

**ME 355: Compressible Flows, Spring 2016**  
**Stanford University**  
**Midterm Exam**  
 Tuesday, May 10

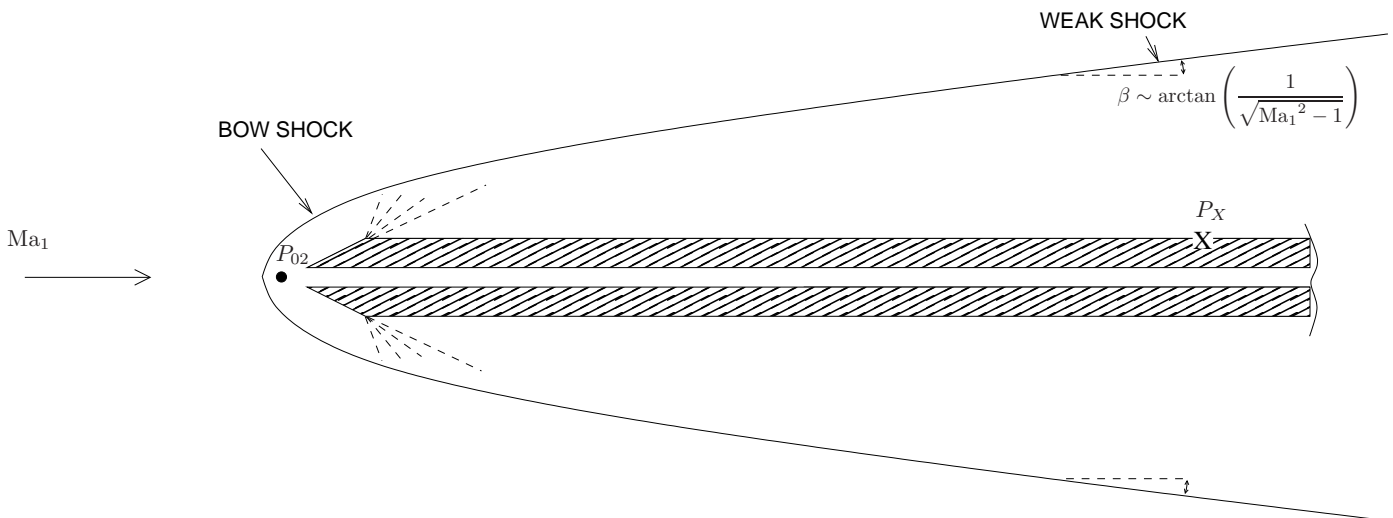
**Guidelines:** Please turn in *neat* and *clean* exam solutions that give all the formulae that you have used as well as details that are required for the grader to understand your solution. Attach these sheets to your solutions. Assume  $\gamma = 1.4$  and  $c_p = 1.0 \text{ KJ/KgK}$  for all problems.

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

**PART I: Closed books, closed notes, calculators allowed**  
**Time: 20 mins**

**Questions (30 pts)**

1. Explain what is supersonic wave drag and how it differs from viscous drag.
2. The stagnation temperature upstream from a normal shock wave at  $Ma_1 = 1.5$  is  $T_{01} = 335 \text{ K}$ . The static pressure downstream is  $P_2 = 3 \text{ bar}$ . What is the stagnation enthalpy downstream  $h_{02}$ ?
3. A Machmeter for a supersonic aircraft consists of a very long central duct connected to a manometer that measures the post-shock stagnation pressure  $P_{02}$ , along with a lateral probe far away from the tube nose that measures the static pressure  $P_X$  at that position  $X$  (see fig. below). Based on those two quantities, how would you compute the Mach number of the free stream  $Ma_1$ ?



