Motors and ESCs
1. Design
2. Selection

Lecture 4B: Motors and ESCs

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In this lecture you will learn:

- The fundamentals of converting stored energy into thrust
- The elements of a propulsion system

Most propulsion system for drones are based on lithium polymer battery technology

Motors and ESCs
1. **Design**
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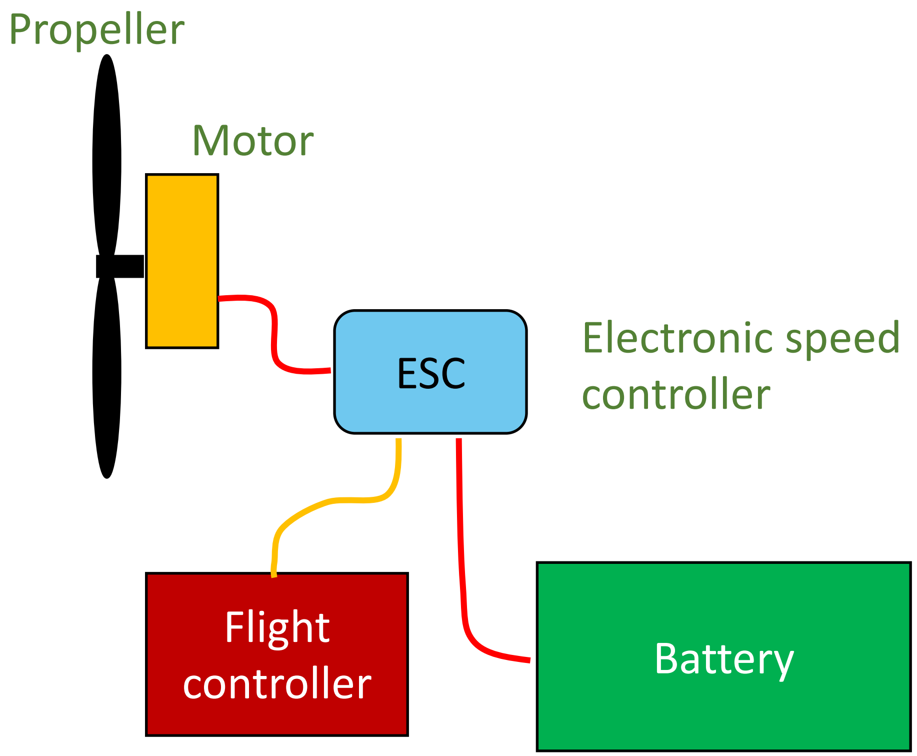
- The main elements of a propulsion system include:
  - Propellers
  - Motors
  - Speed controllers
  - Batteries
  - Sensors (feedback and health monitoring)



VTOL propulsion: Motors

Motors and ESCs
1. **Design**
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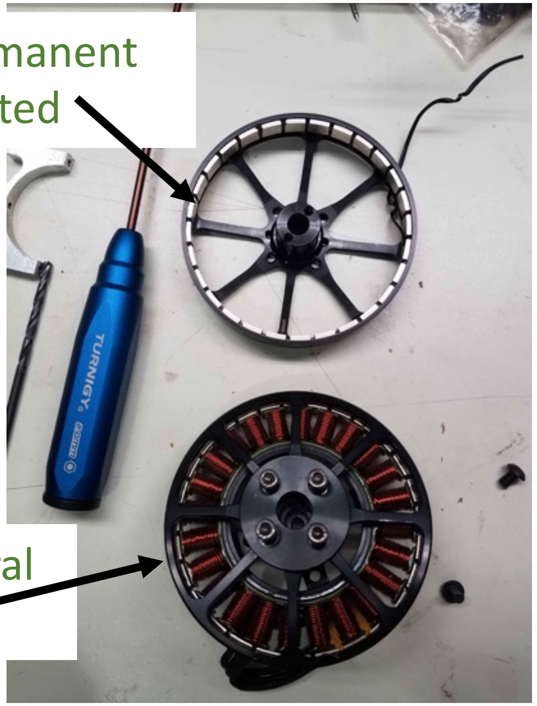
- Brushed and brushless DC motors work by energizing a series of electromagnets that are radially mounted within the motor body
- Combined with a series of magnets, a controlled magnetic force is created between the stator (fixed electromagnets) and the rotor (rotating outer shell with permanent magnets)
- Controlling the timing of the magnetic force results in a torque applied to the rotor

VTOL propulsion: Motors

- Outrunner motors are simple and lightweight which has contributed to their popularity
  - In an outrunner motor, the magnets rotate (rotor) about the wound magnets (stator) which remain stationary
  - The stator magnets are controlled by the electronic speed controller (ESC)
  - Because of this configuration, the motor does not have brushes and it runs about 10% more efficient than a brushed motor version



