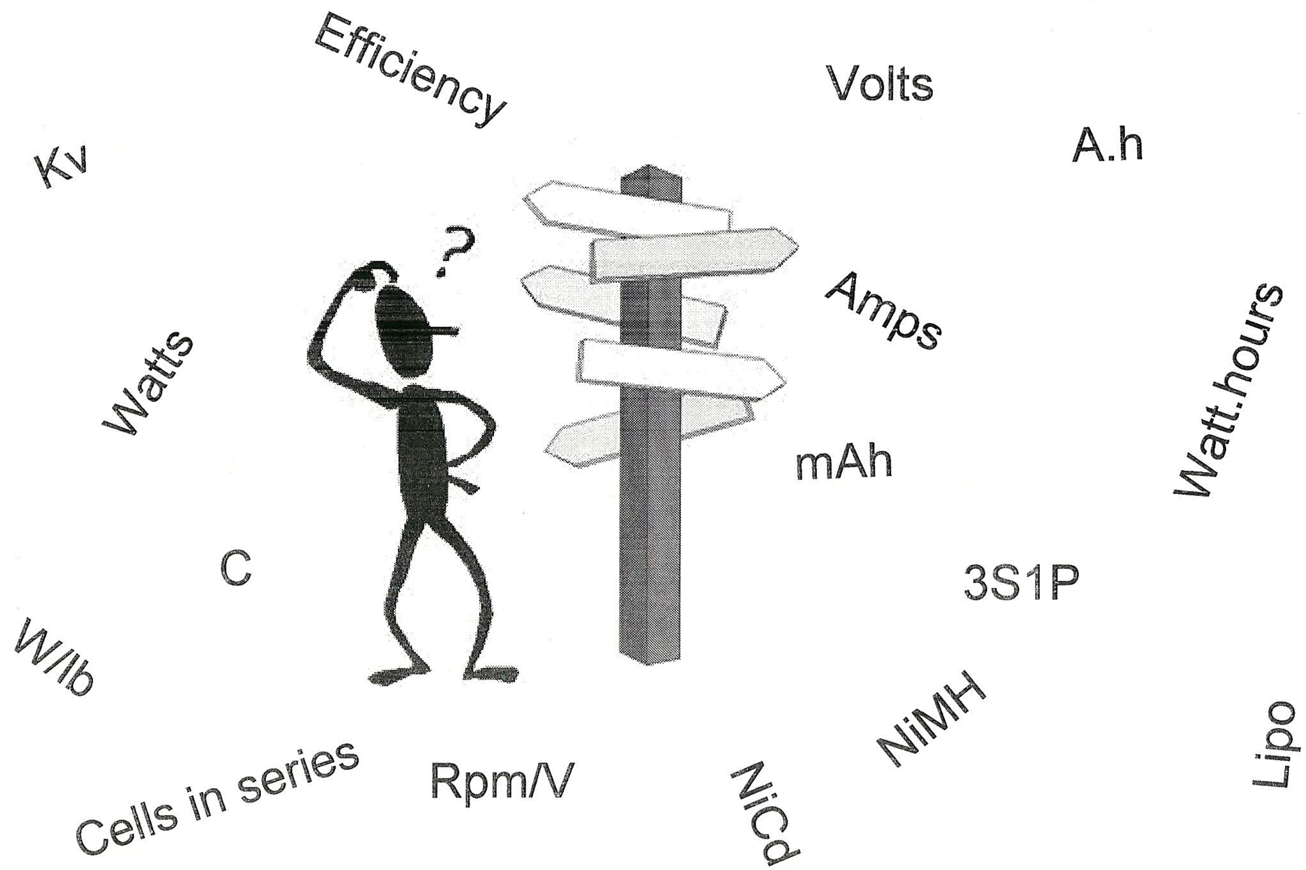
How to Specify an Electric Flight System

A Simple Walk-through

Electric Confusion



The I.C. Engine Approach

- Most I.C. aircraft have a specified engine size, whether building from a plan, kit, or ARF, E.g.
  - 0.46 – 0.61 2-stroke
  - 0.61 – 0.91 4-stroke
- This worked because all engine makes & models developed roughly the same power per cubic capacity.
  - Through years of trial and error modellers had developed a feel for engine size vs aircraft size + flying style
  - E.g. 2.5kg sport-model intended for aerobatics will fly well with 0.40 C.I. 2-stroke
- Each engine came with a recommended propeller size + fuel type
- Install the right engine with the recommended prop, use the right fuel, and success was virtually guaranteed

The Electric Conundrum

- Electric Motors have a multitude of "rating numbers"
- However, the same fundamental rule applies:

  Each model will require a certain amount of power to achieve a certain flying style

- A powered aircraft needs thrust to fly, and thrust is proportional to power
  - Most IC modellers are not aware how much power their engines develop
  - Manufacturers specs are usually optimistic, e.g. 1.6 BHP @ 16,000rpm, open exhaust!

