ME 355: Compressible Flows, Spring 2016

Stanford University

Final Exam

Friday, June 3

Guidelines: Please turn in *neat* and *clean* exam solutions that give all the formulae that you have used as well as details that are required for the grader to understand your solution. Attach these sheets to your solutions. Assume $\gamma = 1.4$ and $c_p = 1.0$ KJ/KgK for all problems.

Student's Name:.. **Student's ID:**............................

PART I: Closed books, closed notes, calculators allowed
Time: 40 mins

Questions (30 pts)

1. Using the conservation equations in a control volume that includes an oblique shock front, state the continuity, momentum and energy jump constraints across the shock wave, indicating which variables (or group of variables) remain invariant and which ones are discontinuous.
2. Explain why a curved shock wave generates vorticity in an initially irrotational flow.
3. Explain the structure of a ZND detonation indicating its main regions in terms of pressure, temperature and velocity variations across the front, and sketch the approximate thermodynamic trajectory of a fluid particle in a pressure / specific-volume diagram.

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PART II: Open books, open notes, calculators allowed

Time: 120 mins

Problem 1 (40 pts)

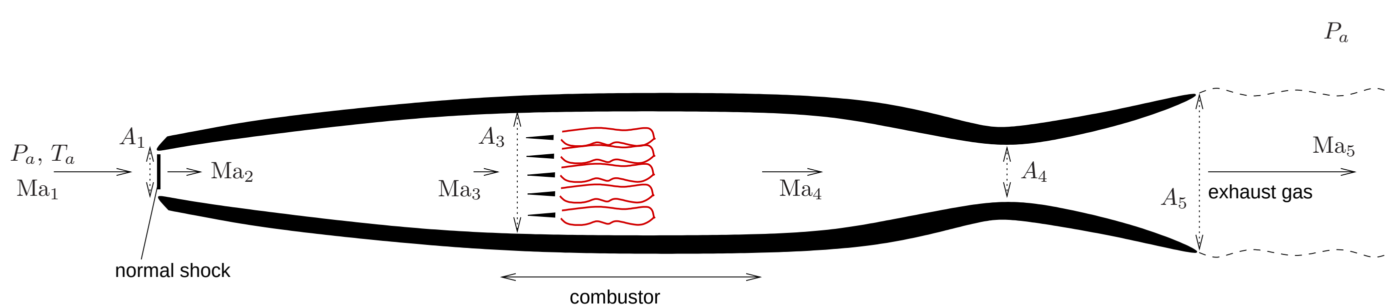
A simplified model of a RAMJET engine is depicted in the figure below. RAMJETS differ from SCRAMJETS in that combustion in the former occurs subsonically rather than supersonically. Supersonic air at $U_1 = 2$ km/s, $T_a = 270$ K and $P_a = 0.1$ bar is ingested through a nozzle of cross section $A_1 = 20$ cm^2 that creates a normal shock. The flow passes through a diffuser of area ratio $A_3/A_1 = 2$ before entering the combustion chamber. The heat release from combustion leads to a 20% increase in the stagnation temperature. The combustion products flow through a converging-diverging nozzle of area ratio $A_4/A_5 = 0.2$, with $A_4/A_3 = 0.5$.

a) The Mach number, pressure and temperature of the air entering the combustor.

b) The Mach number, pressure and temperature of the gas leaving the combustor.

c) The Mach number, pressure and temperature of the exhaust gases.

d) The specific impulse of the engine, $I_s = F/(\dot{m}g)$, where F is the engine thrust, $\dot{m}$ is the mass flow rate, and g is the gravitational acceleration.



Problem 2 (30 pts)

A closed duct of length $2L$ is initially divided into two equal cavities filled with the same gas at the same temperature T_o and separated by a diaphragm. Initially, the pressure of the gas in the right cavity is P_o, while the pressure of the gas in the left cavity is $P_o(1+\epsilon)$, with $\epsilon \ll 1$. At $t=0$ the diaphragm is removed and acoustic waves propagate into both cavities. Draw the velocity and pressure profiles in the duct as a function of x for a) $t = L/(2a_0)$, b) $t = L/a_0$, and c) $t = 2L/a_0$, where a_0 is the speed of sound. Justify your sketches by appropriately computing the flow variables using the acoustics theory.