How to use the Multirotor Motor Performance Data Charts

Here at Innov8tive Designs, we spend a lot of time testing all of the motors that we sell, and collect a large amount of data with a variety of propellers. We then make that information available to our customers in concise, easy to follow formats, which simplify the motor selection process. Our Propeller Data charts provide full throttle performance values on a wide range of propellers, and show which propellers provide the best performance for each of our motors.

These Propeller Data charts work great for airplanes, but when the motors are used in multirotor aircraft, you never fly at full throttle. Most of the flight time in a multirotor is spent hovering in a range between 40% and 60% throttle. Because of this, the motor performance data in the mid-range region is most important to pilots of multirotor aircraft. To provide this data in an easy to read, and easy to understand manner, we have created sets of four graphs for each of the recommended propellers for our Multirotor motors. These graphs show Motor Current, Propeller RPM, Propeller Thrust and Propeller Efficiency as a function of throttle position for each motor and propeller combination. With these charts, the pilot can calculate power requirements, motor current and overall system efficiency, and then use this data to make a good estimate of expected flight times based on the size of the battery that is used. In the step-by-step example that follows, we will walk through the procedure to properly interpret the data contained in these charts, and then use that data to calculate the performance and estimated flight time of our power system.

To begin, let us assume that we have Quadcopter multirotor that will weigh 3-1/2 pounds, or 56 ounces when completed, and we will power the quadcopter with a 3-cell, 5000mah Li-Po battery. When selecting a motor for a multirotor, you want to have an absolute minimum of a 2 to 1 thrust-to-weight ratio at full throttle. For longer flight times a 3 to 1 thrust to weight ratio is a great starting point. If the estimated weight of our quadcopter is 56 ounces, 3 times this weight would be equal to 168 ounces. If we divide this total thrust by 4 motors, each motor needs to make about 42 ounces of thrust.

Next we need to find a motor that will provide around 42 ounces of thrust at full throttle when running on a 3-cell Li-Po battery (11.1 volts). Looking on the Innov8tive Designs website, and going through the prop charts on several motors we found the Cobra CM-2217/20 motor. Looking at the prop data for operation on 3 cells, with an APC 12x4.5-MR prop, we can see that this motor makes 41.2 ounces of thrust at full throttle. This is very close to the desired 42 ounces, so we will select this motor and prop combination for our multirotor power system.

