FW stability and control

1. Static stability
2. Effects of camber and tail volume
3. Control

Lecture 7A: Fixed wing aircraft stability and control

Lecture Presented By: Kevin Kochersberger

In this lecture you will learn:

- What makes an airplane fly in a stable manner?
- What can be done to enhance aircraft stability?

Static stability is built into aircraft so that they fly "hands-off"

- An aircraft that is configured to exhibit static stability will be self correcting to gusts
- A moment balance is used to illustrate static stability by summing torques about the center of gravity (CG):

$$\sum M_{cg} = -Lift * l_w + TD * l_t = 0$$

$$\sum M_{cg} = -\frac{1}{2}\rho V^2 S C_{Lw} * l_w + \underbrace{\frac{1}{2}\rho V^2 S_t C_{Lt}}_{} * l_t = 0$$

The C_{Lt} term in the tail includes the additional lift component due to elevator deflection

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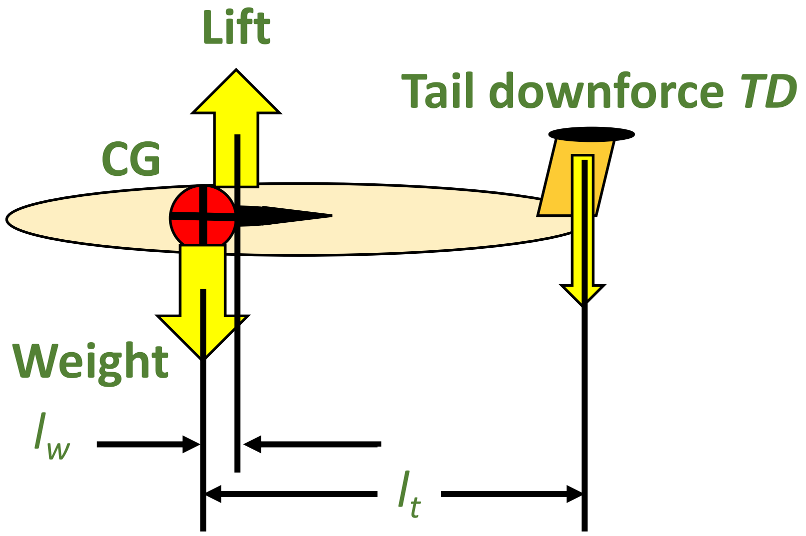

A non-dimensional pitching moment coefficient C_m can be created:

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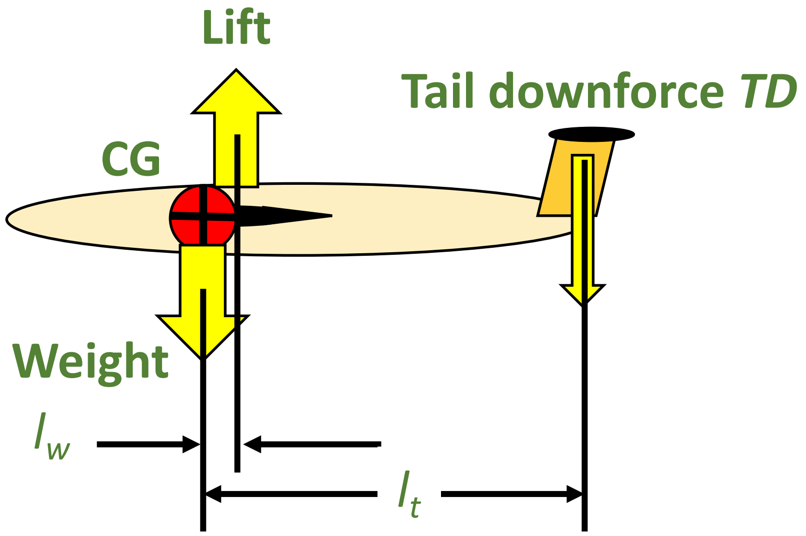
$$\frac{\sum M_{cg} = -\frac{1}{2}\rho V^2 S C_{Lw} * l_w + \frac{1}{2}\rho V^2 S_t C_{Lt} * l_t}{\frac{1}{2}\rho V^2 S\bar{c}}$$

$$C_m = -\frac{C_{Lw} l_w}{\bar{c}} + \frac{C_{Lt} S_t l_t}{S\bar{c}}$$

$$C_m = -\frac{C_{Lw} l_w}{\bar{c}} + C_{Lt} V_H$$

The term V_H is the horizontal tail volume which describes the effectiveness of the tail



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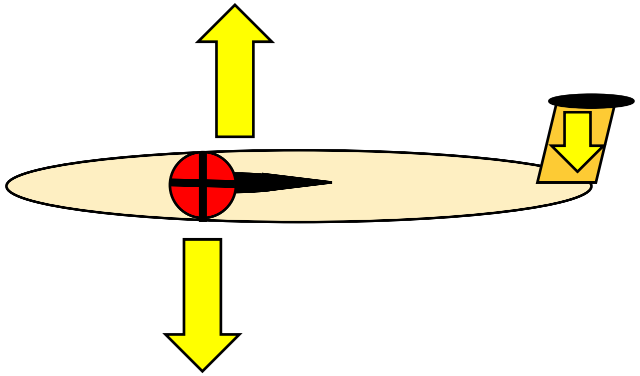
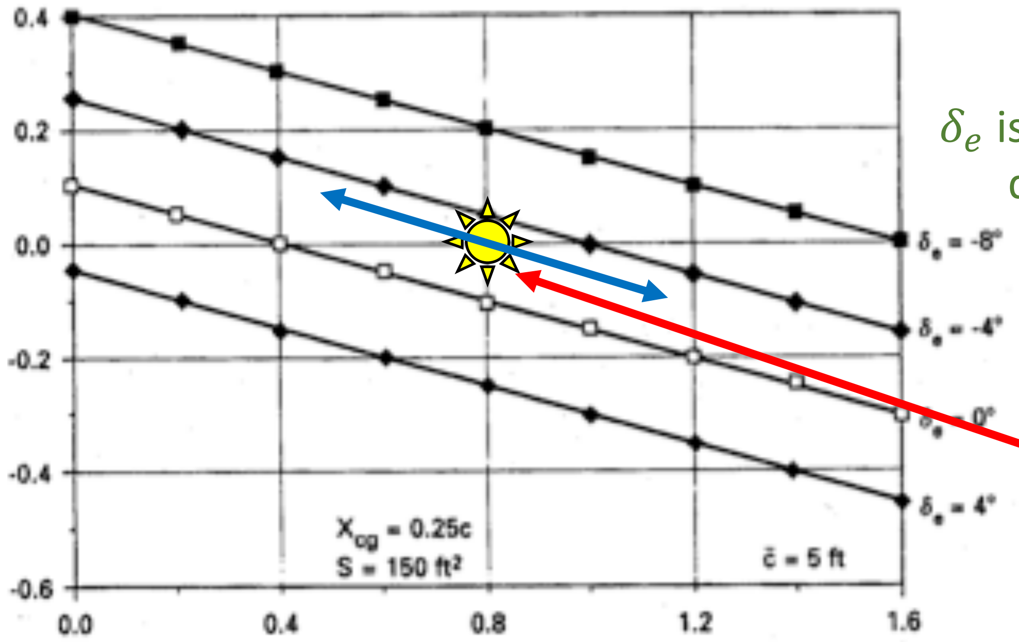
- The diagram below is called a "pitching moment" diagram and it shows how restoring moments act on the aircraft when disturbed



