UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Pertama
Sidang Akademik 2006/2007
First Semester Examination
2006/2007 Academic Session

Oktober/November 2006
October/November 2006

ESA 473/3 – Aero-Anjalan
Aero-Elasticity

Hour : *[3 hours]*
Masa : [3 jam]

ARAHAN KEPADA CALON :
INSTRUCTION TO CANDIDATES

Sila pastikan bahawa kertas peperiksaan ini mengandungi **EMPAT BELAS (14)** mukasurat dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan ini.
*Please ensure that this paper contains **FOURTEEN (14)** printed pages and **FIVE (5)** questions before you begin examination.*

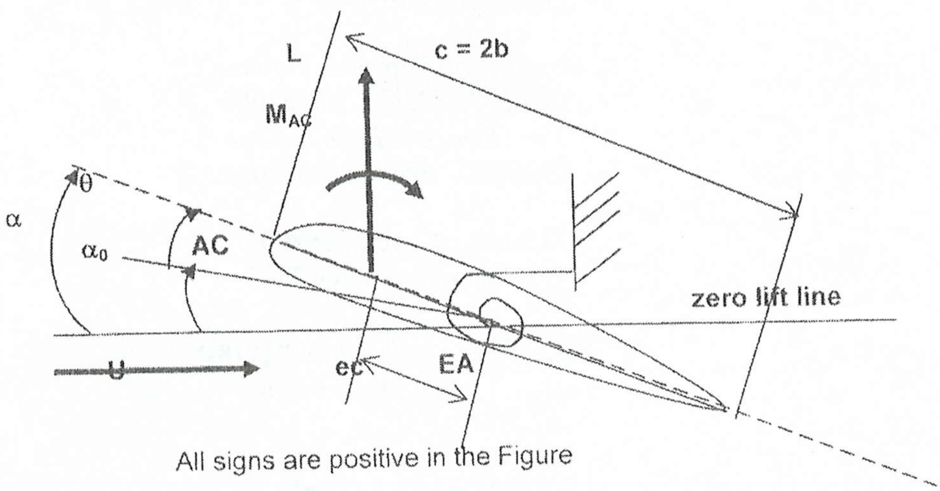
Soalan 1 hingga 4. Sila pilih **TIGA (3)** soalan
Soalan 5. **MESTI** dijawab.
*Question 1 to 4. Please choose **THREE (3)** questions.*
*Question 5. **MUST BE** answered.*

Soalan boleh dijawab dalam Bahasa Inggeris kecuali satu soalan mestilah dijawab dalam Bahasa Malaysia.
The questions can be answered in English but one question must be answered in Bahasa Malaysia.

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

1. Pertimbangkan sayap yang ditunjukkan sebagai bahagian biasa, di mana piuhan terhalang di EA.

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



All signs are positive in the Figure

Pesongan lenturan dianggap tidak penting (untuk sayap lurus).
Di sini:

α_0	-	sudut asal	
θ	-	sudut piuhan akibat aliran udara	
L	=	$C_L\, q\, S$,	q = tekanan dinamik
			S - luas permukaan sayap
			$q = ½ \rho U^2$

Tork asal akibat elastisiti sayap (diwakilkan dengan spring piuhan K_α):

$$T = K_\alpha \theta$$

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

α_0	-	*initial angle of attack*	
θ	-	*angle of twist due to airflow*	
L	=	$C_L\, q\, S$,	q = *dynamic pressure*
			S - *wing surface area*
			$q = ½ \rho U^2$

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

$$T = K_\alpha \theta$$

(a) Tuliskan (buktikan) ungkapan sudut terpiuh berkaitan dengan daya aerodinamik dan momen.

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 halaju kritikal kecapahan iaitu fungsi kepada kekukuhan kilasan sayap, parameter-parameter sayap ialah e, c, S, $C_{L\alpha}$ dan tekanan dinamik alur 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) Pertimbangkan sayap Isogai- dengan

$C_{L\alpha} = 2\pi$ s = rentangan sayap separuh
$\alpha_0 = 0$ S = permukaan kawasan sayap separuh
$C_{MAC} = 0$ $\cong$ cs
$e = 0.25$
$\mu = 100 = m / (\pi \rho b^2 s)$
$r_\alpha^2 = 3.48$

dan ambil kira:

$K_\alpha = \omega_\alpha^2 I_\alpha$
$I_\alpha = r_\alpha^2 mb^2$

Kirakan halaju kecapahan sebagai fungsi ferkuensi kilasan ω_α

Consider an Isogai-like wing with:

$C_{L\alpha} = 2\pi$ s = *half wing span*
$\alpha_0 = 0$ S = *half wing surface area*
$C_{MAC} = 0$ $\cong$ *cs*
$e = 0.25$
$\mu = 100 = m / (\pi \rho b^2 s)$
$r_\alpha^2 = 3.48$

and note that:

