UTHM
Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2016/2017

TERBUKA

COURSE NAME	:	FLIGHT STABILITY AND CONTROL
COURSE CODE	:	BDL 30102
PROGRAMME	:	3 BDC
EXAMINATION DATE	:	DECEMBER 2016/JANUARY 2017
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **FOUR (4)** QUESTIONS **ONLY**

THIS QUESTION PAPER CONSISTS OF **SEVEN (7)** PAGES

Q1 (a) The schematic diagram of forces exerted on the wing–body– tail configuration is shown in Figure **Q1**. Derive the pitching moment coefficient, $C_{M_{cg}}$ and the neutral point equation for such configuration.

(25 marks)

Q2 (a) Given a wing-body-tail configuration with data as follows:

Wing area reference, $S = 1.5\ m^2$
Chord length, $c = 0.45\ m$
Wind speed, $U = 100\ m/s$
The angle of attack, $\alpha = 50°$
Air density standard sea level, $\rho = 1.225\ kg/m^3$
The pitching moment coefficient at wing body's aerodynamic center (a.c), $C_{M_{acwb}} = -0.003$
The distance between wing body's a.c to center of gravity (c.g): ${}^{\ell w}/_{c} = 0.02$
The distance between tail's a.c to c.g, $\ell_t = 1.0\ m$, ${}^{\ell_t}/_{c} = 2.222$
Tail area, $S_t = 0.4\ m^2$
Tail incidence angle, $i_t = 2°$
The down wash angle at the wing zero lift, $\varepsilon_0 = 0°$ and ${}^{d\varepsilon}/_{d\alpha} = 0.42$
The slope tail lift coefficient, ${}^{dC_{L_t}}/_{\alpha_t} = 0.12°$
Lift at $\alpha_{wb} = 5°$ is $L = 4132\ N$

Determine the pitching moment coefficient and the moment coefficient at center of gravity (c.g) for above configuration according to Anderson's method.

(25 marks)

Q3 (a) A light aircraft has a rectangular wing plan form with wing span, $b = 12.8\ m$ and wing chord length, $c = 2.14\ m$. The maximum lift coefficient, $C_{L_{max}} = 1.5$ and the wing loading is $850\ N/m^2$. The aircraft is rolled through 45° in one second when flying at three times its stalling speed. Estimate the rolling moment created by the ailerons at steady motion.

(25 marks)

Q4 The open loop pitch rate response to elevator transfer function for the Lockheed F-104 Starfighter is given by the following transfer function:

$$\frac{q(s)}{\delta_e(s)} = \frac{-4.66s(s+0.133)(s+0.269)}{(s^2+0.015s+0.021)(s^2+0.911s+4.884)}$$

(a) The root locus plot of the transfer function is given in Figure **Q4**. With the aid of the root locus plot, explain how can the root locus plot may be used to evaluate the effect of feedback on the characteristics modes of motion?

(4 marks)

(b) Determine the damping ratio and undamped natural frequency for short period and phugoid mode.

(4 marks)

(c) Design a pitch rate feedback controller, K_q to bring the closed loop short period mode in agreement with minimum specification for damping ratio and natural frequency. Assume the following Level 1 flying qualities are used in the analysis:

Phugoid damping ratio $\zeta_p \geq 0.04$
Short period damping ratio $\zeta_s \geq 0.5$
Short period undamped natural frequency $0.8 \leq \omega_s \leq 3.0$ rad/s

(11 marks)

(d) Compare the augmented short period damping ratio and natural frequency with those of the unaugmented aircraft. How does pitch rate feedback to elevator input improve the longitudinal flying qualities? Explain your answer based from your findings and the given root locus plot.

(6 marks)

Q5 (a) The longitudinal equation of motion and aerodynamic data for A-7A Corsair II aircraft were given in the following state space model. The flight condition corresponds to level cruising flight at an altitude of 15000 ft at Mach 0.3:

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} 0.0501 & 0.00464 & -72.9 & -31.34 \\ -0.0857 & -0.545 & 309 & -7.4 \\ -0.00185 & -0.00767 & -0.395 & 0.00132 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} 5.63 \\ -23.8 \\ -4.51576 \\ 0 \end{bmatrix} \eta$$

Establish the state space model of the aircraft based on the simplest form of short period mode approximation.

