# King Fahd University of Petroleum and Minerals

# AE-540
# FLIGHT DYNAMICS & CONTROL I

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# Simulation and Auto Pilot Design for BEAVER Airpalne


**Prepared For**

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# Trimming & Simulation

# Trimming Conditions

**Trimming Assumptions :**

$$u_0 = 45$$

$$v = w = p = q = r = 0$$

$$\delta_f = 0$$

$$\psi = \beta = \dot{\beta} = 0$$

**Equations of Motion :**

$$Fx - mg\sin\theta = 0$$

$$Fy + mg\cos\theta\sin\psi = 0$$

$$Fz + mg\cos\theta\cos\psi = 0$$

$$L = 0$$

$$M = 0$$

$$N = 0$$

**Unknowns to solve for :**

$$\alpha$$

$$\delta_a$$

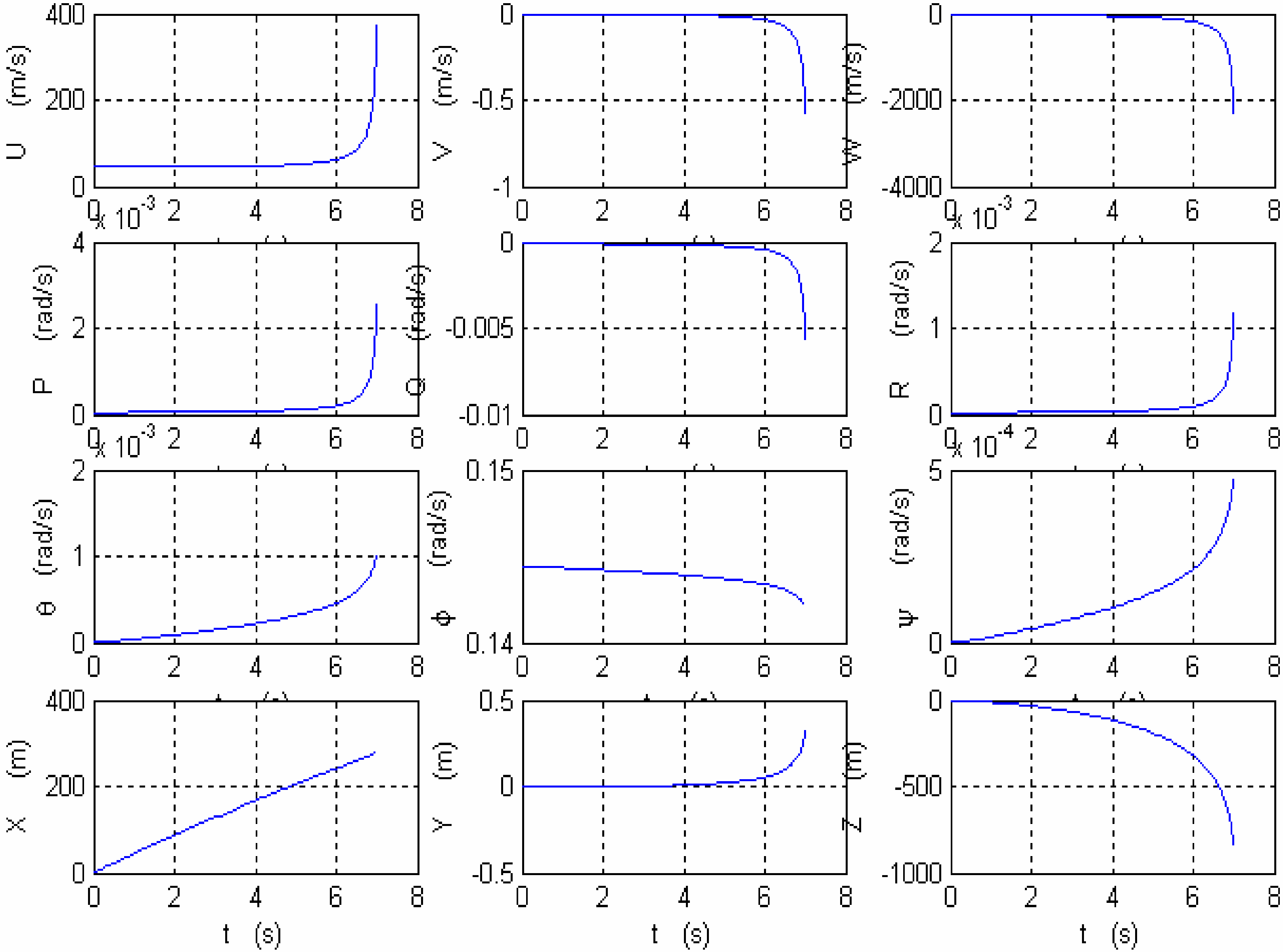
$$\delta_r$$

$$\delta_e$$

$$\theta$$

$$dpt$$

# Simulation Using Trimmed Valued



# Classical Control

# $\Delta h/\Delta\delta_e$ Transfer Function (Original System)

$$\frac{\Delta h}{\Delta\delta_e} = \frac{u_0}{s}\left(\frac{\Delta q}{s\Delta\delta_e} - \frac{\Delta\alpha}{\Delta\delta_e}\right)$$

$$\frac{\Delta h}{\Delta\delta_e} = \frac{4.182\,s^3 + 1.344\,s^2 - 584\,s - 7.187}{s^5 + 4.354\,s^4 + 10.69\,s^3 + 0.6385\,s^2 + 0.7282\,s}$$

$$\frac{\Delta h}{\Delta\delta_e} = \frac{4.1822(s+11.97)(s-11.66)(s+0.01231)}{s\,(s^2 + 0.03228s + 0.06947)(s^2 + 4.321s + 10.48)}$$

