AIRCRAFT FLIGHT CONTROL SYSTEMS II

Control Systems Applied to Aviation

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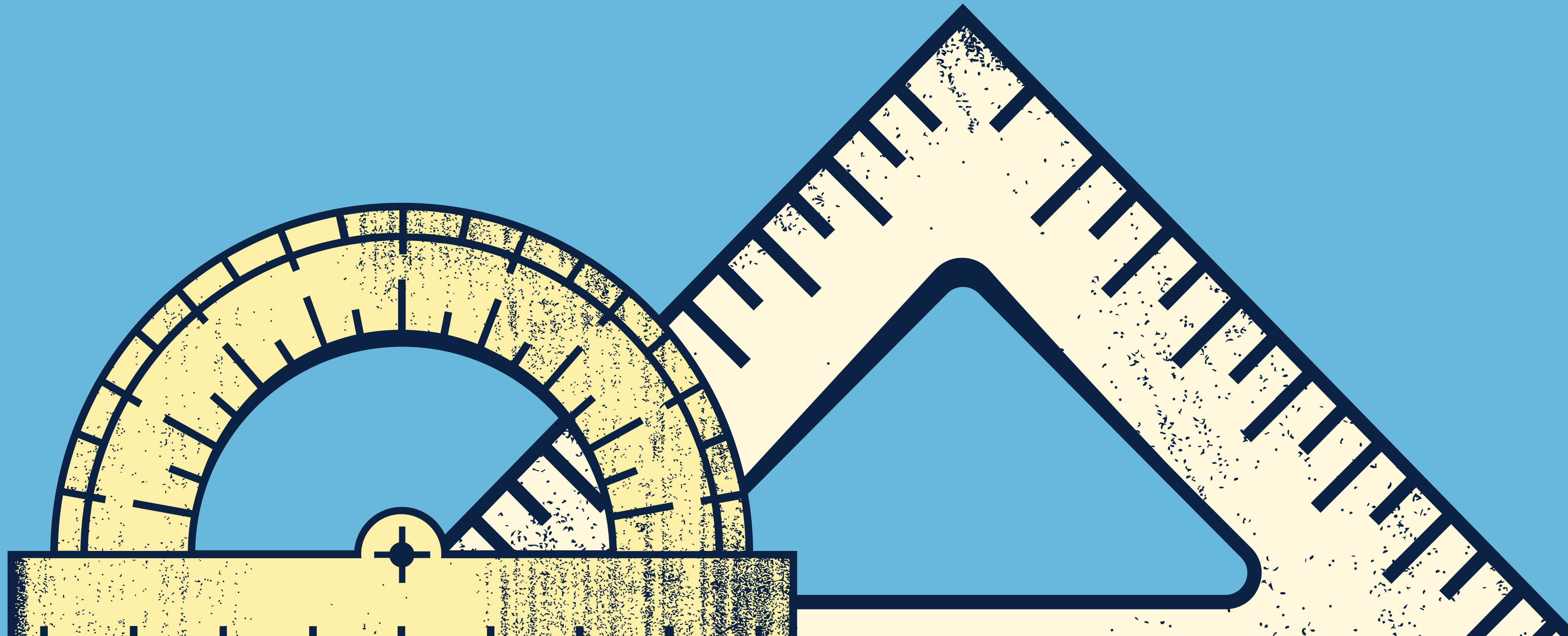
Summary

Objectives

01 Describe the analysis methodology of a control system using root locus

02 Identify the flight dynamics modes of an aircraft in the root locus diagram

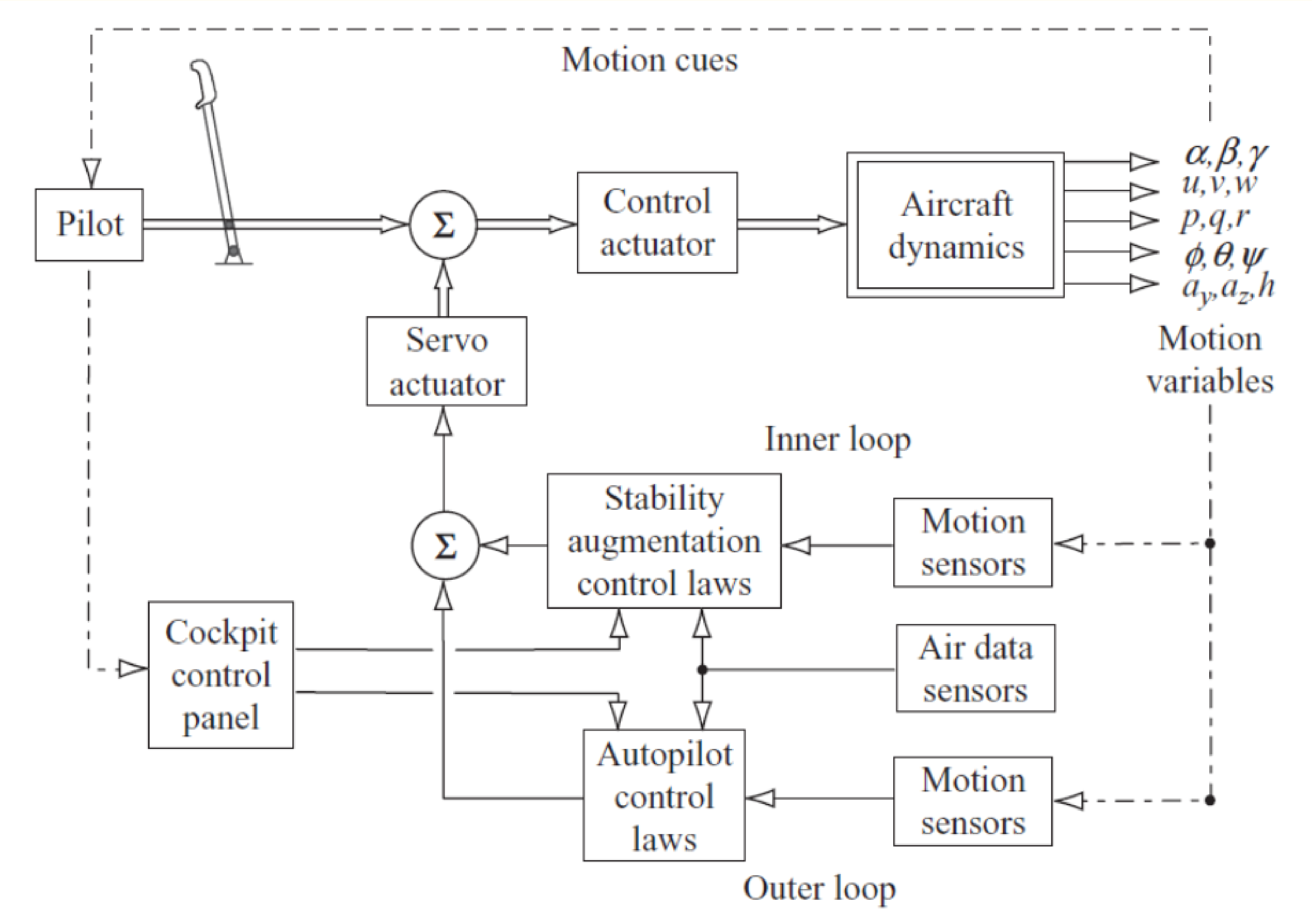
03 Apply the gain adjustment method to a stability augmentation system