C_m is the non-dimensional pitching moment



C_L is the lift coefficient

δ_e is the elevator deflection

- **If the aircraft is flying at a trimmed C_L = 0.8, then this point represents the "balance" point for the aircraft**
- **Any disturbance to the aircraft that results in a higher or lower C_L will result in a new applied moment that causes the aircraft to return to its original state**

Static stability is built into aircraft so that they fly "hands-off"

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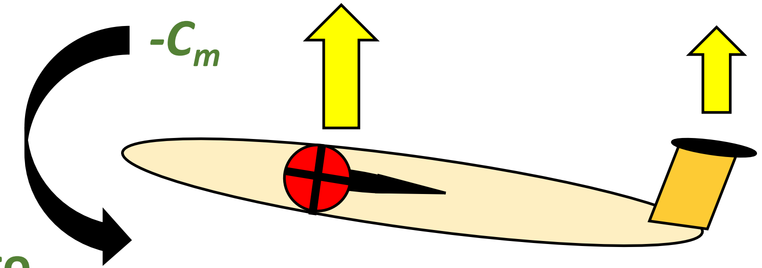
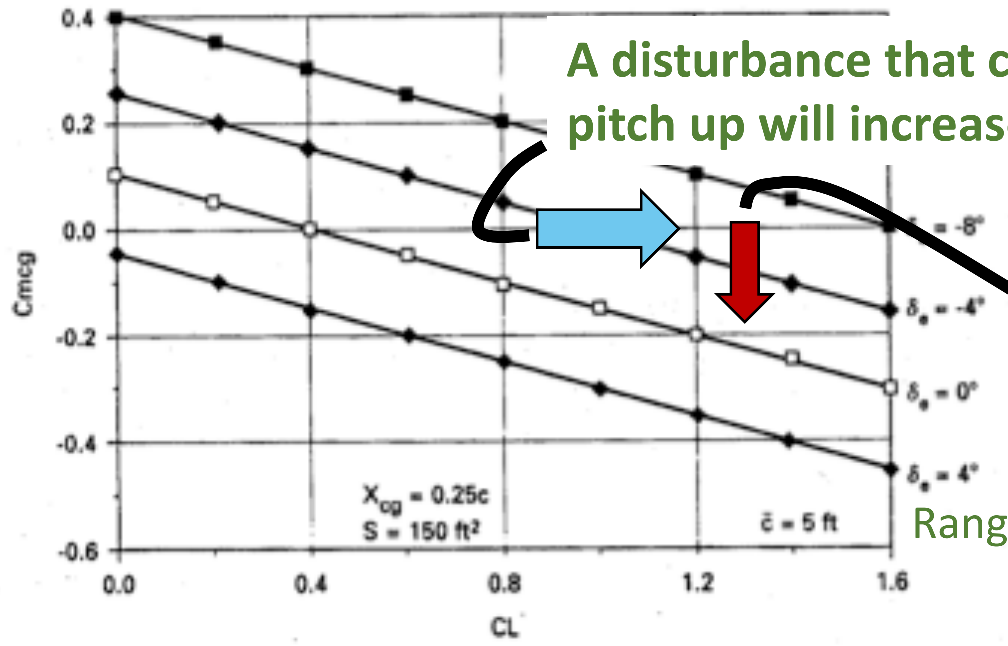
- A pitch-up of the aircraft causes the C_L to increase which results in a negative pitching moment





A disturbance that causes the aircraft to pitch up will increase the lift coefficient

When the aircraft pitches up, the moments on the aircraft become negative and force the nose back down

Range of elevator deflection

Static stability is built into aircraft so that they fly "hands-off"

