Quadcopter Overview, Moment & Center of Gravity

October 15, 2018

Quadcopter Overview

- Quadcopter
  - A multi-rotor helicopter that is lifted and propelled by four rotors.
  - Unmanned Aerial Vehicle (UAV)
  - Drones
- Characteristic
  - **Rotorcraft vs. Fixed Wing Aircraft**
  - Control of the vehicles motion is done by altering the rotation rate of one or more rotors at the same time, thus changing its torque load and thrust.
- Options
  - Remotely piloted
  - Autonomous (follow a fixed flight plan)

Quadcopter Overview

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- History of Multirotor copter (piloted)
  - A solution to vertical flight
  - Counter-rotation and the relatively short blades for ease of construction.
    - Breguet-Richet Gyroplane (1907)
    - Oehmichen No.2 (1920)
    - de Bothezat helicopter (1922)
    - Convertawings Model A Quadrotor (1956)
    - Curtiss-Wright VZ-7 (1958)
    - Ehang 184 (2016)

Quadcopter Overview

- Early appearances in “Maker Faire”
- Commercial Usage
  - Aerial Photography and Video
  - Delivery
  - Entertainment
- Military Function
  - Surveillance
  - Search and Rescue
- Quadcopter Products
  - DJI
    - Phantom
      - Horizontal flight speed up to 52.5 ft/s
      - Vertical flight speed up to 16.4 ft/s
  - Parrot
    - Controlled by an App from tablet or mobile phone
  - Walkera
  - Hubscan


DJI Phantom

Parrot AR Drone


Quadcopter for aerial photography.

Quadcopter Overview

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- Advancement in Technology
  - Wearable format
  - Drivable Quadcopter
  - Foldable Format

DJI Mavic

Nixie

Expandable drones
(various brands)

Quadcopter Overview

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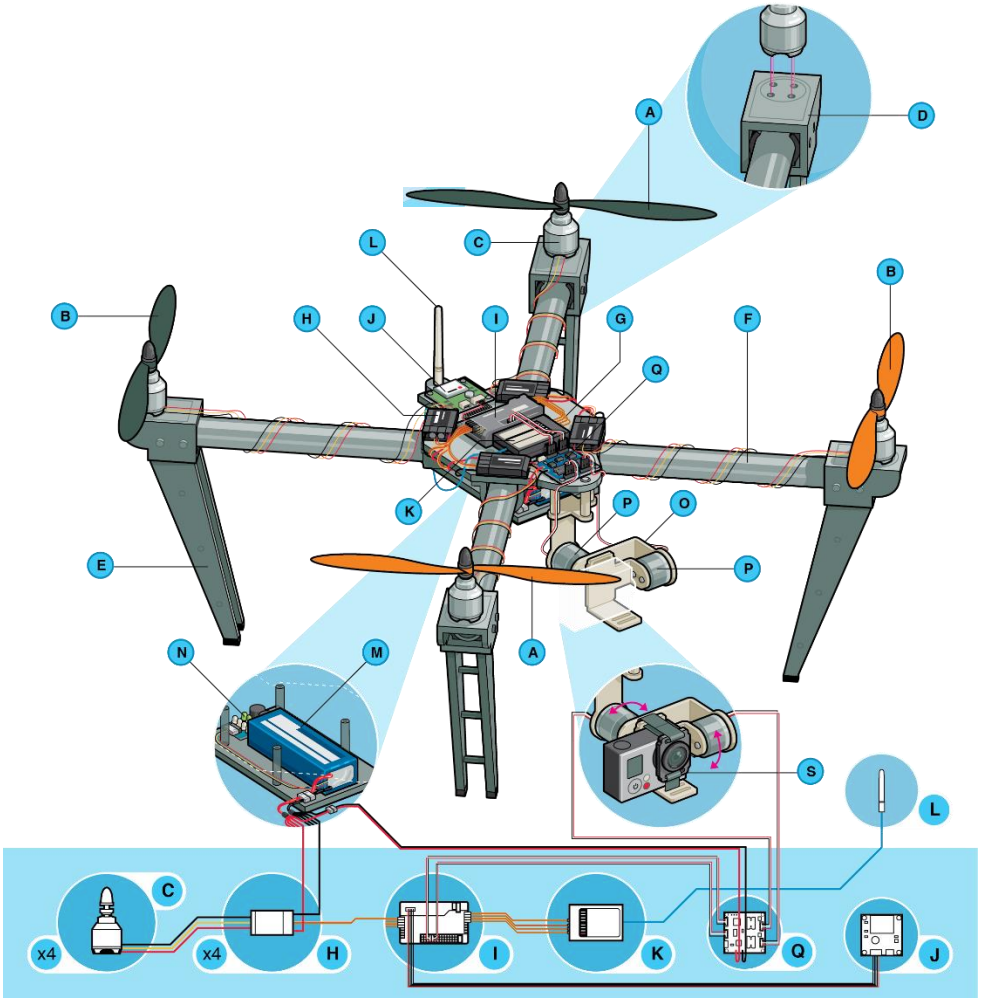
- Anatomy of Quadcopter



Propeller (Prop)
Motor
Motor Mount
Landing Gear
Boom
Main Body
Electronic Speed Controller (ESC)
Flight Controller
Receiver
Battery

Optional:
GPS Module
Antenna
Gimbal and Gimbal Motor
Camera

Moment

- Moment is the tendency of a force to twist or rotate an object.

