MAE 426 Fall 2018 - Class Project

100 Points total – Due Friday, 12/7/18 (after last day of classes)

Label plots well in order to facilitate grading. Use proper axis labels and legends or label lines directly. Quality and legibility of plots will be important in the parametric study.

Work is to be done in groups of 3-4 students. Design case calculations (Part A.) should be typed up, while the deliverable for the parametric study, Part B, will include code or spreadsheet (printed and electronic submission) and all plots listed in Part B. 1.0 - 7.0 <u>with some brief discussion</u>. Printed submission should be in a report format with a title page listing student team members, contribution and signature. Organization and clarity of report will be a part of your grade.

Performance Analysis of a high bypass ratio turbofan engine:

In this project you will first develop a code using either Matlab of Excel or other software to calculate the performance of a high bypass ratio (α) turbofan engine using given design parameters. The code can be verified by using homework problems you will be working for homework in Chapter 4. In the second part of the project, you will perform a "parametric analysis" of engine performance by varying certain design parameters independently, while fixing the other design parameters. This analysis will demonstrate the dependence and sensitivity of engine performance on each parameter.

A. Engine design operating point parameters (design case):

<u>Flight conditions</u>:

Altitude of 11 km Mach number of M_o = 0.75

<u>Engine inlet</u>:

Inlet pressure recovery, π_d = 0.98

<u>Fan/bypass/nozzle section</u>:

Bypass ratio, α = 10 Fan pressure ratio, π_f = 1.6

Fan <u>polytropic efficiency</u>, e_f = 0.9 Bypass nozzle pressure ratio, π_{fn} = 0.9

<u>Compressor section</u>:

Compressor pressure ratio, π_c = 30 (Note: includes pressure ratio of the fan)

Compressor <u>polytropic efficiency</u>, e_c = 0.9

<u>Combustor section</u>:

Combustor thermal limit parameter, τ_λ = 7.0 Fuel ideal heating value, Q_R = 42 MJ/kg

Combustor pressure ratio, π_b = 0.95 Combustor efficiency, η_b = 0.98

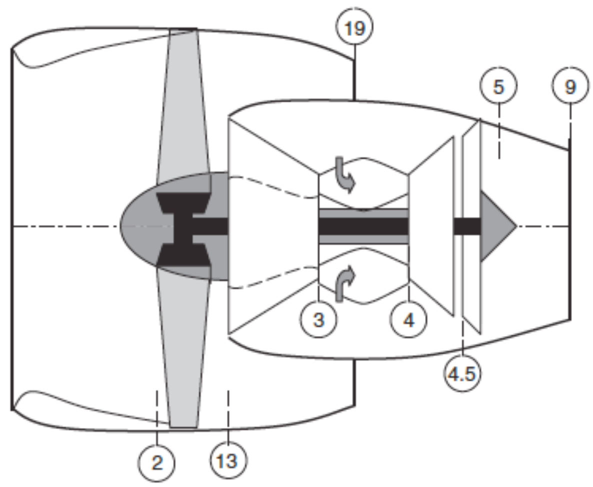
Turbine section:

Turbine polytropic efficiency, $e_t = 0.9$ Mechanical efficiency, $\eta_m = 0.98$

Core nozzle section:

Core nozzle pressure ratio, $\pi_n = 0.9$

Engine diagram with station identification:



From these design parameters, determine the following performance parameters for this engine:

a) Compressor core to bypass power ratio, $\frac{\dot{W}_{core}}{\dot{W}_{bypass}}$

b) Combustor fuel-air ratio, f

c) Nozzle velocity ratio, V_{19}/V_9

d) Ratio of fan to core gross thrust, $F_{G,fan}/F_{G,core}$

e) Total non-dimensional specific net thrust, $F_N / (1+\alpha)\dot{m}_o a_o$

f) Thrust specific fuel consumption, TSFC

g) Thermal efficiency, η_{th}

h) Propulsive efficiency, η_p (use full equation, not approximate)

i) Overall efficiency, η_o

B. Engine performance parametric study:

With the engine design operating point defined and performance determined, we will vary parameters independently. Below are details of parameters to be varied and performance parameters to be plotted. Note, as some of the parameters are varied, this may affect whether the core and bypass nozzles are choked, so your code should determine if the nozzles are choked and calculate exit velocity, temperature, pressure and area accordingly.

