

# Automatic Flight Control Systems

- Autopilot
  - Controls a/c trajectory w/o requiring input from pilot
- Stability Augmentation System (SAS) ← adjusting stability derivatives
  - Designed to improve dynamic stability
  - Relies on sensors, not on pilot inputs
- Control Augmentation System (CAS) ← adjusting control derivatives
  - Pilot input has two paths to control surfaces
    - Mechanical system
    - through the CAS electrical path
- Fly by Wire (FBW) ← choose your own derivatives
  - No mechanical link from pilot to actuators
    - (a CAS with complete authority)



Autopilot: 1910s  
(A/C: Lockheed Vega (1930s))



SAS (F-104) 1950s



CAS (F-15) Early '70s



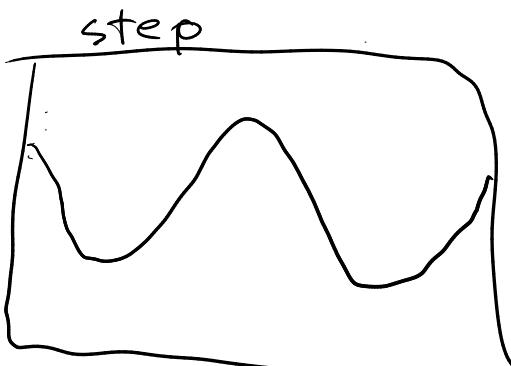
FBW (F-16) Late '70s

## Control Design Task 1: Pitch Attitude Controller

Input:  $\theta_r$       Goal:  $\theta \rightarrow \theta_r$  quickly (minimal Phugoid)

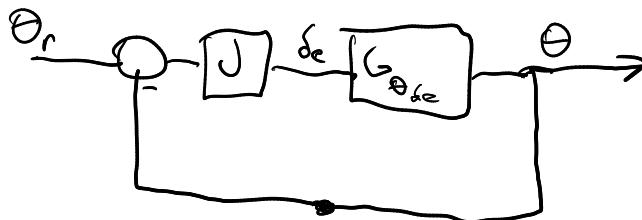


$J=1$

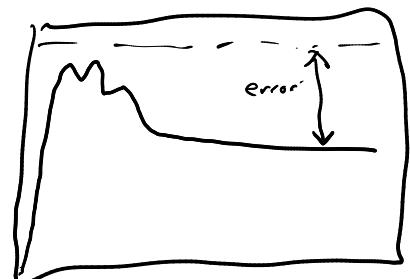
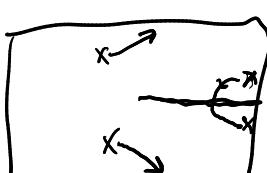


$J=K$

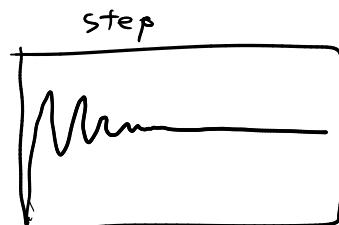
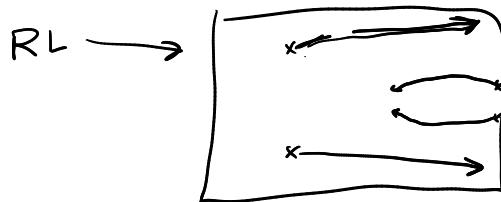
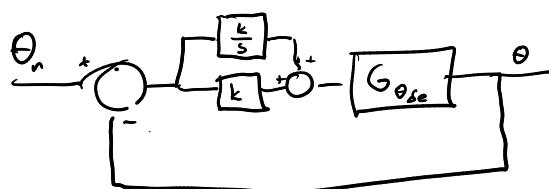
$K = -0.5$



