An Interview With Lucien Miller

For the April 2022 "Electrics" column in 'Model Aviation', Terry interviewed Lucien Miller (of Innov8tive Designs) to address common misconceptions about electric power systems. Due to space limitations, Lucien's responses seen in the magazine are abbreviated. You data geeks will enjoy his complete input, which is presented here:

Misconception #1: You cannot use propellers for glow or gasoline engines on electric motors.

Lucien: Yes, you can use propellers for internal combustion (IC) engines on electric motors. Electric props will often provide better performance because they are lighter, but that is not always true. In some extreme cases, like pylon racers, you might actually need to use IC propellers on an electric motor because electric-only props may not stand up to the higher RPMs. Likewise, it is not a good idea to use a "Slow Fly" type electric propeller on a fast-spinning motor of any type. APC lists the RPM limits for their propellers. Obey those limits!
On the flip side, you NEVER want to use an electric prop on a glow engine. The hubs on electric propellers are not designed for the stresses of IC engines. They will eventually throw a blade. You don't want to be anywhere nearby when that happens!

Misconception #2: Running an electric motor (brushless or brushed) without a load will cause it to "over-rev" and become damaged.

Lucien: This is definitely not true. It is a line of thought is a carry-over from glow engines. When you compare Glow Engines to Electric Motors, they are essentially the exact opposite of one another. Glow Engines are essentially "Constant Power" machines. Every time the piston fires it makes a specific finite amount of energy. This energy is then transferred to a prop through the crankshaft. The speed that the prop rotates will be equal to whatever it takes to absorb all the power being produced by the piston, converting that into thrust and drag. For example, if you have a .40 size glow engine and put a standard 10x6 prop on it, the prop will spin at around 12,000 RPM. At that speed the prop absorbs all the power created by the engine. If you take the 10x6 prop off and replace it with a 9x6 prop, the engine will then spin up to around 14,000 RPM, because that is how fast the smaller 9x6 prop has to spin to absorb all the power being created. If you switch to an 8x6 prop, then the engine will probably spin up around 16,000 or more. Again, the reduced prop size requires a higher rotational speed to absorb the engine power. As you run smaller and smaller props, the engine spins faster and faster until one of two things happens. The engine may reach a speed limit where the carb and crankshaft passages can no longer supply enough fuel/air to feed the motor and it simply cannot run any faster. The other, more destructive thing, would be that the motor can breathe well enough and keeps increasing RPM until you reach the structural limits to the engine components and you either snap a connecting rod in half or snap off the crank pin and the engine comes to a screeching halt.

On the other side of the spectrum, if you run larger than normal props on Glow Engines they just spin the prop slower. On the same .40 engine, if we go from a 10x6 to an 11x6, the engine may slow from 12,000 RPM to 10,500 RPM, once again the prop spins as fast as it need to in order to absorb all the power being created by the engine. Go to a 12x6 prop, and the speed will further reduce to maybe 9,000 RPM. The performance of the engine will suffer a bit as larger and larger props are used, but this will not really damage the engine.

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When you look at Electric Motors, they can be considered "Constant RPM" machines. The speed at which they turn, with no load applied, is equal to the Kv value of the motor multiplied by the battery voltage. If you have a motor with a Kv value of 1000 RPM/Volt, and run it from a 4-cell battery that puts out 14.8 volts, the motor will spin at 14,800 RPM. An electric motor will always "Try" to spin at that speed, but as you put larger and larger prop on the motor, this causes more drag on the motor and it slows down a bit, and draws more current in the process. You can run an electric motor with no prop on it all day long and it will not damage the motor. This is of course assuming that the motor does get some cooling and does not get too hot. Every electric motor has a value called Io or the No-Load current. This is how much current the motor will pull, with no prop installed, in order to make it spin. There is a certain amount of magnetic cogging resistance that must be overcome as a motor spins. There is also the drag of the motor rotating in the bearings as well as the air drag on the surface of the motor and on the air being pulled through the motor by built-in cooling fans that may be designed into the motor. This Io current is usually rather small, ranging from less than an amp to several amps, depending on the size of a motor. However, when there is no prop on the motor, the Io current drawn does not do much work, so all it can really do is get converted not heat in the motor. So if you have a motor with an Io value of 2.5 amps and you run it in a no-load situation on a 4-cell battery there is 14.8 volts x 2.5 amps or 37 watts of heat energy being generated inside the motor. This will warm up the core of the motor as it runs in a no-load condition.

