

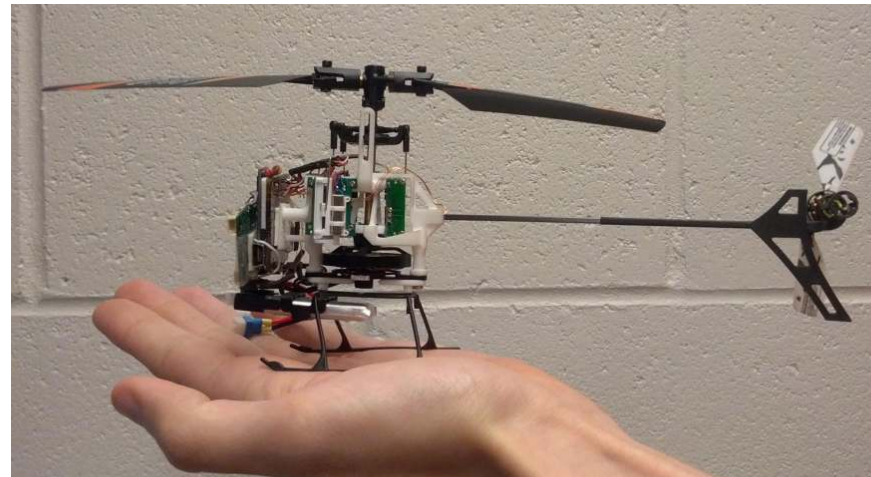


Introduction to Motor and Propeller Testing and Selection for
Quadcopters Designers
© Tyto Robotics December 2015

Objective

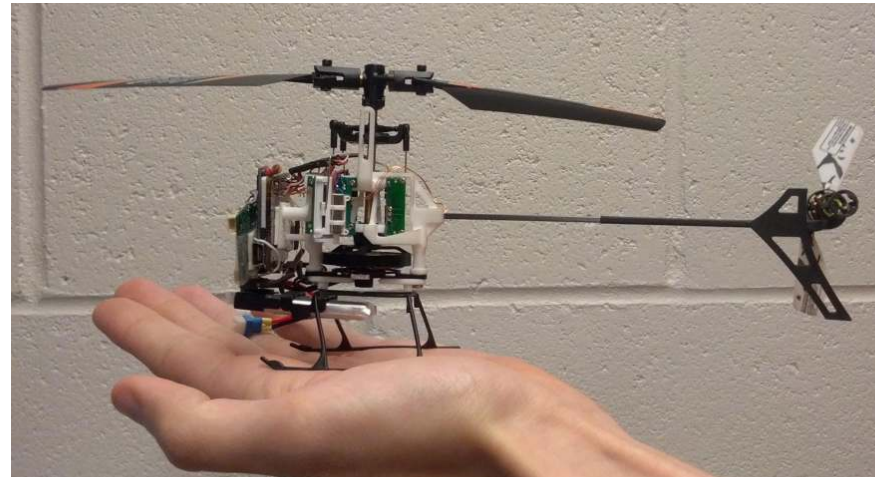
Problem

- Low flight time
- <30% Efficiency



Objective

- Understand
 - Basic motor and propeller theory
 - Motors and propeller testing
- Improve
 - Performance
 - Range
 - Flight time in your design



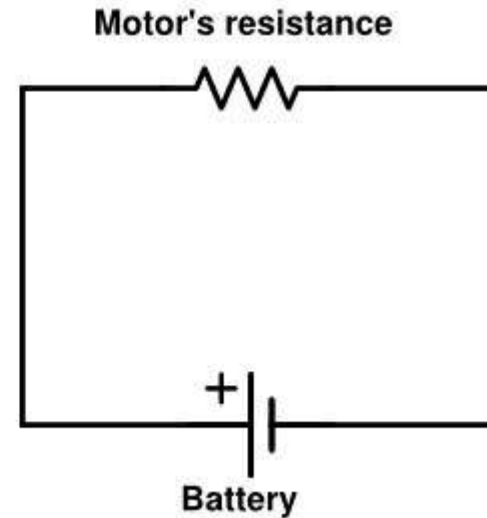
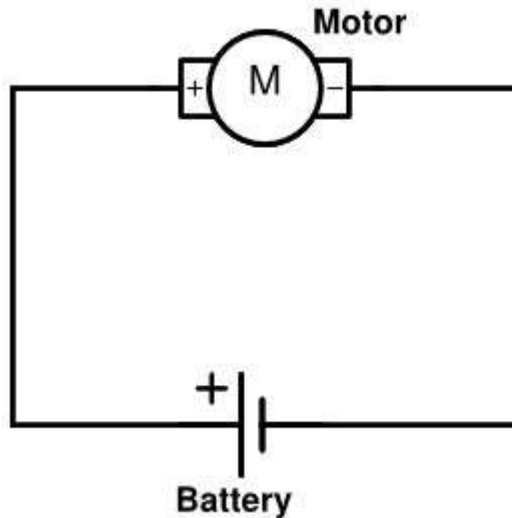
Coil and magnet model



Stall motor model

Voltage and power relationship

$$V = RI$$



Stall motor model

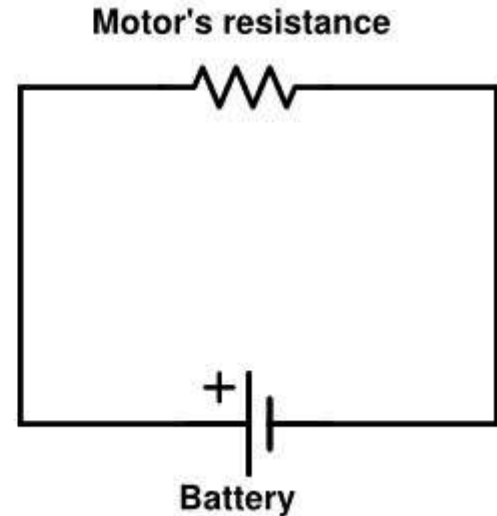
Power loss (heat)

$$P = RI^2$$

Example

11.4V battery with 0.3116Ohms

36.5A and 417W.

