Reg.No.										

MANIPAL INSTITUTE OF TECHNOLOGY

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V SEMESTER B.TECH. (AERONAUTICAL ENGINEERING)

END SEMESTER EXAMINATIONS, JAN/FEB 2021

SUBJECT: FLIGHT DYNAMICS [AAE - 3157]

REVISED CREDIT SYSTEM

(04/02/2021)

Time: 3 Hours MAX. MARKS: 50

Instructions to Candidates:

- Answer **ALL** the questions.
- Missing data may be suitably assumed.
- Draw figures wherever necessary

1A. A subsonic aircraft is trimmed in level flight at a speed of V_1 at certain altitude h_1 at an angle of attack $\alpha = 4°$ using an elevator deflection of δ_{e1}. The aircraft (same weight & CG) flying level at a higher altitude of h_2 (> h_1) needs a higher α of 8° at a slightly higher flight speed of V_2 and uses an elevator deflection of δ_{e2} to trim. For these level flight conditions in subsonic regime, assume that the longitudinal trim curve, δ_e Vs α does not depend on speed/ altitude/Mach No. Draw δ_e Vs α curve for the level flight and obtain a relationship between δ_{e0}, δ_{e1} and δ_{e2}, where δ_{e0} denotes elevator angle extrapolated for trim at $\alpha = 0$. **(04)**

1B. For the above aircraft the following data is supplemented for estimation of trim elevator required for level flight: **(04)**

Stall angle $\alpha_{stall} = 12°$, $\delta_{e0} = +2.5°$ and $\delta_{emax} / \delta_{emin} = \pm 20°$.

If the maximum available up elevator (δ_{emin}) is used for trimming the manoeuvre flight at α_{stall}, for the forward most CG and the static margin SM for forward most CG is 0.8 MM (Manoeuvre Margin) at the same CG, obtain the elevator angle δ_{etrim} required for level flight at α_{stall}. Show your result in a typical longitudinal trim curve (δ_e Vs α).

1C What is trim drag? Draw a side view of an aircraft showing CG, neutral point (NP) and AC of the tail and the forces acting to illustrate your answer **(02)**

2A A transport aircraft has 4 engines symmetrically mounted on its wings of 65 m span and area 525 m^2. Inboard and outboard engines are located respectively at 11.7 m and 21.7 m from aircraft plane of symmetry. The SL maximum thrust (T_{SL}) per engine is 282 kN. The engine thrust T at any altitude h is related to its thrust T_{SL} at sea level and the density ratio σ at the altitude h by $T = T_{SL}\sigma$. The aircraft encounters **starboard** outboard engine failure at V_F = 160 m/s at h_F = 2000 m (σ_F= 0.8216). The engines were set at 80% throttle for trimmed level flight prior to engine failure. Following the engine failure, the Pilot is advised to **(04)**

descend to recommended control altitude h_C with $\sigma_C = (4/3)\sigma_F$ (for a 4 engine aircraft) and also reduce the flight speed to recommended control speed $V_C = [\sqrt{(3/4)}]V_F$ (also for a 4 engine aircraft), retaining the throttle setting (80%) and fly level at h_C after the descent. Calculate the yawing moment $(N_E)_F$ and the yawing moment coefficient $(C_{NE})_F$ due to asymmetric power, immediately following the engine failure and $(N_E)_C$ and $(C_{NE})_C$ after descending to control altitude h_C and decelerating to control speed V_C

2B. Given rudder control power $C_{N\delta r} = - 0.0014/°$, obtain the rudder deflection δ_r required to trim the asymmetric yawing moment to maintain zero side slip angle at **(04)**

i) the initial altitude h_F and

ii) the lower altitude h_C after descent.

Show in a plan view of the aircraft, the asymmetric thrust, the resulting yawing moment and the rudder deflection required to trim the yawing moment at both the altitudes h_F and h_C.

State briefly how the side force due to rudder is trimmed in such a flight.

2C. If the aircraft encounters a side gust following the engine failure, which one of the following two side gust cases is critical from trimming the yawing moment: **(02)**

i) the side gust from the failed engine side or

ii) the side gust from the side where both the engines are working?