$$M = Fd$$

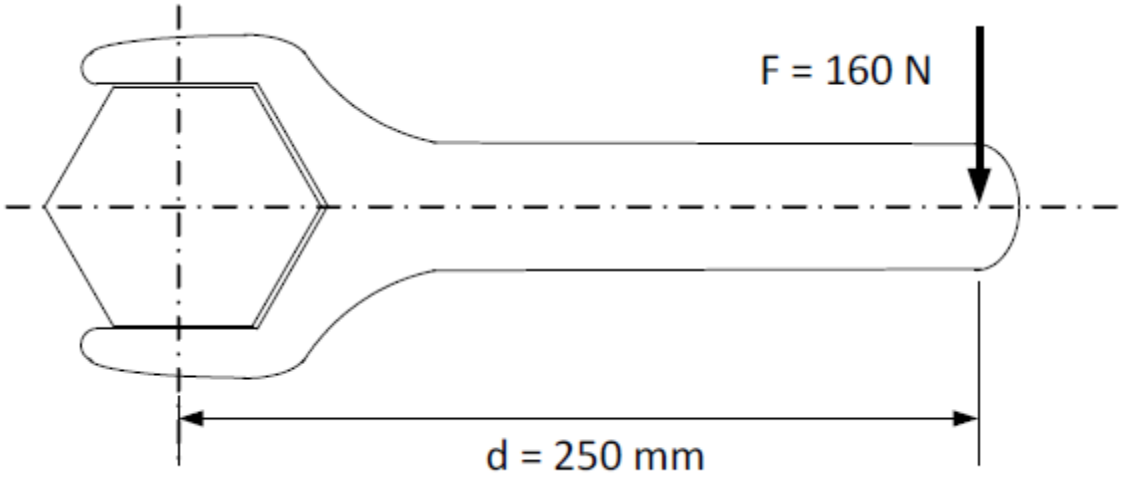
- F, force (N), F=ma (m: mass, a: acceleration)
- d, distance between the location where the force is applied and a reference point (m)
- Direction of moment is demonstrated with right-hand rule.
  - Positive – Counter Clockwise motion
  - Negative – Clockwise motion

- For a balanced not spinning object, the moments of all forces should be equal to zero, $\sum M_i = 0$

Moment

- Moment is the tendency of a force to twist or rotate an object.

$$M = Fd$$



M = Fd = - (160N)(0.25m) = – 40Nm

The rotation is clockwise in reference to the bolt

Quadcopter Overview

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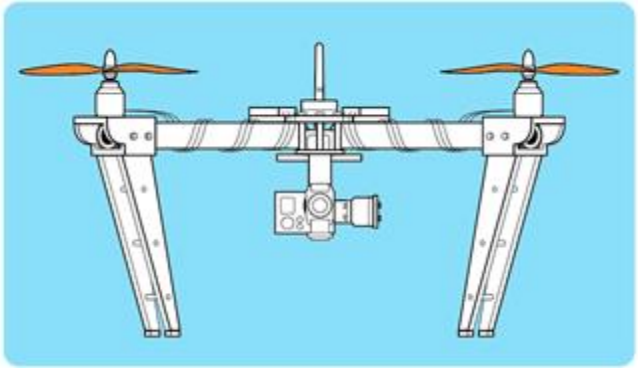
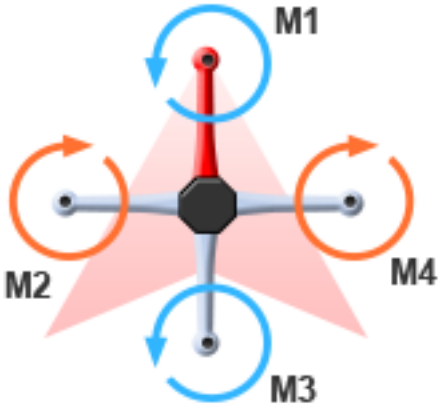
- Anatomy of Quadcopter
  - Examples: Side view of a quadcopter with camera system
  - Configurations



Side view

Top view with
a X Configuration



Top view with
a Cross or Plus Configuration

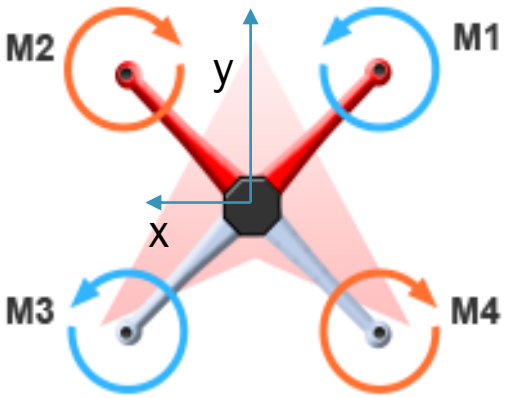
4 Rotors: 2 clockwise (CW) and 2 counter-clockwise (CCW)

Pitch

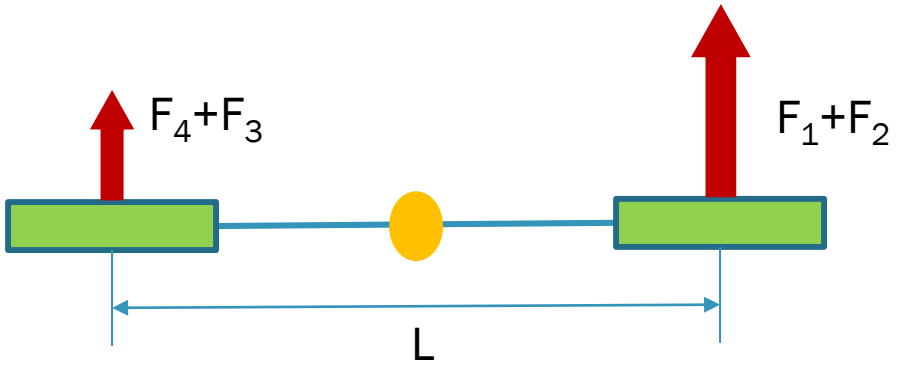
- Moment Produces Pitching

$$M = Fd$$

Front



X Configuration



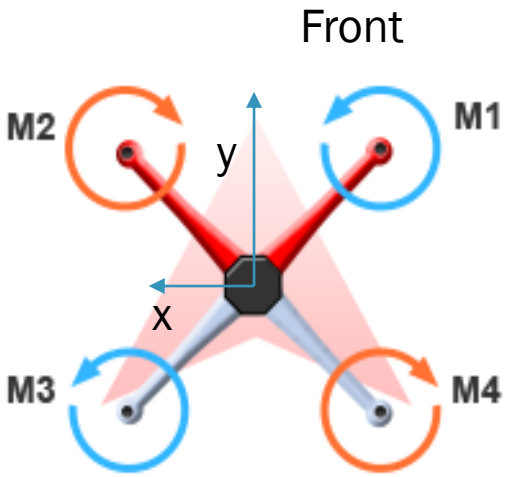
Side view
Increasing the speed on 1 and 2 Rotor