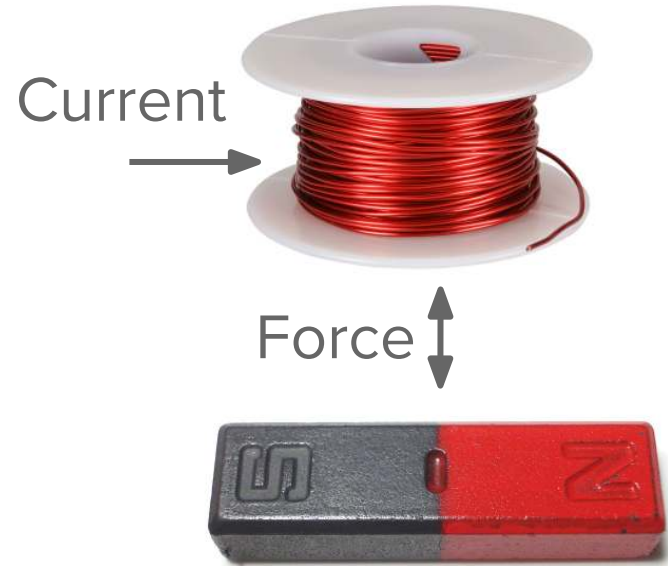


Model with electromagnetism

Force is proportional to current I
and number of turns on coil N_c

$$\text{Force} \propto \text{Current} * N_c$$

$$\text{Torque} = \text{Current} * K_T$$

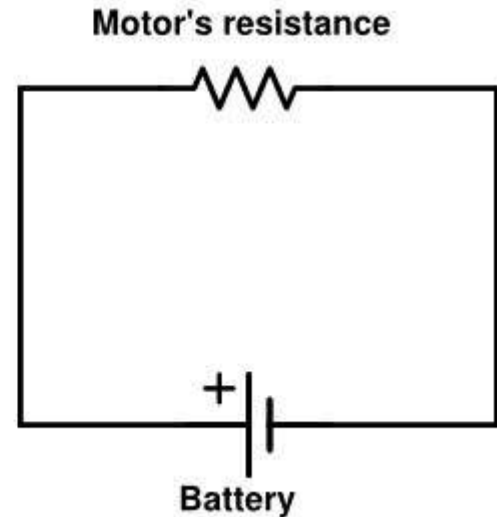


Stall motor model

Force is proportional to current I
and number of turns on coil N_c

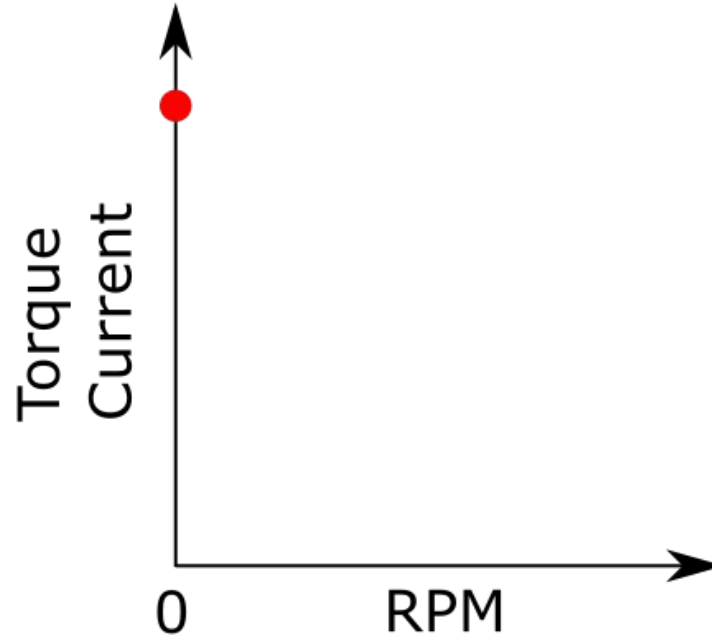
$$\text{Force} \propto \text{Current} * N_c$$

