Quadcopter Electrical System

November 14, 2018

Outline

- Brushless Motors
- Pulse Width Modulation
- Electronic Speed Controller
- Transmitter and Receiver
- Flight Controller
- Lithium Polymer Battery
  - Flight Time Estimation
- Assembly Procedures
- Flight Safety Procedures
- Final Competition Course

Brushless Motors

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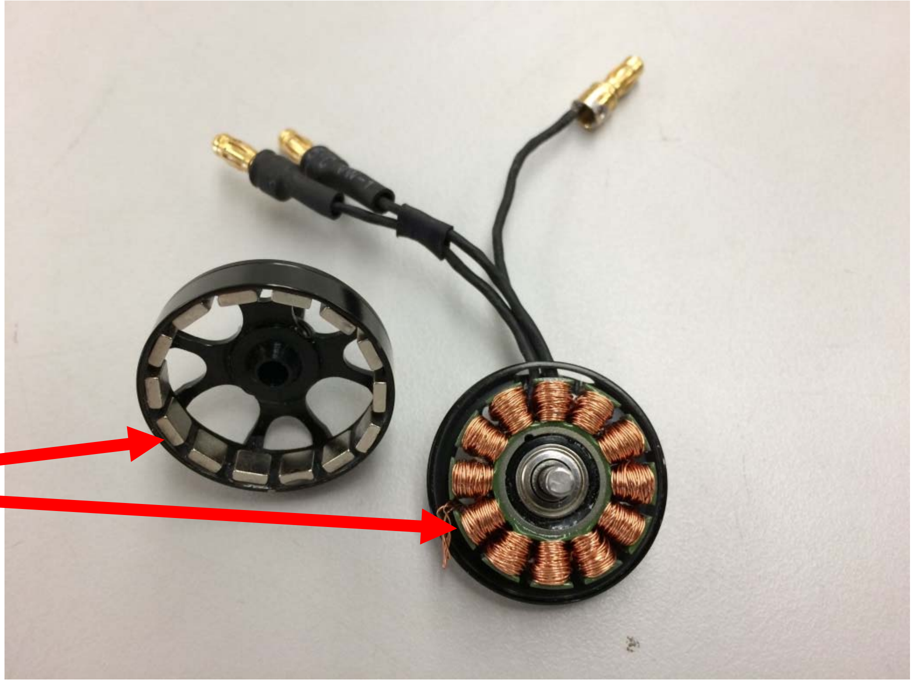
Rotor – Rotating Outer Structure

- Permanent magnets

Stator – Stationary Inner Structure

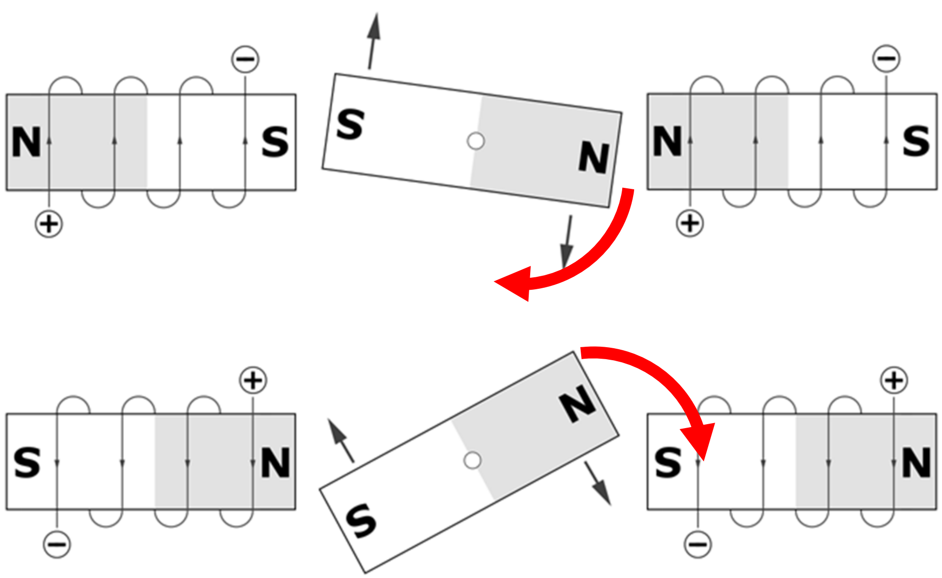
- Electromagnets



Electromagnets quickly alternating polarity causes permanent magnets to move.

Brushless Motors

- Permanent magnets: Constant polarity
- Electromagnets: Current direction determines polarity



