VTOL stability and control
1. Multirotor
2. Transitional aircraft

VTOL aircraft stability and control

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In this lecture you will learn:

- What makes a multirotor fly in a stable manner?
- What other VTOL configurations are possible?

Flight performance of VTOL aircraft

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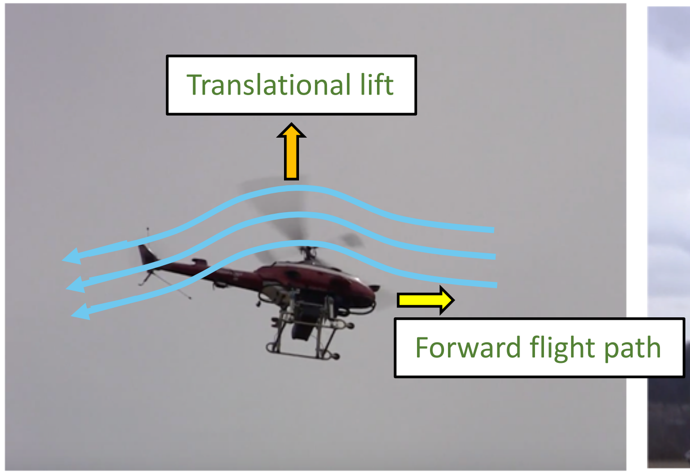
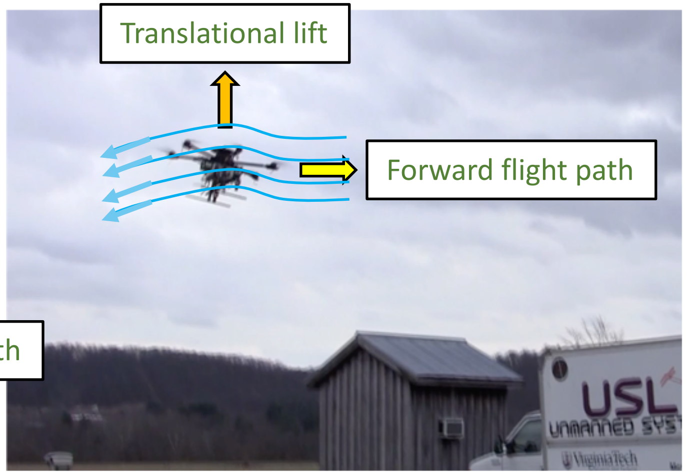
- VTOL aircraft have an advantage that they can hover, however we have seen that they consume much more power than a fixed wing aircraft
- VTOL are more efficient when flying forward as opposed to hovering
  - This is called “translational lift”
- Translational lift is **additional lift** that a VTOL aircraft produces when it **flies forward**
- The downwash created by the rotor(s) act similar to wing with camber that turns the relative air downward



RMAX helicopter



Hexacopter

Power consumption may decrease 20% for certain multi-rotor aircraft that are flown with forward speed

VTOL flight control

- One of the reasons that multirotor aircraft are so popular is that they are relatively easy to control using modern electronic systems
  - High processor speeds on relatively small form factors allow high bandwidth control applied to a system of several motors
  - The Pixhawk 4 mini, which we use, is an open-source platform for developing novel flight control programs
    - There are many aircraft configurations already available to "plug into" the flight controller
    - If a new flight control scheme is needed, the code can be written to accomplish the flight control task

VTOL control: how flight control functions on a quadcopter

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- The sensed aircraft states by the flight controller require sensors and electronics that convert the analog values to digital values
  - Magnetometer senses attitude (pitch, roll and yaw)
  - MEMS gyro senses pitch,roll and yaw rates
  - Accelerometers sense $\ddot{x}$, $\ddot{y}$, $\ddot{z}$
  - A MEMS pressure sensor senses barometric pressure
  - A digital airspeed sensor (on fixed wing) senses airspeed
  - The GPS receiver senses position