VTOL propulsion: Motors

- Outrunner motors also have the advantage of having many more poles than a typical brushed motor which gives them higher torque at lower RPM
  - This is better suited to the operating conditions for a motor/prop system
  - Motor performance may be described in terms of tested thrust as a function of power consumed
    - This represents a single datapoint of maximum thrust generated, whereas these motors will operate normally at much lower power settings
    - The propulsion data is also dependent on the selection or the propeller

The T-Motor Antigravity 1005 is a 255g motor that claims to provide 11.5g thrust/Watt

VTOL propulsion: Motors

- Common classifications of outrunner motors:
  - Some companies use a four digit reference to classify motors
    - A 2207 motor, for instance, would be 22mm in diameter with a 7mm stator height
  - KV rating of a motor is also used to define the speed at which the motor rotates
    - The KV value multiplied by the nominal voltage represents the theoretical no-load RPM of the motor
    - A 2300 KV motor running on a 2S battery would, for instance, turn at RPM = 2300 x 3.7 x2 = 17020 RPM

The VT hex on the right uses T-motor 7005 KV230 motors, the S-500 on the left uses KV880 motors

VTOL propulsion: Motors

- The KV rating tells a lot about motor performance
  - The KV rating provides, most fundamentally, the rotational speed of the motor for a given applied voltage
  - KV also indicates the relative torque we can expect from the motor
    - A low KV motor has more windings of a thinner gauge wire which will carry fewer amps but at higher voltage, providing a higher torque output at low RPM
    - A high KV motor has fewer windings of a thicker gauge wire which will carry more amps at a lower voltage, turning the motor at a higher RPM with lower torque

The S-500 has 2216 KV880 motors and uses a 4S battery

T-Motor performance chart for the 7005 KV230 that powers the VT hex

Motors and ESCs
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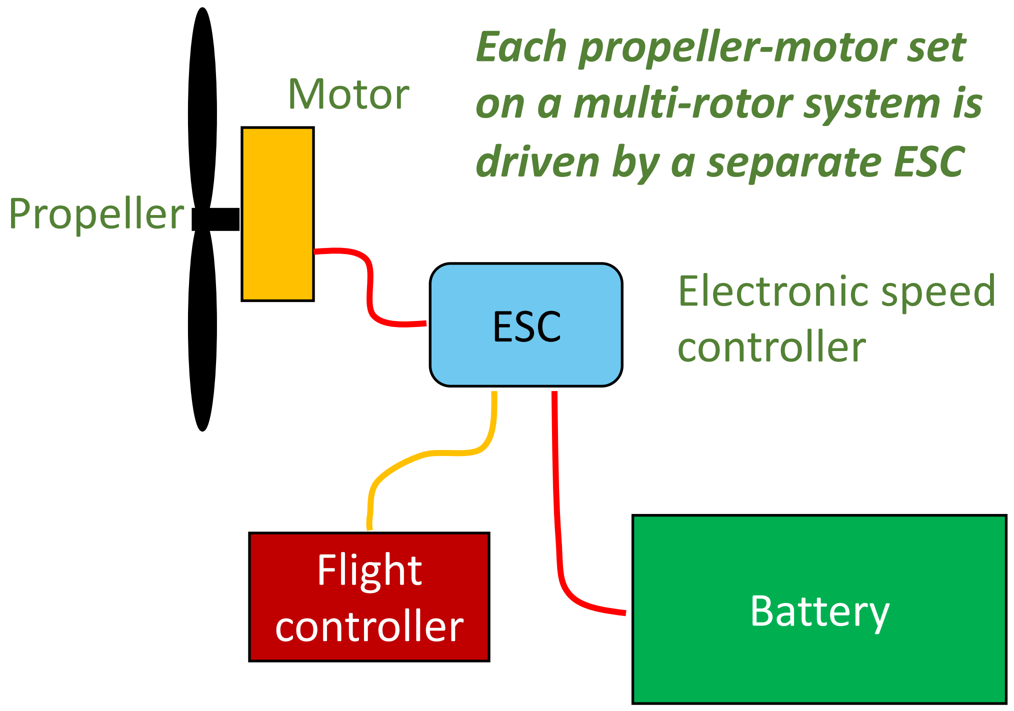
Item No.	Propeller	Throttle	Voltage (V)	Current (A)	Input power (W)	RPM	Torque (N*m)	Thrust (g)	Efficiency (g/W)	Operating Temperature
MN7005 KV230	T-motor P24*7.2CF	40%	23.79	4.40	104.60	2023	0.39	1407	13.44	64℃ (Ambient temperature ：21℃)
		42%	23.78	4.79	113.88	2104	0.42	1501	13.17	
		44%	23.77	5.18	123.19	2165	0.43	1592	12.92	
		46%	23.75	5.71	135.63	2266	0.46	1698	12.51	
		48%	23.73	6.43	152.48	2347	0.49	1837	12.04	
		50%	23.71	7.04	167.01	2456	0.52	1951	11.68	
		52%	23.69	7.65	181.11	2531	0.54	2063	11.39	
		54%	23.67	8.18	193.69	2596	0.57	2153	11.11	
		56%	23.65	8.83	208.71	2684	0.60	2261	10.83	
		58%	23.62	9.53	225.12	2762	0.63	2378	10.56	
		60%	23.60	10.23	241.40	2835	0.65	2491	10.31	
		62%	23.58	10.96	258.50	2906	0.69	2605	10.07	
		64%	23.56	11.60	273.39	2967	0.72	2708	9.90	
		66%	23.52	12.64	297.29	3050	0.75	2841	9.55	
		68%	23.50	13.50	317.15	3120	0.78	2948	9.29	
		70%	23.47	14.31	335.87	3182	0.81	3060	9.10	
		75%	23.40	16.53	386.77	3335	0.89	3344	8.64	
		80%	23.33	18.79	438.46	3479	0.96	3632	8.28	
		90%	23.16	23.77	550.60	3763	1.12	4184	7.59	
		100%	22.99	29.15	670.20	4016	1.28	4691	6.99	