$$\frac{\Delta q}{\Delta\delta_e} = C\left[sI - A\right]^{-1} B$$

$$C = \begin{bmatrix} 0 & 0 & 1 & 0 \end{bmatrix}$$

$$\frac{\Delta\alpha}{\Delta\delta_e} = C\left[sI - A\right]^{-1} B$$

$$C = \begin{bmatrix} 0 & 1 & 0 & 0 \end{bmatrix}$$

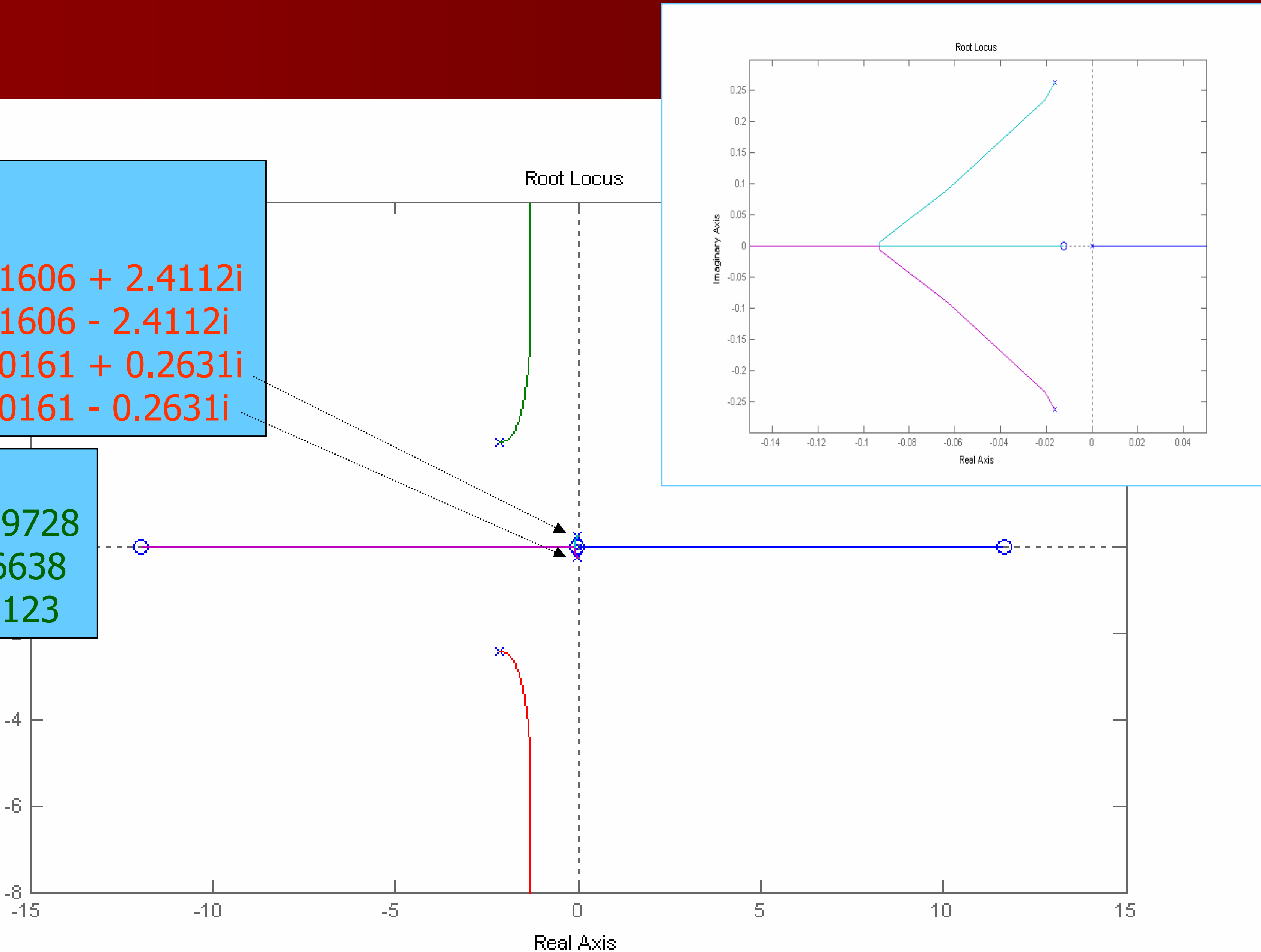
# Root Locus (Original System)

**Poles**

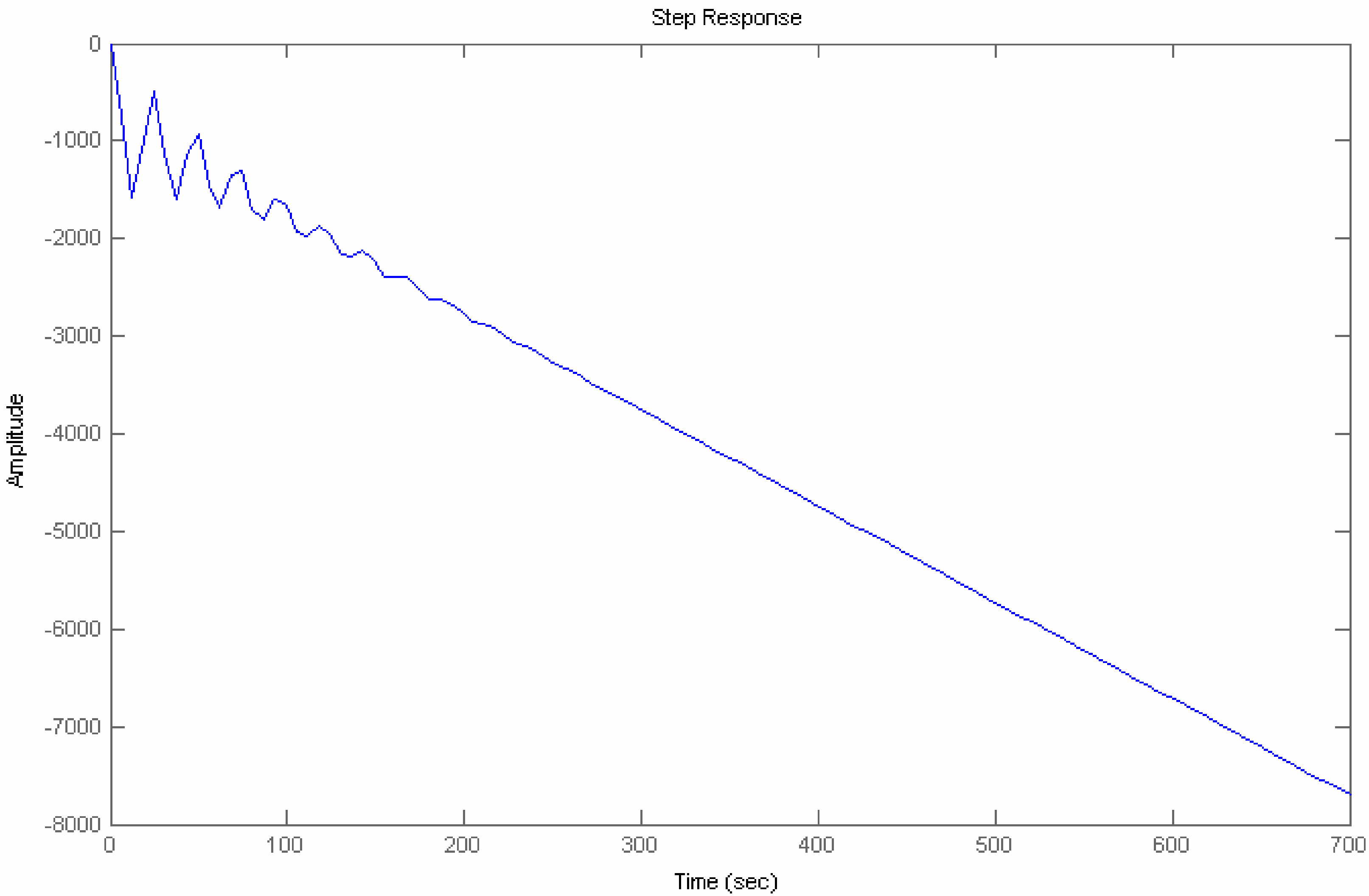
p = 0
p = -2.1606 + 2.4112i
p = -2.1606 - 2.4112i
p = -0.0161 + 0.2631i
p = -0.0161 - 0.2631i

