UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 2008/2009
Second Semester Examination
2008/2009 Academic Session

April/Mei 2009
April/May 2009

ESA 372/3 – Aerodinamik Pesawat
Aircraft Aerodynamics

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

ARAHAN KEPADA CALON :
INSTRUCTION TO CANDIDATES

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

*Answer **ALL** questions.*
All questions carry the same marks.
Jawab **SEMUA** soalan.
Semua soalan membawa jumlah markah yang sama

Student may answer the question in English.
Pelajar boleh menjawab soalan dalam Bahasa Inggeris.

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

1. (a) In the aircraft aerodynamic analysis, one requires to understand some of aerodynamic terms. Explain what does it means with the (1) " Mean aerodynamic center ", (2) " wing twist angle ", (3) "wing dihedral angle ", (4) " profile drag " dan (5) " wave drag"

Dalam analisis aerodinamik pesawat terbang, seseorang perlu memahami berapa istilah aerodinamik, Terangkan apa yang yang dimaksudkan dengan istilah berikut : (1) " Mean aerodynamic center ", (2) " wing twist angle ", (3) "wing dihedral angle ", (4) " profile drag " dan (5) " wave drag"

[10 marks/*markah*)

(b) An experiment result from wind tunnel conducted by NASA for the NACA series airfoil 2412 at Reynolds number R_L = 3.250.000 as shown in the **Figure 1.1**

*Hasil Eksperimen dengan menggunakan terowongan angin yang dilakukan oleh NASA untuk airfoil NACA serie 2412 pada nombor Reynolds R_L 3.250.000 seperti diperlihatkan pada **Rajah 1.1***

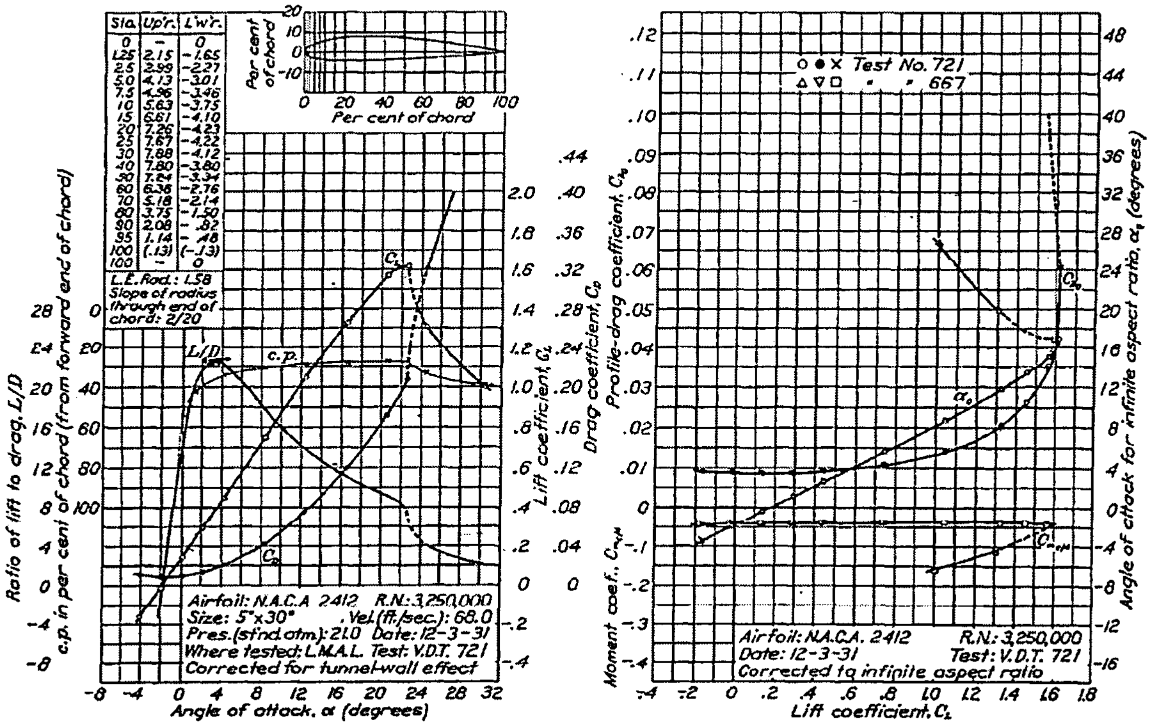

FIGURE 18.—N.A.C.A. 2412 airfoil.