1.0 Inlet Mach number (M_o): Vary between M_o = 0.5 - 0.75

Figure 1.1: Plot non-dimensional specific net thrust ($F_N/(1+\alpha)\dot{m}_o a_o$) vs. inlet Mach number (M_o)

Figure 1.2: Plot TSFC vs. inlet Mach number (M_o)

Figure 1.3: Plot thermal efficiency (η_{th}) vs. inlet Mach number (M_o)

Figure 1.4: Plot propulsive efficiency (η_p) vs. inlet Mach number (M_o)

2.0 Inlet pressure recovery (π_d): Vary between π_d = 0.8 - 1.0

Figure 2.1: Plot non-dimensional specific net thrust ($F_N/(1+\alpha)\dot{m}_o a_o$) vs. inlet pressure recovery (π_d)

Figure 2.2: Plot TSFC vs. inlet pressure recovery (π_d)

Figure 2.3: Plot thermal efficiency (η_{th}) vs. inlet pressure recovery (π_d)

Figure 2.4: Plot propulsive efficiency (η_p) vs. inlet pressure recovery (π_d)

3.0 Compressor pressure ratio (π_c) and combustor thermal limit parameter (τ_λ):

Vary between π_c = 30 - 36 and τ_λ = 6, 6.5 and 7

Figure 3.1: Plot non-dimensional specific net thrust ($F_N/(1+\alpha)\dot{m}_o a_o$) vs. compressor pressure ratio (π_c)

Figure 3.2: Plot TSFC vs. compressor pressure ratio (π_c)

Figure 3.3: Plot thermal efficiency (η_{th}) vs. compressor pressure ratio (π_c)

Figure 3.4: Plot propulsive efficiency (η_p) vs. compressor pressure ratio (π_c)

Vary independently, but plot on the same figure for varying combustor thermal limit parameter (τ_λ). You will then have 3 curves per plot.

4.0 Compressor polytropic efficiency (e_c): Vary between e_c = 0.85 - 1.0

Figure 4.1 Plot non-dimensional specific net thrust ($F_N/(1+\alpha)\dot{m}_o a_o$) vs. compressor polytropic efficiency (e_c)

Figure 4.2: Plot TSFC vs. compressor polytropic efficiency (e_c)

Figure 4.3: Plot thermal efficiency (η_{th}) vs. compressor polytropic efficiency (e_c)

Figure 4.4: Plot propulsive efficiency (η_p) vs. compressor polytropic efficiency (e_c)

5.0 Turbine polytropic efficiency (e_t): Vary between e_t = 0.85 - 1.0

Figure 5.1: Plot non-dimensional specific net thrust ($F_N / (1+\alpha)\dot{m}_o a_o$) vs. turbine polytropic efficiency (e_t)

Figure 5.2: Plot TSFC vs. turbine polytropic efficiency (e_t)

Figure 5.3: Plot thermal efficiency (η_{th}) vs. turbine polytropic efficiency (e_t)

Figure 5.4: Plot propulsive efficiency (η_p) vs. turbine polytropic efficiency (e_t)

6.0 Nozzle efficiency (π_n and π_{fn}): Vary both together between 0.85 - 1.0

Figure 6.1 Plot non-dimensional specific net thrust ($F_N / (1+\alpha)\dot{m}_o a_o$) vs. nozzle efficiency (π_n and π_{fn})

Figure 6.2: Plot TSFC vs. nozzle efficiency (π_n and π_{fn})

Figure 6.3: Plot thermal efficiency (η_{th}) vs. nozzle efficiency (π_n and π_{fn})

Figure 6.4: Plot propulsive efficiency (η_p) vs. nozzle efficiency (π_n and π_{fn})

7.0 Bypass ratio (α): Vary between α = 4 - 12

Figure 7.1: Plot non-dimensional specific net thrust ($F_N / (1+\alpha)\dot{m}_o a_o$) vs. bypass ratio ($\alpha$)

Figure 7.2: Plot TSFC vs. bypass ratio (α)

Figure 7.3: Plot thermal efficiency (η_{th}) vs. bypass ratio (α)

Figure 7.4: Plot propulsive efficiency (η_p) vs. bypass ratio (α)

The "density" of points selected when varying parameters should be high enough to capture the shape of the trends. This should be done by trial and error. Too few points (low density of points) will not capture trends, while too many points is more computationally intensive (but likely not an issue).

Be careful with scales on plots. The X-axis should only span the min and max values. The Y-axis should be set such that the trends are shown reasonably. As an example, if an efficiency spans from 34% to 35% for a given parameter, DO NOT set scale from 34-35%, or it will look like the efficiency is sensitive to that parameter on the plot. Instead, choose 30-50% for the Y-axis scale or something similar.

Please feel free to ask questions in class over the next few weeks, and to stop by during office hours with questions and troubleshooting help.