**Zeros**

z = -11.9728
z = 11.6638
z = -0.0123



# Response to Step Input (Original System)

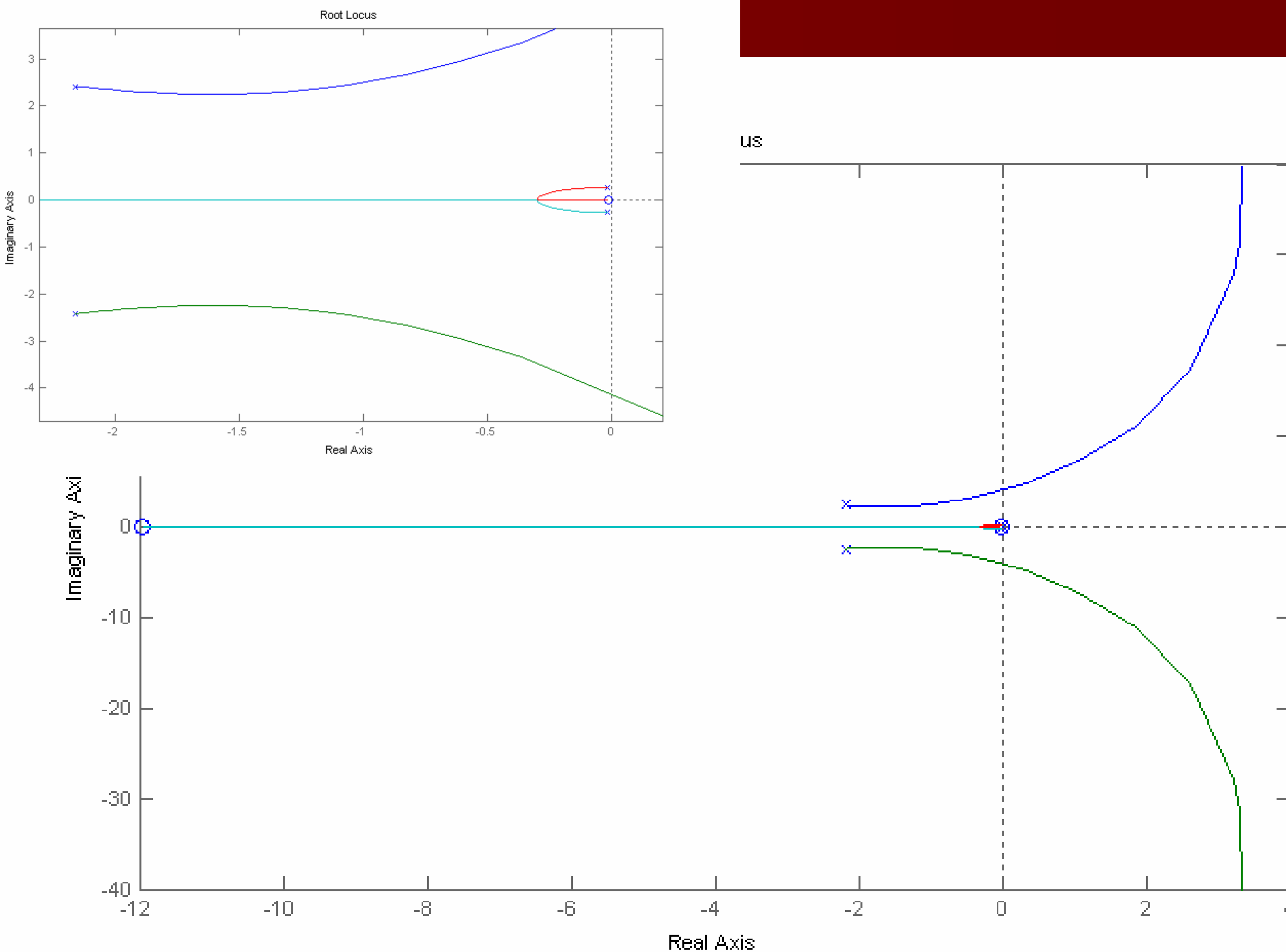


# $\Delta h/\Delta\delta_e$ Transfer Function (Adding Compensator)

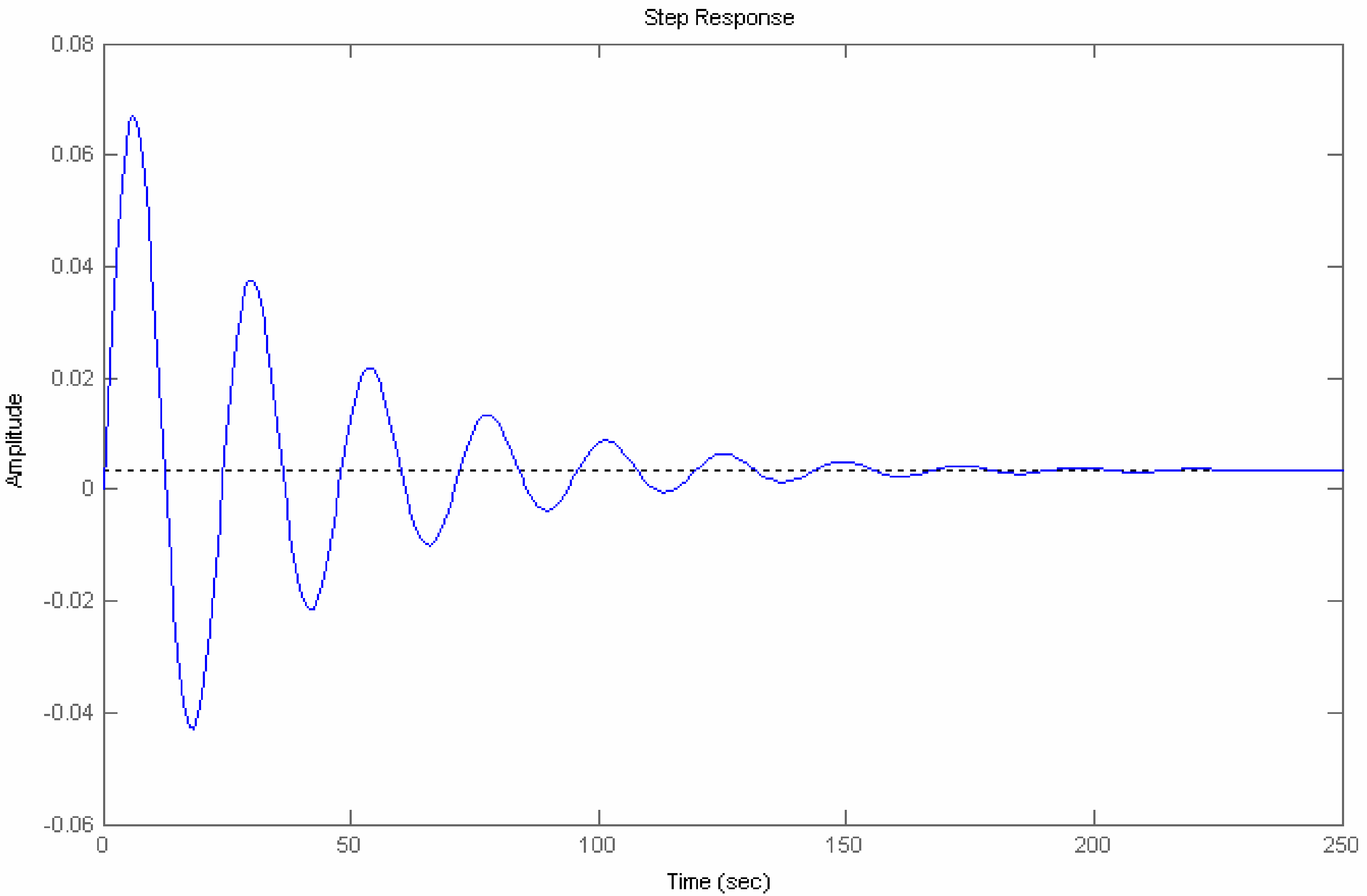
$$\frac{\Delta h}{\Delta \delta_e} = \left(\frac{s+z}{s+p}\right) \times \frac{u_0}{s}\left(\frac{\Delta