King Fahd University of Petroleum and Minerals

Aerospace Engineering Department

Aerospace Propulsion

(AE 422)

Term Project

SALMAN AL-FIFI

ID # 991694

OBJECTIVES:

- To determine the best performance of a turbofan engine for different design compressor ratios and different bypass ratios.
- To check for the case of off design by changing different mach number and turbine inlet temperature and then determine the best performance.

BACKGROUND:

The following equations are used to calculate all the needed parameters:

By using the efficiencies values from table 5.1 and 5.2:

At 12 km we have:

P_a = 19399 pa
ρ = 0.31194 kg/m^3
T_a = 216.65 k
a = 295.069 m/s

$u_e = [2\ \eta_n\ cp\ T_{06}\ (1-(p_a / p_{06})^{(\gamma-1/\gamma)})]^{0.5}$

$u_{ef} = [2\ \eta_{fn}\ cp\ T_{08}\ (1-(p_a / p_{08})^{(\gamma-1/\gamma)})]^{0.5}$

$f = [(T_{04}/ T_{03})-1]/[Q/(cp\ T_{03})- (T_{04}/ T_{03})]$

$p_{02} = p_a\ [1+ \eta_d\ (T_{02}/ T_a)]^{(\gamma/ \gamma-1}$

$T_{02} = T_a\ [1+ 0.2\ M^2\ ]$

$T_{08} = T_{02}\ [1+ 1/\eta_f * (p_{rf} -1)]$

$u = M * a$

$p_{04} = (p_{03} / p_{02})* p_{02} *[(T_{04}/ T_{03})]^{(\gamma/ \gamma-1)}$

$T/m = (1+f)* u_e + \beta\ u_{ef} – (1+ \beta)\ u$

$TSFC = f/ (T/m) = f/ [(1+f)* u_e + \beta\ u_{ef} – (1+ \beta)\ u]$

Calculation Analysis:

Part 1:

➔Turbofan engine at mach (M=0.85), Altitude (h=12 km) with a turbine inlet temperature (T_{04} = 1560 k).
Find the optimum compressor pressure (P_{rc}) and bypass ratio.

By using the above equations, we got the following calculated results:

P_{02} = 30700 pa

T_{02} = 248 k

T_{08} = 283.9 k

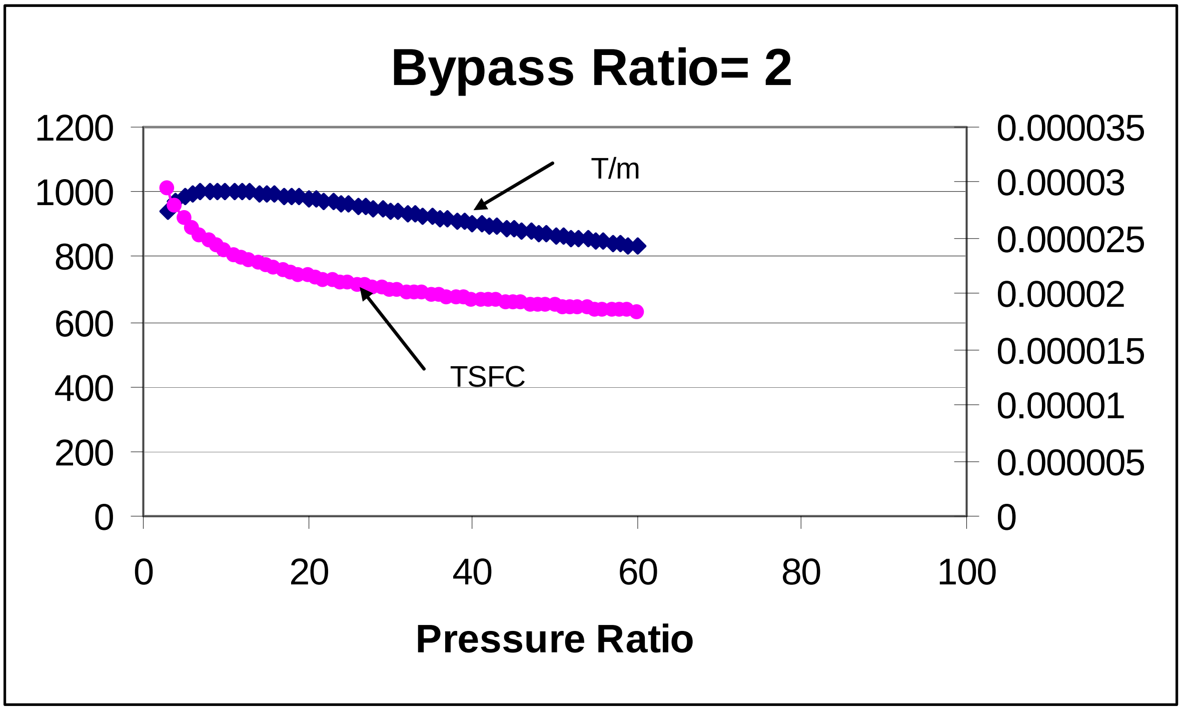
u = 250.8 m/s

P_{08} = 46050 pa

For $\beta = 2$, we have:

po3/po2	T/moa	TSFC
3	941.5778203	2.94432E-05
4	969.1178069	2.77927E-05
5	984.7436804	2.66836E-05
6	993.9919662	2.58622E-05
7	999.4170889	2.52161E-05
8	1002.372453	2.46867E-05
9	1003.645544	2.42398E-05
10	1003.726759	2.38541E-05
11	1002.937649	2.35154E-05
12	1001.497766	2.32137E-05
13	999.5619899	2.29419E-05
14	997.2425487	2.26948E-05
15	994.6226044	2.24684E-05
16	991.7649596	2.22594E-05
17	988.7178156	2.20654E-05
18	985.5186868	2.18845E-05
19	982.1971254	2.17149E-05
20	978.7766586	2.15554E-05
21	975.2761905	2.14048E-05
22	971.7110338	2.12622E-05
23	968.0936809	2.11268E-05
24	964.4343865	2.09979E-05
25	960.7416144	2.08749E-05
26	957.022383	2.07572E-05
27	953.2825359	2.06445E-05
28	949.5269546	2.05363E-05
29	945.7597286	2.04324E-05
30	941.9842914	2.03323E-05
31	938.2035297	2.02358E-05
32	934.4198735	2.01426E-05
33	930.6353684	2.00527E-05
34	926.851736	1.99656E-05
35	923.0704232	1.98813E-05
36	919.2926437	1.97997E-05
37	915.5194122	1.97204E-05
38	911.7515734	1.96435E-05
39	907.9898258	1.95688E-05
40	904.2347429	1.94961E-05
41	900.4867901	1.94255E-05
42	896.7463393	1.93567E-05
43	893.0136823	1.92897E-05
44	889.2890405	1.92244E-05
45	885.5725749	1.91607E-05
46	881.8643941	1.90986E-05
47	878.1645607	1.9038E-05

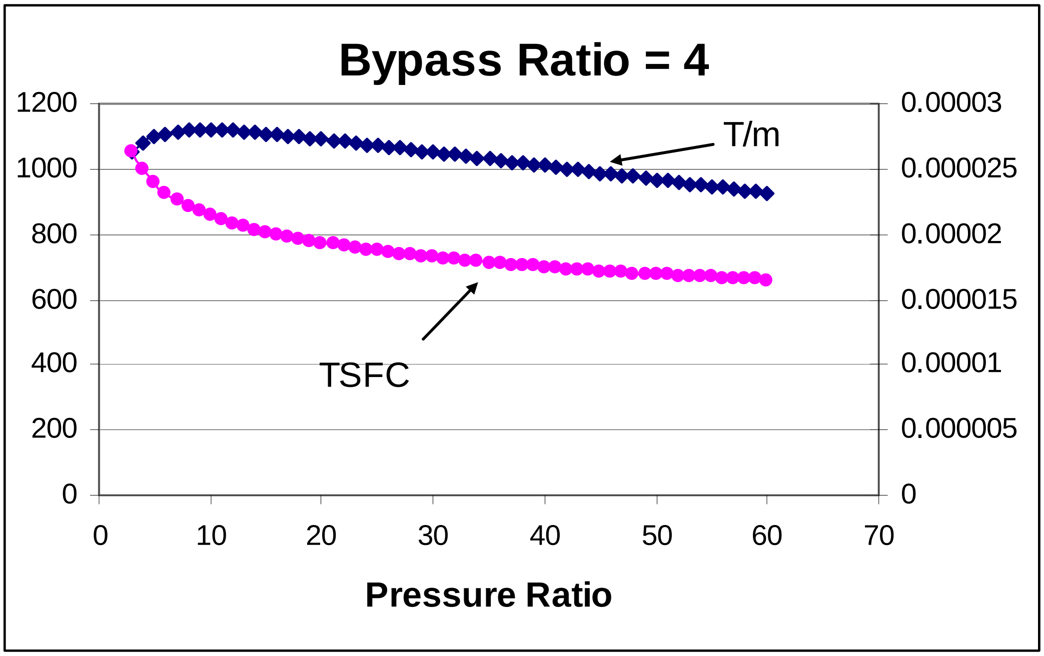
48	874.4730972	1.89789E-05
49	870.7899918	1.89211E-05
50	867.1152022	1.88647E-05
51	863.4486597	1.88096E-05
52	859.7902725	1.87557E-05
53	856.1399287	1.8703E-05
54	852.497499	1.86514E-05
55	848.8628384	1.8601E-05
56	845.2357889	1.85517E-05
57	841.6161806	1.85034E-05
58	838.0038335	1.84561E-05
59	834.3985587	1.84099E-05
60	830.8001596	1.83646E-05



For $\beta = 4$, we have:

po3/po2	T/moa	TSFC
3	1050.455527	2.63915E-05
4	1080.710766	2.49229E-05
5	1097.829291	2.39349E-05
6	1107.955241	2.3202E-05
7	1113.90221	2.26244E-05
8	1117.153936	2.21503E-05
9	1118.570989	2.17493E-05
10	1118.688069	2.14028E-05
11	1117.855196	2.10979E-05
12	1116.311072	2.08261E-05
13	1114.223934	2.0581E-05
14	1111.715611	2.0358E-05
15	1108.876334	2.01533E-05
16	1105.774228	1.99644E-05
17	1102.461566	1.97889E-05
18	1098.979028	1.96251E-05
19	1095.35866	1.94716E-05
20	1091.625977	1.93271E-05
21	1087.80148	1.91907E-05
22	1083.901777	1.90615E-05
23	1079.940419	1.89388E-05
24	1075.928532	1.8822E-05
25	1071.875298	1.87105E-05
26	1067.788331	1.8604E-05
27	1063.673972	1.85019E-05
28	1059.537514	1.84041E-05
29	1055.383392	1.831E-05
30	1051.215326	1.82195E-05
31	1047.036442	1.81324E-05
32	1042.849367	1.80483E-05
33	1038.656311	1.79672E-05
34	1034.459128	1.78887E-05
35	1030.259373	1.78129E-05
36	1026.058344	1.77394E-05
37	1021.857121	1.76683E-05
38	1017.656597	1.75993E-05
39	1013.457505	1.75323E-05
40	1009.260437	1.74673E-05
41	1005.065867	1.74042E-05
42	1000.874165	1.73429E-05
43	996.6856093	1.72832E-05
44	992.5004006	1.72252E-05
45	988.3186711	1.71688E-05
46	984.1404925	1.71138E-05