So all we need is Power?

- Fundamentally YES...
- BUT... there are MANY variables we must correctly specify to make a system work:
  - Battery voltage
  - Battery capacity and C-rating
  - Speed Controller size (voltage and current capacity)
  - Motor speed constant (Kv)
  - Propeller size
- No aircraft comes with all of these items covered, and usually they are not covered at all!
- To specify an electric power system you need to be prepared to apply some <u>simple MATH</u>

Measuring Power

- Electrical Power (P_{IN}) is determined by voltage (V) x electrical current (I):

$$P_{IN} = V.I$$

- Motor Power (P_{OUT}) is determined by torque (τ) x angular velocity (ω):

$$P_{OUT} = \tau.\omega$$
$$= \tau \times rpm \div 0.105$$

- The system's efficiency (ε) is determined by:

$$\varepsilon = P_{IN} \div P_{OUT}$$

- Torque is difficult to measure.
- For simplicity we work from input power, and assume an efficiency

Determining the Required INPUT Power

- The required power is a function of the weight of the plane, and the flying style desired
- Experience has yielded the following INPUT Power requirements:

Power Loading		
W/lb	W/kg	Flying type
50	112	Slow-speed - will barely fly
75	167	Sport flyer, non aerobatic
100	223	Mild aerobatics, slow climbing
125	279	Good aerobatics, strong climbing
150	335	3D flight, unlimited vertical
200	446	Hot aerobatics, fast vertical
250	558	F3A pattern - speed control in vertical
300	670	Ducted fan jet

Note that these are based on BRUSHLESS motor systems

Case Study

- A modeller purchases an ARF electric powered glider
- The instructions come with no details about the necessary power system
- The model specifications say the glider should weigh 800g ready to fly

Input Power Requirement

- We are seeking a strong climb-out but not "hotliner" out-of-site vertical
- The table suggests we need a Power Loading of **280**W/kg for a strong climb
- The required input power is therefore:

$$P_{IN} = \text{Power Loading} \times \text{Weight}$$
$$= 280 \times 0.800$$
$$\mathbf{= 224W} \quad (\sim 225W)$$

- The power system including motor, ESC and battery must be capable of drawing *at least* 225W

Battery Specification

- With known power required from the battery, we can then start to specify the battery
- We need to specify the voltage (V), and also the charge capacity (Q)
- Voltage is determined by the number of cells
- Charge capacity is determined by the "mAh" rating of the cells (chemical energy stored in the cells)

Specifying the Battery Voltage

- This must be done by ITERATION
- We nominate a voltage, and try to minimise the current
- Assuming a Lipo battery, we will have a working voltage (voltage under load) of around 3.4V per cell <u>IN SERIES</u>
- Assume 3 x cells (3S) Lipo:
  - Working voltage = 3 x 3.4 = 10.2V
- Since P = V.I, we rearrange to get:

$$I = P \div V$$
$$= 225 \div 10.2$$
$$\mathbf{= 22.0\ Amps\ (A)}$$

  - When our system is working at full power, the motor will draw a current of 22.0 Amperes from the battery
  - If we had nominated 4S, V = 13.6V, I = 16.5A… not much less current
  - If we had nominated 2S, V = 6.8V, I = 33.0A… considerably more current!
- A 3S battery that needs to supply 22A is a good specification for this system

Lipo Cell Voltage	
Nominal:	3.7V
Fully charged:	4.2V
Working:	**3.4V**
Discharged:	3.0V

Specifying the Battery Charge Capacity

- Charge = current x time
- Equation is Q = I.t
  - Expressed as A.h or mA.h
  - NOT expressed as Amps, mA, or milli-amps
- By nominating the run-time of the system, we can calculate the charge
- Let's expect it takes 1 minute to get the glider to gliding height, and we want to do this 4 x times per flight – i.e. 4 minutes of motor run-time

$$Q = I.t$$
$$= 22.0 \times 4 \div 60$$
$$= 1.46 \text{ A.h or } 1470\text{mA.h}$$

for a throttled system we would use the AVERAGE current

- A 1460mAh charge capacity 3S battery will work, but it will be absolutely dead at the end of the flight.
  - It is best to only deplete 75% of the full charge capacity for long cell life
  - We therefore need Q = 1460 ÷ 75% = 1960mA.h
- We require a 3S battery with ~2000mA.h charge capacity