- Electromagnets initially configured to repel magnet
  → causes rotation

- Current switches to pull magnet
  → continues rotation

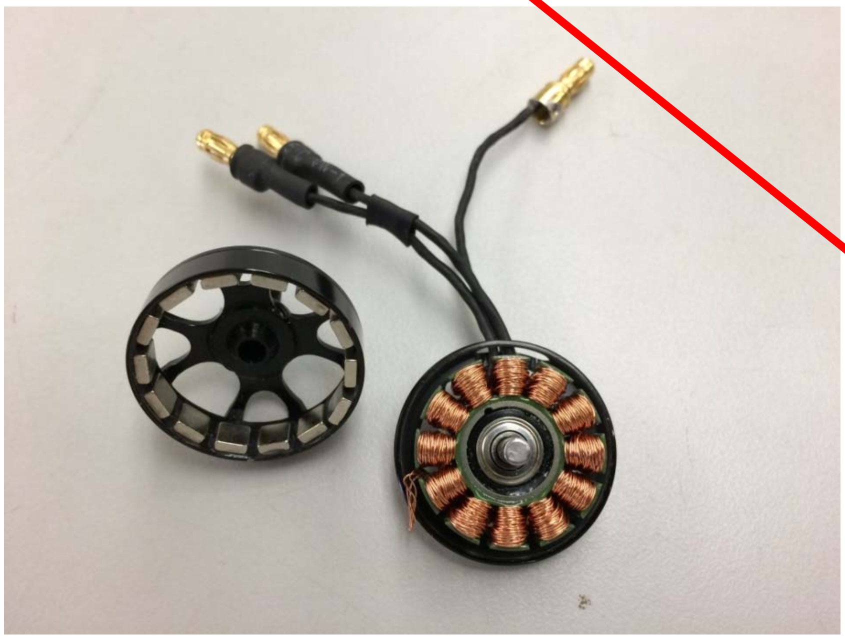
Brushless Motors

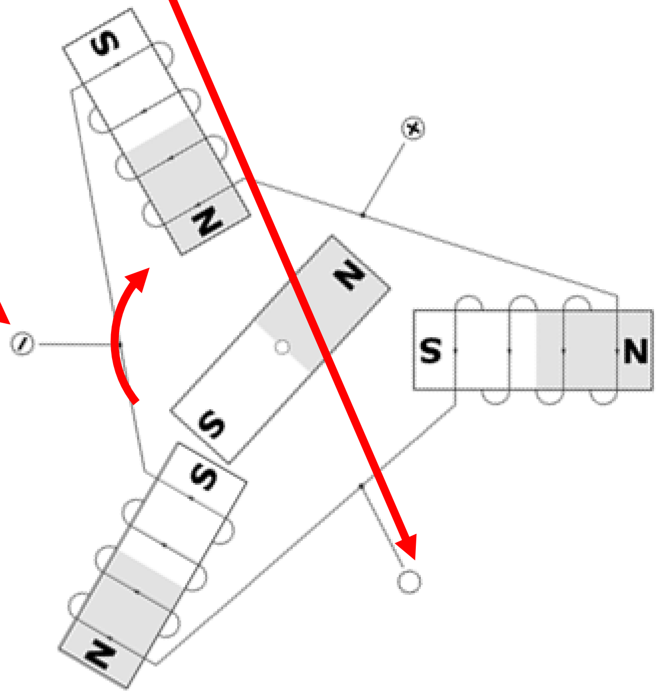
Three motor wires used to alternate electromagnet charges

<u>At one given moment:</u>

- Two wires: positive or negative charge
- One wire: inactive

Current goes IN the positive wire, and OUT the negative wire



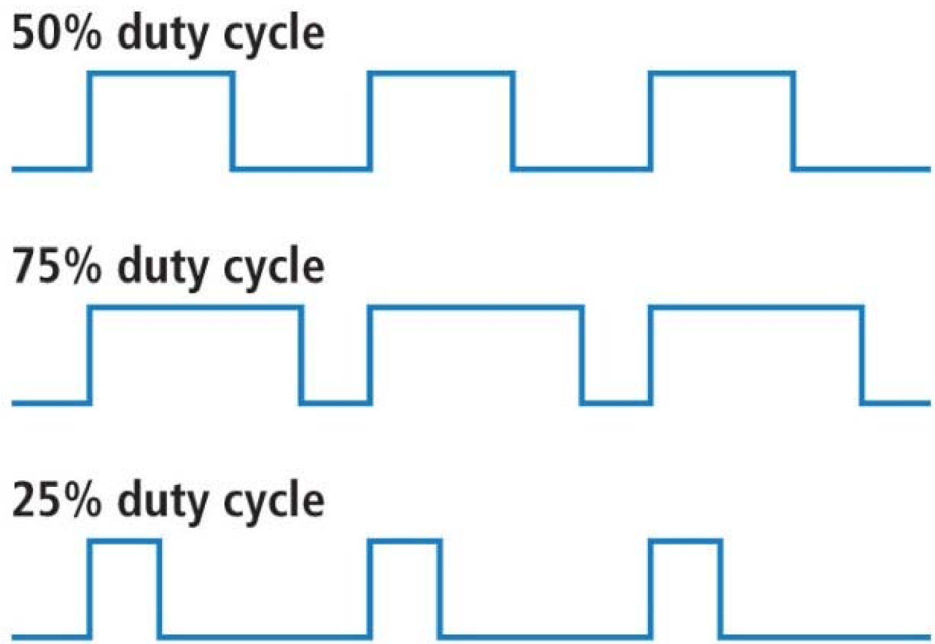


Pulse Width Modulation (PWM)

Imitate an ANALOG signal from a DIGITAL source

Analog: Continuous, variable (e.g. sine wave, sloping line)
Digital: Discrete (e.g. on/off, high/low, 1/0)

- Duty Cycle – amount of time that the signal is on high
- Frequency – inverse of time between pulses



Pulse Width Modulation (PWM)

<u>Given</u>: 5 volt digital source

What analog <u>voltages</u> do these PWM signals imitate?