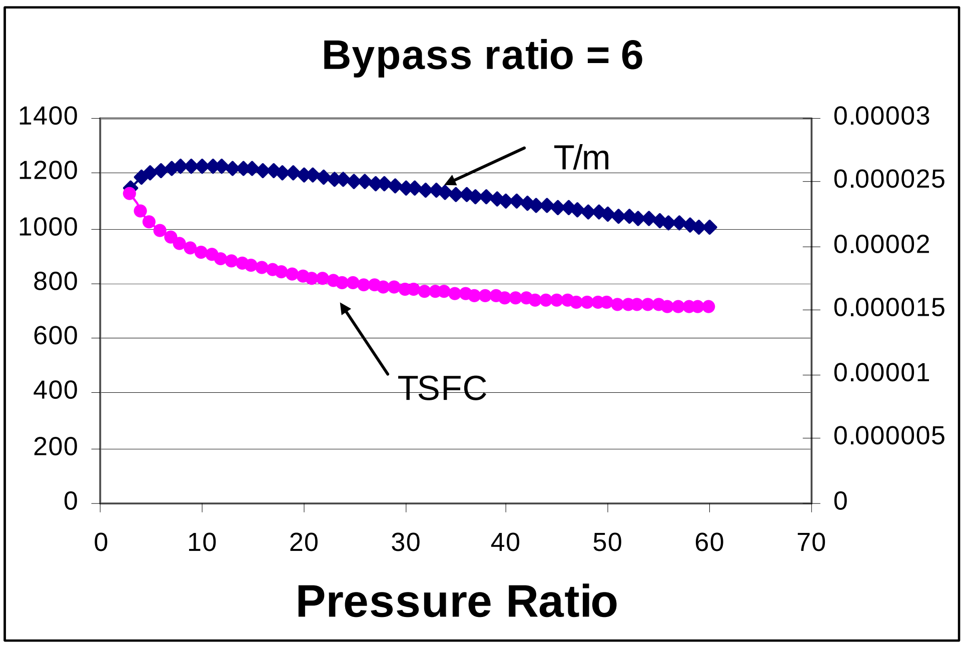
47	979.9658842	1.70603E-05
48	975.7948196	1.70082E-05
49	971.6272311	1.69575E-05
50	967.4630155	1.6908E-05
51	963.3020378	1.68598E-05
52	959.1441349	1.68128E-05
53	954.9891189	1.67671E-05
54	950.8367796	1.67224E-05
55	946.6868869	1.66789E-05
56	942.5391931	1.66365E-05
57	938.3934343	1.65951E-05
58	934.2493324	1.65548E-05
59	930.106596	1.65155E-05
60	925.9649221	1.64772E-05



For β = 6, we have:

po3/po2	T/moa	TSFC
3	1149.597915	2.41154E-05
4	1183.459338	2.27591E-05
5	1202.517687	2.18512E-05
6	1213.763398	2.11794E-05
7	1220.361793	2.06508E-05
8	1223.970525	2.02172E-05
9	1225.546517	1.98509E-05
10	1225.682336	1.95344E-05
11	1224.764917	1.92563E-05
12	1223.057633	1.90085E-05
13	1220.745843	1.87851E-05
14	1217.963614	1.8582E-05
15	1214.810157	1.83959E-05
16	1211.360314	1.82242E-05
17	1207.671481	1.80649E-05
18	1203.788298	1.79164E-05
19	1199.745913	1.77774E-05
20	1195.572291	1.76467E-05
21	1191.289895	1.75236E-05
22	1186.916907	1.74071E-05
23	1182.46815	1.72966E-05
24	1177.955781	1.71917E-05
25	1173.389821	1.70918E-05
26	1168.778568	1.69965E-05
27	1164.128913	1.69054E-05
28	1159.446597	1.68182E-05
29	1154.736413	1.67346E-05
30	1150.002364	1.66545E-05
31	1145.247795	1.65774E-05
32	1140.475498	1.65034E-05
33	1135.687803	1.64321E-05
34	1130.886639	1.63634E-05
35	1126.073605	1.62972E-05
36	1121.250008	1.62334E-05
37	1116.416911	1.61718E-05
38	1111.575165	1.61123E-05
39	1106.725435	1.60548E-05
40	1101.868227	1.59993E-05
41	1097.003908	1.59456E-05
42	1092.132724	1.58937E-05
43	1087.254812	1.58435E-05
44	1082.370215	1.5795E-05
45	1077.478893	1.57481E-05
46	1072.580728	1.57027E-05
47	1067.67554	1.56588E-05
48	1062.763084	1.56164E-05

