



The Dead Stick Flyer

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Tech Corner – Electric Flight Information

Written by Ron Lazzeri with technical assistance from Steve Snyder

This article is a basic introduction to electrical information tailored to electric flight but applies to airplanes, drones, cars, and boats alike. I am not an electrical engineer and do not pretend to possess a deep knowledge of all electrical theories and equipment. However, I do want to provide some basic information to electric fliers who want to know more about what their electric airplanes are doing and what's required for them to operate successfully.

I will provide several electrical definitions, formulas, and explanations on how to calculate specific electrical performance ratings that will help you understand what makes your electric airplane tick and what to consider if you want to put together your own electric airplane from scratch.

Most of us buy electric planes and proceed to follow the manufacturer's instructions and suggestions regarding how to program the transmitter with the plane's receiver and what batteries to use for successful operation. For the most part it works great and we don't ask any more questions about the electrical gear installed in the airplane. It just works great and we fly!

Maybe you are more curious and want to know additional information about what makes your electric airplane run smoothly or maybe you currently own or have bought a plane that you want to put some electric gear in it. Or maybe your plane is currently powered by a

gas or glow engine and you want to convert it to electric flight. In a lot of instances there are no instructions lying around that can help you size up the electrical gear needed for your project. This article may help you determine what equipment is needed and why. Read on if this pertains to you and maybe you'll know what to look for when putting your new plane together.

Topics covered in this article include basic electrical definitions, formulas, and equivalencies for calculating amps, volts, watts, watt-hours, amp-hours, battery amperage capacity, electric motor peak amperage draw, electric motor KVs, and electric motor peak watts. Other topics include considerations for sizing up an electric motor, ESC, and battery combination, what the electric motor designations mean, and information regarding why there's a need for electric RC flyers to own and use a Watt Meter.

Electrical Definitions:

It is good to start with some electrical definitions and equivalencies to provide a point of reference and a better understanding of the electrical terms.

AMP: *An Amp (Ampere) is the measurement of electric current flow in a circuit. It is the current drawn by devices, like an electric motor, dictated by the power (Watts) consumed by it.*

VOLT: *A Volt is a unit used to measure the electrical force of an electrical current.*

WATT: *A Watt is a unit of measurement of electrical power. WATTS refers to the power of an electrical device like a motor.*

WATT-HOUR: *A Watt-Hour (Wh.) is a measure of electrical energy equivalent to a power consumption of one Watt for one hour (Time Factor). A Watt-Hour is the cumulative measurement of how much power a device, like an electric motor, consumes in one hour.*

AMP-HOUR: *An Amp-Hour (Ah.) is a measurement of current flow for one hour.*

KV: *A motor's KV is the rpm per volt at which the motor will turn without a propeller attached.*

K = a motor's rpm per volt V = the voltage supplied to the motor

Note: *The manufacturer's stated KV (rpm) rating is stated at one volt without a prop. To get the motor's working KV based on the voltage supplied to the motor at full power, you would calculate the rated KV x supplied battery voltage = total motor KV. In actual use, the motor's true KV performance is affected by the prop's pitch and diameter.*

BATTERY MAH CAPACITY:

The MAH (Milliamp Hour) capacity of a battery refers to the stored usable electric capacity for a specific sized battery for one hour. A battery with a capacity rating of 1800mah can deliver a current of 1800ma (1.8 amps) for 1 hour.

BATTERY C RATINGS:

A battery's C rating is a measure of the rate at which a battery can be discharged relative to its maximum stored amperage capacity. A 1C rated battery means the battery's nominal MAH capacity will be fully discharged to its absolute minimum voltage in 1 hour. Additionally, discharging a battery at 0.5C (half the battery's rated discharge potential) will discharge the battery in 2 hours and conversely discharging at 2C will discharge the battery in 30 minutes.

Electrical Formulas and Equivalencies:

Here are some basic electrical formulas needed to calculate and analyze power, performance, and electrical capacity in electric model flight. You will find that in order to calculate certain formulas you will have to calculate other formulas to arrive at its value.

For purposes of calculating the volts in RC electric power system formulas, you can safely use 3.6 volts per LIPO battery cell on-load. For example, a 3S LIPO battery's on-load voltage would be calculated as 3.6 volts x 3 cells = 10.8 volts. Reason is 3.6 volts is the approximate sustained operating voltage per cell under normal load.

