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Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2021/2022

COURSE NAME	:	FLIGHT STABILITY AND CONTROL
COURSE CODE	:	BDL 30102
PROGRAMME CODE	:	BDC
EXAMINATION DATE	:	JULY 2022
DURATION	:	2 HOURS
INSTRUCTION	:	1. ANSWERS **FOUR (4)** QUESTIONS **ONLY** 2. THIS FINAL EXAMINATION IS CONDUCTED VIA CLOSED BOOK. 3. STUDENTS ARE PROHIBITED TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

THIS QUESTION PAPER CONSISTS OF **TEN (10)** PAGES

Q1 (a) Aircraft is flying at a constant velocity with pitch angle, angle of attack and flight path angle at θ, α and γ, respectively.

i. Illustrates the corresponding angles at X-Z plane of symmetry.

(4 marks)

ii. Assume the flight path angle is zero, examine the relationship of the corresponding angles in terms of equation. Give a conclusion about the state of aircraft when pitch angle, θ is positive.

(6 marks)

(b) If the aircraft flying at positive sideslip angle β is banking with an angle of ϕ, resolve the observed velocities due to free stream velocity V_0 and lateral introduced velocity V_L in generalized aircraft body axes. Examine and illustrates the movement of the aircraft from the equation when banking angle ϕ is null.

(12 marks)

(c) Describe the role of Stability Augmentation System (SAS) in aircraft.

(3 marks)

Q2 Assume fuselage aerodynamics effects are neglected. At α = 2.6° the lift coefficient for the wing is measured as 0.48. The lift is found to be zero at a geometric angle of attack α = −1.1°. The moment coefficients about center of gravity for α = 1.3° and α = 4.8° are −0.01 and 0.05, respectively. The location of the center of gravity is 0.3.

(a) Calculate $C_{M,ac_{wb}}$ and location of the aerodynamic center of the wing. If lift due to the aerodynamic forces are neglected, examine the pitch direction of the wing.

(8 marks)

(b) Now assume that a horizontal tail is added to model with the characteristic of tail is shown in **Table Q2(b).** Compute the $C_{M,cg}$ at α = 4.8°. Analyze the stability of the aircraft as a whole in term of longitudinal mode.

(12 marks)

(c) If aircraft flying at steady state is pertubated with upward gust of wind. Compare the stability of an aircraft with respect to both moment coefficient curves illustrated in **Figure Q2(c).**

(5 marks)

Q3

$$\begin{bmatrix}\dot{u}\\ \dot{w}\\ \dot{q}\\ \dot{\theta}\end{bmatrix}=\begin{bmatrix}-0.04225 & -0.11421 & 0 & -32.2\\ -0.20455 & -0.49774 & 317.48 & 0\\ 0.00003 & -0.00790 & -0.39499 & 0\\ 0 & 0 & 1 & 0\end{bmatrix}\begin{bmatrix}u\\ w\\ q\\ \theta\end{bmatrix}+\begin{bmatrix}0.00381\\ -24.4568\\ -4.51576\\ 0\end{bmatrix}\eta$$

The longitudinal state equation with input η elevator defectlion above shows full order models of A-7A Corsair II aircraft.

(a) Describe and illustrates the dynamic stability modes contain in longitudinal motion.
(5 marks)

(b) By using the reduced model, analyze the stability corresponding to the short period approximation. Compare and illustrate the pitch rate, q response of the model with high and low damping ratio.
(15 marks)

(c) Determine the steady state of pitch rate response in rad/s when unit step input of 1°.
(5 marks)

Q4 (a) The governing equation of flight motion in a six degrees of freedom aircraft can be written as:

The equation of translational motion:

In x-direction : $m(\dot{U} + QW - RV) = -mg \sin\theta + F_{Ax} + F_{Tx}$

In y-direction : $m(\dot{V} + UR - PW) = mg \cos\theta \sin\Phi + F_{Ay} + F_{Ty}$

