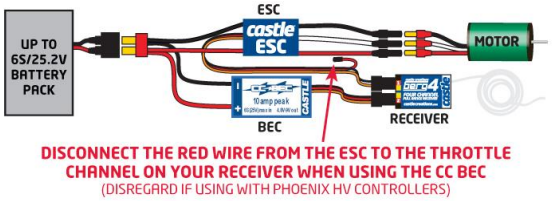
Sizing an Electric Power System

A Guide for Modelers Not Familiar with Electric Systems

1. **The four main components of electric power system**
   A. Brushless electric motor
   B. Electronic speed control (ESC)
   C. Lipoly Battery
   D. Propeller

2. **Brushless electric motors – there are two basic types of brushless electric motors:**
   A. Inrunners – very few if any of the electric motors used by our club members are inrunners.
      a. Are constructed with the magnets attached directly to the shaft, which is surrounded by the fixed copper windings. Because the magnets are so close to the shaft it spins very quickly. This means high rpm but low torque.[1]
      b. High rpm and low torque translates into small diameter propellers.
   B. Outrunners – almost all of the electric motors used by our club members are outrunners.
      a. Are constructed with the fixed copper windings on the inside. The shaft is attached to the "bell", or casting that contains the magnets that spin around the fixed copper windings. Because of the extra weight of the bell and magnets that are further from the shaft it acts like a flywheel.[2] This means lower rpm and higher torque.
      b. Lower rpm and higher torque translates into larger diameter propellers.

3. **Electronic speed controls (ESC's) –**The ESC receives throttle signals through the receiver and controls the speed (in rpm) of the motor. An ESC's function in an electric power system is similar to that of the servo and throttle in a glow power system.
   A. Sizing an ESC: allow 10-20% greater amperage than the maximum amperage the motor requires. ESCs are also, rated for their maximum voltage. Make sure the ESC can handle the voltage of the battery.
   B. Most ESC's that we use have a BEC feature which stands for battery eliminator circuit.
      a. The BEC provides power through the ESC to the receiver and servos from the motor battery thereby eliminating a separate receiver battery as in glow powered airplane.
      b. BECs are limited on the number of servos they can handle at a given input voltage. This can become a serious weakness especially with larger airplanes. The BEC on a 60a ESC produces 3a to power up to 4 standard size servos. A .40 size airplane will use a 60a ESC and may have from 4 to 7 servos, the 5th servo could be electric retractable landing gear and the 6th and 7th servos could be for flaps. In this case you can use a 4.8v battery to power the receiver and servos or you can use an UBEC.
      c. A standalone BEC is referred to as a UBEC and they produce 5a to 10a of power to the receiver and servos. Like an ESC, a UBEC is powered by the motor battery and it plugs into the receiver to deliver the power to the receiver and servos. **Important note:** If you use a UBEC plugged into the battery port of the receiver and if your ESC has a BEC and is plugged into the throttle port of the receiver, **there are two power supplies to the receiver and servos. This is not good!** To remedy that disconnect the power (red) wire from the ESC throttle connector as indicated below.



C. ESC programming – most ESCs are programmable through the transmitter, which is difficult at best and impossible at worst (in my opinion). There are now several "Programming Cards" available that are a great improvement but most are only compatible with one line of ESCs. We have used the HobbyKing.com Turnigy Plush ESCs[3] and their compatible programming card for years. More recently we have found that HeadsUphobby.com[4] sells a programming card for their HURC[5] line of ESCs and they are compatible with the Turnigy Plush line of ESCs[6]. Both of these cards are compatible with both of these ESCs.
The following programming discussion will be based on the Turnigy Plush[7] and the HURC[8] lines of ESCs and programming cards. These ESCs have seven programmable features. Each feature has a default position that it comes with. Below are three features that you should or may want to change.

Turnigy Plush Programming Card

a. *Low voltage cutoff* – this is a safety feature that monitors the voltage of the battery while motor running. If the voltage goes below the *low voltage cutoff* value set in the ESC, the power to the motor is cutoff but leaves power on to the radio (receiver) to land under control, **quickly**! The **default** value of the *low voltage cutoff* is in the *medium* position with a value of about 2.8v per cell, as you will see in the next section the recommended minimum voltage per cell is 3.0v. Therefore, always change the *low voltage cutoff* from the **default** *medium* position to the *high* position. This change will extend your battery's life. Better yet, time your flights and land before the battery voltage is rundown to the point that the safety cutoff is activated.

b. *Timing* – The brushless ESC synchronizes the circulating magnetic field to make the motor rotate.[16] It does that with electronics and programming.[17] The **default** position of the *timing* is *low*. Some motor/ESC combinations will make a squealing sound when the throttle is advanced. Changing the *timing* from *low* to *medium* or *medium* to *high* will usually stop the squealing. Also changing the *timing* to *medium* or *high* will usually increase the overall power of the motor; however, be aware that doing so does increase the temperature at which the motor operates. I have been setting the *timing* on my ESCs to *medium* with good results.

c. *Brake* – a feature of the ESC when set *on,* stops the propeller from windmilling when power is removed from the motor. The default setting is *off*, which allows the propeller to windmill when power is removed from the motor. If gliding performance is important, *brake on* is a necessity. If a folding propeller is being used, turn *on* the *brake*. Also, any propeller will give better glide performance stopped rather than windmilling.