(6 marks)

(b) Determine whether the system is state controllable.

(4 marks)

(c) Design a pitch displacement autopilot system for the aircraft using Bass-Gura method (state feedback) so that the aircraft has the following short period characteristic:

$$\xi_{sp} = 0.6$$
$$\omega_{n,sp} = 1.5\ rad/s$$

(15 marks)

-END OF QUESTION-

FINAL EXAMINATION

SEMESTER/SESSION	:	SEM 1 / 2016/2017	PROGRAMME	:	3 BDC
COURSE	:	FLIGHT STABILITY AND CONTROL	COURSE CODE	:	BDL30102

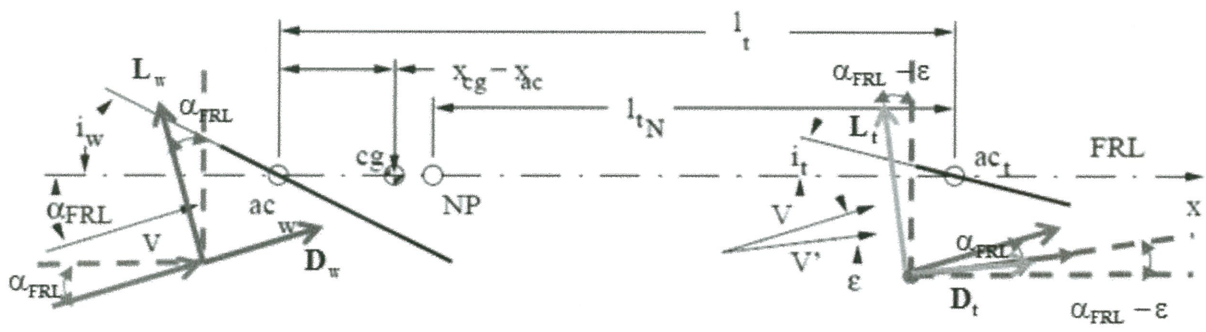

FIGURE Q1 The force diagram on wing–body–tail configuration.

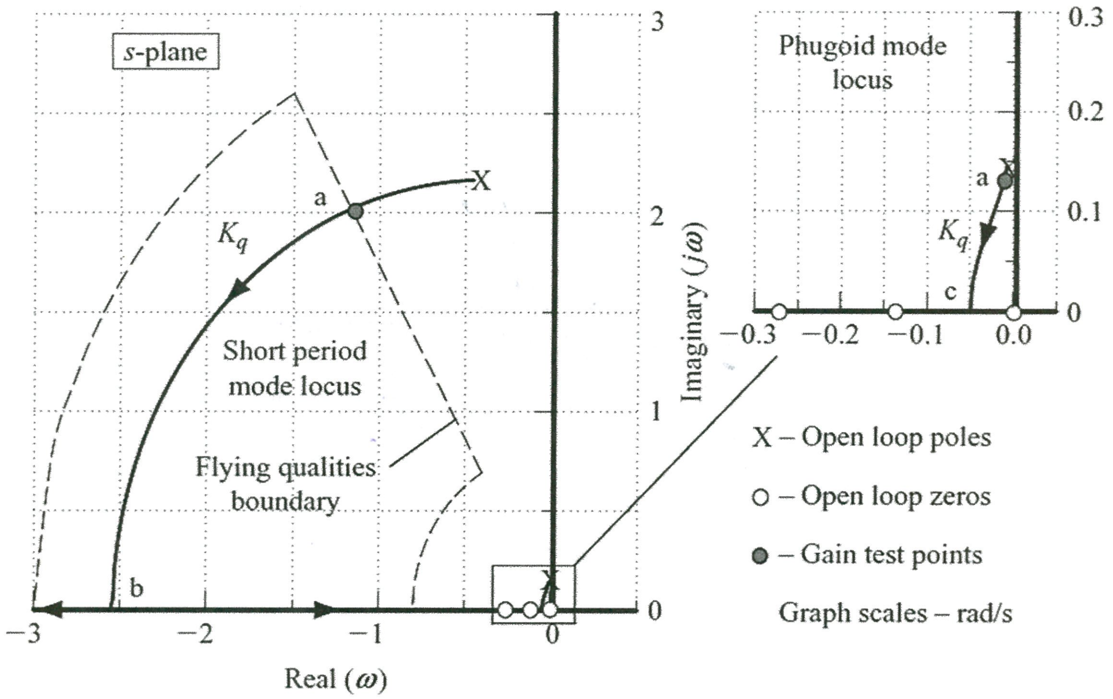

FIGURE Q4 Root locus plot showing pitch rate feedback to elevator.