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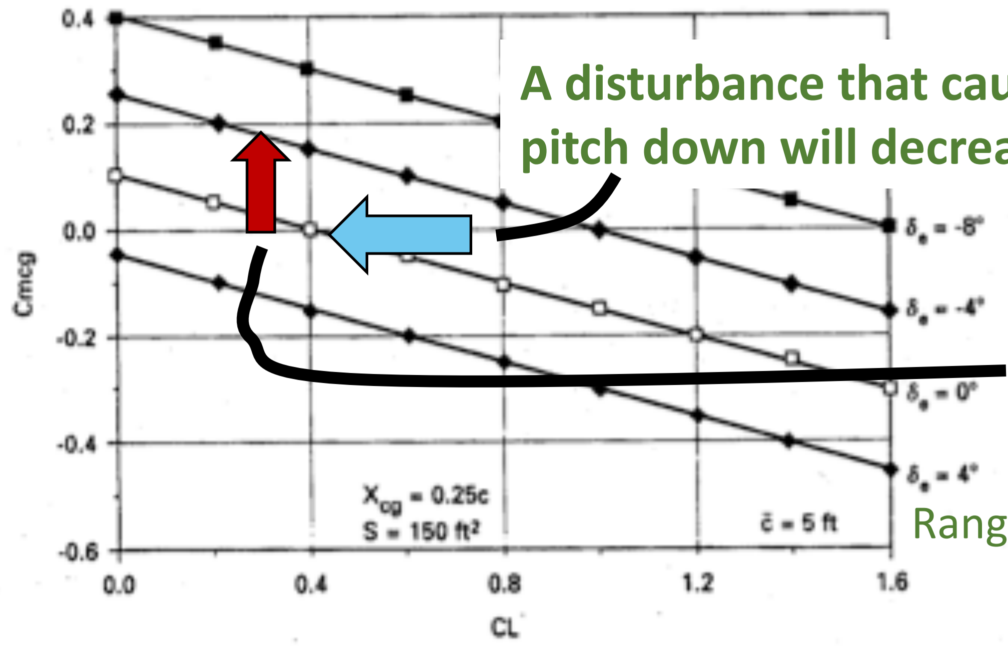
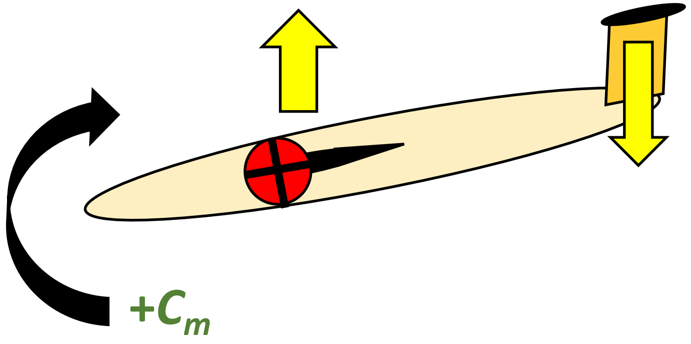
- A pitch-down of the aircraft causes the C_L to decrease which results in a positive pitching moment



A disturbance that causes the aircraft to pitch down will decrease the lift coefficient

When the aircraft pitches down, the moments on the aircraft become positive and force the nose back up

Range of elevator deflection



The Wright Flyer with its canard was an inherently unstable aircraft

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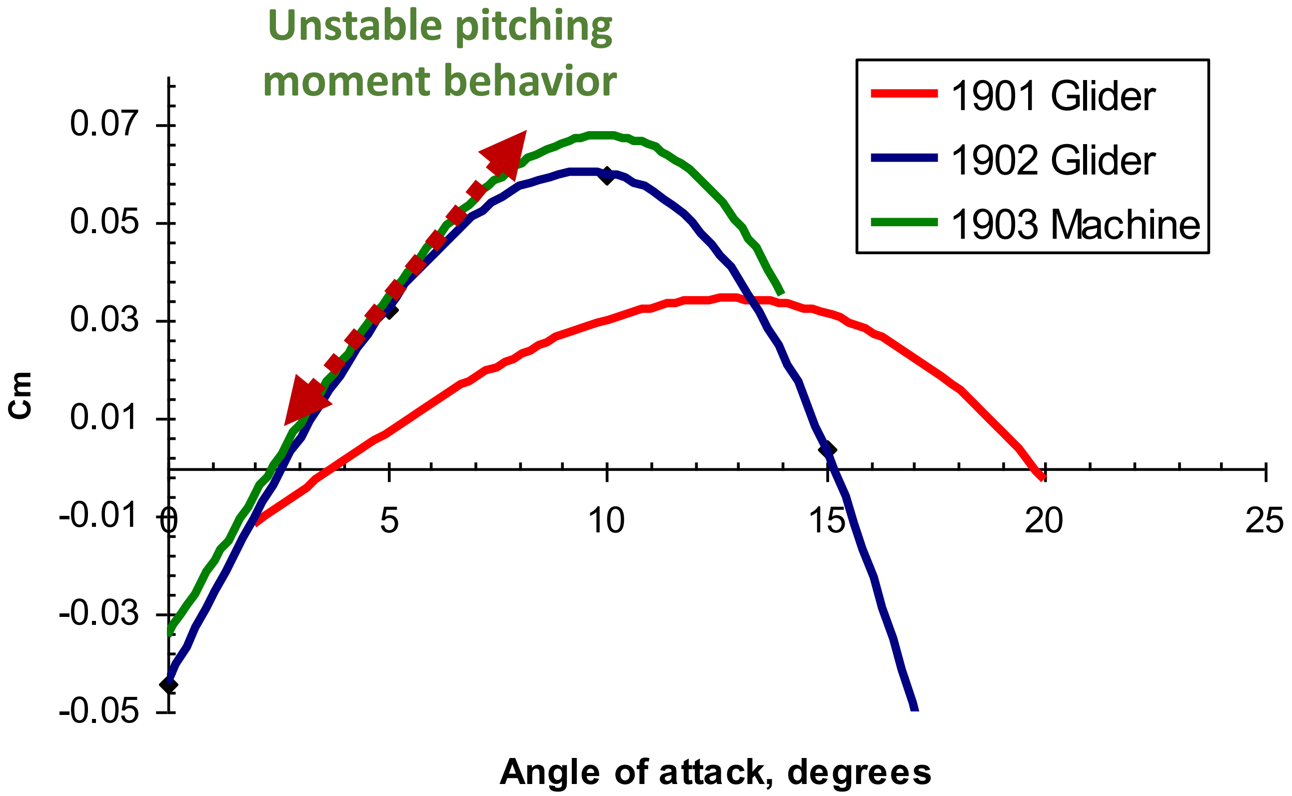
- This aircraft wants to pitch up more when it pitches up, and pitch down more when it pitches down



A few measures can be taken to ensure a fixed wing aircraft will be statically stable