Formula for Calculating AMPS: $AMPS = WATTS \div VOLTS$

Formula for Calculating WATTS: $WATTS = AMPS \times VOLTS$

Formula for Calculating VOLTS: $VOLTS = WATTS \div AMPS$

Formula for Calculating WATT-HOURS (Wh.): $WATT-HOURS (Wh.) = WATTS \times TIME (*)$

Formula for Calculating AMP-HOURS (Ah.): $AMP-HOURS (Ah.) = AMPS \times TIME (*)$

Horsepower to Watts Equivalency:

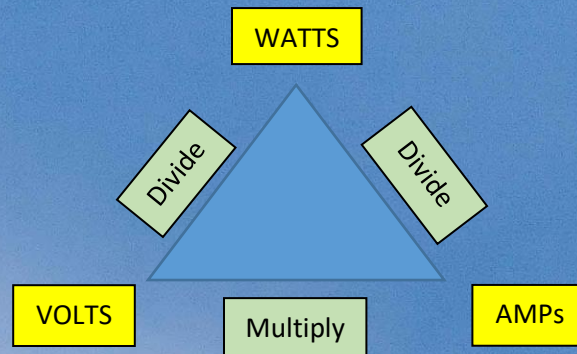
One horsepower is approximately equivalent to 750 Watts

Example: a 2.45 HP (40.0cc) glow/gas motor would be equivalent to 1,837 Watts

$2.45 \text{ HP} \times 750 \text{ Watts} = 1,837 \text{ Watts}$

(*) In calculating Wh. and Ah. the time factor is based on units of an hour.

Electrical Power Triad Formula:



Calculating Continuous Battery Max Amperage Draw:

Formula: Battery amperage = battery MAH x C-Rating ÷ 1000

Example: 2200 Mah LIPO, 3S, 11.1v, 35C (continuous) - 45C (burst)

Calculation: Continuous battery peak amperage = 2200mah x 35c ÷ 1000 = 77 amps

Calculating Electric Motor Amperage Draw:

Formula: Motor peak amperage draw = motor watts ÷ battery voltage

Specs: Electric motor = 450KV, 1,800 watts and LIPO battery = 18.5v (5S) to 22.2v (6S)

Calculation: Electric motor's peak amperage draw at different cell counts/voltages:

5S battery = 1800W ÷ 18.5v = 97 amps draw

6S battery = 1800W ÷ 22.2v = 81 amps draw

Note in the example above, the motor draws less amps proportionately with a higher voltage battery, the propeller's diameter and pitch must be tested and adjusted accordingly in order to maintain the motor's constant peak power of 1800Watts. The higher voltage will make the motor try to spin faster but if the propeller is not properly matched for the correct peak Watts, it may over-heat and burn up. Before putting a higher voltage battery in your plane, it is best to check with the manufacturer to verify that the motor and ESC can handle the higher voltage. Note: While you can use a lower voltage battery than 5S with this motor you will not get the performance needed to fly the plane correctly.

Calculating Electric Motor's Peak KV (RPMs):

What is KV? A motor's KV is the rpm per volt at which the motor will turn without a propeller attached. You would need to calculate the rated KV x supplied battery voltage = total motor KV. In actual use, the motor's true KV performance is affected by the prop's pitch and diameter.

Formula: $K = \text{a motor's rpm per volt}$ $V = \text{the voltage supplied to the motor}$
 $\text{Motor's stated KV} \times \text{battery voltage} = \text{peak motor KVs}$

Calculations: Peak KV with an 18.5v-5S battery = 450KV x 18.5v = 8,325 KV or RPMs

