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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]*

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**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.

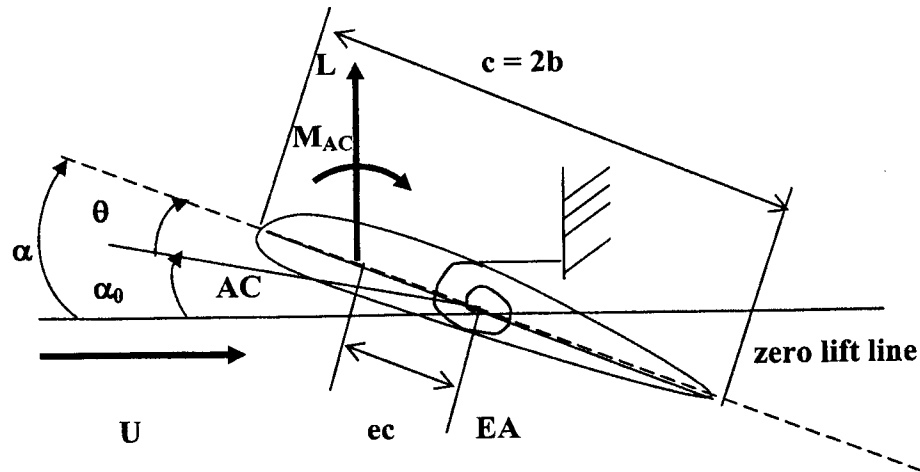
*Answer all questions in Bahasa Malaysia.*

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 pihan 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:*

$\alpha_0$  - sudut serang mula  
 $\theta$  - sudut pih akibat aliran udara  
 $L = C_L q S$ ,  $q =$  tekanan dinamik  
 $S =$  luas permukaan sayap  
 $q = \frac{1}{2} \rho U^2$

$\alpha_0$  - *initial angle of attack*  
 $\theta$  - *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  $K_\alpha$ ):

$$T = K_\alpha \theta$$

*Restoring torque due to elasticity of wing (represented by torsional spring  $K_\alpha$ ):*

$$T = K_\alpha \theta$$

- (a) Tulis (terbitkan) pernyataan bagi sudut piuh  $\theta$  akibat daya dan momen aerodinamik

*Write (derive) the expression for the angle of twist  $\theta$  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
$CMAC = 0$		$\cong bs$
$e = 0.25$		
$\mu = 100$		$= m / (\pi \rho b^2 s)$
$r_\alpha^2 = 3.48$		

$$\begin{array}{llll}
 C_{L\alpha} = 2\pi & & s & = \text{half wing span} \\
 \alpha_0 = 0 & & S & = \text{half wing surface area} \\
 CMAC = 0 & & & \cong bs \\
 e = 0.25 & & & \\
 \mu = 100 & = m / (\pi \rho b_2 s) & & \\
 r_\alpha^2 = 3.48 & & & 
 \end{array}$$

dan perhatikan bahawa:

$$\begin{array}{ll}
 K_\alpha & = \omega_\alpha^2 I_\alpha \\
 I_\alpha & = r_\alpha^2 mb^2
 \end{array}$$

and note that:

$$\begin{array}{ll}
 K_\alpha & = \omega_\alpha^2 I_\alpha \\
 I_\alpha & = r_\alpha^2 mb^2
 \end{array}$$

Kira laju kecapahan sebagai fungsi kepada frekuensi kilasan  $\omega_\alpha$

*Calculate the divergence speed as a function of torsional frequency  $\omega_\alpha$*

**(20 markah/marks)**

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

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

**(20 markah/marks)**

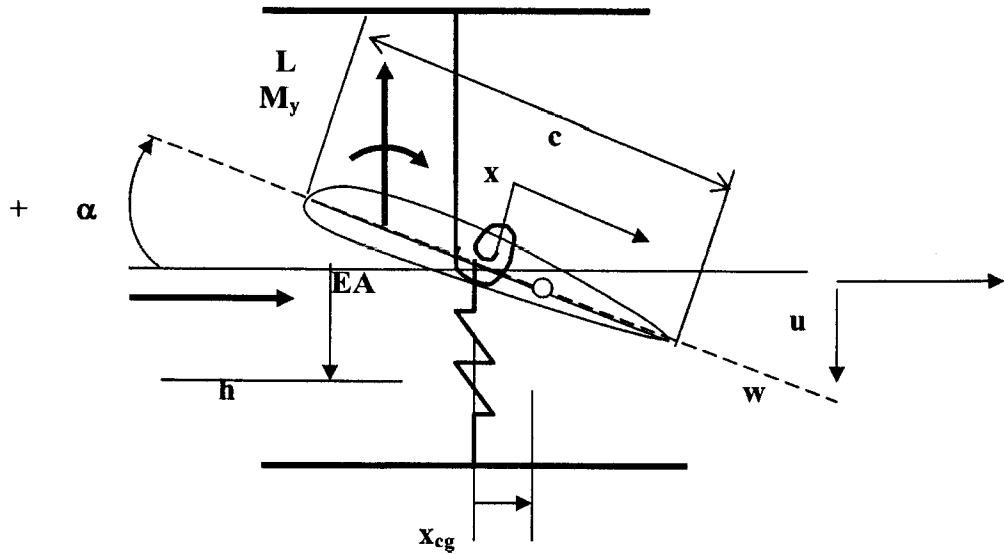
- (e) Apakah cara lain untuk meningkatkan  $U_D$ , jika  $\omega_\alpha$  tidak dimodifikasikan?