q}{s\Delta\delta_e} - \frac{\Delta\alpha}{\Delta\delta_e}\right)$$

$$\frac{\Delta h}{\Delta \delta_e} = \left(\frac{s}{s-11.66}\right) \times \left(\frac{4.1822(s+11.97)(s-11.66)(s+0.01231)}{s(s^2+0.03228s+0.06947)(s^2+4.321s+10.48)}\right)$$

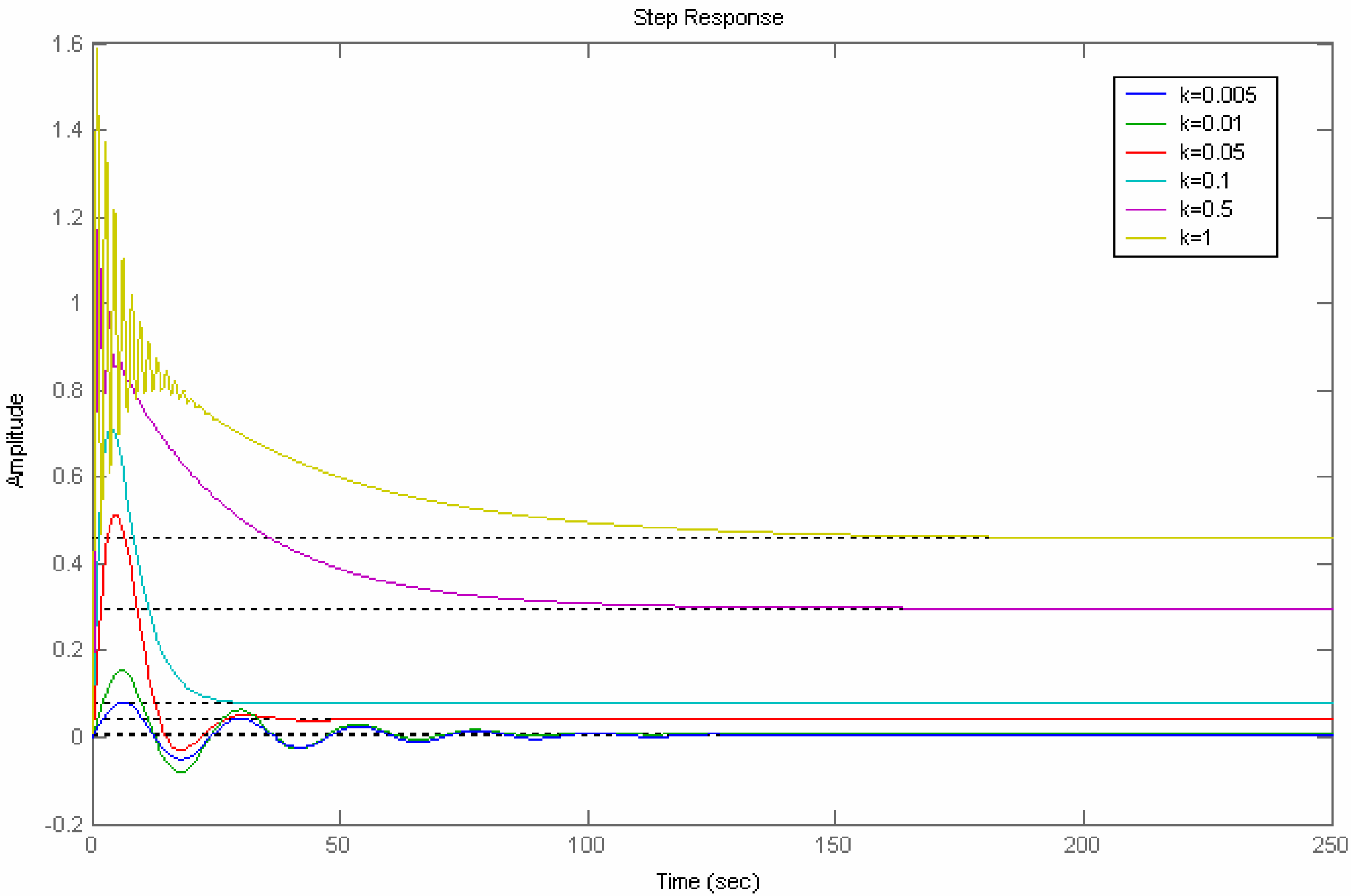
# Root Locus (Zero Added to System)