$$\text{Torque} = \text{Current} * K_T$$



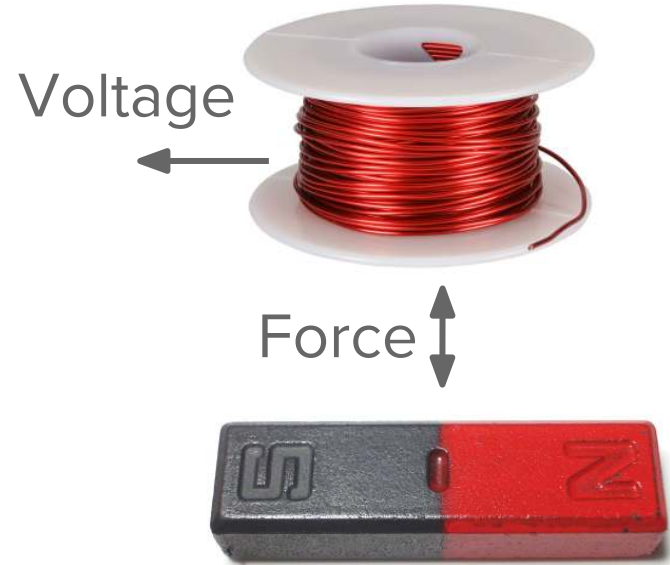
Torque-RPM graph

$$\text{Current} * K_t = \text{Torque}$$



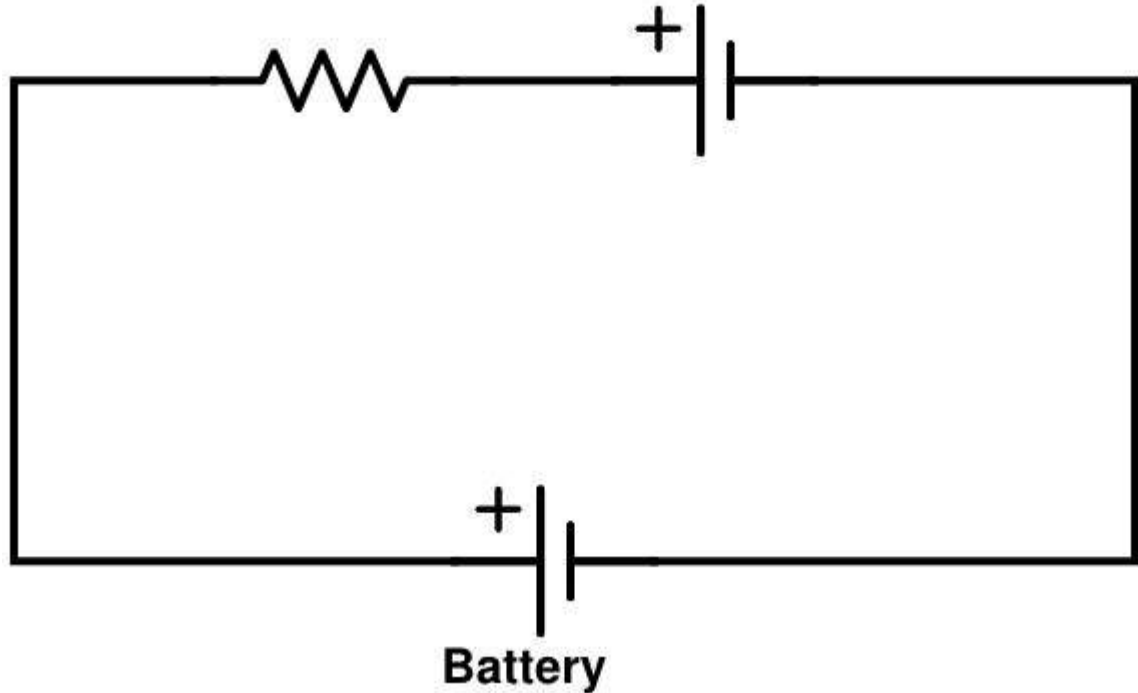
Back EMF

A magnet moving close to the coil will generate a voltage



Motor with back EMF

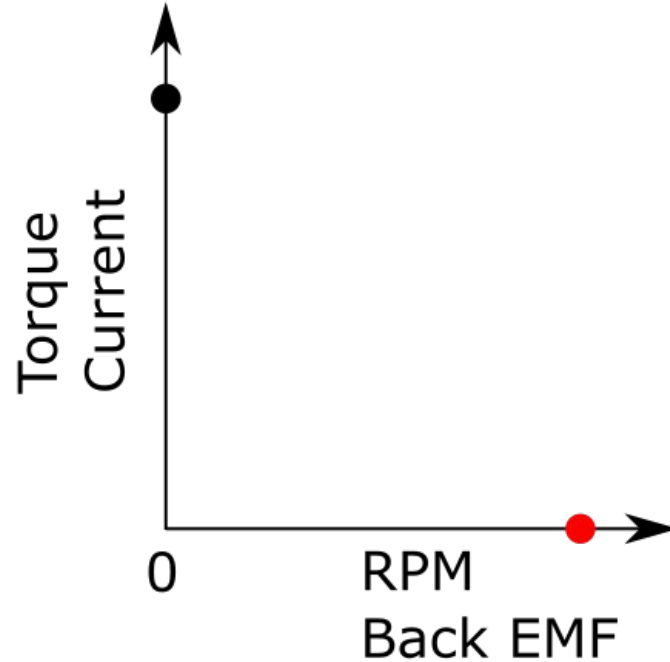
Motor's resistance Motor back EMF



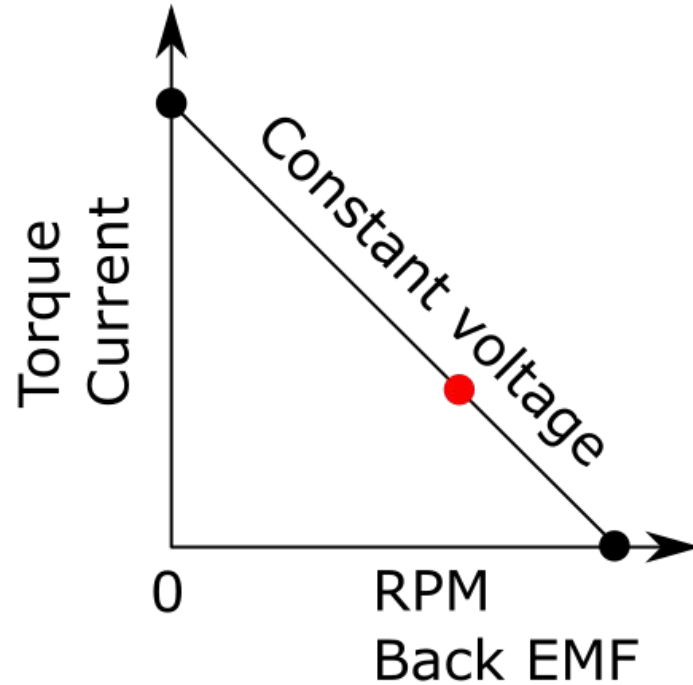
$$\text{RPM} \propto \text{Back EMF}$$

No load motor

