Control Tower - October 1998

Part 2 of "Understanding Electric Power Systems".

By Jim Bourke | Oct 01, 1998, 12:00 AM

Understanding Electric Power Systems Part 2

This month I will be continuing my series on "Understanding Electric Power Systems". If you have not read last month's column, then please do so before reading further.

Recap

Last month I presented our Ideal Motor and Ideal Cell. These perfect, imaginary devices enable us to examine an electric power system without having to worry about losses or other frustrating considerations that the real world imposes on us. Our Ideal Motor is defined as a perfect device that turns its shaft at exactly 1000 RPM per volt of energy applied to it. Our Ideal Cell is defined as a perfect device that produces exactly 1 volt of electrical energy. We also learned that **watts** is the product of **volts** and **amps** and we learned how propeller size and current consumption relate to each other.

At the end of last month's lecture, I asked some questions. Here they are again - this time with answers:

Q&A

How many RPM will my Ideal Motor spin if I apply 17 volts?

17,000 RPM. This is true regardless of what prop I put on the motor because the motor always turns at exactly 1000 RPM for every volt regardless of the load. Our perfect, Ideal Motor is an irrestible force.

How much current will my Ideal Motor draw if I bolt a 12x8 prop on it and attach it to an Ideal Cell? 2 Ideal Cells? 3 Ideal Cells?

According to the tables in the article, the current values are 10, 20, and 33 amps, respectively. Note that the current goes higher and higher as the voltage increases. Note also that these current values are mythical and were chosen simply for demonstration purposes (but that doesn't mean they don't mirror reality in certain ways).

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Suppose I had an Ideal Airplane that was lacking in power, but I didn't want to add cells, what would you suggest that I do?

> Switch to a bigger propeller. Our Ideal Motor will turn the new propeller at the same RPM as the smaller propeller, which will provide the airplane with more power. The new propeller will draw more current than the old propeller.

Current Consumption and Cell Capacity

Today we are going to expand our Ideal power system model by improving our definition of the Ideal Cell. Thus far, we have described an Ideal Cell based on a single characteristic: the fact that it produces exactly 1 volt of electricity.

We have also explored how much power is demanded by the motor based on the kind of propeller we stick on the shaft and the number of cells we use. But it is at this point that reality rears its ugly head and forces its way into our discussion. Alas, we cannot have all the energy we want forever. Even our Ideal Cell has a limit to how much energy it can store and, therefore, provide to the motor. This limit is the cell's *capacity*.

Lets fix our Ideal Cell's capacity at a nice round number of 1 Amp-Hour. This means that our cell can store enough energy that it can produce 1 amp for 1 hour. If we take out more than 1 Amp then the Cell will run out of energy earlier than one hour. For example, a 2 amp draw would deplete the cell of energy in half an hour and a 4 amp draw would deplete the cell of energy in 15 minutes.

Table 1. Length of Time a 1 Amp-Hour Cell Can Supply Energy at Various Current Draws

Current	Time
1 Amp	60 minutes
2 Amps	30 minutes
3 Amps	20 minutes
4 Amps	15 minutes
...	...
20 Amps	3 minutes

The Duration Equation

Lets express the above as an equation. Our Ideal Cell makes this easy for us:

Duration = 60 / Current

The duration is the length of time (in minutes) that a cell can provide energy, given the measured current draw. Note that the above formula is only valid for Ideal Cells. The real-world formula is slightly more complicated.

Adding Cells Together

Last month, I discussed using more than one cell to power a motor. These cells were assumed to be wired together in series. This simply means that the cells are wired together in a chain, with the positive end of each cell connected to the negative end of the next cell. Series wiring adds up the voltage but keeps the capacity the same as a single

cell.

Table 2. Voltage and Capacities of Cells Connected in *Series*		
# of Cells	**Voltage**	**Capacity**
1	1 volt	1 Amp-Hour
2	2 volts	1 Amp-Hour
3	3 volts	1 Amp-Hour
4	4 volts	1 Amp-Hour

As you can see in the above table, wiring cells in series does not change the capacity of the battery.