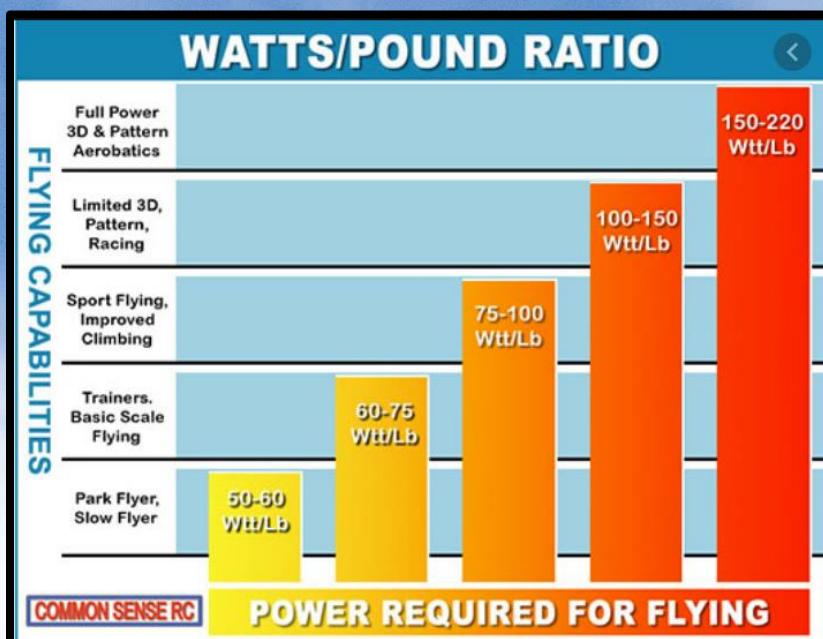
Peak KV with a 22.2v-6S battery = 450KV x 22.2v = 9,990 KV or RPMs

Note: In this example, the motor's peak KV is higher with the 22.2v battery which could translate to more RPMs and speed depending on the prop's pitch and diameter. It is important to verify with the manufacturer that your chosen ESC and motor can handle the higher voltage.

Calculating Electric Motor Total Watts Power:

What is Total Watts Power? A motor's Total Watts Power is an indication of how much pulling power the motor will have in relation to the size, weight and flying characteristics of your plane. Consider this to be a similar comparison to that being made with a glow or gas engine for your plane with the only difference being that this is an electric motor.

Total Watts Power is calculated based on the plane's desired overall performance you want to achieve. The following list of estimated sizing factors are provided as a general guide for this calculation:



Formulas:

- **You know plane's weight but want to find motor's watts needed:**
Motor watts needed = plane's weight x desired flying watts/pound
For Sport Flying you want 75-100 watts/pound and know the plane weighs 15Lbs.
Calculation: 15 lbs. x 100 watts/pound = 1500 watt motor is needed
- **You know motor's watts but want to know plane's possible weight:**
Possible plane weight = motor watts ÷ desired flying watts/pound
For Sport Flying you want 75-100 watts/pound and know motor = 1800 watts
Calculation: 1800 watts ÷ 100 watts/pound = 18Lb weight possible plane weight

Electric Motor Designations/Markings:

What do the markings on an electric motor mean? On this motor here's what the designations mean:

A2212/6T 2200KV

- **22** refers to the radius size of the motor can
- **12** refers to the height of the motor can
- **6T** refers to the number of rotor wire turns on each pole
- **2200KV** refers the motor's stated RPMs at 1 volt



Notes:

- **Not all motors provide this exact same information so you will have to do some research**
- **The radius/height of the motor provides cowl and firewall installation dimensions.**
- **The number of wire turns indicates information about the performance characteristics of the motor. In most cases the number of wire turns can tell you the following: a low number of turns indicates a higher RPM with a less torque motor and a high number of turns indicates a lower RPM with a higher torque motor.**
 - **There is a balance between the motor's number of turns, RPMs, and torque. It is important to look at the manufacturer's specs to see exactly which motor will satisfy your flight performance needs.**
- **There are brushless versus brushed motors and out-runner versus in-runner motors. Make sure that whichever type of motor you choose you get the appropriate ESC for that motor type.**
 - **With a brushed motor, the windings are fixed onto the central shaft inside the motor case and spin with the shaft when current is applied. Power is supplied to the motor windings by two brushes (positive and negative) that push against the commutator on the central shaft.**
 - **A brushless motor doesn't require a physical commutator. The advantages of a brushless RC motor are low maintenance, no brushes to wear out, higher efficiency and higher speeds**

- Below are charts to show the general application of brushless In-Runner vs Out-Runner motors:

Application	Motor Choice
3D Airplane	Out-Runner
Trainer Airplane	Out-Runner
Pylon Racer Airplane	In-Runner
Electric Ducted Fan Jet	In-Runner
RC Car, Stadium Truck, Monster Truck	In-Runner
RC Fast Electric Boat	In-Runner
RC Scale Electric Boat	Out-Runner
Drones, Quadcopters, Helicopters	Out-Runner

Summary of Motor Differences	Brushless In-Runner	Brushless Out-Runner
Can Diameter	Smaller	Larger
Can Length	Smaller	Larger
KV/RPM per volt	Higher	Lower
Torque	Lower	Higher
Efficiency	Best	Least
Heat Dissipation	Best	Least
Watts	Various	Various

The Electronic Speed Controller (ESC):

The Brushless ESC's function is to do the following:

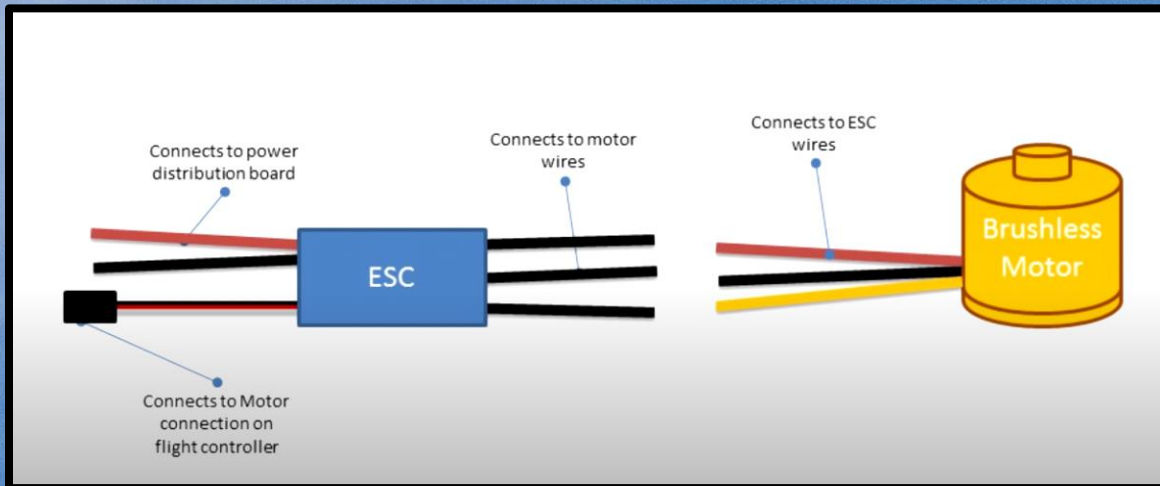
- Control the motor's throttle, RPMs per voltage, from 0-100%
- Convert LIPO battery DC input voltage to 3 Phase AC output voltage to the motor
- Handle the amperage draw of the motor from the LIPO battery
- Provides a Battery Eliminator Circuit connection for the RC receiver
- Connects to the LIPO battery's 2 wire DC connection
- Connects to the brushless motor's 3 wire AC connection
- Controls the timing phase of the motor
- There are many other advanced features that can be programmed in the ESC and there are several ways that the programming can be achieved.

Calibrating the ESC and the Throttle:

A basic programming function of the ESC is to be calibrated with your transmitter's throttle so there are no dead spots at low throttle and maximum power can be achieved from 0-100%. Please check the ESCs manufacturer's exact calibration procedure for your chosen ESC.

Calibration Process: (Safety tip: Have someone hold the plane securely for this procedure or remove the prop)

Example Calibration Procedure: Turn-on the transmitter only; set the throttle to 100%; plug-in the battery on the plane; listen for the initialization beeps; after the beeps stop; reduce the throttle to zero (0); the throttle should now be calibrated; test the throttle at all settings to make sure that it works correctly.



Testing the Electrical System with a Watt Meter:

There is a definite need for owning and testing your airplane's electrical configuration with a WATT Meter. If you're an electric RC flyer who wants to know that your airplane's electrical gear is operating as it should this is the tool for you. For the Ready-to-Fly electric planes, the manufacturer has figured everything out and all you have to do is buy the appropriate battery, put it in the plane, and go fly. Most RC electric flyers fall into this category and everything works out just fine and you should be successful. However, if you want to build or modify an electric airplane and select each component (motor, ESC, and battery) separately, you will want to know that everything is right sized and that it won't blow up or catch fire. Correctly using a Watt Meter will provide the following information and will help confirm that you have done a good job right sizing the battery and ESC with the motor.

