AE4451
Seitzman
Summer 2024

Problem Set #4: Turbojet and 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.

1. Turbojet Performance

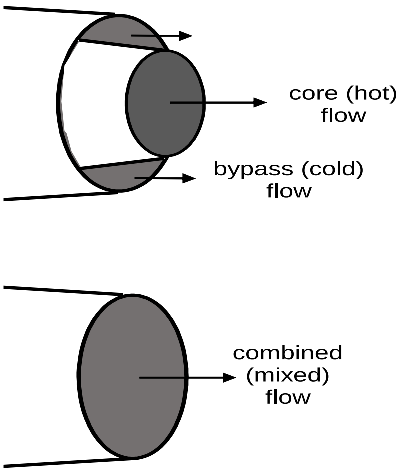
A turbojet (without afterburner) is operating on an aircraft flying at 69.3 m/s that has just lifted off the ground at an airport where the local ambient pressure is 90.9 kPa. The engine's compressor uses 616.6 kJ per kg of air and the combustor, using a fuel-air ratio of 0.0130 and a fuel with a heating value of 43.52 MJ/kg, outputs a gas with a stagnation temperature of 1349 K, a stagnation pressure of 31.03 bar, a molecular weight of 28.5 and a specific heat at constant pressure of 1.20 kJ/kgK. Furthermore, the engine's turbine has an adiabatic efficiency of 92%.

a) What is the maximum possible thermal efficiency this turbojet could be producing based on the given conditions, and assuming the engine's nozzle is perfectly expanded and the gas passing through the turbine and nozzle is calorically perfect?

b) If the combustor's fuel-air ratio were increased without changing the flight and compressor operating conditions, what would happen to the thermal efficiency of the engine; would it increase, decrease or stay the same? Note - you need to justify your answer.

c) For the same situation described in part b (e.g., an increase in fuel-air ratio), what would happen to the propulsive efficiency of the engine; would it increase, decrease or stay the same? Note - you need to justify your answer.

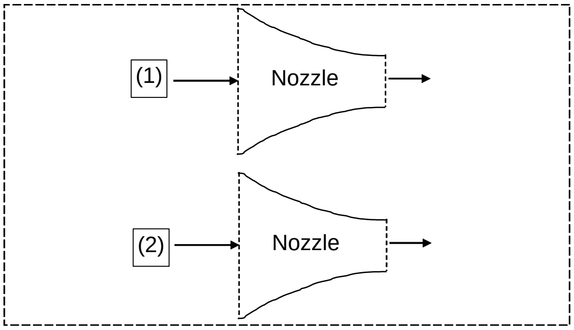
2. Turbofan Performance and Nozzle Mixing

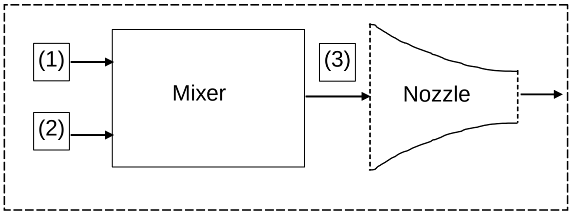


In turbofan engines, there are two gas streams: a *hot* or *core* flow, which passes through the engine core (compressor, combustor, and turbine); and a *cold* or *bypass* flow, which goes through the fan but not the core.

As illustrated in the figure to the right, the engine can be designed to expand each of these flows through **separate nozzles** (top), or to first combine (**mix**) them and then expand the mixed stream through a single nozzle (bottom).

Schematically, these two options can be illustrated in the two (boxed) flow diagrams. For the combined nozzle option, the mixing of the two streams is modeled as a separate process occurring before the flows pass through the nozzle in a component denoted as the “mixer”.





To compare the performance of these two options, consider a case where while the bypass stream (1) has a stagnation pressure of 1.22 bar and a stagnation temperature of 47.3 °C, and the core stream (2) has a stagnation pressure of 3.524 bar and a stagnation temperature of 721.0 °C, Furthermore, the bypass ratio is 4.92, i.e., $\dot{m}_1$ =4.92 $\dot{m}_2$. Furthermore, the engine is operating where the ambient pressure is 0.800 bar.

For this problem, assume both streams have the same molecular weight (28.85) and same specific heat ratio (1.39). Also assume that the amount of fuel burned produces a negligible change in the core mass flow rate, i.e., the mass flow rate exiting the core is essentially the same as that of the air that entered it, and that all nozzles are reversible, adiabatic and perfectly expanded.

a) What is the **static** specific thrust of the option that employs separate nozzles, where the air flow rate ($\dot{m}_a$) used to normalize the thrust is defined as the air flow rate that passes through the core (hot) flow?

b) Now you are to analyze just the ***mixer***. Inside it, we allow the two inlet streams to interact, i.e., mass, momentum and energy exchange can take place. Assume the *mixer* is adiabatic and mechanically rigid (i.e., there is no exchange of energy as heat or work with the environment). What are the maximum possible stagnation pressure and stagnation temperature for the stream exiting the mixer, denoted (3) in the schematic above.

c) Determine the **static** specific thrust for the combined nozzle using your results from part b) for the mixder output, using the same definition of $\dot{m}_a$ from part a).