1. The “tao” of flight control design

1. Control surfaces are deflected based on aircraft states i.e. feedback

2. Design of the feedback control system depends on available sensors.

3. Feedback of any one state to improve flying qualities can have unintended side effects.

4. Typically flight controls are designed using linear approximations about a trim condition.

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3. Simple example of a stability augmentation system (SAS)

Short period approximation, small perturbation model

\[
\begin{bmatrix}
\dot{\alpha}' \\
\dot{q}'
\end{bmatrix} = \begin{bmatrix}
-1.16668 & 1 \\
-49.4425 & -1.47961
\end{bmatrix}
\begin{bmatrix}
\alpha \\
q
\end{bmatrix} + \begin{bmatrix}
-0.121741 \\
-22.4739
\end{bmatrix} \delta e
\]

c/o \quad \dot{x}' = [A] x + [B] u

Open loop short period eigenvalues: \(-1.32315 \pm 7.0298 \text{ I}\)

diagnosis?
Effect of a 0.1 rad perturbation in AOA

Is this acceptable?

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3.1 Effect of aoa feedback

\[ \delta e = \begin{bmatrix} k_a & 0 \end{bmatrix} \begin{bmatrix} \alpha \\ q \end{bmatrix} \]

K : gain matrix

Feedback control law is of the form \( u = [K] x \)

Why does this improves stability?
Closed loop system: Set \( u = [K]x \)

i.e. \( x' = [A]x + [B][K]x \)

\[
= [A + BK]x
\]

\( A_c : \) Closed loop system matrix

\[
A_c = \begin{bmatrix}
-1.16668 & -0.121741k_a & 1 \\
-49.4425 & 22.4739k_a & -1.47961
\end{bmatrix}
\]

What does this term do?

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Closed loop eigenvalues of $A_c$ (for $k_a = 5$) : $-1.6275 \pm 12.7197 \ I$

What are the side effects?

aoa vs time

q vs time

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Summary – Effects of AOA feedback to the elevators

• Improves stability via effect on $m_\alpha$ i.e. static pitch stability parameter

• Improves short period damping

• Side effects
  – increases short period frequency
  – Increases peak pitch response
3.2 Effect of $q$ feedback

\[
\delta e = \begin{bmatrix} 0 & k_q \end{bmatrix} \begin{bmatrix} \alpha \\ q \end{bmatrix}
\]

Closed loop system matrix:

\[
A_c = \begin{pmatrix} -1.16668 & 1 - 0.121741 k_q \\ -49.4425 & -1.47961 - 22.4739 k_q \end{pmatrix}
\]

What does this term do?
Closed loop eigenvalues of $A_c$ (for $k_q = 0.1$) : $-2.44684 \pm 6.87036 \, I$

aoa vs time

q vs time

Comments ?
Summary of pitch rate feedback to the elevators

• Improves stability via effect on $m_q$ i.e. pitch damping parameter

• Effective in reducing short period damping

• Smaller effect on short period frequency
Exercise: Multiple gains selection

For satisfactory closed loop response, both AOA and $q$ can be fed back together to the elevator

$$\delta e = \begin{bmatrix} k_a & k_q \end{bmatrix} \begin{bmatrix} \alpha \\ q \end{bmatrix}$$

This allows the simultaneous adjustment of both short period damping and frequency or responses of $\text{aoa}$ and $q$.

So what is a good combination of gains?

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$K = [0.5, 0.5]$, closed loop eigenvalues: $-6.97205 \pm 4.89762 \ I$

Looks good but did we forget anything?
Don’t forget to check the control deflection!

$$\delta e = 0.5 \alpha + 0.5 q$$

Physically what is happening?

Can we automate the gain selection?

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The SAS may be represented by a block diagram

So how does a real life flight control system look like?

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