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Selecting Electrical Power Systems
By Bob Aberle

MA Technical Editor Bob Aberle with sport/aerobatic Acrovolt constructed in 1995. As designed by Tom Hunt, it would have been comfortable with 60-size glow engine but was powered by DeWALT 18-volt cordless-drill motor with belt drive. Text tells how it was greatly improved with new brushless motor and Li-Poly batteries.

FOREWORD: At the 2004 Weak Signals expo in Toledo, Ohio, former AMA District II vice president and current AMA Flying Site Coordinator for the Eastern Region Joe Beshar, who is an experienced electric-power enthusiast, made a suggestion. He mentioned to AMA Director of Publications Rob Kurek that we badly need a standard reference document that will allow any modeler to size the proper electric-motor system to model aircraft of any size and weight. What you are about to read resulted from Joe's suggestion.

Background: When a person enters model aviation, he or she has a choice of power sources for his or her aircraft. Years ago those options included rubber power, hand launching (as with a glider), towing a glider with a cord or a fueled engine, and gasoline/spark-ignition engines or later glow-fueled engines.

As time went on and the glow engine became the most popular source of model-aircraft power, modelers quickly became adept at selecting the right-size engine for every size and weight of model. An engine's cu. in. displacement was related to model weight and model size (usually wing area expressed in square inches).

Engine classes became known as 1⁄2A, A, B, C, and even D. Each category covered a range of engine displacements (such as—if my memory serves me correctly—0.09-.199 cu. in. was considered Class A). Early FF competition rules related engine displacement to weight, so that a .19 cu. in.-engine-powered model had to weight 19 ounces, etc.

When RC started to come of age in the 1950s, we learned (by experience) that 1⁄2A RC models could weigh as much as 18-20 ounces, Class A RC models could weigh as much as 30 ounces, and so on. Although these engines are rated in horsepower (and thrust), to this day most modelers simply relate engine displacement to model weight and size!

Hobbico SuperStar EP is intended for glow power. Bob explains in the text how to convert it to electric power.

Bonnie 20 electric-powered ARF is featured in Sport Aviator review. It could have been powered by .20-.32 glow engine. It also makes a wonderful electric-powered advanced RC trainer.

Enter Electric Power: Although some of the first electric-powered flights were made in the late 1950s and early 1960s, electric power as we know it today didn't really come into its own until the early 1970s. Then it became obvious that engine displacement, for identification purposes, would not work with electric. To make an early distinction between fuel and electric, it was decided to refer to fueled power as "engines" and electric power as "motors."

Bob Boucher—one of the leaders of electric-powered flight in the USA—began referring to his motors by equivalent glow-engine displacements. His "05" motor was supposed to be equivalent to an .049 cu. in. glow engine, a "40" motor was equivalent to a .40 cu. in. glow engine, etc.

While this was going on, Germany's Graupner company was assigning names such as Speed 400, Speed 500, and the like. The numbers were rounded off from the Mabuchi manufacturer's model numbers; "RS-380" became a Speed 400, "RS-540" became a Speed 500, and so on. Surely that fact couldn't help you select a motor for a particular size and weight of model.

What to Do? Approximately 30 years have now gone by since that start in electric-powered flight. Although many still have questions, we know much more now and have developed some excellent techniques for "sizing," or matching the correct motor to any size and weight of model aircraft.

When you look back at this time frame, you can compare it with the advent of the gasoline engines in the early 1930s, which ultimately led to the cu. in.-displacement sizing of those engines in the 1940s. Identifying fueled and electric engines/motors has taken time.

The main thrust of this article is to explain how to select, or size, your motors to make them suitable for powering models in flight. I hope to cover such things as motor identification, motor types, direct vs. gear drive, motor power (in watts) as it relates to aircraft weight, and many other details. I hope to make this a standard reference so that no one will have to ask, “What motor should I use?”