Computing Duration of Various Power System Combinations

Now that we know how to compute duration, we can take another look at the power systems presented last month and compare them in more detail.

Table 3. Duration of Various Power Systems					
# of Ideal Cells	**Current**	**Propeller**	**RPM**	**Power**	**Duration**
1	1	5x5	1000	1 watt	60 minutes
2	2	5x5	2000	4 watts	30 minutes
3	3	5x5	3000	9 watts	20 minutes
4	6	5x5	4000	24 watts	10 minutes
# of Ideal Cells	**Current**	**Propeller**	**RPM**	**Power**	**Duration**
1	10	12x8	1000	10	6 minutes
2	20	12x8	2000	40	3 minutes
3	33	12x8	3000	90	2 minutes
4	63	12x8	4000	240	1 minute

In each row of the table, note that the value in the "Duration" column is equal to 60 divided by the value in the "Current" column. The duration starts off at 60 minutes but drops dramatically as current goes up or the propeller size is increased.

One thing that escapes many newcomers to electric fliers is that **adding cells will decrease the full-throttle duration of a power system**. Take a look at the above table and see for yourself how the duration drops as cells are added. This is because the current draw goes up as the voltage increases. The result is that adding a cell will give you more power for less time. Of course, if you have an Electronic Speed Control (ESC) to vary the throttle setting in-flight then this is not an important concern.

Watt-Hours

Since our Ideal Cell can deliver 1 volt and 1 amp for 1 hour, and since we know that volts

and amps combine to make a watt, we can also describe our Ideal Cell using the term Watt-Hours. A Watt-Hour is a unit that describes how much total power is available from a cell over a given amount of time.

Watt-Hours = Volts x Amp-Hours

Naturally, I've thought ahead on this and chosen really easy values that make the Watt-Hour rating easy to compute. Our cell is rated at exactly 1 Watt-Hour because it provides 1 volt and has a 1 Amp-Hour capacity.

If we combine cells into a battery through a series connection then we are adding up watt-hours. Lets jump back to an earlier table and add a Watt-Hour column.

Table 4. Voltage, Capacities, and Watt-Hours of Batteries With Various Cell Counts

# of Cells	Voltage	Capacity	Watt-Hours
1	1 volt	1 Amp-Hour	1 Watt-Hour
2	2 volts	1 Amp-Hour	2 Watt-Hours
3	3 volts	1 Amp-Hour	3 Watt-Hours
4	4 volts	1 Amp-Hour	4 Watt-Hours

Imagine for a moment that our Ideal Cell supplied two volts. This would double the amount of energy in the cell and thereby double how much power we could get out of it in an hour. This kind of cell would have a Watt-Hour rating of 2. Likewise, doubling the capacity of the Ideal Cell would double the watt-hour rating.

Based on the idea of a Watt-Hour, we can start to check our work. Since our perfect motor system has no losses, we can double-check the Watt-Hours coming out of the power system based on the Watt-Hours going into the power system. From now on I'll be abbreviating Amp-Hours and Watt-Hours as Ah and Wh, respectively.

Table 5. Comparison of Watt-Hours In and Out of a Power System

# of Ideal Cells	Current	# of Watt-Hours In	Propeller	RPM	Power	Duration	# of Watt-Minutes Out	# of Watt-Hours Out
1	1	1 Wh	5x5	1000	1 watt	60 minutes	60	1 Wh
2	2	2 Wh	5x5	2000	4 watts	30 minutes	120	2 Wh
3	3	3 Wh	5x5	3000	9 watts	20 minutes	180	3 Wh
4	6	4 Wh	5x5	4000	24 watts	10 minutes	240	4 Wh
# of Ideal Cells	**Current**	**# of Watt-Hours In**	**Propeller**	**RPM**	**Power**	**Duration**	**# of Watt-Minutes Out**	**# of Watt-Hours Out**
1	10	1 Wh	12x8	1000	10	6 minutes	60	1 Wh
2	20	2 Wh	12x8	2000	40	3 minutes	120	2 Wh
3	30	3 Wh	12x8	3000	90	2 minutes	180	3 Wh
4	60	4 Wh	12x8	4000	240	1 minute	240	4 Wh

So, referring to Table 5, we can see that a 3 cell battery pack contains 3 Watt-Hours of power. This is because it is composed of 3 cells, each of which contain 1 watt-hour.