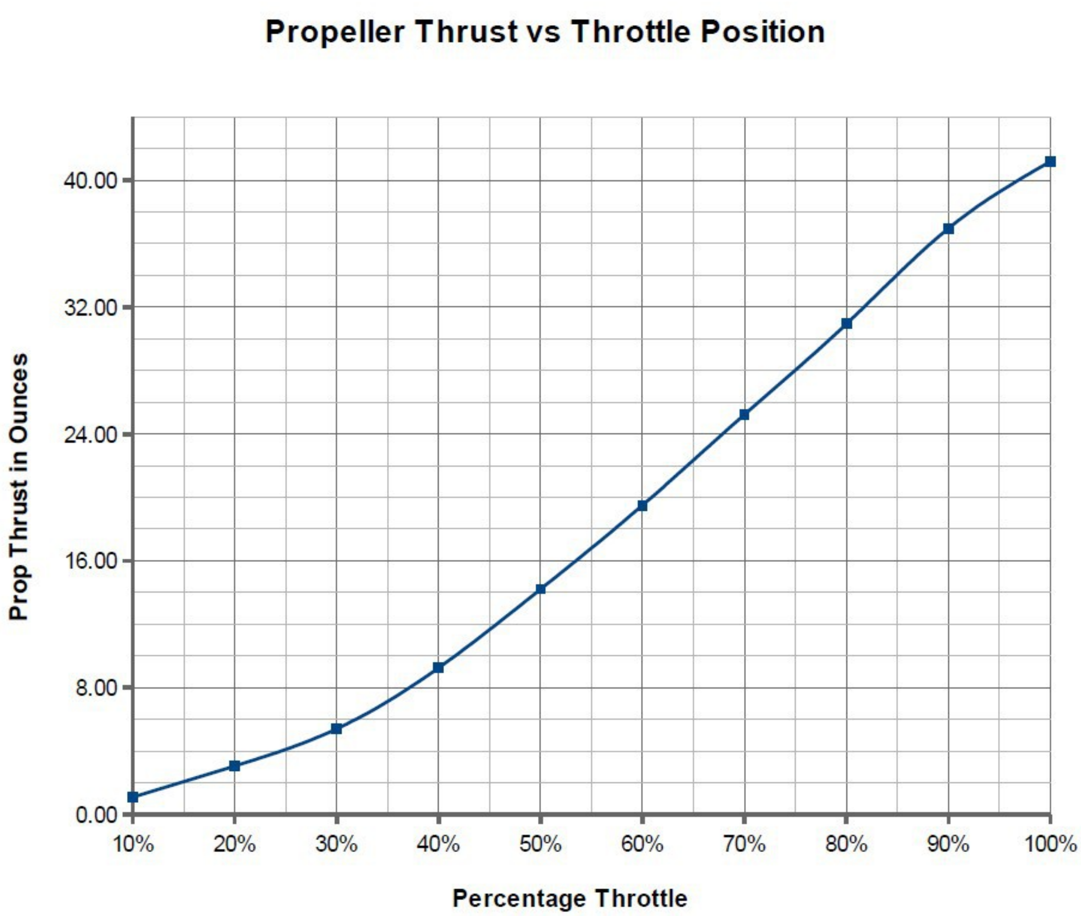
Cobra CM-2217/20 Motor Propeller Data										
Magnets 14-Pole	Motor Wind 20-Turn Delta		Motor Kv 950 RPM/Volt		No-Load Current Io = 0.53 Amps @ 12v		Motor Resistance Rm = 0.188 Ohms		I Max 20 Amps	P Max (3S) 220 W
Stator 12-Slot	Outside Diameter 27.0 mm, 1.063 in.		Body Length 33.0 mm, 1.299 in.		Total Shaft Length 35.1 mm, 1.382 in.		Shaft Diameter 3.17 mm, 0.125 in.		Motor Weight 76 gm, 2.68 oz	
Test Data From Sample Motor		Input Io Value	10.0 V 0.49 A	12.0 V 0.53 A	14.0V 0.58 A	16.0V 0.63 A	Measured Kv value 890 RPM/Volt @ 10v		Measured Rm Value 0.188 Ohms	
Prop Manf.	Prop Size	Li-Po Cells	Input Voltage	Motor Amps	Input Watts	Prop RPM	Pitch Speed in MPH	Thrust Grams	Thrust Ounces	Thrust Eff. Grams/W
APC	10x4.5-MR	3	11.1	11.83	131.3	7,536	32.1	875	30.86	6.66
APC	11x4.5-MR	3	11.1	14.00	155.4	7,107	30.3	1012	35.70	6.51
APC	12x4.5-MR	3	11.1	16.98	188.5	6,507	27.7	1168	41.20	6.20
APC	14x5.5-MR	3	11.1	22.02	244.4	5,324	27.7	1322	46.63	5.41
GemFan	8x4.5-MR	3	11.1	8.81	97.8	8,147	34.7	633	22.33	6.47
GemFan	9x4.7-MR	3	11.1	9.96	110.6	7,926	35.3	731	25.79	6.61
GemFan	10x4.5-MR	3	11.1	13.84	153.6	7,174	30.6	935	32.98	6.09
GemFan	11x4.7-MR	3	11.1	16.54	183.6	6,619	29.5	1098	38.73	5.98
GemFan	12x4.5-MR	3	11.1	19.02	211.1	6,085	25.9	1099	38.77	5.21
GemFan	10x4-MR-W	3	11.1	12.28	136.3	7,448	28.2	855	30.16	6.27
GemFan	11x4-MR-W	3	11.1	13.11	145.5	7,307	27.7	963	33.97	6.62
GemFan	12x4-MR-W	3	11.1	16.17	179.5	6,671	25.3	1115	39.33	6.21
GemFan	13x4.5-MR-W	3	11.1	18.61	206.6	6,120	26.1	1225	43.21	5.93
GemFan	14x4.5-MR-W	3	11.1	20.41	226.6	5,725	24.4	1297	45.75	5.72

Now that we have selected a motor that will provide the required thrust at full throttle, we can download the performance data charts for the Cobra 2217/20 motor, running an APC 12x4.5-MR prop on 3 Li-Po cells. This chart shows the data collected for the motor running at evenly spaced throttle level intervals of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% throttle. The following chart shows this data set.