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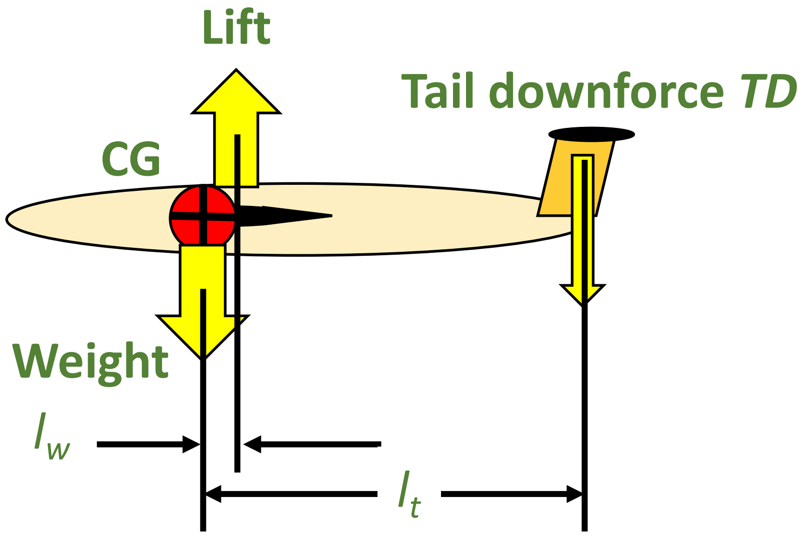
- Recall that the **tail volume** is determined from the tail area and distance aft of the CG: $V_H = \frac{l_t S_t}{S\bar{c}}$
- By **increasing V_H** we can **increase the effectiveness of the tail**, and that in turn will cause the aircraft to become **more stable**
- Graphically, this is observed as steeper C_m curves:



An airplane that is "statically" marginally stable will have trouble holding altitude

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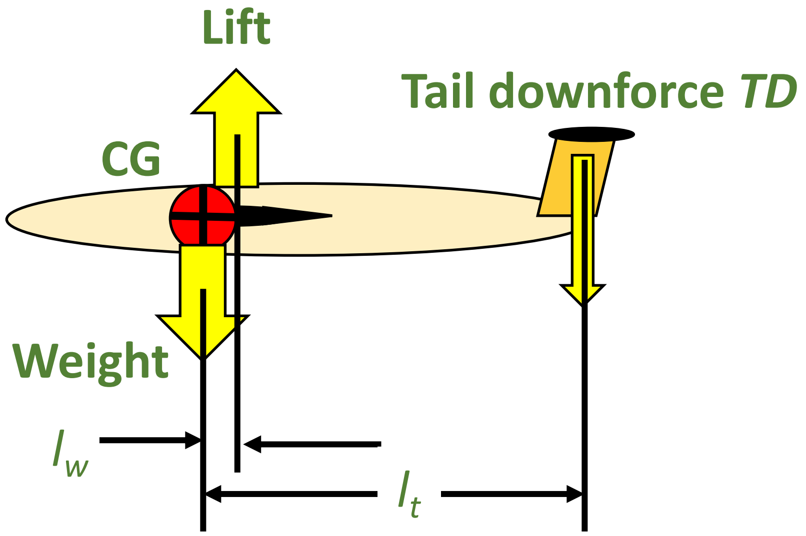
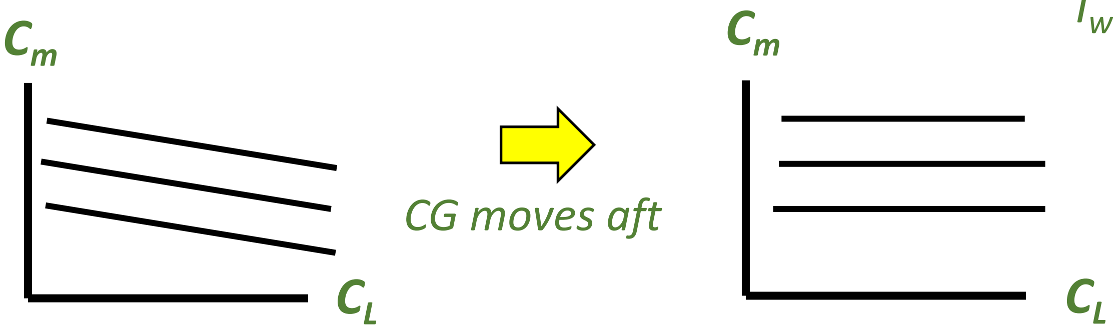
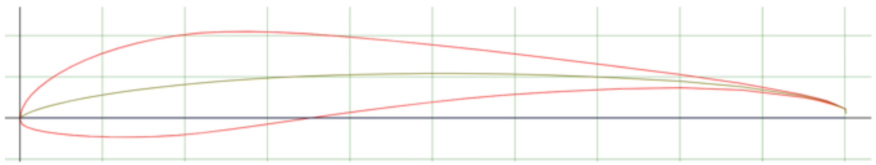
- If the CG moves aft, it will have the same effect as making the tail volume smaller and causing the C_m curve to become flatter
- A marginally stable aircraft will have trouble holding altitude and will potentially be uncontrollable by the pilot
  - The aircraft may rapidly pitch up as well, causing a stall and crash





The camber of the wing can also contribute to instability

- Camber in a wing has a destabilizing effect on aircraft stability
- A highly cambered wing generates more lift at low angles of attack, but it also requires a bigger tail (bigger tail volume) to compensate for the camber effect
- Some aircraft have no tail at all, and these require an airfoil specifically designed to have stable performance



Recall the Selig S1221 airfoil which is highly cambered - ***destabilizing***

The MH60 airfoil used on the EcoSoar flying wing has a **slight upward reflex at the end** which contributes to its stability

A rule for aircraft is to place the center of gravity slightly ahead of the ¼ chord point on the wing

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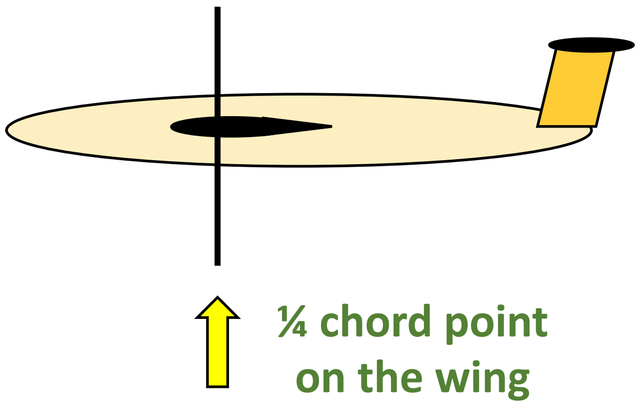
- The aerodynamic center (AC) of a wing is typically close to the ¼ chord position
  - The AC is the point where the lift due to angle of attack (not camber) is located
  - If the CG is slightly in front of this point, then any increase in angle of attack will result in a restoring pitch down moment to stabilize the aircraft
- The balance point can be used to find the center of gravity
- From this point, the AC is determined to ensure the CG is in front of the AC



Aircraft control is equally important to maintaining flight as is the lift generated by a wing