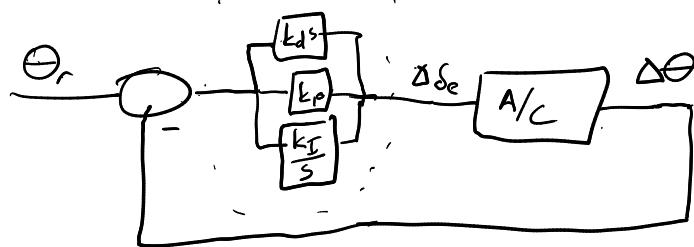
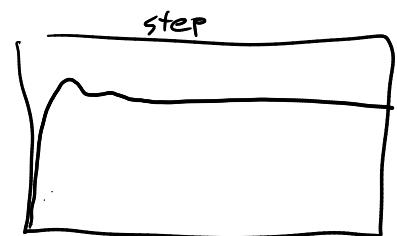
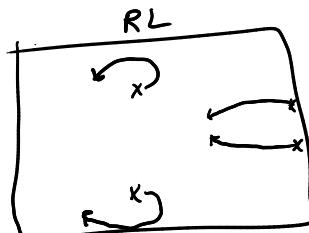
RL



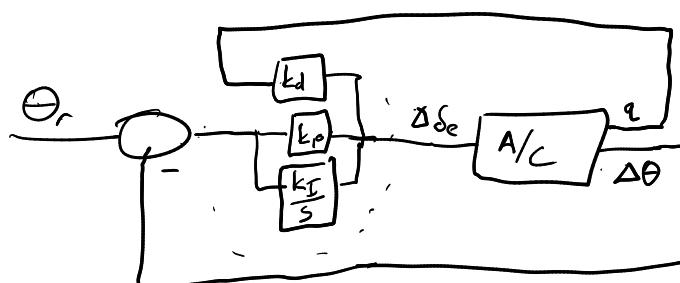
$$J = K \left(1 + \frac{1}{s}\right)$$



$$J = K \left(1 + \frac{1}{s} + s\right)$$



$\Delta \theta$   $\int \frac{d\Delta \theta}{dt}$  very large



$$\Delta \theta_e = -k_p \Delta \theta$$

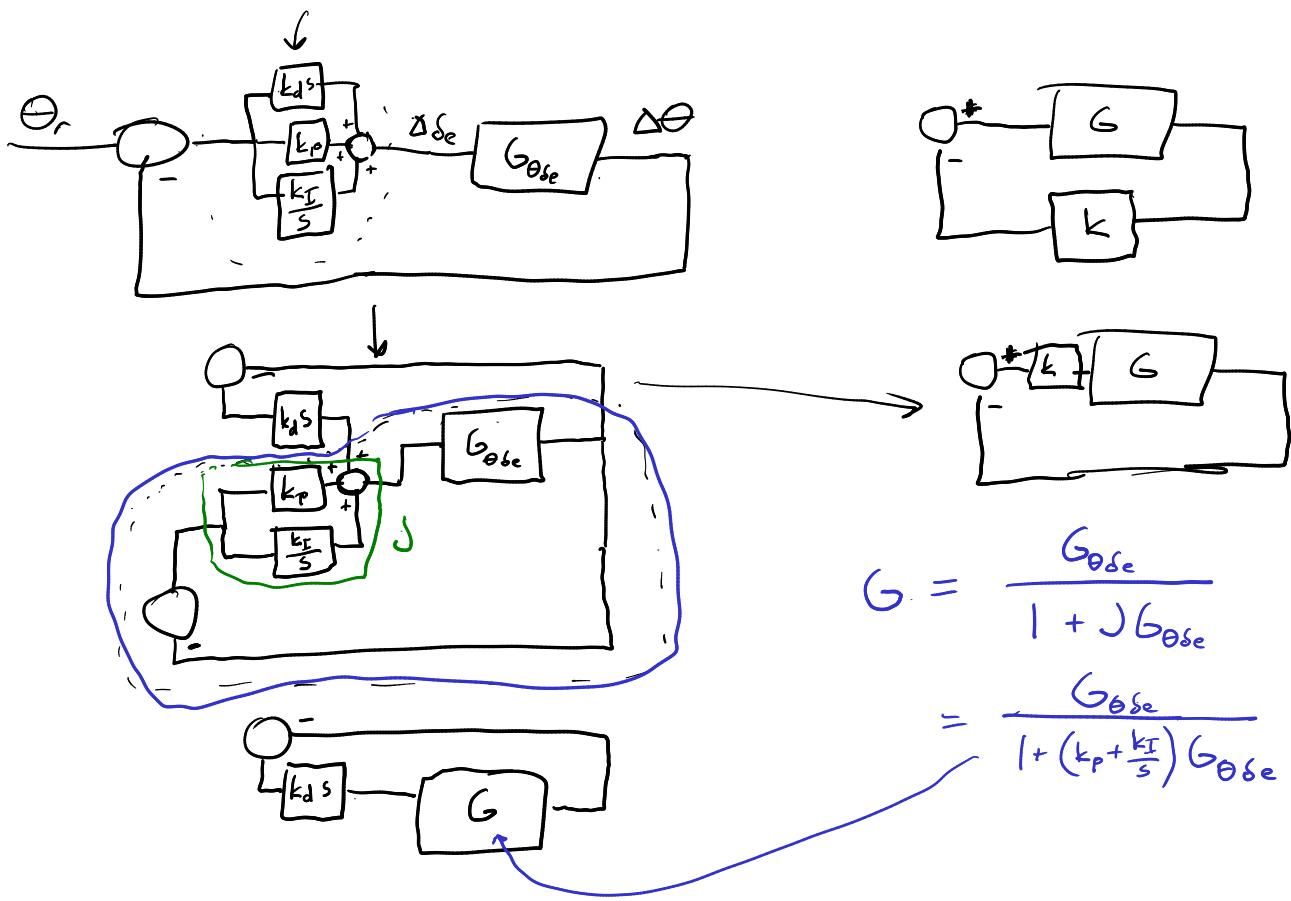
$$\bar{u} = -K \bar{x}$$

