AE 5535 **Assigned: March 5, 2021**
Due: March 29, 2021

<u>Project: Turbojet Engine Design/Off-Design Performance Analysis</u>

Consider a single-spool fixed-area turbojet missile-class engine which has compressor and turbine maps attached. The engine has a simple converging nozzle (i.e. station 8 is the exit of the engine). For consistency and simplicity, assume that $\dot{m}_{fuel} << \dot{m}_{air}$ (i.e. f << 1). The engine "design point" values are as follows:

$M_0 = 0.8$ Altitude = sea level (T_0 = 288K, P_0 = 101325 N/m^2)

π_C = 15 A_1 (inlet face area) = 0.00318 m^2 π_b = 1.0 η_t = .90

$M_2 = 0.5$ RPM_{design} = 60,000 RPM T_{t4} = 1500K π_d = .9904

A. The flow is choked at both turbine inlet and nozzle throats. Assume fuel-air ratio is much less than 1.0 throughout all your work (including in part B and C) and use constant specific heats, etc. (γ=1.4, C_P = 1004.5 J/kg-K, R = 287 J/kg-K.) The heating value of the fuel is 4.45x10^7 J/kg (fuel). At the design point, the compressor maintains constant axial velocity (i.e., $u_3 = u_2$) and the turbine exit velocity is 80% of the turbine entrance velocity (i.e., u_5=0.8u_4). Also assume that the engine is sized to mandate *full mass capture* at this 'design point'.

   Completely define the on-design engine fluid dynamics, areas. and performance. Specifically, fill out the relevant information (data table and other information) relevant to this section as given below.

B. Determine, tabulate (fill in information on the attached data table provided below for this section), and plot on the compressor map the steady-state operating line for this engine. Use a convergence requirement (between right hand side and left-hand side of the nozzle matching criteria) of at least 0.01 for all operating points.

   Assume that that the flow remains choked at both *turbine* inlet and nozzle throats for the operating range of interest and that the turbine efficiency (η_t) is constant for the development of the operating line. Perform your analysis assuming that the engine control system prevents compressor ratios higher than 19, shaft RPM greater than 66000 and burner exit temperatures higher than 1800K. After the operating line is developed, comment very briefly on the effect of the approximation of constant turbine efficiency by examining the turbine performance map provided and comparing the approximated turbine characteristics against the actual turbine performance map.

C. Develop the performance envelope of this engine by calculating and plotting raw engine thrust (uninstalled), turbo-machinery RPM, and engine spillage characteristics for flight Mach numbers from zero to 2.4, a full range of possible fuel throttle settings (ranging – as possible - from 20% of design throttle to max feasible throttle, in increments of 20% design fuel flow rate), and three altitudes (sea level, 4500m, and 9000m). Assume in this performance analysis that the inlet (diffuser) total pressure drop is given using the following empirical inlet relationship: $\pi_d = 1 - 0.015 * {M_o}^2$. This will result in nine plots (see attached summary of required plots).

Presentation (besides the requested data/plots): Besides the requested data tables, information, operating line plot, and nine operating envelope plots, also include in appendices work (neatly presented) and code(s) used and methodology description, etc. I am looking for an intelligible summary of your work that is not everything you did, but provides a clear picture of what you did, how you did it.

Note: This project will be graded based on 70% technical content, 30% presentation.

Data tables/information/plots required

A. On-Design Operation (fill in all information)

	Engine Station						
	0	1	2	3	4	5	8
u (m/s)							
P (N/m^2)							
T (K)							
Mach (M)							
ρ (kg/m^3)							
A (m^2)							
P_t (N/m^2)							
T_t (K)							