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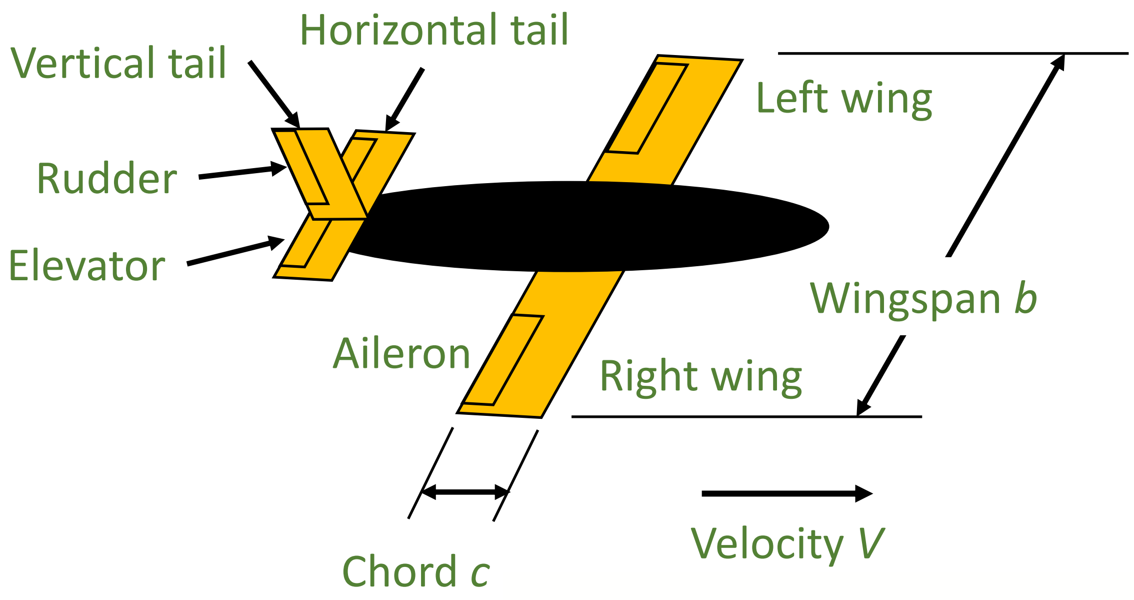
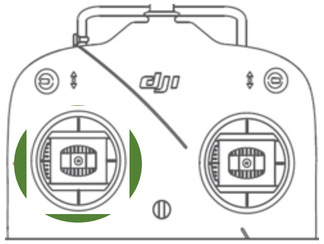
- ***Manual*** control of the aircraft is usually described as the pilot's input through the transmitter to actuate the aircraft control surfaces





Pilot technique in remote control is similar to manned aircraft control for stall prevention and recovery

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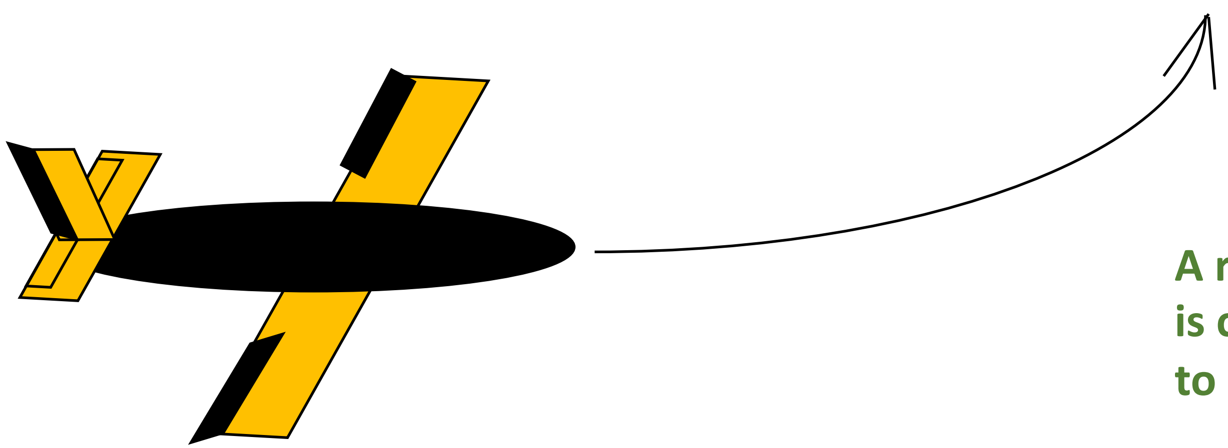
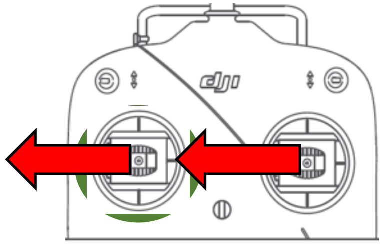
- At all times, the aircraft should fly in a ***coordinated*** manner
  - This means that the rudder is used to trim the nose so that the airflow is aligned with the longitudinal axis of the aircraft





A roll is initiated and the rudder is commanded at the same time to coordinate the turn

Inputting a rolling command to the right results in an **adverse yaw** to the left - corrected with rudder input