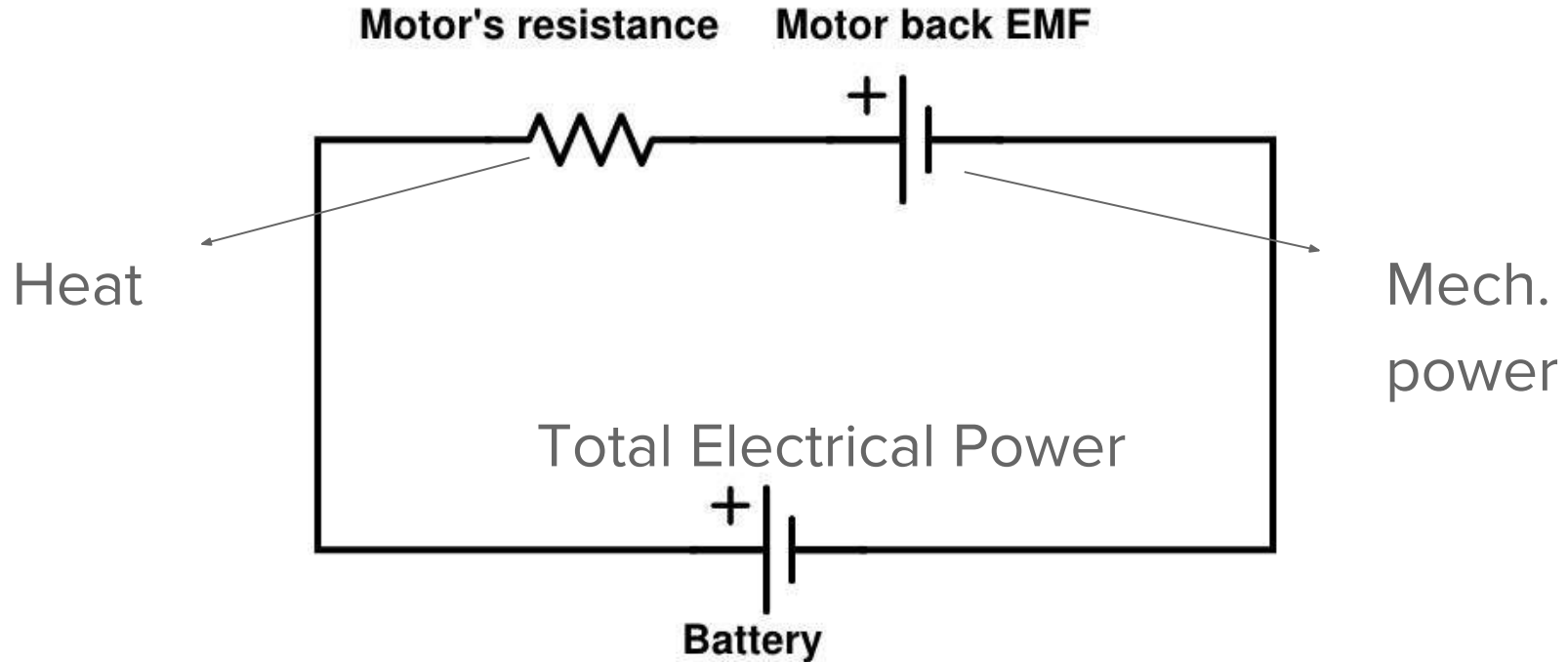
$$K_V * V_{batt} = \text{No load RPM}$$



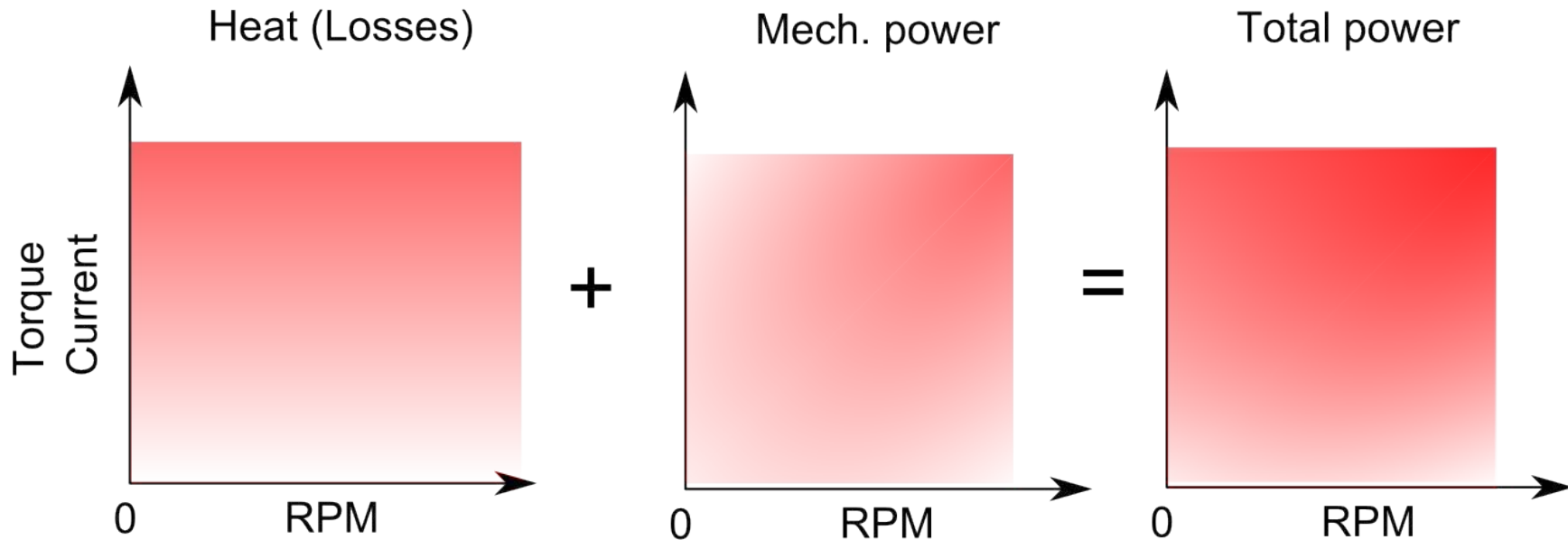
Constant Voltage - ESC input



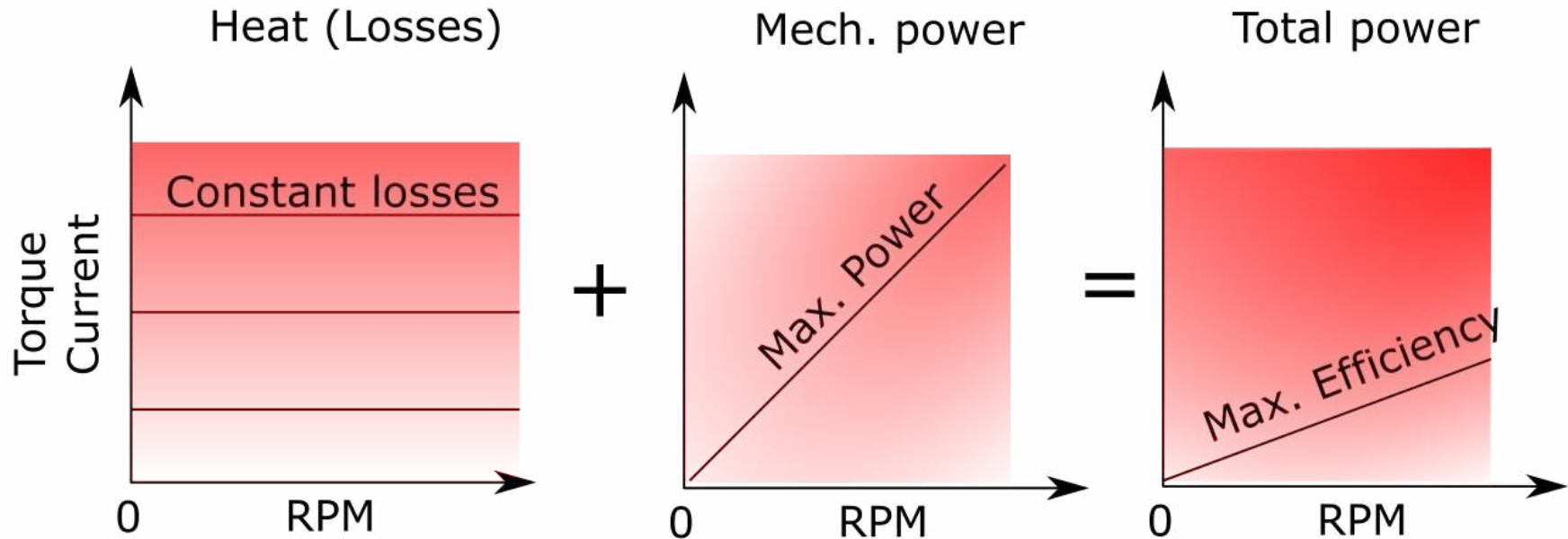
Power



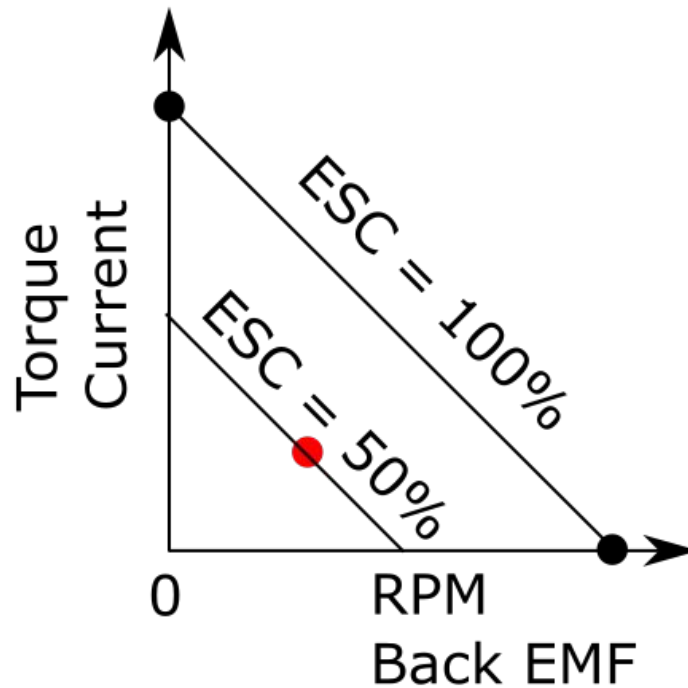
Energy distribution in motor



Energy distribution in motor



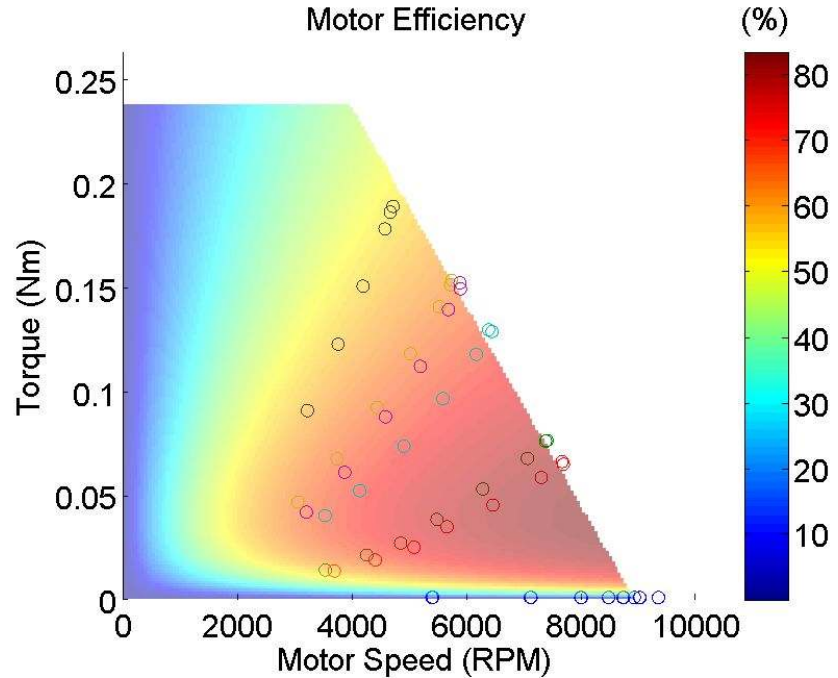
Varying voltage



Motor Efficiency

Efficiency =

$$\frac{\text{Mechanical power}}{\text{Electrical power}}$$