Figure1.1 Experiment Result Aerodynamic Characteristics Airfoil NACA 2412

Rajah 1.1 Hasil ujian ciri ciri aerodinamik airfoil NACA 2412

Based on those experiment, determined :
Berdasarkan hasil ekperiment tersebut tentukan :

(i) The zero lift angle of attack $\alpha_{L=0}$
Sudut serang pada daya angkat sifar $\alpha_{L=0}$

(ii) Slope of lift coefficient curve $\left(\frac{\partial c_\ell}{\partial \alpha}\right)$

Kecerunan lengkung pemalar daya angkat $\left(\frac{\partial c_\ell}{\partial \alpha}\right)$

(iii) The maximum lift coefficient $c_{\ell max}$
Pemalar daya angkat maksimum $c_{\ell max}$

(iv) The angle of attack at the maximum lift coefficient $\alpha_{c_{\ell max}}$
Sudut serang pada pemalar daya angkat maximum $\alpha_{c_{\ell max}}$

(v) The zero lift pitching moment coefficient c_{mo}

Pemalar "pitching moment" pada daya angkat sifar c_{mo}

(vi) Design lift coefficient " $c_{\ell i}$ "
Rekabentuk pemalar daya angkat " $c_{\ell i}$ "

(vii) The angle of attack at design lift coefficient α_i
Sudut serang pada "design lift coefficient" α_i

(viii) *The position of mean aerodynamic center in % of chord length xa.c*
Posisi "mean aerodynamic center" dalam % panjang perentas $x_{a.c}$

(ix) The meaning of digit 2412
Erti bagi digit 2412

(x) The linear limit of angle of attack α^*
Had linear sudut serang α^*

(10 marks/*markah*)

c) Explain why by decreasing the wing aspect ratio will give the angle of attack at the maximum lift coefficient of that wing $\alpha_{C_{L\max}}$ is greater than the $\alpha_{c_{\ell\max}}$ of its airfoil.

Terangkan mengapa dengan "Aspect ratio" suatu sayap yang semakin kecil mempunyai sudut serang pamalar maksimum $\alpha_{C_{L\max}}$ *sayap tersebut lebih besar dibandingkan dengan* $\alpha_{c_{\ell\max}}$ *airfoilnya.*

(5 marks/*markah*)

2. a) Given a fuselage of cruise missile with a circular cross section as depicted in the **Figure 2.1.**

Di berikan satu fuselaj dari "cruise missile" dengan bentuk irisan melintang lingkaran seperti yang ditunjukkan pada ***Rajah 2.1***

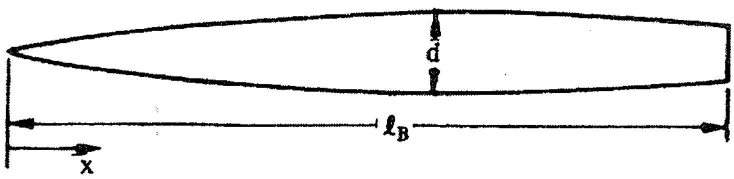

Figure 2.1 : Missile Fuselage
Rajah 2.1 : Fusalaj Peluru Berpandu

The fuselage geometry is given as follows :
Data geometri fuselaj di berikan sebagai berikut:

Distribution of fuselage radius r(x/)
Distribusi jejari fuselaj r(x/)

$$r(x) = 0.255\left(1.0 - \left(1.0 - \frac{2x}{6.375}\right)^2\right)^{3/4}$$

Fuselage length L_B = 5.0 m
Panjang fuselaj L_B = 5.0 m

Determine/ *Tentukan* :