Now when we start putting props on an electric motor the motor slows down a bit, because of the extra drag, and pulls more current. As the prop gets larger and larger the current continues to increase. Let's look at the BadAss 2826 size motor with a Kv value of 1030, which has a max current rating of 70 amps. On a 4-cell battery, with no prop installed, this motor will spin at 15,240 RPM with a no-load current of 2.4 amps. If you put a 7x6 prop on it, the motor will slow down to 14,000 RPM and pull around 20 amps of current. With an 8x6 prop the speed will drop to 13,500 RPM and the current will rise to 35 amps. With a 10x6 prop the speed drops to 12,775 and the current goes up to 50 amps. With an 11x6 prop the speed further reduces to 12,000 RPM and the current goes up to 65 amps. We have now reached close to the maximum operational current of the motor. At this point if we use a larger prop the motor will still spin it, but it will pull more current than it is rated for. For example, a 12x6 prop will reduce the motor speed to 11,500 RPM and the current will climb to about 85 amps. The motor will continue to run, but it will get hot. Eventually the insulation on the winging wires that are deep inside the motor, which get no cooling air, will eventually get hot enough to melt the insulation coating on the wire and the motor will begin to develop internal shorts in the windings. Once this happens the situation gets worse and worse until you "Let the Magic Smoke" out of the motor and it dies.

In electric motors, the prop you use is what determines how much power the motor makes. On a motor like the BA-2826-1030, it is capable of making the power of a .50 glow engine when you use the right prop, such as a 10x8 or 11x5.5. However, if you put an 8x6 prop on it, it will only make the power of a .25 glow engine. With a 10x5 prop it will make the power of a .32 glow engine and with a 10x7 prop it will make the power of a .45 glow engine.

In a nutshell Glow Engines are Constant Power machines that Push power into the prop. They can be damaged by running too small of a prop, which allows the engine to spin at a speed high enough to structurally damage the internal parts.

On the other hand, Electric Motors are Constant RPM machines, and the prop that you use Pulls the power out of the motor. They can be damaged by running too large of a prop, that puts too much load on the motor and causes it to pull too much current that will thermally damage the motor.

Misconception #3: If my power system pulls 40 amps at full throttle, I can use a 30-amp ESC if I set the throttle end point to 75%.

Lucien: This is generally a very bad idea! One mistake that people often make is thinking that the ESC varies the voltage applied to the motor in order to regulate the motor speed. The FET transistors in a speed controller are essentially electronic switches that can only turn on or off. Because of this, there are only 3 states that speed controller output lead can be at. It can either be turned on and connected to the positive battery terminal, turned on and connected to the battery ground or turned off and floating. At any point in time on a 3-phase brushless ESC, this condition exists. On the first power cycle Phase A is connected to the Positive battery terminal, phase B is connected to ground and phase C is disconnected and floating. On the next power cycle, phase B is connected to positive, phase C is connected to ground and phase A is open and floating. On the next power cycle phase C is connected to the positive battery lead, phase A is connected to ground and phase B is open and floating. This process continues through all the possibilities and then repeats over and over again with the motor rotating through 2 magnets during each full cycle of phase changes. When the motor is running at full throttle, the transistor stays on during the full phase cycle and then turns off.

In order to run at less than full throttle conditions, during each phase cycle, the transistors are quickly turned on and off several times during each cycle, regulating the total amount of power that goes to the motor. If you look at the voltage applied to a motor phase at full throttle with an oscilloscope, you will get a waveform like the one shown below. In this diagram, the motor is running from a 3-cell battery at about 9000 RPM.

When you reduce the throttle, instead of each power pulse being on 100% of the time, it gets switched on and off several times per cycle. The next diagram shows the voltage to a phase with the motor running at 60% throttle.

In this image you can see that now the transistors are being turned on and off 4 times per power cycle. If you look at the bottom on the trace you can see that the output was pulled to ground about 60% of the time and turned off 40% of the time. You can also see that the time distance between each pulse is 0.125 milliseconds. This works out to a frequency of 8 Kilohertz, which is the PWM frequency of the ESC.

One thing that you will notice is that the voltage ALWAYS goes to the full battery voltage whenever a transistor turns on. Because of this, the ESC experiences the Full Throttle current during each pulse, but it is at a lower duty cycle so the Average Current is lower. If you have a motor that pulls 40 amps at full throttle, when you run it at 50% throttle, each pulse will still pull 40 amps, but since they are on half of the time and off half of the time, the average current you would read with a wattmeter is 20 amps, BUT the ESC is still seeing 40 amps each and every pulse. This is the reason why you should ALWAYS size an ESC for the full rated current of the motor, even if you are not pulling that much current. If you repeatedly run 40 amp pulses through an ESC that is rated for 30 amps, it will not fail immediately, but over time it will accumulate small amounts of damage which will eventually add up and cause the ESC to fail.