$$\begin{bmatrix} \dot{\theta}_e \\ \dot{\theta}_t \end{bmatrix} = - \begin{bmatrix} 0 & 0 & 0 & k_p \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \bar{u} \\ \bar{w} \\ q \\ \Delta \theta \end{bmatrix}$$

$A_{lat} - BK$  ?

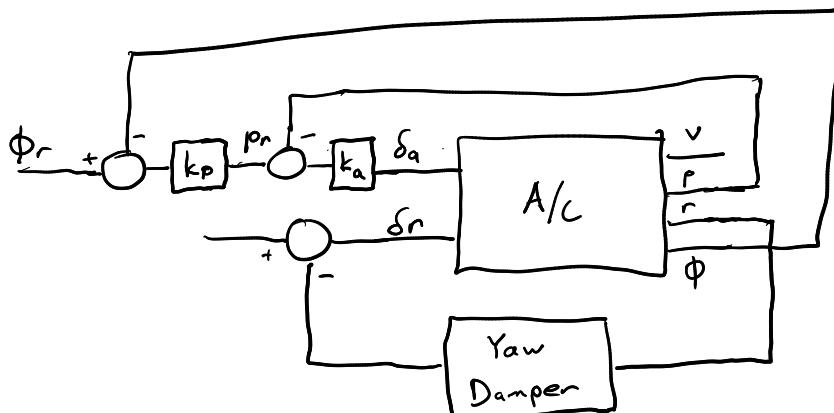
$$A_{lat} - \begin{bmatrix} 0 & 0 & 0 & k_p \\ -0.1431 & 0 & 0 & 0 \\ 0.0037 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$A_{lat} - \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0.14k_p \\ 0 & 0 & 0 & 0.0037k_p \\ 0 & 0 & 0 & 0 \end{bmatrix}$$



