16.333 Handout #4
Prof. J. P. How Oct 26, 2004
Due: Nov 16, 2004

16.333 Homework Assignment #4

Please include all code used to solve these problems.

1. Given the following model of the aerosonde vehicle extracted from the (trim condition, level flight at 23 m/s at sea level)

$$
\begin{aligned}
G_{u\delta_e(s)} &= \frac{152.2s + 913.1}{\Delta(s)} \\
G_{\alpha\delta_e}(s) &= \frac{-25.72s^2 - 2.439s - 3.85}{\Delta(s)} \\
G_{q\delta_e}(s) &= \frac{-24.18s^3 - 99.13s^2 - 9.672s}{\Delta(s)} \\
G_{\theta\delta_e}(s) &= \frac{-24.18s^2 - 99.13s - 9.672}{\Delta(s)} \\
G_{u\delta_t^a}(s) &= \frac{1.236s^3 + 10.46s^2 + 131.4s + 38.5}{\Delta(s)} \\
G_{\alpha\delta_t^a}(s) &= \frac{-1.192s^2 + 0.3228s - 0.1366}{\Delta(s)} \\
G_{q\delta_t^a}(s) &= \frac{-0.7646s^3 + 3.058s}{\Delta(s)} \\
G_{\theta\delta_t^a}(s) &= \frac{-0.7646s^2 + 3.058}{\Delta(s)}
\end{aligned}
$$

where

$$\Delta(s) = s^4 + 8.28s^3 + 105.1s^2 + 14.22s + 24.29$$

and $\delta_t^a = H(s)\delta_t^c$, with $H(s) = \frac{3}{s+3}$ to capture the engine lag. The elevators on this aircraft are fast enough that they can be ignored.

Part of the system model available on-line is shown in the figure. u and α are available as the first and third outputs of `VelW`, q is available as the 5th element of `States`, and θ is available as the second element of `Euler`. The elevator is the second control input, the throttle (δ_t^c) is the fourth. Note that a very simple roll loop has been added to facilitate analysis of the longitudinal dynamics.

- Compare the OL dynamics to the 747 - any surprises?
- Given these dynamics, design an altitude autopilot

- Use classical, multi-loop closure techniques as discussed in class
- Use Full state feedback. Discuss you rationale for where to locate the regulator poles.
- Use output feedback with u, θ, and α measurements. Discuss you rationale for where to locate the estimator poles.
- Use the simplified block diagram available on the class web page, implement the controller in simulink. Compare the nonlinear simulation response with your predictions - any surprises?

2. Continue Question #4 of HW3, but this time use the short period model and design the controller using *state space* techniques. As part of this design,

   (a) Develop a full state feedback controller that puts the *regulator* poles where required.

   (b) Then develop a *closed-loop* estimator for the system assuming that you can measure the pitch angle θ. Choose estimator pole locations that have the same imaginary part as the regulator poles, but a real part that is 3–4 times larger (in magnitude).

   (c) Put the regulator and estimator together to form the *compensator* $G_c(s)$ that maps $y = \theta$ to $u = \delta_e$ (recall that actually $u = -G_c y$). To implement this design, perform the same trick that we did in the notes, and use $u = G_c e$, where $e = \theta_c - \theta$. You should now be able to perform closed-loop simulations of the response of the system to a step in θ_c.

   (d) Check your pole locations on the full set of longitudinal dynamics. Is the response stable?

   (e) Compare the frequency response of this state space controller and the controller that you designed in HW3.

3. Using the same approach given in class, design a heading autopilot for the F-4C (i.e. one that can track a given Ψ_d) using the dynamics in condition 2. Assume that the actuator servo dynamics has the transfer function $H_s(s) = 20/(s + 20)$.

   (a) This design will consist of a yaw damper, a roll controller, and a feedback on the heading ψ.

   (b) Simulate the response to an interesting Ψ sequence (like a sequence of 45 deg turns) and comment on the performance. Include a limiter on the desired bank angle of ± 15 degs.

4. Write a brief summary of the paper by Vincenti that was handed out. In particular, be sure state his main point and whether or not you agree with it.