This 3 cell pack produced 9 watts for 20 minutes when powering our Ideal Motor fixed to a 5x5 propeller. This is the same as 180 Watt-Minutes, or 3 Watt-Hours. As you can see, the number of Watt-Hours going into the system is the same as the number of Watt-Hours coming out of the system.

With the 12x8 propeller, our 3 cell pack produced 90 watts for 2 minutes. Again, this is 180 Watt-Minutes, or 3 Watt-Hours.

Summary

Lets summarize our model of an Ideal Power System:

- The Ideal Motor spins at 1000 RPM for every volt of energy supplied to it, regardless of load.
- The Ideal Cell produces exactly 1 volt of energy and has a capacity of 1 Amp-Hour

And lets summarize what we've learned today:

- The duration of an Ideal Cell is equal to 60 divided by the current being drawn.
- Capacity is specified in Amp-Hours (Ah). A Cell rated at 1 Ah can provide one amp for one hour.
- Ideal Cells connected in series to form a battery have their voltages added, but their capacities do not add together.
- The amount of power a cell can produce over time is indicated by its Watt-Hour rating. This is the product of the cell's voltage and Amp-Hour rating. Our Ideal Cell is rated at 1 Wh, meaning that it can provide one watt for a full hour.
- The number of watts going into our perfect motor system is equal to the number of watts coming out. Likewise, the number of Watt-Hours going into our perfect motor system is equal to the number of Watt-Hours coming out.
- **A battery can deliver a little power for a long time or a lot of power for a little while. Either way the total amount of energy coming out is fixed by its Wh rating.**

I think that last point is the most important one for today, which is why I displayed it in boldface. To state this point another way:

> **A battery has enough power to take my plane from point A to point B. The only question I have to answer is: how fast do I want it to get there?**

Q&A

- What happens to the full throttle duration of a model if I add a cell and change nothing else? Why?
- How long can an Ideal Cell produce 15 watts of power?
- Suppose I had a cell that provided 2 volts of electricity and had a capacity of 2 Amp-Hours. How many Watt-Hours would that be? How long could the cell produce 20 watts? How long could the cell provide 8 amps of current?
- Suppose you were designing an airplane to compete in a distance task. What could you do to the battery to make your airplane travel farther?
- What does increasing propeller size do to power? Duration? How can I increase both power and duration of an electric power system?
- I need a power system that provides 300 watts from a battery composed of Ideal Cells. List two different volt/current combinations to accomplish this and the duration they will provide at full throttle.

Speaking of electric power systems, it just so happens that I have received a press release from Capable Computing announcing the release of MotoCalc version 5.0. Best of all, a trial version is available for free from their website at: www.capable.on.ca.

Press Release

Capable Computing Debuts *MotoCalc*™ 5.0 at KRC'98

The world's best electric flight performance prediction software just got better!

Allentown, September 18, 1998: Capable Computing, Inc. of Moorefield Ontario has released *MotoCalc* 5.0, the latest version of its electric flight performance prediction program for Microsoft® Windows® 3.1, 95, 98, and NT. *MotoCalc* now supports electric **ducted fans** (EDF), making it the first full-featured electric aircraft performance prediction program to do so. Other significant new features include:

The ability to specify the **flying field elevation**, which affects factors such as lift, drag, thrust, and propeller or fan input power.

New data columns, with **customizable reporting** to best suit the needs of the individual electric modeler.

Propeller constants, to better account for differences between manufacturers.

Increased limits, allowing up to 99 cells, and propellers up to 100 inches.

