ME EN 5830/6830: Aerospace Propulsion
Problem Set #6: Airbreathing Propulsion I, II, III
Due date: 02/27/2025 by 11:59pm

Submission

Assignments can only be submitted on Gradescope, which can be accessed through Canvas. If you have any questions about submission, please email the class TA, John Gardner at john.w.gardner@utah.edu. Submissions will be automatically locked at the due date given above.

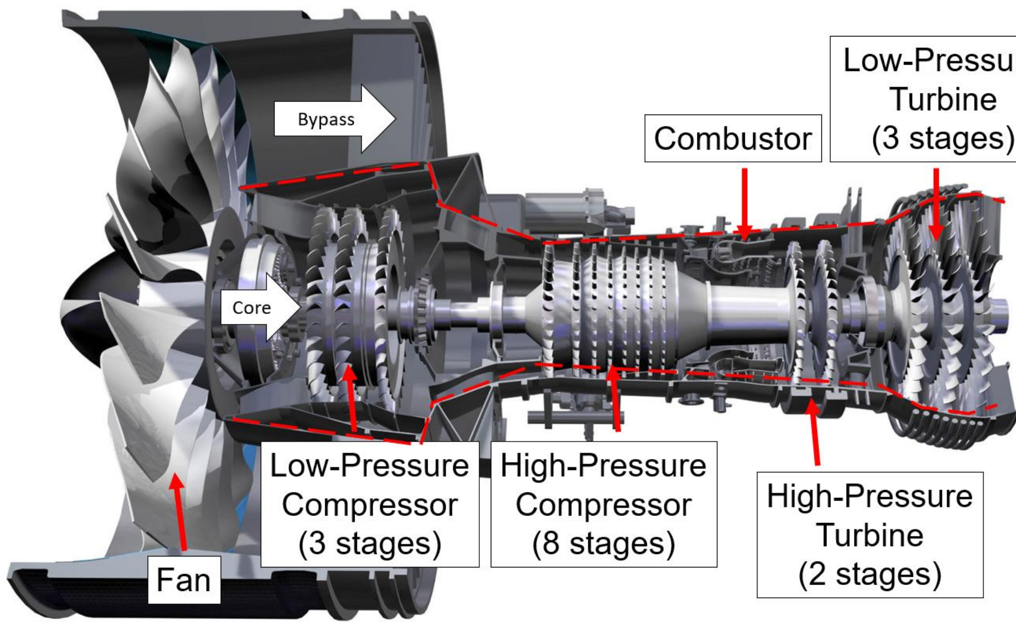
Introduction

This problem set primarily covers the material from Lectures 11, 12, and 13. The goal is for students to work with the thermodynamic analysis of a turbofan engine. By completion, students will be able to

- Compute all states within a turbofan engine.
- Compute the specific net thrust and thrust specific fuel consumption.
- Understand the effect of pressure ratio and bypass ratio on a turbofan engine.

Assignment

Problem #1: In this problem, you will analyze the PW1000G-JM, the turbofan engine used to power the Airbus A320Neo, pictured below. In your analysis, use the same station numberings as in Lecture 13. All compressor stages should be treated as a single stage in your analysis.



Assume the following for the engine:

Bypass Ratio: $BPR = 12.5$

Fan pressure ratio: $r_f = p_{t13}/p_{t2} = 1.5$

Total compressor pressure ratio: $r_p = p_{t3}/p_{t13} = 60$

Fan efficiency: $\eta_f = 0.95$

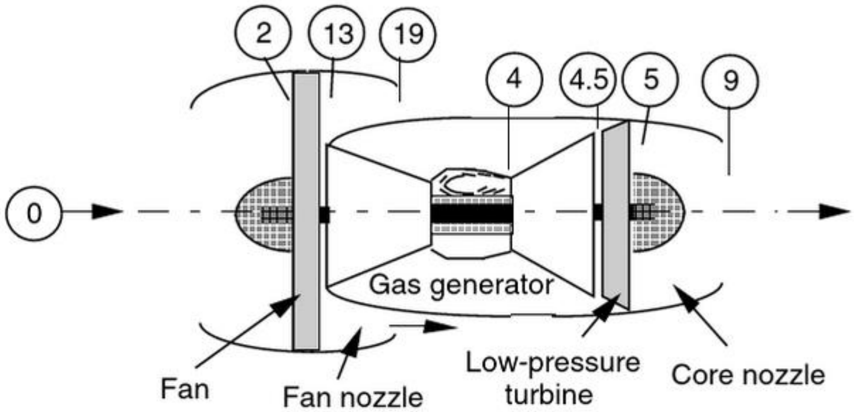
Compressor efficiency: $\eta_c = 0.95$

Turbine efficiency: $\eta_{HPT} = \eta_{LPT} = 0.9$

*Assume all other efficiencies to be 1.0

Station	T_t (K)	P_t (kPa)
1		
2		
13		
3		
4		
4.5		
5		
9		
19		

Assume this engine is on an aircraft flying at 37,000 ft with a Mach number $M = 0.78$. At this elevation, the ambient temperature is $T_0 = 216.65$ K and the ambient pressure is $p_0 = 21.4$ kPa. In the burner, n-dodecane ($C_{12}H_{26}$) is used as the fuel with a lower heating value of $LHV = 42.8$ MJ/kg. This fuel is burned with air at an equivalence ratio of $\phi = 0.25$. You will analyze the stagnation temperature and pressure at all stations and fill out the table above. In addition, you will determine the specific net thrust and thrust specific fuel consumption. Assume $\gamma = 1.4$ and $R = 287$ J/kg-K throughout the entire analysis. **For this assignment, show all equations and values used on paper. However, solve the actual equations dynamically using Excel, MATLAB, or some other program. Treat all inputs as variables as you will be modifying some of them in a later part of the problem.**



a) Compute the stagnation pressure and temperature at state 2. Recall that this portion of the analysis is identical between a turbofan and a turbojet engine.

b) Moving across the fan, compute the stagnation pressure and temperature at state 13.

c) Ignoring the bypass flow for the moment and focusing on the core flow, compute the stagnation pressure and temperature at state 3 as we move across the compressor. Treat all stages of the compressor (i.e., low-pressure, high-pressure) as a single compressor.

d) Next you will analyze the combustor. First, for a mixture of n-dodecane and air, compute the stoichiometric reaction at an equivalence ratio of $\phi = 1$.

e) From this stoichiometric reaction, compute the fuel-air ratio at stoichiometric $(F/A)_{st}$. Remember, the fuel-air ratio can be generally computed as $\left(\frac{F}{A}\right) = \frac{n_F \overline{m}_f}{n_{O_2}\overline{m}_{O_2} + n_{N_2}\overline{m}_{N_2}}$ where n_i is the number of moles of i and $\overline{m}_i$ is the molar mass of i.

f) From the above calculated values, compute the stagnation pressure and temperature at state 4.

g) Treating the 2 stages of the high-pressure turbine as a single turbine that powers all compressor stages, compute the stagnation temperature and pressure at state 4.5.

h) Treating the 3 stages of the low-pressure turbine as a single turbine that powers the fan, compute the stagnation temperature and pressure at state 5.

i) The stagnation temperature and pressure at state 9 are the same as at state 5. Why?

j) Compute the exhaust velocity of the core flow. ($V_c \approx 424\ m/s$)

k) Following the same reasoning as part i), the stagnation properties at state 19 are the same as at state 13. Compute the exhaust velocity of the bypass flow.

l) Compute the specific net thrust of the entire engine. Note that this is defined as the net thrust divided by the mass flow rate of the core flow.

m) Compute the thrust specific fuel consumption. *Hint:* $\frac{\dot{m}_f}{\dot{m}_c} = \phi \left(\frac{F}{A}\right)_{st}$

n) Assuming $BPR = 12.5$, plot the specific net thrust as a function of the compressor pressure ratio from $r_{p,min} = 13$ to $r_{p,max} = 60$. Based on this plot, is a smaller or larger compressor pressure ratio preferred?

o) Assuming $BPR = 12.5$, plot the thrust specific fuel consumption as a function of the compressor pressure ratio from $r_{p,min} = 13$ to $r_{p,max} = 60$. Based on this plot, is a smaller or larger compressor pressure ratio preferred?

p) Assuming $r_p = 60$, plot the specific net thrust as a function of the bypass ratio from $BPR_{min} = 7$ to $BPR_{min} = 14.5$. You should see a maximum at approximately $BPR = 13$. Why does adding more bypass decrease the specific net thrust past this point?