τ_t (T_{t5}/T_{t4}) =

π_t (P_{t5}/P_{t4}) =

Thrust (uninstalled) =

$\dot{m}_{air}$ =

$\dot{m}_{fuel}$ =

f (fuel/air ratio) =

$\dot{m}_{corr4}$ =

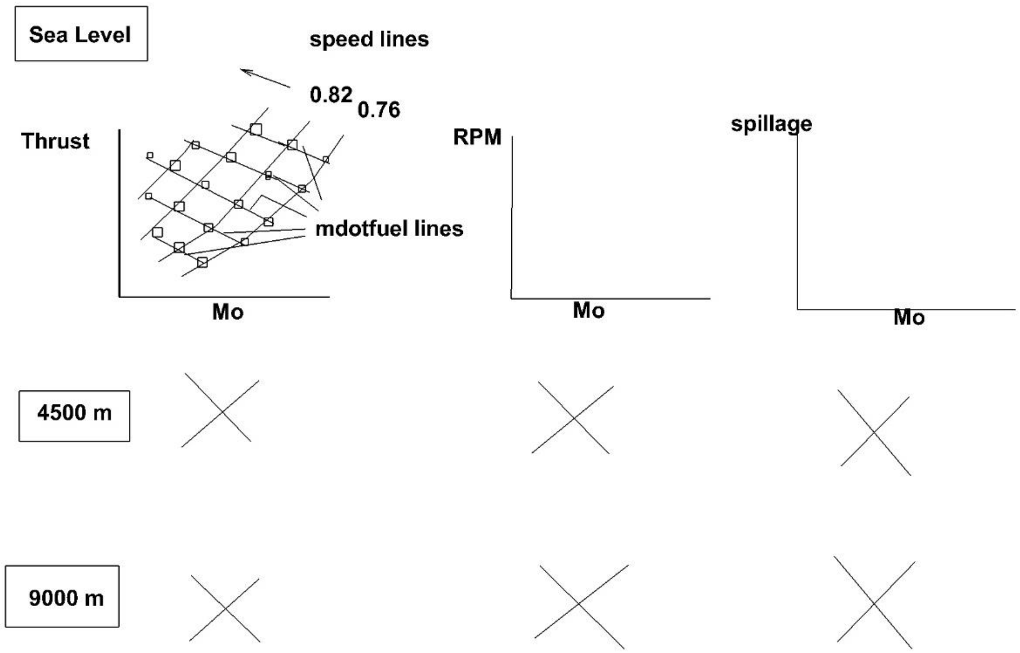
$\dot{m}_{corr8}$ =

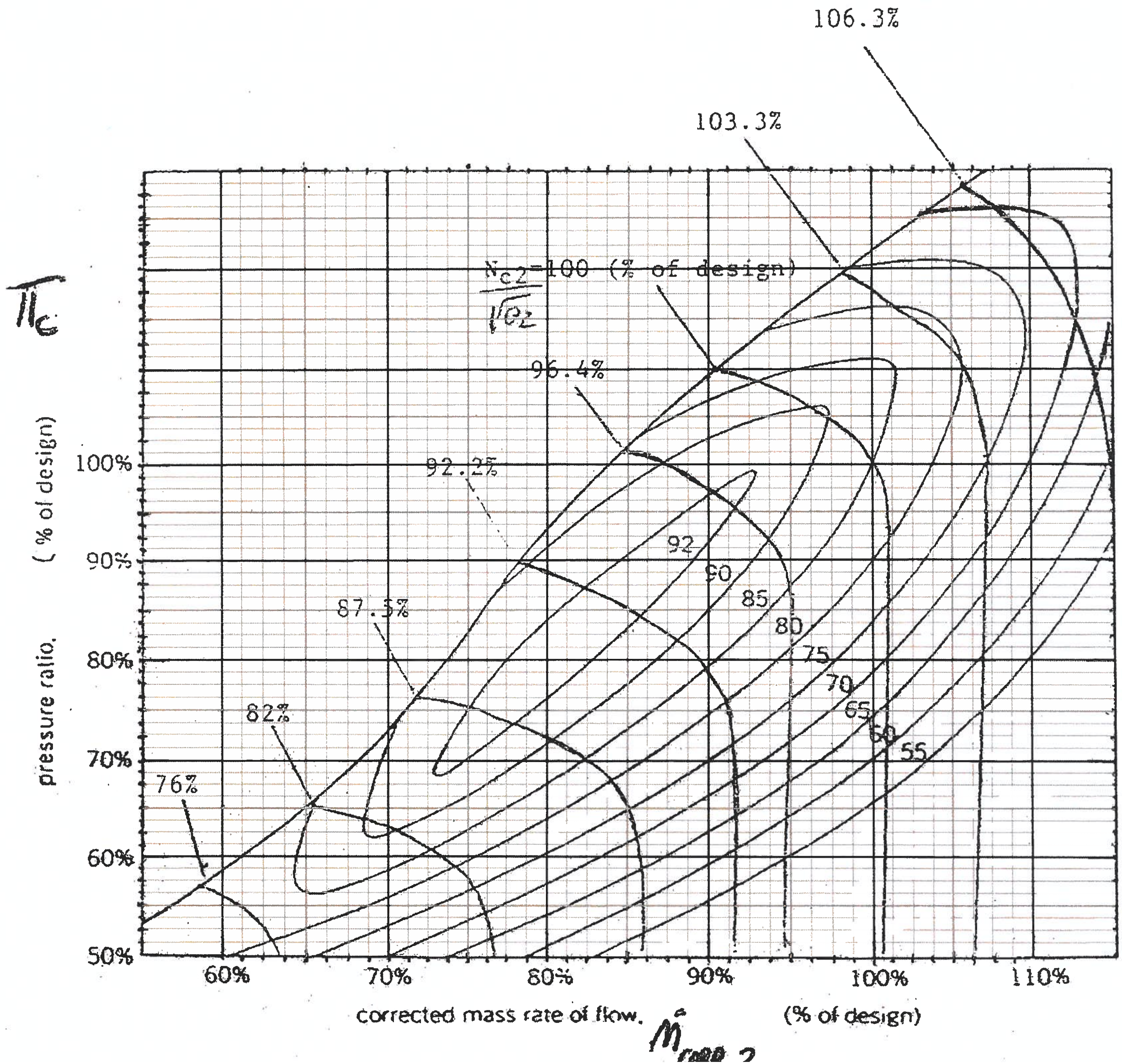
B. Operating Line Table (fill in all information)

