UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 2004/2005
Second Semester Examination
2004/2005 Academic Session

Mac 2005
March 2005

ESA 473/3 – Aero-Anjalan
Aero-Elasticity

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

ARAHAN KEPADA CALON :
INSTRUCTION TO CANDIDATES:

Sila pastikan bahawa kertas soalan ini mengandungi **TIGA BELAS (13)** mukasurat dan **EMPAT (4)** soalan sebelum anda memulakan peperiksaan.
Please ensure that this paper contains ***THIRTEEN (13)*** *printed pages and* ***FOUR (4)*** *questions before you begin examination.*

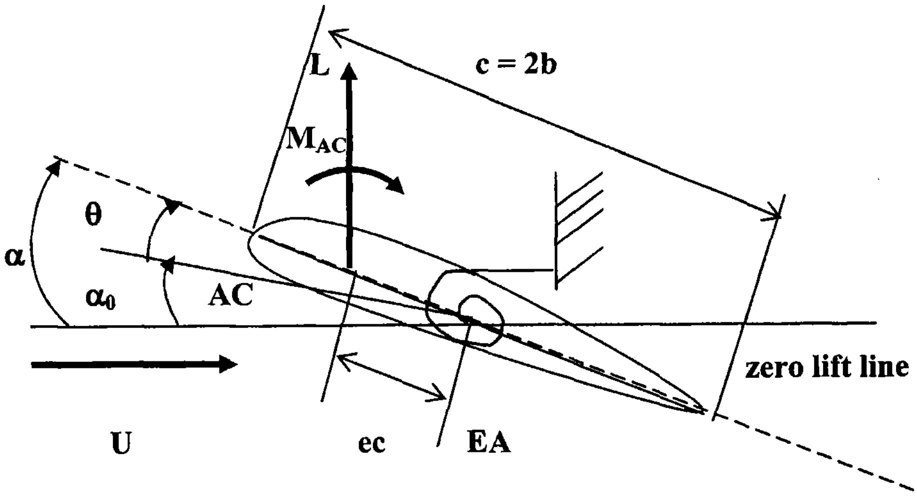
Jawab **TIGA (3)** soalan sahaja.
Answer ***THREE (3)*** *the questions only.*

Jawab semua soalan dalam Bahasa Malaysia.
Answer all questions in Bahasa Malaysia.

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

1. Pertimbangkan sebuah sayap yang diwakili oleh keratan tipikal, yang terhalang pada piuhan di EA.

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



Semua tanda dalam Rajah adalah positif
All signs are positive in the Figure

Pesongan lentur dianggap tidak penting (bagi sayap lurus).

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

Di sini:
Here:

α_0	-	sudut serang mula	
θ	-	sudut piuh akibat aliran udara	
L	=	$C_L q S$,	q = tekanan dinamik
			S - luas permukaan sayap
			$q = \frac{1}{2} \rho U^2$

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

Penyimpanan semula tork akibat sifat kenyal sayap (diwakili oleh spring kilasan K_α):

$$T = K_\alpha \theta$$

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

$$T = K_\alpha \theta$$

(a) Tulis (terbitkan) pernyataan bagi sudut piuh θ akibat daya dan momen aerodinamik

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

(20 markah/*marks*)

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

(20 markah/*marks*)

(c) Pertimbangkan sayap yang mempunyai ciri setanding sayap Isogai dengan:

Consider an Isogai-like wing with:

$C_{L\alpha}$	$= 2\pi$		s	= separuh rentang sayap
$\alpha 0$	$= 0$		S	= separuh luas permukaan sayap
CMAC	=	0		≅ bs
e	=	0.25		
μ	=	100	$= m / (\pi \rho b_2 s)$	
r_α^2	=	3.48		

$C_{L\alpha} = 2\pi$		s	$=$ *half wing span*
$\alpha 0 = 0$		S	$=$ *half wing surface area*
$CMAC =$	0		$\cong bs$
$e =$	0.25		
$\mu =$	100	$= m / (\pi \rho b_2 s)$	
$r_\alpha^2 =$	3.48		

dan perhatikan bahawa:

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

and note that:

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

Kira laju kecapahan sebagai fungsi kepada frekuensi kilasan ω_α

Calculate the divergence speed as a function of torsional frequency ω_α

(20 markah/*marks*)

(d) Plot U_D lawan ω_α (dalam rad/saat atau cps), dan kira ω_α jika $U_D > 400$ m/sec.

Plot U_D versus ω_α (in rad/sec or cps), and calculate ω_α if it is desired to have $U_D > 400$ m/sec.