Note: Motor temperature is motor surface temperature @100% throttle running 10 mins
(Data above based on benchtest are for reference only.Comparion with that of other motor types is not recommended.)

VTOL propulsion: Electronic speed controllers (ESC)

- The ESC manages the power from the battery using commands from the flight controller to precisely regulate the speed of the motors, either for fixed wing or VTOL flight
- The signal from the flight controller is a pulse-width modulated (PWM) signal typically 1ms to 2 ms to represent the full power range of the motor



Each propeller-motor set on a multi-rotor system is driven by a separate ESC

VTOL propulsion: Electronic speed controllers (ESC)

Motors and **ESCs**
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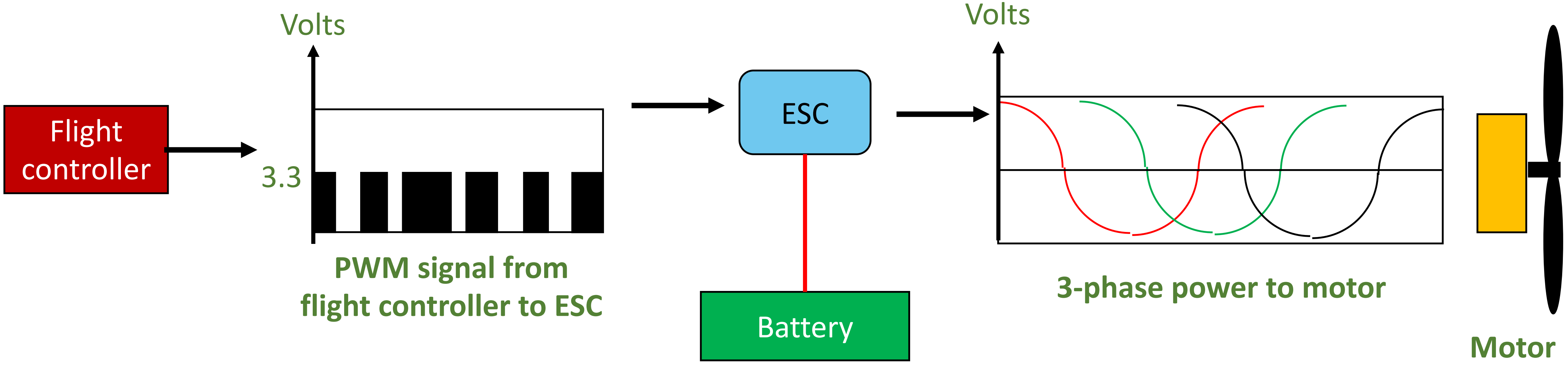
- The PWM signal to the ESC commands the ESC to send a three-phase variable frequency voltage to the motor



The selection of a speed controller is mainly based on its ability to carry required motor power

- An ESC controls power to the motor at a high frequency - in the kilohertz range – to provide low-latency control
- A microcontroller in the ESC is programmable to achieve desired start-up behavior, or RPM control to improve response

ESC INSTALLATION AND WIRING