Adverse yaw is the reason that rudder input is required when initiating a turn

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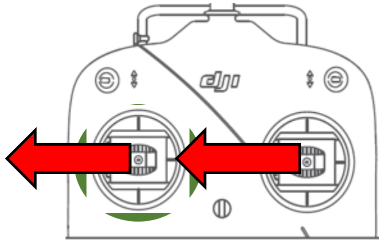
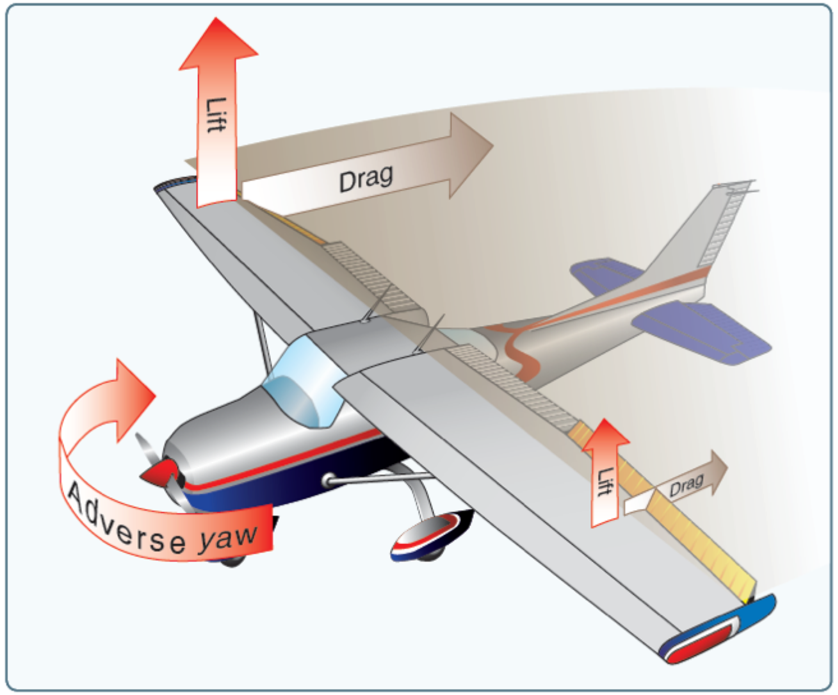
- When the ailerons are deflected, **drag is higher** on the aileron which is **deflected downward** because it is generating more lift that than upward moving aileron
- The rudder is used to keep the nose from moving in the opposite direction of the turn

To initiate a coordinated turn:

Generally, the rudder is commanded with aileron input initially, then the two surfaces are brought to neutral while the aircraft is slightly trimmed throughout the turn





Stalls and spins

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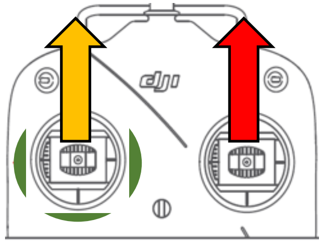
- If the aircraft gets too slow during flight, it has a good chance of stalling and possibly entering a spin
  - *These are dangerous flight conditions that need to be avoided*
- If you notice the nose of the aircraft rising during flight and the speed seems to be decreasing, **lower the nose immediately** to prevent the aircraft losing lift on one or both wings
  - **Increase throttle** if it appears that you have sufficiently executed a recovery



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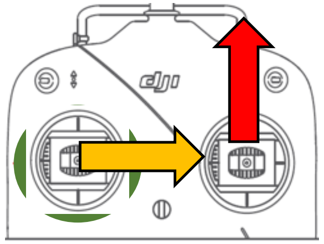
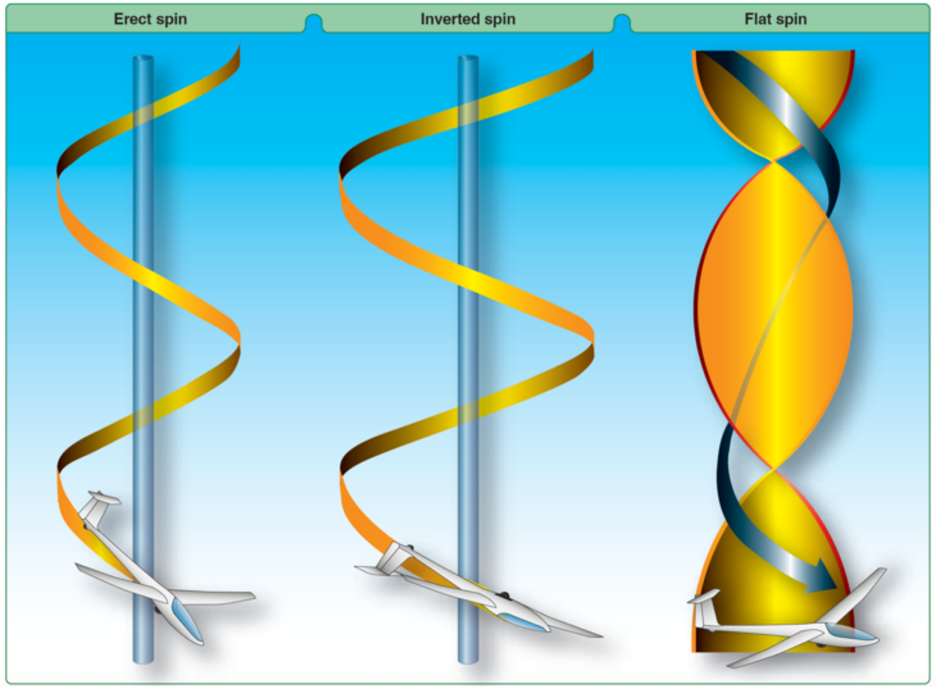
- A spin may result if the aircraft has some yawing behavior during the stall
- One wing stalls before the other one, and it drops, pushing the aircraft into a stable turning descent called a spin
- The recovery technique is to drop the nose, and apply opposite rudder to the turn





Stalls and spins

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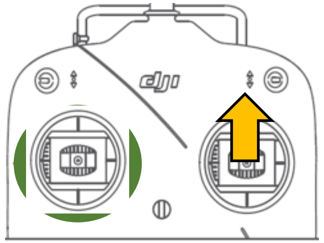
- Departure stalls and spins are common with small aircraft
- If the aircraft pitches up on takeoff, the likelihood of one wing stalling and causing the plane to roll uncontrollably is good
  - These are very difficult flight regimes to recover from - they aircraft may be too low to recover
  - Flying wing aircraft without a rudder have a limited ability to recover
  - Solution: reduce pitch attitude until sufficient altitude is reached that a recovery may be initiated



Feedback control is the augmentation of aircraft stability through a flight control system