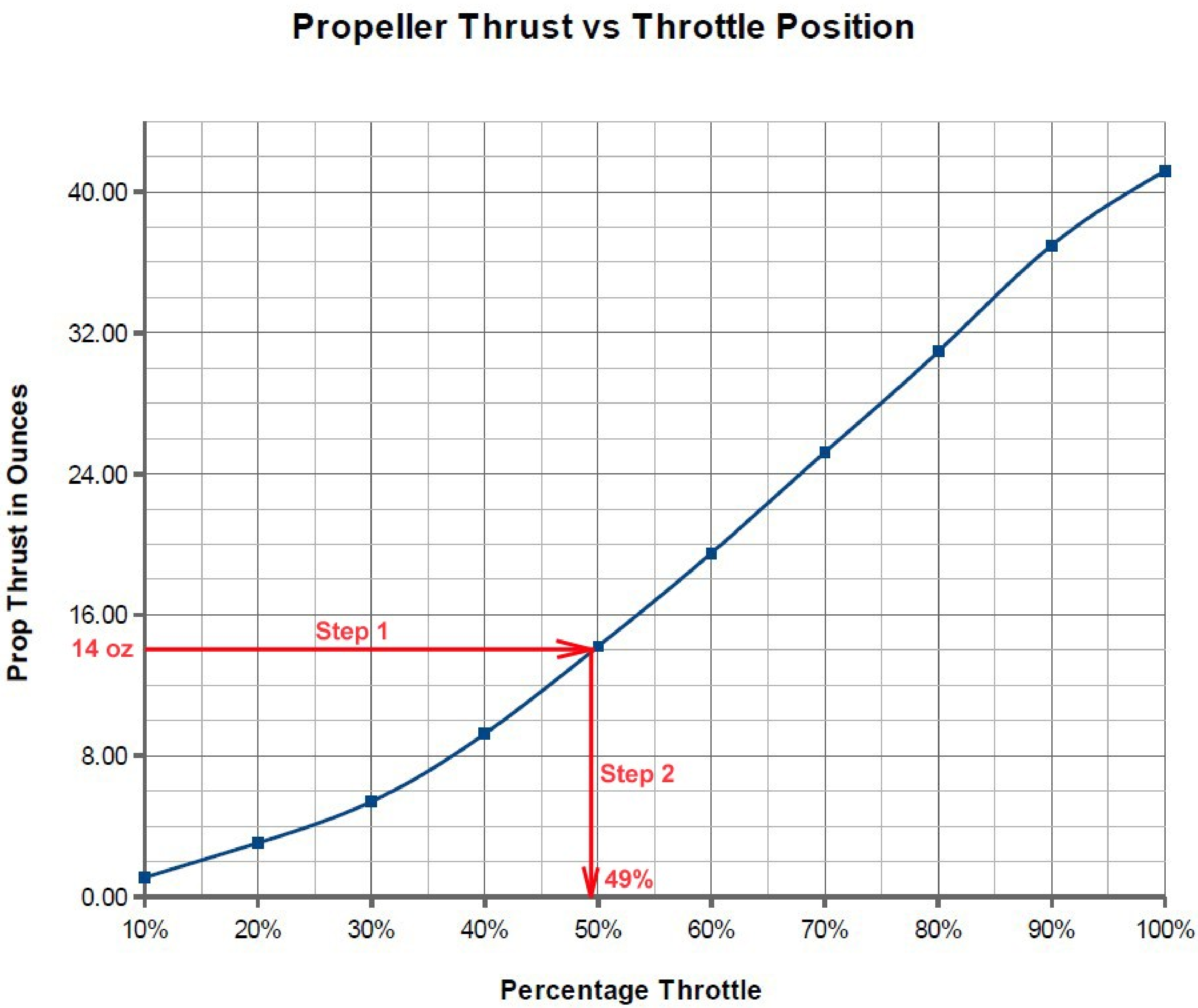
Cobra CM-2217-20 Motor Test Data, Kv=950

Data Collected at 11.1 volts with APC 12x4.5-MR Prop						
Throttle Setting	**Motor Amps**	**Input Watts**	**Prop RPM**	**Thrust (Grams)**	**Thrust (Ounces)**	**Efficiency Grams/W**
10%	**0.22**	2.39	1,267	31.3	1.10	13.12
20%	**0.56**	6.24	1,994	87.0	3.07	13.95
30%	**1.05**	11.68	2,589	153.5	5.41	13.15
40%	**2.04**	22.63	3,320	262.6	9.25	11.60
50%	**3.58**	39.72	4,010	403.3	14.21	10.15
60%	**5.53**	61.37	4,635	553.5	19.51	9.02
70%	**8.00**	88.84	5,218	715.8	25.23	8.06
80%	**11.06**	122.77	5,776	877.9	30.94	7.15
90%	**14.60**	162.03	6,288	1048.8	36.96	6.47
100%	**16.98**	188.49	6,507	1168.4	41.18	6.20

The first graph that we are going to use is the Propeller Thrust versus Throttle Position graph shown here. This graph will be used to calculate what power level the motor will need to run at to create enough thrust to hover our multirotor.