Speed-Line	π_c	τ_c	$\dot{m}_{corr2}$	η_c	$N_c/\sqrt{\theta_2}$	$N_t/\sqrt{\theta_4}$	τ_t	π_t	T_{t4}/T_{t2}	Δ (convergence criteria)
0.76										
0.82										
0.875										
0.922										
0.964										
1.0										
1.033										
1.063										

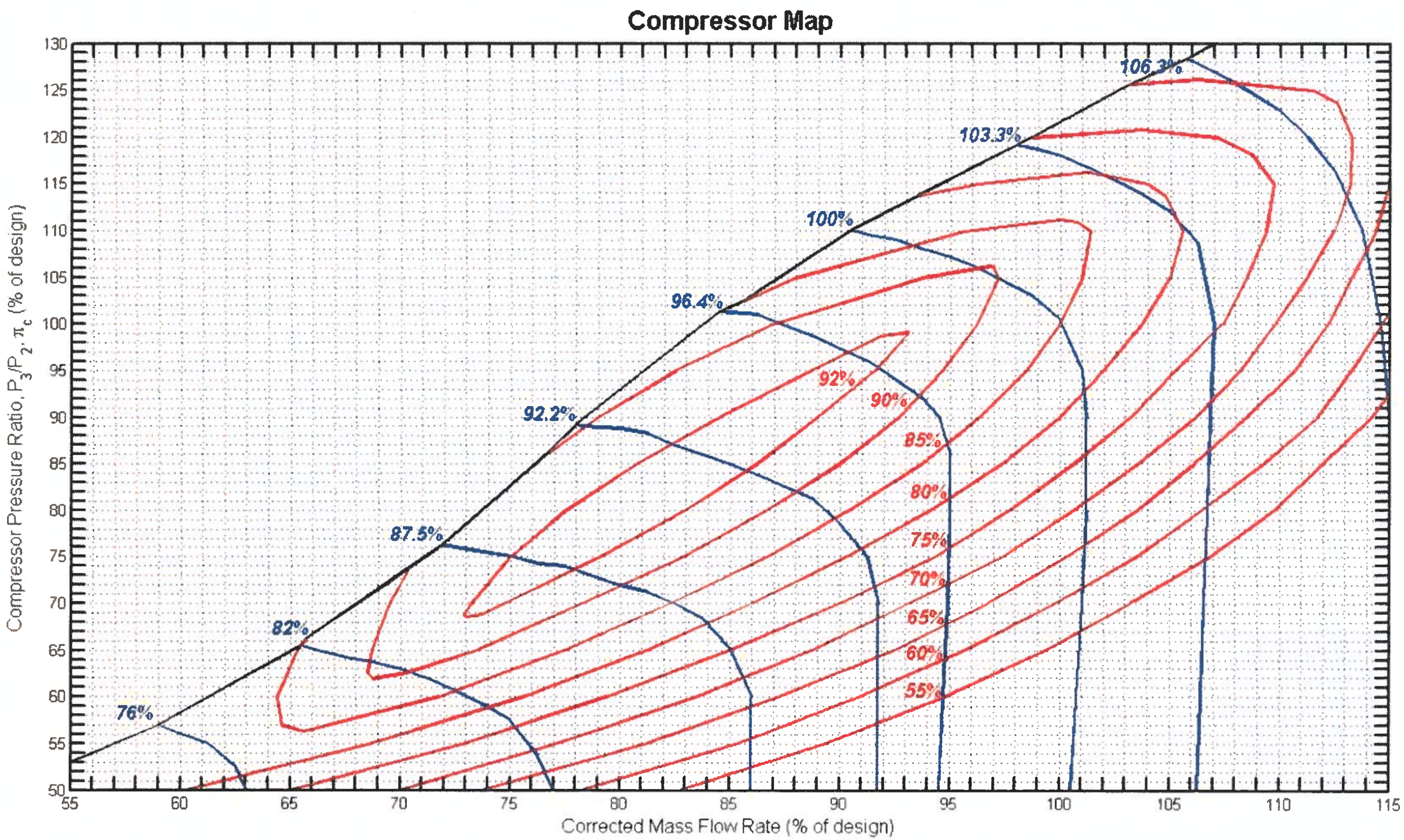
Plot on compressor map provided your operating line (Provide map with operating line):