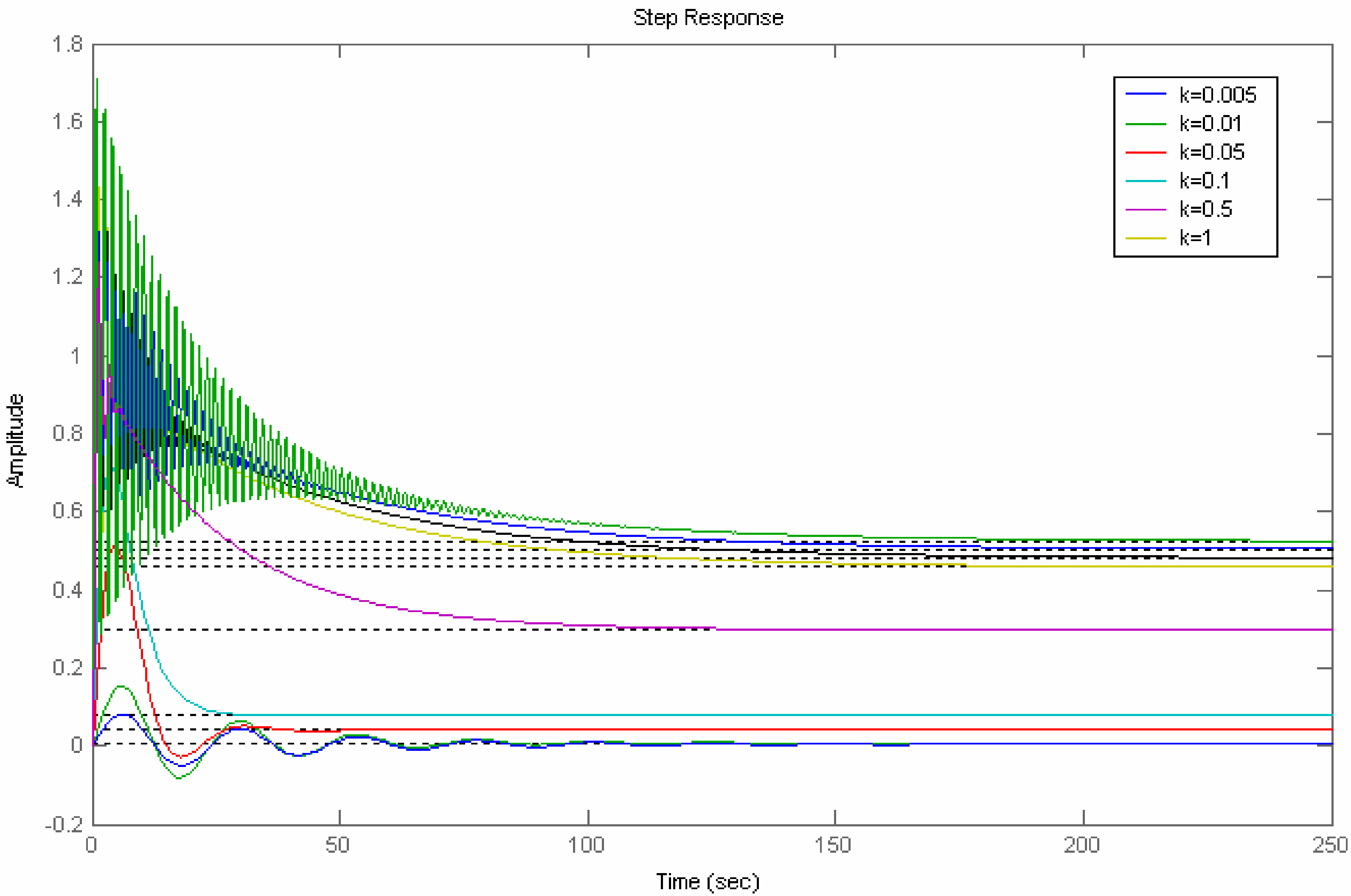
# Response to Step Input (Adding Compensator)