(i) Position of x_{max} and its maximum of fuselage cross section area S_{max}.
Posisi x_{max} dan besar luasan irisan maksimum S_{max}

(ii) Fuselage Volume V_B
Volume fuselaj V_B

(iii) *Fuselage wetted surface area* S_{wett}
Luasan permukaan basah fuselaj S_{wett}

(iv) The Fuselage Projected area S_p
Luasan projeksi fuselaj S_p

(v) Fuselage Fineness ratio F_N
Fuselage Fineness ratio F_N

(vi) Explain what does it means with base drag C_{Db}
Terangkan apa yang dimaksudkan dengan "Base Drag" C_{Db}

(10 marks/ *markah*)

(b). The fuselage shape of an aircraft model with circular cross section as depicted in the **Figure 2.1:**

*Satu bentuk fuselaj pesawat model dengan irisan melintang lingkaran seperti pada **Rajah 2.2** di bawah ini* :

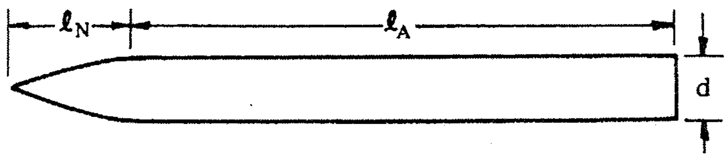

Figure 2.2 Fuselage Model
Rajah 2.2 Model Fuselaj

The fuselage nose length ℓ_N = 2 m and the distribution of fuselage radius r(x) is given as :

Panjang muncung fuselaj ℓ_N = 2 m dan distribusi jejari fuselaj r(x) di berikan sebagai :

$$\mathbf{r(x) = 0.5 \left(\frac{x}{L_N}\right)^2 \ (meter) \qquad 0 \le x \le L_N}$$

The fuselage mid section length ℓ_A = 8 m with a uniform circular cross section r(x) = 0.5 m

Panjang fuselaj bahagian tengah ℓ_A = 8 m dengan serangam irisan lingkaran seragam r(x) = 0.5 m

For the purpose of aerodynamics analysis, the fuselage noses is divided into two segment, while the mid fuselage section with 4 segment, hence the fuselage geometry data can be given as presented in the **Table 2.1** belows :

*Untuk keperluan analisis aerodinamik, bahagian muncung dibahagi menjadi 2 segment dan fuselaj bahagian tengah dibahagi dengan 4 segmen sehingga dapatkan data geometri fuselaj seperti dalam **Jadual 2.1** di bawah :*

No	Fuselage Station	Fuselage radius r(x)	Position of centroid area x_c
1	0.0	0.0	0.666
2	1.0	0.125	1.666
3	2.0	0.5	3.0
4	4.0	0.5	5.0
5	6.0	0.5	7.0
6	8.0	0.5	9.0
7	10.0	0.5	

Table 2.1 Fuselage geometry data
Jadual 2.1 Data geometri fuselaj

This aircraft model designed to fly at Mach number $M = 0.3$ and the Reynolds number $R_L = 3.0x10^6$ with the center gravity position at $x_m = 5$ m

Pesawat terbang model ini dirancang untuk terbang pada nombor Mach $M = 0.3$ dan nombor Reynolds $R_L = 3.0x10^6$ serta posisi pusat gravitasi $x_m = 5$ m

The fuselage aerodynamics characteristics in term of lift coefficient C_L, drag coefficient C_D and pitching moment coefficient C_M can be written as :