$$M_p = \sum M = (F_1 + F_2)(\frac{L}{2}) - (F_3 + F_4)(\frac{L}{2})$$

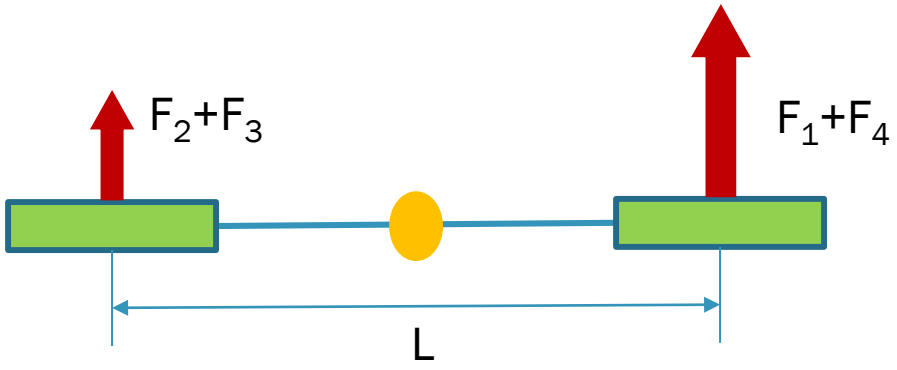
Roll

- Moment Produces Rolling

$$M = Fd$$



X Configuration



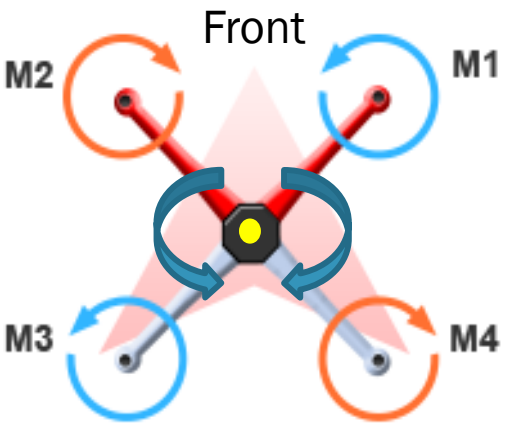
Side View
Increasing the speed on 1 and 4 Rotor