This graph shows how thrust increases as the throttle percentage increases, and with it, we can calculate how much throttle it will take to generate the thrust required to make our multirotor aircraft fly in a stable hover. For our example, our quadcopter weighs 3-1/2 pounds, or 56 ounces ready to fly. In order for a multirotor aircraft to hover, the combined thrust of all 4 motors must equal the weight of the craft. If we take 56 ounces, and divide that by 4, each motor would need to make 14 ounces of thrust to support the weight of the quadcopter. Now that we know each motor needs to make 14 ounces of thrust, we can go through the step by step process to calculate the rest of the power system.



Step 1: To figure out what throttle setting is needed, you start at the left side of the graph at the point that corresponds to the amount of thrust each motor needs to make. In this case, it is 14 ounces. Starting at the 14 ounce point, move to the right until the line intersects the blue line on the graph.

Step 2: When you reach the blue line, draw another line straight down until it intersects the throttle axis. In this example, the line falls a little to the left of the 50% throttle point, which is approximately 49% throttle. Now we know that in order to fly our quadcopter in a hover, each motor needs to be at 49% throttle to produce the required thrust.

Now that we know the throttle position needed to generate the required hovering thrust, we can use that value to read the other 3 graphs that are included in the data set.

Next we will use the Motor Current versus Throttle Position graph to see how much current each of our motors will be pulling from the battery in a stable hover. Since we calculated that it will take 49% throttle to produce the required thrust, we will use that value in the next steps.

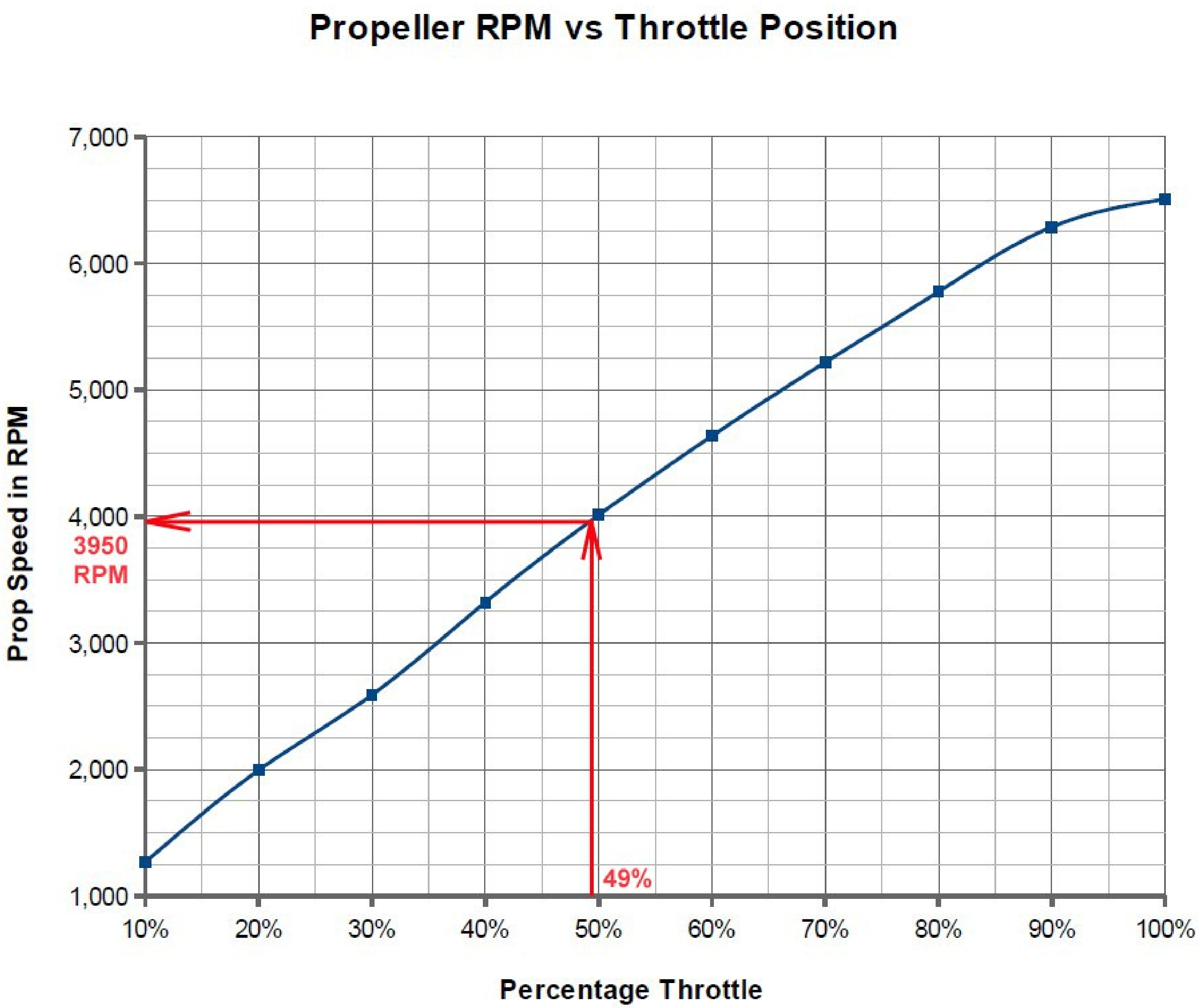
Step 3: Starting at the bottom of the graph at the 49% throttle point, draw a line straight up until it intersects the blue line.

