Department of Mechanical and Aerospace Engineering
MAE – 275

Take-Home Final Exam

Due: Tuesday, June 9, 5:00 PM

This problem will involve the design of pitch-rate-command and airspeed-hold (auto-throttle) Stability and Command Augmentation Systems (SCASs) for an A-7E aircraft in a landing approach to an aircraft carrier. Pilot models will be provided. A drawing of the aircraft is enclosed. The two controls effectors will be elevator δ_e (rad) and thrust δ_T (here denoted ΔT) (lbf). Aerodynamic data for the aircraft are enclosed. The carrier approach will include a model of the carrier air wake, consisting of u_g and w_g components (this wake is often referred to as the "burble"). This burble is in effect in the last 10 sec before landing:

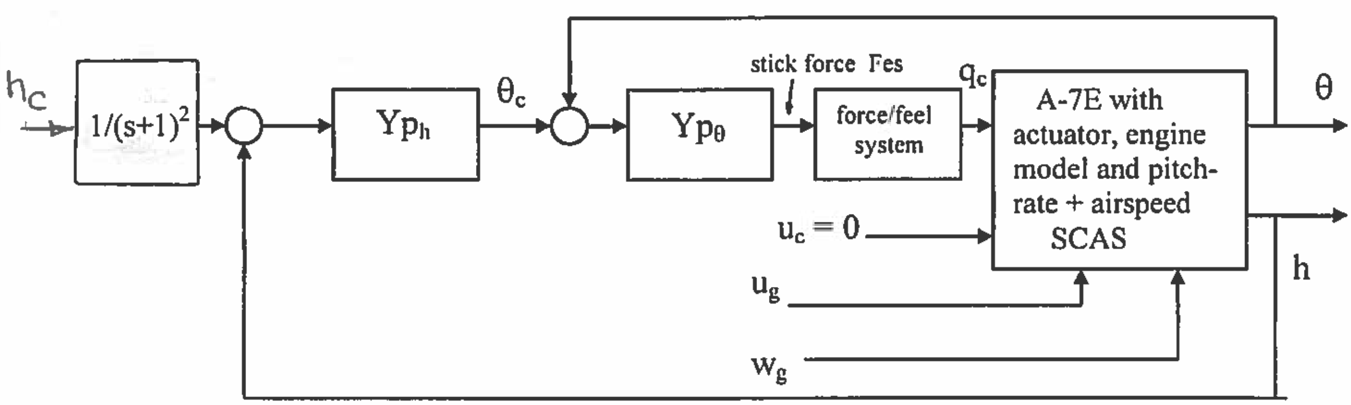
$$u_g(t) = t \text{ ft/sec} \quad 0 \le t \le 10 \text{ sec}$$
$$= 10 \text{ ft/sec} \quad t > 10 \text{ sec}$$

$$w_g(t) = -5\sin[(0.2\pi)(t)] \text{ ft/sec} \quad 0 \le t \le 10 \text{ sec}$$
$$= 0 \text{ ft/sec} \quad t > 10 \text{ sec}$$

where t = 0 is the time at which the burble is encountered. Include $q_g(t)$ in your simulation.

You will design a "square" control system, to control pitch rate and airspeed. Use elevator to control pitch-rate and thrust to control airspeed. You will also include an elevator actuator model, a simple engine model, and a model of the cockpit force feel system in your design and simulation.

Finally, you will use a pair of pilot models, emulating the pilot's control of altitude (through pitch attitude) in the serial loop closure as shown below as the aircraft is flown through the burble. Airspeed will be controlled by the "auto-throttle" system you created.



The SCAS performance specifications are:

Pitch-rate loop: bandwidth of at least 5 rad/sec (crossover frequency of 5 rad/sec in pitch-rate loop. Use the -3 dB criterion for bandwidth.

Airspeed loop: bandwidth of 0.5 rad/sec (crossover frequency of 0.5 rad/sec in airspeed loop) and no steady-state error to a step command

The pilot models are $Y_{p_\theta} = K_\theta e^{-0.35s}\ 1/\sec$; $Y_{p_h} = K_h\ rad/ft$; Choose K_θ to give a 2 rad/sec crossover frequency in the θ-loop and K_h to give a 0.35 rad/sec crossover frequency in the h-loop. These models obey the "crossover model" of the human pilot.

Finally, simulate your pilot/vehicle system encountering the burble given on the previous page. Stop your simulation at t = 12 sec (approximately the time it takes for the A7_E aircraft to travel from the start of the burble encounter to the carrier ramp.

Your results should include:

1.) Design details for your SCASs and pilot models, including Bode plots of open and closed-loop systems.