Average Voltage Over Time

50% Duty Cycle

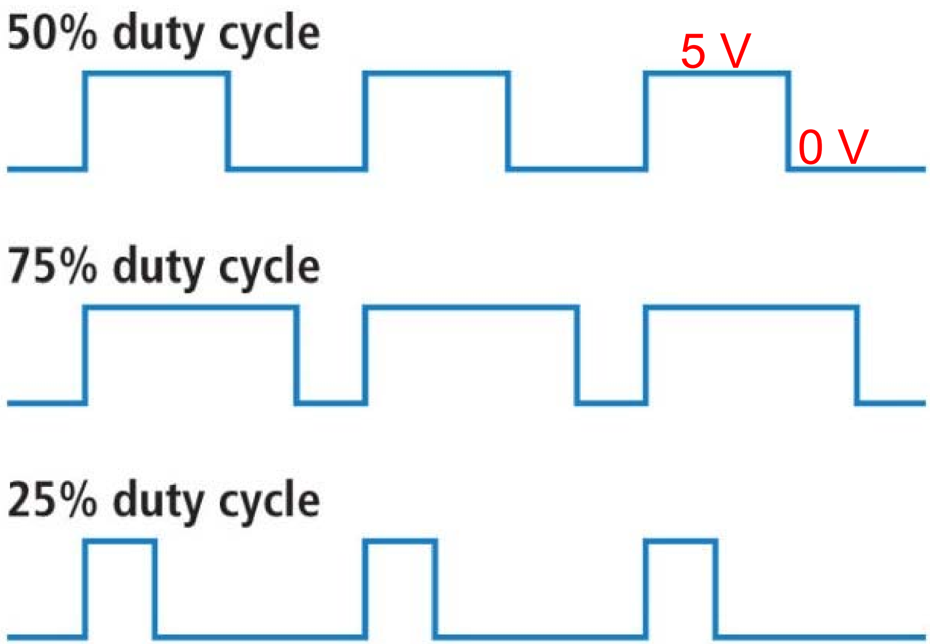
$$5\,V * (0.50) = 2.5\,V$$

75% Duty Cycle

$$5\,V * (0.75) = 3.75\,V$$

25% Duty Cycle

$$5\,V * (0.25) = 1.25\,V$$

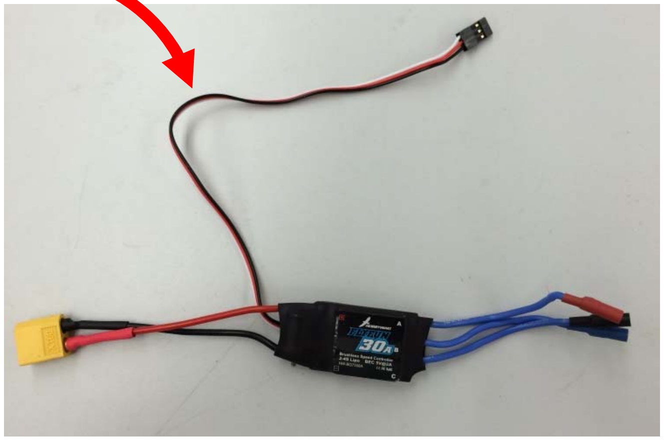


Pulse Width Modulation (PWM)

Quadcopter components that use PWM:

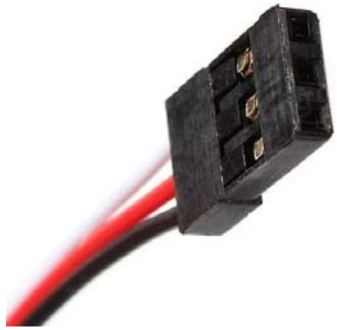
<u>Receiver</u> | <u>NAZA FC</u> | <u>ESC</u>

Motor Control



Pilot Commands

Electronic Speed Controller (ESC)



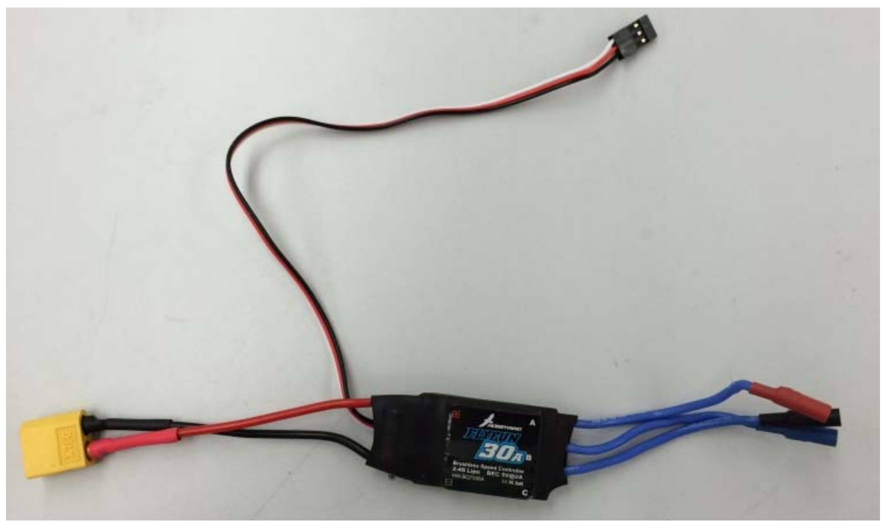
Signal from NAZA

White: Signal (PWM)

Red: 5 Volts

Black: Ground (0 Volts)

From Battery



To Motor

Max Current: 30 A

Electronic Speed Controller (ESC)

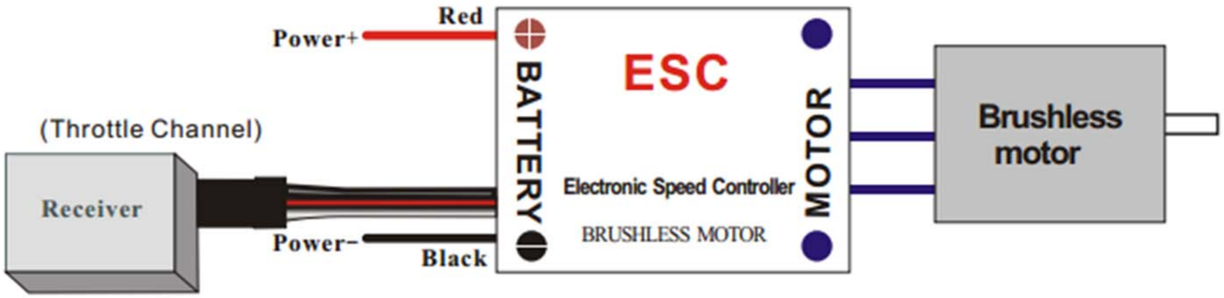
Throttle Calibration Required BEFORE ASSEMBLY

"Throttle Range Setting"

Set minimum and maximum throttle speeds for each ESC.