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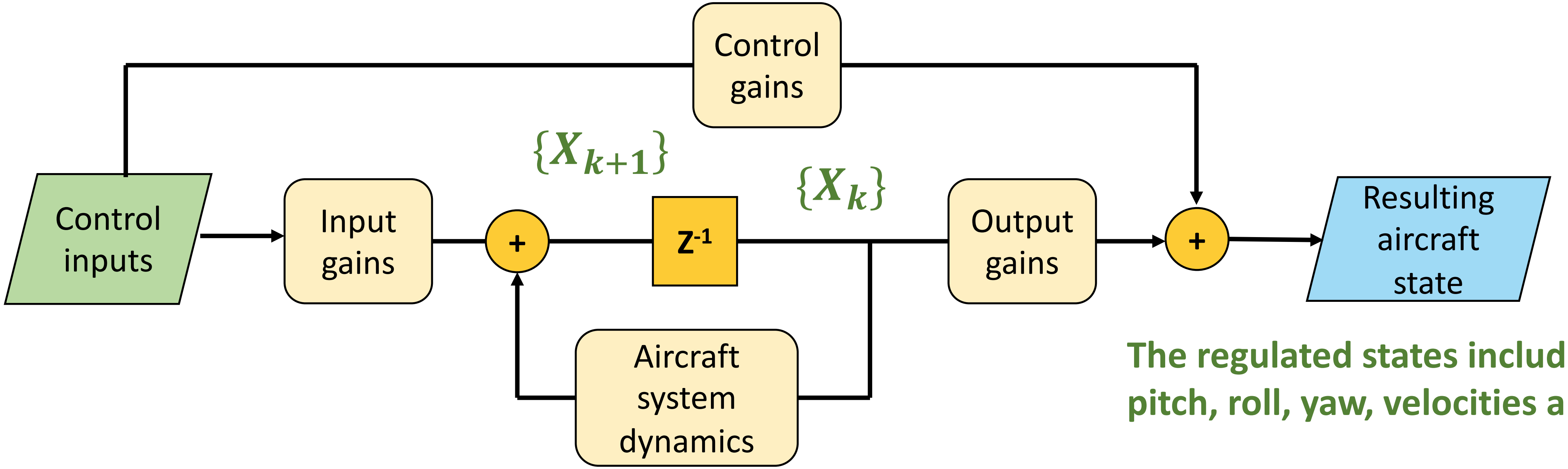
- An aircraft feedback control system provides a level of stability and control not achievable through passive means



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

The Pixhawk flight controller is configured using QGroundControl for the particular airframe flown

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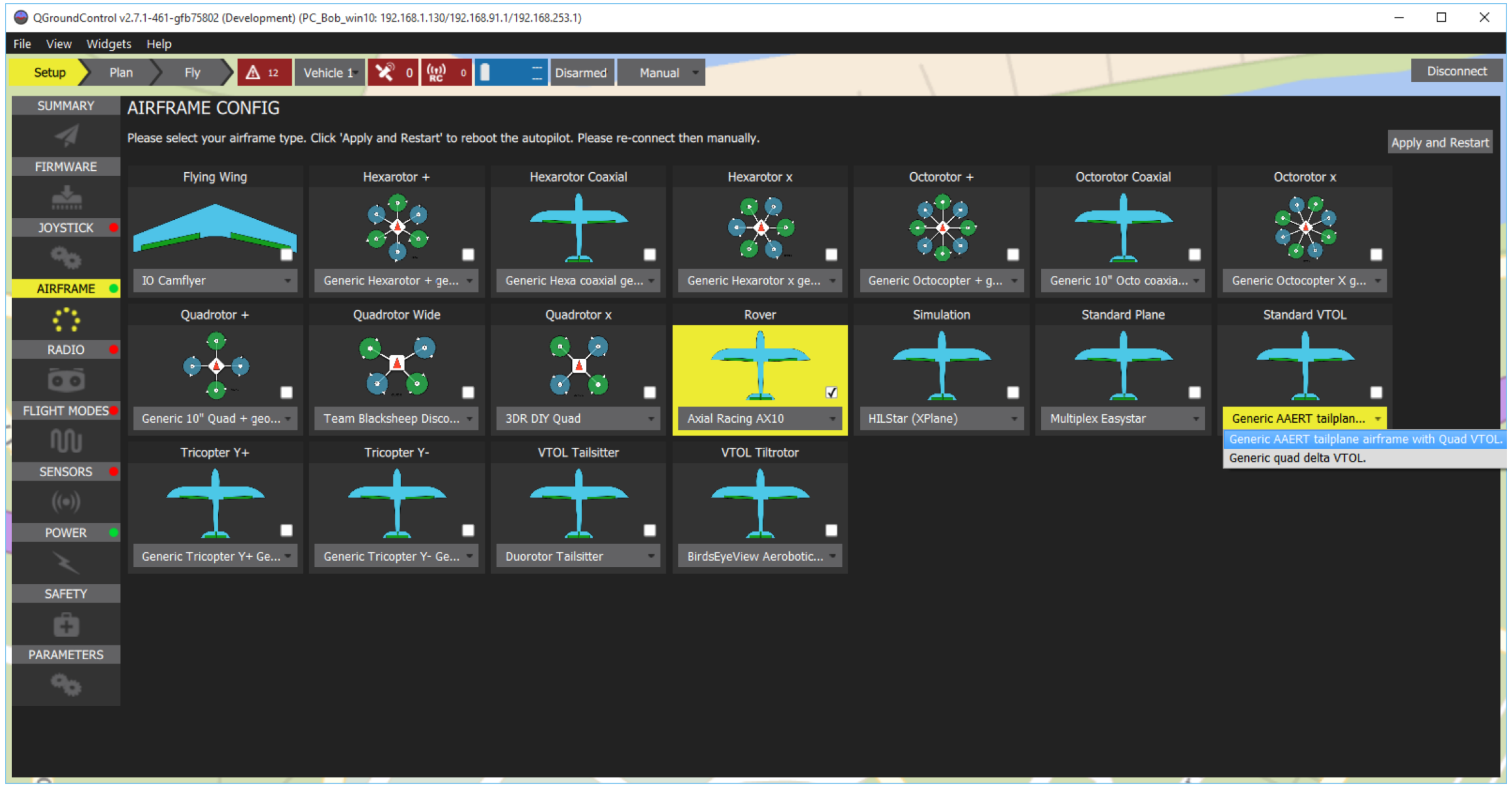
- Once the aircraft configuration is chosen, a **process of tuning** must occur so that feedback gains will provide the desired flight handling qualities
  - These include the flight control speed of response, damping, and minimization of altitude and flight path error



Flight control code is frequently simplified by decoupling motion in the principle axes