You must know aircraft’s exact weight to select motors. Pelouze Model PE-5 scale (L) weighs items as heavy as 5 pounds in 0.1-ounce increments. My Weigh digital scale (R)—from www.goodscale.com/scale—is intended for parking lot and indoor micro RC models.

Aircraft Categories:

1) Use electric-powered kits, ARF models, and published plans. We currently enjoy the fact that many kits, ARFs, and published plans exist for all kinds of electric-powered models. In this category, the aircraft designer or manufacturer has selected the motor for you. You might want to improve on the initial choice, but you can easily get in those first few flights before you fine-tune the selection process.

2) Make a glow-fuel-powered kit electric powered. There may be a particular glow-fueled kit or ARF that you want to build, from inception, as an electric-powered model. You want to be able to select a motor, the type of drive (direct or geared), the type of battery pack, and the battery pack’s capacity, but you want to make these selections so that you can install the electric power-system components as you construct the model.

3) Convert a glow-fuel-powered RC model you already have to electric power. Let’s say you have a built-up and flying glow-fueled airplane, and you decide to remove that engine and retrofit an electric power system. How would you go about making that selection?

4) Update an old electric-powered model that uses old-style technology to use all of the latest equipment. How would you make the specific selections based on the aircraft’s current size and weight? In this case you would be looking at a new brushless motor, a dedicated sensorless ESC, and probably lightweight and high-capacity Li-Poly batteries.

Abstract: My close friend, flying partner, and fellow Model Aviation Hall of Famer Tom Hunt is probably one of the most famous and experienced electric-power fliers in the country. He has been my primary consultant throughout this article’s preparation. He recently made a thought-provoking observation, which follows.

“The main problem in the selection process is that the electric motor has a much broader operating range than an IC [internal combustion] engine. I can have an AXI 2212/34 brushless motor fly a 10-ounce [total weight] aircraft at 60 watts input, a 14-ounce aircraft at 95 watts input [that’s a 50% power increase—try that with a glow engine!], and a 22-ounce model at 120 watts input [that’s a 100% increase].”

As you can see from Tom’s examples, any specific motor will have far more application than a comparable glow engine. Because of this, there are many more choices in the selection process when going to electric power. That is what mystifies most modelers, and I hope this article will help clear things up.

Measuring Motor Input Power (Watts): Motors are not referred to by cu. in. displacement (as glow engines are). Motors are defined by the term “power,” which is measured in watts. All references to power in watts is input to the motor (or output of the battery). The motor’s output power is a function of its efficiency.

As Tom pointed out, a motor can run at 60, 95, or even 120 watts. The primary rule is that power (in watts) equals motor current (in amperes, or amps) multiplied by the voltage.

The voltage is determined by the battery and will vary according to battery type (Ni-Cd, NiMH, or Li-Poly) and the number of cells employed in the particular battery pack. The current is determined by several things, including the resistance of the motor windings, the size of the propeller, and the type of drive (direct, with a gear reduction, or belt-reduction drive).

So you have the variables current (amps) and voltage that yield power (watts). This is where the fun starts since you can vary everything, including the propeller size, the motor drive, and the battery. Each variable will produce different results.

With a fueled engine, you can listen to the sound and adjust the carburetor (by ear) until you reach the correct power level. With a motor, there is essentially no noise and therefore nothing to listen to. So how do you obtain a figure for power (watts)?

It would be nice if the motor manufacturers had printed on the box “100 watts (maximum short duration, 75 watts continuous),” much as engine manufacturers indicate “.049 cu. in., or 1¼2A.” The variables make that type of identification impractical. Most motor manufacturers publish excellent motor data that I will write about later, along with computer programs that support this process.

For now, you must learn that the most important “tool” for the electric-power flight enthusiast is the ammeter and wattmeter. We primarily use the AstroFlight Model 101 Super Whattmeter, which you can purchase for roughly $60. It is the latest version and will measure to 10 mA instead of 100 mA. It can also read below 4.0 volts by adding a four-cell receiver battery pack. Make sure you purchase this new version.