Procedure: See Instructions in ESC packaging,
or Electrical Fabrication, Calibration, & Assembly PowerPoint,
or ESC Calibration Video Tutorial

Setup: Receiver → ESC → Motor



Transmitter and Receiver

Transmitter Pilot Input → Radio Signal
→ Receiver PWM Signal → NAZA

Six Channel Transmitter and Receiver

- Four channels correspond with the sticks (A, E, T, R)
- Two channels associated with the switches

ENGR 7: Use first 5 channels

5th Channel: “Fail Safe”

Fail Safe ON = Car In Park

Fail Safe OFF = Ready to Drive

FAILSAFE USE

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FAIL SAFE ALWAYS ON WHEN PEOPLE ARE NEAR THE QUADCOPTER.

FAIL SAFE OFF ONLY WHEN READY TO FLY.

FAIL SAFE ON WHEN DONE FLYING.

DO NOT TURN ON FAILSAFE WHEN FLYING!

→ YOU LOSE ALL MOVEMENT CONTROL

Flight Controller

Translates pilot input into motor control.

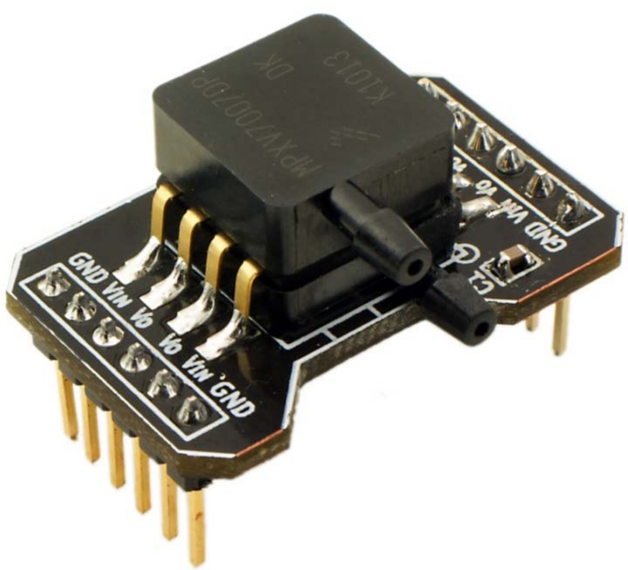
Attitude (orientation) control with a collection of sensors:

- Pressure Sensor (altitude)
- 3 axis gyroscope (roll, pitch, yaw)
- 3 axis accelerometer (linear acceleration)
- Magnetometer (compass)
- GPS (not included in this course)

Pressure Sensor

Pressure sensor measures relative altitude from a reference value

Pressure decreases as altitude increase



Used for Altitude Hold:

→ Flight controller measures pressure when enabled, and adjusts motors to maintain it

Altitude Hold not used in this class.

Mechanical Gyroscope

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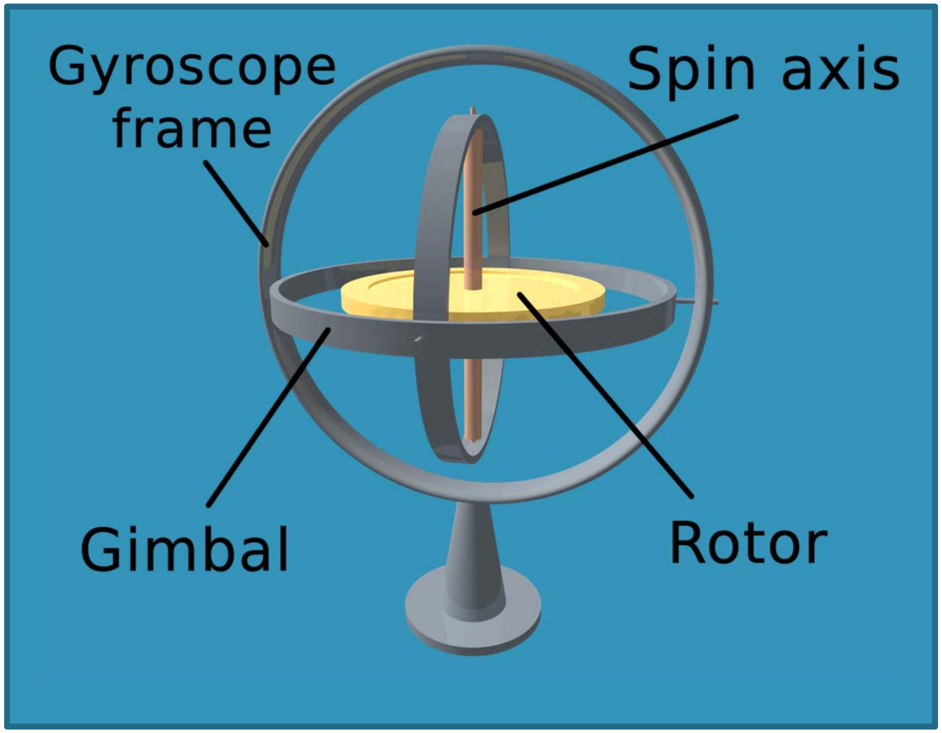
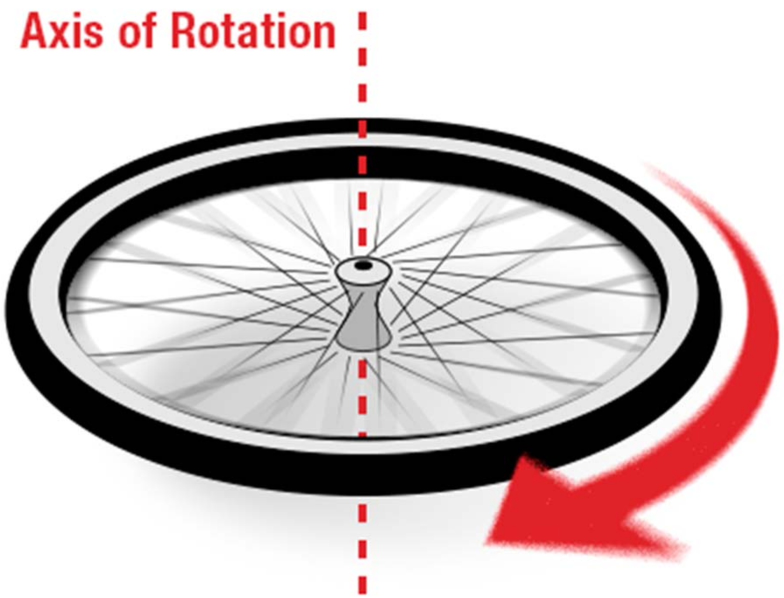
A mechanical gyroscope uses angular momentum to <u>maintain</u> or <u>manipulate</u> orientation

