The test will be closed book, closed note. The test will involve several homework-style problems + questions about definitions, explanations, and/or assumptions. You will need a calculator to do the test, but no other electronic devices are permitted. Tables and or charts will be provided with the test paper, as needed. The honor code is in effect. The following material will be tested. Don’t forget to bring a calculator and blank paper to the test. You are also permitted to prepare and bring to the test a formula sheet/review notes covering one 11x8 sheet of paper.

Unsteady 1D Flows

Know and understand how the flow pattern in a shock tube develops after the diaphragm is ruptured. Be able to identify the various waves and parts of the flow. Be able to explain/draw the pressure distribution along the tube. Be able to explain the motion of the shock (including reflection), expansion wave (both leading and trailing edges) and the contact surface accurately on an x-t diagram and interpret the slopes of these features. Be able to sketch accurately a particle path on the x-t diagram. Be able to identify the mass motion velocity. Know what the contact surface is and what is constant across it. Be able to prove, beginning with the equation for speed of sound \(a^2 = \gamma RT\), why unsteady compression waves coalesce into shocks and unsteady expansion waves spread out. Know that a moving shock induces a following mass motion velocity and know how to compute it. Know how to analyze unsteady normal shocks using steady normal shock relations/tables by using a moving frame of reference. Know how to handle stagnation properties the moving and stationary frames of reference. Be able to explain and (given the reflected shock relation) calculate the reflection of a moving shock and know what this does to the gas. Be able to explain what happens when a moving shock reflects, and why it reflects. Know the expression \(2a/\left(\gamma - 1\right) + u = \text{const.}\) and where it comes from. Be able to use it along with \(\rho RT\) and \(\rho/\rho^2 = \text{const.}\) to calculate the mass motion velocity and other changes produced by an expansion wave. Know that an expansion wave produces an opposing mass-motion velocity and understand why. Be able to compute the complete 1-D flow produced from the collapse of a known pressure difference.

Steady flow with heat addition (H) and friction (F).

Be able to state the assumptions we made in deriving the equations for these flows \((H,F)\). Know the equation \(T_{o2} = T_{o1} + q/C_p\) and be able to explain where it comes from and define the variables that appear in it \((H)\). Know where the equation \(dp + \rho u du = -4\tau_w dx/D\) comes from, and be able to define the variables that appear in it \((F)\). Know the definition of the hydraulic diameter, the friction coefficient and its average \((F)\). Know precisely what is meant by sonic conditions in a given context \((H)\) \((F)\) and particularly the significance of the sonic length \(L^*\). Know why we use sonic conditions to relate flow conditions at two points \((H)\) \((F)\) and be able to use tables \((A.3, A.4 \text{ and NACA TR1135})\) to analyze heat addition and friction flow problems. Know how to interpret fuel to air ratio in connection with heat addition problems \((H)\). Know the typical range of fuel to air ratio and energy density of fuel \((H)\). Know the typical ranges for average friction coefficient and the qualitative effect of Mach number on friction \((F)\). Know what is meant by choked flow in these contexts, and what happens to a choked flow when you add more heat or more length of friction \((H)\) \((F)\). Be able to combine heat addition \((H)\) and friction \((F)\) calculations with other calculations for unheated/friction free portions of a flow, such as nozzles, area changes and control volume force calculations. Know qualitatively what the effects of heat addition or friction are in subsonic or supersonic flow on the various flow and thermodynamic properties. Be able to draw, label, explain Molier charts \((i.e. \text{Rayleigh and Fanno curves})\) and be able to use them to explain the physical behavior of a flow.

Steady 2-D compressible flow.

Be able to illustrate the propagation of disturbances in flows of different Mach number. Know what is meant by zone of silence, zone of action, Mach wedge, Mach cone. Know and be able to derive the equation for the Mach angle. Know its physical significance to point disturbances in supersonic flow and to isentropic compression and expansion turns. Be able to identify when isentropic compression and expansion turns occur, be able to sketch the waves they produce (including coalescence and the formation of a slip line if relevant) and explain precisely what they do to the flow and its properties. Know where the Prandtl-Meyer function comes from, the assumptions used to derive it, and the equation \(\theta = v(M_2) - v(M_1)\). Be able to use it (along with isentropic tables) to compute the flow changes produced by isentropic compression and expansion turns (when they occur in isolation, or after oblique shocks). Be able to compute such turns also from pressure or other ratios, and compute the trailing and leading edge angles of compression and expansion turns.
Be able to identify when oblique shocks occur and precisely what they do to the flow and the flow properties. Know the distinctions between these and isentropic compression waves. Know the geometric relationships $M_{2n} = M_1 \sin \beta$ and $M_{2n} = M_1 \sin (\beta - \delta)$. Know the functional form of the $M-\beta-\delta$ relationship and the assumptions it implies and be able to use the charts related to it along with normal shock tables to calculate an oblique shock and the effects it has on a flow for both explicit and implied turns. Know what is meant by the 'weak-shock solution' and the 'strong-shock solution' and know which to use. Be able to determine when an oblique shock will detach, and the details of the kind of flow that this produces. Know qualitatively what an oblique shock does to the various flow properties.

**Homeworks, class examples and Tables**

Know how to do all the homeworks (4 thru 6), class examples and variations under test conditions. **Questions similar to the homeworks and class examples will appear on the test.** Solutions to all homeworks will be posted on the web. Know how to use the NACA 1135 charts and tables and Anderson tables A.3 and A.4 to perform all calculations.