Exam questions for SG2215

Course book: Modern Compressible Flow, with historical perspective, 3rd edition
by John D. Anderson. McGrawHill, 2004.

Questions likely to be asked at the oral exam.

The emphasis will be on the understanding of basic ideas and physical aspects of compressible flow. Also, the mathematical principles used for the analysis will be discussed, and the student can be asked to carry out simple derivations. The questions are marked with $(*)$, $(**)$ or $(* * *)$. The first category $(*)$ should be successfully answered to obtain grade E–D, the second category $(**)$ should be successfully answered for grade C–B and the third category $(* * *)$ for grade A.

1. Describe qualitatively the flow over a two-dimensional airfoil at different Mach numbers ($M < 1,\ M \approx 1,\ \text{and} M > 1$). $(*)$
2. (a) How are the specific heat capacities c_p and c_ν defined? $(*)$
   (b) Show how they are related to the specific gas constant. $(**)$
3. (a) State the first and second law of thermodynamics. $(*)$
   (b) Derive the isentropic relations for a perfect gas. $(**)$
4. Show that the entropy change for a calorically perfect gas can be related to the gas temperature and gas pressure before and after the change respectively. $(* * *)$
5. Derive
   (a) the mass conservation equation,
   (b) the momentum conservation equation,
   (c) the energy conservation equation
   in integral form. $(*)$
6. Derive an expression for the velocity of sound. Which assumptions have been made? $(*)$
7. Describe the Fanno flow and how it can be calculated. $(**)$
8. How does the total temperature vary over a stationary normal shock? Explain! $(*)$
9. What is the Mach angle? $(*)$
10. Show how one determines the properties across an oblique shock. Show that the velocity component parallel to the chock does not change across the shock. $(**)$
11. Make a graph of the relation between deflection angle (θ), the shock-wave angle (β) and the Mach number (M) for oblique, attached shock waves. $(*)$

(a) What happens for large deflection angles? $(*)$

(b) What happens for very small deflection angles? $(*)$

(c) Explain the difference between strong and week solutions. $(**)$

(d) Show how the $(\theta\beta M)$–relation is derived. $(***)$

12. What is a Prandtl-Meyer expansion and how are the conditions downstream the expansion calculated? $(**)$

13. What is wave drag and how is it calculated for a parallelogram without angle of attack? $(*)$

14. Describe some basic principles for supersonic wind tunnels. $(**)$

15. Describe the flow in a convergent-divergent nozzle for different pressure ratios between the inlet and the outlet. $(**)$

16. What is choked flow? How does the mass flow rate change when

    (a) the exit pressure is reduced? $(*)$

    (b) the stagnation pressure is increased? $(**)$

17. Derive the continuity, momentum and energy equations in differential form. $(**)$

18. Derive Croccos theorem? What does it say? $(***)$

19. Show how the relations for a stationary normal shock can be used to calculate the properties for a moving normal shock wave. $(**)$

20. What is a Riemann invariant and how is it derived? $(***)$

21. Gas at rest in a pipe of length L is expanded by means of a piston which at time $t = 0$ is given a constant velocity (V). Draw an xt-diagram showing the piston, particle paths as well as the two sets of characteristic lines which describe the wave propagation. Show how the temperature in the gas next to the piston can be calculated. $(***)$

22. How is the velocity potential defined? Why is it convenient to introduce the velocity potential? $(*)$

23. Under what conditions is the following equation for the disturbance velocity potential obtained: $(**)$

$$(1 - M_\infty^2)\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} = 0 \ .$$

24. Derive an expression for the linearized pressure coefficient. $(**)$

25. Show how the Prandtl-Glauert rule is derived. What does it mean? $(**)$

26. Show, using the linearized theory, how the position of a streamline above an airfoil change as the Mach number (< 1) is increased. $(***)$

27. Show how the pressure coefficient for linearized supersonic flow is derived. How do shock waves influence the solutions? For the derivation you can assume that the expression $c_p = -2u/U_\infty$ is known. ($**$)

28. What is meant by the critical Mach number for an airfoil? ($*$)

29. Consider subsonic flow with the Mach number M_∞ over a wavy wall described by $y_w = h\ \cos(2\pi x/l)$, where y_w is the ordinate of the wall, h is the amplitude and l is the wave length. The amplitude h can be assumed to be small as compared to the wavelength l. Using linearised theory, derive the surface pressure coefficient ($c_{p,w}$). ($**$)

30. Consider the same wall as in the previous problem (29.). Derive the surface pressure coefficient for the case of supersonic flow over the wavy wall. ($**$)

31. What is the difference between transonic flow over an airfoil as compared to subsonic and supersonic flow respectively. ($**$)

32. What is meant by the area-rule for transonic flow? ($**$)

33. Show how the transonic similarity equation is derived. What is the transonic similarity parameter? How does the pressure coefficient vary with the thickness of the profile in the transonic flow regime? ($***$)

34. Give some examples of physical effects that appear in hypersonic flows. Sketch the specific heat, c_v, versus temperature for atomic and diatomic gases. ($**$)

35. What is meant with Newtonian theory for the flow of a gas? Derive an expression for the pressure coefficient for a flat plate in Newtonian theory. What makes Newtonian theory relevant for hypersonic flows? Try to give a physical explanation. ($***$)