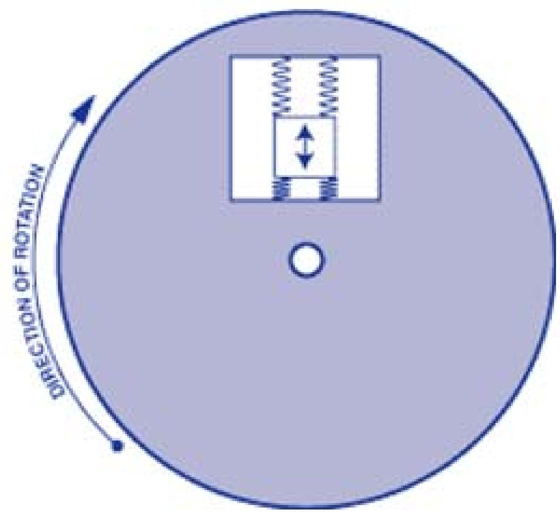
- http://www.youtube.com/watch?v=n_6p-1J551Y

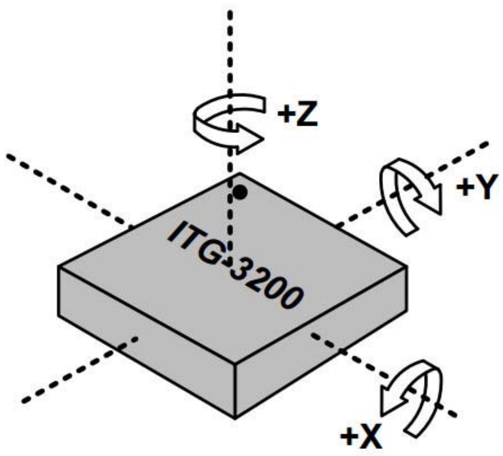




MEMS Gyroscope

- MEMS (<u>M</u>icro<u>e</u>lectro<u>m</u>echanical <u>S</u>ystems) are used in the flight controller to <u>measure</u> angular displacement
- Rotation causes a displacement of a mechanical device (3 separate axes)
  - Displacement converted to output voltage signal
  - Signal interpreted by NAZA and translated to motor control

