UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama
Sidang Akademik 2007/2008
First Semester Examination
2007/2008 Academic Session

Oktober/November 2007
October/November 2007

ESA 473/3 – Aero-Anjalan
Aero-Elasticity

Masa : 3 jam
[Duration : 3 hours]

ARAHAN KEPADA CALON
INSTRUCTION TO CANDIDATES

Sila pastikan bahawa kertas soalan ini mengandungi **TUJUH BELAS (17)** mukasurat bercetak dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan.
*Please ensure that this paper contains **SEVENTEEN (17)** printed pages and **FIVE (5)** questions before you begin examination.*

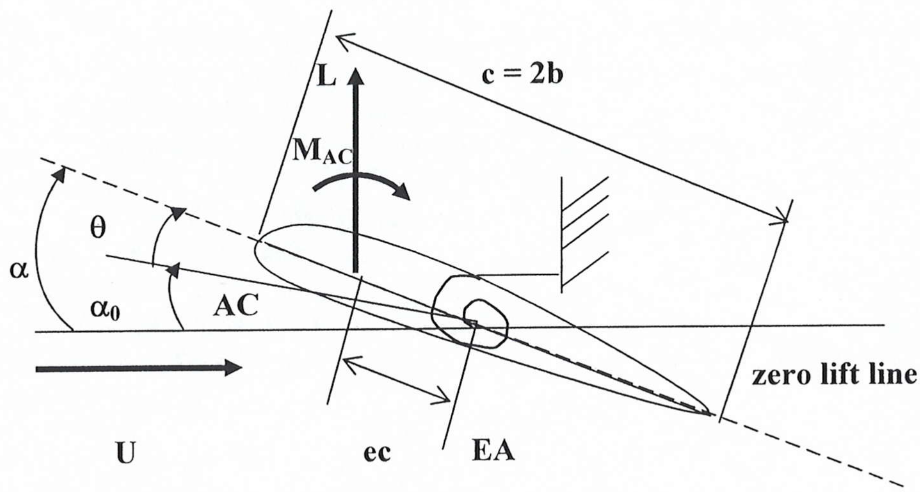
Jawab **EMPAT (4)** soalan.
*Answer **FOUR (4)** questions.*

Pelajar boleh menjawab soalan dalam Bahasa Inggeris atau Bahasa Malaysia.
Student may answer the questions either in English or Bahasa Malaysia.

Setiap soalan mestilah dimulakan pada mukasurat yang baru.
Each questions must begin from a new page.

1. Anggapkan sebuah sayap yang diwakili oleh bahagian khusus yang dikekang pada EA oleh piuhan.

Consider a wing represented by a typical section, which is restrained in twisting at EA.



Rajah 1: Semua petunjuk di dalam rajah adalah positif
Figure 1: All signs are positive in the figure

Lentur pesongan dianggap tidak penting (untuk sayap lurus). Di bawah:

Bending deflection is assumed to be unimportant (for straight wings). Here:

α_0 - sudut serang awal
initial angle of attack

θ - sudut piuhan disebabkan aliran udara
angle of twist due to airflow

$L = C_L q S$,
q = tekanan dinamik
dynamic pressure

S - luas permukaan sayap
wing surface area

$q = \frac{1}{2} \rho U^2$

Gantikan kilasan disebabkan keanjalan sayap (diwakili oleh kilasan spring K_α):

Restoring torque due to elasticity of wing (represented by torsional spring K_α):

$$T = K_\alpha \theta$$

(a) Terbitkan persamaan sudut piuhan θ disebabkan daya dan momen aerodinamik.

Write (derive) the expression for the angle of twist θ due to aerodynamic force and moments

(30 markah/*marks*)

(b) Apakah tekanan dinamik kecapahan dan laju kecapahan kritikal, sebagai fungsi kekukuhan kilasan sayap, parameter sayap wing parameters e, c, S, $C_{L\alpha}$ dan tekanan dinamik aliran bebas?

What is the divergence dynamic pressure and critical divergence speed, as a function of wing torsional stiffness, wing parameters e, c, S, $C_{L\alpha}$ and the dynamic pressure of free stream?

