Reg. No.										

MANIPAL INSTITUTE OF TECHNOLOGY

MANIPAL

(A constituent unit of MAHE, Manipal)

V SEMESTER B.TECH. (AERONAUTICAL ENGINEERING)

END SEMESTER EXAMINATIONS, NOV 2018

SUBJECT: AIRCRAFT DESIGN I [AAE 3104]

REVISED CREDIT SYSTEM
(30/11/2018)

Time: 3 Hours MAX. MARKS: 50

Instructions to Candidates:

- Answer **ALL** the questions.
- Missing data may be suitable assumed.
- Draw suitable graphs or schematic plot/s whenever possible to give final results

1A. In drawing constraint diagram for an aircraft, meeting design requirements on take-off distance ($\leq$ 1800 m), cruise (0.85 M at 11 km), landing distance ($\leq$ 1800 m) and FAR requirements on climb gradient (3% for OEI case), the following relationships between wing loading (W_{TO}/S) and thrust to weight ratio (T_{SSL}/W_{TO}), were obtained using preliminary design inputs: **(02)**

Take Off: $(T_{SSL}/W_{TO}) = 7.045 \times 10^{-5} (W_{TO}/S) + 0.02$

Cruise: $(T_{SSL}/W_{TO}) = 770.6 / (W_{TO}/S) + 1.0317 \times 10^{-5} (W_{TO}/S)$

Landing: $(W_{TO}/S) = 7840 \text{ N/m}^2$

Climb: $(T_{SSL}/W_{TO}) = 0.2452$

Starting from FAR climb gradient requirement (CGR = 3%) for one engine inoperative (OEI) case of a multi-engine aircraft with N engines, obtain climb performance curve relating (W_{TO}/S) and (T_{SSL}/W_{TO}). You may use the climb angle given by $\sin \gamma = (T - D)/W$.

1B. Solving Take off and Cruise equations given above graphically or otherwise, obtain design point $[(T_{SSL}/W_{TO})_1, (W_{TO}/S)_1]$ meeting this pair of performance requirements. **(02)**

1C. Solving Take-off and Landing equations given above graphically or otherwise, obtain design point $[(T_{SSL}/W_{TO})_2, (W_{TO}/S)_2]$ meeting this pair of performance requirements. **(02)**

1D. Draw or plot approximately the constraint diagram in design space $[(T_{SSL}/W_{TO}), (W_{TO}/S)]$, showing relevant boundaries representing performance and FAR requirements capturing above two design points and show clearly the feasible design space on this diagram. **(02)**

1E. Choose your design point, show the same in above constraint diagram and explain the basis for selecting your design point. **(02)**

2A. A long-haul transport aircraft with a passenger capacity of 350 (mixed seating) and range of 10000 km, has an estimated pay load (mass) of 52 T. Mission analysis carried out with initial design inputs gave a fuel fraction $W_{Fuel}/W_{TO} = 0.28$. Correlation of aircraft empty weight including aircraft structure, equipment and systems onboard (W_{Empty} in N) with take-off weight (W_{TO} in N) for all metal aircraft is given to be $W_{Empty} = 0.911 W_{TO}^{0.947}$. Assume a Technology Factor $K_S = 0.8$ to account for effect of advanced technologies in designing and building a lighter empty aircraft. **(07)**

Obtain Take-off weight, Empty weight and Fuel weight in kN for the above aircraft. Also, briefly outline your formulation to determine W_{TO} and W_{Empty} and illustrate your approach with figures/tables used. Use straight line fit and linear interpolation/extrapolation wherever required. Range of take-off mass may be taken to be between 2.5 and 3 times the pay load for solving the equation relating W_{Empty} and W_{TO}

2B. In the next design iteration with component mass build up approach, the empty mass of the aircraft was found to be 8% lighter than the previously estimated value. The mission fuel mass estimated with revised aerodynamic and engine data, was found to be 32.3 T. Calculate the revised take-off weight in kN with no change in pay load. **(03)**