Stability augmentation

- Stability augmentation (inner loop)
  - May be deactivated

- Autopilot (outer loop)
  - Climb to level
  - Fixed velocity
  - Approach slope

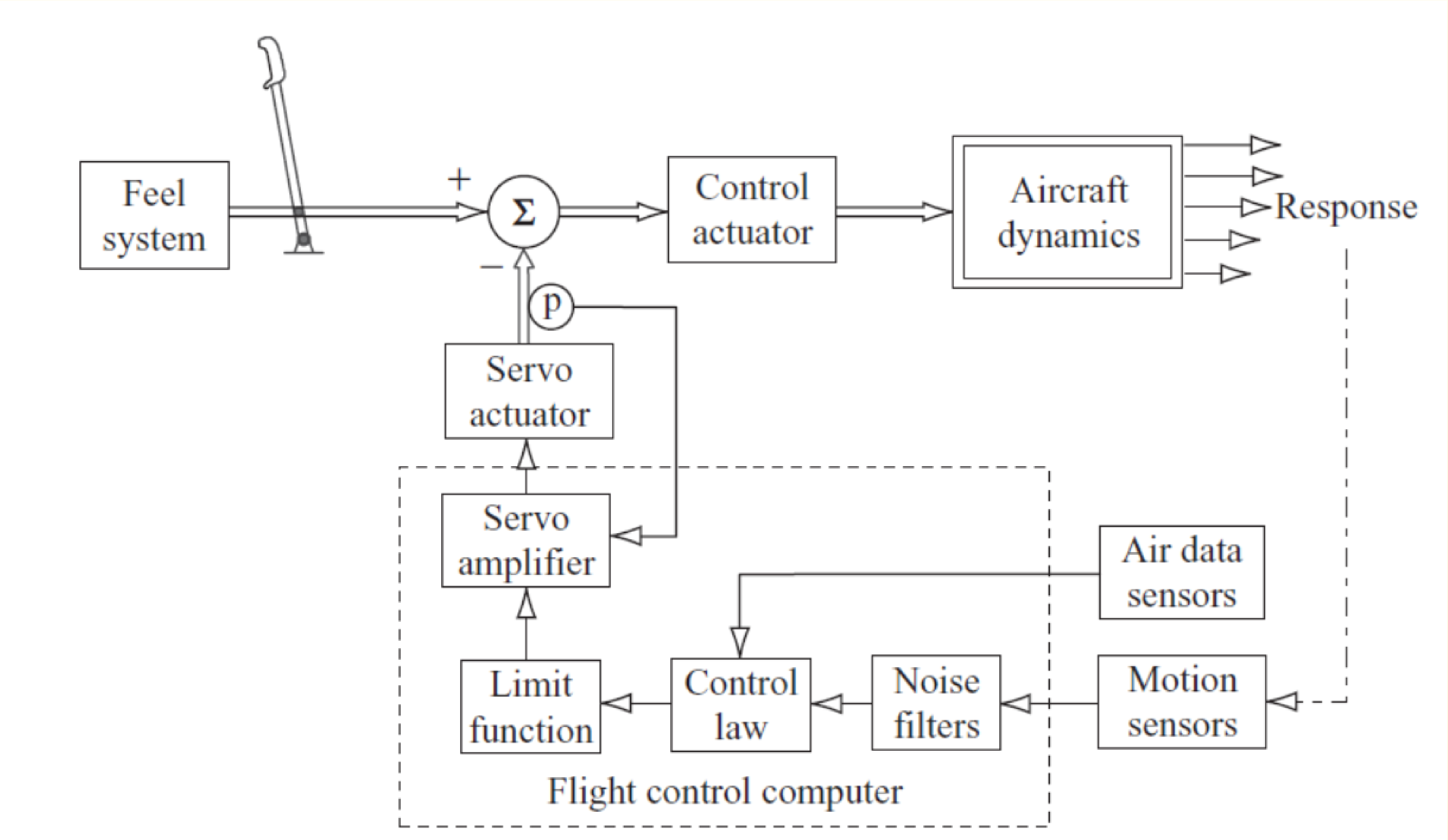


Source: Cook, M. V. (2007)

