun, product data sheet is on pages 13 and 14.

When reviewing the Topgun battery data sheets please take note of the weight, packaging dimensions, and discharge values.

Again looking at data for the first entry on the motor performance chart, the worst case lifting and maneuvering requires all the motors to work to at least 80% to achieve the 2:1 thrust to weight ratio, 475 grams is more than twice 230 grams.

Therefore, the 4 motors x 72.9 watts yields 292 watts of total power consumption, which means the current will peak at 19.7 amps for our Topgun 14.8 volt battery when climbing, braking, and maneuvering.

For another perspective take a look at the data from the flight weight vs power and battery life graph below, it shows that a single motor propeller (helicopter) should not exceed 61 ounces (1700 grams). At that weight, 61 watts of power is used, which is 5.5 amps at 11.1 volts.



V. Flight Time

To estimate the flight time for out theoretical quadcopter we will take our AUW (All up weight = body + payload) which we assume is the same 920 grams used above.

We then use the average of the 50% hovering current and the 80% lift and maneuvering current which is (7.7A + 19.7A) / 2 for an average current draw of 13.7A.

Our Topgun battery can provide 10000mAh or 10Ah. You divide 10Ah by 13.7A and multiply by 60 (minutes) to get a raw flight time of 43.8 minutes.

Then multiply the raw 43.8 minutes by 0.8 to allow for a 20% loss of efficiency and powering the other electrical components that make up the overall system.

The result is an estimated flight time of 35 minutes that will accommodate lift-off, hovering, and gentle flight. High end drone users will pay a premium for flight time that can be greatly extended.

VI. Flight Environment

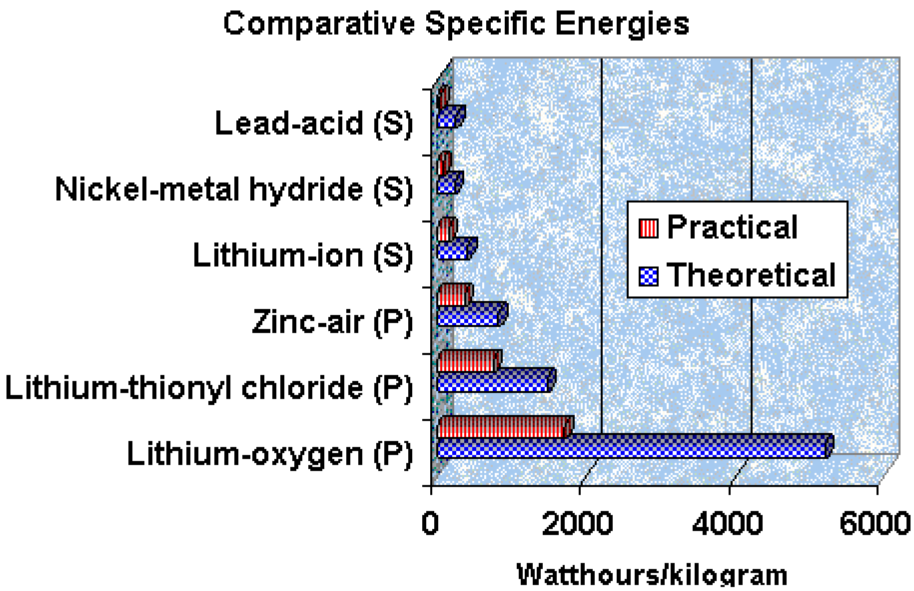
While comparing battery technology the flight environment must be taken into account as well the ability to withstand hard landings and crashes. Additionally, the operator will expect a direct correlation between throttle and maneuver commands and drone airborne response.

