UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2007/2008 Academic Session
*Peperiksaan Semester Kedua*
*Sidang Akademik 2007/2008*

April 2008
*April 2008*

# ESA 474/3 – Helicopter Design Element
*Elemen Rekabentuk Helikopter*

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

**INSTRUCTION TO CANDIDATES**
***ARAHAN KEPADA CALON :***

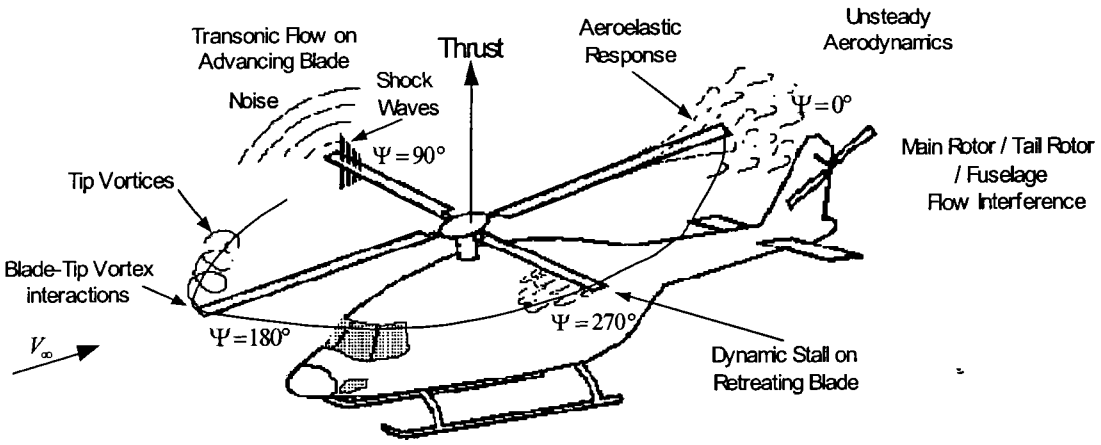
Please ensure that this paper contains **ELEVEN (11)** printed pages and **FIVE (5)** questions before you begin examination.
*Sila pastikan bahawa kertas peperiksaan ini mengandungi **SEBELAS (11)** mukasurat bercetak dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan ini.*

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

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

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

1. (a) Figure 1.1 shows a typical aerodynamics problems appears around the flow past through rotor blade helicopter.
*Rajah 1.1 menunjukkan soalan-soalan aerodinamik yang terjadi aliran di sekitar rotor blade helikopter.*




Rajah 1.1 : Aerodynamics problems around the rotor blade helicopter
*Soalan aerodinamik di sekitar bilah rotor helikopter*

From Figure 1.2, explain what does it mean with the following aerodynamics problems : (1) " Blade Tip Vortex interaction, (2) Unsteady Aerodynamic phenomena, and (3) dynamic stall.
*Dari Rajah 1.1, terangkan apa yang dimaksudkan dengan soalan soalan aerodinamik berikut : (1) " Blade Tip Vortex interaction , (2) Unsteady Aerodynamic phenomena, dan (3) dynamic stall ".*

**(15 marks/*markah*)**

(b) Explain why the rotor blade helicopter required to be twisted and need to have a conning angle.
*Terangkan mengapa bilah rotor helikopter perlu di twist dan juga perlu mempunyai sudut conning.*

**(5 marks/*markah*)**

(c) Explain the following technical terms of (1) the figure of merit (2) rotor blade solidity, and (3) ideally twisted rotor.
*Terangkan pengertian teknik berikut ini : (1) "Figure of merit ", (2) "rotor blade solidity" dan (3) ideally twisted rotor.*

**(5 marks/*markah*)**

2. (a) A helicopter's data is given bellows :
*Helikopter dengan data data berikut :*

- Rotor blade radius $\mathbf{R_B = 5\,m}$
*Jejari bilah pemutar* $\mathbf{R_B = 5\,m}$

- The blade number $\mathbf{N_B = 3}$
*Bilangan Bilah* $\mathbf{N_B = 3}$

- The average drag coefficients $\mathbf{c_{do} = 0.012}$
*Purata pekali geseran* $\mathbf{c_{do} = 0.012}$

- The tip speed $\Omega R_B = \mathbf{210}\,\frac{\mathbf{m}}{\mathbf{sec}}$
*Kelajuan tip* $\Omega R_B = \mathbf{210}\,\frac{\mathbf{m}}{\mathbf{sec}}$

- The mean blade chord $\bar{c} = 0.15\,R_B$
*Min perentas bilah* $\bar{c} = 0.15\,R_B$

If the helicopter has mass weight 6000 kg and in hover flight conditions at sea level (assume the air density $\rho = 1.225\,\frac{kg}{m^3}$ and the gravitational accelerations $g = 10\,\frac{m}{sec^2}$)
*Jika berat helikopter ialah 5000 kg dan dalam keadaan penerbangan hover pada paras laut (anggap ketumpatan udara* $\rho = 1.225\,\frac{kg}{m^3}$*) dan pecutan graviti* $g = 10\,\frac{m}{sec^2}$.