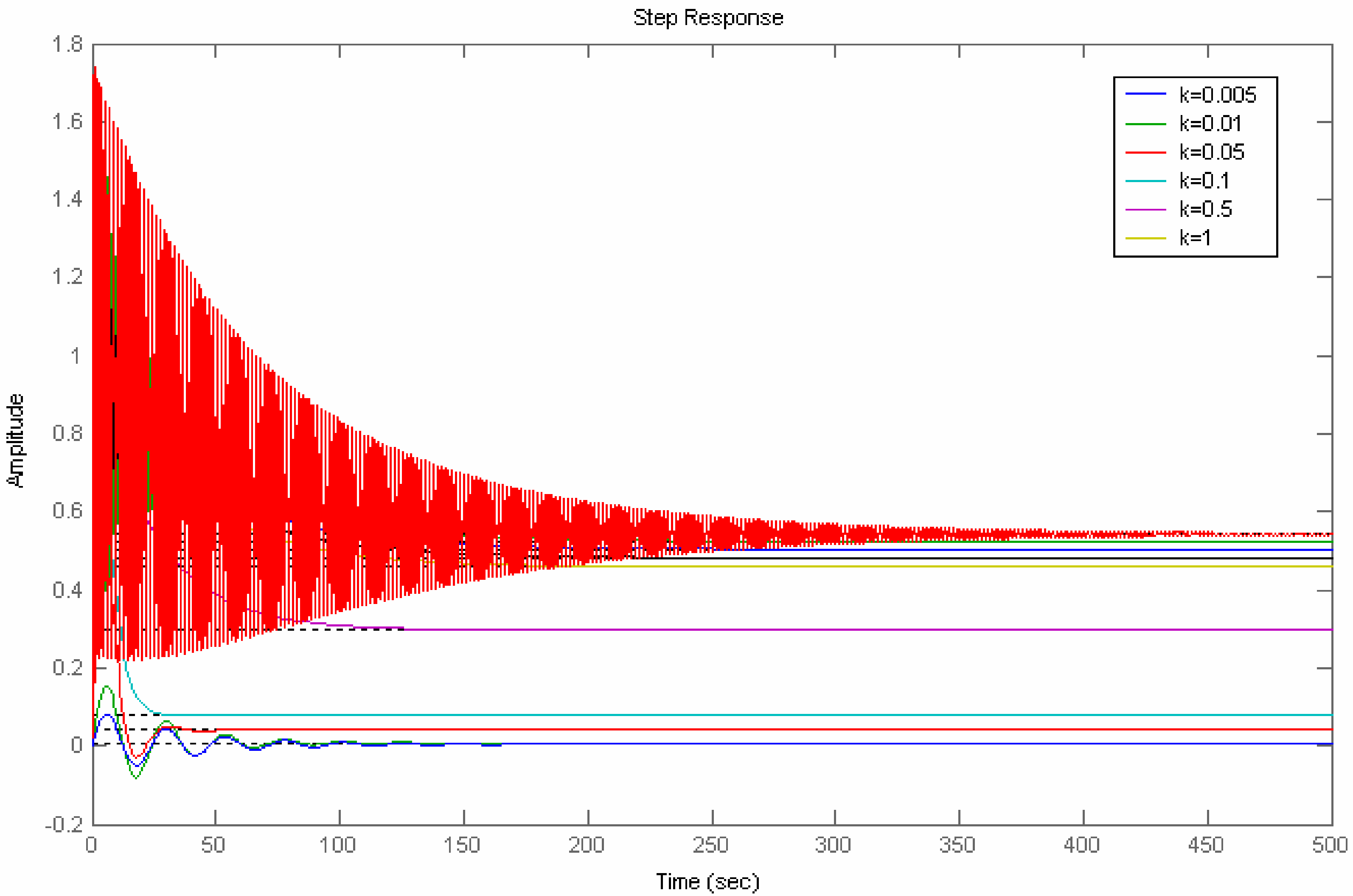
# Response to Step Input (Adding Compensator)



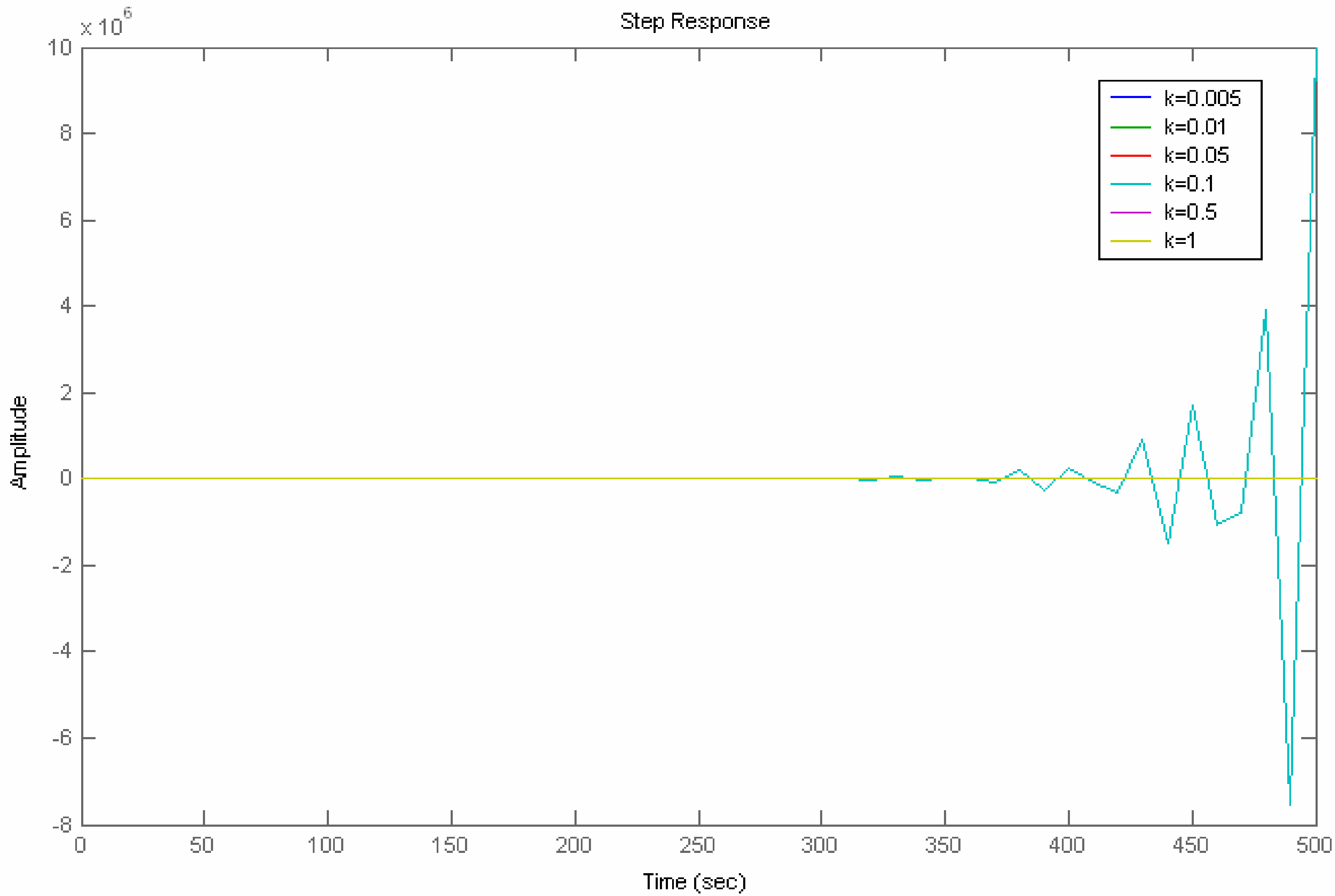
# Response to Step Input (Adding Compensator)