Stability augmentation

Control law - Yaw damper

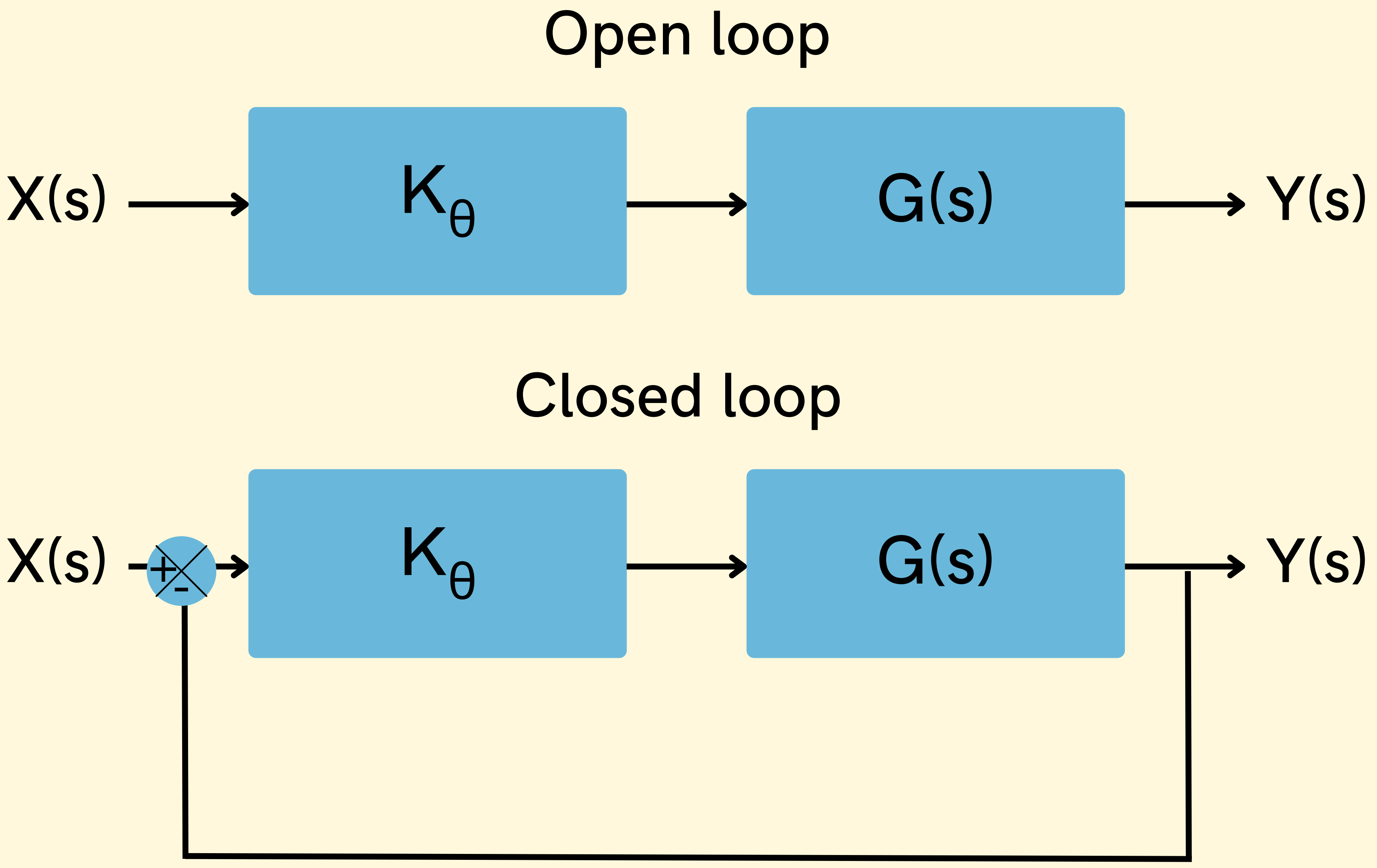
$$\zeta(s) = K_{\zeta}\delta_{\zeta}(s) - K_r\left(\frac{s}{1+sT}\right)r(s)$$



Source: Cook, M. V. (2007)

Root locus

- Estimate characteristics of the closed-loop system from the open-loop system for a proportional driver



K_θ - Gain

G(s) - Transfer function

$$G(s) = \frac{Y(s)}{X(s)} = \frac{\text{numerator}}{\text{denominator}}$$

Pole - Denominator root

Zero - Numerator root

$$\lambda_{1,2} = r_{1,2} \pm \omega_{1,2} \qquad \omega_n = \sqrt{r^2 + \omega^2}$$

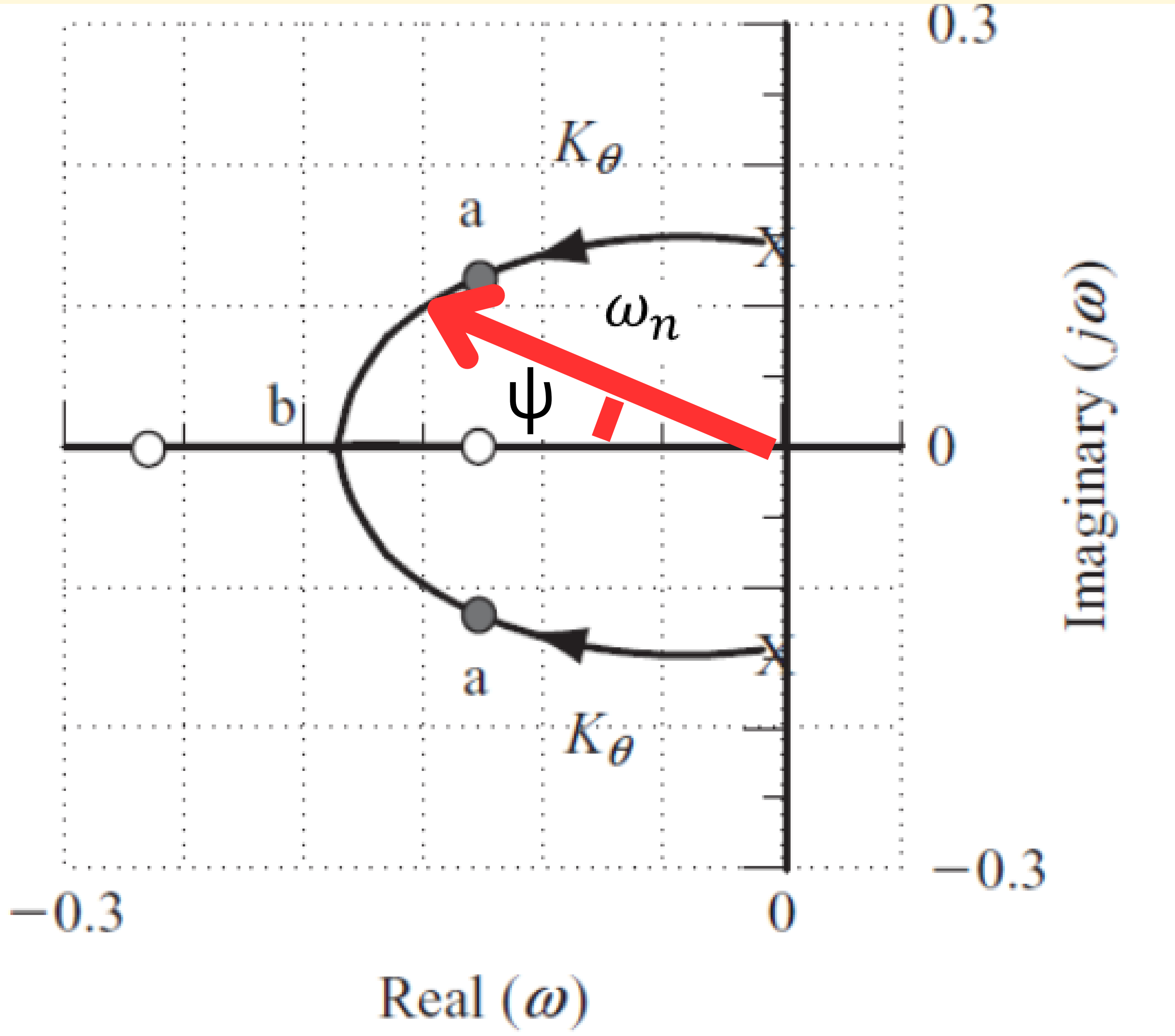
$$\lambda_{3,4} = r_{3,4} \pm \omega_{3,4} \qquad \zeta = -\frac{r}{\omega_n}$$