$$M_r = \sum M = (F_1 + F_4)(\frac{L}{2}) - (F_2 + F_3)(\frac{L}{2})$$

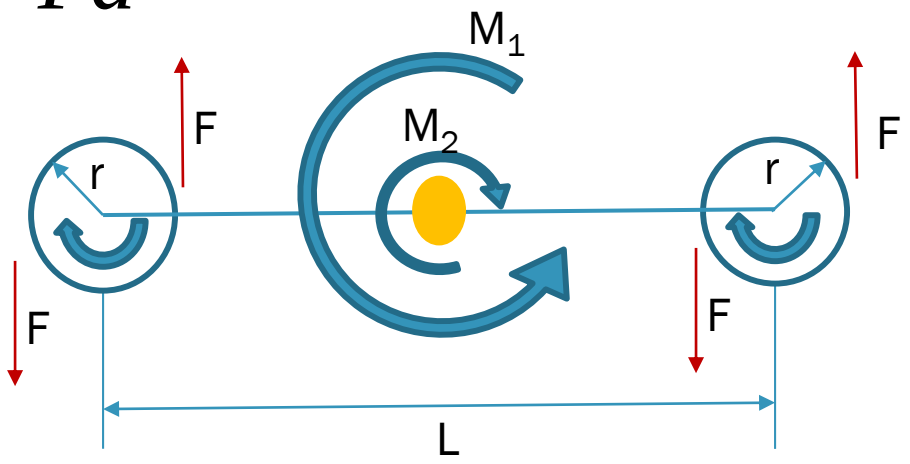
Yaw

- Moment Produces Yawing

$$M = Fd$$



X Configuration



Top View
Increasing the speed on 2 and 4 Rotor

$$M_y = \sum M = M_1 - M_2$$

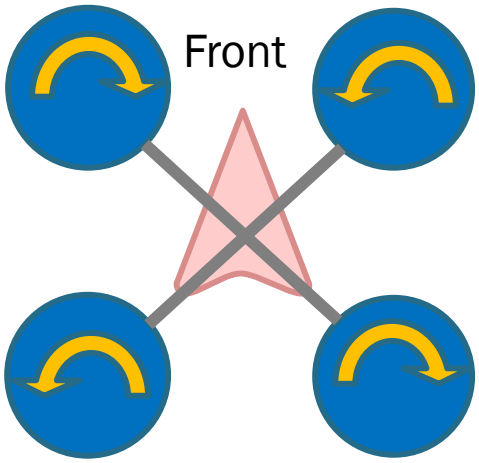
$$M_1 = 2F(\frac{L}{2} + r)$$

$$M_2 = 2F(\frac{L}{2} - r)$$

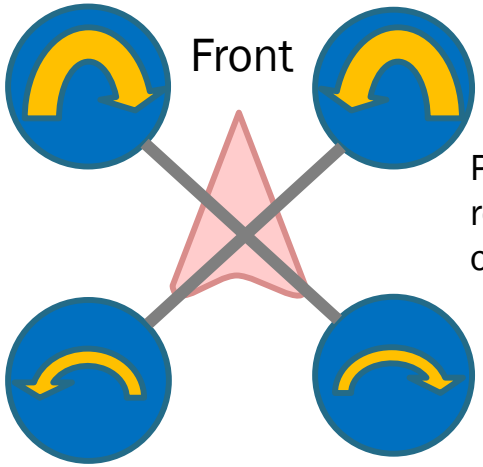
M1>M2 → Counter Clockwise Rotation

Pitch, Roll, Yaw

- Moment Produces Movements of the X Configured Quadcopter

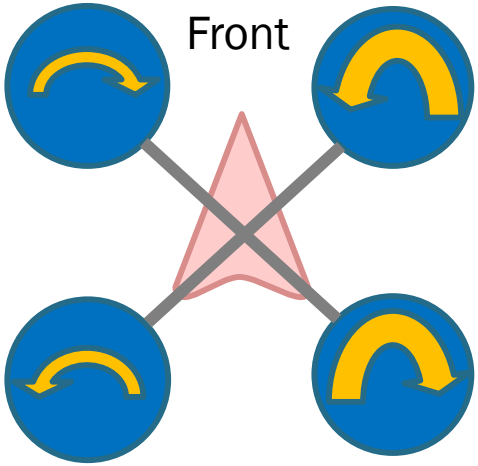


Adjusts its altitude by applying equal thrust to all four rotors.

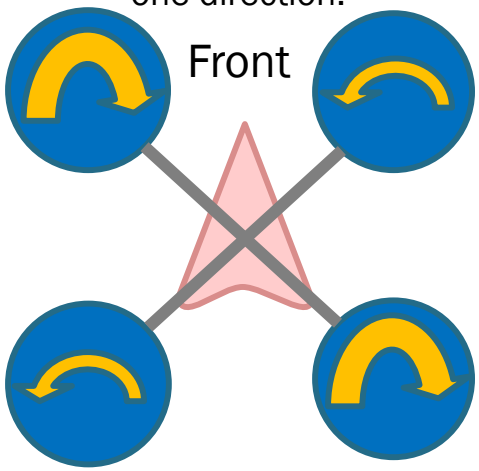


Pitch by applying more thrust to two rotors and less thrust to its diametrically opposite rotors.

Roll by applying more thrust to two rotor and less thrust to its diametrically opposite rotors.

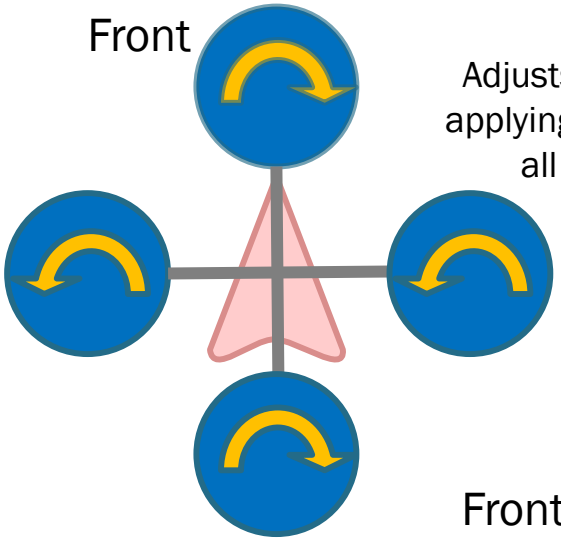


Yaw by applying more thrust to rotors rotating in one direction.

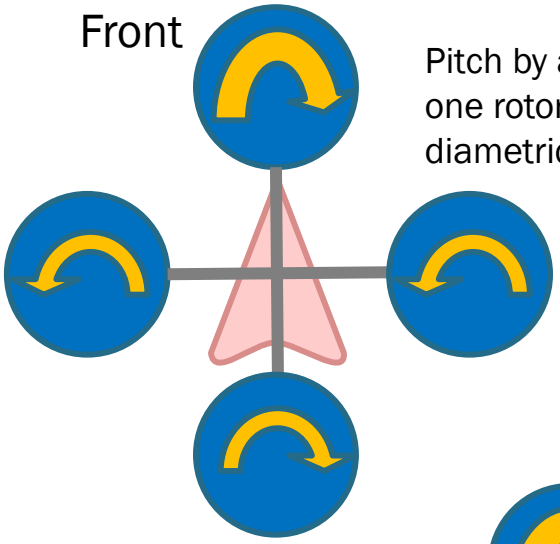


Pitch, Roll, Yaw

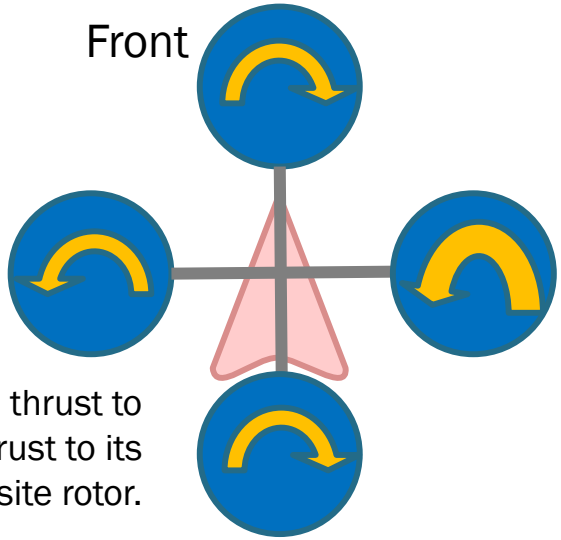
- Moment Produces Movements of the Plus Configured Quadcopter



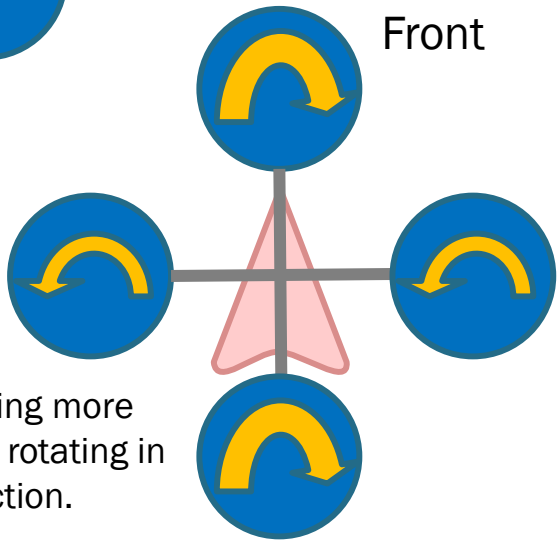
Adjusts its altitude by applying equal thrust to all four rotors.