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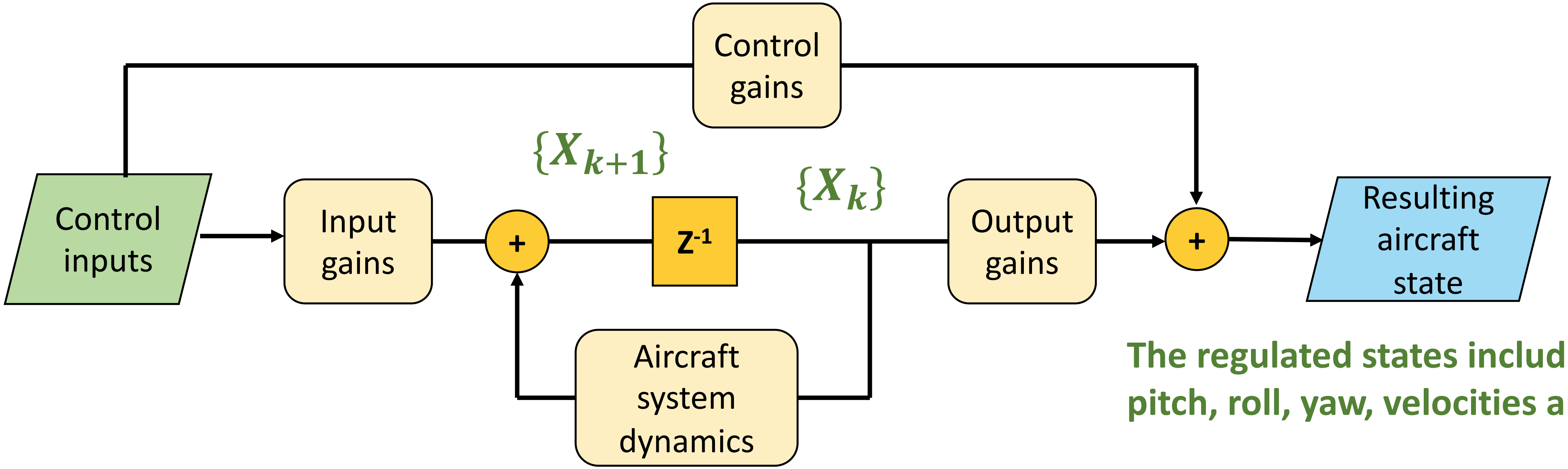
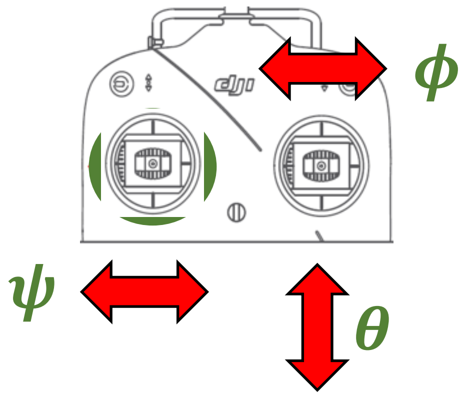
- The Pixhawk 4 Mini contains a full inertial measurement unit (IMU) to sense the state of the aircraft and provide feedback to regulate the RPM of the motors

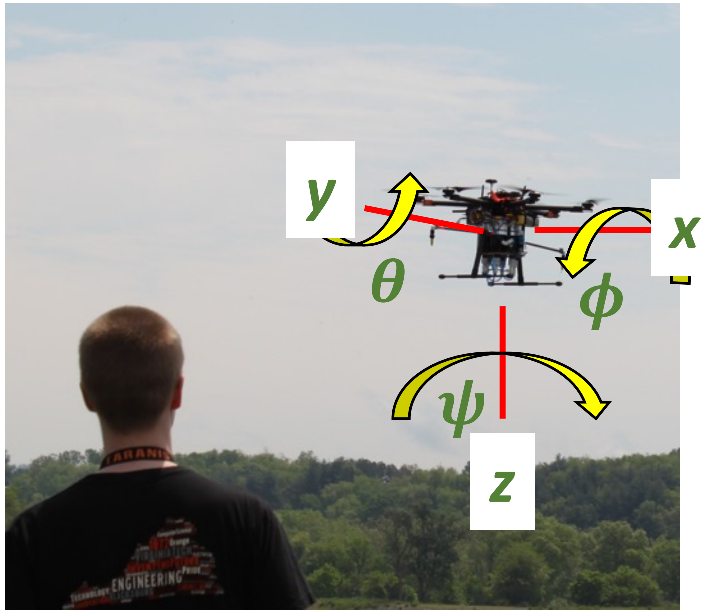


The regulated states include aircraft pitch, roll, yaw, velocities and positions

The control inputs and responses on a multicopter function similar to a fixed wing aircraft