FINAL EXAMINATION

SEMESTER/SESSION	:	SEM 1 / 2016/2017	PROGRAMME	:	3 BDC
COURSE	:	FLIGHT STABILITY AND CONTROL	COURSE CODE	:	BDL30102

A Key Equations

The relevant equations used in this examination are given as follows:

1. Determinant of 3 × 3 matrix:

$$\begin{vmatrix} a & b & c \\ d & e & f \\ g & h & i \end{vmatrix} = a\begin{vmatrix} e & f \\ h & i \end{vmatrix} - b\begin{vmatrix} d & f \\ g & i \end{vmatrix} + c\begin{vmatrix} d & e \\ g & h \end{vmatrix} \quad (1)$$

2. Partial fraction for $F(s)$ with real and distinct roots in denominator:

$$F(s) = \frac{K_1}{(s+p_1)} + \frac{K_2}{(s+p_2)} + \cdots + \frac{K_m}{(s+p_m)} \quad (2)$$

3. Partial fraction for $F(s)$ with complex or imaginary roots in denominator:

$$F(s) = \frac{K_1}{(s+p_1)} + \frac{K_2 s + K_3}{(s^2 + as + b)} + \cdots \quad (3)$$

4. General first order transfer function:

$$G(s) = \frac{s}{s+a} \quad (4)$$

5. General second order transfer function:

$$G(s) = \frac{K}{s^2 + 2\xi\omega_n s + \omega_n} \quad (5)$$

6. The closed loop transfer function:

$$T(s) = \frac{G(s)}{1 + G(s)H(s)} \quad (6)$$

where $G(s)$ is the transfer function of the open loop system and $H(s)$ is the transfer function in the feedback loop.

7. The final value theorem:

$$\lim_{t\to\infty} y(t) = \lim_{s\to 0} sY(s) \quad (7)$$

8. Time response:

$$T_r = \frac{2.2}{a} \quad (8)$$

$$T_s = \frac{4}{a} \quad (9)$$

$$\%OS = e^{-\left(\frac{\xi\pi}{\sqrt{1-\xi^2}}\right)} \times 100\% \quad (10)$$

$$\xi = \frac{-\ln\left(\%\frac{OS}{100}\right)}{\sqrt{\pi^2 + \left(\ln\left(\%\frac{OS}{100}\right)\right)^2}} \quad (11)$$

FINAL EXAMINATION

SEMESTER/SESSION	:	SEM 1 / 2016/2017	PROGRAMME	:	3 BDC
COURSE	:	FLIGHT STABILITY AND CONTROL	COURSE CODE	:	BDL30102

$$T_p = \frac{\pi}{\omega_n\sqrt{1-\xi^2}} = \frac{\pi}{\omega} \qquad (12)$$

$$T_s = \frac{4}{\xi\omega_n} = \frac{4}{\eta} \qquad (13)$$

$$P = \frac{2\pi}{\omega} \qquad (14)$$

$$t_{1/2} = \frac{0.693}{|\eta|} \qquad (15)$$

$$N_{1/2} = 0.110\frac{|\omega|}{|\eta|} \qquad (16)$$

9. Estimation of parameter q (Paynter Numerical Method)

$$q = \max\left|A_{ij}\Delta t\right| \qquad (17)$$

10. Estimation of integer value of p (Paynter Numerical Method)

$$\frac{1}{p!}(nq)^p e^{nq} \leq 0.001 \qquad (18)$$

11. Numerical solution of state equation:

$$\mathbf{x}_{k+1} = \boldsymbol{M}\mathbf{x}_k + \boldsymbol{N}\boldsymbol{\eta}_k$$

with matrix $\boldsymbol{M}$ and $\boldsymbol{N}$ are given by the following matrix expansion:

$$\boldsymbol{M} = e^{\boldsymbol{A}\Delta t} = \boldsymbol{I} + \boldsymbol{A}\Delta t + \frac{1}{2!}\boldsymbol{A}^2\Delta t^2 \ldots \qquad (19)$$

$$\boldsymbol{N} = \Delta t\left(\boldsymbol{I} + \frac{1}{2!}\boldsymbol{A}\Delta t + \frac{1}{3!}\boldsymbol{A}^2\Delta t^2 + \cdots\right)\boldsymbol{B}$$