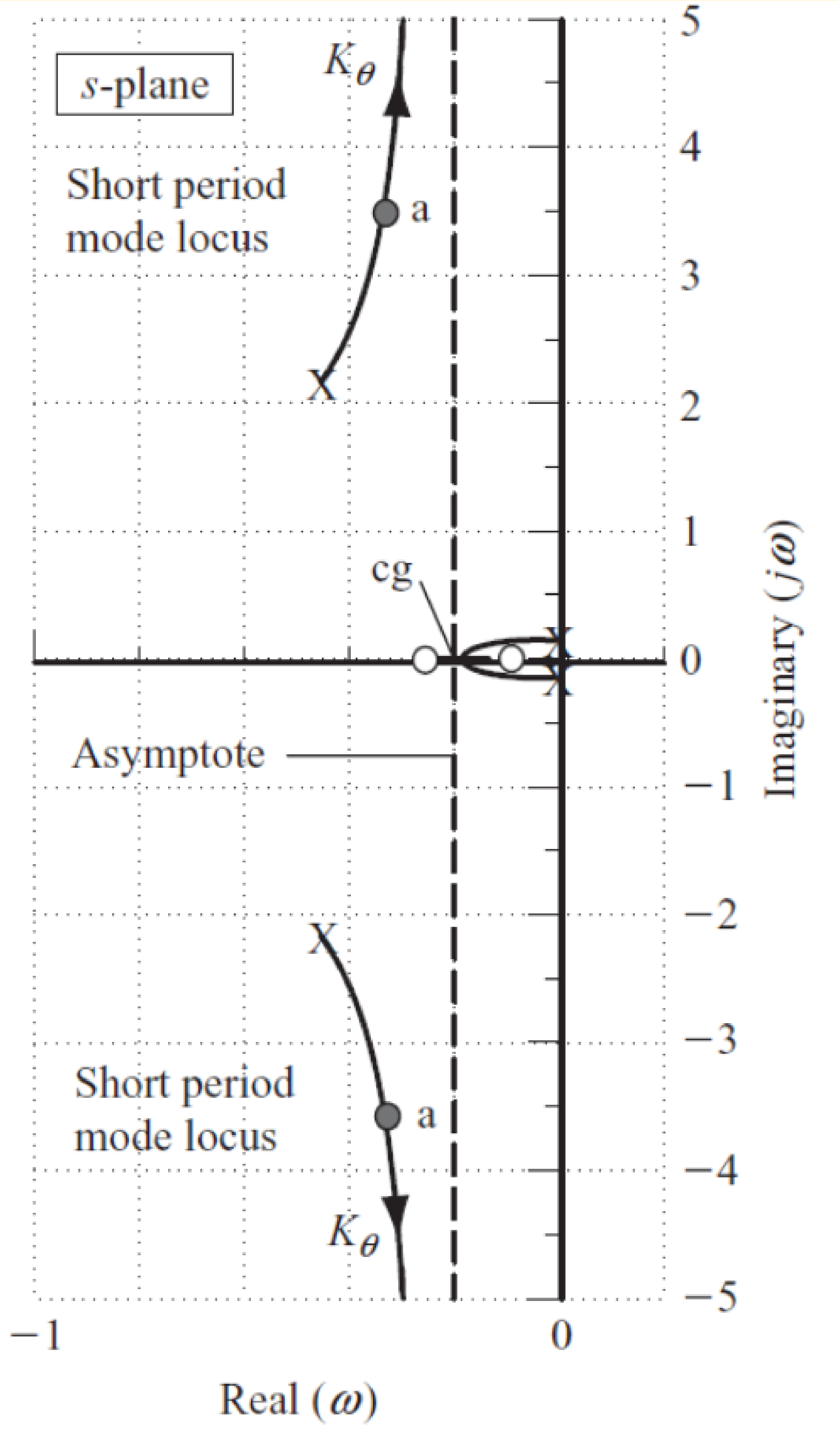
Root locus

$$\frac{\theta(s)}{\eta(s)} = \frac{-4.66K_\theta(s+0.133)(s+0.269)}{(s^2+0.015s+0.021)(s^2+0.911s+4.884)} \text{ rad/rad}$$

r = ωn
cos(ψ)=ζ

X – Open loop poles
○ – Open loop zeros
● – Gain test points





Source: Cook, M. V. (2007)