In z-direction : $m(\dot{W} + PV - QU) = mg \cos\theta \operatorname{Cos}\Phi + F_{Az} + F_{Tz}$

The equation of rotational motion:

In x-rotation : $\dot{P}I_{xx} - \dot{R}I_{xz} - PQI_{xz} + RQ(\dot{I_{zz}} - I_{yy}) = I_A + I_T$

In y-rotation : $\dot{Q}I_{yy} + PR(I_{xx} - I_{zz}) + (P^2 - R^2)I_{xz} = M_A + M_T$

In z-rotation : $\dot{R}I_{zz} - \dot{P}I_{xz} + PQ(I_{yy} - I_{xx}) + QR\,I_{xz} = N_A + N_T$

Where

U, V, W : translational velocity in x, y and z direction

$\dot{U}, \dot{V}, \dot{W}$: translational acceleration in x, y and z direction

P, Q, R : translational velocity in x, y and z direction

$\dot{P}, \dot{Q}, \dot{R}$: translational acceleration in x, y and z direction

I_{xx}, I_{yx}, I_{zx} : Inertia and moment of moment inertia in x-direction

I_{xy}, I_{yy}, I_{zy} : Inertia and moment of moment inertia in y-direction

I_{xz}, I_{yz}, I_{zz} : Inertia and moment of moment inertia in y-direction

F_{Ax}, F_{At}, F_{Az} : aerodynamic forces in x, y and z-direction

T_{Ax}, T_{At}, T_{Az} : engine thrust in x, y and z direction

L_A, M_A, N_A : aerodynamic moment of rolling, pitching and yawing

L_T, M_T, N_T : rolling, pitching and yawing moment due to engine thrust.

Based on general equation of motion listed above formulate the following cases:

i. Aircraft flies in steady state

(7 marks)

ii. Aircraft flies in steady state with rectilinear flight condition

(8 marks)

(b) Examine the stability of the system with the following transfer function:

$$G(S) = \frac{S+4}{S^2+4S+6}$$

(5 marks)

(c) $$\Delta(S) = s^4 + 1.326s^3 + 1.219s^2 + 1.096s - 0.015 = 0$$

The above equation shows the lateral–directional characteristic equation for the Douglas DC-8 aircraft in a low altitude cruise flight condition. Analyze the stability of the aeroplane by using Routh-Hurwitz method.

(5 marks)

Q5

$$\frac{\theta(s)}{\eta(s)} = \frac{-20.6(s+0.0131)(s+0.618)}{(s^2+0.0161s+0.00103)(s^2+1.453s+15.49)}$$

(a) **Table Q5(a)** shows the acceptable limit of short period mode and Phugoid mode and **Figure Q5(a)** illustrates the short period mode frequency requirement. Examine the flying qualities requirement in longitudinal mode by using the above pitch attitude response to elevator transfer function with Normal load factor derivative 22.4 g/rad.

(10 marks)

(b) $$\Delta(S) = (s + 0.0065)(s + 1.329)(s^2 + 0.254 + 1.433s) = 0$$

The above equation shows the lateral–directional characteristic equation for an aircraft.

i. Calculate time constant for roll subsidence mode, spiral mode, damping ratio and undamped natural frequency for dutch roll mode.

(4 marks)

ii. Do you think the time constant in **Q5(b(i))** for roll subsidence mode and spiral mode are correct? Justify your answer.

(4 marks)

(c) The matrix below shows the eigenvectors represent the dynamic mode content for unknown aircraft. Analyze the lateral-directional dynamic stability modes for this aircraft in v, p, r, and ϕ.

$$\begin{vmatrix} -0.845 + 0.5291j & -0.845 - 0.5291j & -0.9970 & 0.9864 \\ 0.0012 - 0.0033j & 0.0012 + 0.0033j & -0.0619 & -0.0011 \\ 0.0011 + 0.0021j & 0.0011 - 0.0021j & 0.0006 & 0.0111 \\ -0.0029 - 0.0007j & -0.0029 + 0.0007j & 0.0466 & 0.1641 \end{vmatrix} \begin{matrix} v \\ p \\ r \\ \phi \end{matrix}$$

(5 marks)

(d) Illustrates the roll subsidence mode response in roll rate, p.