(30 markah/*marks*)

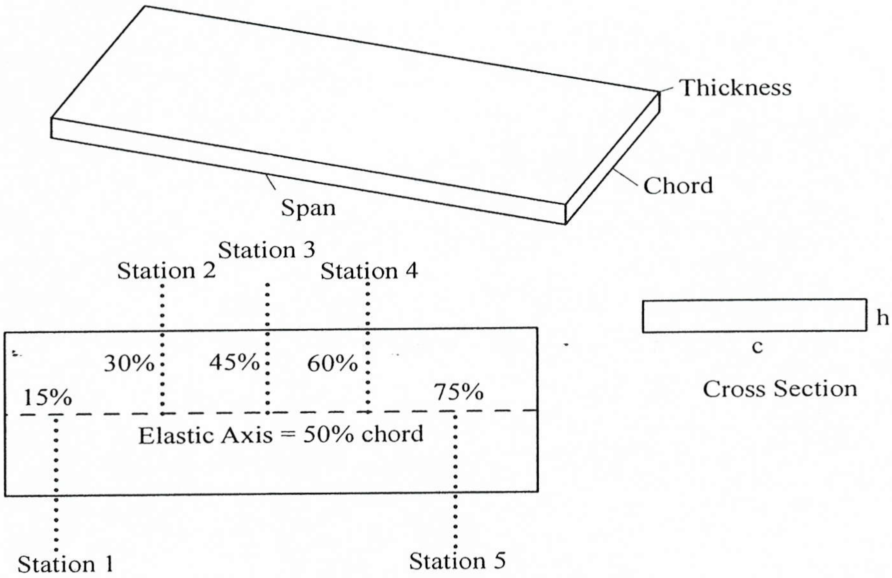
(c) Anggapkan sayap berbentuk Isogai dengan:

Consider an Isogai-like wing with:

$C_{L\alpha} = 2\pi$
s = rentang sayap separuh
half wing span
$\alpha_0 = 0$
S = luas permukaan sayap separuh
half wing surface area
C_{MAC} = 0 ≅ cs
e = 0.25
μ = 100 $= m / (\pi \rho b^2 s)$
r_α^2 = 3.48
K_α = $\omega_\alpha^2 I_\alpha$
I_α = $r_\alpha^2 mb^2$

2. Anggapkan sayap berbentuk BAH dengan pelantar segiempat tepat.

Consider the following BAH-like wing with rectangular platform.



Rajah 2/*Figure 2*

Anggapkan bahawa pelantar sayap segiempat tepat mempunyai ciri-ciri berikut:

Assumed that the rectangular wing planform has the following properties;

(a) Ciri-ciri struktur dan geometrik:

Geometrical and structural properties:

Rentang = S = 12.7 m
Span = S = 12.7 m

# Perentas = c = 5.715 m
Chord = c = 5.715 m

Ketebalan = t = 0.18 m
Thickness = t = 0.18 m

Keanjalan Modulus bagi Aluminium = E = 1.42 E09 N/cm2=1.42 E13 N/m2=1.42 GPa
Modulus Elasticity Aluminum = E =1.42 E09 N/cm2=1.42 E13 N/m2=1.42 Gpa

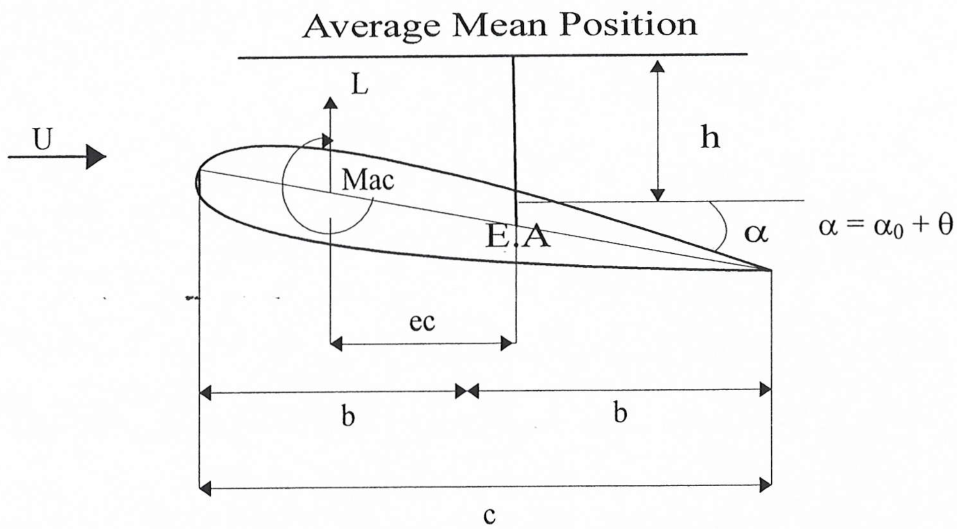
Keanjalan Modulus bagi Aloi Titanium = 70 MPa=0.07GPa
Modulus Elasticity Titanium Alloy =70 MPa=0.07GPa