AstroFlight Super Whattmeter is the heart of any motor-selection process. When inserted between battery and motor, it indicates motor current, voltage, power (watts), and amount of energy going into or out of battery (in Ah).

The meter is self-powered by the system you are measuring. It provides four important motor parameters: voltage (volts), current (amps), power (watts), and the capacity going into or out of the battery, measured in ampere-hours (Ah). A list of articles and Web sites at the end of this article will provide the details about the specific use of the Whattmeter.

Some modelers already own digital-type multimeters, sold by stores such as RadioShack. Those meters are fine, but most are somewhat limited in current range.

If you try to check a 25-amp motor with some of these meters, you will probably end up blowing a fuse or even damaging the device. Many of these multimeters are of the newer “auto-ranging” type which can also get complicated during regular use. I suggest that you stick with the AstroFlight meter for its proven ability to easily do the job!

Using Whattmeter to take motor data of electric power equipment in Hobby Lobby Bonnie 20, note battery packs lined up in foreground for test purposes. In front is TNC tachometer for measuring propeller rpm.

Aircraft Weight and Power Loading: Now that you have the motor “identified” by power, how do you relate it to a specific-size model? There are actually two aircraft parameters you need to be interested in, one of which is the model’s total weight. This is generally measured in ounces for the smaller airplanes and pounds for the larger models.

If you are in the planning stages of selecting a motor, you may be estimating an aircraft’s weight as a starting point. If you are dealing with an existing model, you will have to weigh it on a scale. There are many digital-type scales on the market that read to within 0.1 ounce. You can buy one at a stationery store such as Staples, Office Max, and others. After constructing or assembling an ARF, you will also have to weigh it to verify your motor selection or help you improve performance by selecting a different motor.

Knowing the motor’s power and the model’s weight, you can come up with one of the most important “combination parameters,” known as watts/ounce or watts/pound. These “power loading” values are used for judging aircraft performance.

The term watts/ounce is generally used to describe the power loading of models that weigh as much as 1 pound. Watts/pound is a more common term for models that weigh more than 1 pound.

Through the years, experienced electric-power enthusiasts have come up with a series of watts/ounce and watts/pound figures that relate to an airplane’s expected performance. Table 1 and Table 2 provide the accepted parameters that cover most aircraft types. These numbers aren’t absolute; they are only to be used as a guide.

Wing Loading and Skill Level: After determining motor power (watts) and aircraft weight, you must focus on airplane size, which involves wing area and then wing loading (which takes into account wing area and aircraft weight).

The term “power loading” that I described (watts/ounce and watts/pound) involves motor power and model weight; they are aircraft related. The term “wing loading” relates to the pilot’s skill level and directly to the minimum speed the model can fly (stall speed). Aircraft with light wing loadings will be easier to fly (for beginners and sport fliers) than those with high wing loadings (favored by the experienced or expert fliers).

To determine wing loading, you need to know your model’s wing area and weight. Wing area is the wingspan multiplied by the wing’s average width (wing chord) and is expressed in square feet (sq. ft.).

Wing area may be a given with kits, ARFs, and even published plans. The specifications that accompany these usually include the wing area. A pure rectangular-shaped wing is easy to figure out (span multiplied by chord), but an elliptical-shaped wing is much more complicated. You typically do it by estimating the average wing chord (width).

Once you know the wing area expressed in square inches (sq. in.), you must convert that to sq. ft. by dividing it by 144. Let’s say your aircraft has 400 sq. in. of wing area. Divide that by 144, and you get 2.78 sq. ft. The aircraft weighs 40 ounces, so divide that by the 2.78 sq. ft. to obtain the wing loading of 14.4 ounces/sq. ft.

Table 3 provides acceptable wing loadings for various pilot-skill levels. Values start at 5 ounces/sq. ft. and can exceed 35 ounces/sq. ft.