Anatomy of an outrunner

Rotor

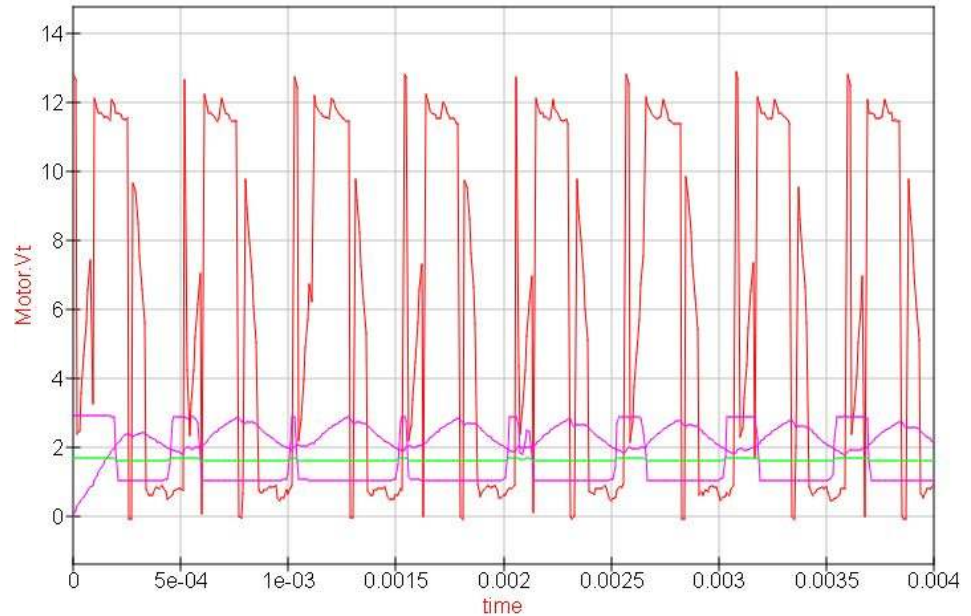


Stator

3 Phases, 10 poles, 12 coils

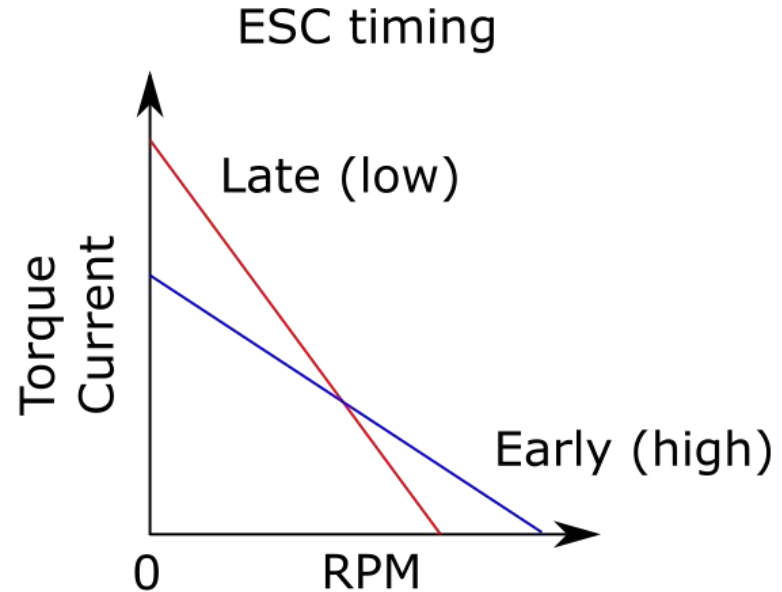
Note on ESC and phases

- Half sine wave or triangular wave.
- Generated by rapid switching of transistors.



Timing

- Phase timing changes K_v
- Dynamic timing can maximize power or efficiency.



Other effects

Bearing friction

No-load current

ESC settings

Thermal limitation



Propeller definition