J=0.010995 kg-m^2

(b) Sifat-sifat Aerodinamik:

Aerodynamic Properties:

Airfoil NACA 0012,
$\alpha_0 = 2°$, $\rho = 1.225$ Kg/m^3, $C_{L\alpha} = 0.1788$, $C_{MAC} = -0.0011$



Rajah 3/*Figure 3*

Berikut adalah definasi bahagian tipikal jarak di antara pusat aerodinamik dan paksi keanjalan, ec = 0.25 c or 0.5 b.

Following the definition of typical section the distance between the aerodynamic center and elastic axis is ec = 0.25 c or 0.5 b.

Berpandukan mekanik dan kekuatan bahan, hubungan yang berikut boleh digunakan:

From mechanics and strength of materials, the following relationships can be applied:

$$I_x = \frac{1}{12}ch^3 \qquad G = \frac{E}{2(1+v)}$$

$$K_h = -\frac{3EI(y)}{y} \qquad K_\alpha = -\frac{GJ(y)}{y}$$

Biar $U_\infty = 50$ m/s,

Let $U_\infty = 50$ m/s,

(i) Tentukan Kh dan Kα pada setiap stesen 2, 3, dan 5.

Calculate Kh and Kα at each station 2, 3 and 5.

Respon anjalan-aero statik disebabkan momen aerodinamik pada struktur sayap

The static aeroelastic response due to aerodynamic moment on the wing structure

$$\theta = \frac{cqS}{K_\alpha}\frac{C_{L_\alpha}\alpha_0 e + C_{MAC}}{1 - \frac{ecqS}{K_\alpha}C_{L_\alpha}}$$

(25 markah/*marks*)

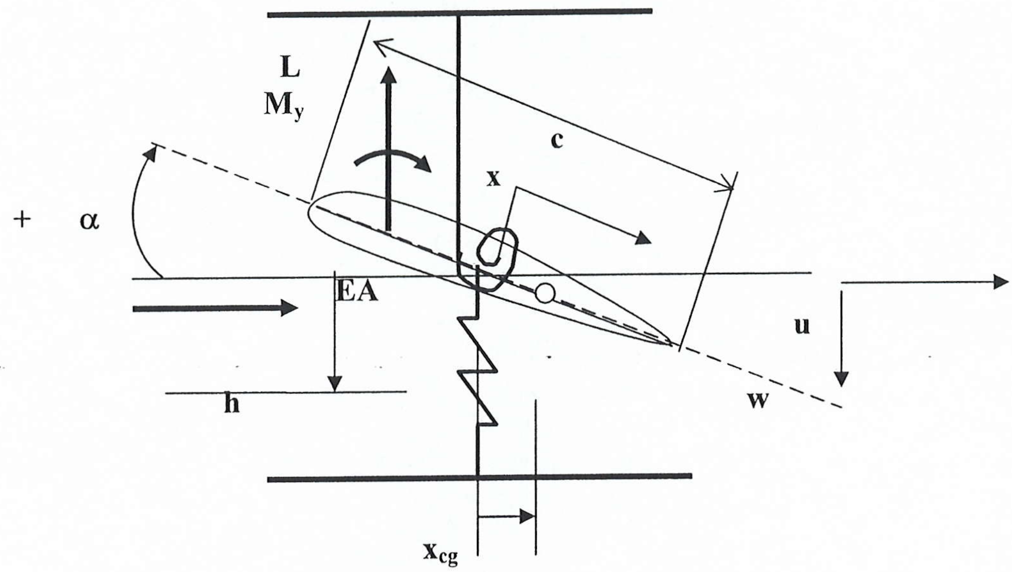
(ii) Tentukan tekanan kecapahan dinamik kritikal dan laju kecapahan kritikal pada stesen-stesen tersebut.

Calculate the critical dynamic divergence pressure and the critical divergence speed at those stations.

(25 markah/*marks*)

3. Anggapkan sebuah bahagian sayap tipikal seperti di bawah:

Consider a typical wing section below :



Rajah 4/*Figure 4*

x diukur sepanjang perentas dari EA
x is measured along chord from EA.