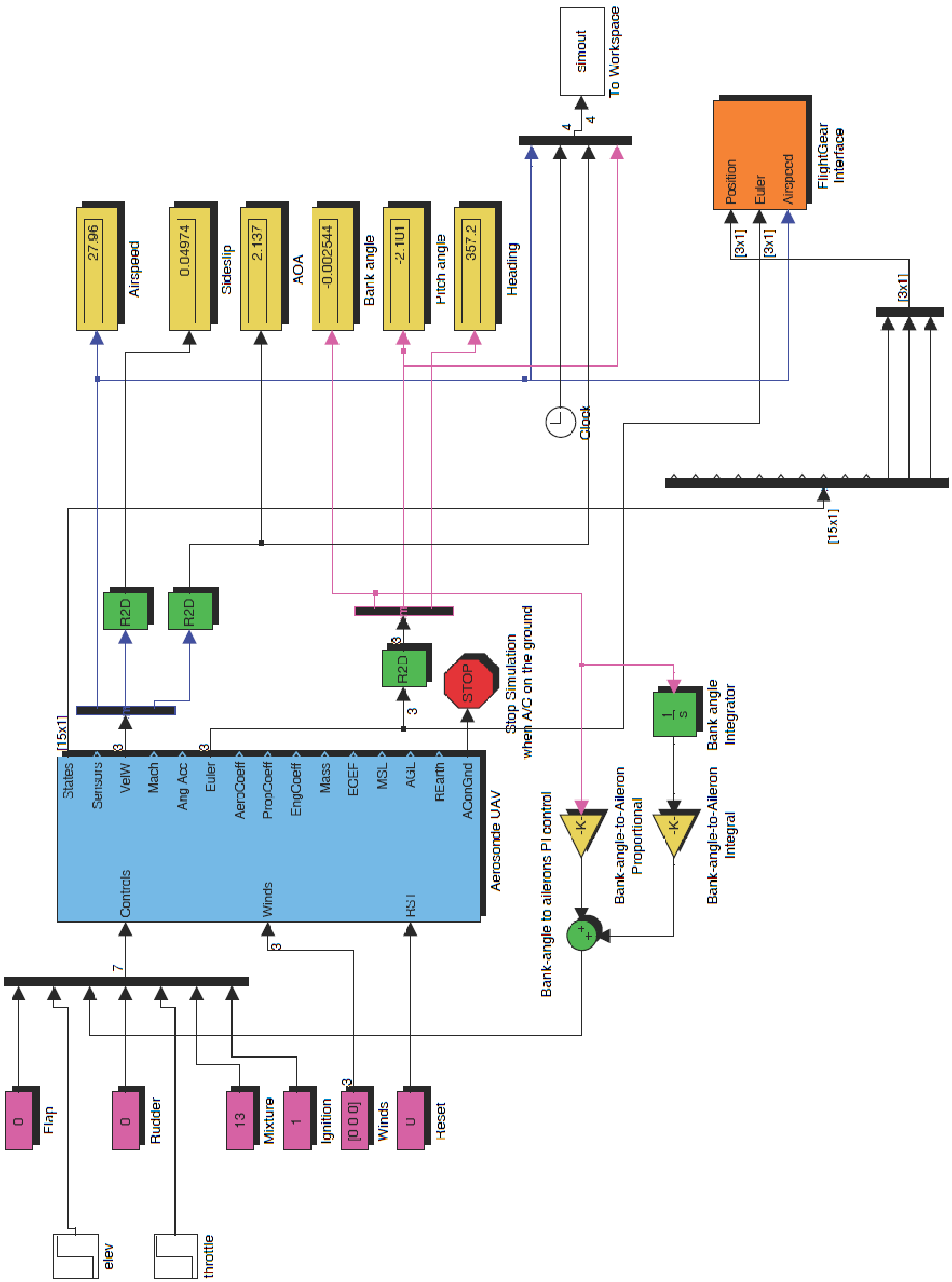

Figure 1: Simplified block diagram for the Aerosonde