$K_\alpha = \omega_\alpha^2 I_\alpha$
$I_\alpha = r_\alpha^2 mb^2$

Calculate the divergence speed as a function of torsional frequency ω_α

(40 markah/*marks*)

2. Pertimbangkan sayap BAH- dengan planform segiempat

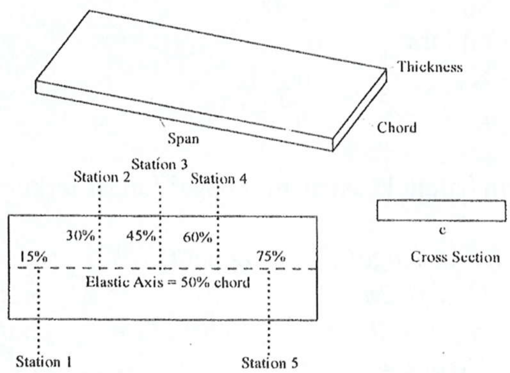
Anggapkan sayap planform segiempat mempunyai ciri-ciri berikut :

Ciri-ciri geometri dan struktur
rentangan = S = 12.7 m - perentas = c = 5.715 m
ketebalan = t = 0.18 m
modulus keanjalan aluminium = E =1.42 E09 N/cm2=1.42 E13 N/m2=1.42 GPa
Modulus keanjalan Titanium Alloy =70 MPa=0.07GPa
J=0.010995 kg-m^2

Consider the following BAH-like wing with rectangular planform

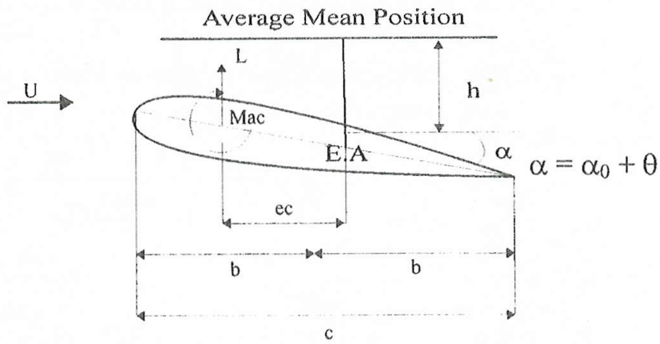
Assumed that the rectangular wing planform has the following properties :

Geometrical and Structural properties:
 # Span = S = 12.7 m - Chord = c = 5.715 m
 # Thickness = t = 0.18 m
 # Modulus Elasticity Aluminum = E =1.42 E09 N/cm2=1.42 E13 N/m2=1.42 GPa
 # Modulus Elasticity Titanium Alloy =70 MPa=0.07GPa
 # J=0.010995 kg-m^2



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

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



Berikut ialah definisi biasa yang terdapat dalam bahagian jarak di antara paksi tengah dan elastik aerodinamik ialah ec = 0.25 c or 0.5 b.

Dalam mekanik dan kekuatan material, berikut ialah hubungan yang boleh diaplikasikan:

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

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

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

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

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

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

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

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

(i) Kirakan Kh dan Kα di setiap bahagian 2,3 dan 5.

Aeroelastik kaku yang bertindak terhadap momen aerodinamik kepada Struktur sayap ialah

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

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

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) Kirakan tekanan kecapahan dinamik kritikal dan halaju kecapahan kritikal pada setiap stesen.

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

(25 markah/*marks*)

(iii) Kirakan sudut terpiuh bagi setiap stesen.

Calculate the angle of twist at those stations.

(25 markah/*marks*)

(iv) Lukis graf 1, 2 dan 3 yang berfungsi di setiap koordinat stesen.

Draw the graphs of 1, 2, and 3 as the function of the station coordinate.

(25 markah/*marks*)

3. Pertimbangkan bahagian sayap biasa di bawah:

X diukur di sepanjang perentas dari EA.
Pertimbangkan koordinat teritlak berikut:

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

sesaran di mana-mana titik di atas kerajang udara ialah

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

daripada geometri

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

biarkan

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

Dan tenaga upaya

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

Dan kerja tidak keabadian:

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

Di mana

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

Buktikan persamaan bagi gerakan untuk bagaian biasa seperti sistem binary menggunakan Prinsip Hamilton dan persamaan Lagrange.

Consider a typical wing section below :

x is measured along chord from EA.
Consider the following generalized coordinate:

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

Displacement of any point on the airfoil is

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

From geometry

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

Let

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

4. Pertimbangkan getaran sayap mudah seperti ditunjukkan sebagai sistem bebas dua darjah.

Sayap pesawat pengangkutan diwakilkan sebagai bahagian biasa dengan jisim m dan polar momen inersia I_θ di titik EA (Paksi Elastik). Untuk tujuan ini, sayap dianggap dilekatkan dengan kilasan dan kekakuan spring linear K_α dan K_h setiap satunya, pada Paksi Elastik EA. Titik tengah graviti CG terletak pada jarak e di hadapan EA.