Anggapkan koordinat am yang berikut:
Consider the following generalized coordinate:

$$q_1 = h$$
$$q_2 = \alpha$$

Sesaran pada mana-mana titik pada airfoil ialah
Displacement of any point on the airfoil is

$$r = u\,\mathbf{i} + w\,\mathbf{k}$$

Menurut geometri
From geometry

$$u = 0$$
$$w = -h - x\alpha$$

Biar
Let

$$m = \int \rho dx$$
$$S_\alpha = \int \rho x dx = x_{cg} m$$
$$I_\alpha = \int \rho x^2 dx$$

Dan tenaga keupayaan:
And the potential energy:

$$U = \frac{1}{2} K_h h^2 + \frac{1}{2} K_\alpha \alpha^2$$

Kerja yang tidak diabadikan:
The non-conservative work:

$$\delta W_{NC} = \delta h(-L) + \delta\alpha(M_y)$$

Di mana
where

$$L \equiv \int p dx = -Q_h$$
$$M \equiv \int p x dx = Q_\alpha$$

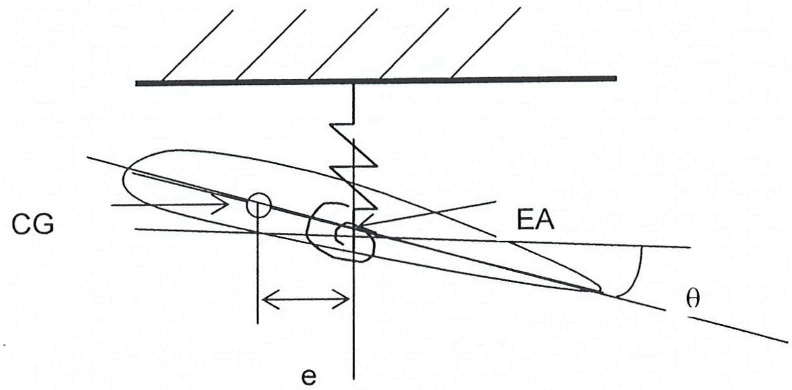
Terbitkan persamaan gerakan bagi bahagian tipikal dalam bentuk sistem binari dengan menggunakan Prinsip Hamilton dan Persamaan Lagrange.

Derive the equation of motion for the typical section as a binary system using Hamilton Principle and Lagrange equations.

(100 markah/*marks*)

4. Anggapkan sebuah modul getaran sayap yang dipermudahkan sebagai suatu sistem dua-darjah-kebebasan.

Consider a simplified wing vibration model shown as a two-degree-of-freedom system.



Rajah 5/*Figure 5*

Sayap sesebuah kapal terbang pengangkut diwakili oleh satu bahagian tipikal di mana jisim m dan momen polar inersia I_θ pada titik EA (Paksi Elastik). Untuk tujuan ini, sayap berkenaan di anggap dihubungkan oleh spring kilasan dan linear yang mempunyai kekuatan K_α and K_h masing-masing pada Paksi Elastik EA. Pusat gravity CG berada pada jarak kehadapan e dari EA.
Sayap berkenaan mengalami pemesongan menegak h dan pemesongan kilasan θ. Anggapkan sayap berkenaan tidak mengalami kesan gravity.

The wing of a transport aircraft is represented by a typical section with mass m and polar moment of inertia I_θ about point EA (Elastic Axis). For this purpose, the wing is assumed to be attached by a torsional and linear springs of stiffness K_α and K_h, respectively, at the Elastic Axis EA. The center of gravity CG is located at a distance e forward of EA.
The wing is experiencing vertical deflection h and torsional deflection θ. Ignore gravitational effects.

Persamaan gerakan diwakili oleh

The equation of motion is given by:

Arah h (mencancang ke bawah)
In the h direction (vertical downward, heaving):

$$m\ddot{h} + S_\theta \ddot{\theta} + K_h h = 0 \qquad \textbf{[a]}$$

Pada arah θ (kilasan, positif, ekor ke atas)
In the θ direction (torsional, positive tail up):

$$S_\theta \ddot{h} + I_\theta \ddot{\theta} + K_\theta \theta = 0 \qquad \textbf{[b]}$$

Di mana
Where

S_θ - momen statik pada EA
static moment about EA

(a) Terbitkan (tuliskan) persamaan gerakan dalam bentuk matriks

Write the equation of motion in matrix form

(50 markah/*marks*)