In addition to all these new features, *MotoCalc* continues to provide the most comprehensive facilities for electric flight performance prediction, including:

Predicts Volts, Amps, input and output Watts, efficiency, Watts/lb, RPM, thrust, pitch speed, and run time.

Tests entire **ranges** of cells, props, and gear ratios to analyze hundreds of possible combinations in just a few seconds.

Filters out undesirable combinations by any combination of current limit, power loss, efficiency, thrust, pitch speed, or run-time.

Sorts report tables by any parameter, in forward or reverse order, to find the best set-up quickly.

In-flight analysis predicts performance over the entire flight speed range, at any throttle setting.

Computes level flight time, and **climb** and

sink rates (great for sailplanes) at any throttle setting..

Graphs any one or two parameters against any other.

Very **easy to use**, with extensive motor, cell, drive system, speed control, airframe, and filter databases.

Lets you **add your own** components at any time.

Supports **Multi-bladed props** and **multi-motors** (series, parallel, multiple motors per prop, or multiple props per motor).

Provides a **motor designer** to predict the effect of different motor windings.

Visual lift and drag coefficient estimator lets you easily determine the aerodynamic information needed to accurately predict flight characteristics.

Selectable **English or Metric** measurement units.

Comprehensive **on-line manual**, with context-sensitive help.

MotoCalc 5.0 is available for download for a 30-day free try-before-you-buy evaluation from our web site, http://www.capable.on.ca/motodown.htm. *MotoCalc* on diskette is available for US $35 plus shipping and handling. Downloaded upgrades are free for already registered users, or available on diskette for US $10, shipping and handling included.

For further information, please contact Stefan Vorkoetter or Lori Albrough at 519-638-5470, or e-mail to motocalc(at)capable.on.ca.

In the U.K. and Europe, *MotoCalc* is also available from Gordon Tarling, 87 Cowley Mill Road, Uxbridge, Middlesex, UB8 2QD, Tel/Fax 01895 251551.

Reader Email

Concerning last month's column, here is an excellent letter with a lot of valuable criticisms. I like letters like this because it means that people are reading and are interested in what I am writing. Please don't hesitate to offer me encouragement and/or criticism where appropriate with this series on electric power systems. The small percentage of my readers that email me determine what the rest of you will see each month.

Email me at jbourke(at)ezonemag.com

From: Valland, Anders (Anders.Valland(at)dnv.com)

Hi Jim!

This is not meant as a grumpy mail, although you might have that feeling after reading it. You are warned. :-)

I read the column this month, and have a few comments:

* Why is it that 'everyone' seems to be so defensive when talking about maths and eflight? There is no need to be, as the maths we apply are extremely simple, and the more people who use it the better for all of us. I suggest in the future you proudly present the formula as something anyone should know or at least be able to understand. If they don't, they would probably be lost in modelling anyway.

* With reference to the first comment, don't you think anyone who has a problem understanding POWER = VOLTS x AMPS would be quite lost when you also say: 'Given a fixed propeller and motor, increasing voltage will increase current at an exponential rate. ' ?

* Since I am an engineer, I get sort of a breathing problem when you state that voltage is only half of the energy equation. Voltage IS energy. Potential energy. PERIOD.

* Power and energy are not the same, but related through time. Power is the energy spent divided by the time it takes to spend it. Which is to say that work is energy.

As I stated at first, this may seem grumpy. It is not intended to be, though. The intention is to show that the true explanation is just as simple as the one you gave. The error may not seem important, at first, but it will certainly cause confusion for those who choose to study beyond your 'freshman' course.

Before I end this mail I would like to say that I think your column is good, and that you of course should continue the course next month. I also hope you will consider my comments.

Best regards,

Anders Valland
Norway

My response is simply that Anders is right, especially in regards to my misuse of the word "energy." I will try to be more diligent in the future. At some point I will go back and correct the old articles but I will let them stand for now and allow Anders' comments to serve as the correction.

Discussion

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