(2 marks)

-END OF QUESTIONS –

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Table Q2(b): Aircraft with tail characteristics

Wing area	0.2 m^2
Wing chord	0.25 m
Distance C.g to A.c of tail	0.19 m
Tail area	0.04 m^2
Tail setting angle	3 degrees
Tail slope	0.2 /degree
Downwash angle	1 degree
$\partial\varepsilon/\partial\alpha$	0.4

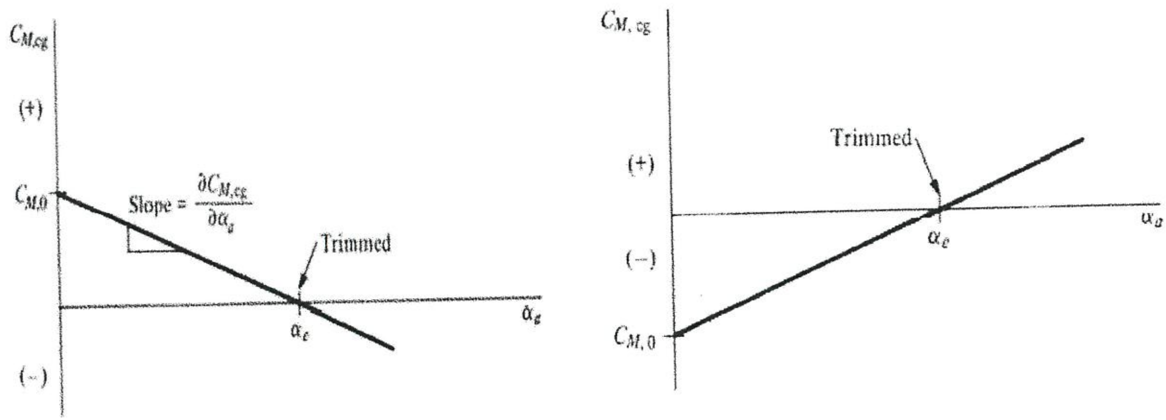

Figure Q2(c): Moment coefficient curves

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Table Q5(a): Acceptable limit

Short period

	Level 1		*Level 2*		*Level 3*
Flight phase	ζ_s *min*	ζ_s *max*	ζ_s *min*	ζ_s *max*	ζ_s *min*
CAT A	0.35	1.30	0.25	2.00	0.10
CAT B	0.30	2.00	0.20	2.00	0.10
CAT C	0.50	1.30	0.35	2.00	0.25

Phugoid

Level of flying qualities	*Minimum* ζ_p
1	0.04
2	0
3	Unstable, period $T_p > 55$ s