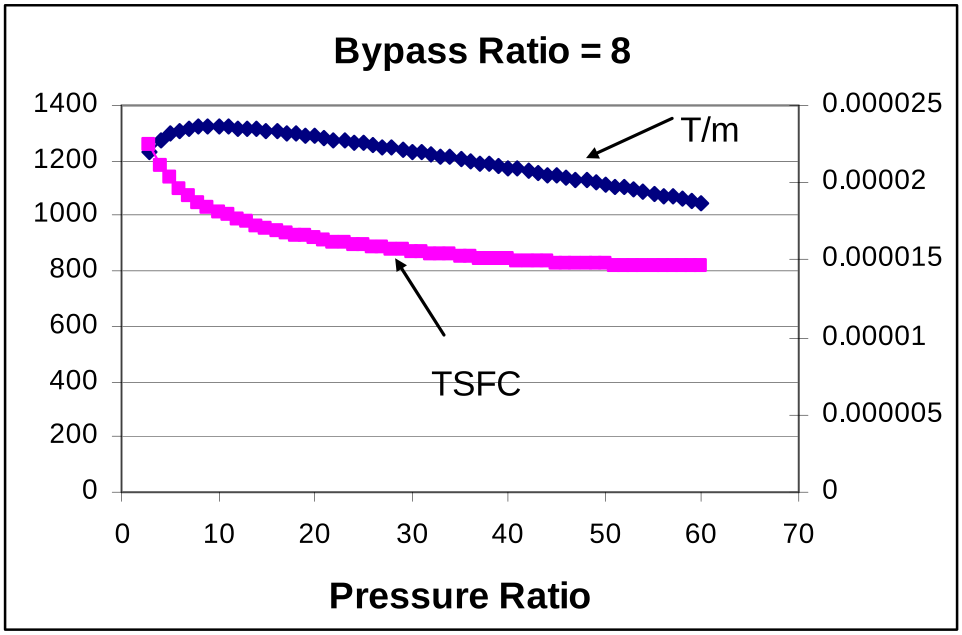
49	1057.843062	1.55754E-05
50	1052.915129	1.55358E-05
51	1047.97889	1.54975E-05
52	1043.033911	1.54606E-05
53	1038.079719	1.5425E-05
54	1033.115803	1.53906E-05
55	1028.141619	1.53575E-05
56	1023.156589	1.53256E-05
57	1018.160106	1.5295E-05
58	1013.151531	1.52655E-05
59	1008.130195	1.52373E-05
60	1003.095403	1.52102E-05



For $\beta = 8$, we have:

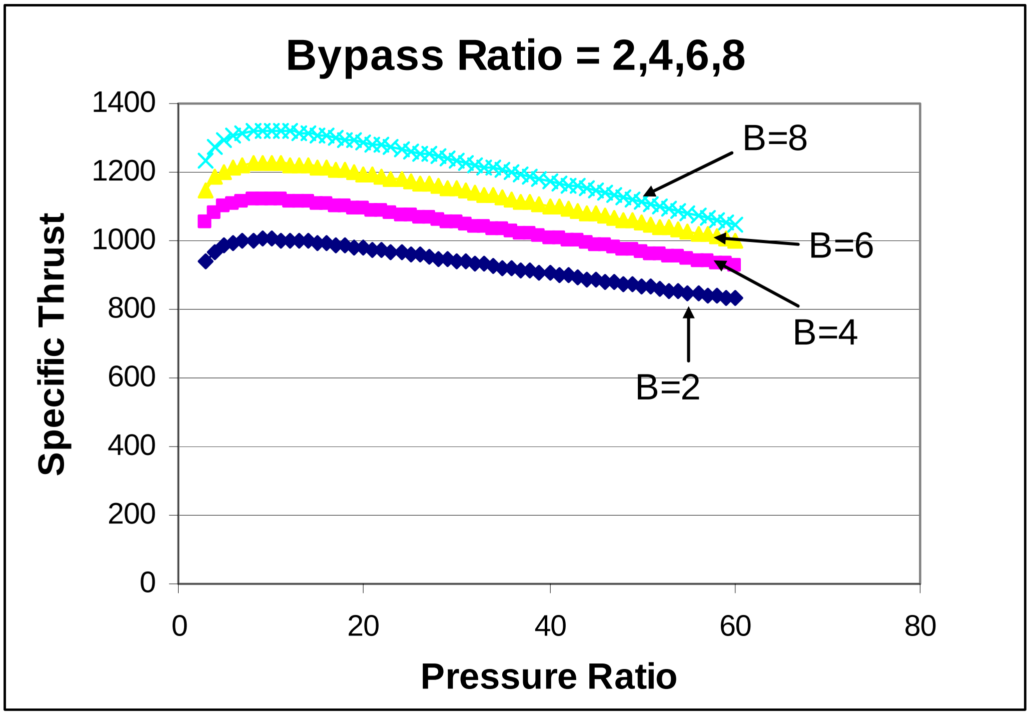
po3/po2	T/moa	TSFC
3	1234.884599	2.24499E-05
4	1273.9047	2.11432E-05
5	1295.654366	2.02805E-05
6	1308.416983	1.96472E-05
7	1315.874386	1.91518E-05
8	1319.933286	1.87474E-05
9	1321.686163	1.84069E-05
10	1321.805906	1.81139E-05
11	1320.730131	1.78571E-05
12	1318.755781	1.76291E-05
13	1316.091307	1.74242E-05
14	1312.887163	1.72385E-05
15	1309.254481	1.70689E-05
16	1305.276951	1.6913E-05
17	1301.018649	1.67688E-05
18	1296.529326	1.66349E-05
19	1291.848079	1.65099E-05
20	1287.005954	1.6393E-05
21	1282.027818	1.62833E-05
22	1276.933744	1.618E-05
23	1271.740035	1.60825E-05
24	1266.459996	1.59903E-05
25	1261.104535	1.5903E-05
26	1255.682614	1.58202E-05
27	1250.201612	1.57415E-05
28	1244.667603	1.56667E-05
29	1239.085583	1.55955E-05
30	1233.459645	1.55276E-05
31	1227.79313	1.54629E-05
32	1222.088736	1.54012E-05
33	1216.34862	1.53424E-05
34	1210.574473	1.52863E-05
35	1204.767582	1.52327E-05
36	1198.928889	1.51816E-05
37	1193.059028	1.51329E-05
38	1187.158369	1.50864E-05
39	1181.227039	1.50422E-05
40	1175.264955	1.50001E-05
41	1169.271842	1.49601E-05
42	1163.247246	1.4922E-05
43	1157.190556	1.4886E-05
44	1151.101008	1.48519E-05
45	1144.977698	1.48197E-05
46	1138.81959	1.47894E-05
47	1132.625517	1.47609E-05