Ciri ciri aerodinamik fuselaj dalam besaran pemalar daya angkat C_L, pemalar daya seret C_D dan pemalar momen angguk C_M dan sebagai fungsi dari sudut serang α dapat dituliskan sebagai:

$$C_L(\alpha) = \frac{(k_2 - k_1)}{V_B^{2/3}} 2\alpha S_0 + \frac{2\alpha^2}{V_B^{2/3}} \int_{x_0}^{L_B} \eta \, r \, c_{dc} \, dx$$

$$C_D(\alpha) = (C_{D0}) + \frac{(k_2 - k_1)}{V_B^{2/3}} 2\alpha^2 S_0 + \frac{2\alpha^3}{V_B^{2/3}} \int_{x_0}^{L_B} \eta \, r \, c_{dc} \, dx$$

$$C_M(\alpha) = \frac{(k_2 - k_1)}{V_B} 2\alpha \int_0^{x_0} \frac{dS}{dx}(x_m - x_c)dx + \frac{2\alpha^2}{V_B} \int_{x_0}^{L_B} \eta \, r \, c_{dc} \, (x_m - x_c)dx$$

And/*Dan*

$$(C_{D0})_b = C_f \left[1 + \frac{60.0}{\left(\frac{L_B}{d}\right)^3} + 0.0025 \left(\frac{L_B}{d}\right) \right] \frac{S_S}{S_{max}} + $$

$$+ \frac{0.029}{\sqrt{C_f \left[1 + \frac{60}{\left(\frac{L_B}{d}\right)^3} + 0.0025 \left(\frac{L_B}{d}\right) \right] \frac{S_S}{S_{max}}}} \left(\frac{d_b}{d}\right)^3$$

The definition of variable appear in above equation also the required graph may refer to the Formula Book as provided.

Definisi dari variable beserta graf yang terdapat pada persamaan di atas sila merujuk pada Buku Formula yang disediakan

Assume the position of $x_0 = 2.0$
Anggap posisi $x_0 = 2.0$

Determine/ *Tentukan :*

i) The lift coefficient C_L, drag coefficient daya seret C_D dan pitching moment coefficient C_M at angle at attack $\alpha = 3^0$.

Pemalar daya angkat C_L, *pemalar daya seret* C_D *dan pemalar moment angguk* C_M *pada sudut serang* $\alpha = 3^0$.

ii) The slope of lift cioefficient curve $\left(\frac{\partial C_L}{\partial \alpha}\right)$ and the slope of pitching moment coefficient $\left(\frac{\partial C_M}{\partial \alpha}\right)$

Kesan kecerunan pemalar daya angkat $\left(\frac{\partial C_L}{\partial \alpha}\right)$ *dan kecerungan pemalar moment angguk* $\left(\frac{\partial C_M}{\partial \alpha}\right)$

(15 marks/*markah*)

3. *Given a wing planform in the form of tapered wing with the coordinates as shown in the* ***Figure 3.1***

Di berikan suatu sayap dengan bentuk sebagai " Tapered wing Plan form " dengan koordinat seperti ditunjukkan dalam ***Rajah 3.1.***