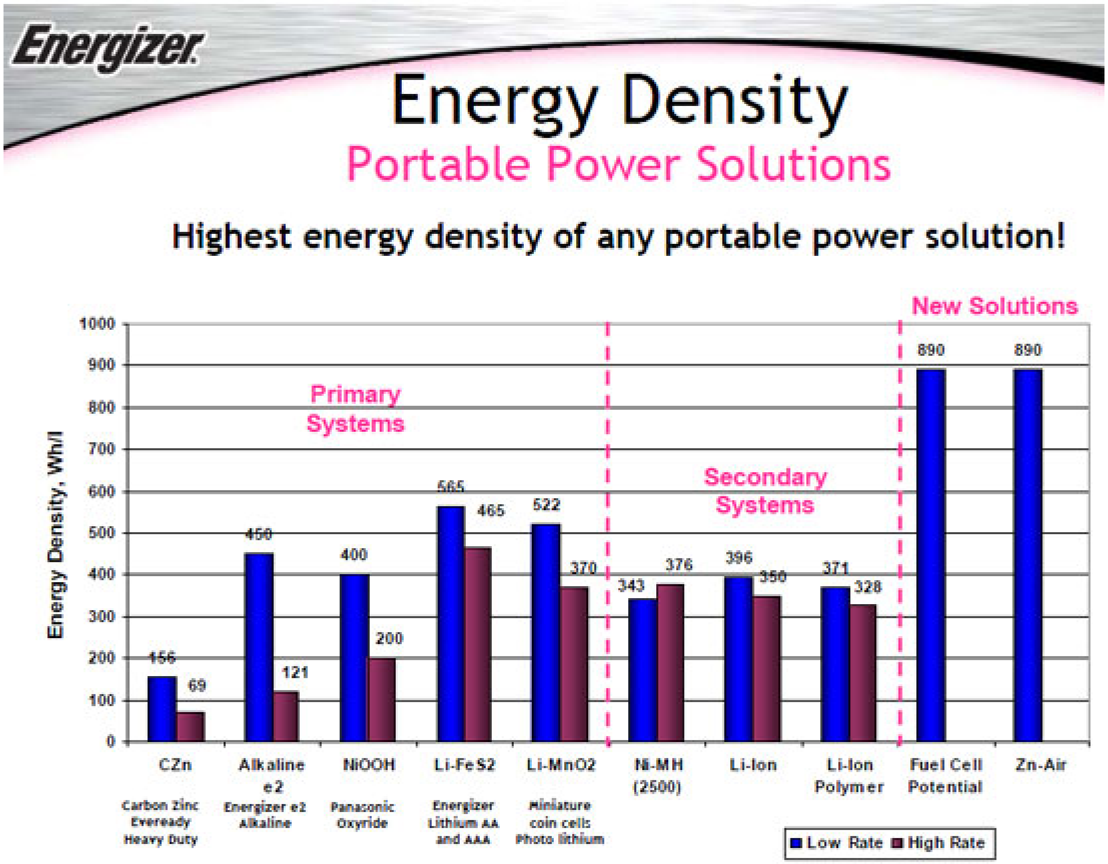
In-flight vibration is encountered when propellers and or motors are not balanced prior to flight. Maneuvers in flight will induce low g forces on the platform and payload. At times the platform may be flown inverted or at steep angles of attack. Most importantly, the vehicles must withstand a crash landing or two.

The popular LiPo batteries are immune to harsh flight environments and can withstand regular crash landing abuse. I have spent as much time crashing my drone into walls and the ground as I have watching it hover and maneuver.

VII. Battery Energy Density

As background consider the energy density of battery technology. How much power per unit weight the battery is capable of providing is shown in the following graph. The issue is to get longer flight times without increasing weight, consider some of the other available technologies.





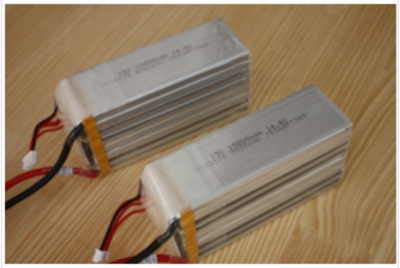
VIII. Drone Battery Basics

The best overview can be had by referencing the “Gear Guide” pages that follow. The article provides an explanation of battery terminology used in the Drone world as well as depicting what is available.

IX. Small Hobbyist Drone

Depicted is my personal hobbyist drone. It runs on one very small battery providing about 5 minutes of flight time. It downlinks video from its onboard camera which is displayed on a screen integral to the hand held controller (not shown). The drone depicted was purchased for $129 which included the controller and battery with battery charger.


MADE IN U.S.A.
600 752036
380mAh 25C Va01



Brand | TOPGUN

Place of Origin | CN

Category |
Electrical Equipment & Supplies > Batteries > Battery Packs

Keyword | unmanned aerial vehicle , drone battery , uav battery , unmanned aircraft

Product Detail Information

TG10000-4S2P/15C
Capacity: 10000mAh
Number of cells in series: 8
Rated voltage: 14.8V
Max charge voltage: 16.8V
Min discharge voltage: 12V
Continuous discharge current: 150 A(15C)
Burst discharge current: 300A(30C)
Pack dimension:69.5*45*138mm (Brick)
Weight: about 865g (Brick)
This battery professional for the UAV

lipo battery 5000mAh

[Basic Infomation]

Place of Origin | CN

Category |
Electrical Equipment & Supplies > Batteries > Battery Packs

Keyword | lipo battery , lithium ion battery , lithium polymer battery , rc aircraft battery

Product Detail Information

TG5000-2S1P/15C

This is the TOPGUN RC helicopter series polymer lithium-ion battery with balance connector. Apply for the receiver.
Capacity: 5000mAh
Number of cells in series: 2
Rated voltage: 7.4V
Max charge voltage: 8.4V
Min discharge voltage: 6.0V
Continuous discharge current: 75A(15C)
Burst discharge current: 150A(30C)
Pack dimension: 18*44*136mm
Weight: about 230g

References

1. THE ECONOMIC IMPACTOF UNMANNED AIRCRAFT SYSTEMS INTEGRATION IN THE UNITED STATES

   March 2013

2. http://www.suasnews.com/2014/06/29851/five-reasons-the-auvsi-got-its-drone-market-forecast-wrong/

http://www.c-span.org/video/?317226-1/hearing-benefits-risks-drones
Recorded