Diameter: usually in inches.

Pitch: How much the propeller would move forward in one turn in a gel like medium.

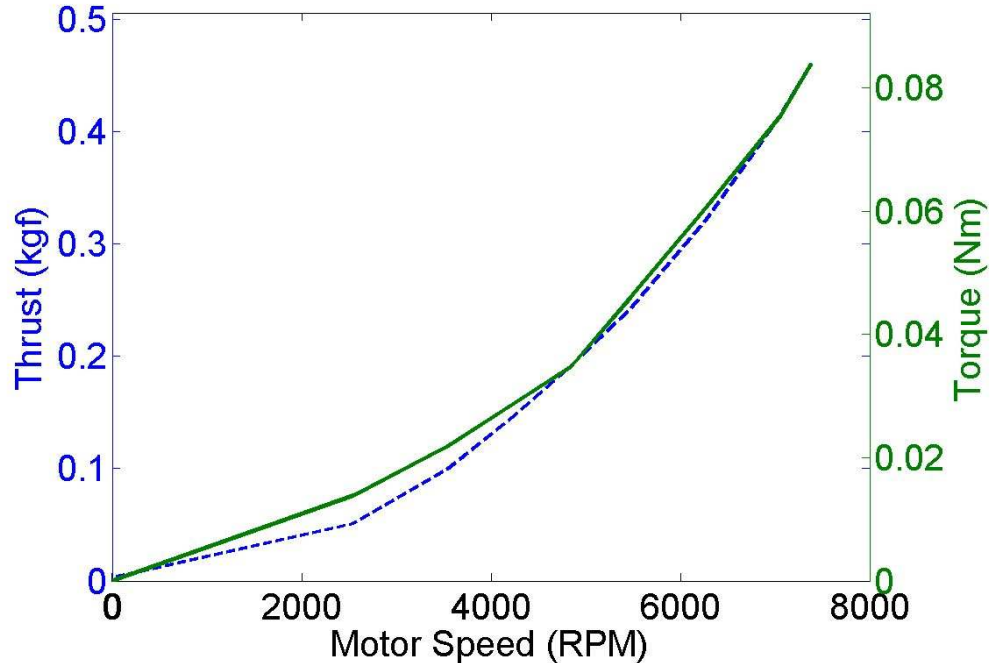


Static thrust

$$\text{Thrust} = C_T * \text{speed}^2$$

$$\text{Torque} = C_R * \text{speed}^2$$

Static torque and thrust of a 8x6 propeller



Dynamic thrust

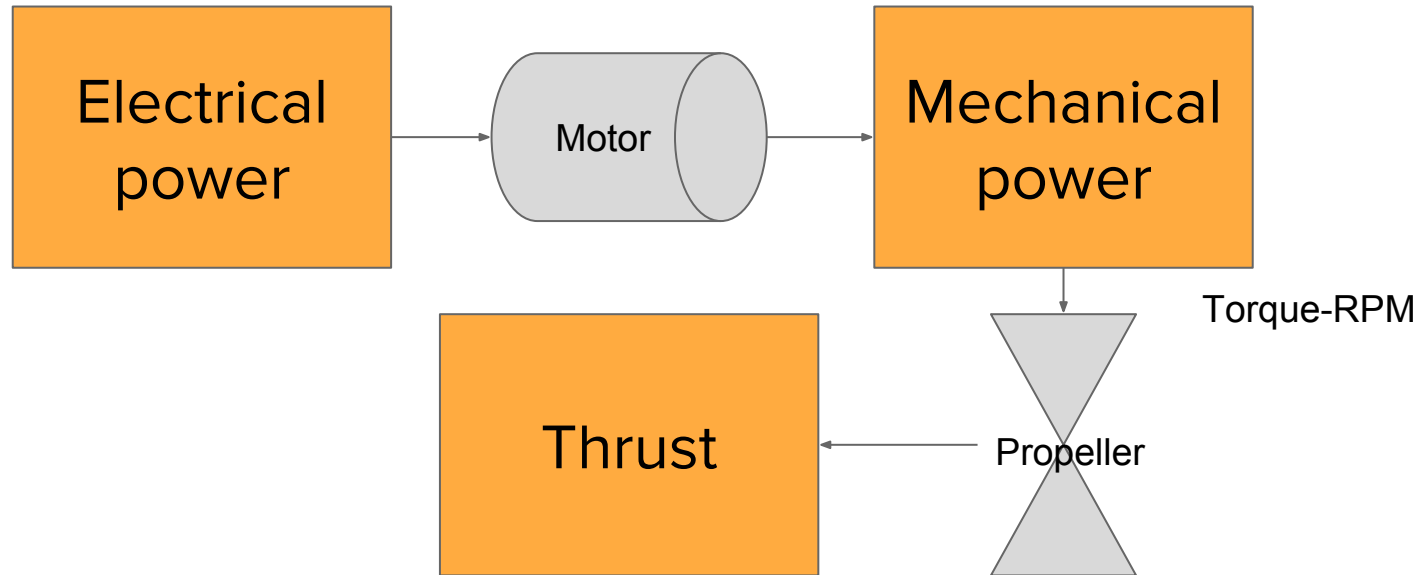
Higher airspeed: Use high pitch

Low airspeed: Use low pitch

Use equations to correct for airspeed.