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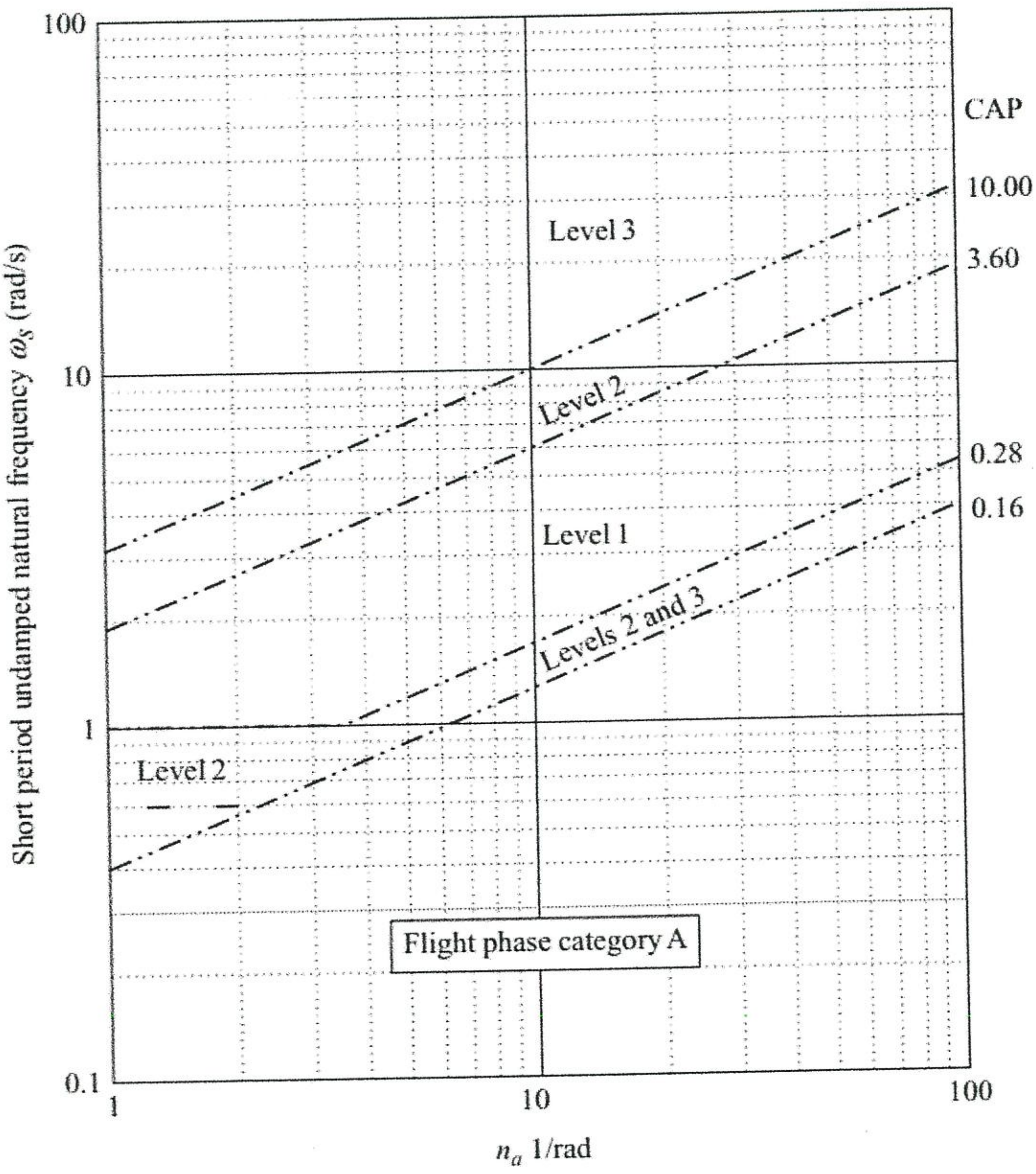