3A. Table below shows mass and CG location of fully equipped fuselage, wing, empennage and engine. The CG locations are given in terms of aircraft stations, indicating distance from aircraft nose in centimetres. Similarly, mass and CG of pay load and fuel contents of inboard (IB) and outboard (OB) fuel tanks are also given in the table. **(06)**

Assembly/System	Mass in T	CG Location – Aircraft Station
Fuselage with Equipment	70 T	Stn 3700
Wing with Equipment	55	Stn 3800
Propulsion System	19	Stn 2950
Empennage	12	Stn 6800
Pay Load	56	Stn 3600
Fuel IB Tank	87	Stn 3450
Fuel OB Tank	58	Stn 4100

Accompanying Figure 1 shows these stations representing CG locations, front (Stn 1300) and rear (Stn 5900) ends of passenger cabin and location of main landing gear (MLG) (Stn 5900).

Obtain the following 4 corners defining basic 4 boundaries of aircraft weight Vs CG carpet plot:

Corner 1	W_{Empty} + 00% Pay Load + 00% Fuel (156 T)
Corner 2	W_{Empty} +100% Pay Load + 00% Fuel (212 T)
Corner 3	W_{Empty} + 00% Pay Load + 100% Fuel (301 T)
Corner 4	W_{Empty} + 100% Pay Load + 100% Fuel (357 T)

Draw or plot approximately the carpet plots (CG location in x-axis and aircraft mass in y-axis), identifying coordinates of 4 corners, also showing constant Pay Load and constant Fuel boundaries.

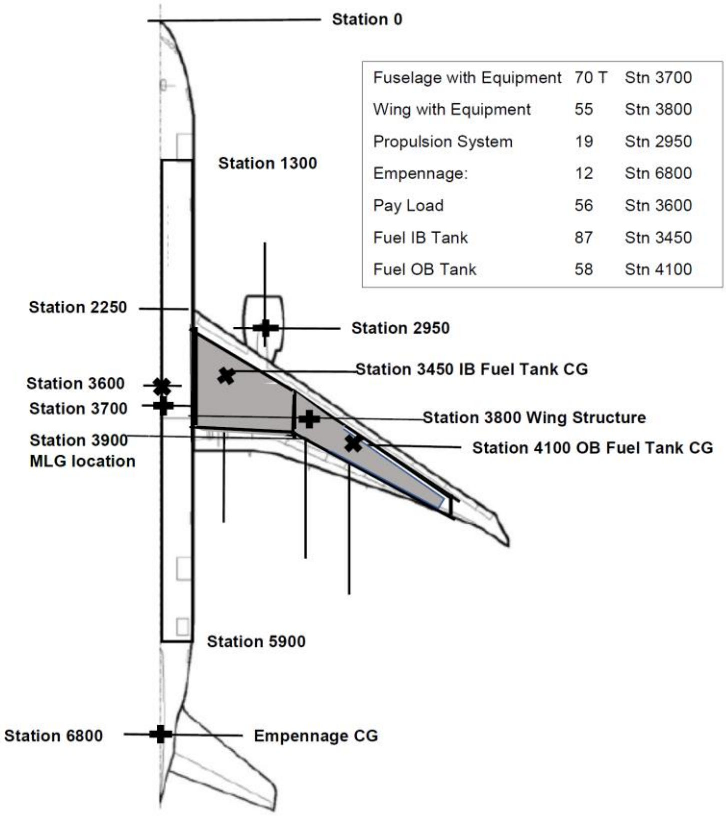

Figure 1

3B. Given MAC of aircraft wing to be 8.5 m, calculate aircraft CG traverse in percentage of MAC. **(02)**

3C. Is the location of main landing gear (Stn 3900) acceptable for ground handling of the aircraft? If so why? **(02)**

4A. For estimation of aircraft take off distance of a multi-engine aircraft as per FAR we have to calculate normal take off distance for all engine operative case (AEO) and balanced field length (BFL) for one engine inoperative (OEI) case. Towards this, the following basic aircraft data is given for take-off condition: **(02)**