Lock Number $\gamma = 8$
*Nombor Lock* $\gamma = 8$

Effective angle of attack $\alpha_{eff} = 3^0$
*Sudut serang efektif* $\alpha_{eff} = 3^0$

Use a momentum theory to calculate :
*Dengan menggunakan teori momentum, kirakan :*

(i) The disk loading
*Pembebanan cakera*

**(3 marks/*markah*)**

(ii) Induced inflow ratio
*Nisbah aliran masuk teraruh*

**(3 marks/*markah*)**

(iii) Ideal induced power coefficients
*Pengkali kuasa teraruh unggul*

**(3 marks/*markah*)**

(iv) Figure of merit
*Angka merit*

**(3 marks/*markah*)**

(v) Effective blade ratio
*Kesan nisbah bilah*

**(3 marks/*markah*)**

(vi) Conning angle $\beta_0$
*Sudut kon* $\beta_0$

**(3 marks/*markah*)**

(b) Explain the basic concept of the blade element theory.
*Terangkan konsep dasar dari teori elemen bilah*

**(3 marks/*markah*)**

(c) Explain the difference between the prescribed wake method and the the free wake method in the aerodynamics analysis of the rotor blade for helicopter.
*Terangkan perbezaan antara "a prescribed wake method" dan "free wake method" dalam analisis aerodinamik bilah untuk helikopter.*

**(4 marks/*markah*)**

3. The helicopter's data is given as bellows :
*Diberikan data helikopter berikut :*

Rotor blade radius $\mathbf{R_B = 6\,m}$
*Jejari bilah pemutar* $\mathbf{R_B = 6\,m}$

The blade number $\mathbf{N_B = 4}$
*Bilangan bilah* $\mathbf{N_B = 4}$

The average drag coefficients $c_{do} = 0.010$
*Purata pekali geseran* $c_{do} = 0.010$

The tip speed $\Omega R_B = 220 \frac{m}{sec}$
*Kelajuan tip* $\Omega R_B = 220 \frac{m}{sec}$

The mean blade chord $\bar{c} = 0.15 R_B$
*Min perentas bilah* $\bar{c} = 0.15 R_B$

Helicopter weight : 10000 Newton
*Berat helikopter : 10000 Newton*

*Helikopter terbang di atas paras laut (ketumpatan udara* $\rho = 1.225 \frac{kg}{m^3}$ *dan pecutan gravitasi* $g = 10 \frac{m}{sec^2}$*).*
*Dengan menggunakan teori momentum, kira*

(i) The thrust coefficient
*Pengkali tujah*

**(2 marks/*markah*)**

(ii) The induced velocity at hover
*Nisbah aliran masuk teraruh pada hover*

**(2 marks/*markah*)**

(iii) The induced velocity at climb with speed 15 m/sec
*Nisbah aliran masuk teraruh pada climb dengan halaju 15 m/saat.*

**(2 marks/*markah*)**

(iv) Descent velocity at vortex ring state
*Penurunan halaju descent semasa terjadinya keadaan gelang vortex.*

**(2 marks/*markah*)**

(v) Descent velocity at turbulent wake state
*Penurunan halaju descent semasa terjadinya keadaan keracak gelora.*
**(2 marks/*markah*)**

(vi) Descent velocity at the wind mill brake state
*Penurunan halaju descent semasa terjadinya keadaan brek kincir angin.*
**(2 marks/*markah*)**

(vii) Figure of merit at hover
*Angka merit semasa hover*
**(2 marks/*markah*)**

(viii) Figure of merit at climb speed 20 m/sec
*Angka merit semasa mendaki dengan halaju 20 m/saat*
**(2 marks/*markah*)**

(ix) If the helicopter descent with speed of descent equal to the induced velocity, calculate the ideal induced power coefficient
*Jika helikopter tersebut menurun pada kelajuan sama dengan halaju teraruh, kirakan pekali kuaasa teraruh unggul yang diperlukan.*
**(3 marks/*markah*)**