Step 4: From the intersection point, draw a line straight to the left until it intersects the Motor Current axis. In this example, the line is about halfway between the 3 amp and 4 amp lines, so we will call it 3.5 amps of current. If each motor needs to pull 3.5 amps of current from the battery in a hover, and we have 4 motors in our quadcopter, the total current required is equal to 3.5 x 4, which is equal to 14 amps.

The other two graphs in the set provide information about propeller speed and propeller efficiency at the hovering point. Let's take a look at these two graphs and see how that data can be calculated.

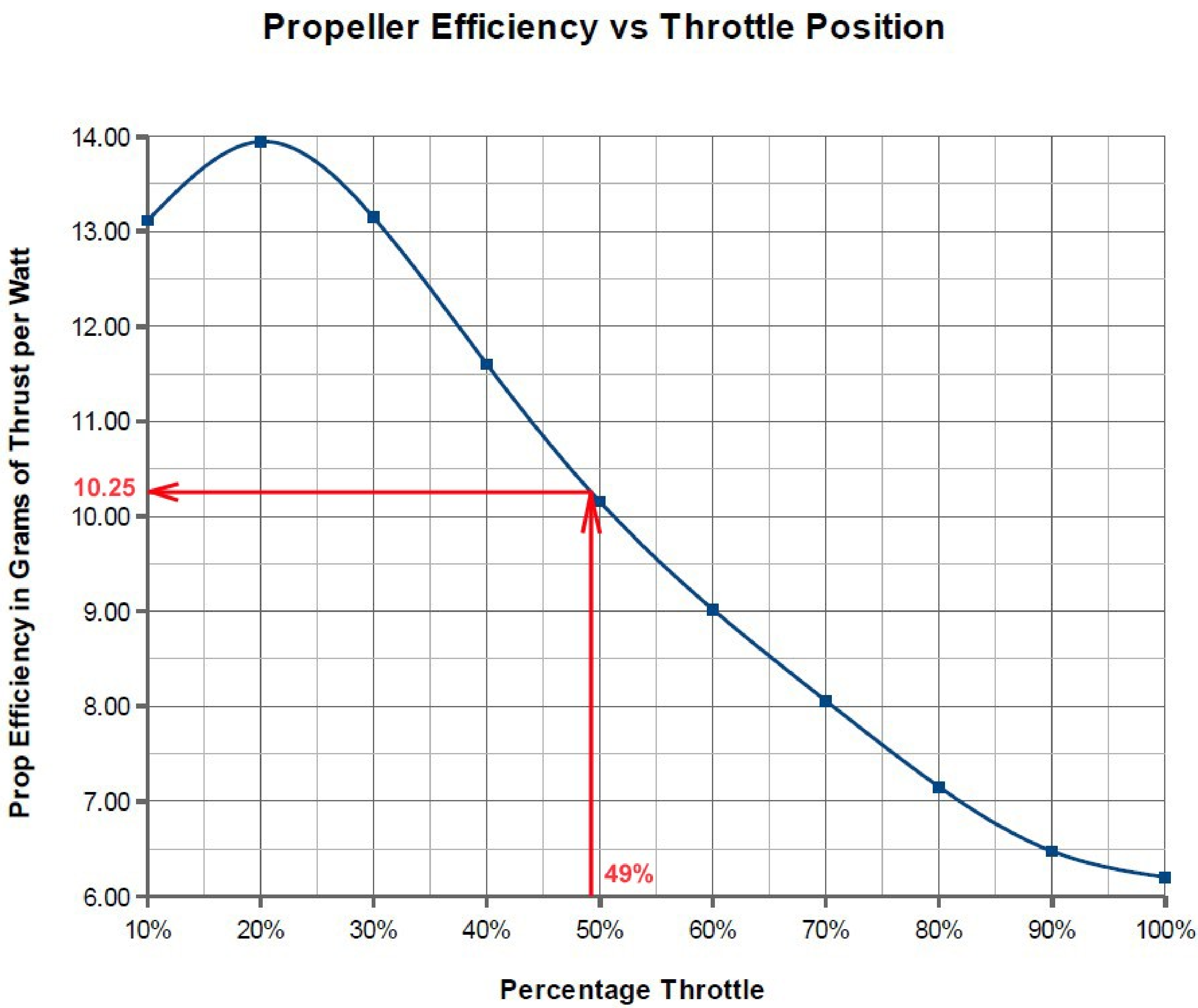
The next graph below shows Propeller RPM versus Throttle Position. Once again, we will start at the bottom of the graph at the 49% throttle point and draw a line straight up until it intersects the blue line. Then another line is drawn from the intersection point over to the left until it intersects the Prop Speed axis. In this case the line is just a bit below 4000 RPM or approximately 3950 RPM. (**Note:** The data in these charts is collected at an altitude of 512 feet above sea level. If you are at a higher elevation, the props will actually spin faster to generate the same amount of thrust in the thinner air.)