Aircraft application

McDonnel Douglas A-4D Skyhawk

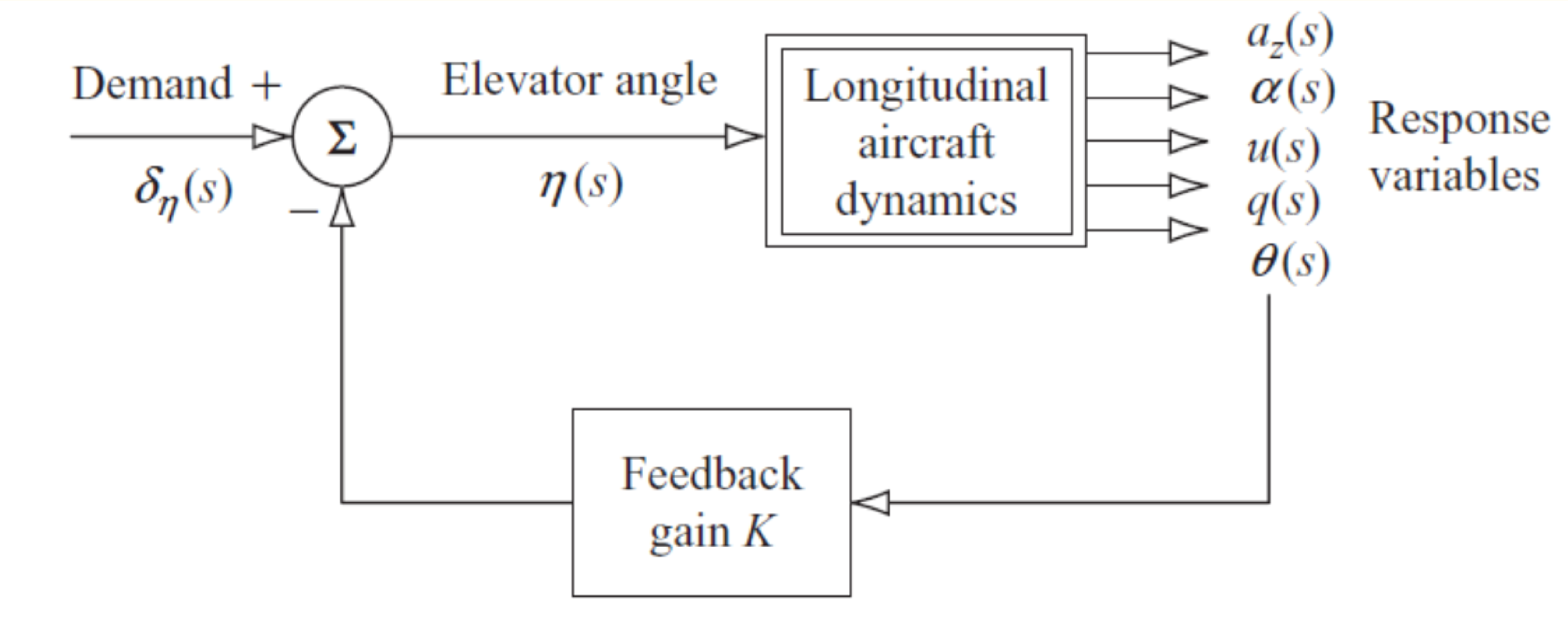
Source: Wikipedia

Aircraft application

Longitudinal movement

- Phugoid
  - Low frequency
  - Low damping

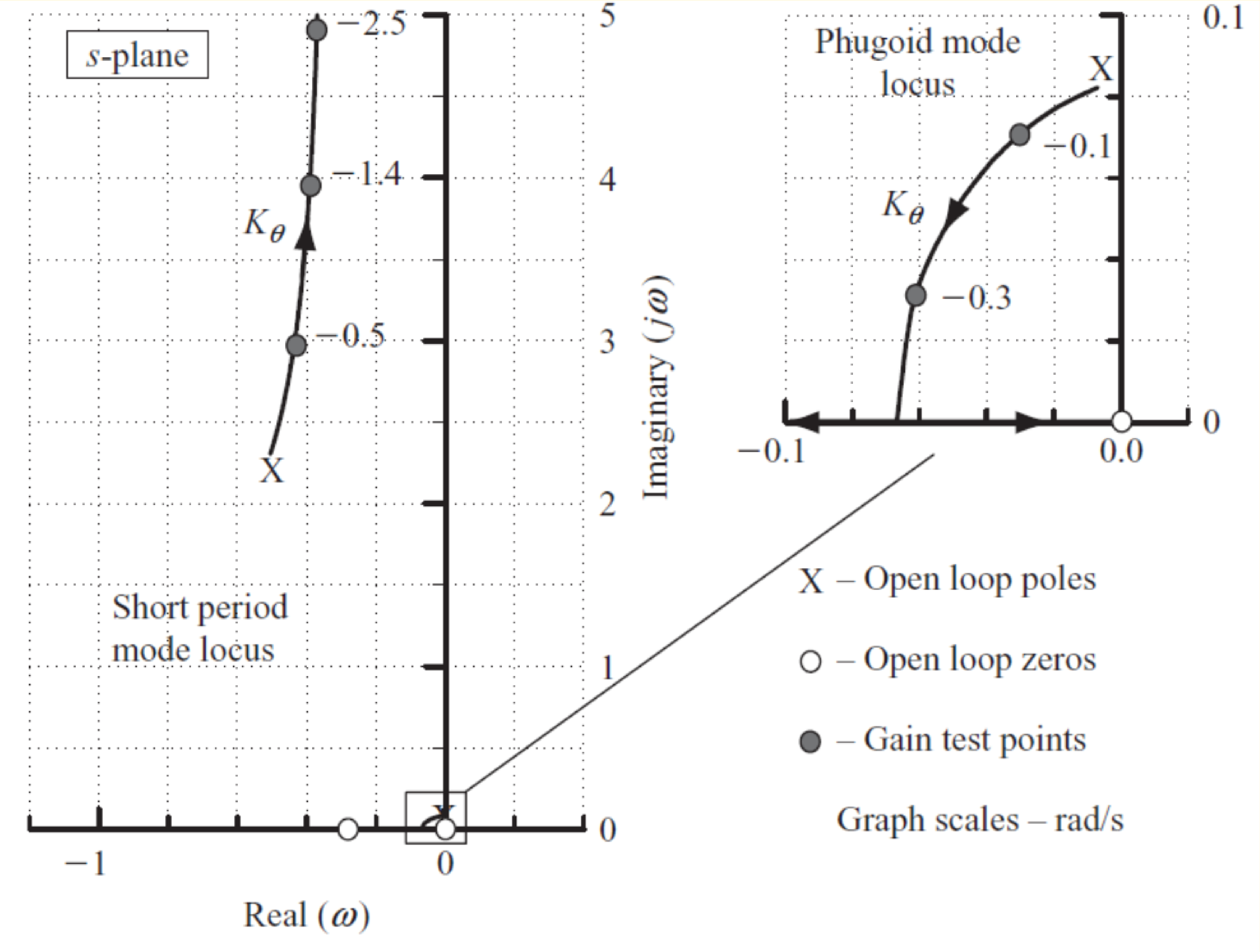
- Short-period
  - High frequency
  - High damping