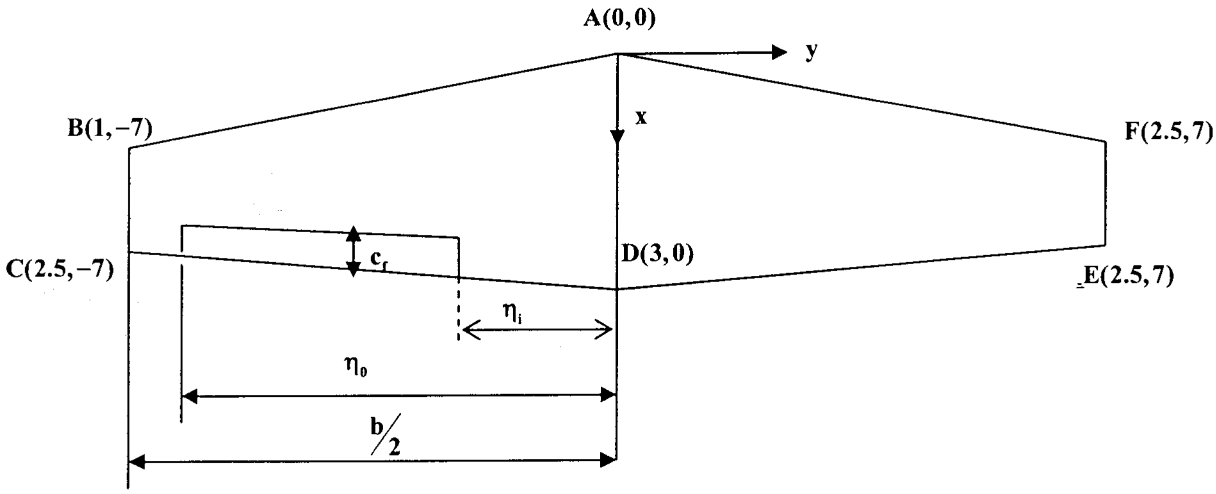

Figure 3.1 Wing Geometry Data
Rajah 3.1 Data geometri sayap

Wing equipped with plain flap and the flap data is given as :

Sayap dilengkapi dengan "Plain Flap" , dengan data kepak sebagai berikut :

Chord flap $c_f = 0.25\,c$
Panjang perentas flap $c_f = 0.25\,c$

$$\eta_i = \frac{y_i}{(b/2)} = 0.3$$

$$\eta_0 = \frac{y_i}{(b/2)} = 0.8$$

Wing airfoil section is NACA Series 4412 with its aerodynamics characteristics at Mach Number M = 0.3 and Reynolds number $R_L = 3.10^{10x6}$ as follows :

Airfoil sayap adalah NACA Siri 4412 dengan data ciri ciri aerodinamik airfoil pada nombor Mach M = 0.3 dan nombor Reynolds $R_L = 3\ 10^{10x6}$ *sebagai berikut :*

(i) The zero lift angle of attack $\alpha_{L=0} = -3.8^0$
Sudut serang pada daya angkat sifar $\alpha_{L=0} = -3.8^0$

(ii) The slope of lift coefficients $\left(\frac{\partial c_\ell}{\partial \alpha}\right) = 0.105/\text{deg}$

Kecurunan lengkung pemalar daya angkat $\left(\frac{\partial c_\ell}{\partial \alpha}\right) = 0.105/\text{deg}$

(iii) The maximum lift coefficient $c_{\ell max} = 1.67$
Pemalar daya angkat maksimum $c_{\ell max} = 1.67$

(iv) The angle of attack at maximum lift coefficient $\alpha_{c_{\ell max}} = 14.0^0$
Sudut serang pada pemalar daya angkat maximum $\alpha_{c_{\ell max}} = 14.0^0$

(v) The zero lift pitching moment coefficient $c_{mo} = -0.093$
Pemalar "pitching moment" pada daya angkat sifar $c_{mo} = -0.093$

(vi) Design lift coefficient $c_{\ell i} = 0.5$
Rekabentuk pemalar daya angkat $c_{\ell i} = 0.5$

(vii) Angle of attack at design lift coefficient $\alpha_i = 0.4^0$
Sudut serang pada rekabentuk pemalar daya angkat $\alpha_i = 0.4^0$

(viii) The limit of linear angle of attack $\alpha^* = 7.5^0$
Had sudut serang lelurus $\alpha^* = 7.5^0$

(ix) *Airfoil leading edge radius* $R_{LE} = 1.58$ % c
Jejari leading edge airfoil / $R_{LE} = 1.58$ % c

(x) Airfoil bluntness ratio Δy = **3.1 % c**
Nisbah ketumpulan airfoil Δy = **3.1 % c**

(xi) The ordinate of airfoil upper surface at x = 0.90 dan x = 0.99 :
Ordinat permukaan atas airfoil pada x = 0.90 dan x = 0.99:

$$\frac{y_{x=0.90}}{2} = 1.465\ \%\ c \quad ; \quad \frac{y_{x=0.99}}{2} = 0.27\ \%\ c$$

The airfoil trailing edge *angle is given by*
Sudut trailing edge airfoil diberikan sebagai

$$: \Phi_{TE} = 2\,\Phi_{\frac{1}{2}TE} \quad ; \quad \Phi_{\frac{1}{2}TE} = \text{Arctg}\left(\frac{y_{x=0.90} - y_{x=0.99}}{0.09}\right)$$

If this wing plan form designed for the airplane which has a flight speed at the Mach number M = 0.3 and Reynolds number $R_L = 3\ 10^6$.