*What are other options to increase  $U_D$ , if  $\omega_\alpha$  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:

$$\begin{aligned} q_1 &= h \\ q_2 &= \alpha \end{aligned}$$

*Consider the following generalized coordinate:*

$$\begin{aligned} q_1 &= h \\ q_2 &= \alpha \end{aligned}$$

Anjakan pada mana-mana titik di atas airfoil ialah:

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

*Displacement of any point on the airfoil is:*

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

Daripada geometri

$$\begin{aligned} u &= 0 \\ w &= -h - x \alpha \end{aligned}$$

*From geometry*

$$\begin{aligned} u &= 0 \\ w &= -h - x \alpha \end{aligned}$$

Biar

*Let*

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

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:

$$m\ddot{h} + K_h h + S_\alpha \ddot{\alpha} = -L \quad (1)$$

$$S_\alpha \ddot{h} + I_\alpha \ddot{\alpha} + K_\alpha \alpha = M_y \quad (2)$$

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

$$m\ddot{h} + K_h h + S_\alpha \ddot{\alpha} = -L \quad (1)$$

$$S_\alpha \ddot{h} + I_\alpha \ddot{\alpha} + K_\alpha \alpha = M_y \quad (2)$$

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 terganggu ditakrifkan sebagai:

$$\omega_h^2 = \frac{K_h}{m}$$

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

*The uncoupled natural frequencies are defined as:*

$$\omega_h^2 = \frac{K_h}{m}$$

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



Anggapan gerakan bentuk sinus:

$$\begin{aligned}L &= \bar{L}e^{i\omega t} \\M_y &= \bar{M}_ye^{i\omega t} \\h &= \bar{h}e^{i\omega t} \\\alpha &= \bar{\alpha}e^{i\omega t}\end{aligned}$$

*Assume sinusoidal motion:*

$$\begin{aligned}L &= \bar{L}e^{i\omega t} \\M_y &= \bar{M}_ye^{i\omega t} \\h &= \bar{h}e^{i\omega t} \\\alpha &= \bar{\alpha}e^{i\omega t}\end{aligned}$$

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

where  $\bar{L}$ ,  $\bar{M}_y$ ,  $\bar{h}$  and  $\bar{\alpha}$  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 for system (1) and system (2)*

**(50 markah/marks)**

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

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

*The response of the system due to aerodynamic forces  $L$  and  $M_y$  are the amplitudes of the linear displacement  $\bar{h}$  and angular 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*

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

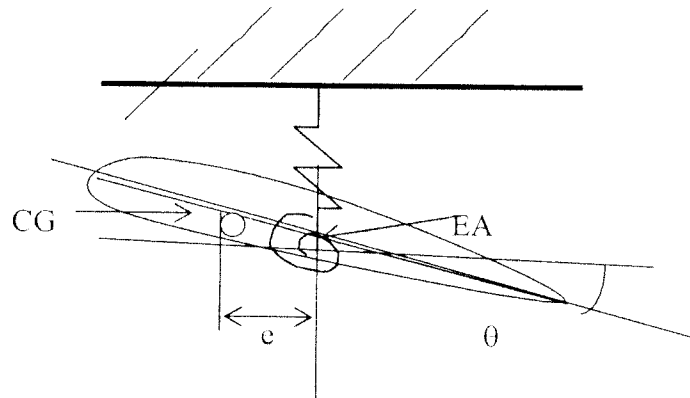
*Cari ungkapan  $\frac{\bar{h}}{\bar{L}}$  sebagai fungsi kepada parameter keratan tipikal.*

*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 lurus dan kilasan dengan kekukuhan  $K_\alpha$  dan  $K_\theta$ , masing-masing pada paksi kenyal EA. Pusat graviti CG terletak pada jarak  $e$  di hadapan EA. Sayap mengalami pesongan menegak  $h$  dan pesongan kilasan  $\theta$ . 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  $K_\alpha$  and  $K_\theta$ , 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  $\theta$ . Ignore gravitational effects.*

*The equation of motion is given by:*

Pada arah  $h$  (ke bawah menegak, melambung):

*In the  $h$  direction (vertical downward, heaving):*

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

Pada arah  $\theta$  (kilasan, ekor naik positif):

*In the  $\theta$  direction (torsional, positive tail up):*

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

di mana:

*where:*

$S_{\theta}$  - 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 terganggu dinamik, atau terganggu kenyal?

*Is the system dynamically coupled, or elastically coupled?*

**(25 markah/marks)**

- (c) Anggapkan selanjutnya, hubungan berikut didapati:

$$\begin{aligned} K_h &= m \Omega_h^2 & , & & K_\theta &= I_\theta \Omega_\theta^2 \\ S_\theta &= m x_\alpha b & & & I_\theta &= m r_\alpha^2 b^2 \end{aligned}$$

*Let us assume further, that the following relations hold:*

$$\begin{aligned} K_h &= m \Omega_h^2 & , & & K_\theta &= I_\theta \Omega_\theta^2 \\ S_\theta &= m x_\alpha b & & & I_\theta &= m r_\alpha^2 b^2 \end{aligned}$$

$x_\alpha$  ialah lengan momen statik, dan  $r_\alpha$  ialah jejari legaran, dan mod asli memenuhi persamaan ciri. Tuliskan persamaan ciri.

*$x_\alpha$  is the static moment arm, and  $r_\alpha$  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:

$$\begin{aligned} x_\alpha &= 1.8 \\ r_\alpha^2 &= 3.48 \\ \text{dan} \quad \Omega_h/\Omega_\alpha &= 1 \end{aligned}$$

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

$$\begin{aligned} x_\alpha &= 1.8 \\ r_\alpha^2 &= 3.48 \\ \text{and} \quad \Omega_h/\Omega_\alpha &= 1 \end{aligned}$$

Dapatkan frekuensi asli.

*Find the natural frequencies.*

**(25 markah/marks)**

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