This number comes in handy to let you know if you are running the prop at a speed that is greater than the recommended maximum. According to APC's safety guidelines, their Multirotor Series props should not be run at a speed that is more than (105,000 / Prop Length) rpm. For a 12 inch prop this value is 105,000/12 or 8,750 RPM. From the graph below you can see that at 100% throttle the prop only turns at approximately 6,500 RPM, so even at full throttle we have a healthy safety margin on the prop speed.



Finally the last graph of the set shows propeller efficiency as related to throttle percentage.

Looking at the final graph below, you can see that the efficiency of the prop starts out rather high at low throttle settings, and decreases in a rather linear fashion as the throttle percentage increases. For the Cobra 2217/20 motor running the APC 12x4.5-MR prop on 3 cells, the maximum efficiency point occurs at 20% throttle, and is just a tiny bit less than 14 grams of thrust per watt of input power. At full throttle the overall prop efficiency drops down to a little over 6 grams of thrust per watt of input power.



A propeller blade is just like a little wing, and basic aerodynamics says that as the speed of a wing moving through the air increases, the drag on the wing increases exponentially. As the propeller spins faster and faster, it takes more and more power to overcome the drag forces, so less of the power is left to be converted into thrust. This is why lighter multirotors always fly better than heavy ones. Not only do they need less power to hover, the propellers operate more efficiently at lighter loads, giving even more flight time.

In our specific example, if we once again start at the bottom at the 49% throttle point, and then draw a line straight up, it will intersect the prop efficiency curve. From this intersection point, if we draw another line straight to the left until it crosses the Prop Efficiency axis we can see how efficient the prop is running at this power level. In the above example, the line ends up being halfway between the 10.0 and 10.5 lines, or approximately 10.25 grams of thrust per watt of input power. This number can be used to calculate run times from battery size, and the process for calculating this will be detailed later in these instructions.

Putting it all Together

Now we can bring all the data together from the charts we just went through, and show you how to use this data to calculate run time for your model. Here is what we have discovered from the data charts so far.

1. After looking at the prop data charts for several different motors, we selected the Cobra CM-2217/20 motor with the APC 12x4.5-MR prop.

2. For our 56 ounce quadcopter we need to have 14 ounces of thrust per motor to stay in a stable hover.

3. To generate 14 ounces of thrust, our motor and prop combo needs to run at 49% throttle.

4. At 49% throttle, each motor pulls 3.5 amps, for a total of 14 amps from all four motors.

5. Our motors will be spinning at approximately 3950 RPM in a hover.

6. The thrust efficiency of the props at this power level is approximately 10.25 grams per watt of input power.

You may remember that in the beginning we said that the model would be powered with a 3-cell 5000mah Li-Po battery. We can now use the data collected from the motor performance charts to calculate our maximum available flight time.