In the past few paragraphs you learned about motor power (watts). Then you learned how power relates to model weight. Last, you learned how model size and weight are related to the pilot's skill level. You must take all of these parameters into consideration when selecting the proper motor for your model.

Thrust: I don't use it because in general it is not a reliable figure. The thrust one measures on the bench has little to do with the thrust the propeller produces as it moves through the air.

Some modelers came up with a factor indicating that your model can weigh as much as three or four times the rated motor thrust. That's fine, if you really know what that thrust is. So I avoid using this parameter!

Selection Process Details: Before I provide some examples of motor selection, I want to introduce you to the subject of motor data. When you set out to make a specific motor selection, you need a large volume of motor-parameter data at your disposal.

That information should contain such things as motor current, voltage, and watts for a range of recommended propellers (identified by diameter and pitch). It should also provide a range of voltages so that you can choose a battery type and capacity to suit the application.

It would be nice to have that kind of data available for every type of motor available on our hobby market or, better still, have in one place. I would love to have it on one Web site, but that hasn't happened yet. Information is available on many Web pages, and I'll steer you to the major ones.

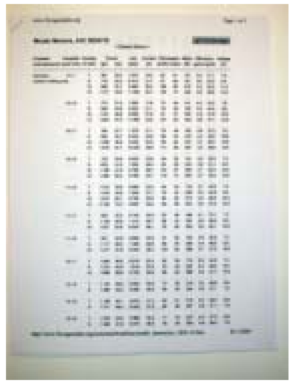
But before I do that, I want to discuss "voltage." Much of the motor data presented on manufacturers' Web sites indicate numbers of battery cells and the type of battery, but it will not state the voltage!

When referring to numbers of cells of Ni-Cd- or NiMH-type batteries, each cell has a nominal 1.2 volts. If the data indicates eight NiMH cells, the nominal voltage will be eight multiplied by 1.2, or 9.6. If there are two Li-Poly cells, the voltage will be two mulitiplied by 3.7 (that is peculiar to Li-Poly batteries), or 7.4.

Some sites are kind enough to indicate the measured voltage under load, which is really what you want, but others will make you use the battery cell count, and that takes extra time. Be aware!

Motor Data Web Sites: The following sites are not in any particular order, and they are not all that are available. They are what I think you will need as a starting point for most of your motor selections.

• www.flyingmodels.org. Webmaster Fredrik Wergeland of Stockholm, Sweden, is responsible for this data. After getting on the site, select "The Great Electric Motor Test," and then you have a choice of standard or brushless motors.



Page from The Great Electric Motor Test—one of many sources for motor data. It provides such parameters as motor current, voltage, power (watts), propeller sizes, and rpm.

There are not many standard motors, but there are quite a few brushless including Mega, Model Motors (AXI 22 and 28 series and Mini AC), Nippy Black, MP Jet, Kontronik, and Jeti Phasor. There is a promise that data will be posted for Speed 280 through Speed 600 ferrite motors in the future.

This Web site has nothing to do with the popular Flying Models magazine.

• www.aircraft-world.com/default.asp?id=18. This site—run by Dave Radford of Air Craft Inc. (of Japan)—provides data for GWS, Hacker, Mega, Model Motors (including the AXI 41 series), MP Jet, and QRP motors.

• www.astroflight.com. When you access this site, you can select brushless motors or cobalt airplane motors. In some cases only one propeller choice is given for a particular motor/battery combination. That should still provide a good starting point!

• www.hackerbrushless.com/motors.shtml. Hacker USA provides data for all of its brushless motors. After accessing the site, select the motor you are interested in, such as the "B20 Series." Then scroll down and click on "Click here for B20 Series Application Chart." You will be surprised by the extent of this data because it goes as far as relating motor type to specific model aircraft by name!

• www.balsapr.com/catalog/motors. This is part of the Balsa Products site. Under brushless motors you will find the new Feigao brand. There is a category for Outrunner Brushless motors. After that is the entire series of GWS motors, including the IPS series, LPS series, EPS series, and more!