Source: Cook, M. V. (2007)

Aircraft application

Longitudinal movement



Source: Cook, M. V. (2007)

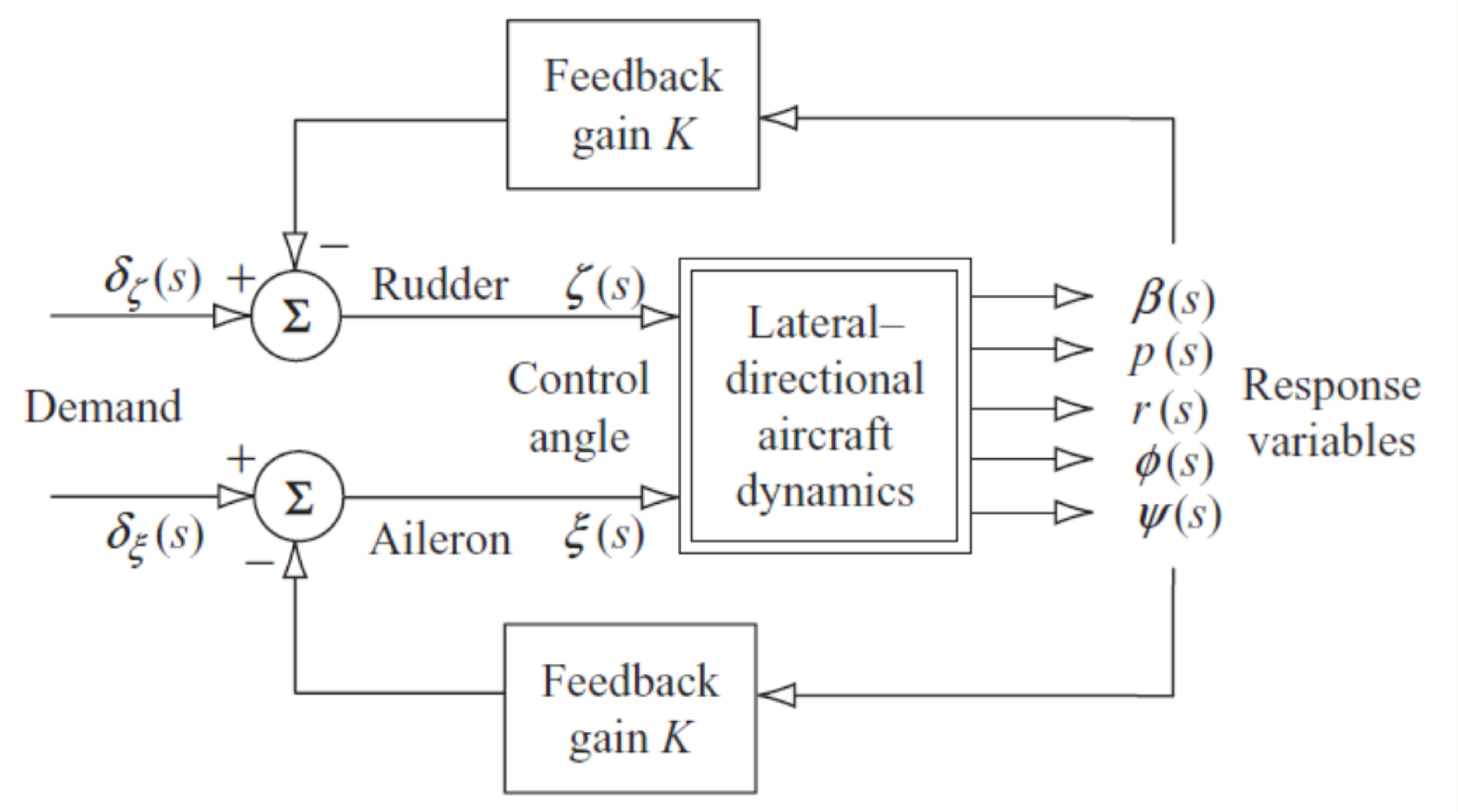
TF of the pitch due to elevator deflection

$$\frac{\theta(s)}{\eta(s)} \equiv \frac{-8.096(s-0.0006)(s+0.3591)}{(s^2+0.014s+0.0068)(s^2+1.009s+5.56)} \text{ rad/rad}$$