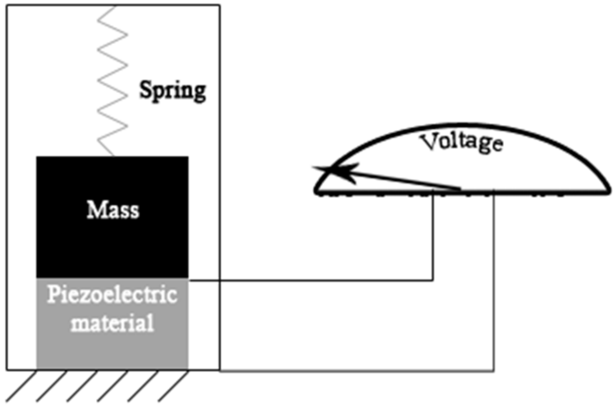


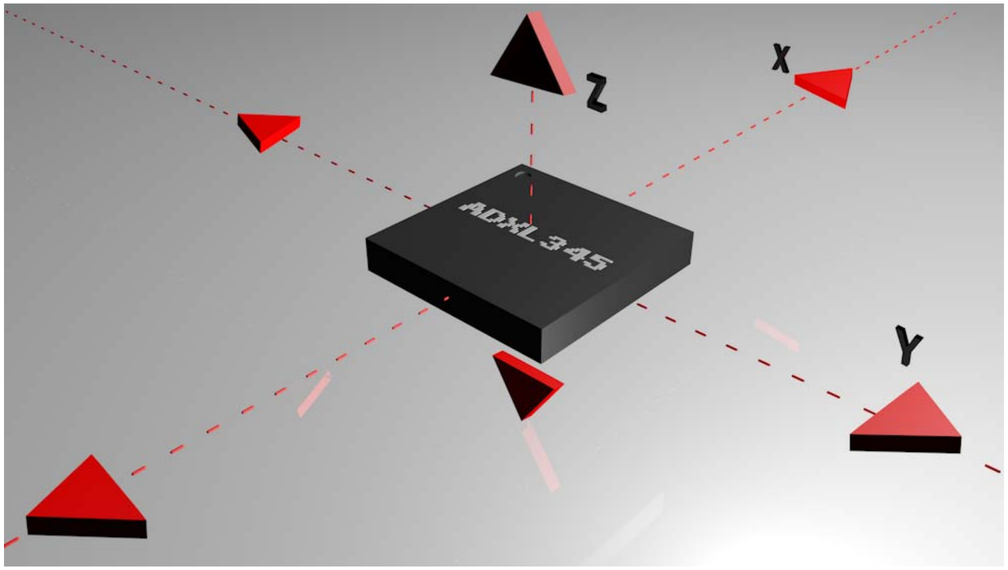


Accelerometer

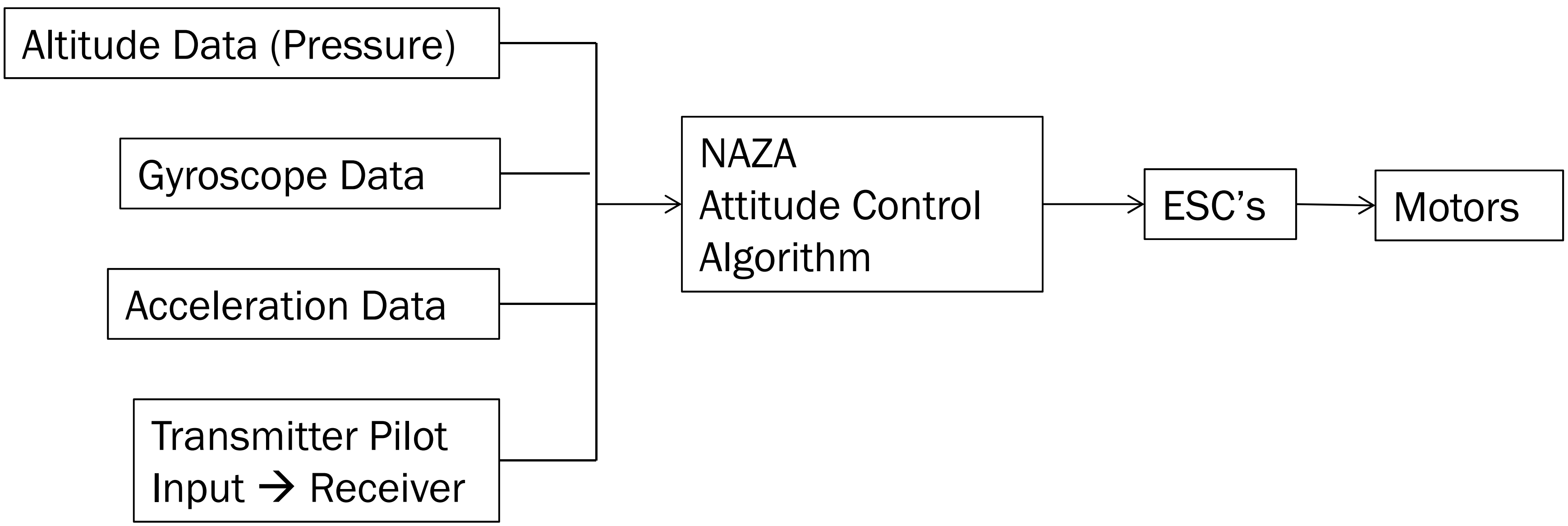
Measures the acceleration along the three axes.

- A mass-spring system reacts to changes in velocity
- The moving mass on a piezoelectric material changes the measured voltage.
  "Piezo" = Greek for "squeeze" or "press"
- Voltage interpreted by NAZA, translated to motor control





Summary of Flight Control



Battery Safety

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- 3 Cell, Lithium Polymer (LiPo) battery
- Cutoff (minimum) voltage: 3.0 V/cell (9 V total)
- Nominal Voltage: 3.7 V/cell (11.1 V total)
- Peak Voltage: 4.2 V (12.6 V total)

Discharging battery too much will permanently damage the battery.

Recommended minimum voltage: 9.9 V

Battery Safety

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- Only TAs will be responsible for charging batteries.
- Monitor for a hot battery or flames.
- Never let the battery's positive and negative wires touch
  → Short Circuit = uncontrolled energy release = fire
- Always inspect the battery for damage or deformity before use.
- Always check the battery voltage before use.
- Disconnect battery when not in use.
  - Do not store batteries in your team containers.
- Always keep batteries away from water.
  - Do not fly on wet grass, near puddles, in wet weather.