(20 markah/*marks*)

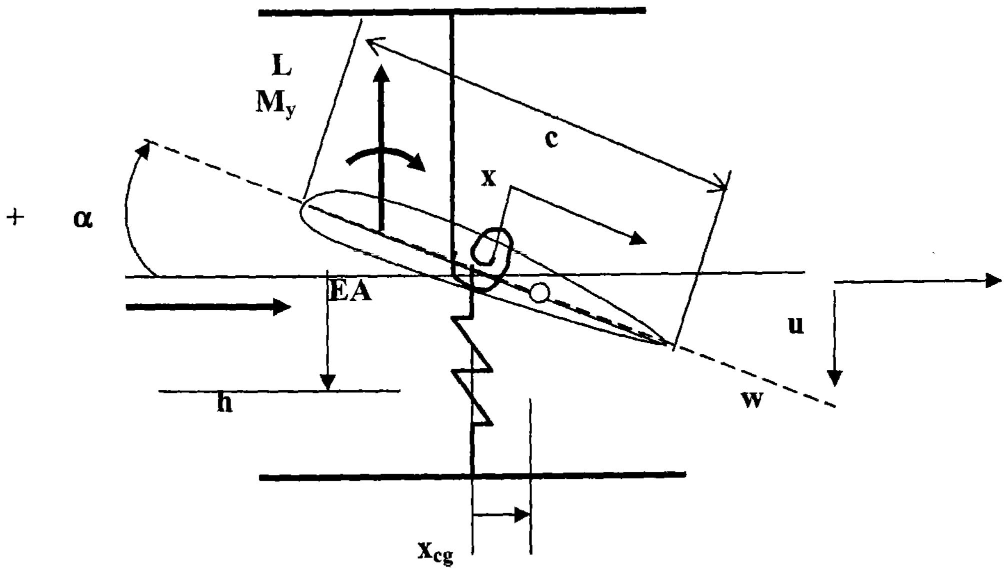
(e) Apakah cara lain untuk meningkatkan U_D, jika ω_α tidak dimodifikasikan?

What are other options to increase U_D, if ω_α cannot be modified at will?

(20 markah/*marks*)

2. Pertimbangkan keratan sayap tipikal di bawah:

Consider a typical wing section below :



x diukur melalui perentas daripada EA

x is measured along chord from EA.

Pertimbangkan koordinat am berikut:

$q_1 = h$

$q_2 = \alpha$

Consider the following generalized coordinate:

$q_1 = h$

$q_2 = \alpha$

Anjakan pada mana-mana titik di atas airfoil ialah:

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

Displacement of any point on the airfoil is:

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

Daripada geometri

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

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:

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

And the potential energy:

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

Kerja tak mengabadi:

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

The non-conservative work:

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

where

dimana

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

Terbitkan persamaan gerakan untuk keratan tipikal sebagai sistem perduaan 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*)

3. Pertimbangkan dinamik keratan tipikal yang diwakili oleh sistem perduaan:

$$m\ddot{h} + K_h h + S_\alpha \ddot{\alpha} = -L \qquad (1)$$
$$S_\alpha \ddot{h} + I_\alpha \ddot{\alpha} + K_\alpha \alpha = M_y \qquad (2)$$

Consider the dynamics of a typical section represented by the binary system:

$$m\ddot{h} + K_h h + S_\alpha \ddot{\alpha} = -L \qquad (1)$$
$$S_\alpha \ddot{h} + I_\alpha \ddot{\alpha} + K_\alpha \alpha = M_y \qquad (2)$$

seperti ditakrifkan kebiasaannya:

$$L \equiv \int p dx$$
$$M \equiv \int p x dx$$

as defined in the usual manner:

$$L \equiv \int p dx$$
$$M \equiv \int p x dx$$

Frekuensi asli tak terganding ditakrifkan sebagai:

$$\omega_h^{\ 2} = \frac{K_h}{m}$$
$$\omega_\alpha^{\ 2} = \frac{K_\alpha}{I_\alpha}$$

The uncoupled natural frequencies are defied as:

$$\omega_h^{\ 2} = \frac{K_h}{m}$$
$$\omega_\alpha^{\ 2} = \frac{K_\alpha}{I_\alpha}$$

Anggapan gerakan bentuk sinus:

$$L = \overline{L}e^{i\omega t}$$
$$M_y = \overline{M}_y e^{i\omega t}$$
$$h = \overline{h}e^{i\omega t}$$
$$\alpha = \overline{\alpha}e^{i\omega t}$$

Assume sinusoidal motion:

$$L = \overline{L}e^{i\omega t}$$
$$M_y = \overline{M}_y e^{i\omega t}$$
$$h = \overline{h}e^{i\omega t}$$
$$\alpha = \overline{\alpha}e^{i\omega t}$$

di mana $\overline{L}$, $\overline{M}_y$, $\overline{h}$ dan $\overline{\alpha}$ adalah amplitud.

where $\overline{L}$, $\overline{M}_y$, $\overline{h}$ and $\overline{\alpha}$ are the amplitudes.