2.) An estimate of the handling qualities for the pitch-rate SCAS using the bandwidth-phase-delay criterion included. This is a Class IV aircraft in a Category C flight condition with a rate-response type in attitude. The "input" to the transfer function in question is right before the force-feel system. The output is θ.

3.) Simulation results:
   a. Disconnect your burble inputs and show the response of the aircraft to $h_c = 50$ ft (step command). Filter this command with $1/(s+1)^2$. Show $\delta_e(t)$, $\Delta T(t)$, $u(t)$, $\theta(t)$, and $h(t)$ for $0 \le t \le 25$ sec

   b. Now connect the burble inputs, set $h_c = 0$ and show $\delta_e(t)$, $\Delta T(t)$, $u(t)$, $\theta(t)$, u_g, w_g and $h(t)$ for $0 \le t \le 12$ sec

Elevator Actuator Model

$$\frac{\delta_e}{\delta_{c_e}}(s) = \frac{30^2}{s^2 + 2(0.7)30s + 30^2}$$ where δ_{c_e} is the command to the actuator

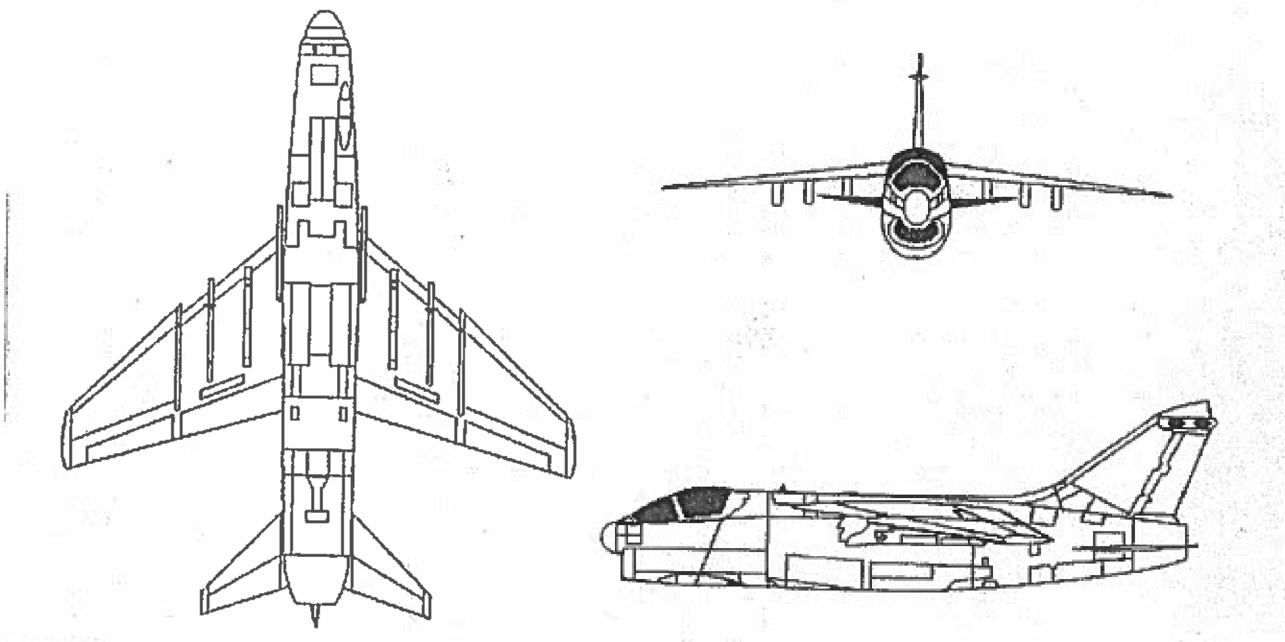
Force/Feel System Model

$$\frac{q_c}{stick\ \ force}(s) = \frac{25^2}{s^2 + 2(0.7)25s + 25^2}\ rad/\sec/lbf$$

Engine Model

$$\frac{\Delta T}{\Delta T_c} = \frac{1}{(s+1)}\ \text{where } \Delta T_c \text{ is the command to the engine}$$

Vehicle Aerodynamic Model:



DIMENSIONAL DERIVATIVES	
X_u	−0.054534
X_w	0.064327
Z_u	−0.286953
$Z_{\dot{w}}$	0
Z_w	−0.528871
M_u	−0.000165
$M_{\dot{w}}$	−0.000289
M_w	−0.007964
M_q	−0.327532
X_{δ_e}	0.732836
Z_{δ_e}	−14.713536
M_{δ_e}	−2.188878
$X_{\Delta T}$	0.001317
$Z_{\Delta T}$	−0.000250
$M_{\Delta T}$	0.000004