Aircraft application

Latero-directional movement

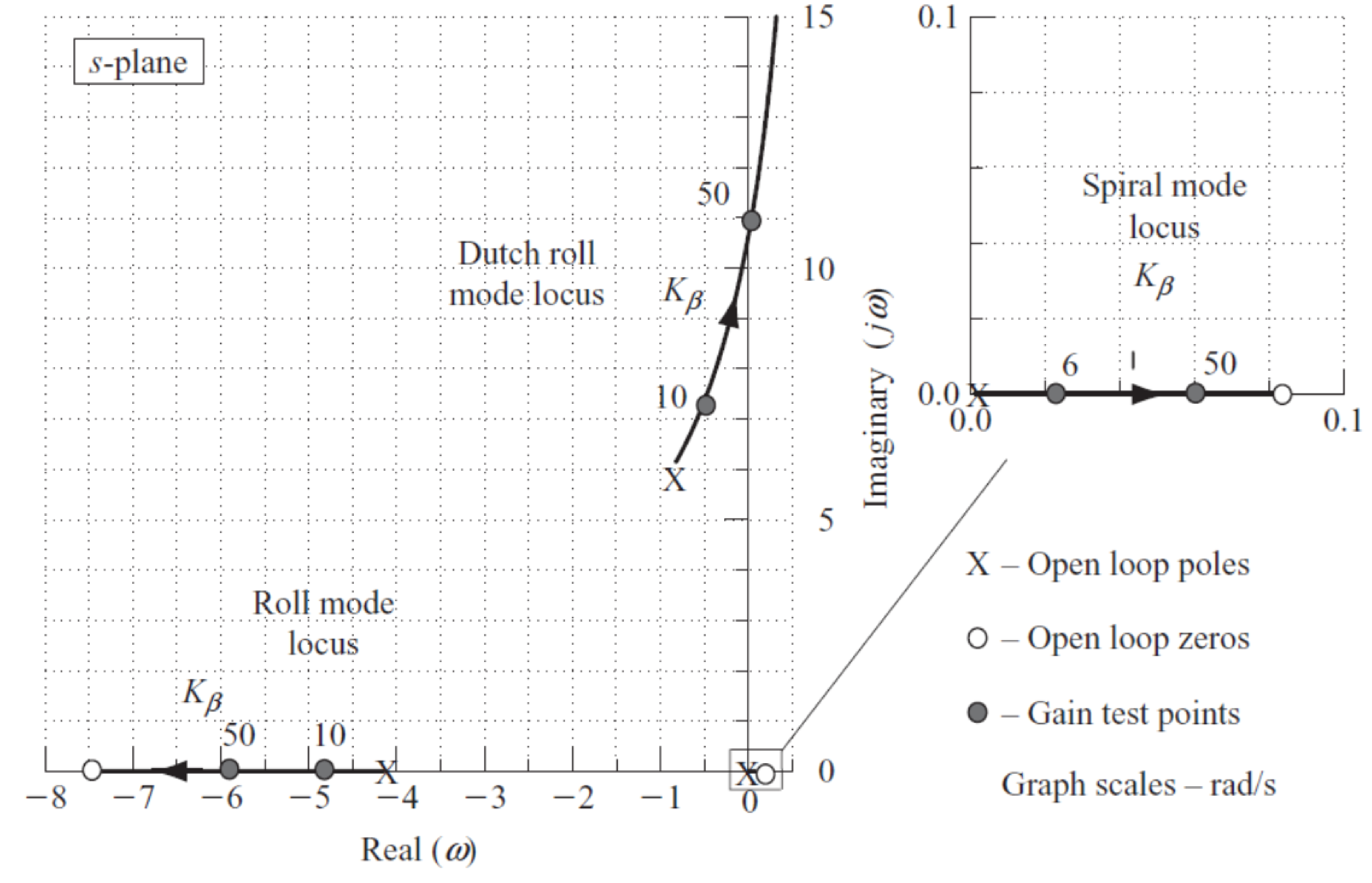
- Dutch roll
  - Oscillatory movement
- Spiral
  - High time constant
- Roll
  - Low time constant



Source: Cook, M. V. (2007)

Aircraft application

Latero-directional movement



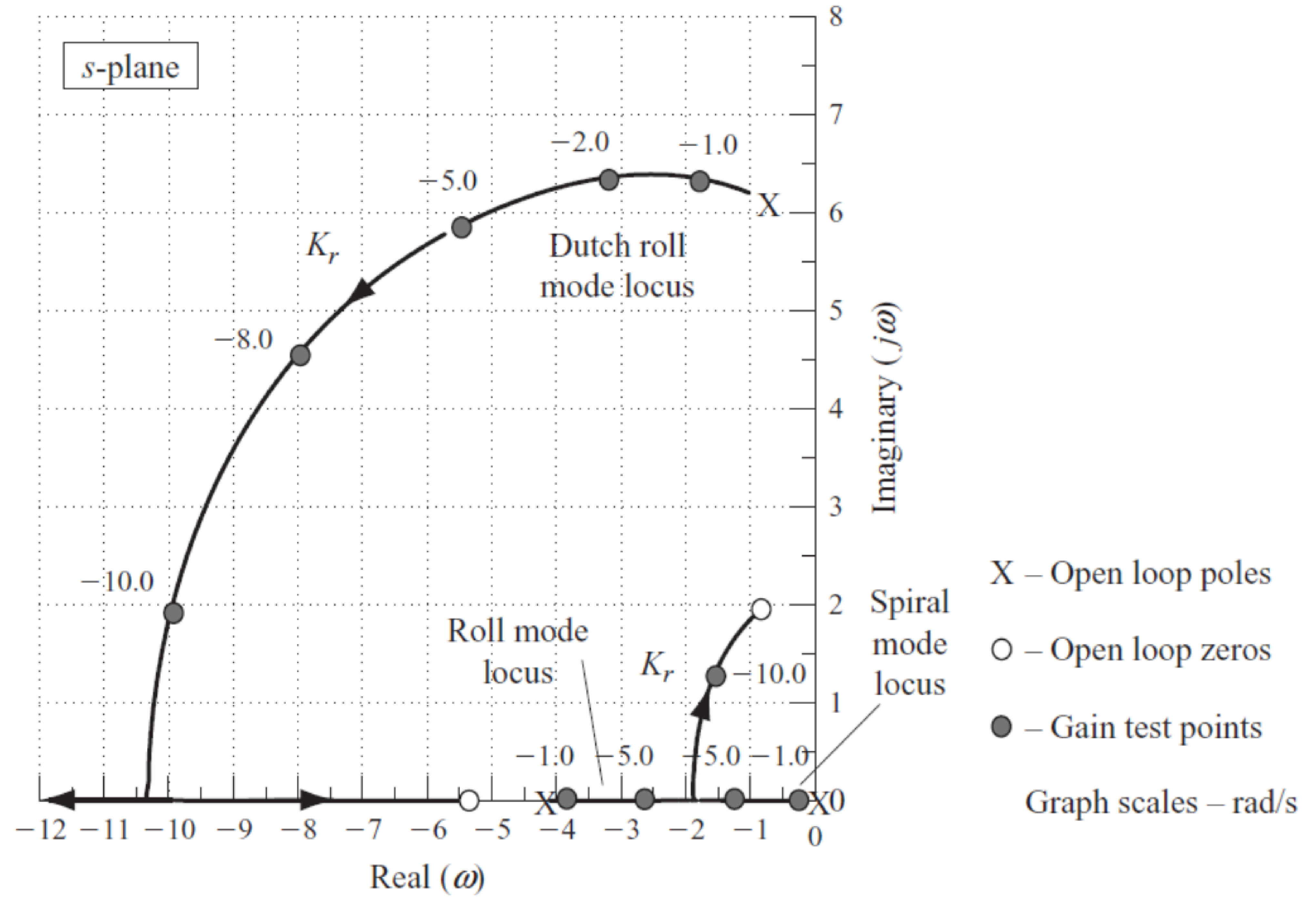
TF of skid due to aileron deflection

$$\frac{\beta(s)}{\xi(s)} \equiv \frac{1.3235(s-0.0832)(s+7.43)}{(s-0.0014)(s+4.145)(s^2+1.649s+38.44)} \text{ rad/rad}$$

