Problem Set #4: Turbofan Performance

- Homework solutions should be neat and logically presented, see format requirements at http://seitzman.gatech.edu/classes/ae4451/homeworkformat.html.
- If appropriate, include **a sketch** of the flow/system, and indicate clearly your choice of **control surface**.
- If you use any results or equations from the class notes or text in your solutions, please note and **reference** them (please make sure they are applicable to the problem at hand).
- Try to **solve** the problem **algebraically** first. Only use numbers/values in the final steps of your solution.

Background

In commercial turbofan engines, there are two gas streams: a *hot or core* flow, which passes through the engine core (compressor, combustor, and turbine); and a *cold* or *bypass* flow, which goes through the fan but not the core.

As illustrated in the figure below, the engine can be designed to expand each of these flows through two **separate nozzles** (top), denoted the core nozzle and bypass nozzle, or to combine (**mix**) them and expand them through a single (combined) nozzle (bottom).

Schematically, ways to model these two options are illustrated in the two (boxed) flow diagrams. For the combined nozzle option, one simplified way to model the process is to have the two streams combine in a separate process in a virtual component denoted as the "mixer", before the flows pass through the nozzle (note: there is no separate mixer in an actual turbofan engine; the mixing and expansion processes could occur simultaneously).



1. Turbofan Performance with Separate Nozzles

Consider a turbofan with separate nozzles for the bypass and core flows that is operating on an aircraft with an airspeed of 69.3 m/s that has just lifted off the ground at an airport where the local ambient air conditions are 98.4 kPa and 289.0 K. The engine's bypass ratio (flowrate of air going around the core divided by the flowrate of air entering the core) is 5.01. The stagnation pressure of the air entering the fan (so after passing through the inlet/diffuser) is 1.00 bar, while the stagnation properties exiting the fan are 1.33 bar and 44.20 C. In the engine core, the combustor is operating with a fuel-air ratio of 0.0182 using a fuel with a heating value of 43.52 MJ/kg, and the core flow properties exiting the turbine section are a stagnation pressure of 4.182 bar and a stagnation temperature of 926.9 K.

For this problem, assume air has a molecular weight of 28.88 and specific heat (c_p) of 1009 J/kgK that does not change between the temperatures of 280 K and 500 K. Furthermore, assume the core flow exiting the turbine also has a molecular weight of 28.88, and that the appropriate averaged c_p value to use to model the core nozzle flow is 1088 J/kgK. Finally, assume the engine inlet and both nozzles are adiabatic, and that both nozzles are reversible and perfectly expanded.

- a) What is the fan's adiabatic efficiency?
- **b)** What is the specific thrust of the engine (in kNs/kg), where the air flow rate (\dot{m}_a) used to normalize the thrust is the air flow rate that passes through the core?
- c) At these conditions, what are the engine's thermal and propulsive efficiencies?

2. Turbofan Performance with a Combined Nozzle

Now consider the same engine from Problem 1 operating with all the same conditions (e.g., airspeed, ambient conditions, fuel-air ratio, bypass ratio, and fan and turbine exit stagnation properties), except it now employs a single combined nozzle. To analyze the engine performance in this problem, use the *mixer* + *nozzle* model described in the Background. Inside the mixer, we allow the two inlet streams to interact, i.e., mass, momentum and energy exchange can take place between the streams, and we assume the mixer is adiabatic and mechanically rigid (i.e., there is no exchange of energy as heat or work with its surroundings).

- a) What are the maximum possible stagnation pressure <u>and</u> stagnation temperature values for the stream exiting the mixer? Again assume that the bypass air has a constant c_p of 1009 J/kgK for temperatures in the range 280-500 K, and for the core flow, the appropriately averaged value for c_p between the turbine exit stagnation temperature and the mixer exit stagnation temperature is 1088 J/kgK.
- b) Based on your mixer results, what is the specific thrust for the combined nozzle? Assume the combined nozzle is adiabatic, reversible and perfectly expanded, and that the mixed flow has a constant cp of 1009 J/kgK.
- c) At these conditions, what are the engine's thermal and propulsive efficiencies?