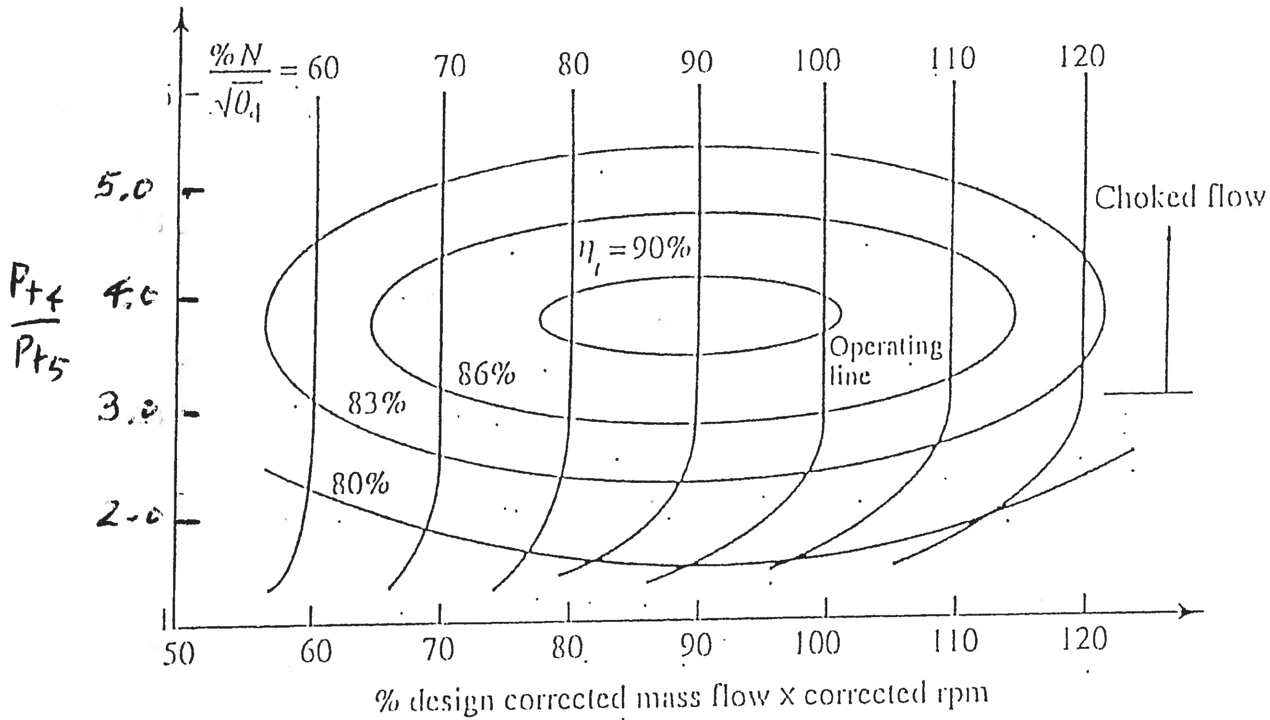
C. Engine Performance Deck (Thrust, RPM, spillage) – Provide 9 plots defining slices of engine operating space for throttle settings as required/allowable/make sure you span the allowable performance space:





106.3%
103.3%
$\frac{N_{c2}}{\sqrt{\theta_{c2}}}$=100 (% of design)
96.4%
92.2%
87.5%
82%
76%
92
90
85
80
75
70
65
60
55
π_c
pressure ratio. (% of design)
100%
90%
80%
70%
60%
50%
60%
70%
80%
90%
100%
110%
corrected mass rate of flow. $\hat{m}_{corr\,2}$ (% of design)


Compressor Map
Compressor Pressure Ratio, P_3/P_2, π_c (% of design)
Corrected Mass Flow Rate (% of design)
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
55
60
65
70
75
80
85
90
95
100
105
110
115
106.3%
103.3%
100%
96.4%
92.2%
87.5%
82%
76%
92%
90%
85%
80%
75%
70%
65%
60%
55%



$\frac{P_{t4}}{P_{t5}}$
5.0
4.0
3.0
2.0
$\frac{\% N}{\sqrt{\theta_4}} = 60$
70
80
90
100
110
120
$\eta_t = 90\%$
86%
83%
80%
Operating line
Choked flow
50
60
70
80
90
100
110
120
% design corrected mass flow x corrected rpm