Pitch by applying more thrust to one rotor and less thrust to its diametrically opposite rotor.



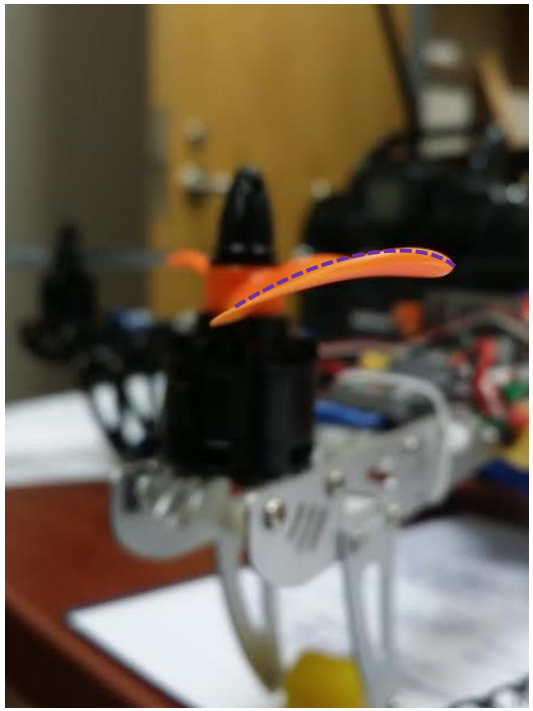
Roll by applying more thrust to one rotor and less thrust to its diametrically opposite rotor.



Yaw by applying more thrust to rotors rotating in one direction.

Quadcopter Overview

- Practical Tips on Propeller
  - How do you know whether the propeller is up or down?
    - Letters (writings) are on top
    - “Concave down”, side profile from the tip of the propeller



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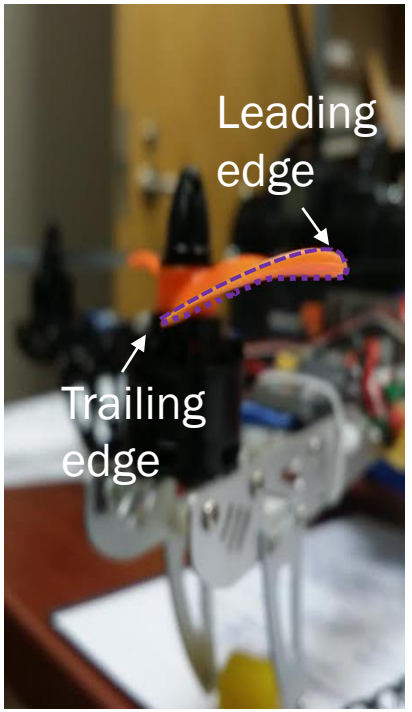
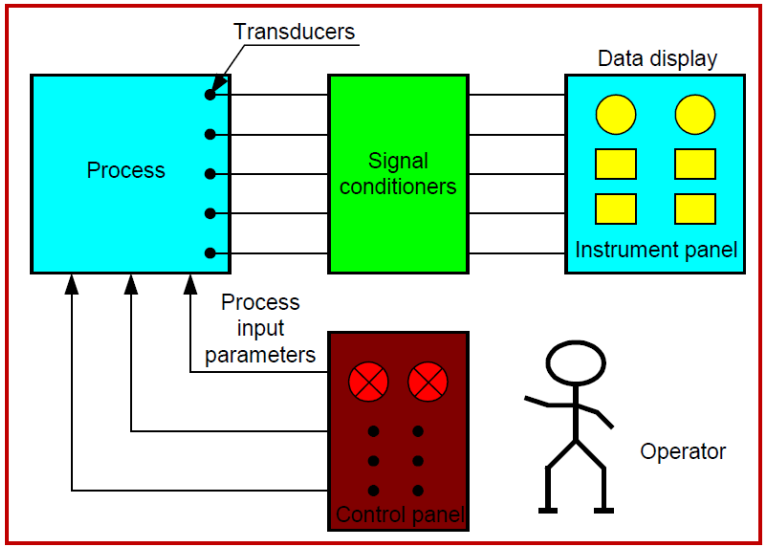
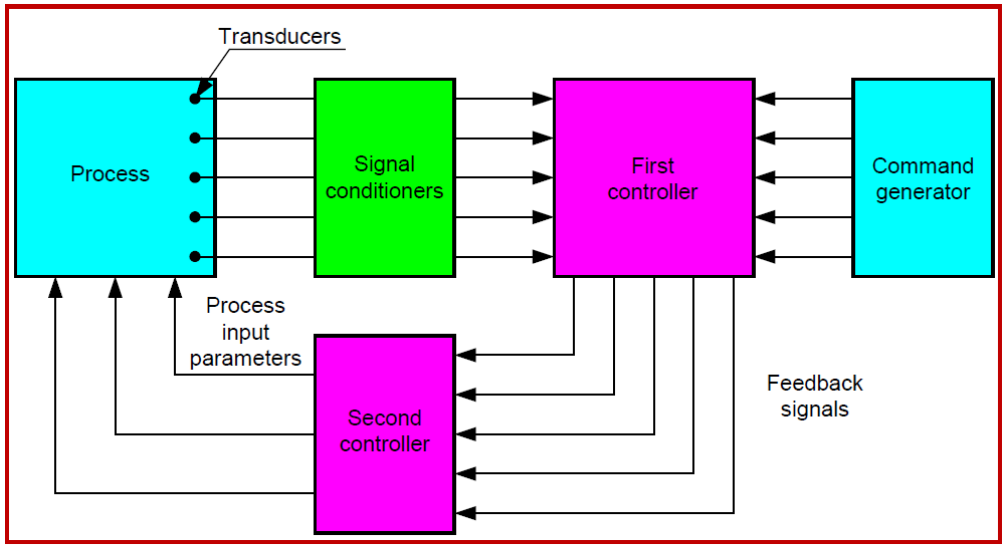
- Practical Tips on Propeller
  - Same design of propeller blades as a pair placed across from each other
  - Same color propellers often come as one clockwise and one counter-clockwise
  - Blade will turn toward the direction of leading edge of the airfoil