- Yaw is still controlled by the left stick
  - Can function independently of other flight control axes regardless of the current state of flight
- Roll and pitch are controlled by the right stick
  - Necessary to visualized the orientation of the aircraft correctly throughout all maneuvering
  - Sometimes it is helpful to mark the aircraft landing gear or arms to recognize orientation





VTOL flight control - the layout of hardware and signal routing

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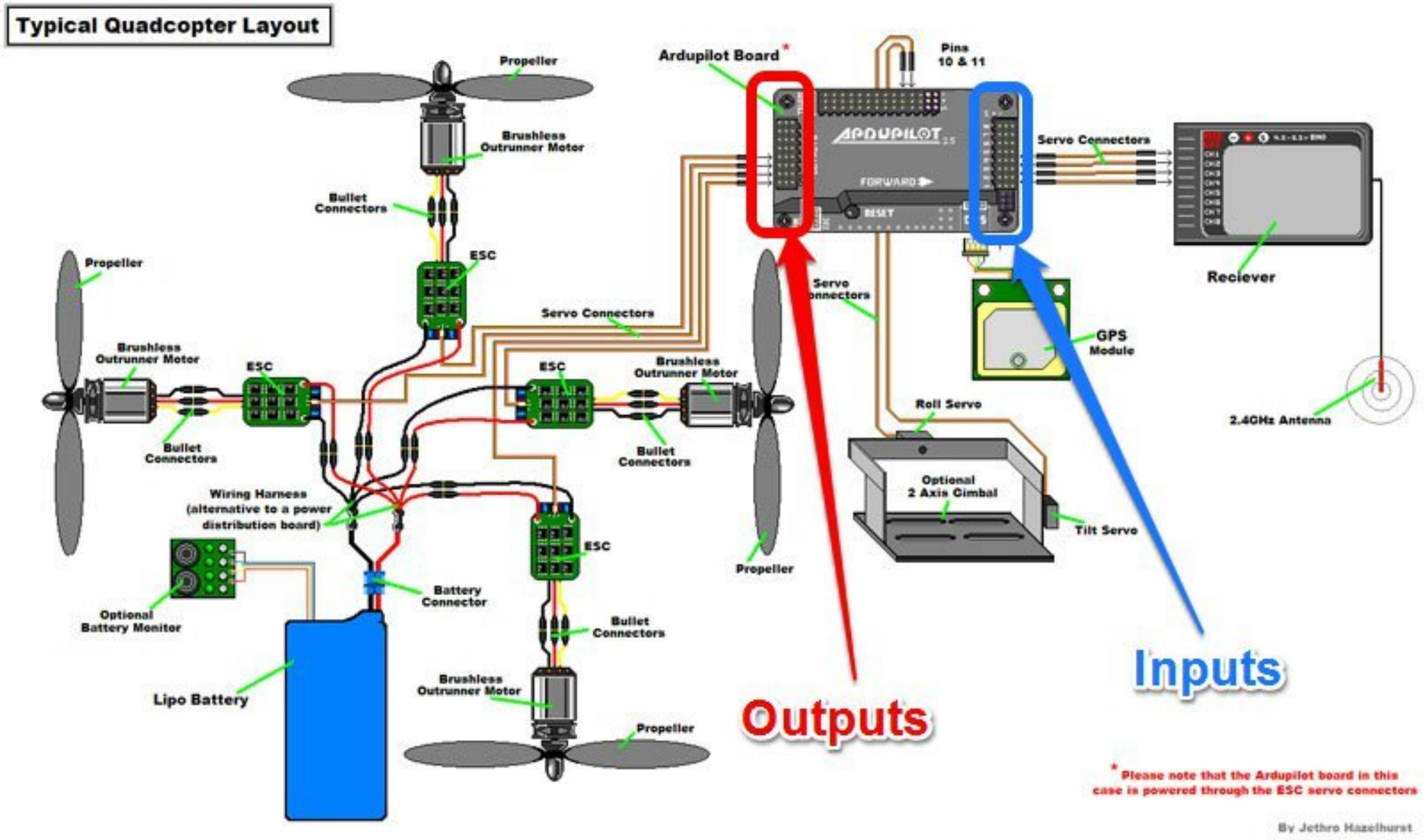