Note: Data for body-fixed stability axes

$S = 375\ ft^2$, $\bar{c} = 10.84$ ft ,

$W = 24{,}000$ lb , $m = 746$ slugs ,

$I_{yy} = 68{,}000$ slug-ft^2

$h = 0$ ft , $M = 0.1953$, $U_o = 218$ ft/sec

$\rho = 0.002378$ slugs/ft^3 , $a = 1{,}117$ ft/sec

Phase Delay:

$$\tau_p = \frac{\Delta\Phi 2\omega_{180}}{57.3\,(2\omega_{180})}$$

Note: if phase is nonlinear between ω_{180} and $2\omega_{180}$, τ_p shall be determined from a linear least squares fit to phase curve between ω_{180} and $2\omega_{180}$

Rate Response-Types:

ω_{BW} is lesser of $\omega_{BW_{gain}}$ and $\omega_{BW_{phase}}$

Attitude Response-Types:

$\omega_{BW} \equiv \omega_{BW_{phase}}$

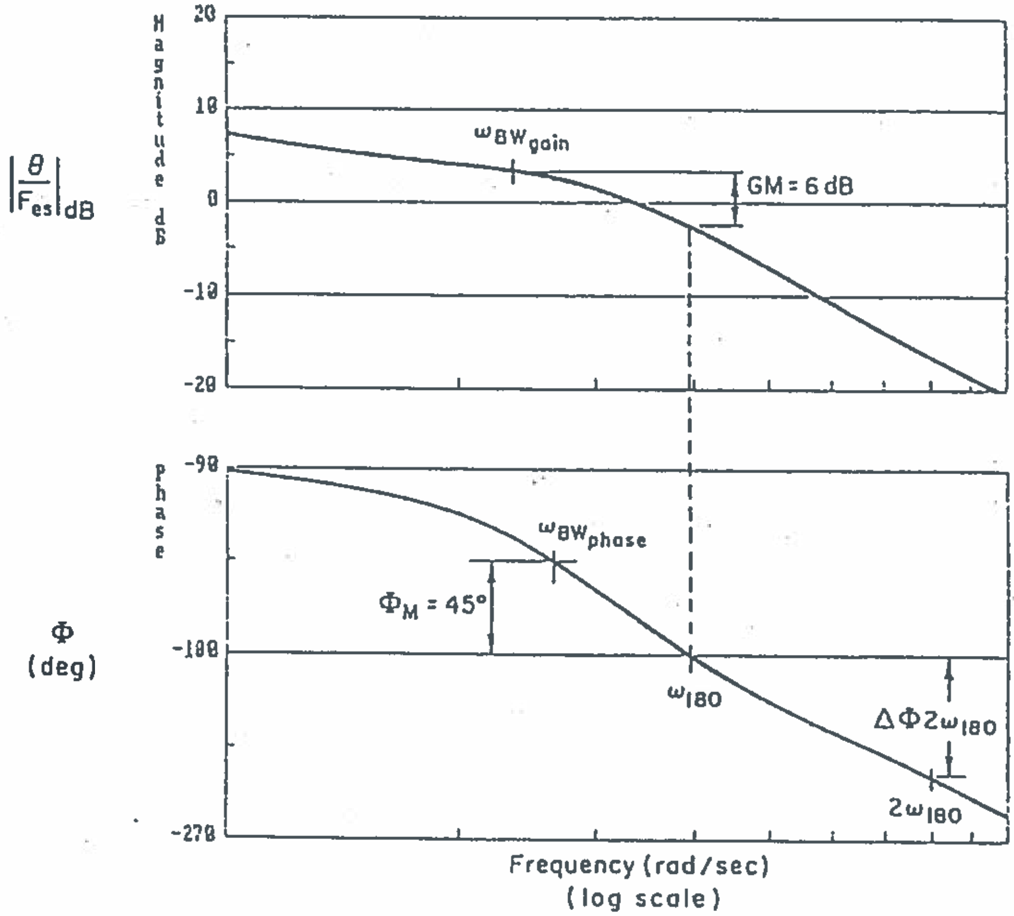
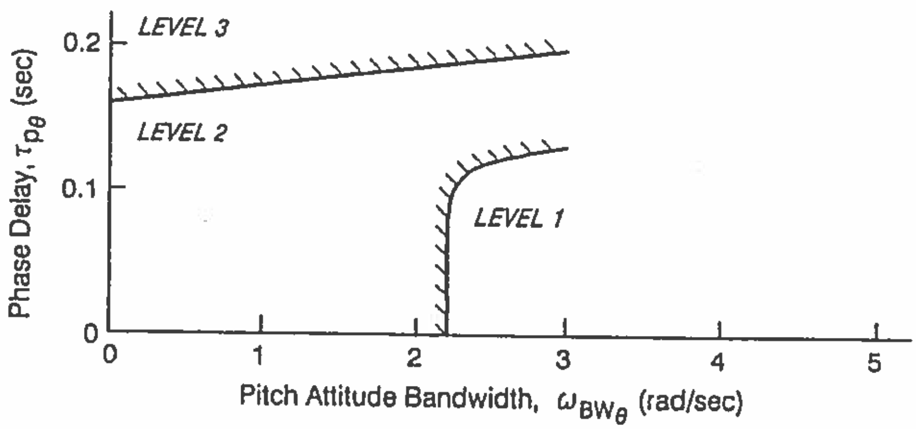
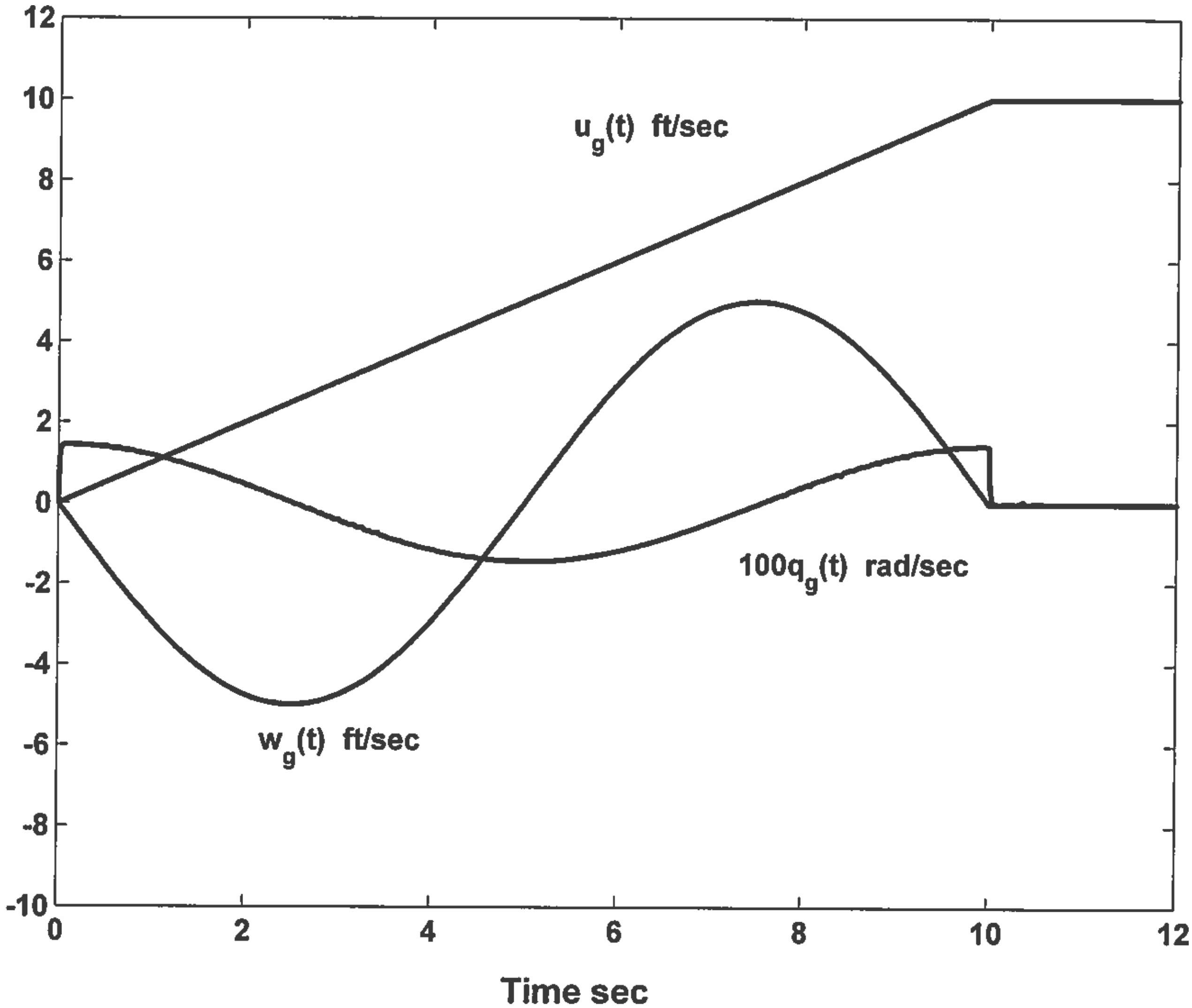