Battery Safety

Electric Energy = Controlled release of high energy reactions

Bad idea to release all that energy at once…

Smoke, gaseous fumes, fire…
https://www.youtube.com/watch?v=aEK-lYtf-t8

One of the first signs of a damaged battery is bloating…
https://www.youtube.com/watch?v=BLc74Qpvweg

Battery Energy

Total Capacity: 3000 mA-h

$$Energy\ [mA-h] = Current[mA] * Time[hrs]$$

3000 mAh = 3Ah

→ Will run 1 hour on 3 amp current draw

→ 30 minutes on 6 amp current draw

<u>SunnySky 1500KV</u>

Max Current / Motor = 20 A

Full Throttle Flight Time

$$= \frac{3Ah}{20A * 4} = 0.0375\ hrs = 2.25\ mins$$

Flight Time Calculation

Calculate the flight time for your quadcopter:

$$T = 2\left(\frac{sa}{16}\left[\sqrt{1+\frac{64}{3sa}\theta} - 1\right]\right)^2 \rho(\Omega R)^2 A$$

<u>Known</u>:

Maximum Thrust

Maximum Current

Quadcopter Weight ← This is the same as thrust force when hovering

Flight Time Calculation

$$T = 2\left(\frac{sa}{16}\left[\sqrt{1+\frac{64}{3sa}\theta} - 1\right]\right)^2 \rho(\Omega R)^2 A$$

T = Thrust

Ω = RPM

All other values are constant!

$$T = constant * (\Omega)^2$$

Flight Time Calculation

$$T = constant * (\Omega)^2$$

Motor KV Rating: KV = RPM / Volt = Ω / V

Ohm's Law: V = IR

Solving for Ω:

$$\Omega = (KV\ Rating) * V$$

$$= (KV\ Rating) * (IR)$$

$$\Omega = constant * (I)$$

Combine the constants & plug into top equations:

$$T = constant * (I)^2$$

Flight Time Calculation

$$T = constant * (I)^2$$

$$constant = \frac{T}{I^2}$$

State 1: Maximum

T_{max} , I_{max} ← From thrust test data

State 2: Hover

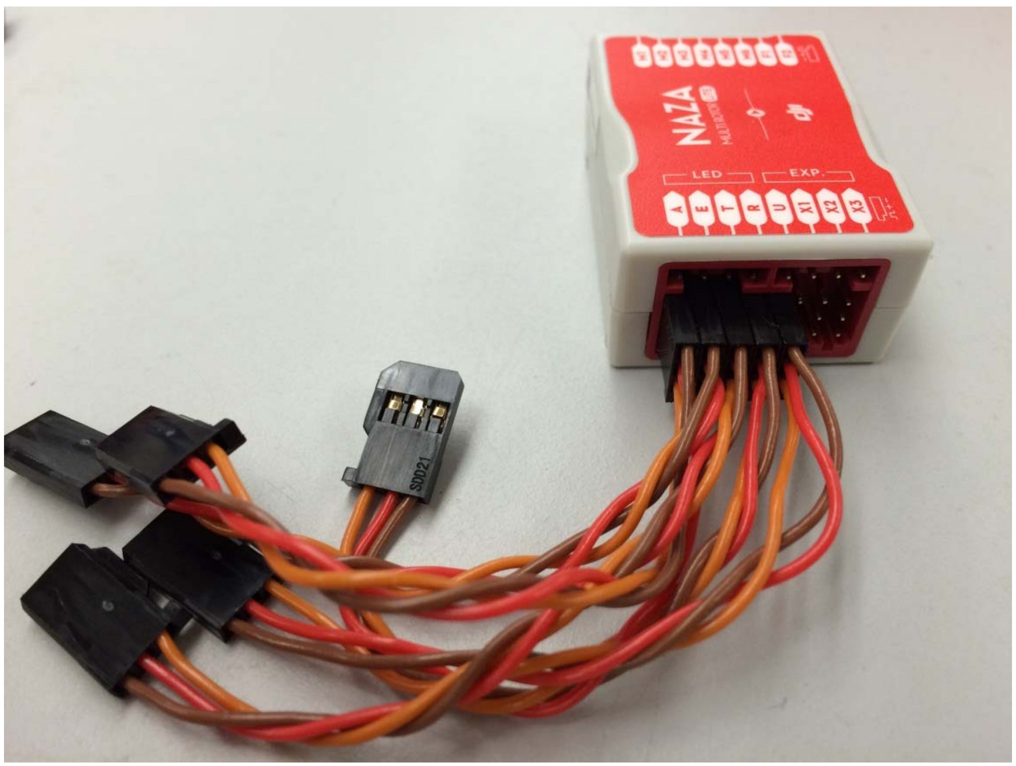
$T_{hover} = W_{quad}$, I_{hover} unknown

$$\frac{T_{max}}{I_{max}^2} = \frac{W}{I_{hover}^2} = constant$$

Solve for I_{hover} → $3000\ mA - h = I_{hover} * t_{flight}$

Electrical Assembly Procedures

Connect the servo-type connectors to the flight controller ports labeled A, E, T, R, U.



- A: Aileron
- E: Elevator
- T: Throttle
- R: Rudder
- U: Failsafe switch

GROUND WIRE ON TOP

Electrical Assembly Procedures

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Connect LED above receiver connections

Light color and frequency indicates battery life, fail safe mode, etc.