Wing loading (W_{TO}/S) = 6500 N
Thrust to weight ratio (T_{SSL}/W_{TO}) = 0.275
C_{Lmax} = 1.8
Runway rolling friction coefficient μ = 0.02
Climb angle γ achievable for AEO case = 10 deg
Sea Level air density ρ = 1.225 kg/m^3

For AEO condition the ground acceleration may be assumed to be 90% of initial acceleration at brake release point given by $[(T_{SSL}/W_{TO}) - \mu]g$. The acceleration and climb angle γ following one engine failure during take off (OEI case), may be assumed to be 50% of corresponding values for AEO case respectively. Obtain normal take off distance for AEO case making suitable assumptions.

4B. Calculate TODR - take off distance required and ASDR - accelerate-stop distance required, following one engine failure, for two cases of failure speeds (V_F) of 0.65 V_R and 0.85V_R, where V_R is rotation speed (=1.2 V_{Stall})). Assume 3 seconds of response time following the engine failure, for pilot to decide aborting the take-off, initiate **(06)**

cutting off working engine/s and apply brakes to achieve average deceleration of 0.25g required to bring the aircraft to rest. By suitably interpolating/extrapolating estimated values of TODR and ASDR at two failure speeds V_F, obtain decision speed V_{Dec} and BFL.

4C. Estimate the take-off distance of above aircraft as per FAR? **(02)**

5A. The following aircraft mass, drag polar and engine data generated during preliminary design of a transport aircraft is provided for assessing adoptability of the aircraft in handling higher range segments in Pay Load Vs Range trade off studies: **(07)**

Aircraft Empty Mass M_{Empty} = 167.8 T
Max Pay Load M_{PL}= 66.7 T
Mission Fuel on board $M_{MisFuel}$= 120 T
Max Take off Mass M_{TO} = 354.5 T
Max Fuel tank capacity = 1.3 $M_{MisFuel}$
Drag Polar of aircraft $C_D = 0.013 + 0.0335C_L^2$
Density at cruise altitude of 11 km = 0.3639 kg/m^3
Thrust Specific Fuel Consumption c_t at cruise altitude =1.52 x10^{-4} N/Ns
Aircraft Lift curve $C_L = 0.0802\ (\alpha + 1.4)$ (α in deg.)

Draw Pay Load Vs Range trade off diagram considering the following 3 cruise segments AB, CD, OE:

AB:
Take off with design pay load of M_{PL}, mission fuel of $M_{MisFuel}$ and take off mass M_{TO}
CD:
Take off with payload of (M_{PL}–0.3$M_{MisFuel}$), fuel of 1.3M_{MisFue} and take off mass M_{TO}
OE:
Take off with zero payload, max fuel of 1.3 $M_{MisFuel}$ and reduced take off mass (<M_{TO})

For Range Vs Pay Load trade off studies, consider the following fuel availability in the beginning and at end of all the three cruise segments:
0.04 $M_{MisFuel}$ utilised in reaching cruse altitude of 11 km and 0.08 $M_{MisFuel}$ to be retained as unused fuel for meeting any flight exigencies before landing.
You may use the following range formula for maximum range

$$R = \frac{2}{c_t}\sqrt{\frac{2}{\rho_\infty S}}\frac{C_L^{1/2}}{C_D}\left(W_0^{1/2} - W_1^{1/2}\right)$$

where C_L (= $\sqrt{[C_{D0}/3k]}$ and $C_D = (4/3)C_{D0}$ giving

$$\left(\frac{C_L^{1/2}}{C_D}\right)_{max} = \frac{3}{4}\left(\frac{1}{3KC_{D_0}^3}\right)^{1/4}$$

Tabulate range, take off mass, pay load and onboard fuel mass for all the three cruise segments analysed for range and pay load trade off studies.

5B. Calculate C_L for max range cruise, optimum angle of attack for max range cruise and wing setting for above aircraft. **(03)**