# Response to Step Input (Adding Compensator)



# Response to Step Input (Adding Compensator)



# Modern Control

# Flying Quality Requirements

**BEAVER is :**

- Level 2
- Class II
- Category B

**Damping is :**

- Long Period (Phugoid) Mode
  $\zeta_{ph} > 0$
- Short Period Mode
  $0.2 < \zeta_{sp} < 2$

- Long Period (Phugoid) Mode
  $\zeta_{ph} = 0.1$
- Short Period Mode
  $\zeta_{sp} = 0.9$

My Design

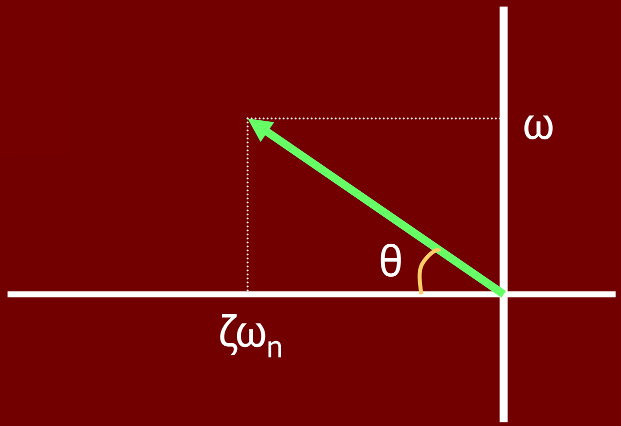
# Design Requirements & Poles Placement

$$\theta = \cos^{-1}\zeta$$

$$t_{ss} = 4T$$

$$\eta = \zeta\omega_n = \frac{1}{T} = \frac{4}{t_{ss}}$$

$$\omega = \zeta\omega_n \tan\theta = \frac{4}{t_{ss}}\tan\theta = \frac{4}{t_{ss}}\tan\left(\cos^{-1}\zeta\right)$$




$$s = -\zeta\omega_n \pm i\omega$$

$$s = -\frac{4}{t_{ss}} \pm i\frac{4}{t_{ss}}\tan\left(\cos^{-1}\zeta\right)$$

$$s = \frac{4}{t_{ss}}\left[-1 \pm i\tan\left(\cos^{-1}\zeta\right)\right]$$

# Design Requirements & Poles Placement

## Long Period (Phugoid) Mode :

$$t_{ss} = 200 \text{ seconds}$$
$$\zeta_{ph} = 0.1$$

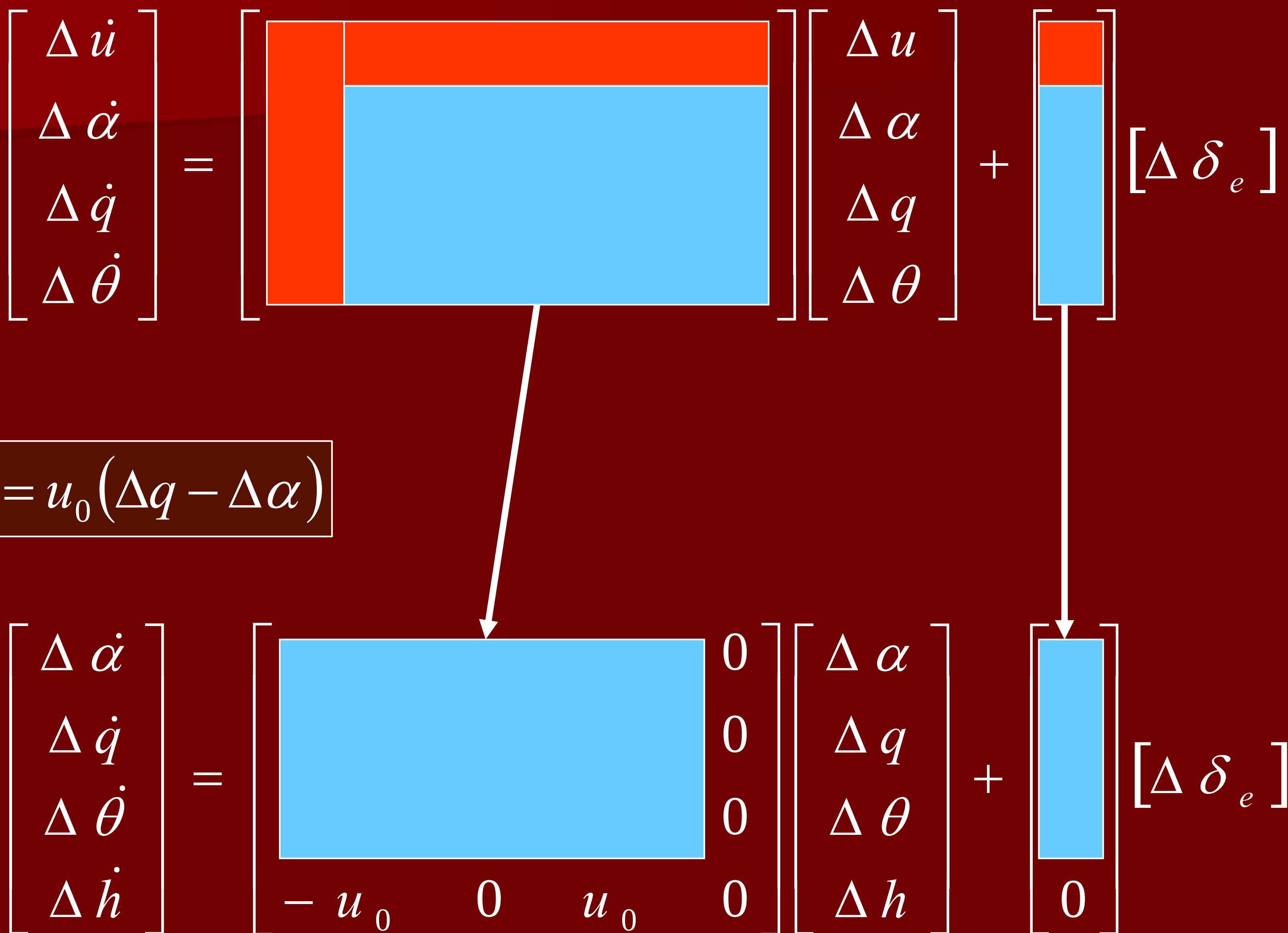
$$\Longrightarrow \quad s = -0.02 \pm i0.2$$

