# AA103 Homework 9

Cantwell Spring 2020-21

Due June 3, 2021

## Suggested Reading

AA283 Course reader Chapter 4.

### Problem 1

A test facility designed to measure the mass flow and pressure characteristics of a jet engine compressor is shown in Figure 1. An electric motor is used to power the compressor. The facility draws air in from the surroundings which is at a pressure of one atmosphere and a temperature of 300 K. The air passes through the inlet throat at station 1, is compressed from 2 to 3 and then exhausted through a simple convergent nozzle at station e. Assume the compressor (2-3) operates ideally. Relevant area ratios of the

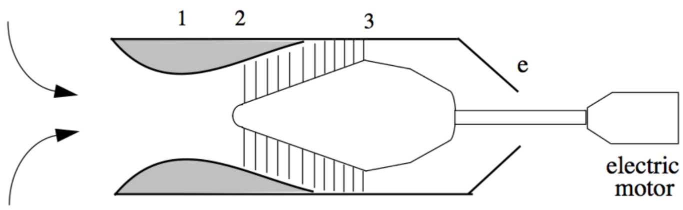


Figure 1: Compressor test facility.

rig are $A_1/A_e = 8$ and $A_1/A_2 = 1/2$. Suppose the power to the compressor is slowly increased from zero.
1) Determine the compressor pressure ratio $P_{t3}/P_{t2}$ at which the nozzle chokes.
2) Determine the compressor pressure ratio $P_{t3}/P_{t2}$ at which the inlet throat chokes.
3) Plot the overall pressure ratio $P_{te}/P_0$ versus the temperature ratio $T_{te}/T_0$ over the full range from less than sonic flow at station $e$ to beyond the point where a normal shock forms in the inlet.
4) It has been proposed to put a compressor facility like this in one of the basement labs in Durand to support propulsion research. It would operate up to a maximum air mass flow rate of $10 kg/sec$. How much power would be required to operate the facility? Stanford pays about $\$0.20$ per kilowatt-hour for energy. What would be the hourly cost for energy to run the facility?

### Problem 2

A turbojet engine is at rest, set for takeoff. The inlet, compressor, burner, turbine and nozzle operate ideally.

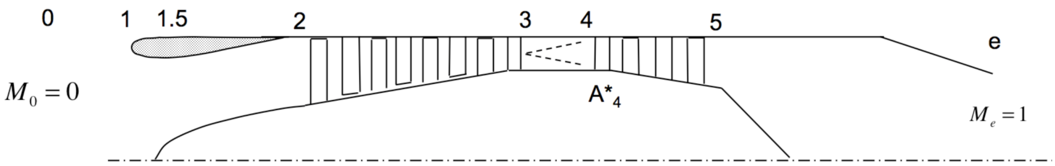


Figure 2: Turbojet ready for take-off.

The nozzle is of simple convergent type with $M_e = 1.0$. Assume $f \ll 1$. The free stream temperature is

$300K$ and the turbine inlet temperature is $1500K$. Relevant area ratios are $A_e/A_4{}^* = 2$ and $A_4{}^*/A_2 = 1/8$.
1) Determine $\tau_t$ and $\pi_t$.
2) Determine $\tau_c$ and $\pi_c$.
3) Determine $f(M_2)$.
4) Suppose the pilot reduces the throttle to the point where the engine is idling and the exit nozzle is on the verge of un-choking. The engine continues to operate ideally. What value of $T_{t4}$ would produce this condition? Note that the nozzle being on the verge of unchoking means that $M_e = 1.0$ *and* $P_e = P_0$.

## Problem 3

Figure 3 shows a turbojet engine flying supersonically. Figure 4 shows typical stagnation pressure and stagnation temperature ratios at various points inside the engine (the figures are not drawn to scale).

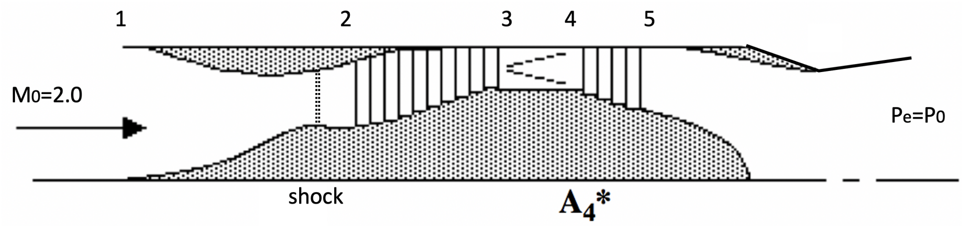


Figure 3: Turbojet flying at Mach 2.0.

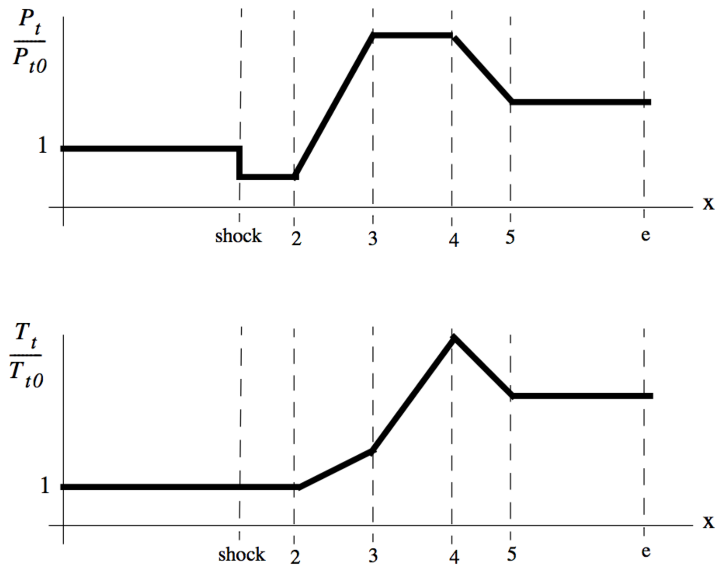


Figure 4: Stagnation pressure and stagnation temperature through a turbojet engine with inlet shock.

The turbine inlet and nozzle throat are choked, and the compressor, burner and turbine operate ideally. At the condition shown $P_e = P_0$. Supersonic flow is established in the inlet and a normal shock is positioned downstream of the inlet throat. Neglect wall friction and assume $f \ll 1$.

Suppose $\tau_\lambda$ is increased while the flight Mach number and engine areas including the nozzle throat and exit area are all constant.
1) Show whether $P_{t3}/P_{t0}$ increases, decreases or remains the same.
2) At each of the stations indicated above explain how the stagnation pressure and stagnation temperature change in response to the increase in $\tau_\lambda$.
3) Does $P_e/P_0$ increase of decrease?