To begin, we need to understand battery discharge and what "C-Rate" means. In battery terminology, "C" stands for battery capacity. Most of the Li-Po batteries used in RC today have the capacity rated in milli-amp-hours or mah. This is an indication of the energy storage capacity of the battery or "The size of the fuel tank" in glow engine terms. By definition, if a battery is discharged at a 1C rate, it will take 1 hour to fully discharge the battery pack. A 2C discharge rate will deplete the battery in 1/2 of an hour or 30 minutes. A 3C discharge rate will deplete the pack in 1/3 of an hour or 20 minutes and so on.

When doing battery C-rate calculations, the battery capacity needs to be expressed in Amp-Hours instead of milli-amp-hours. Since there are 1000 mah in 1 AH, a 5000mah battery can also be called a 5 AH battery, and this is the value we will use for calculating run times.

Getting back to our quadcopter, we calculated earlier that each motor would be pulling 3.5 amps of current in a hover, so the total current for all 4 motors would be 14 amps. If the capacity of our battery 5 AH and we are pulling 14 amps with all 4 motors, then the C-rate of discharge can be calculated by taking 14 amps and dividing it by 5 AH, which gives a discharge rate of 14/5, or 2.8C. Based on this, if we now take 60 minutes, and divide it by 2.8C, we get a maximum run time of 21.4 minutes. While this is the theoretical maximum run time for our quadcopter, you should never attempt to fly this long.

Li-Po batteries work best, and last the longest, if you use no more than 80% of their total capacity per flight. Discharging the batteries more than this can damage the cells over time, and greatly reduce their life expectancy. There are a couple different ways you can compensate for this when doing the flight time calculations, and we will go over both of them right now.

Method 1: De-rate the battery capacity: Since we are using a 5000mah (5 AH) battery, if we take 80% of the battery capacity before we do the calculations, this will give a flight time that will leave 20% of the total energy in the pack at the end of the flight. If we do the calculations we just performed once again, and use a 4000mah (4 AH) battery instead, this will take the 80% discharge into account. Our total current draw for all 4 motors was 14 amps. This time if we divide that by 4 instead of 5, 14/4 is a C-rate of 3.5. Now if we take 60 minutes and divide that by 3.5 we get 17.1 minutes.

Method 2: De-rate the flight time: In this method, instead of using 60 minutes for the calculation, we only use 80% of this value or 48 minutes when doing the C-Rate calculation. Like we did in the first set of calculations, the C-rate of discharge is 14/5 or 2.8C. Now if we use 48 minutes instead of 60 and take 48/2.8 we get 17.1 minutes once again. As you can see, either of these two methods will provide the same result, just use the one that makes the most sense to you.

Propeller Efficiency:

Earlier we used one of the charts to determine that the thrust efficiency of the propellers on our motor was 10.25 grams per watt. This number can also be used to calculate the energy required to hover the craft and determine flight times. Since there are 454 grams to the pound, and our quadcopter weighs 3.5 pounds, To convert the Quad weight from pounds to grams you take 3.5 x 454, which is 1589 grams. If we take the total weight of the quadcopter and divide that by the prop efficiency, or 1589/10.25, we get 155 watts of power required to hold the quadcopter in a hover. Since we are running a 3-cell battery, which puts out 11.1 volts under load, if we take 155 watts and divide that by 11.1 volts we get 14 amps of current. This value is exactly the same as we calculated from our charts earlier, so this makes perfect sense, and it also serves as a cross check to see if you did the math right in the other method..

Other Considerations:

Once you have calculated the maximum flight time for hovering flight, there are other things that need to be taken into account. Most people do not simply take off, climb to an altitude of 8-10 feet, and just hover there for the entire flight. Most of the time, the multirotor is maneuvering from one place to another, climbing and descending, and quite often fighting a cross-wind. Whenever you do any maneuvering, other than a controlled steady hover in calm air, one or more of the motors will have to spin faster, and thus pull more current. This higher current draw will shorten the flight time of the multirotor, so this needs to be taken into account. For aerial photography work, where there is minimal moving around, you should start with about 75% of the max available flight time. From our de-rated calculations above, the flight time was 17.1 minutes. If you take 75% of that value, you end up with a flight time of 12.8 minutes.

