SPC 307 - Aerodynamics
Sheet 1
Introduction to Aerodynamics

Problems 1 through 5 deal with the Energy-Maneuverability Technique for a T-38A that is powered by two J85-GE-5A engines. Presented in Fig. 1 are the thrust available and the thrust required for the T-38A that is cruising at 20,000 ft. The thrust available is presented as a function of Mach number for the engines operating at military power ("Mil") or operating with the afterburner ("Max"). With the aircraft cruising at a constant altitude (of 6.096 Km), the speed of sound is constant for Fig. 1 and the Mach number (M = U/a) could be replaced by the velocity, that is by the true air speed.

When the vehicle is cruising at a constant altitude and at a constant attitude, the total drag is equal to the thrust required and the lift balances the weight. As will be discussed in Chapter 5, the total drag is the sum of the induced drag, the parasite drag, and the wave drag. Therefore, when the drag (or thrust required) curves are presented for aircraft weights of 35,585.77 N, 44,482.22 N, and 53,378.66 N, they reflect the fact that the induced drag depends on the lift. But the lift is equal to the weight. Thus, at the lower velocities, where the induced drag dominates, the drag is a function of the weight of the aircraft.

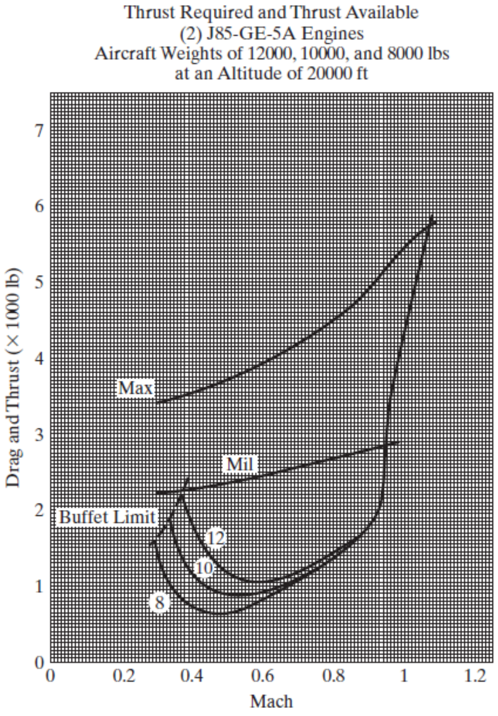

Fig. 1.

1. The maximum velocity at which an aircraft can cruise occurs when the thrust available with the engines operating with the afterburner lit ("Max") equals the thrust required, which are represented by the bucket shaped curves. What is the maximum cruise velocity that a 22,241.11 N T-38A can sustain at 26,000 feet?
   As the vehicle slows down, the drag acting on the vehicle (which is equal to the thrust required to cruise at constant velocity and altitude) reaches a minimum (D_{min}). The lift-to-drag ratio is, therefore, a maximum [$(L/D)_{max}$]. What is the maximum value of the lift-to-drag ratio [$(L/D)_{max}$] for our 22,241.11 N T-38A cruising at 26,000 ft? What is the velocity at which the vehicle cruises, when the lift-to-drag ratio is a maximum? As the vehicle slows to speeds below that for [$(L/D)_{min}$], which is equal to [$(L/D)_{max}$], it actually requires more thrust (i. e., more power) to fly slower. You are operating the aircraft in the region of reverse command. More thrust is required to cruise at a slower speed. Eventually, one of two things happen: either the aircraft stalls (which is designated by the term "Buffet Limit" in Fig. 1) or the drag acting on the aircraft exceeds the thrust available. What is the minimum velocity at which a 22,241.11 N T-38A can cruise at 26,000 ft?
   Is this minimum velocity due to stall or is it due to the lack of sufficient power?
2. What are the total energy, the energy height, and the specific excess power, if our 44,482.22 N T-38A is using "Mil" thrust to cruise at a Mach number of 0.65 at 20,000 ft?
3. What is the maximum acceleration that our 44,482.22 N T-38A can achieve using "Mil" thrust, while passing through Mach 0.65 at a constant altitude of 20,000 ft? What is the maximum rate-of-climb that our 10,000-lbf T-38A can achieve at a constant velocity (specifically, at a Mach number of 0.65), when using "Mil" thrust while climbing through 20,000 ft?
4. Compare the values of $(L/D)_{max}$ for aircraft weights of 35,585.77 N, 44,482.22 N, and 53,378.66 N, when our T-38A aircraft cruises at 20,000 ft. Compare the velocity that is required to cruise at $(L/D)_{max}$ for each of the three aircraft weights.
5. Compare the specific excess power for a 44,482.22 N T-38A cruising at the Mach number required for $(L/D)_{max}$ while operating at "Mil" thrust with that for the aircraft cruising at a Mach number of 0.35 and with that for the aircraft cruising at a Mach number of 0.70.