Peak Amps: Connecting a Watt Meter to your airplane and doing a full power run up of the electric motor will tell you the peak amperage drawn on the system (ESC and battery) by the motor. This will tell you if the peak amperage draw of the motor equals, exceeds, or falls below the amperage capacity of the ESC and battery. If the motor's peak amperage draw does not exceed the amperage capacity of the ESC and/or battery, then you have chosen well. If the motor's amperage draw exceeds the amperage capacity of the ESC and/or battery, you will need to get a larger amperage capacity ESC or battery, which ever needs to be increased.

It is worth noting that the amperage draw on the system is greatly affected by the propeller's pitch and diameter. When changing and testing different prop combinations, the diameter of the prop has a bigger effect on the system's amperage draw than the pitch of the prop.

Peak Watts: A full power run up of the motor will tell you two things about watts:

- **First,** obtaining the motor's peak watts will help you verify, whether or not, the motor is performing close to the manufacturer's rated watts. Your goal is to get the motor to perform at the manufacturer's rated watts with the appropriate propeller pitch and diameter combination within a margin of 10% +/- . Think of this as using a tachometer on a gas or glow airplane to check its peak RPMs.
 - **If the motor's peak watts exceed the manufacturer's rated watts,** then the propeller's pitch and diameter must be adjusted in order to get as close to or within 10% of the rated watts. If this is not done correctly, the motor could overheat and burn up.
- **Secondly,** after getting the motor operating at the correct rated watts, you will be able to determine if the motor is generating the appropriate amount of watts (RPMs) needed to achieve the Watts/Pound flying performance you want for your airplane.

Minimum Voltage: A full power run up will tell you if the battery's voltage has dropped ahead of its expected normal discharge capabilities. Most ESCs have a minimum cut-off voltage that is set at approximately 9-10 volts. A quick run up won't tell you much about the low voltage cut-off if the battery is fully charged, but it will tell you if the battery can handle the short full power draw.

Other Information: The Watt Meter will also provide battery voltage, amp-hours, and watt-hours.

Watt Meters: This is an example of the G. T. Power Watt Meter (sold by Motion RC). There are other brands on the market but this model stores and provides peak readouts instead of having to read them in real time.



Right Sizing the Electric Gear for Your Plane:

If you're putting together a new electric airplane or if you just want to determine if your current airplane's set up is adequately sized for its best performance, here are some basic principles to follow. It is best to set up an electric airplane so that all of the electrical components support each other from the electric motor and the prop, to the ESC, and finally the LIPO battery.

Sizing the Electric Motor: The first step in the process is to appropriately size and acquire an electric motor (or test an existing motor) that produces the amount of watts needed to fly your airplane the way you want. For example, let's say in the selection process you chose an 1800 Watt, 450 KV, 5S-6S electric motor which meets the Watts/Pound calculation you want for your airplane.

Calculating the Electric Motor's Amperage Draw: The next step would be to calculate the amperage draw of the electric motor with the battery capacity you intend to use. This will provide the amperage draw and voltage of the electric motor you chose and will help in selecting the appropriately sized ESC. Be sure to select an ESC that can handle the motor's voltage and amperage draw with a 20% or higher amperage buffer. You should calculate the motor's amperage draw with the manufacturer's suggested battery combinations and then decide which one you will use in the plane as follows:

- ***Motor's amperage draw using a 5S-30C, 18.5 volt LIPO battery:***
 - ***1800 Watt motor ÷ 18.5 volt-5S battery = 97 Amp Draw x 1.2 = 116 Amps (+20%)***
- ***Motor's amperage draw using a 6S-40C, 22.2 volt LIPO battery:***
 - ***1800Watt motor ÷ 22.2 volt-6S battery = 81 Amp Draw x 1.2 = 97 Amps (+20%)***

Sizing the ESC and Battery: The next step should be finding an ESC that can support the voltage and amperage draw of the motor with an additional 20% or higher amperage buffer and select an appropriate LIPO battery with the correct number of cells to produce the desired voltage. You can size the ESC higher than the 20% amperage draw buffer but it would not be advisable to size it lower than 20% unless the manufacturer states it can be done. In this case, a good choice would be a 120 amp ESC, or the closest rated one.