Specifying the Battery C-rating

- C-rating is a measure of a battery's current capacity as a function of its charge:

  $C = I \div Q$
- The higher the C-rating, the more current the battery can deliver
- In this example, we are drawing 22A from a 2000mA.h battery (2.0 A.h):

  $$C = 22 \div 2.0 = 11$$

  i.e. **the battery must be rated at least to <u>11C</u>**
- Most modern batteries are rated to at least 15C, and many are 20+
- A 2000mA.h battery (2.0 A.h) rated to 20C is capable of delivering 2.0 x 20 = 40A of current!

Speed Controller Selection

- Electronic Speed Controllers (ESCs) are specified by current and voltage capacity, e.g. “2S – 6S, 40A”
- Brushless controllers must be used with brushless motors
  - Brushed controllers and motors have 2 x power supply wires
  - Brushless controllers have 3 supply wires
  - All controllers have 2 wires that connect to the battery
- Specification is simple:
  - Voltage must meet (or preferably exceed) our requirements
  - Current capacity must exceed our requirements by at least 20%
- We need a 3S+ capable ESC
- To handle 22A, the controller must be rated to handle at least 25A, and preferably 30A
- A good selection is a **3S 30A brushless ESC**

Motor Specification

- Motors often have confusing specifications, e.g.:
  - Graupner Speed 380BB
  - Axi 2808/16
  - HiMax C3030-1000
- Most of these numbers are **IRRELEVANT**
- We need only 2 x numbers:
  - Rated Power
  - Speed Constant (Kv)

Motor Specification 1 – Max Power

- Sadly the POWER is not usually listed.
- A good rule of thumb is:

  Max Motor Power = Motor Weight (g) ~~÷~~ × 4
- **If a supplier cannot tell you either a motor's (1) max power or (2) weight, then don't buy their motor!**
- We want a motor capable of handling 225W and ~13V
  - A 250W motor will have no trouble
  - We will be doing relatively short runs, so we can push a slightly lower rated motor (e.g. 200W)
  - Alternatively, we want a motor that weighs at least 56g (224 ÷ 4)

Motor Specification 2 – Speed Constant

- Every electric motor will want to turn at a certain speed (rpm) depending on the applied voltage
  - This is expressed as a motor speed constant (Kv), e.g. 1000rpm/V

$$\text{Motor Speed (rpm)} = Kv \times V$$

- We will be sending 10.2V to the motor. Resulting motor speeds will be:
  - 500rpm/V will attempt to achieve 5200rpm
  - 1000rpm/V will attempt to achieve 10200rpm
  - 6000rpm/V will attempt to achieve 61200rpm!!!
- GREAT! Let's go for 61200rpm and select 6000rpm/V… WRONG! WRONG! WRONG!

Motor Speed Constant vs Propeller Selection

- The higher the rpm, the higher the load on the motor, and hence the greater the power draw
- The bigger the propeller, the higher the motor load, and the greater the power draw
  - A 7x5 propeller draws more than twice the power of a 6x3 at the same rpm
- High revving propellers are less efficient than low revving propellers
- Clearly we want to specify a propeller and a motor constant that will draw 225W at full motor power, at reasonable efficiency
- A good rule of thumb for electric is to target 6000 – 10,000rpm
  - Higher rpm is less efficient
  - Lower rpm will need a big propeller to draw the power

Motor Speed Constant Selection

- The speed constant (Kv) is the UNLOADED speed of the motor
  - As the load increases, the motor will slow down – called SLIP, BUT it will draw more power (unlike IC)
  - Slip is typically 20% - 30%
- The 1000rpm/V motor on 3S will turn at 10,200rpm with no load, but at about 7000rpm under load – IDEAL!