48	1126.394187	1.47342E-05
49	1120.124189	1.47094E-05
50	1113.813986	1.46864E-05
51	1107.461924	1.46652E-05
52	1101.066221	1.46458E-05
53	1094.624975	1.46282E-05
54	1088.13615	1.46124E-05
55	1081.597579	1.45985E-05
56	1075.006952	1.45864E-05
57	1068.361815	1.45763E-05
58	1061.659557	1.4568E-05
59	1054.8974	1.45618E-05
60	1048.072391	1.45575E-05



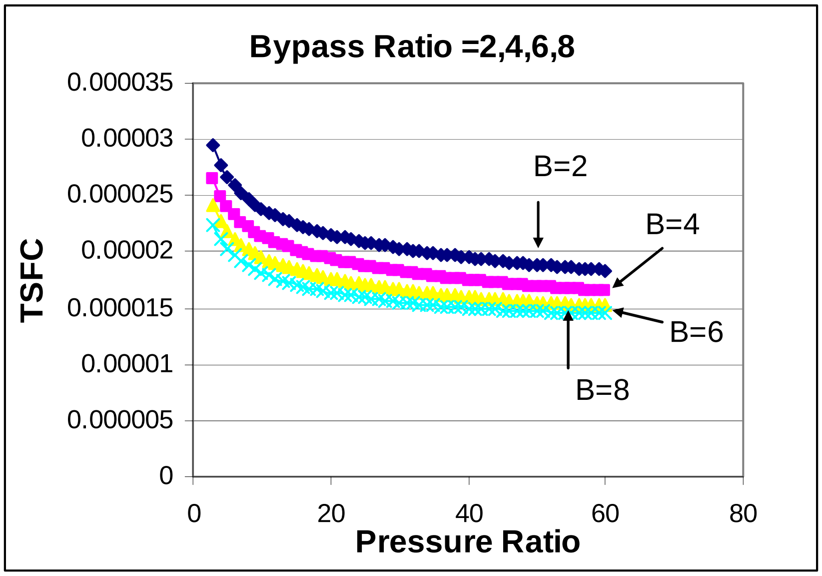
Choosing the best performance:

We consider the compressor pressure against the specific thrust:



By looking to different values of bypass ratio, it is found that at bypass ratio value = 8, we have the best performance of specific thrust at compressor pressure ratio = 10

Also, we consider the compressor pressure against the specific fuel consumption:



At bypass ratio = 8 it gives the best performance since we have minimum TSFC at compressor pressure ratio = 60

As noted at bypass ratio = 8 we the maximum specific thrust and minimum TSFC but at different values of compressor pressure ratios.
But since the TSFC is more dominant than the specific thrust, so we would choose the compressor ratio according to have the minimum TSFC.

So finally:

The optimum is at:

$P_{03}/P_{02} = 60$

$B = 8$

Part 2:

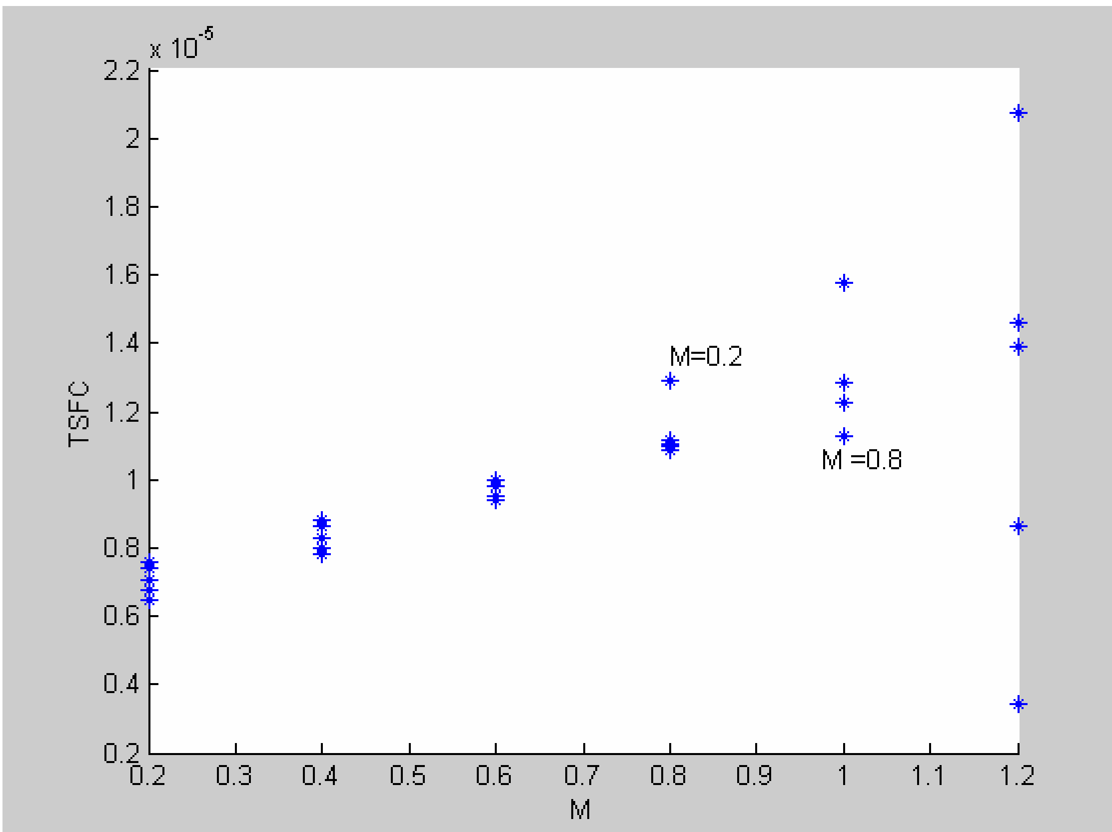
Now we are looking to the best performance when operating in certain off-design by changing Mach number an altitude.

By writing the following matlab program:

```
cp=1000;
QR=45000;
lan=1.4;
lan1=0.4;
Ta=216.66;
Pa=1.9399e4;
T04=1560;
% efficiencies:
etad=0.97;etac=0.85;etab=1;etat=0.9;etan=0.98;etaf=0.85;etafn=0.97;Prf=1.5;
% from obtimum Prc=60 and Beta=8 (gives minimum TSFC)
Beta=8;
Prc=60;
 for M=0.2:0.2:1.2
    for h=4000:2000:14000;
        Ta=289-6.5e-3*h;
         if h>10000
            Ta=216.66;
        end

        Pa=1.01e-5*exp(-(9.81/(287*Ta))*h);
        T0a=Ta*(1+(lan1/2)*M^2);
        T02=T0a;
        T03=T02*(1+(1/etac)*(Prc^(lan1/lan)-1));
        T08=T02*(1+(1/etaf)*(Prf^(lan1/lan)-1));
        T05=T04-(T03-T02)-Beta*(T08-T0a);
        T06=T05;
        P02=Pa*(1+etad*((T02/Ta)-1))^(lan/lan1);
        P03=P02*Prc;
        P04=P03*(T04/T03)^(lan/lan1);
        P05=P04*(1-(1/etat)*(1-(T05/T04)))^(lan/lan1);
        P06=P05;
        P7=Pa;
        P08=P02*Prf;
        f=((T04/T03)-1)/((QR/T03)-(T04/T03));
        u=M*sqrt(lan*287*Ta);
        uef=sqrt(2*etafn*(lan/lan1)*287*T08*(1-(Pa/P08)^(lan1/lan)));
        ue=sqrt(2*etan*(lan/lan1)*287*T06*(1-(P7/P06)^(lan1/lan)));
        Tmoa=(1+f)*ue+Beta*uef-(1+Beta)*u;
```

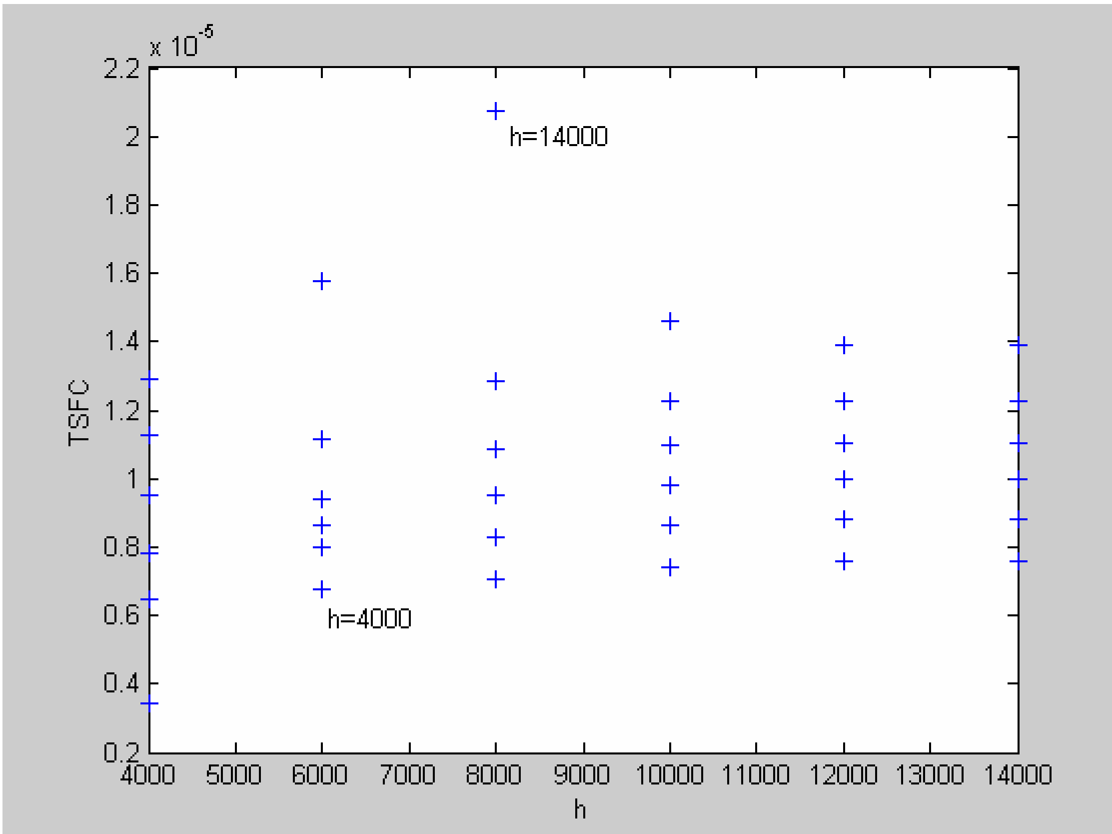
```
        TSFC=f/Tmoa;
       hold on
       figure(1)
     plot(M, TSFC,'*');xlabel('M');ylabel('TSFC')
     figure(2)
      plot(h, TSFC,'+');xlabel('h');ylabel('TSFC')

end
hold on
end
```