Control System

- Electronic Measurement systems are used in two types of process control
  - Open Loop Control (Manual, Remote Control)
  - Close Loop Control (Autonomous)





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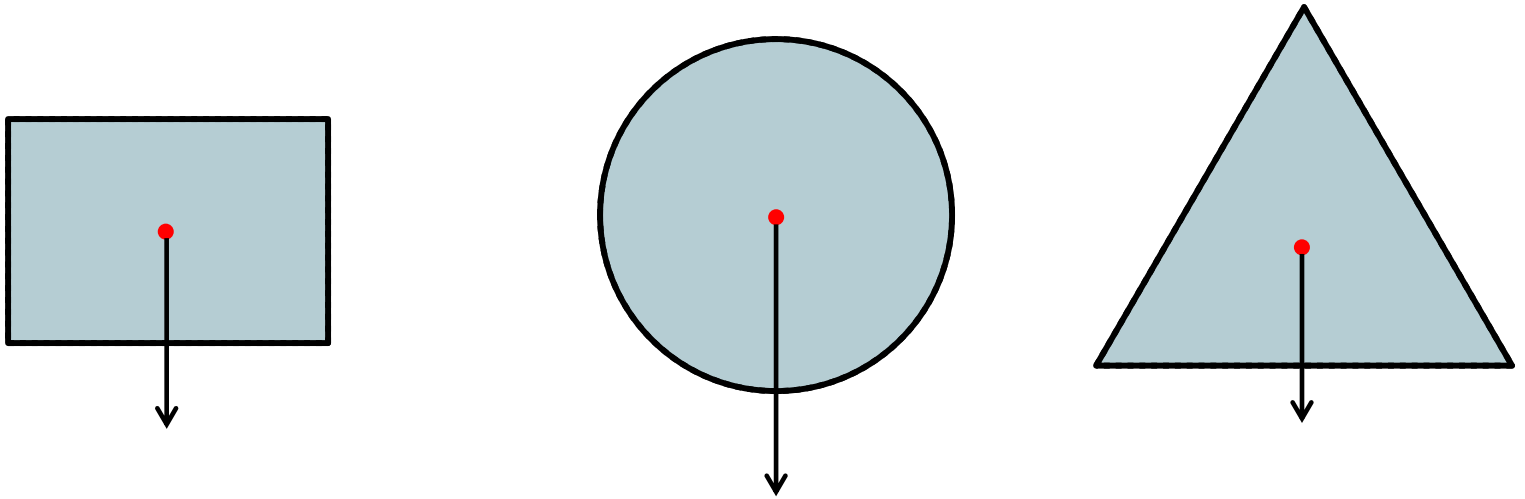
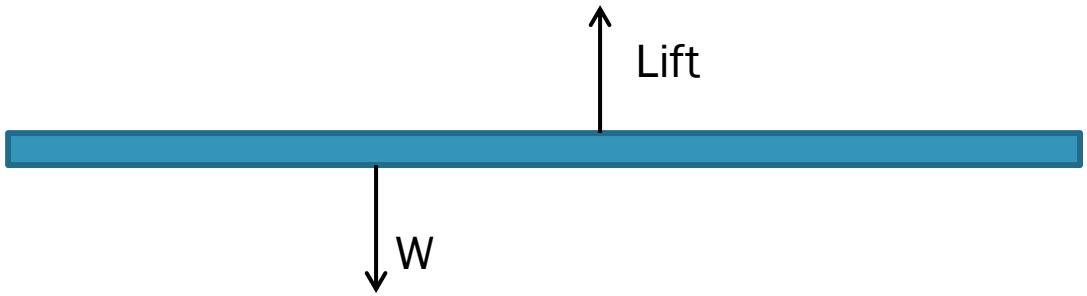
- Advancement in Technology
  - Quadcopters in Formation

Center of Gravity (COG)

- Center of gravity is the weighted average location of all the mass in a body or group of bodies.



- The calculation of COG is important for Quadcopter design.



COG in Action

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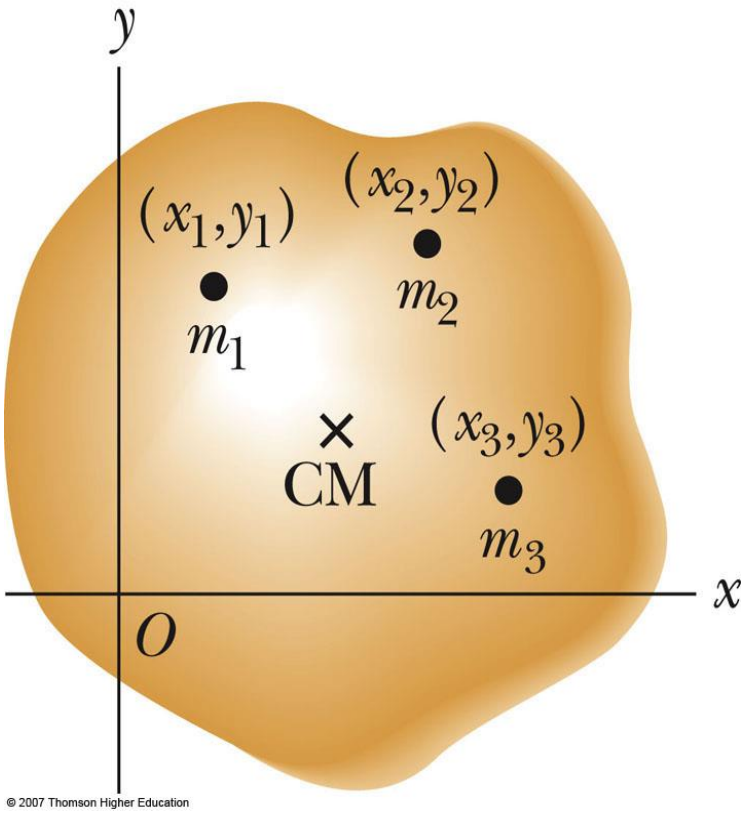
- Demo