(a) Dengan menggunakan gerakan bentuk sinus, tulis persamaan matriks untuk sistem (1) dan sistem (2)

Using sinusoidal motion,write the matrix equation fro system (1) and system (2)

(50 markah/*marks*)

(b) Reaksi sistem akibat daya aerodinamik L dan M_y ialah amplitud anjakan lelurus $\overline{h}$ dan anjakan sudut $\overline{\alpha}$ sebagai fungsi kepada amplitud pengujaan (aerodinamik) $\overline{L}$, $\overline{M}_y$. Untuk memudahkan lagi (supaya pembolehubah tunggal $\overline{L}$ sahaja diperlukan), takrifkan

$$d \equiv \frac{\overline{M}_y}{\overline{L}}$$

The response of the system due to aerodynamic forces L and M_y are the amplitudes of the linear displacement $\bar{h}$ and anguler displacement $\bar{\alpha}$ as a function of the excitation amplitudes (aerodynamic) $\bar{L}$, $\bar{M}_y$. For further simplification (so that we have to deal with single variable $\bar{L}$ only),define

$$d \equiv \frac{\bar{M}_y}{\bar{L}}$$

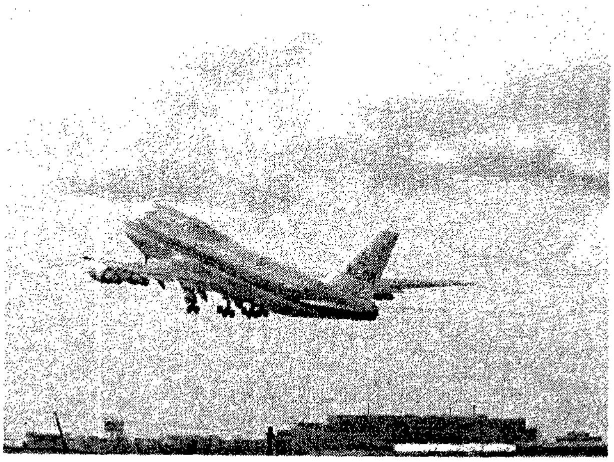
Cari ungkapan $\frac{\bar{h}}{\bar{L}}$ sebagai fungsi kepada parameter keratan tipikal.

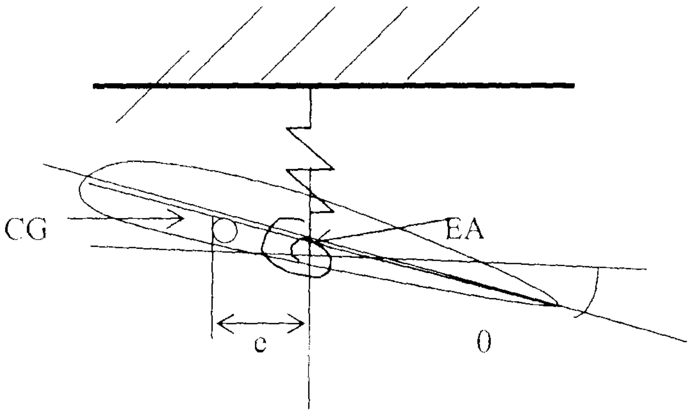
Find the expression of $\frac{\bar{h}}{\bar{L}}$ *as the function of the typical section parameters.*

(50 markah/*marks*)

4. Pertimbangkan model getaran sayap mudah, sebagai sistem dua darjah kebebasan seperti ditunjukkan.

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





Sayap sebuah pesawat pengangkut adalah diwakili oleh keratan dengan jisim m dan momen inersia kutub I_0 pada titik EA (paksi kenyal). Untuk tujuan ini, sayap dianggap terikat oleh spring lelurus dan kilasan dengan kekukuhan K_α dan K_h, masing-masing pada paksi kenyal EA. Pusat graviti CG terletak pada jarak e di hadapan EA. Sayap mengalami pesongan menegak h dan pesongan kilasan θ. Abaikan kesan graviti.
Persamaan gerakan diberi oleh:

The wing of a transport aircraft is represented section with mass m and polar moment of inertia I_0 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:

Pada arah h (ke bawah menegak, melambung):

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, ekor naik positif):

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) Tulis persamaan gerakan dalam bentuk matriks

Write the equation of motion in matrix form

(25 markah/*marks*)

(b) Adakah sistem terganding dinamik, atau terganding kenyal?

Is the system dynamically coupled, or elastically coupled?

(25 markah/*marks*)

(c) Anggapkan selanjutnya, hubungan berikut didapati:

$K_h = m\,\Omega_h^2$, $K_\theta = I_\theta\,\Omega_\theta^2$
$S_\theta = m\,x_\alpha\,b$ $I_\theta = m\,r_\alpha^2\,b^2$

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 lengan momen statik, dan r_α ialah jejari legaran, dan mod asli memenuhi persamaan ciri. Tuliskan 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. Write the characteristic equation.

(25 markah/*marks*)

(d) Anggapkan selanjutnya, bahawa sayap mempunyai ciri yang setanding dengan sayap Isogai:

$x_\alpha = 1.8$
$r_\alpha^2 = 3.48$
dan $\Omega_h/\Omega_\alpha = 1$

Let us assume further, that the wing has characteristic comparable to Isogai wing:

$x_\alpha = 1.8$
$r_\alpha^2 = 3.48$
and $\Omega_h/\Omega_\alpha = 1$

Dapatkan frekuensi asli.

Find the natural frequencies.

(25 markah/*marks*)

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