12. Characteristic equation of the closed loop system:

$$1 + KG(s)H(s) = 0 \qquad (20)$$

13. Asymptotes: angle and real-axis intercept:

$$\sigma = \frac{[\sum Real\ parts\ of\ the\ poles - \sum Real\ parts\ of\ the\ zeros]}{n-m} \qquad (21)$$

$$\phi_a = \frac{180°[2q+1]}{n-m} \qquad (22)$$

14. Solution to find real axis break-in and breakaway points:

$$\frac{dK(\sigma)}{d\sigma} = 0 \qquad (23)$$

FINAL EXAMINATION

SEMESTER/SESSION	:	*SEM 1 / 2016/2017*	*PROGRAMME*	:	*3 BDC*
COURSE	:	*ELECTROMECHANICAL AND CONTROL SYSTEM*	*COURSE CODE*	:	*BDL30102*

15. Alternative solution to find real axis break-in and breakaway points:

$$\sum \frac{1}{\sigma + z_i} = \sum \frac{1}{\sigma + p_i} \tag{24}$$

16. Angle of departure of the root locus from a pole of $G(s)H(s)$:

$$\theta = 180° + \sum (angles\ to\ zeros) - \sum (angles\ to\ poles) \tag{25}$$

17. Angle of arrival at a zeros:

$$\theta = 180° - \sum (angles\ to\ zeros) + \sum (angles\ to\ poles) \tag{26}$$

18. The steady state error:

$$e_{ss} = \lim_{t \to \infty} e(t) = \lim_{s \to 0} sE(s) \tag{27}$$

where the error signal is given as:

$$E(s) = \frac{1}{1 + K(s)G(s)H(s)} \times U(s) \tag{28}$$

19. Linear system (SISO) with state feedback:

$$\dot{\boldsymbol{x}} = (\boldsymbol{A} - \boldsymbol{B}\boldsymbol{K}^{\boldsymbol{T}})\boldsymbol{x} + \boldsymbol{B}u$$

$$\text{or, } \dot{\boldsymbol{x}} = \boldsymbol{A}_{\boldsymbol{new}}\boldsymbol{x} + \boldsymbol{B}u \tag{29}$$

where $\boldsymbol{A}_{\boldsymbol{new}}$ is the augmented matrix and $u = \boldsymbol{K}^{\boldsymbol{T}}\boldsymbol{x} + \delta_{ref}$

20. The characteristic equation for the standard form of the second-order differential equation:

$$\lambda^2 + 2\xi\omega_n\lambda + \omega_n^2 = 0$$

The roots of the characteristic equation are: (30)

$$\lambda_{1,2} = -\xi\omega_n \pm \omega_n\sqrt{1 - \xi^2} \cdot i$$

$$\lambda_{1,2} = \sigma \pm \omega_d$$

21. Controllability matrix:

$$\boldsymbol{V} = [\boldsymbol{B} \quad \boldsymbol{AB} \quad \boldsymbol{A}^2\boldsymbol{B} \quad \dots \quad \boldsymbol{A}^{n-1}\boldsymbol{B}] \tag{31}$$

22. Transformation matrix:

$$\boldsymbol{W} = \begin{bmatrix} 1 & a_1 & \cdots & a_{n-1} \\ 0 & 1 & \cdots & a_{n-2} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix} \tag{32}$$

23. Bass-Gura formula to determine feedback gains:

$$\boldsymbol{K} = [(\boldsymbol{VW})^{\boldsymbol{T}}]^{-1}[\bar{\boldsymbol{a}} - \boldsymbol{a}] \tag{33}$$