Center of Mass

- An object can be divided into many small particles
  - Each particle will have a specific mass and specific coordinates
- The x coordinate of the center of mass will be

$$x_{CM} = \frac{\sum_i m_i x_i}{\sum_i m_i}$$

- Similar expressions can be found for the y coordinates



COG Calculation

- All the various gravitational forces acting on all the various mass elements are equivalent to a single gravitational force acting through a single point called the center of gravity (CoG)

$$Mg_{CG}x_{CG} = (m_1 + m_2 + m_3 + \cdots)g_{CG}x_{CG}$$
$$= m_1 g_1 x_1 + m_2 g_2 x_2 + m_3 g_3 x_3 + \cdots$$

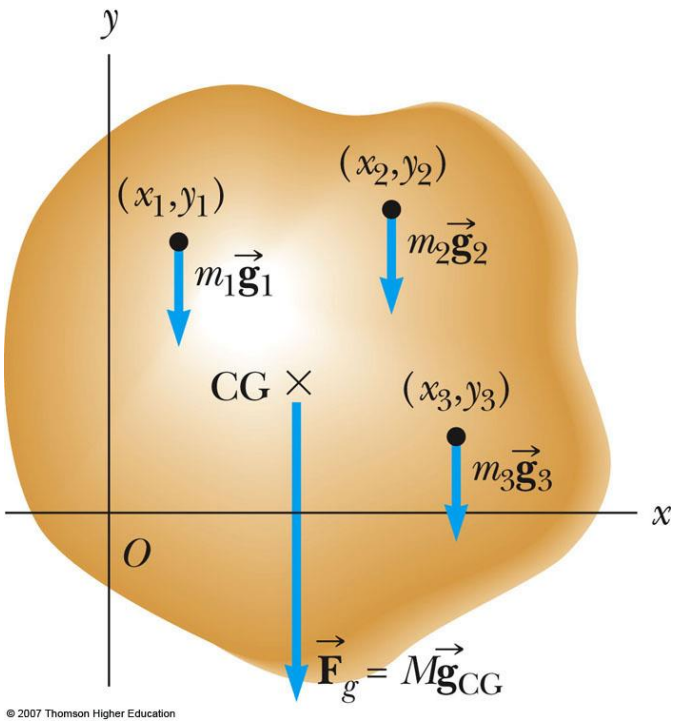
- If

$$g_1 = g_2 = g_3 = \cdots$$

- then

$$x_{CG} = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3 + \cdots}{m_1 + m_2 + m_3 + \cdots} = \frac{\sum m_i x_i}{\sum m_i}$$

$$y_{CG} = \frac{m_1 y_1 + m_2 y_2 + m_3 y_3 + \cdots}{m_1 + m_2 + m_3 + \cdots} = \frac{\sum m_i y_i}{\sum m_i}$$



COG in Action

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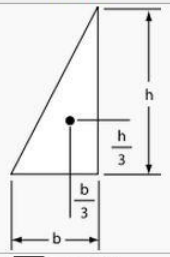
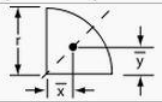
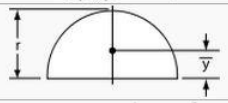
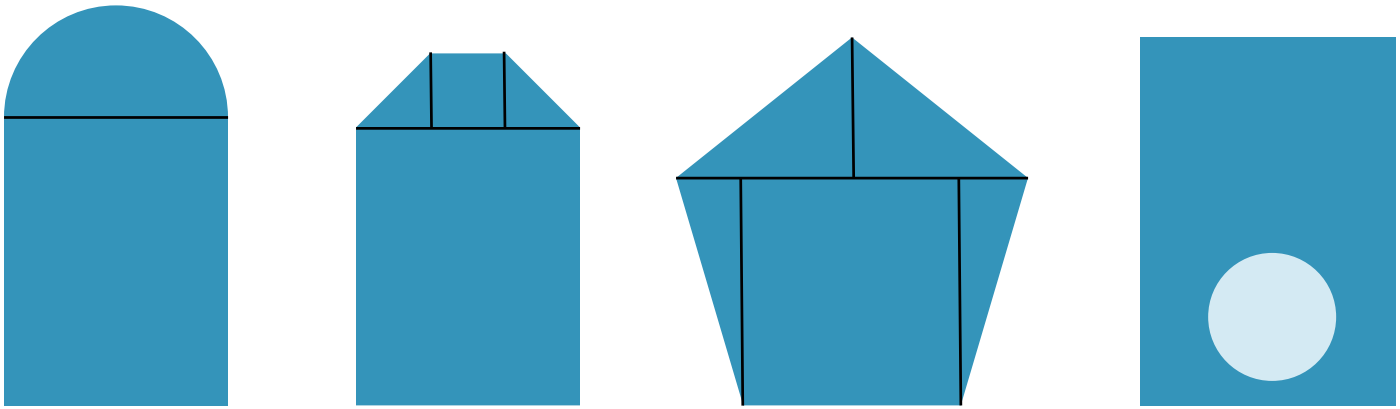
Shape	Figure	$\bar{x}$	$\bar{y}$	Area
Right-triangular area		$\frac{-b}{3}$	$\frac{h}{3}$	$\frac{bh}{2}$
Quarter-circular area		$\frac{4r}{3\pi}$	$\frac{4r}{3\pi}$	$\frac{\pi r^2}{4}$
Semicircular area		0	$\frac{4r}{3\pi}$	$\frac{\pi r^2}{2}$