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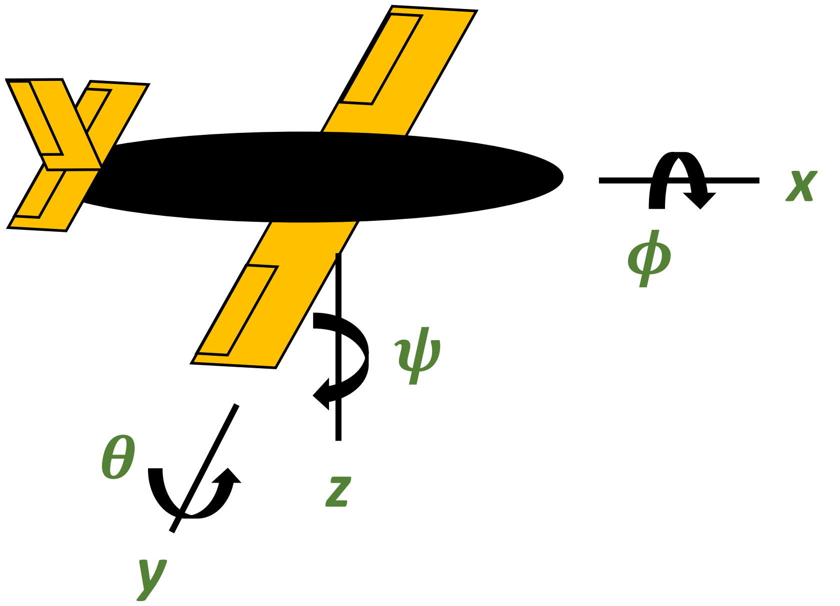
- Motion about the pitch axis (***y***) is assumed to be independent of roll axis (***x***) motion
  - Coupling terms are small and can be neglected
- Altitude is controlled in a **feedback loop** that includes **throttle** and **pitch control** using **airspeed** and **altitude inputs**
- Proportional, Integral, Derivative (PID) feedback control loops are written to minimize coupling terms where their contribution can be neglected



Gain tuning creates desired, stable flight characteristics - can be done manually or automatically

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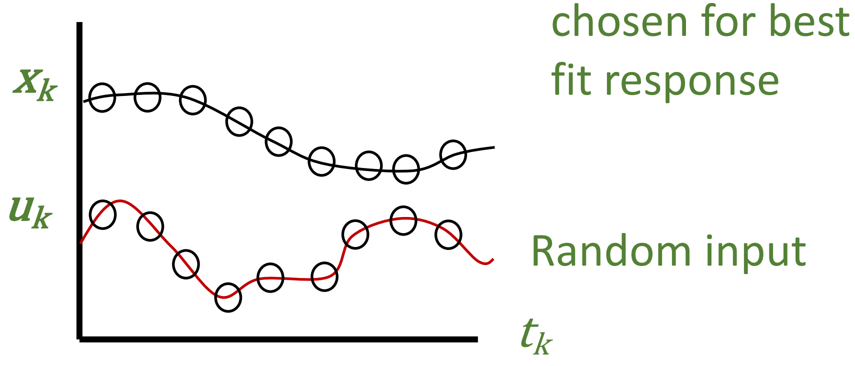
- A **flight mode** with random control inputs can be used to invoke a **system ID** process
  - Inputs and the resulting aircraft motion (output) are **modeled** in a **discrete state space process**
  - The **error** between the actual and modeled aircraft response is **minimized** to determine *"M"* and *"N"* matrices describing aircraft behavior
  - The state space description may either express the entire aircraft state, or be decoupled with independent equations to simplify tuning

Discrete time:

$$\{x_{k+1}\} = [M]\{x_k\} + [N]\{u_k\}$$



To accomplish tuning, an aircraft is manually maneuvered by the pilot while the aircraft computes control gains

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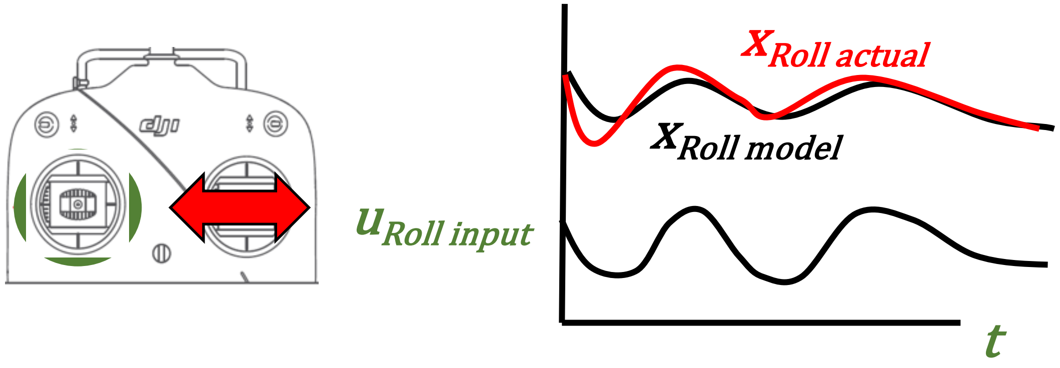

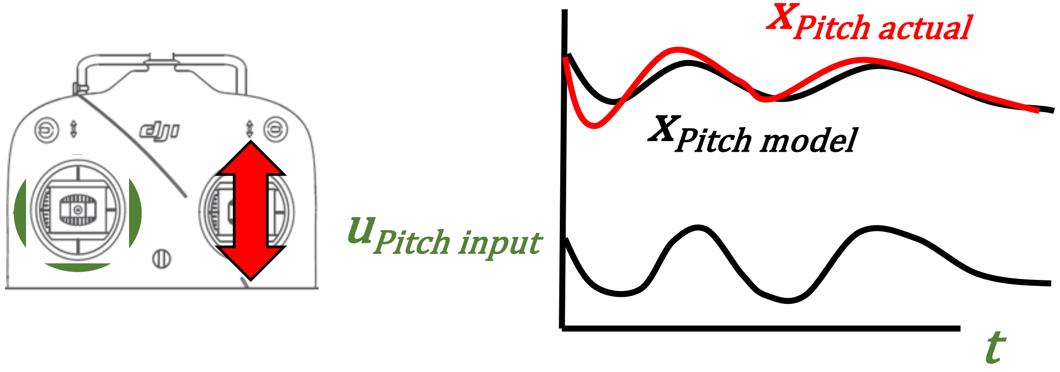

The modeled response converges to the actual response as the system ID improves during training