Illustrate this in the above figure showing plan view with rudder deflections

3A. Following the standard notations, the 6 Force and Moment equations governing aircraft motion are given below: **(05)**

$$(-mg \sin \theta) + X = m (U\_dot + qW - rV)$$
$$(mg \cos \theta \sin \varphi) + Y = m (V\_dot + rU - pW)$$
$$(mg \cos \theta \cos \varphi) + Z = m (W\_dot + pV - qU)$$
$$L = I_x\, p\_dot - I_{xz}(pq + r\_dot) + (I_z - I_y)\, qr$$
$$M = I_y\, q\_dot + (I_x - I_z)\, rp + I_{xz}(p^2 - r^2)$$
$$N = I_z\, r\_dot - I_{xz}(p\_dot - qr) + (I_y - I_x)\, pq$$

where (X, Y, Z), (L, M, N) are aerodynamic forces and moments. Considering the dependence of inertia force components on two of the three Euler angles (φ, θ, ψ), as seen above, suggest two additional equations to close the above set of 6 equations for the motion parameters (U, V, W), (p, q, r) and (φ, θ). Starting from this set of 8 equations, obtain the 2 decoupled sets of equations for Longitudinal motion and Lateral – Directional motion of aircraft. State clearly your assumptions made in obtaining decoupled sets of equations.

3B. The characteristic equation of coupled longitudinal and lateral-directional aircraft motion is known to be an 8th order equation. A typical set of 8 roots of such a characteristic equation for some flight condition is given below: **(05)**

$\lambda_{1.2} = -4.4 \pm i\, 65.5$, $\lambda_3 = -2$, $\lambda_4 = 0.05$, $\lambda_{5,6} = -0.35 \pm i\, 12.5$ and $\lambda_{7,8} = -1.4 \pm i\, 41.5$

Show these roots in the λ (η, ω) plane indicating the nature of dynamic modes of the aircraft, associated with the 3 pairs of complex conjugate roots - period (short/ medium/ long period) and damping (highly/ moderately/ lightly damped) and the 2 real roots (highly/ negatively damped). Also name the aircraft modes associated with all the 8 roots including 2 real roots. Obtain the time to half $T_{½}$

or time to double T_2 as applicable for all the modes and the period T for periodic modes.

4A. A set of 3 linearised Force and Moment equations given below are used for studying lateral – directional dynamics and response of an aircraft **(06)**

$$\Delta\dot{v} = Y_v\,\Delta v + Y_p\,\Delta p + (Y_r - u_0)\Delta r + \left(g\cos\theta_0\right)\Delta\phi + Y_{\delta_r}\,\Delta\delta_r$$

$$\Delta\dot{p} - (I_{xz}/I_{xx})\Delta\dot{r} = L_v\,\Delta v + L_p\,\Delta p + L_r\,\Delta r + L_{\delta_a}\,\Delta\delta_a + L_{\delta_r}\,\Delta\delta_r$$

$$\Delta\dot{r} - (I_{xz}/I_{zz})\Delta\dot{p} = N_v\,\Delta v + N_p\,\Delta p + N_r\,\Delta r + N_{\delta_a}\,\Delta\delta_a + N_{\delta_r}\,\Delta\delta_r$$

From this set of equations, choose relevant 2 equations used for studying spiral dynamics and carry out applicable simplifications for capturing essential features of spiral mode of lateral - directional dynamics of the aircraft. Obtain the root(s) of the characteristic equation for this spiral motion and describe the aircraft motion with suitable sketches.

4B. Calculate the time to half or time to double as applicable for the spiral characteristics of the aircraft with the following data: **(04)**

$C_{l\beta}$ = −0.103 /rad C_{lr} = 0.11 /rad $C_{n\beta}$ = 0.137 /rad C_{nr} = −0.16 /rad

5A. The transfer function given below is for one of the longitudinal dynamic responses (SPO) of angle of attack of aircraft α for elevator control input δ_e: **(06)**

$$[LT(\alpha)/LT(\delta_e)] = \{-0.8952s - 250.3\} / \{810\, s^2 + 1633.9s + 6542.9\}$$

Find the natural frequency and damping ratio for this mode. Using the final value theory or otherwise, find the steady state value of angle of attack α in response to step elevator input of -3°.

5B. The following three qualitative descriptions for the three important attributes of an aircraft in flight are used in classifying the Handling Qualities of the aircraft: **(04)**

Pilot Load : Excessively High / Moderately High / Acceptable,

Mission Accomplishments: Partially accomplished & not acceptable/ Accomplished with some deterioration / Fully accomplished

Flight Safety: Safe/Unsafe,

Using the above descriptions, classify the Aircraft Handling Quality into Levels 1, 2 and 3. What are the dynamic characteristics of the aircraft which affect the Pilot in his flying mission and the Handling Quality Levels?