UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 8 Examination in Engineering: November 2017

Module Number: ME8311 **Module Name: Aerospace Engineering**

[Three Hours]

[Answer **all questions**, each question carries **twelve** marks]

NOTES:
Use carefully labelled sketches to support your answers where necessary.
You may make additional assumptions, but clearly state them in your answers.
Data and formulae are given from page 3 to page 5.

Q1. a) Differentiate between the absolute altitude and the pressure altitude.

[1.0 Mark]

b) Consider maneuvering of an aircraft from runway to the final altitude of a particular flight. What are the various control surfaces used by the pilot? Explain your answer.

[3.0 Marks]

c) Starting from the first principles derive an expression for static pressure variation with respect to altitude within the troposphere.

[5.0 Marks]

d) A passenger transport aircraft cruises with 550 km/h at a pressure altitude of 15.7 km. Estimate the reading of the pitot pressure probe of the aircraft.

[3.0 Marks]

Q2. a) Sketch following airfoil shapes:
i) NACA 0015,
ii) NACA 2300.

[1.0 Mark]

b) Describe three methods to minimize boundary layer separation over an airfoil.

[6.0 Marks]

c) The pressure distribution over an airfoil at 4° of angle of attack could be approximate as follows: Upper surface: Cp constant at -0.8 from leading edge to 60% of chord, then increasing linearly to +0.1 at the trailing edge. Lower surface: Cp constant at -0.4 from leading edge to 60% of chord, then increasing linearly to +0.1 at the trailing edge. Estimate the lift coefficient of the airfoil at 4° angle of attack.

[5.0 Marks]

Q3. a) Differentiate between the geometric angle of attack (AoA) and effective AoA in relation to flow over a finite wing. Hence describe how the induced drag is generated.

[4.0 Marks]

b) Explain: "Although elliptic planform shapes yield minimum induced drag, elliptic wings are not commonly used in commercial aircraft".

[2.0 Marks]

c) The wings of a commercial aircraft are made of NACA 2412 airfoil section. The tapered planform wings have a total span of 19.2 m; while the root chord length and the tip chord length are 2.1 m and 6.2 m, respectively. The aircraft having 20500 kg of gross weight cruises at an altitude of 8.6 km with a constant speed of 575 km/h.
The lift coefficient and the drag coefficient variations for the NACA 2442 as a function of AoA are presented in Table Q3. Further the induced drag factor as a function of taper ratio and the aspect ratio is given Fig. Q3 (c) and assume $\delta = \tau$. If the total power requirement of the aircraft is 2.5 MW, determine;

i) The required AoA during the cruise,
ii) The induced drag and the skin friction drag acted on the aircraft,
iii) The wave drag acted on the aircraft.

[6.0 Marks]

Q4. a) State the cockpit control commands that a pilot could not be used during pure longitudinal flight.

[1.0 Mark]

b) Comment on the statement "Negative control surface deflections results positive responses of the aircraft".

[2.0 Marks]

c) The pilot has decreased the elevator deflection by an amount of δm when an aircraft performs a pure longitudinal flight with an equilibrium angle of attack α_e, flight path angle γ_e and equilibrium velocity V_e. When the aircraft reaches the new steady state flight condition, with usual notation derive expressions for;

i) Change in flight path angle $\Delta\gamma_e$,
ii) Change in flight velocity ΔV_e.

[6.0 Marks]

d) Using the results from part (c) above, plot the variation of flight speed and flight path angle as the aircraft switches from the starting equilibrium state to next equilibrium state.

[3.0 Marks]

Q5. a) Briefly describe "Safe life" and "Fail safe" design strategies in relation to aircraft design. Support your answer with relevant examples.

[2.0 Marks]

b) Derive an expression for the load factor and the bank angle when an aircraft performs steady turning maneuver.

[2.0 Marks]

c) Consider a medium size aircraft described in Table Q5.

i) Determine allowable limit load factor.

[2.0 Marks]

ii) Indicating all the important points, draw the v-n diagram.

[3.0 Marks]

iii) Calculate the gust load factor experienced by the aircraft at the corner velocity.