Source: Cook, M. V. (2007)

Aircraft application

Latero-directional movement



Source: Cook, M. V. (2007)

TF of yaw due to aileron deflection

$$\frac{r(s)}{\xi(s)} = \frac{1.712(s+5.405)(s^2+1.788s+4.465)}{(s-0.0014)(s+4.145)(s^2+1.649s+38.44)} \text{ rad/s/rad}$$

Problem

- Calculate
  - Natural frequencies
  - Damping ratio
- Identify the longitudinal movement modes
- Elaborate the root locus in Matlab
- Identify the longitudinal movement modes in the graph
- Adjust the gain to ensure:

$$\text{Phugoid damping ratio } \zeta_p \geq 0.04$$

$$\text{Short period damping ratio } \zeta_s \geq 0.1$$

$$\text{Short period undamped natural frequency } 0.8 \leq \omega_s \leq 3.0 \text{ rad/s}$$

TF of the pitch due to elevator deflection

$$\frac{\theta(s)}{\eta(s)} = \frac{4.66(s+0.133)(s+0.269)}{(s^2+0.015s+0.021)(s^2+0.911s+4.884)}$$

Lockheed F-104 Starfighter

Source: Wikipedia

Final remarks

- Aircraft flight dynamics can be represented by transfer functions correlating the inputs on the control surfaces of the aircraft and its attitude, speeds, and angle of attack and slip
- The root locus method is a useful tool to determine the gains of a stability augmentation system using a proportional controller

References

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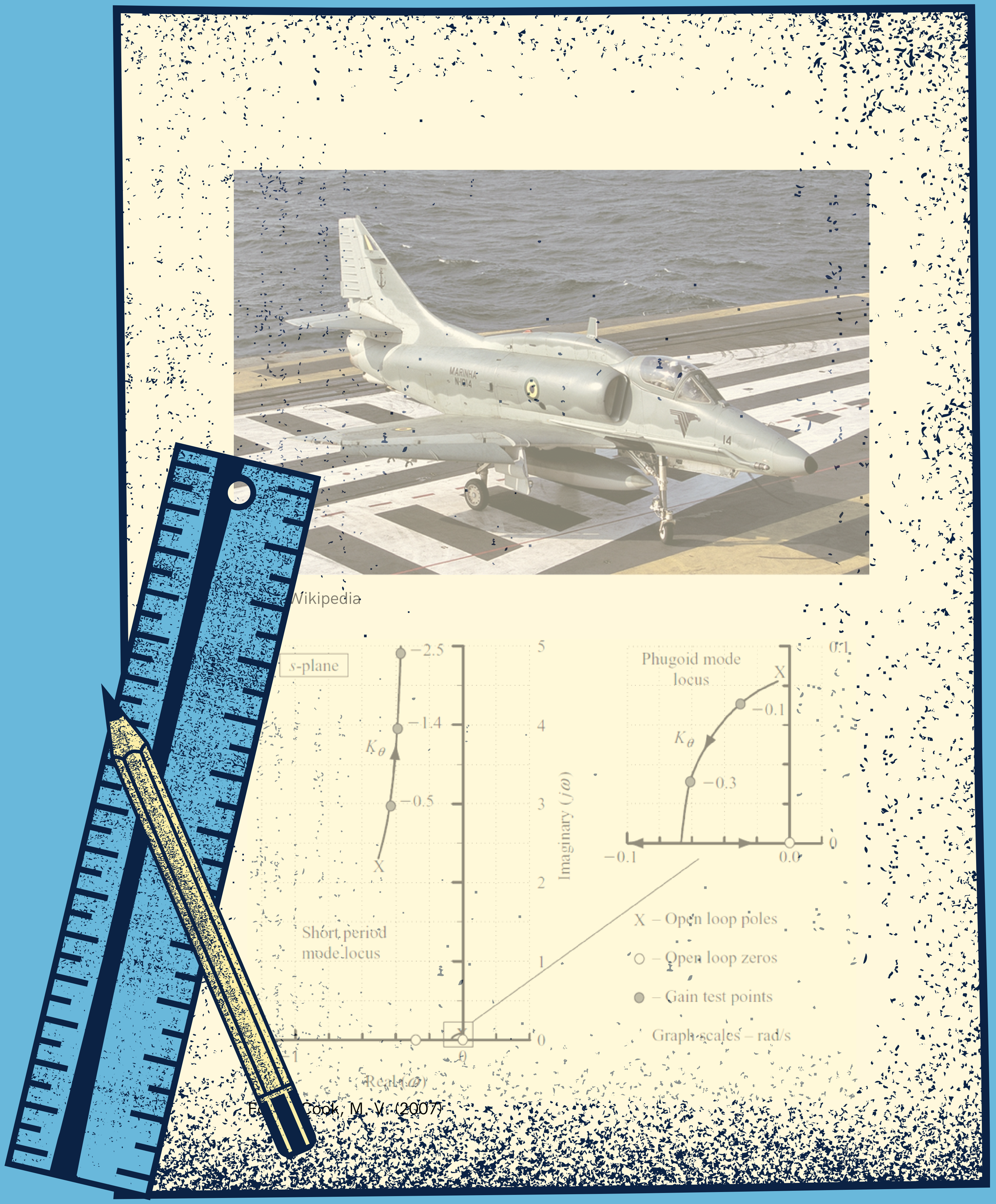

Thank you!

Questions?