4. Lipoly batteries – always use your lipo packs safely.

A. Lipoly batteries consists of a number of cells. Generally, we use between 2 and 6 cell batteries. Each cell can produce a minimum 3.0v when run down to 4.2v when fully charged. Batteries are classified by nominal voltage of 3.7v per cell.

# Cells	Minimum Volts	Nominal Volts	Maximum Volts
1	**3.0**	**3.7**	**4.2**
2	6.0	7.4	8.4
3	9.0	11.1	12.6
4	12.0	14.8	16.8
5	16.0	18.5	21.0
6	18.0	20.1	25.2

B. Battery capacity is measured in Milliamp Hours (mAh). mAh is commonly used to describe the total amount of energy a battery can store at one time. Divide mAh by 1000 to convert to amp Hours (Ah). ex. 2200mAh = 2.2Ah. Lipo battery capacity is specified by either mAh or Ah therefore you may see a 2200mAh as 2.2Ah or a 4000mAh as 4.0Ah. A fully charged 4000mAh battery discharged at 4.0a would take 1 hour to lower the voltage to the minimum 3.0v per cell.

C. The "C" rating is a guide to how much current (amps) can be discharged from a battery.[10] The "C" rating is also used as a guide to how much current (amps) can be used when charging a battery. The value of one "C" = value of 1Ah. ex. 1C for a 2000mah battery = 2.0a.
   a. Charging example – to charge a 2200mAh battery at 1C is to charge at 2.2a
   b. Discharging example – a 20C 2000mAh can be discharged at a rate that (20 x 2.0) = 40a.

5. Propellers – converts rotary motion into thrust to propel aircraft.

A. Propeller size is expressed as *length* x *pitch* ex. 11x7
   a. The length (diameter in inches) is 11" in the example.
   b. The pitch (the distance in inches that a propeller would advance in 1 rotation if it was 100% efficient) is 7" in the example.

B. Two kinds of propellers.
   a. Tractor (puller) propellers are positioned ahead of the motor and pull the airplane.
   b. Pusher propellers are positioned behind the motor and push the airplane.
   c. Electric motors rotate in either direction by switching two wires. If you have an airplane that requires to be pushed, you can use a pusher propeller or you can just reverse the direction of rotation and still use a tractor propeller.
   d. Regardless of whether you are using a tractor or pusher propeller the face (where the printing is) of the propeller must always face forward "into the wind".

C. KV – the rpm an electric motor will spin per volt under no load conditions.[11]
   a. At a given voltage a high kv number means high rpm and therefore a small propeller.
   b. At a given voltage a low kv number means low rpm and therefore a large propeller.

D. Determine required diameter and pitch.
   a. Many suppliers specify recommended propeller size for their motors. Two examples follow.
      - HobbyKing.com [12] usually specifies the required range of batteries and propeller sizes. See specs below, note: the 2 cell (7.4v) prop is 11x7 & the 4 cell (14.8v) prop is 7x3.

Turnigy D2836/8 1100KV Brushless Outrunner Motor

Specifications:	Internal resistance: 0.107 ohm
Battery: 2~4 Cell /7.4~14.8V	Weight: 70g (including connectors)
RPM: 1100kv	Diameter of shaft: 4mm
Max current: 20A	Dimensions: 28x36m
No load current: 1A	**Prop size: 7.4V/11x7 14.8V/7x3**
Max power: 336W	Max thrust: 1130g

      - HeadsUphobby.com[9] actually show propeller test results below:

Propeller test data when using a 2 & 3 cell lipo batteries - Power Up 450 Sport Motor:

Battery Size	Propeller Size	Thrust (oz.)	Amps	Notes
3-Cell 11.1v	APC 10 x 5E	38 oz.	22 amps	
3-Cell 11.1v	GWS 1060	37 oz.	19 amps	Best for maximum performance
3-Cell 11.1v	GWS 9050	32 oz.	15 amps	
3-Cell 11.1v	GWS 9050x3	34 oz.	17 amps	Nice for scale looks
3-Cell 11.1v	APC 9 x 6E	33 oz.	18 amps	
3-Cell 11.1v	GWS 8040	22 oz.	9 amps	
3-Cell 11.1v	APC 8 x 4E	23 oz.	12 amps	
3-Cell 11.1v	APC 8 x 6E	24 oz.	17 amps	
3-Cell 11.1v	GWS 8060HD	23 oz.	15 amps	
2-Cell 7.4v	GWS 1170	27 oz.	15 amps	
2-Cell 7.4v	GWS 1060	21 oz.	11 amps	

E. If you do not have prop information for your motor start using a prop recommended for a motor with similar specs of max amps, volts or number of cells and kv. Test using a watt meter to determine the proper size propeller. It is best to start testing with a slightly smaller propeller and move up in size than to start with a larger propeller and never get a chance to move down to the proper size propeller.

F. We generally use two blade propellers but a three blade propeller works fine with electric motors.

6. What's a Watt?

A. The most important terms used in understanding power system sizing are Amps, Volts and Watts and their relationship.

B. Watts: amps X volts = watts. To use a water analogy, the size of the hole that the water comes out of a faucet is the "amps", the pressure behind the hole is the "volts", and the combination of how much water comes out is "watts".

7. Watts/Pound Ratio Performance Table.

A. The right size motor for the airplane. Refer to the "performance table" below to determine the requite watts.

B. 50-70 watts/lb: small models and park flyers.

C. 70-100 watts/lb: Trainer and slow flying aerobatic models

D. 100-125 watts/lb: Trainer and Sport aerobatics.

E. 125-150 watts/lb: Advanced aerobatic and fast flying scale models.

F. 150-175 watts/lb: Lightly loaded3D models and ducted fans.

G. 175-200+ watts/lb: Unlimited performance 3D models.

8. Choose the right combination of equipment for your electrical application. The airplane used will be a Horizon Hobby T-28 with a wingspan of 44" and of foam construction.

A. Determine your airplane's "ready to fly weight" either from the manufacturer's specifications or weigh it allowing for uninstalled equipment.
Horizon Hobby[13] lists Flying weight as 32 oz or 2 lbs.

B. Refer to the "performance table" above and determine which performance category you want for your airplane.
125 to 150 watts/lb Advanced aerobatic and fast flying scale models.[14]

C. Using the performance category you chose and the flying weight of the plane to determine the watts required for the motor.
*125 x 2 = **250** watts or 150 x 2 = **300** watts*

D. Select the motor – Heads Up Hobby [14] - Power Up 450 Sport Outrunner motor.
Power Up 450 Sport Specifications
Weight = 2.5 ounces
Diameter = 1.1 inch
Length = 1.35 inch
Shaft = 4mm x 0.5 inch
Voltage = 7.2 – 13.0
Current = maximum of 22 amps for 30 seconds
KV = 1100
Calculated watts: 22a x 12v = **264w**

E. Select the Electronic Speed Control (ESC) - HURC 30 amp ESC from Heads UP Hobby.
The HURC 30 amp Electronic Speed Control works with most brushless motors, and comes pre-set for use with 2, 3 and 4 cell Lipo batteries. The built-in 5 volt, 2 amp Battery Elimination Circuit (BEC) will power 3 to 4 sub-micro servos when using a 3 cell Lipo battery.
The HURC ESC is compatible with the Turnigy Programming Card.

F. Select the Battery – Glacier 30C 2200mAh, 3S 11.1V from BuddyRC.com[15]
2200mAh, 30C, 11.1V, 3 cells – 30C x 2.2a = 66a exactly 3 times the max 22a of the motor.
105 x 24 x 33 mm
185g (6.5 oz)
JST-XH balance connector
T Plug (Deans compatible)
This batteries capacity is 2.2Ah. 2.2a draw will drain the battery 1 hour. That means you could draw 22a and drain the battery in 1/10 hour or 6 minute flight. More realistically, you could fly for 12 minute flights if you wisely used the throttle for an average of 11a.

G. Select the Propeller – APC 10 x 5E based on the Propeller Test Data on page 4 1st entry.
The Propeller Test Data Chart shows this propeller, the selected motor, ESC and battery will produce 38 oz of thrust while drawing 22 amps (the maximum for the motor). The 32 oz T-28 will have very good performance with this electric power system.

Footnotes:

Wattflyer.com Chris F.	1, 2, 10, 11, 12
Wattflyer.com – flydiver	16, 17
HobbyKing.com – Turnigy Plush esc	3, 5, 7
HeadsUPhobby.com – HURC	4, 6, 8, 9, 13, 14
BuddyRC.com – Glacier Battery	15