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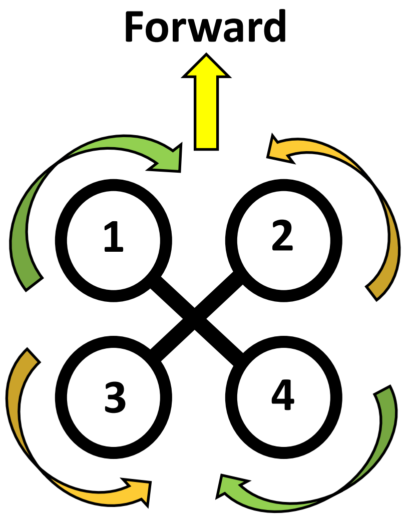

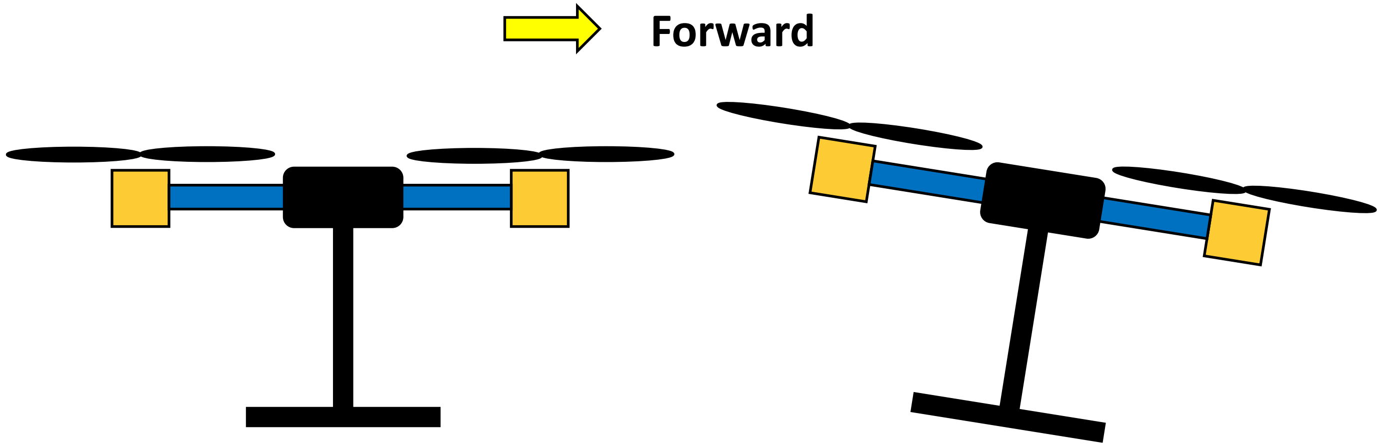

- The motors on the quadcopter turn in alternating directions to cancel the torque of the system
- Changes in RPM of rotor pairs results in pitch, roll and yaw control of the aircraft
- For instance, to pitch the aircraft forward, rotor speeds for 1 and 2 are decreased and 3 and 4 are increased, while the net thrust is not changed

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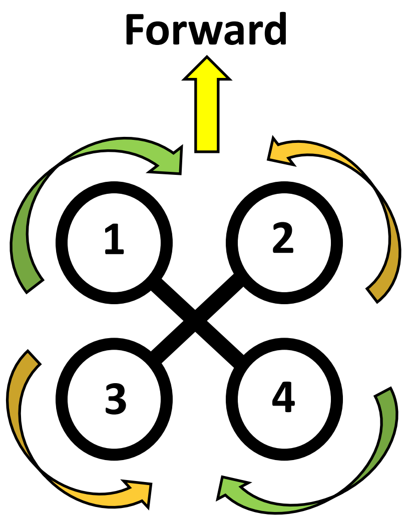
- Likewise, changing the RPM of different combinations of rotors will affectively maneuver the aircraft in all axes

Maneuver	Rotor speed change
Pitch forward	Decrease 1,2 and increase 3,4
Roll right	Decrease 2,4 and increase 1, 3
Yaw left	Increase 1, 4 and decrease 2, 3



Transitional aircraft

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- As drone applications grow, so do the range of aircraft configurations
- Hybrid aircraft that can perform as VTOL aircraft but transition efficiently to forward flight are becoming popular
- “H” configurations are popular for light cargo delivery