Testing Efficiency

Motor efficiency * Propeller Efficiency = Overall efficiency



Propeller efficiency

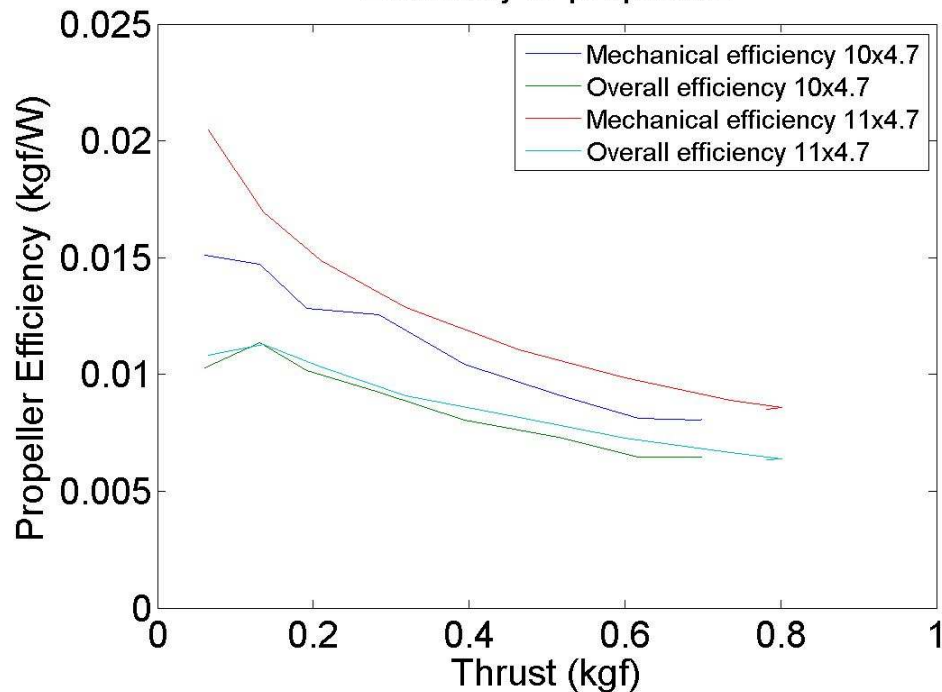
Propeller Efficiency =

$$\frac{\text{Thrust}}{\text{Mechanical power}}$$

Overall Efficiency =

$$\frac{\text{Thrust}}{\text{Electrical power}}$$

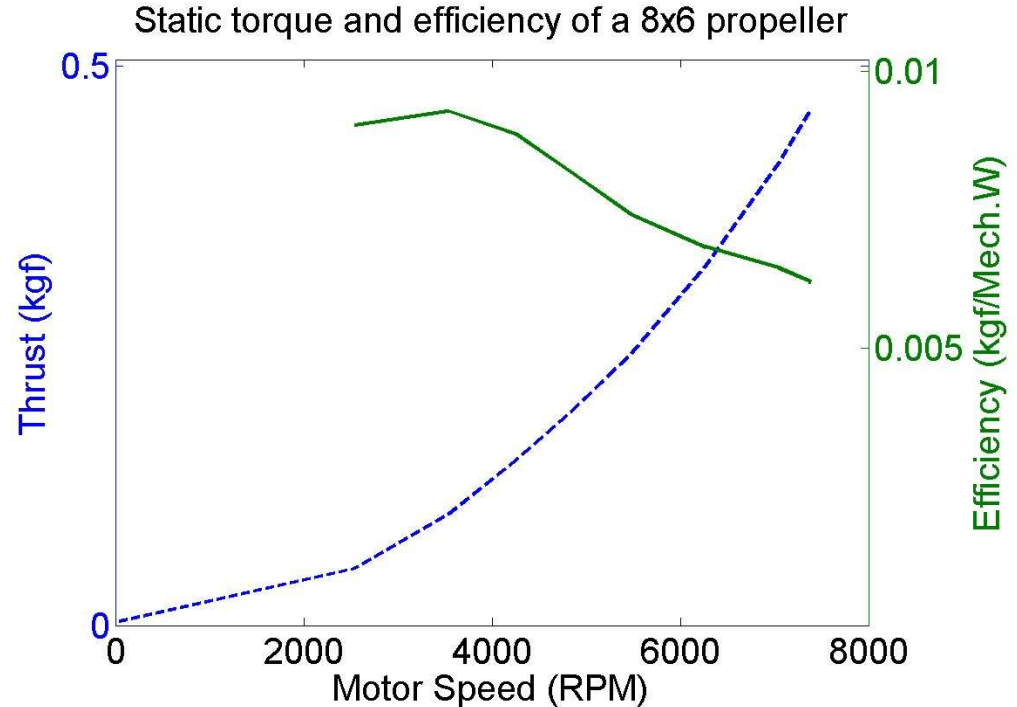
Efficiency of propellers



Propeller testing

Increase propeller efficiency with:

- Large propeller
- Slow propeller



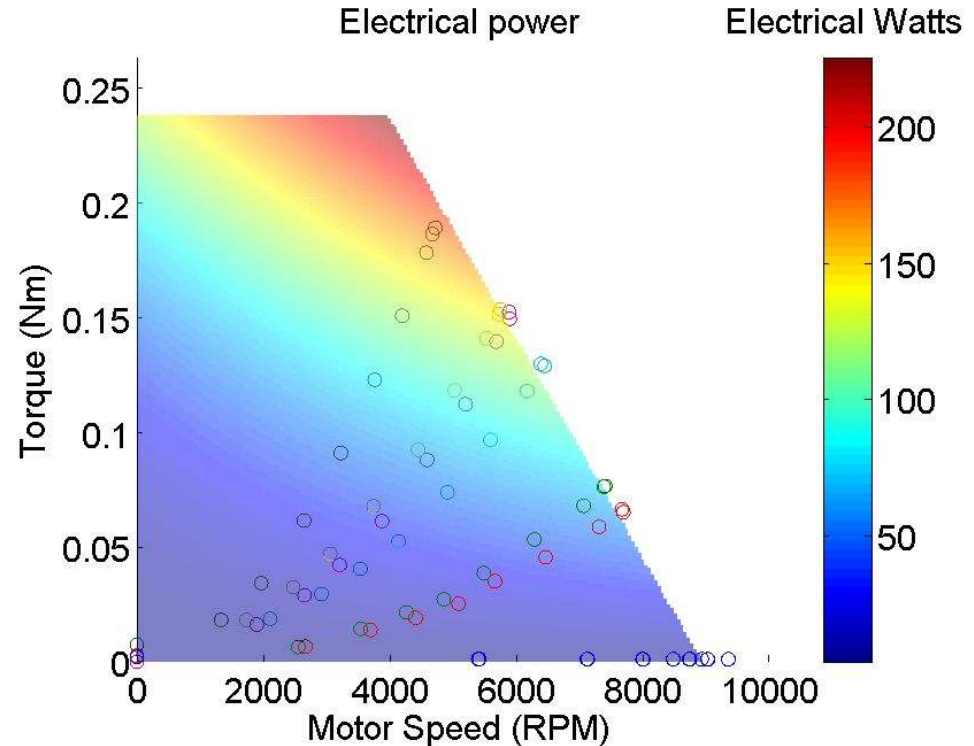
Motor testing

Objective:

Test multiple torque-RPM combination

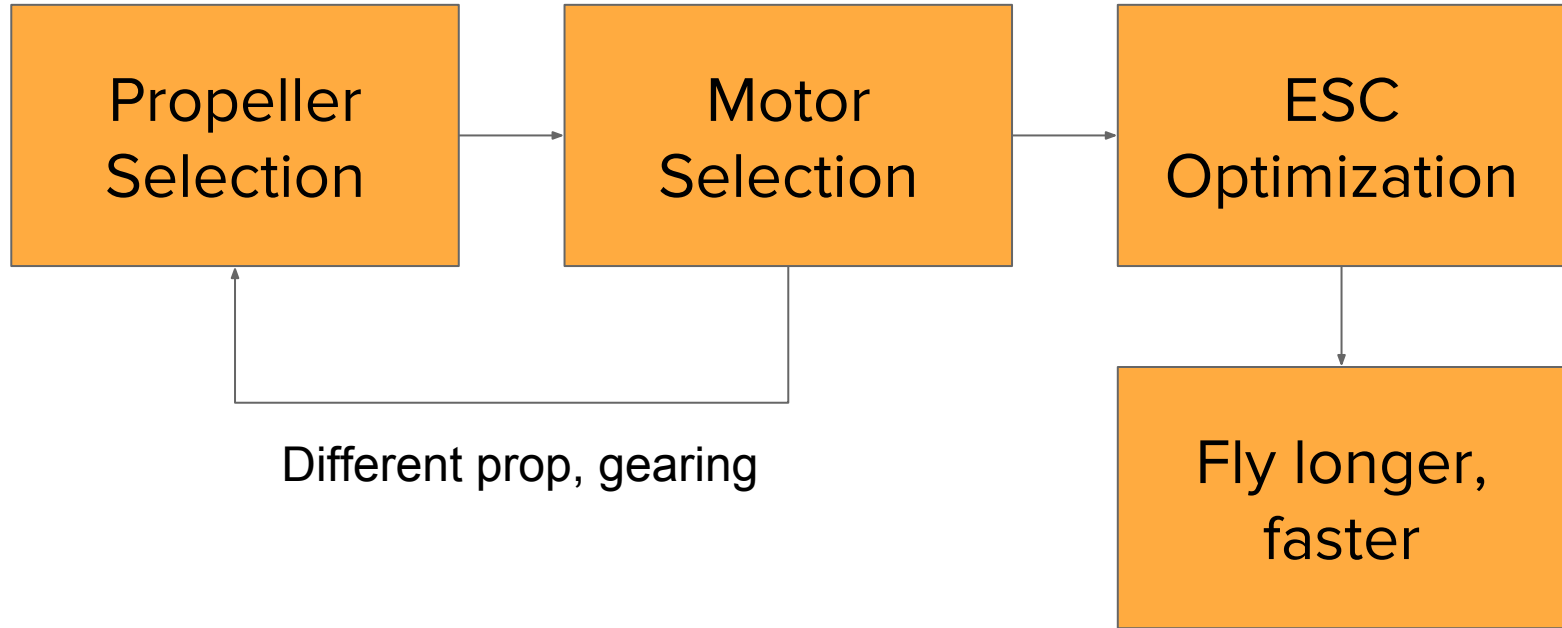
Loading:

Load with propellers



Selection of motor/propeller

Torque-RPM



RCbenchmark overview

- Thrust
- Torque
- RPM
- Voltage
- Current
- Mechanical power
- Electrical power
- Motor efficiency



- Propeller efficiency
- Overall efficiency
- Coil resistance

RCbenchmark overview

- Manual tests
- Automated tests
- Scripting

The screenshot displays the RCbenchmark software interface. On the left is a navigation menu with options: Welcome, Setup, Utilities, Safety Cutoffs, Manual Control, and Automatic Control (highlighted). Below the menu, it shows 'COM5' selected and a 'Disconnect' button. Hardware status is 'Connected!' (Series 1580, firmware v1.7). Sensor data includes Voltage: 0.00 V, Current: 0.00 A, Elec. Power: 0 W, Thrust: 0.326 kgf, Torque: -0.210 N·m, Weight: 0.272 kg, and Vibration: 0.1 g. Motor speed is 0 RPM for both 10 poles and 1 tape. A 'Tare Load Cells' button is present. A warning message states: 'Warning: wear safety goggles, keep away from rotating parts, and check fasteners are tight. Operating equipment beyond operating limits is a safety hazard. Do not operate unattended. Safety is the responsibility of the user. Pressing SPACEBAR will cut throttle.' A large red 'Stop' button is overlaid on the warning. The main window shows 'Script: Sweep - discrete' with 'Return' and 'Clone' buttons. The console log contains the following text:


```
> Started script: Sweep - discrete.js
> Initializing ESC...
> Setting "esc" to 1000
> Waiting 4 seconds...done
> Creating new log file with "StepsTest" prefix in working directory
> Starting Steps Up...
> Stepping esc from 1000 to 1400 in 4 steps.
>   step 1 of 4 (val: 1100).
```

 At the bottom, the 'Real-time plots' section has checkboxes for Acc, RPM (checked), Torque, Thrust, ESC Power, and Efficiency. The plot shows a single data point for RPM at approximately 1100. The x-axis is labeled with values 650, 700, 750, 800, 850, and 900. On the right, the plot title is 'Motor rotation speed' with sub-values: Electrical: 0 RPM and Optical: 0 RPM.

Questions?