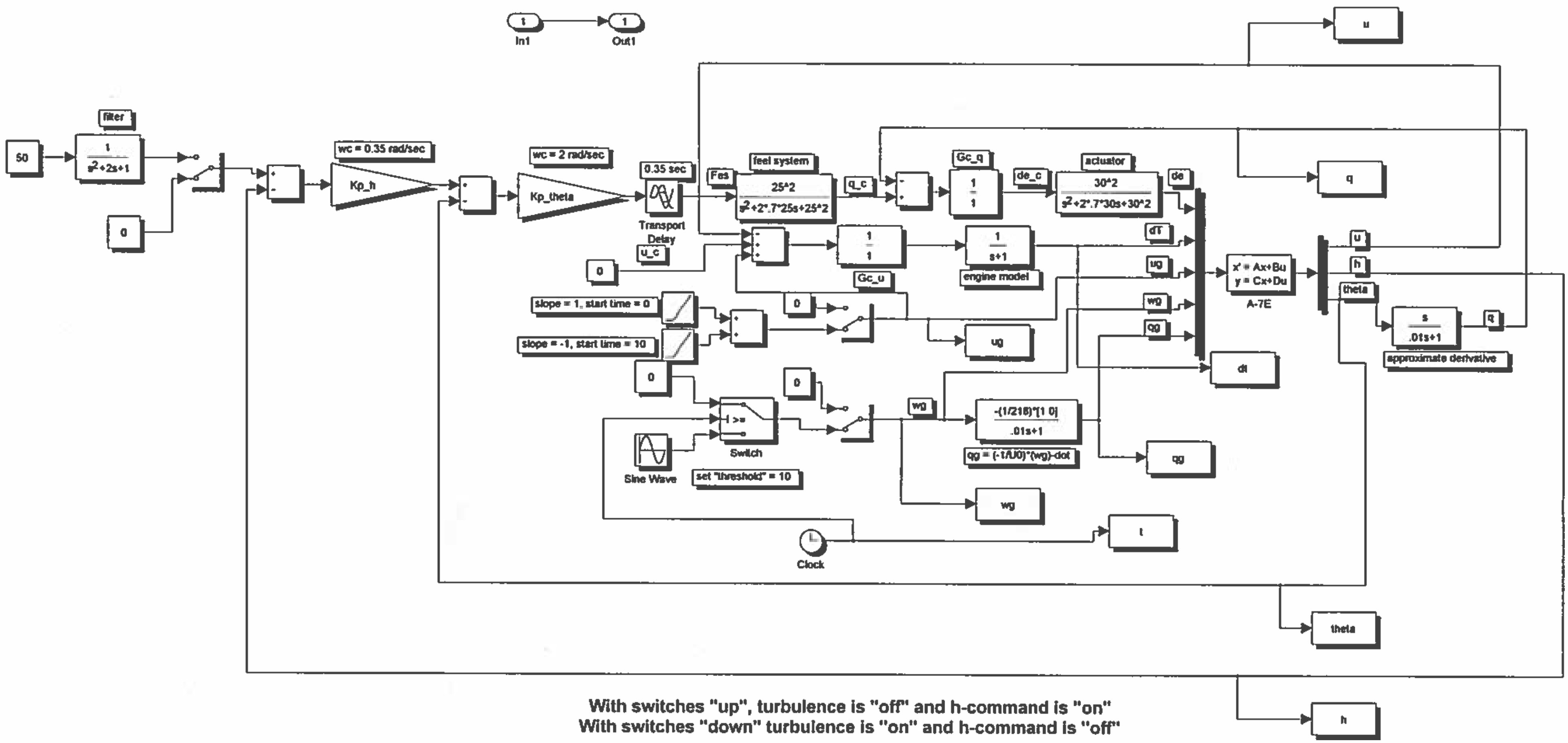
Figure 2(4.2.1.2). Definitions of Bandwidth and Phase Delay



LEVEL 3
LEVEL 2
LEVEL 1
Phase Delay, τ_{p_θ} (sec)
0.2
0.1
0
0
1
2
3
4
5
Pitch Attitude Bandwidth, ω_{BW_θ} (rad/sec)



12
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
2
4
6
8
10
12
$u_g(t)$ ft/sec
$100q_g(t)$ rad/sec
$w_g(t)$ ft/sec
Time sec



With switches "up", turbulence is "off" and h-command is "on"
With switches "down" turbulence is "on" and h-command is "off"