Figure Q5(a): short period mode frequency requirements

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Table A1: List of Equations

1.	$\mathbf{D} = \begin{bmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ \sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi & \sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi & \sin\phi\cos\theta \\ \cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi & \cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi & \cos\phi\cos\theta \end{bmatrix}$
2.	$C_{M,\mathrm{cg_{wb}}} = C_{M,\mathrm{ac_{wb}}} + C_{L_{\mathrm{wb}}}(h - h_{\mathrm{ac_{wb}}})$
3.	$\begin{aligned} m\dot{u} - \mathring{X}_u u - \mathring{X}_{\dot{w}}\dot{w} - \mathring{X}_w w - \left(\mathring{X}_q - mW_e\right)q + mg\theta\cos\theta_e &= \mathring{X}_\eta\eta + \mathring{X}_\tau\tau \\ -\mathring{Z}_u u + \left(m - \mathring{Z}_{\dot{w}}\right)\dot{w} - \mathring{Z}_w w - \left(\mathring{Z}_q + mU_e\right)q + mg\theta\sin\theta_e &= \mathring{Z}_\eta\eta + \mathring{Z}_\tau\tau \\ -\mathring{M}_u u - \mathring{M}_{\dot{w}}\dot{w} - \mathring{M}_w w + I_y\dot{q} - \mathring{M}_q q &= \mathring{M}_\eta\eta + \mathring{M}_\tau\tau \end{aligned}$
4.	$C_{M,\mathrm{cg_{wb}}} = C_{M,\mathrm{ac_{wb}}} + a_{\mathrm{wb}}\alpha_{\mathrm{wb}}(h - h_{\mathrm{ac_{wb}}})$
5.	$V_H \equiv \frac{l_t S_t}{cS}$
6.	$C_{M,\mathrm{cg}} = C_{M,\mathrm{ac_{wb}}} + a\alpha_a\left[h - h_{\mathrm{ac_{wb}}} - V_H\frac{a_t}{a}\left(1 - \frac{\partial\varepsilon}{\partial\alpha}\right)\right] + V_H a_t(i_t + \varepsilon_0)$
7.	$\frac{\partial C_{M,\mathrm{cg}}}{\partial\alpha_a} = a\left[h - h_{\mathrm{ac_{wb}}} - V_H\frac{a_t}{a}\left(1 - \frac{\partial\varepsilon}{\partial\alpha}\right)\right]$
8.	$C_{M,0} = C_{M,\mathrm{ac_{wb}}} + V_H a_t(i_t + \varepsilon_0)$
9.	$h_n = h_{\mathrm{ac_{wb}}} + V_H\frac{a_t}{a}\left(1 - \frac{\partial\varepsilon}{\partial\alpha}\right)$
10.	$\delta_{\mathrm{trim}} = \frac{C_{M,0} + (\partial C_{M,\mathrm{cg}}/\partial\alpha_a)\alpha_n}{V_H(\partial C_{L,t}/\partial\delta_e)}$
11.	$\begin{bmatrix}\dot{u}\\ \dot{w}\\ \dot{q}\\ \dot{\theta}\end{bmatrix} = \begin{bmatrix} x_u & x_w & x_q & x_\theta \\ z_u & z_w & z_q & z_\theta \\ m_u & m_w & m_q & m_\theta \\ 0 & 0 & 1 & 0 \end{bmatrix}\begin{bmatrix}u\\ w\\ q\\ \theta\end{bmatrix} + \begin{bmatrix}x_\eta\\ z_\eta\\ m_\eta\\ 0\end{bmatrix}\eta$

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Table A1: List of Equations (Cont)

12.	$$\frac{w(s)}{\eta(s)} = \frac{z_\eta\left(s + U_e\frac{m_\eta}{z_\eta}\right)}{(s^2 - (m_q + z_w)s + (m_q z_w - m_w U_e))}$$
13.	$$\frac{q(s)}{\eta(s)} = \frac{m_\eta(s - z_w)}{(s^2 - (m_q + z_w)s + (m_q z_w - m_w U_e))}$$
14.	$$\begin{bmatrix}\dot{v}\\\dot{p}\\\dot{r}\\\dot{\phi}\end{bmatrix} = \begin{bmatrix}y_v & y_p & y_r & y_\phi\\ l_v & l_p & l_r & l_\phi\\ n_v & n_p & n_r & n_\phi\\ 0 & 1 & 0 & 0\end{bmatrix}\begin{bmatrix}v\\p\\r\\\phi\end{bmatrix} + \begin{bmatrix}y_\xi & y_\zeta\\ l_\xi & l_\zeta\\ n_\xi & n_\zeta\\ 0 & 0\end{bmatrix}\begin{bmatrix}\xi\\\zeta\end{bmatrix}$$