(x) If the tip speed becomes 150 m/sec at the time helicopter fly climb at speed of 20 m/se, Calculate the percentage of the decrease of the ideal power coefficient compared to the helicopter at tip speed 200 m/sec.
*Jika laju tip menjadi 150 m/saat pada semasa helikopter terbang menanjak (climb) 20 m/saat, kirakan penurunan peratus pekali kuasa teraruh unggul bila dibandingkan laju tip pada 200 m/saat*
**(3 marks/*markah*)**

(xi) Explain the assumptions had been used in the aerodynamic analysis of rotor blade helicopter with the Momentum Theory Method.
*Terangkan anggapan yang digunakan dalam analisis aerodinamik rotor bilah helikopter dengan kaedah teori Momentum*
**(3 marks/*markah*)**

4. The helicopter's data is given as bellows :
*Diberikan data helikopter berikut :*

Rotor blade radius $\mathbf{R_B = 6\,m}$
*Jejari bilah pemutar* $\mathbf{R_B = 6\,m}$

The blade number $N_B = 4$
*Bilangan bilah* $N_B = 4$

The average drag coefficients $c_{do} = 0.012$
*Purata pekali geseran* $c_{do} = 0.012$

The tip speed $\Omega R_B = 200 \frac{m}{sec}$
*Kelajuan tip* $\Omega R_B = 200 \frac{m}{sec}$

The mean blade chord $\bar{c} = 0.6\,m$
*Min perentas bilah* $\bar{c} = 0.6\,m$

Helicopter weight : 14000 Newton
*Berat helicopter : 14000 Newton*

Equivalent flat plate area 30 % luasan rotor bilah (Rotor blade area)
*Luasan plat datar setara*

*Helikopter terbang di atas paras laut (ketumpatan udara* $\rho = 1.225 \frac{kg}{m^3}$ *dan pecutan gravitasi* $g = 10 \frac{m}{sec^2}$*). Bila helikopter ini sedang melakukan terbang kearah depan (forward) dengan halaju 30 m/sec dan sudut serang Tip Path Plane* $\alpha_{TPP} = 5^0$.
*Kirakan :*

(i) Using Iteration Newton's Iteration method (up to 3th iterations) determine the inflow ratio $\lambda_i$
*Dengan menggunakan kaedah iteration Newton (3 iterasi) tentukan nisbah aliran masuk* $\lambda_i$

**(6 marks/*markah*)**

(ii) Ideal induced power coefficients $Cp_i$
*Pekali kuasa teraruh unggul* $Cp_i$

**(2 marks/*markah*)**

(iii) Parsite drag power coefficients $Cp_p$
*Pekali kuasa seret*

**(2 marks/*markah*)**

(iv) Profile drag power coefficients $Cp_{d0}$
*Pekali kuasa susuk seret* $Cp_{d0}$

**(2 marks/*markah*)**

(v) If the angle of attack Tip Path Plane $\alpha_{TPP} = 10^0$ Using Iteration Newton's Iteration method (up to 3th iterations) determine the inflow ratio $\lambda_i$
*Bila sudut serang Tip Path Plane* $\alpha_{TPP} = 10^0$, *dengan kaedah iteration Newton (3 iterasi ) tentukan nisbah aliran masuk* $\lambda_i$

**(6 marks/*markah*)**

(vi) Total power coefficient for the problem No 4(iv)
*Jumlahkan pekali kuasa untuk no soalan 4 (iv)*

**(4 marks/*markah*)**

(vii) Explain why the operational speed of the helicopter can not exceed for the advance ratio $\mu > 0.4$
*Terangkan mengapa opersional halaju helikopter memiliki kecepatan terbang ke depan tidak dapat melebihi nisbah lanjut* $\mu > 0.4$

**(3 marks/*markah*)**

5. The helicopter's data is given as bellows :
*Diberikan data helikopter berikut :*

Rotor blade radius $\mathbf{R_B = 6\,m}$
*Jejari bilah pemutar* $\mathbf{R_B = 6\,m}$

The blade number $N_B = 4$
*Bilangan bilah* $N_B = 4$

The average drag coefficients $c_{do} = 0.008$
*Purata pekali geseran* $c_{do} = 0.008$

The tip speed $\mathbf{\Omega R_B = 180 \frac{m}{sec}}$

*Kelajuan tip* $\mathbf{\Omega R_B = 180 \frac{m}{sec}}$

The mean blade chord $\bar{c} = 0.6\,m$
*Min perentas bilah* $\bar{c} = 0.6\,m$

Pitch distribution : $\theta(\frac{r}{R_B}) = 8^0 - 2^0 \left(\frac{r}{R_B}\right)$