➔For Mach number against TSFC:



From the results of matlab program, we note that if we reach M=1 and more we would have complex numbers, which tells that we can not apply operate turbofan engine in supersonic conditions. So our limit up to M=1.

For altitude against TSFC:



From the previous figures and after compromising the results both Mach number and altitude, we note that we have best performance (minimum TFCF) at M = 0.8, in case we have only h = 4000 m.

The best performance is at:

M = 0.8 h = 4000 m.

Part 3:

Now we are looking to the best performance when operating in certain off-design by changing turbine inlet temperature T_{04}.

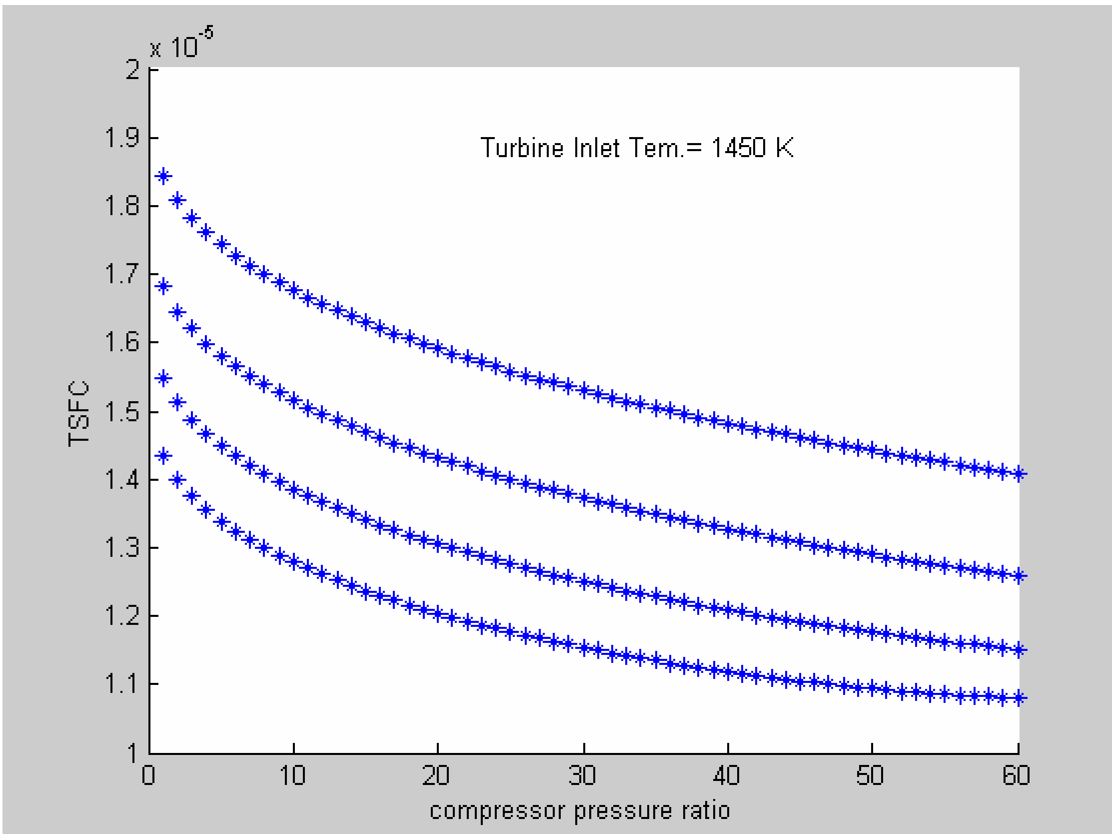
➔We try lower value of inlet turbine temperature than that in the design conditions:

With T_{04} = 1450 K.