## Control Task 2: Roll Controller

Input:  $\phi_r$       Goals:  $\phi \rightarrow \phi_r$  quickly      Alleviate Dutch Roll



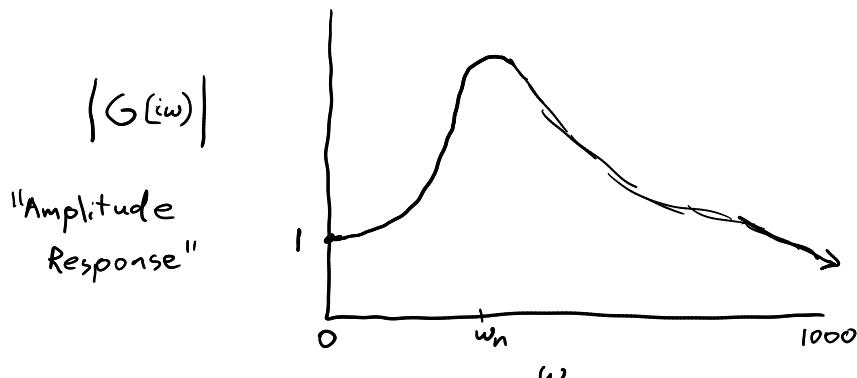
### Part 1: Yaw Damper

$$\delta_r = -k_r r \quad \text{from RL, choose } k_r = -1.9$$

Want:  $\delta_r \rightarrow 0$  at low frequency

$\delta_r = -k_r r$  near dutch roll freq.

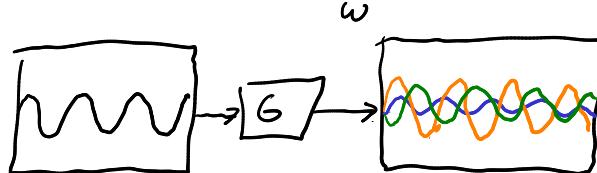
# Review: Frequency Response



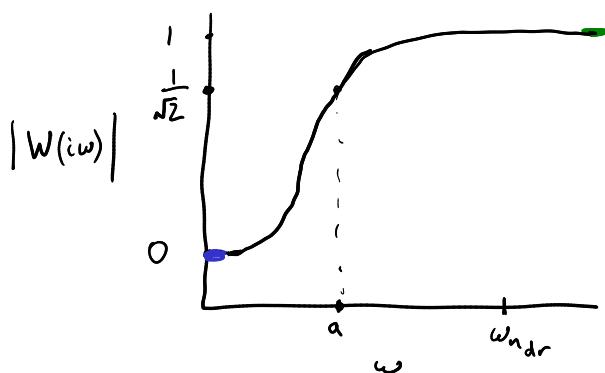
$$G(s) = \frac{\omega_n^2}{s^2 + 2s\omega_n s + \omega_n^2}$$

$$|G(0)| = 1$$

$$\lim_{\omega \rightarrow \infty} |G(i\omega)| = 0$$



"Washout" / high pass filter



$$W(s) = \frac{s}{s+a}$$

$$|W(0)| = 0 \quad \leftarrow$$

$$\lim_{\omega \rightarrow \infty} |W(\omega_i)| = \lim_{\omega \rightarrow \infty} \left| \frac{\omega_i}{\omega_i + a} \right| = 1 \quad \leftarrow$$

$$|W(a_i)| = \left| \frac{a_i}{a + a_i} \right| = \left| \frac{a e^{\frac{\pi i}{2}}}{\sqrt{2} a e^{\frac{\pi i}{2}}} \right| = \frac{1}{\sqrt{2}}$$

$$\frac{a_i}{a} \sqrt{\frac{a_i}{a}}$$

for 747  $\lambda_{dr} = -0.033 \pm 0.947i$

choose  $a = 0.1$

$$\omega_d \quad \omega_{ndr} \approx 1$$

$$\delta_r = -k_r \frac{s}{s+0.1}$$