*Distribusi pitch :* $\theta(\frac{r}{R_B}) = 8^0 - 2^0 \left(\frac{r}{R_B}\right)$

Cyclic pitch $\theta_{1s} = 3^0$
*Collective pitch* $\theta_{1c} = 5^0$

Helicopter weight : 15000 Newton
*Berat helicopter : 15000 Newton*

Equivalent flat plate area 30 % luasan rotor bilah (Rotor blade area)
*Luasan plat datar setara*

*Helikopter terbang diatas paras laut (ketumpatan udara* $\rho = 1.225 \frac{kg}{m^3}$ *dan pecutan gravitasi* $g = 10 \frac{m}{sec^2}$*). Bila helikopter ini sedang melakukan terbang ke arah depan (forward) dengan haluju 30 m/sec dan sudut serang Tip Path Plane* $\alpha_{TPP} = 5^0$.

With assumption that the induced velocity is uniform the coning angle can be formulated as :
*Dengan anggapan kecepatan imbas seragam dapat diformulasikan variasi sudut coning sebagai :*

$$\beta_0 = \gamma\left[\frac{\theta_{80\%R}}{8}\left(1+\mu^2\right)-\frac{\mu^2}{60}\theta_{tw}-\frac{\lambda_{TPP}}{6}+\mu\frac{\beta_{1c}+\theta_{1s}}{6}\right]$$

$$\beta_{1c}+\theta_{1s} = \frac{-\frac{8}{3}\mu\left[\theta_{75\%R}-\frac{3}{4}\lambda_{TPP}\right]}{1+\frac{3}{2}\mu^2}$$

$$\beta_{1s}-\theta_{1c} = \frac{-\frac{4}{3}\mu\beta_0}{1+\frac{1}{2}\mu^2}$$

And the effective angle of attack diberikan sebagai :
*Dan sudut serang effective :*

$$\alpha_{effective} = \frac{U_T\theta - U_P}{U_T} = \frac{1}{U_T}\begin{bmatrix}\Omega r\left\{\theta_0+\left(\theta_{1c}-\beta_{1s}\right)\cos\psi+\left(\theta_{1s}+\beta_{1c}\right)\sin\psi\right\}\\ U_\infty\theta_0\sin\psi+U_\infty\left(\theta_{1c}-\beta_{1s}\right)\cos\psi\sin\psi\\ +U_\infty\left(\theta_{1s}+\beta_{1c}\right)\sin^2\psi-U_\infty\beta_0\cos\psi\\ -V\alpha_{TPP}-v\end{bmatrix}$$

Calculate :
*Kirakan :*

(i) Using Iteration Newton's Iteration method (up to 3th iterations) determine the inflow ratio $\lambda_i$
*Dengan menggunakan kaedah iteration Newton (3 iterasi) tentukan nisbah aliran masuk* $\lambda_i$

**(5 marks/*markah*)**

(ii) Estimate the coning angle coefficients : angle $\beta_0$ , $\beta_{1s}$ dan $\theta_{1c}$
*Anggarkan pemalar t coning angle* $\beta_0$, $\beta_{1s}$ *dan* $\theta_{1c}$

**(5 marks/*markah*)**

(iii) Estimate the effective angle of attack at a control point on the blade which located at r = 0.5 $R_B$ with respect to the rotational axis for the blade azimuth position at $\psi = 0^0$, $90^0$ and $180^0$
*Anggarkan sudut serang efektif pada titik kawalan yang berjarak r = 0.5* $R_B$ *terhadap paksi putar bila bilah terletak pada sudut azimuth* $\psi = 0^0$ , $90^0$ *dan* $180^0$

**(5 marks/*markah*)**

(iv) If the aerodynamic characteristics for the airfoil section of the rotor blade are given as :
*Jika ciri-ciri aerodinamik keronjong udara bilah rotor diberikan sebagai :*

$$c_\ell(\alpha) = 0.108\,(\alpha + 1.2) \quad \text{and}$$
$$c_d(\alpha) = 0.008 + 0.01\alpha + 0.005\alpha^2$$
$\alpha$ in degree

Determine the coefficient lift and drag for the problem as given in 5.4.
*Tentukan besarnya pemalar daya angkat dan daya seret untuk soalan 5.4 diatas.*

**(5 marks/*markah*)**

(v) Determine the coefficient lateral forces and horizontal forces for the helicopter in this forward flight.
*Tentukan besarnya pemalar daya lateral $C_Y$ dan Daya horizontal $C_H$ untuk helikopter yang sedang terbang ke hadapan ini.*

**(5 marks/*markah*)**

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