Typical Speed Constant Requirements

Number of Lipo cells in series	Min kV	Max kV
2	1500	2000
3	900	1500
4	700	1100
5	600	900
6	450	750
7	350	600
8	250	450
10	200	300
12	150	250

Notes:

1. Helicopters and ducted fan jets need vastly higher speed constants
2. Gearboxes step-down the speed constant (e.g. 6000rpm/V into a 6:1 gearbox equates to 1000rp/V)

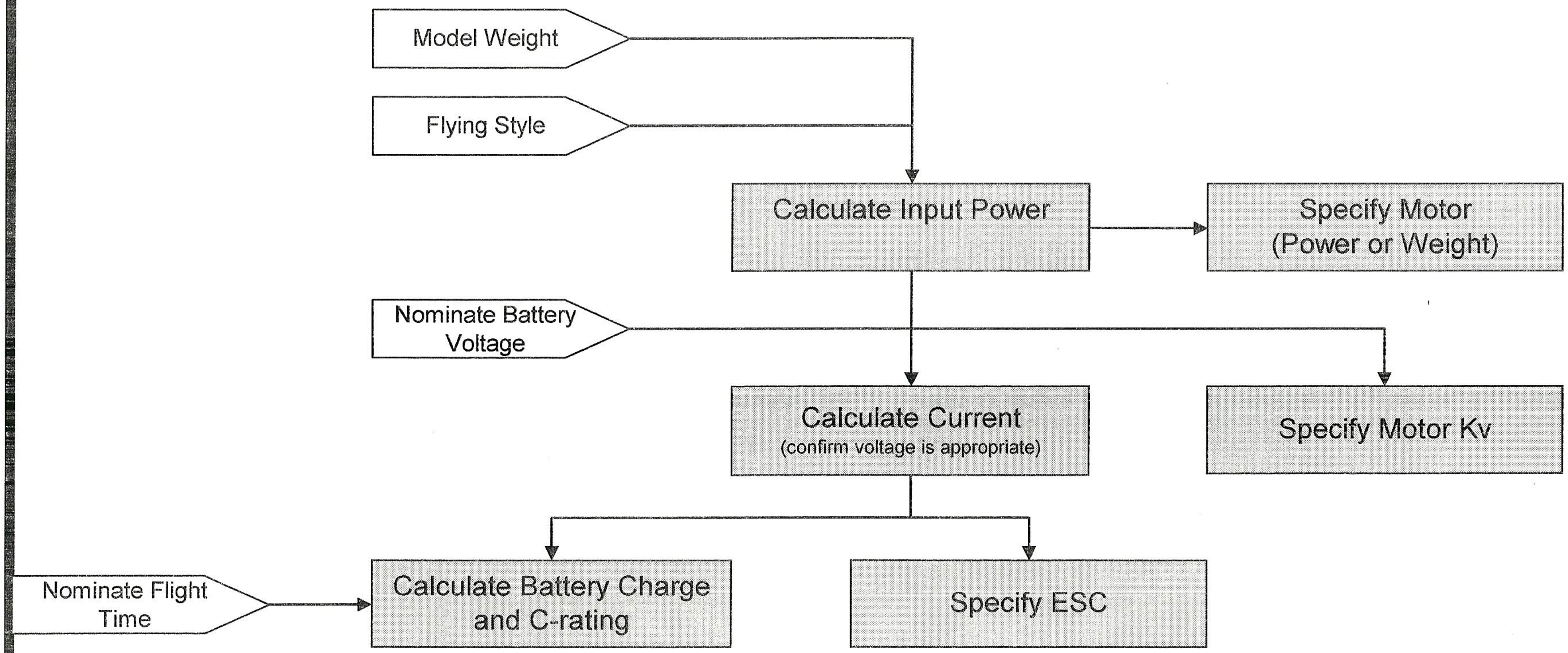
Propeller Selection

- Select a propeller size that will draw the appropriate power at the expected rpm
- Our motor will be turning the prop at ~7000rpm
- From experience, a 10x6 propeller will draw around 200 – 250W at this rpm
- When selecting a motor, check if it has a recommended prop size
- Experimentation will be needed to select the appropriate propeller that loads up the motor to 225W

Resultant Power System

- Brushless Outrunner motor:
  - 200+W power rating or ~55g weight
  - Kv = 1000rpm/V
  - Max Voltage 13+V (or 3S+)
- Brushless ESC:
  - Max Voltage 13+V (or 3S+)
  - 30A current capacity
- Lipo Battery:
  - 3 cells in series (3S)
  - 2000mA.h charge capacity
  - 15+ C-rating
- Propeller ~10x6 (confirm with testing)

How To... Flowchart



<u>Experiment with different Propellers to achieve target power draw</u>

Need help? Feel free to contact me: Lawrie.Henrickson@hotmail.com, or call 905 817 1087