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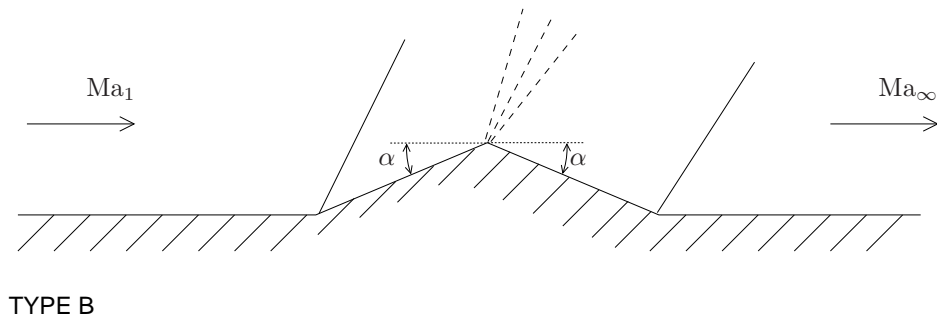
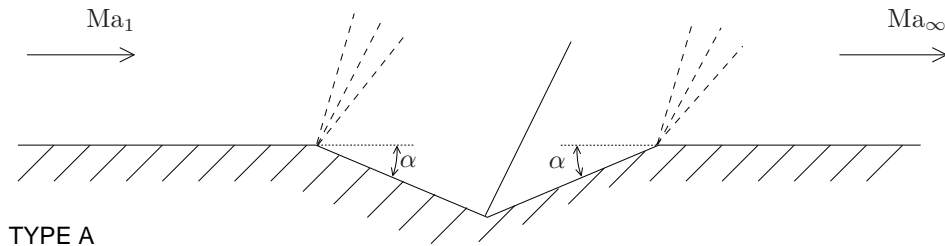
Student's Name:..... Student's ID:.....

**PART II: Open books, open notes, calculators allowed**  
**Time: 60 mins**

**Problem 1 (60 pts)**

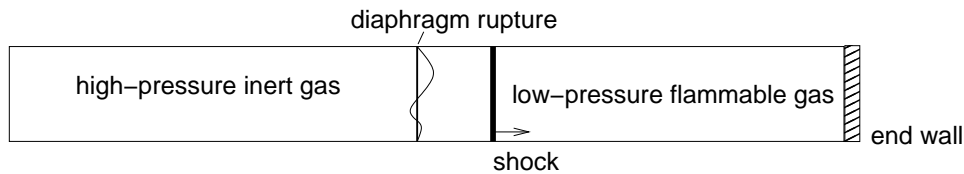
A supersonic stream at  $Ma_1 = 4.0$  flows parallel to a wall and encounters a geometrical disturbance of type A or B, as depicted below. Type A is an indentation and type B is a protrusion, both having the same deflection angle  $\alpha = 20^\circ$ . Determine which configuration (type A or type B) yields

- a) the maximum decrease in static pressure,  $(P_1 - P_\infty)/P_1$
- b) the maximum decrease in stagnation pressure,  $(P_{01} - P_{0\infty})/P_{01}$
- c) the maximum exit Mach number,  $Ma_\infty$
- d) the minimum entropy increase,  $(s_\infty - s_1)/c_v$

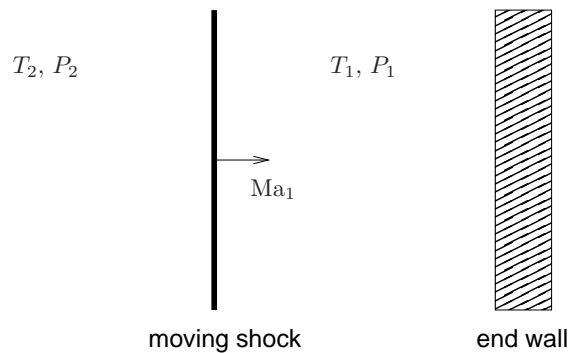


**Problem 2** (10 pts)

Shock tubes are typically used for studies of combustion chemical kinetics. In a shock tube, a diaphragm separates high pressure inert gas from a lower-pressure, flammable gas mixture at temperature  $T_1 = 300\text{K}$  and pressure  $P_1 = 0.1$  bar. At  $t = 0$ , the diaphragm is ruptured and the over-pressure created by the inert gas produces a shock wave that propagates at  $\text{Ma}_1 = 2$  into the reacting gaseous mixture at rest. The reflection of the shock wave plays an important role in the ignition of the reactants. In the first approximation, however, neglect the combustion chemical processes in the shock tube.



- a) Compute the pressure  $P_2$  and temperature  $T_2$  of the flammable gas after the shock has passed (see fig. below).



- b) When the moving shock reaches the wall, it is reflected back towards the left leaving the gas at rest behind,  $U_3 = 0$ , in accordance with the non-penetration boundary condition at the wall. Calculate the Mach number of the reflected shock  $\text{Ma}'_2$ , along with the pressure  $P_3$  and temperature  $T_3$  of the gas between the reflected shock and the end wall.