- ***You can check the battery amperage capacity as follows (ref: formulas):***
 - ***5000 mah-5S LIPO x 30C ÷ 1000 = 150 amps***
 - ***5000 mah-6S LIPO x 40C ÷ 1000 = 200 Amps***

Note In this example, either battery would work well because the amperage capacity of both batteries exceeds the amperage draw of the motor. You will then have to decide if you want to invest in the 6S-40C battery or the 5S-30C battery to achieve the performance you want for the plane. Be sure the ESC of choice can handle the desired voltage.

- Most ESC's come with a Battery Eliminator Circuit (BEC) circuit and power lead for the plane's receiver. You will need to verify if the BEC connection can support the receiver's voltage requirements. The benefit of a BEC connection is that it can eliminate the need for a dedicated battery and switch which helps to make the plane lighter.

Using the Watt Meter to "Test" the Electrical Gear's Performance: The final step in the process of right sizing the electrical gear for your airplane would be to test and evaluate the performance of the gear with a Watt Meter. Most importantly, the Watt Meter will provide peak watts and peak amps that you can use to verify if the gear meets the criteria for optimal performance:

- First, refer to the section on using a Watt Meter to understand what information the Watt Meter provides and how to interpret it. Be sure to use a fully charged battery for the Watt Meter test.
- Second, connect the Watt Meter to your airplane, between the battery and the ESC, and perform a full power run up for about 20 seconds so the Watt Meter can record the peak watts and peak amps, reduce the throttle to zero, and disconnect the meter from the airplane. Please make sure you hold the airplane firmly or have someone hold it for you. Safety should always be your top priority.
 - Note: Depending on which brand Watt Meter you have, it may only provide real time data while the motor is running. Newer meters will provide and retain peak data as long as the LIPO battery stays connected to the source side of the meter or if you are using an auxiliary battery input.
- Third: evaluate the peak watts data to determine if the motor is running at the manufacturer's stated watts with the installed configuration, including the propeller. Your goal is to configure the system so that the motor performs approximately within 10% +/- of the manufacturer's stated Watts, which in this example is 1800 watts.
 - If the peak watts exceed the manufacturer's rated Watts by more than 10%, then you should change-out the propeller's pitch and diameter to get the watts as close to or within 10% of 1800 watts. This is important because the motor may overheat and eventually burn up.
 - Additionally, if the motor's peak watts is more than 10% below the manufacturer's stated watts, the motor may not perform as well as expected.

- ***Fourth:*** evaluate the peak amps data to verify that the overall amperage draw of the motor is not exceeding the amperage capacity of the ESC with the 20% or higher amperage buffer and the battery. If the amperage draw looks good you are ready to fly the airplane. If not, you will have to replace either the ESC or the battery with a higher amperage capacity to ensure proper performance and longevity of the gear. If your previous sizing calculations were correct this should work out just fine and you should be on your way.
- ***Lastly:*** evaluate if the propeller's diameter and/or pitch needs to be changed in order to better match the amperage and watts performance of the installed motor and battery combination. This process may involve some trial & error and re-testing with multiple prop combinations to achieve better Watt Meter performance results.

In summary: It is a suggestion that all electric flyers own and use a Watt Meter to test and evaluate the operation of their electric airplanes for optimal performance and long-lasting durability of their equipment. Just a thought!

Reference Websites:

- ***DAG214:*** Videos produced and shared by Damon G. Atwood. Damon is an expert electric modeler and can provide some real insight into the world of RC electric aviation. Site provided by Steve Snyder.
<https://www.youtube.com/user/dag214/about>
- ***Gibbs Guides:*** This is an excellent site for RC electric information. The author, RC and full scale pilot is from the United Kingdom. He covers just about all RC electric topics in his guides.
<http://www.gibbsguides.com/>
- ***Motion RC:*** This is a very good RC website. The Watt Meter in this article was purchased for Motion RC.
<https://www.motionrc.com/>
- ***RC Explained:*** This site explains electric RC configurations in a very easy understandable way.
https://www.youtube.com/channel/UCrKM0T_jQkCApz0nSH8lynw