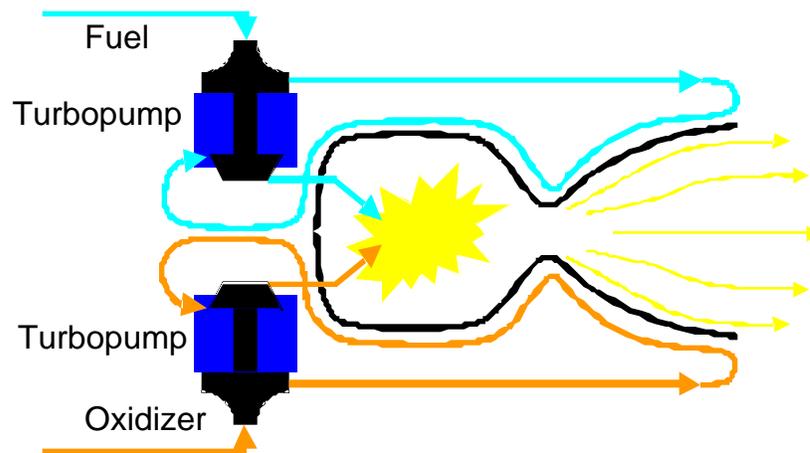


Problem T8 (Unified Thermodynamics)

$R=287 \text{ J/kg-K}$, $c_p=1003.5 \text{ J/kg-K}$, and $c_v = 716.5 \text{ J/kg-K}$. (MO# 5)

Below is a schematic diagram of a rocket engine cycle called an expander cycle. The cold liquid propellants are pumped through the walls of the rocket nozzle to cool them. In doing so, they gain energy and turn into gases. Some of the energy in these propellant gases is then extracted in a turbine. The turbine is connected by a shaft to the liquid propellant pump. After passing through the turbine, the propellant gases flow to the combustion chamber where they are ultimately responsible for producing the heat at the walls of the rocket nozzle. So it is a little like pulling yourself up by your bootstraps. As you might expect, the design of a device like this depends on a careful analysis of the thermodynamics, fluid mechanics and structural/material behavior.



To simplify the problem, we will consider only one of the propellants and assume that it is always in gaseous form and behaves as an ideal gas with constant specific heats. Assume $R=260 \text{ J/kg-K}$, $c_p = 2800 \text{ J/kg-K}$, and $c_v = 2540 \text{ J/kg-K}$. (LO #4)

- The cold propellant enters the pump at $p = 1 \text{ MPa}$, $T = 200 \text{ K}$ and $c = 50 \text{ m/s}$. The flow rate is 100 kg/s . The flow leaves the pump at $p = 5 \text{ MPa}$ and $c = 50 \text{ m/s}$. Assuming the pump behaves adiabatically and quasi-statically, what are the conditions at the pump exit? How much shaft work and flow work were done by propellant during the pumping process?
- Assume that 1300 kJ/kg are absorbed by the gas as it passes along the walls of the rocket nozzle. At entrance to the turbine, it is now flowing at $c=100 \text{ m/s}$ and remains at $p = 5 \text{ MPa}$. What are the thermodynamic conditions at this point of the engine. How much shaft work and flow work were done by the propellant during the heating process?
- Assuming the turbine behaves quasi-statically and adiabatically, what are the conditions at the exit of the turbine assuming the velocity is $c = 120 \text{ m/s}$? How much shaft work and flow work were done by the propellant in the turbine?