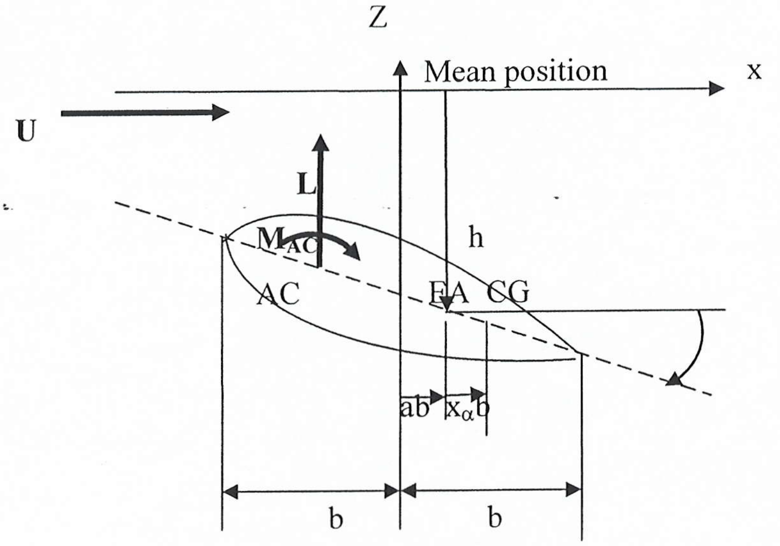
(b) Adakah sistem ini terganding secara dinamik, ataupun, terganding secara elastik?

Is the system dynamically coupled, or elastically coupled?

(100 markah/*marks*)

5. Untuk dapatkan kesan bagus bagi kibaran, kita akan menganggap satu model aerodinamik yang stabil dikenakan ke atas aero-anjalan bagi satu sistem tipikal dua-darjah-kebebasan: lenturan dan kilasan (sistem binary). Hanya gerakan kilasan mengaruhkan daya aerodinamik:

To obtain a good impression of flutter, we will consider steady aerodynamic model applied to aeroelasticity of a two-degree-of-freedom typical section system.: bending and torsion (binary system). Only torsional motion induces aerodynamic forces:



Rajah 6/*Figure 6*

$$L(t) = q\,S\,C_{L\alpha}\;\alpha(t) \qquad [1]$$

$$M_{AC}(t) = 0 \qquad [2]$$

$$M_{EA} = 2\,L\,e\,b + M_{AC} = 2\,q\,S\,e\,b\,C_{L\alpha}\;\alpha(t) \qquad [3]$$

Persamaan kibaran:

Flutter equations :

$$m\ddot{h} + S_\alpha \ddot{\alpha} + K_h h + qSC_{L_\alpha}\alpha = 0 \qquad [4]$$

$$S_\alpha \ddot{h} + I_\alpha \ddot{\alpha} + K_\alpha \alpha - 2qSebC_{L_\alpha}\alpha = 0 \qquad [5]$$

(a) Tuliskan persamaan 4 dan 5 dalam bentuk matriks. Analisis stability kibaran boleh dibuat dengan menganggapkan gerakan harmonik:

Write equation 4 and 5 in matrix notation. Analysis of flutter stability can be carried out by assuming harmonic motion:

(20 markah/*marks*)

$$h = \hat{h}\ e^{pt} \qquad [6a]$$

$$\alpha = \hat{\alpha}\ e^{pt} \qquad [6b]$$

atau

or

$$\{x\} = \{\hat{x}\}e^{pt} \qquad [6c]$$

Gantikan akan memperolehi

Substitution leads to

$$(mp^2 + K_h)\hat{h} + (S_\alpha p^2 + qSC_{L_\alpha})\hat{\alpha} = 0 \qquad [7]$$

$$S_\alpha p^2\hat{h} + (I_\alpha p^2 + K_\alpha - 2qSebC_{L_\alpha})\hat{\alpha} = 0 \qquad [8]$$

Penentu set kepada persamaan 6.11 dan 6.12 ialah:

The determinant of the set of equations 6.11 and 6.12 is:

$$I_\alpha mp^4 - S_\alpha^2 p^4 + p^2\left[mK_\alpha 2qSebC_{L_\alpha}m + I_\alpha K_h\right] - p^2 S_\alpha qSC_{L_\alpha} + K_\alpha K_h - 2qSebC_{L_\alpha}K_h = 0$$

Di mana ia adalah persamaan ciri dalam bentuk

which is a Characteristic Equation of the form

$$a_4 p^4 + a_2 p^2 + a_0 = 0 \qquad [9]$$

dengan

with:

$a_4 = mI_\alpha - S_\alpha^2$ **[10]**

$a_2 = m\,(K_\alpha - 2q\,S\,e\,b\,C_{L\alpha}) + I_\alpha\,K_h - qS\,S_\alpha\,C_{L\alpha}$ **[11]**

$= m\,K_\alpha + I_\alpha\,K_h - (2\,m\,e\,b + S_\alpha)\,q\,S\,C_{L\alpha}$

$a_0 = K_h\,(K_\alpha - 2\,q\,S\,e\,b\,C_{L\alpha})$ **[12]**

Persamaan 9 ialah polinomial urutan keempat (atau urutan kedua dalam p^2) dengan 4 punca:

Equation 9 is 4th order polynomial (or 2nd order in p^2) with 4 roots:

$$p_{1,2,3,4} = (\sigma + i\omega)_{1,2,3,4} = \pm\sqrt{\frac{1}{2a_4}\left(-a_2 \pm \sqrt{a_2^2 - 4a_4a_0}\right)} \qquad \textbf{[13]}$$

Penyelesaian adalah dalam bentuk

Solutions are of the type:

$$\{x\} = \{\hat{x}\}e^{\sigma t}e^{i\omega t} \qquad \textbf{[14]}$$

Dengan berfikir selanjutnya, hubungan yang berikut akan dicapai:

Let us assume further, that the following relations hold:

$K_h = m\,\omega_h^2$, $K_\theta = I_\theta\,\omega_\theta^2$

$S_\theta = m\,x_\alpha\,b$ $I_\theta = m\,r_\alpha^2\,b^2$

x_α ialah momen statik lengan, dan r_α ialah radius legaran, dan moda asli mematuhi persamaan ciri. Dengan berfikir selanjutnya, bahagian tipikal sayap boleh diwakili seperti yang diusulkan oleh Isogai pada tahun 1979, untuk sayap pengangkut moden

x_α is the static moment arm, and r_α is the radius of gyration, and that the natural modes satisfy the characteristic equation. Let us assume further, that the typical section of the wing can be represented as proposed by Isogai, 1979, for a modern .transport wing:

$a = -2.0$ $\qquad C_{L_\alpha} = 2.0\pi$

$x_\alpha = 1.8$ $\qquad$ e = -0.75

$r_\alpha^2 = 3.48$ $\qquad \mu = 100$

$\frac{\omega_h}{\omega_\varepsilon} = 1.0$

(b) Tentukan a_4, a_2 and a_0

Find a_4, a_2 and a_0

(40 markah/*marks*)

Untuk menentukan jenis ketidakstabilan yang akan berlaku, jadual berikut boleh dirujuk.

To consider the type of instability that will occur, one may refer to the following table.

$a_2^2 - 4a_4a_0$	>0			<0
a_0	> 0		< 0	>< 0
a_2	> 0	< 0	>< 0	>< 0
p^2	$-\omega_1^2, -\omega_2^2$	σ_1^2, σ_2^2	$\sigma^2, -\omega^2$	$-g \pm ih$
p	$\pm i\omega_1, \pm i\omega_2$	$\pm\sigma_1, \pm\sigma_2$	$\pm\sigma, \pm i\omega$	$\pm\sigma \pm i\omega$
Jenis gerakan *Type of motion*	Harmonik 2 pos. Frekuensi 2 neg. frekeunsi *Harmonic:* *2 pos. freq.* *2 neg. freq*	Tak berkala 2 mencapah 2 menumpu *Aperiodic:* *2 diverging* *2 converging*	Tak berkala 1 mencapah 1 menumpu harmonik 1 pos.frek. 1 neg.frek.	Ayunan 1 capah pos.frek 1 tumpu pos.frek 1 capah neg.frek 1 tumpu neg.frek

			Aperiodic: *1 diverging* *1 converging* *Harmonic:* *1 pos.freq.* *1 neg.freq.*	*Oscillatory:* *1 div. pos. freq* *1 conv. pos. freq* *1 div. neg. freq* *1 conv. neg. freq*
Jenis ketidakstabilan *Type of instab.*	Neutral *Neutral*	Mencapah *Divergence*	Mencapah *Divergence*	Kibaran *Flutter*
Kategori *Category*	I	III	IV	II

(a) Apakah jenis ketidakstabilan yang berlaku pada kes ω_θ = 1? Terangkan.

What type of instability takes place in the case considered, assuming $\omega_\theta = 1$? *Elaborate.*

(40 markah/*marks*)

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