6. Compare the value of the kinematic viscosity for nitrogen in a wind-tunnel test, where the free-stream static pressure is 586 N/m^2 and the free-stream static temperature is 54.3 K, with the value for air at the same conditions.
   The constants for Sutherland's equation to calculate the coefficient of viscosity (i.e., equation 1.12) are:
   $$C_1 = 1.458 \times 10^{-6} \frac{\mathrm{kg}}{\mathrm{s} \cdot \mathrm{m} \cdot \mathrm{K}^{0.5}} \text{ and } C_2 = 110.4\mathrm{K}$$
   for air. Similarly,
   $$C_1 = 1.39 \times 10^{-6} \frac{\mathrm{kg}}{\mathrm{s} \cdot \mathrm{m} \cdot \mathrm{K}^{0.5}} \text{ and } C_2 = 102\mathrm{K}$$
   for nitrogen. The gas constant, which is used in the calculation of the density for a thermally perfect gas,
   $$\rho = \frac{p}{RT}$$
   is equal to 287.05 $\frac{N \,.\, m}{kg \,.k}$ for air and to 297 $\frac{N \,.\, m}{kg \,.k}$ for nitrogen. What would be the advantage(s) of using nitrogen as the test gas instead of air?
7. A gas is compressed from atmospheric pressure to a pressure of 4 atm. Temperature changes from 300K to 400K. Find the density after compression. Assume perfect gas behavior for gas with initial density of 1.176 kg/m^3.
8. The isentropic expansion of perfect air takes place such that p/p^{γ} is a constant, where $\gamma = 1.4$ for air. If the pressure decreases to one-third of its original value, what happens to the density? If the initial density is 1.176 kg/m^3, what is the final density?
9. Using the values for the pressure and for the temperature given in Table 1.2 , calculate the density [use the equation for density (1.10) for a thermally perfect gas] and the dynamic viscosity [using Sutherland's equation (1.12a) for dynamic viscosity] at an altitude 15 km.
10. Using the dynamic viscosity, density, temperature values for problem 9 at an altitude 15 km, what is the kinematic viscosity at this altitude [use the relation between dynamic viscosity and kinematic viscosity from the equation (1.13)] and speed of sound for a thermally perfect gas?

11. The pilot announces that you are flying at an altitude of 10 km where stagnation temperature is measured to be 625 K, find the speed of aircraft. Use Table 1.2 to obtain the values for the temperature and speed of the sound.
12. The air in Tunnel B is expanded through a convergent/divergent nozzle to the test section, where the Mach number is 7, the free-stream static pressure is 586 N/mm^2 and the freestream temperature is 54.3 K. Using the perfect-gas relations, what are the corresponding values for the test-section density, viscosity, and velocity? Note that $U_\infty = M_\infty a_\infty$.
13. The conditions in the reservoir (or stagnation chamber) of Aero-thermal Tunnel C at the Arnold Engineering Development Center (AEDC) are that the pressure (p_{t1}) is 170 * 10^3 N/m^2 and the temperature (T_t) is 923.15 K. Using the perfect-gas relations, what are the density and the viscosity in the reservoir?
14. The air in Tunnel C accelerates through a convergent/divergent nozzle until the Mach number is 4 in the test section. The corresponding values for the free-stream pressure and the free-stream temperature in the test section are 1100 N/m^2 abs. and 219.15 K respectively. What are the corresponding values for the free-stream density, viscosity, and velocity in the test section? Note that $M_\infty = U_\infty / a_\infty$. Using the values for the static pressure given in Table 1.2 , what is the pressure altitude simulated in the wind tunnel by this test condition?
15. If you are flying at Mach number 0.8 at a height of 10 km, what is the speed of aircraft in m/s, ft/s and knots? Use Table 1.2 to obtain the value of the speed of sound.
16. Using equations (1.21) and (1.22), calculate the temperature and pressure of the atmosphere at 9000 m. Compare the tabulated values with those presented in Table 1.2 .
17. Using an approach similar to that used in Example 1.7, develop metric-unit expressions for the pressure, the temperature, and the density of the atmosphere from 11,000 to 20,000 m. The temperature is constant and equal to 216.650 K over this range of altitude.