Suatu sayap dikenakan pesongan menegak h dan pesongan kilasan θ. Abaikan kesan graviti.

Persamaannya diberikan oleh:

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

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.

The equation of motion is given by:

In the h direction (vertical downward, heaving):

$$m\ddot{h} + S_\theta\ddot{\theta} + K_h h = 0 \qquad (a)$$

In the θ direction (torsional, positive tail up):

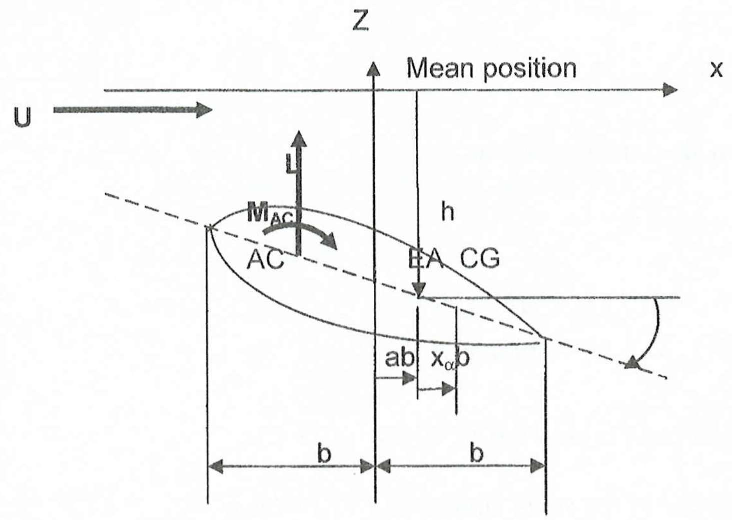
$$S_\theta\ddot{h} + I_\theta\ddot{\theta} + K_\theta\theta = 0 \qquad (b)$$

where

S_θ - *static moment about EA*

5. Untuk mendapatkan gambaran debaran yang baik, kita akan pertimbangkan model aerodinamik pegun yang diaplikasikan kepada aeroanjalan sistem bahagian biasa dengan dua darjah kebebasan: lenturan dan kilasan (sistem penduaan). Hanya pergerakan kilasan yang akan 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:



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

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

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

Persamaan Debaran

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 matrik

Write equation 4 and 5 in matrix notation

(20 markah/*marks*)

Analisis kestabilan debaran boleh dibuat dengan menganggap ianya adalah gerakan harmoni:

Analysis of flutter stability can be carried out by assuming harmonic motion:

$$h = \hat{h} \; e^{pt} \qquad 6a$$
$$\alpha = \hat{\alpha} \; e^{pt} \qquad 6b$$

atau
or

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

Penggantian akan menghasilkan

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 persamaan 6.11 dan 6.12 ialah:

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

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

iaitu 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 adalah polinomial turutan ke-4 (atau turutan ke-2 dlm p) dengan 4 punca:

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

$$p_{1,2,3,4} = (\sigma + i\omega)_{1,2,3,4} = \pm\sqrt{\frac{1}{2a_4}(-a_2 \pm \sqrt{a_2^2 - 4a_4 a_0})} \qquad 13$$

Jenis penyelesaian adalah:

Solutions are of the type:

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

Anggap persamaan-persamaan berikut benar di sini:

Let us assume further, that the following relations hold:

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

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

x_α adalah momen lengan pegun dan r_α adalah jejari legaran, dan ragam tabii memuaskan persamaan ciri.

x_α is the static moment arm, and r_α is the radius of gyration, and that the natural modes satisfy the characteristic equation.

Anggap bahagian biasa sayap boleh digambarkan sebagai yang dicadangkan oleh Isogai, 1979, untuk sayap pesawat pengangkut moden:

Let us assume further, that the typical section of the wing can be represented as proposed by Isogai, 1979, for a modern transport wing:

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

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

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

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

(b) Carikan nilai a_4, a_2 dan a_0

Find a_4, a_2 and a_0

(40 markah/*marks*)

Untuk pertimbangkan jenis ketidakstabilan yang akan berlaku, jadual di bawah harus 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	σ^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 pergerakan Type of motion	Harmonik: 2 frek. positif 2 frek. negatif *Harmonic:* *2 pos. freq.* *2 neg. freq*	Tak berkala: 2 mencapah 2 menumpu *Aperiodic:* *2 diverging* *2 converging*	*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*	Kecapahan *Divergence*	Kecapahan *Divergence*	Debaran *Flutter*
Category	I	III	IV	II

(c) Untuk kes yang dipertimbangkan, ketidakstabilan jenis apakah yang akan berlaku, anggap $\omega_\theta = 1$? Huraikan.

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

(40 markah/*marks*)

- oooOooo -