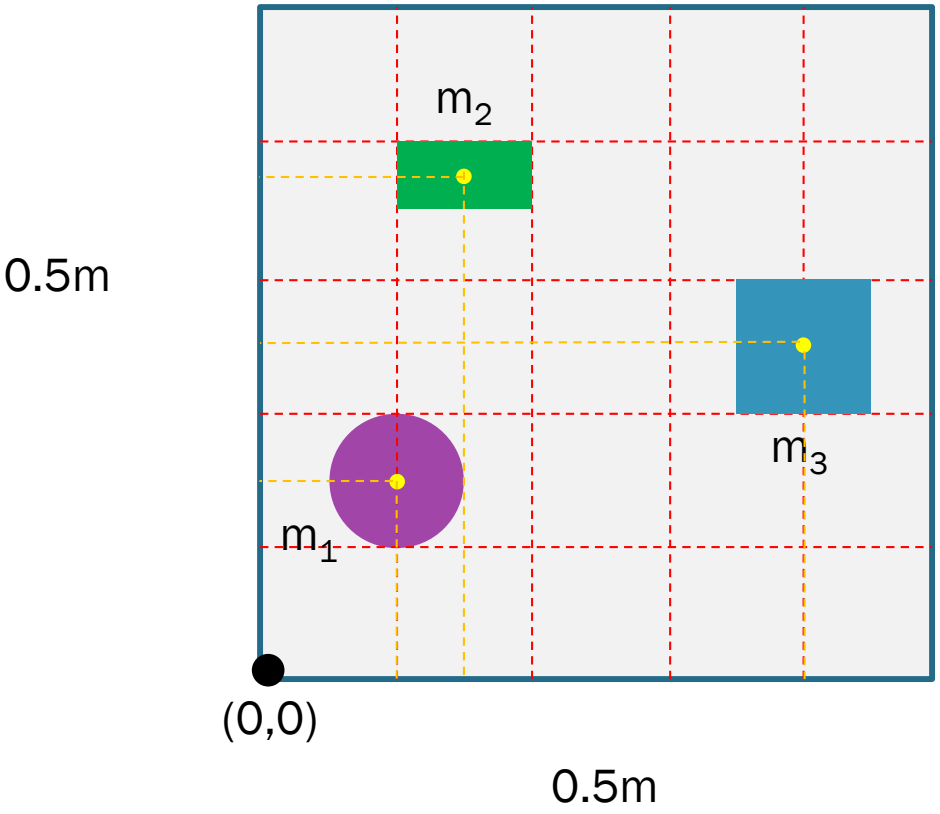
http://en.wikipedia.org/wiki/List_of_centroids



Divide complicated shapes into a combination of easy to calculate shapes

COG Example

- Find the x and y coordinators of the center of gravity on the following platform.



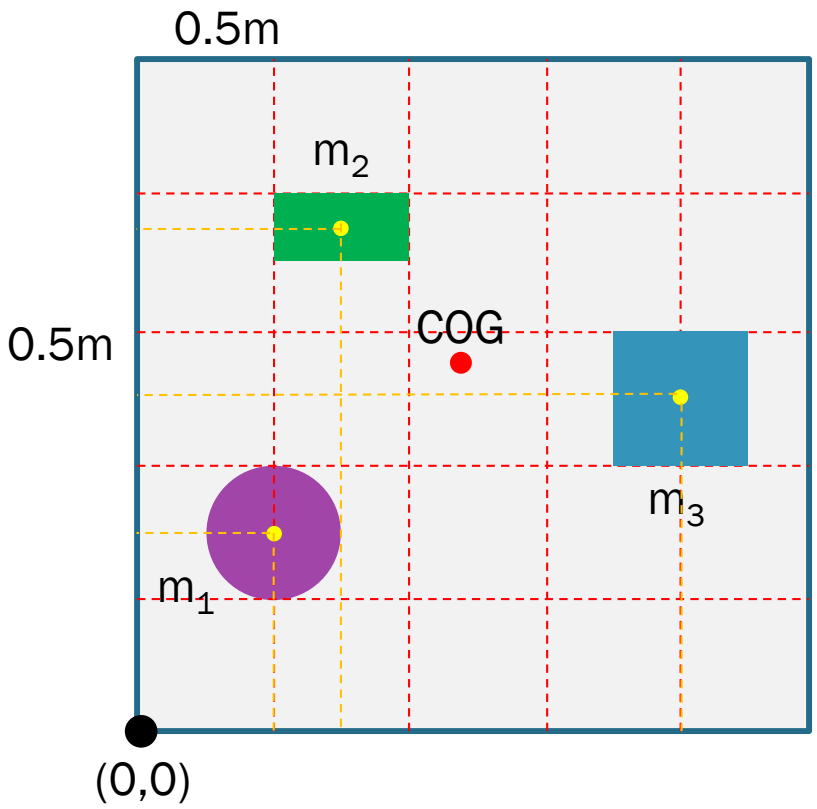
m_1 = 100 g, d = 0.1m

m_2 = 200 g
0.1m x 0.05m

m_3 = 200 g
0.1 m x 0.1m

COG Example

- Find the x and y coordinators of the center of gravity on the following platform.



m_1 = 100 g, d = 0.1m; m_2 = 200 g, 0.1m x 0.05m; m_3 = 200 g, 0.1 m x 0.1m

$$x_{CG} = \frac{\sum m_i x_i}{\sum m_i} = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3}{m_1 + m_2 + m_3}$$

$$= \frac{100g(0.1m) + 200g(0.15m) + 200g(0.4m)}{100g + 200g + 200g} = 0.24m$$

$$y_{CG} = \frac{\sum m_i y_i}{\sum m_i} = \frac{m_1 y_1 + m_2 y_2 + m_3 y_3}{m_1 + m_2 + m_3}$$

$$= \frac{100g(0.15m) + 200g(0.375m) + 200g(0.25m)}{100g + 200g + 200g} = 0.28m$$

Reading Assignment for Week 3

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"Introduction to Engineering Design" Book 11

Engineering Skills and Quadcopter Missions 4th Edition 2017

Chapter 6 "Dynamics and Control of Quadcopters"

Chapter 16 "Generation and Selection of Design Concepts"