Contains USB connection for calibration

Electrical Assembly Procedures

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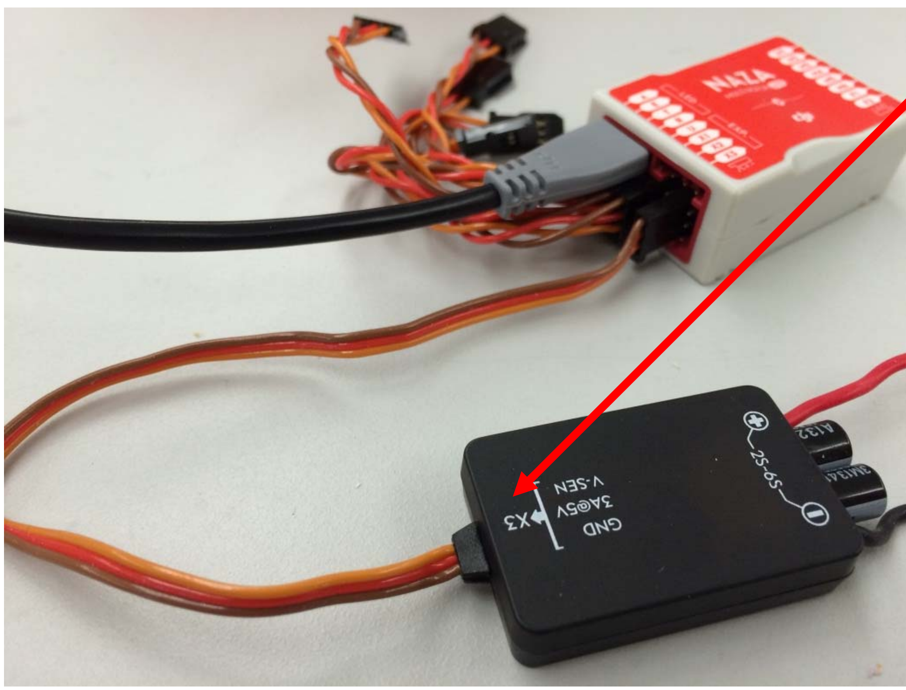
Connect the voltage regulator to the **X3** port

GROUND WIRE ON TOP



Provides a regulated 5v supply voltage to flight controller

→ Other two leads connect to the battery.

Electrical Assembly Procedures

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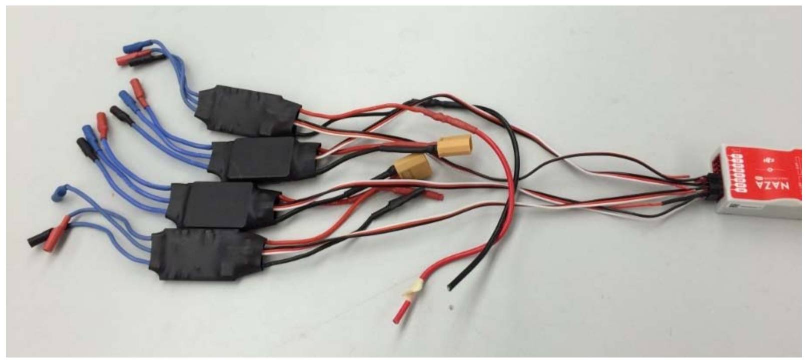
Connect flight controller A, E, T, R, U to receiver 1, 2, 3, 4, 5

<u>For connection instructions:</u>
See Electrical Fabrication, Calibration, & Assembly PowerPoint

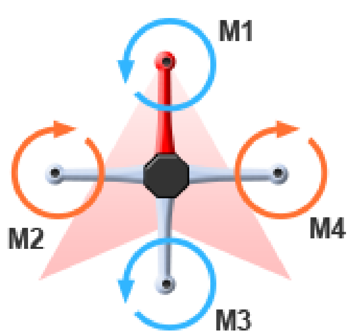
Electrical Assembly Procedures

Connect ESC's to the M1-M4 ports on the flight controller

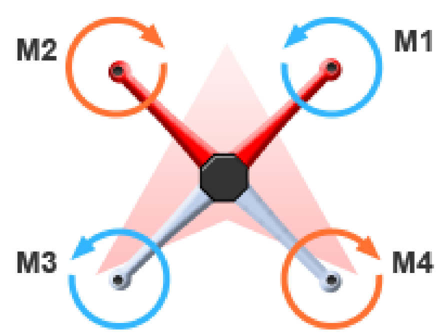


<u>Motor numbers matter!</u> Orientation indicated in NAZA computer software

Plus – Configuration



X – Configuration



Recommended Procedure

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1. Calibrate and test each ESC with motor pair
2. Connect receiver, LED, voltage regulator, and NAZA flight controller
3. Plug in ESCs to NAZA in correct M1 – M4 sequence
4. Assemble electronics onto quadcopter
5. Plug in battery wiring harness to ESCs and voltage regulator

6. ASK TA TO CHECK WIRING → Battery

7. Check and change motor spin direction as needed
8. Calibrate NAZA
9. ASK TA TO CHECK MOTOR RESPONSE → Propellers

Flight Procedure

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1. Check that all connections are correct, secure and insulated
2. Verify clearance for all propellers
3. Make sure failsafe switch is ON
4. Turn on transmitter
5. Connect Battery
6. Turn OFF failsafe
7. Set the motors to idle
8. Verify propeller direction
9. Take off, flight, landing.
10. Stop motors
11. Turn ON Failsafe
12. Unplug battery
13. Turn off transmitter

Final Competition Course

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- Timed Event
- 10ft H x 10ft W x 30ft L netted area
- Course consists of a series platforms and gates set at different locations and elevations
  - Goal is to land on each platform in a specific sequence
- Time stops after landing and propellers stop spinning.

Frame Grading Criteria

Frame fabrication is due by 5:00 pm Friday, 11/16/2018

The frame grade will be dependent on:

- Motor Distance (to be within the max limit)
- Symmetry (equal weight distribution)
- Quality and Completeness of Fabrication
- Structural Rigidity
- Creativity

Upcoming Schedule

Structure deadline – Friday, November 16 at 5 pm

Sign up for Open Labs

No more office hours. For questions, come to open hours.

Next lecture – Monday 11/19/2017 Iris Adam will teach Communication and Leadership development

Weeks 9 and 10 we have guest lecturers who will only present on Mondays. Students from Wed sections, please, attend the Monday 5 pm lectures instead of Wed 5 pm lectures during weeks 8 and 9.

There will be no lectures during week 10 – we'll start final presentations.