When you get to the particular motor series, you have to click again to obtain the actual data. Please be patient.

• http://home.ptd.net/~rcm65/motdata.html. This is Dick Miller's Motor Characteristics data that he has provided as a free service to electric-power modelers for so many years. You can sort the data by motor name or by a typical model's wing area.

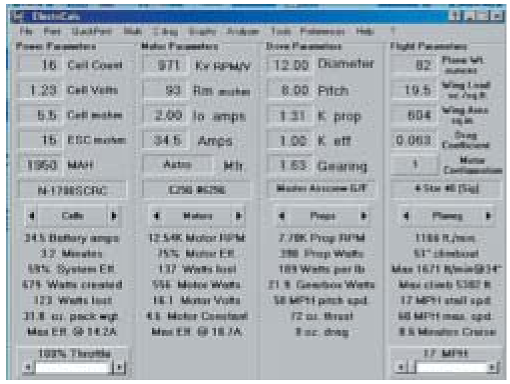
Dick covers the following motors, many of which are the small variety used for parking lot or indoor flying: DC 5-2.4; DC-1717; GWS (all); AstroFlight Firefly; MTM; VL Products; Ikarus; Hi-Line Ltd.; KP-00; Kenway; Nikko; Peck-Polymers; and the Speed 280, 300, and 400 series.

Computer Programs to Help in the Selection Process: Researching many Web sites to obtain motor data can be a real chore. A few years ago two software programs came onto the hobby market that were specifically designed to aid the electric-power enthusiast in choosing a motor. The programs have been continually upgraded through the years to the point where they include a tremendous amount of stored motor (and aircraft) data parameters.

When these programs were first offered, we didn't even have brushless motors. Now they are the most popular item in electric-powered flight. Both programs have literally grown with our hobby, and you don't have to be a computer expert or highly technical to be able to use them.

I have used Sid Kauffman's ElectriCalc for many years. It is up to version 2.20 and has a list price of $49.95. Software is now provided on a CD. It is intended for PCs with operating systems of Windows 98 and up. There are no provisions for Macintosh users—sorry!

You can find the details of this product and order a copy at www.slkelectronics.com./ecalc/index.htm. The program's present version has stored data for 946 motors, and that figure is constantly increasing as new motors come onto the market. There are two ways to use ElectriCalc.



Sample page from ElectriCalc motor-selection computer program. This type of program goes hand in hand with motor-manufacturer data to assist in selection process for specific size/weight aircraft.

1) Enter your aircraft's parameters (wing area, weight, and approximate drag coefficient, which you can obtain by using the simple help function called "Cdrag"). Pick the battery cell type and the number of cells you think you might need. Choose a motor from the extensive list shown, and pick a propeller that will provide enough power to fly the model.

2) When the program is launched, an aircraft will already be chosen (default) from the database or the last one you looked at will be resident in the spreadsheet. Search the "planes" database for the aircraft you are interested in or find one similar in size and weight to your intended model, and rename and revise the parameters to emulate your airplane.

Option 1 requires that you have a good idea of what propulsion system should be in the model. This is seldom the case when one is just getting into electric-powered flight.

Option 2 allows you to "repeat" an aircraft that has already flown. (Much of the database in ElectriCalc on "planes" has been given to SLK Electronics by proficient electric-power modelers.)

Option 2 also allows you to experiment with an existing design to see what other motor or motor/gearbox combinations may work. You can do a lot of "what-iffing" without having to leave your computer station. This can be a big time-saver.

The other popular motor-selection program is MotoCalc, available from Stefan Vorkoetter. His product offers many features of its own and is comparably priced. You can obtain details at www.motocalc.com.

As an active electric-powered-flight enthusiast, you owe it to yourself to own at least one of these fine programs. You may still use much of the manufacturers' data, but these programs do an excellent job as well. Both offer demonstration packages that you can take advantage of before making your final choice. MA