[3.0 Marks]

Table Q3: NACA 2442 airfoil data

Angle of Attack (AoA) (degrees)	Lift coefficient - c_ℓ	Drag coefficient - c_d
-4	-0.45	0.01
-2	-0.09	0.008
0	0.27	0.008
2	0.63	0.007
4	0.99	0.007
6	1.35	0.0075
8	1.71	0.0092
10	1.9	0.0098
12	2.2	0.012

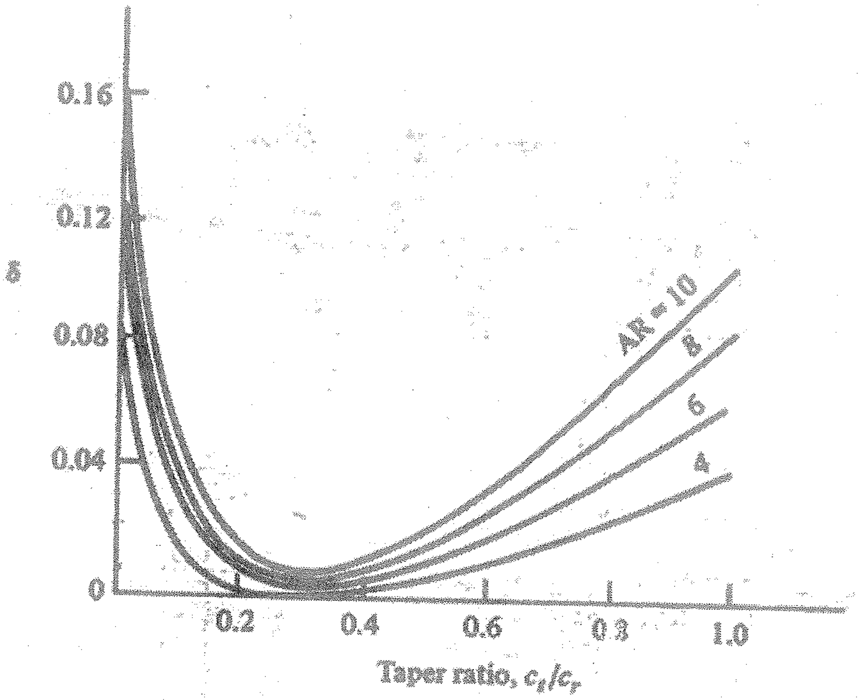

Fig. Q3(c): Induced drag factor variation

Table Q5: Aircraft Data

Aircraft Mass	4,800 kg
Aspect ratio	4.2
Wing span	9.1 m
Lift curve slope	5.85 rad^{-1}
Positive CL_{max}	3.2
Cruising velocity (V_c)	320 knot
Corner velocity	175 knot
Diving velocity	1.75 V_c
Outside Air-Density	0.768 kgm^{-3}

Data and Formulae sheet for Aerospace Engineering

a.) The gust load factor is determined through:

$$n = 1 + \frac{k_g V_{gE} V_E a \rho S}{2W}; \qquad k_g = \frac{0.88\mu_g}{5.3 + \mu_g}; \qquad \mu_g = \frac{2m}{\rho C a S}.$$

where:

m - mass of aircraft,	C - Mean aerodynamic chord,
ρ - density of air,	W - weight of aircraft,
a - lift curve slope,	V_{gE} - equivalent gust speed,
S - wing surface area,	V_E - equivalent airspeed.

1 knot = 0.5144 ms^{-1}

b.) For sea-level atmospheric conditions use followings:

Static pressure (P_0) = 101325 Pa

Temperature (T_0) = 288.15 K

Density (ρ_0) = 1.225 kg.m^{-3}

Acceleration due to gravity (g_0) = 9.81 m.s^{-2}

Specific heat ratio (γ) = 1.4

Real gas constant (R_g) = 287 J.kg^{-1}.K^{-1}

c.) In an ISA the static pressure (*P*) and the temperature (*T*) are given by,

i) Below 11 km:

$$P = P_0\left(1 - 2.2558\times10^{-5}h\right)^{5.2559}\ \text{N.m}^{-2},$$

$$T = T_0 - 0.0065h\ \text{K},$$

ii) From 11 km to 20 km:

$$ln\left(\frac{P}{P_b}\right) = -\frac{g_0}{RT_b}(h - h_b)$$

$$T = Const.$$

Where *h* is measured in meters, note 1 ft = 0.3048 m.

d.) For a steady, adiabatic, isentropic and inviscid flow, the total pressure (P_T), free stream pressure (P_∞) and free stream Mach number (M_∞) are related as,

$$P_T = P_\infty\left[1 + \frac{\gamma - 1}{2}M_\infty^2\right]^{\frac{\gamma}{\gamma-1}}$$

e.) Atmospheric air can be treated as a perfect gas,

$$P = \rho R_g T$$

Speed of sound $a = \sqrt{\gamma RT}$.

f.) Airfoil lift curve slope a_0 and 3-D wing lift curve slope a_1 are related as:

$$a_1 = \frac{a_0}{1 + \left(\frac{a_0}{\pi AR}\right)(1 + \tau)}$$