Flying in a strong cross wind can have a huge effect on the current draw of the motors. In some cases, it can cut the flying time by as much as 50%! This should be taken into account during your flight calculations before flying on windy days. If you are involved in FPV racing, and are flying at high throttle levels, your flight times will degrade dramatically. Looking back at the first propeller chart for the Cobra 2217/20 motor and the APC 12x4.5-MR prop, at full throttle, this combinations pulls about 17 amps of current. This is almost 5 times greater than the current used by the motor in a hover, and this will drain the battery very quickly! Depending on how hard you are flying, FPV racing can take 3 to 4 times as much current as stable hovering does, so even though your multirotor might be able to hover for over 17 minutes, in high speed flight, you might only get 5-6 minutes of flight time.

There are two things you can do to insure that you never "run out of juice" during a flight on your multirotor aircraft. The first is to take actual measurements of how much energy you are using in each flight. For example, we calculated a 17.1 minute hovering flight time in our system above, and then dropped that back to 12.8 minutes to account for the extra power needed for normal maneuvering. To calculate the actual energy consumption of the multirotor, you could fly it for exactly 10 minutes, flying the machine like you normally would doing aerial photography. Try to land the craft exactly 10 minutes after you take off and then remove the battery. When you charge this battery the next time, take note of how many milli-amp-hours of energy gets put back into the pack, then divide that value by 10 to get the average energy consumption per minute.

For example, let's assume we took the machine out and flew for 10 minutes, and then recharged the pack. Once the battery was fully charged, the charger showed that we put 3100mah of energy back into the pack. If we divide that number by 10 we see that the average power use of our multirotor was 310 mah per minute. Going back to our 5000mah battery, if we de-rate this pack to 4000mah and then divide this value by 310, we would get 12.9 minutes of flight time. Once we know this actual energy use, you could set the timer in your transmitter to 12 minutes, and fly knowing that you would be safe on your battery use.

The second thing you can do is to purchase and use a small battery voltage Monitor-Alarm device and plug it into the balance connector of your battery during each flight.

An example of one of these devices is shown to the right. These devices can be purchased at a number of different RC stores for under $10.00. Most of them can have the low voltage alarm level set to anything from 2.7 to 3.8 volts per cell.

As soon as any one of the cells in the battery pack reaches the pre-set minimum voltage level, an alarm will sound to warn you that the battery is getting low. The battery monitor also measures the voltage of each individual cell, and provides the total pack voltage, so you can also use it to determine the balance of your pack from one cell to the next, and the relative charge level of a pack. By using one of these devices, it does not matter how hard your multirotor is flown, the alarm will go off at the pre-set voltage level that you choose, and let you know when it is time to come in and land.

Final Thoughts:

If the weight of your machine ever changes, due to adding a camera gimbal, or a larger battery pack, you can use the charts once again to calculate the new flight times based on the change in weight and/or the additional power available from a larger battery. For example, if you wanted to fly longer, and you added a second 3-cell 5000mah battery, and the battery weighs 14 ounces, you can quickly run through the calculations again. Now the weight of our quadcopter is 56 + 14 or 70 ounces. With 4 motors, each one needs to provide 70/4 or 17.5 ounces of thrust. Going back through the charts we can see that the throttle required to make 17.5 ounces of thrust is about 57%. This requires 4.9 amps of current per motor for a total of 19.6 amps. Our props will be spinning at approximately 4400 RPM, and our thrust efficiency will drop to 9.4 grams per watt. Since we have two 5000mah batteries in parallel, our total battery capacity is now 10,000mah. De-rating this to 80% gives us 8000mah or 8 AH of battery capacity. With a new current draw of 19.6 amps our discharge rate in a hover is 19.6/8 or 2.45C, and this will give us 60/2.45 or 24.5 minutes.

Earlier we calculated that with one 3-cell 5000mah battery pack the quadcopter could hover for 17.1 minutes. From the calculations that were just made, with two batteries, you get just 24.5 minutes. Some may ask, “Why don't you get double the flight time, and end up with 34.2 minutes?” The reason is because the craft weighs more due to the extra weight of the second battery, so you have to use more energy during the entire flight to carry around the second battery, and this cuts into the flight time. To make matters worse, with a heavier model, the prop efficiency is not as good, so it takes even more energy to get the additional thrust due to extra drag on the props. From this it is easy to see that adding weight gives you a “Double Whammy” in the flight time department due to the higher weight and lost prop efficiency.

Hopefully this information has helped you gain a better understanding of multirotor power systems and the ability to accurately calculate flight times based on battery size and the power required to fly the craft. If you do have any other questions, please feel free to send an email to the address shown below, and it will be answered as soon as possible.

Thanks!

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