Jika sayap ini dirancang untuk suatu pesawat terbang dengan kelajuan terbang pada nombor Mach M = 0.3 dan Nombor Reynolds $R_L = 3\ 10^6$.

Determine :
Tentukan :

(a) Aspect ratio AA , Taper ratio λ, The swept angle of leading edge line Λ_{LE}, The angle of c/2 chord line $\Lambda_{c/2}$, Wing area reference S, The wing wetted area S_{wett}, The mean aerodynamics chord $c_{m.a.c}$, the distance of mean aerodynamic chord to the wing main axis x : y_{cmac}.

"Aspect ratio" A , Taper ratio λ, *Sudut swept leading edge* Λ_{LE}, *Sudut c/2 perentas* $\Lambda_{c/2}$, *luasan rujukan S, luasan basah* S_{wett}, *perentas purata aerodinamik* $c_{m.a.c}$, *jarak purata perentas aerodinamik terhadap paksi utama* y_{cmac}.

(b) If the flap section is plain flap with flap deflection $\delta_f = 20^0$, determine the aerodynamic characteristics of this two dimensional high lift devices plain flap for the following quantities :

Jika flap section berupa plain flap dengan sudut defleksi flap $\delta_f = 20^0$, *tentukan ciri-ciri aerodinamik "2-Dimensional High lift Device "plain flap ini untuk kuantiti berikut:*

- The increment of lift coefficient Δc_ℓ
  Kenaikan pemalar daya angkat / Δc_ℓ

- The slope of lift coefficient curve $\left(\frac{\partial c_\ell}{\partial \alpha}\right)_{\text{plain flap}}$

  Kecerunan daya angkat, $\left(\frac{\partial c_\ell}{\partial \alpha}\right)_{\text{plain flap}}$

- The increment of the maximum lift coefficient $\Delta c_{\ell max}$ and the angle of attack at the maximum lift coefficient $\alpha_{c_{\ell max}}$

  Kenaikan pemalar daya angkat maximum $\Delta c_{\ell max}$ *dan sudut serang pada pemalar daya angkat maksimum* $\alpha_{c_{\ell max}}$

(c) Determine the wing aerodynamics characteristics for the following quantities :
Tentukan ciri-ciri aerodinamik sayap tersebut untuk kuantiti berikut

(i) Zero lift angle of attack $(\alpha_{L=0})_w$
Sudut serang daya angkat sifar $(\alpha_{L=0})_w$

(ii) Slope of lift coefficient $\left(\frac{\partial C_L}{\partial \alpha}\right)_w$
Kecerunan pemalar daya angkat $\left(\frac{\partial C_L}{\partial \alpha}\right)_w$

(ii) The zero lift drag coefficient $(C_{D0})_w$
Pemalar daya seret pada daya angkat sifar $(C_{D0})_w$

(iii) The zero lift pitching moment coefficient $(C_{M0})_w$
Pemalar momen angguk pada daya angkat sifar $(C_{M0})_w$

(25 marks/*markah*)

4. For a wing problem as given in the question number 3, and with help of "Buku Formula " as provided, determined :

Untuk soalan sayap seperti yang diberikan pada soalan nombor 3 , dan dengan bantuan buku formula yang disediakan tentukan :

(a) Lift coefficient C_L at angle of attack below stall angle $\alpha = 14^0$
Pemalar daya angkat C_L *pada sudut serang di bawah sudut "stall"* $\alpha = 14^0$

(b) Lift coefficient C_L at angle of attack above stall angle $\alpha = 20^0$
P*emalar daya angkat* C_L *pada sudut serang diatas sudut "stall"* $\alpha = 20^0$

(c) *Drag coefficient* C_M *at angle of attack* $\alpha = 3^0$
Pemalar daya tahan C_D *pada sudut pada sudut serang* $\alpha = 3^0$

(25 marks/*markah*)

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