Busing the following matlab program:

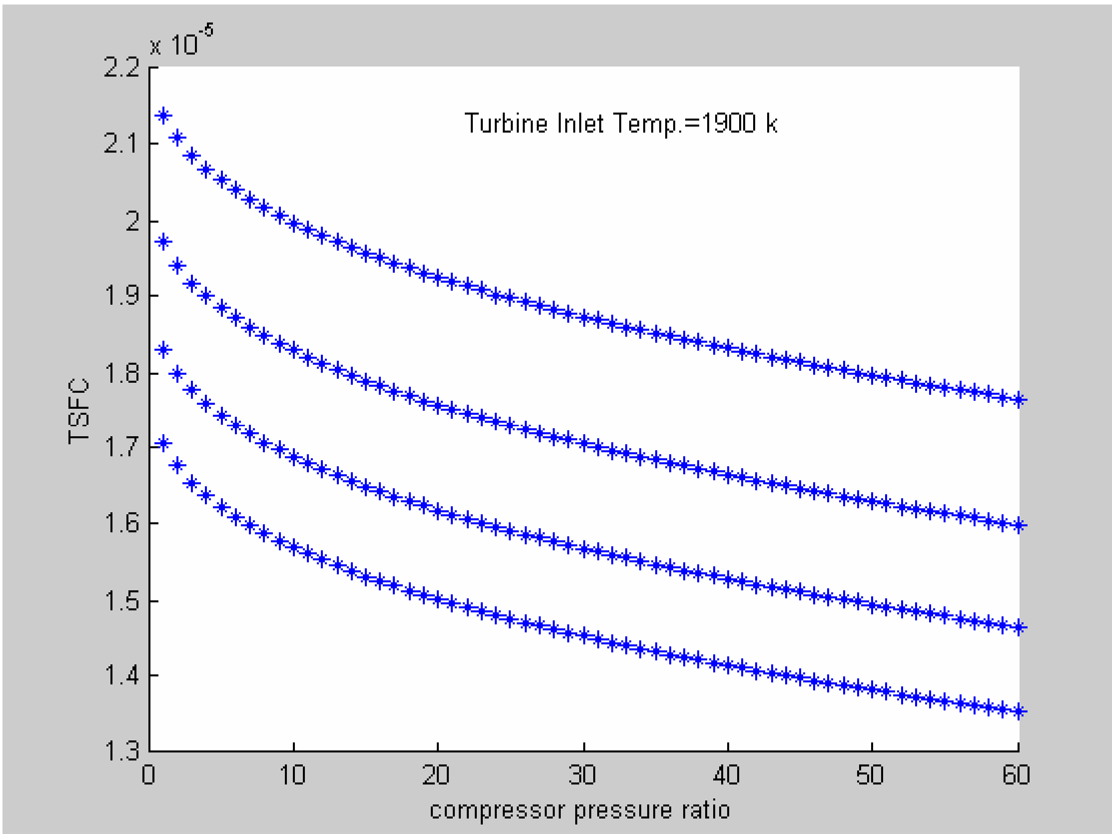
```
M=0.85;
cp=1000;
QR=45000;
lan=1.4;
lan1=0.4;
% at h=12000m:
Ta=216.66;
Pa=1.9399e4;
T04=1450;
% efficiencie values:
etad=0.97;etac=0.85;etab=1;etat=0.9;etan=0.98;etaf=0.85;etafn=0.97;Prf=1.5;
for Prc=1:60;
   for Beta=2:2:8
      T0a=Ta*(1+(lan1/2)*M^2);
      T02=T0a;
      T03=T02*(1+(1/etac)*(Prc^(lan1/lan)-1));
      T08=T02*(1+(1/etaf)*(Prf^(lan1/lan)-1));
      T05=T04-(T03-T02)-Beta*(T08-T0a);
      T06=T05;
      P02=Pa*(1+etad*((T02/Ta)-1))^(lan/lan1);
      P03=P02*Prc;
      P04=P03*(T04/T03)^(lan/lan1);
      P05=P04*(1-(1/etat)*(1-(T05/T04)))^(lan/lan1);
      P06=P05;
      P7=Pa;
      P08=P02*Prf;
      f=((T04/T03)-1)/((QR/T03)-(T04/T03));
      u=M*sqrt(lan*287*Ta);
      uef=sqrt(2*etafn*(lan/lan1)*287*T08*(1-(Pa/P08)^(lan1/lan)));
      ue=sqrt(2*etan*(lan/lan1)*287*T06*(1-(P7/P06)^(lan1/lan)));
      Tmoa=(1+f)*ue+Beta*uef-(1+Beta)*u;
      TSFC=f/Tmoa;
     hold on
   plot(Prc, TSFC,'*');xlabel('compressor pressure ratio');ylabel('TSFC')
```

```
end
hold on
end
```



➔ Trying a lower value of inlet turbine temperature than that in the design conditions:

With T_{04} = 1900 K.



By comparing the previous two figures, we conclude that if we have lower value of T_{04} , we would have better performance (lower TSFC).

At T_{04} = 1450 k➔ TSFC = 1.1 e-5
At T_{04} = 1900 k➔ TSFC = 1.35 e-5
At T_{04} = 1560 k➔ TSFC = 1.45 e-5

The best performance is at:

At T_{04} = 1450 k➔ TSFC = 1.1 e-5

Part 3:

Conclusion:

The best performance of this turbofan engine would be at the following conditions:

- Flying at Mach number M = 0.8
- Compressor pressure ratio $P_{03}/P_{02} = 60$
- Bypass ratio $\beta = 8$
- Flying at altitude h = 4000 m
- Turbine inlet temperature At $T_{04} = 1450$ k

These parameters are the main effective factors that must be put in consideration in case of designing a turbofan engine process.