## Short Period Mode :

$$t_{ss} = 1.5 \text{ seconds}$$
$$\zeta_{sp} = 0.9$$

$$\Longrightarrow \quad s = -2.67 \pm i1.29$$

# Altitude Change Δh

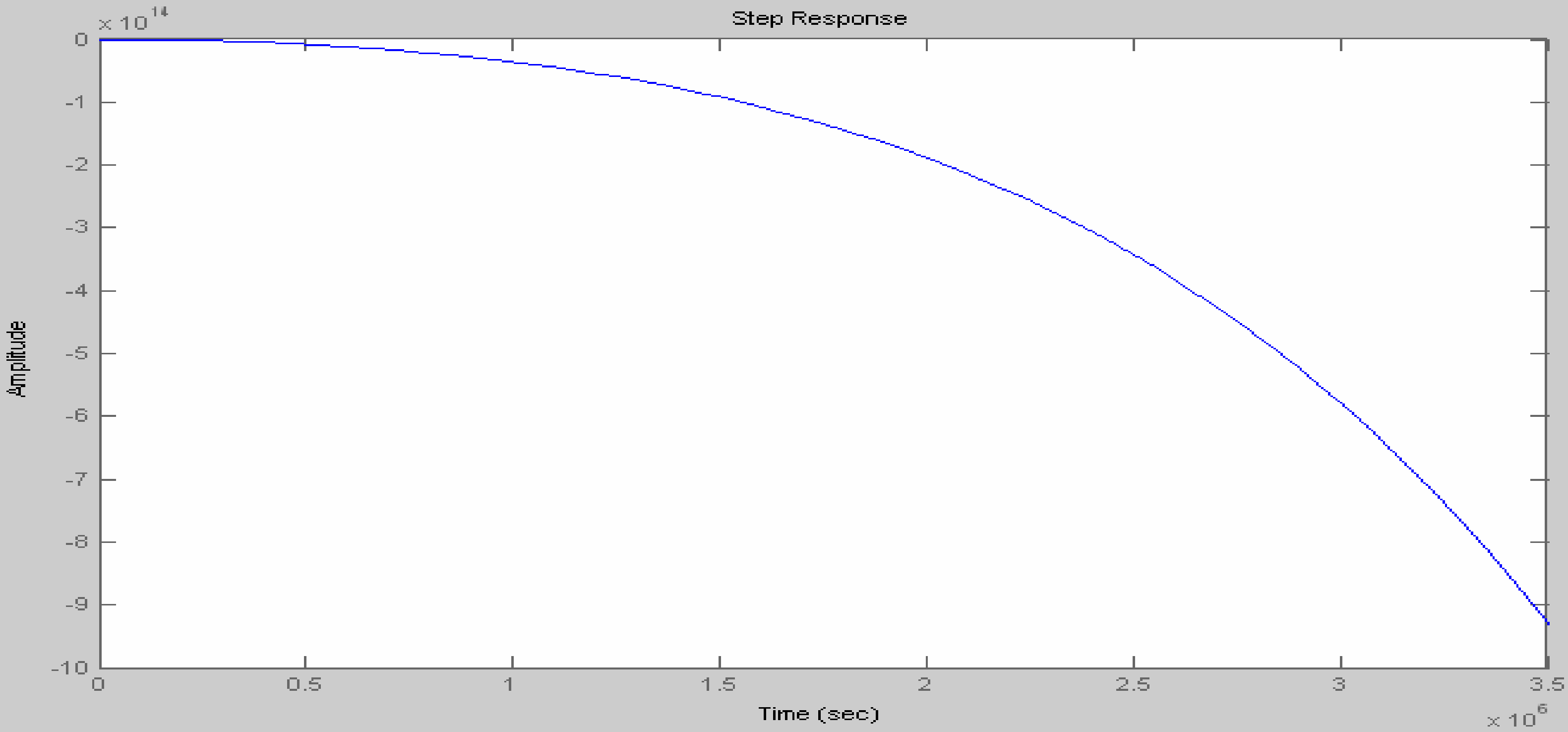



$$\Delta\dot{h} = u_0\left(\Delta q - \Delta\alpha\right)$$

# Step Response (No FeedBack)

$$\frac{\Delta h(s)}{\Delta \delta_e(s)} = C[sI - A]^{-1} B$$

$$C = [0 \quad 0 \quad 0 \quad 1]$$



# Step Response (With FeedBack)

$$\frac{\Delta h(s)}{\Delta \delta_e(s)} = C\left[sI - \left(A - Bk\right)\right]^{-1} B$$

$$s = -0.02 \pm i0.2$$

$$s = -2.67 \pm i1.29$$

$$k = \left[-0.0010 \quad 0.2793 \quad -0.0992 \quad 0.0005\right]$$