UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION — 12 December 1995

FOURTH YEAR GASDYNAMICS — AER-410 F

Examiner: Professor J. J. Gottlieb

Instructions: *(a)* open book exam — type D with calculator 1,
(b) do all problems, if you can,
(c) relative mark values for questions are indicated,
(d) show intermediate steps in obtaining answers,
(e) provide justification for your answers.

20 % *1.* An air flow along a constant-area duct starts at location 1 with a static pressure p_1 =200 kPa, static temperature T_1 =280 K and flow Mach number $M_1 = 0.25$. Downstream at location 2 the flow Mach number is $M_2 = 0.55$.

7 % *(a)* If the average friction factor $\overline{f}_{Darcy} = 0.003$ for a duct that is 0.05 m square, and work and heat transfer are neglected, what is the duct length between locations 1 and 2?

7 % *(b)* Calculate the static pressure p_2 at location 2.

6 % *(c)* Sketch the temperature-entropy diagram, labelling locations 1 and 2. Also, show clearly the stagnation temperatures at locations 1 and 2.

20 % *2.* A conventional constant-area shock tube has the following initial conditions (before the diaphragm is broken): $p_1 = 100$ kPa, $a_1 = a_4 = 340$ m/s, where regin 1 is the low-pressure channel and region 4 is the high-pressure driver. For testing purposes the flow speed behind the shock wave must be $u_2 = 100$ m/s. What is the driver pressure p_4 required to produce this flow?

20 % *3.* A tank of volume V_{tank} is evaculated. An orifice of area A_{tank} in the tank is opened abruptly, the tank fills quickly with air from the atmosphere (p_{atm}, T_{atm},) until the gas in the tank reachex atmospheric pressure, and then the orifice is closed abruptly.

14 % (a) If the filling process occurs over a short time interval such that heat-transfer between the tank and internal air can be ignored, prove that the initial gas temperature is $T_i = \gamma T_{atm}$.

6 % (b) Heat transfer will eventually change the air temperature inside the tank to match that of its surrounding (walls and outside air). Show that the final gas pressure in the tank drops to $p_f = p_{atm}/\gamma$.

20 % 4. A supersonic wind tunnel has a low-pressure dump tank behind the test section which sucks air from the atmosphere ($p_{atm} = 1$ atm, $T_{atm} = 297$ K) through a convergent-divergent duct into a constant-area duct with a test section of area $A_{ts} = 1$ m^2. To avoid air liquefaction (fromation of liquid air), the wind tunnel is designed to operate at a test-section static temperature $T_{ts} = 90$ K.

4 % (a) Calculate the test-section static pressure p_{ts}.

4 % (b) Calculate the test-section flow Mach number M_{ts}.

4 % (c) Calculate the throat area A_{throat}.

4 % (d) Calculate the shut-down dump-tank pressure p_{dt}^{sd} at which the flow in the test section ceases to be supersonic.

4 % (e) Describe the flow in the dump tank for different dump-tank pressures p_{dt} ranging from $p_{dt} = 0$ to $p_{dt} = p_{dt}^{sd}$. For example, what type of free-jet flows occur, when do they occur, and how does the jet energy dissipate.

20 % 5. A horizontal flow at an initial static pressure $p_1 = 100$ kPa, static sound speed $a_1 = 300$ m/s and flow Mach number $M_1 = 2.0$ first moves at constant area (in region 1), then accelerates through a Prandtl-Meyer expansion fan to a flow Mach number $M_2 = 3.0$ in region 2 where it moves at constant area, then is decelerated by an oblique shock wave such that the flow in region 3 is supersonic and once again horizontal, and then moves onward at this new constant area.

5 % (a) Sketch a diagram of this flow.

5 % (b) Determine the static pressure p_2 and sound speed a_2 in region 2.

5 % (c) Determine the static pressure p_3 and sound speed a_3 in region 3.

5 % (d) Calculate the flow area ratios A_2/A_1 and A_3/A_1. Comment on their magnitudes; for example why A_2/A_1 is greater than unity and why A_3/A_1 is not equal to unity. (Be careful that this part of the question does not consume to much of your time.)