18. Using the expressions developed in Problem 12, what are the pressure, the density, the viscosity, and the speed of sound for the ambient atmospheric air at 18 km? Compare these values with the corresponding values tabulated in Table 1.2 .

19. Using the expressions developed in Example 1.7, calculate the pressure, the temperature, and the density for the ambient atmospheric air at 10,000, 30,000, and 65,000 ft. Compare these values with the corresponding values presented in Table 1.2 .

Problems 20 and 21 deal with standard atmosphere usage. The properties of the standard atmosphere are frequently used as the free-stream reference conditions for aircraft performance predictions. It is common to refer to the free-stream properties by the altitude in the atmospheric model at which those conditions occur. For instance, if the density of the free-stream flow is 1.0256 Kg/m^3 , then the density altitude (h_ρ) would be 6000 ft.

20. One of the design requirements for a multirole jet fighter is that it can survive a maximum sustained load factor of 9g at 20,000 ft MSL (mean sea level). What are the atmospheric values of the pressure, of the temperature, and of the density, that define the free-stream properties that you would use in the calculations that determine if a proposed design can meet this requirement?

21. An aircraft flying at geometric altitude of 20,000 ft has instrument readings of P = 57244.20103 Pa and T = 254.38 K.

(a) Find the values for the pressure altitude h_p the temperature altitude h_T and the density altitude h_ρ to the nearest 500 ft.

(b) If the aircraft were flying in a standard atmosphere, what would be the relationship among h_p, h_T and h_ρ.

22. A U-tube manometer is used to measure the pressure in water pipeline “A”. One side of the manometer is connected to the water pipe line and other side is open to atmosphere. If there is a difference of 50 cm in the mercury levels in the two tubes, what is the pressure in the pipe line ”A” ? Neglect the frictional losses. Take specific gravity is 13.6 and p_{atm} = 101325 N/m^2.

23. A U-tube manometer is used to measure the pressure at the stagnation point of a model in a wind tunnel. One side of the manometer goes to an orifice at the stagnation point; the other side is open to the atmosphere (Fig. 2). If there is a difference of 3.0 cm in the mercury levels in the two tubes, what is the pressure difference in N/m^2.

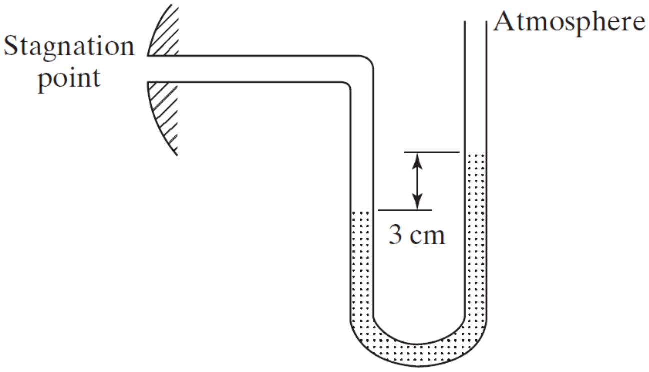

Fig. 2.

24. Consult a reference that contains thermodynamic charts for the properties of air, e.g., Hansen (1957), and delineate the temperature and pressure ranges for which air behaves: as a

(1) thermally perfect gas, i.e., $p = \rho RT$ and
(2) as a calorically perfect gas, i.e., $h = c_p T$, where c_p is a constant.