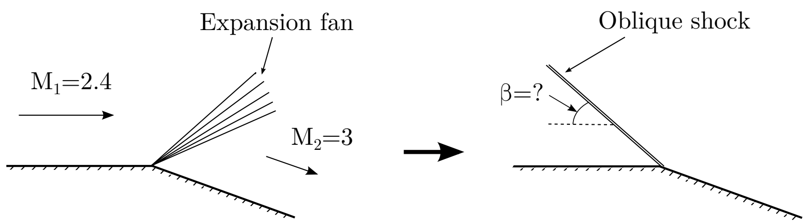
ENAE311H Homework 6 Due:

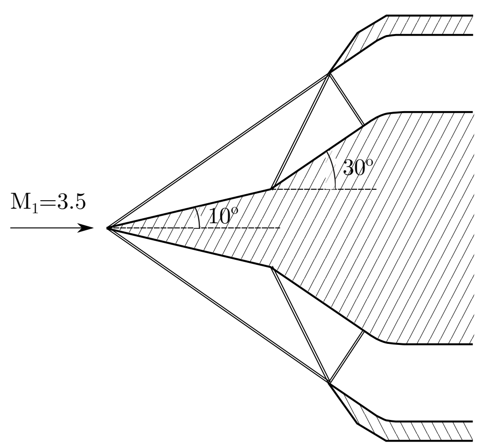
Friday, November 22nd;- online by 11:59pm

1. An F-22 pilot is experiencing a malfunctioning Pitot probe. Fortunately he also has a probe capable of measuring the stagation temperature of the flow; this reads 333.5 K. His altimeter tells him he is at 30,000 feet, where the static pressure and temperature are 30 kPa and 230 K, respectively. Can you estimate his airspeed? What should his Pitot probe be reading? He now decelerates while maintaining the same altitude, which causes his Pitot probe to start working again - it now reads 45.73 kPa. What is his new airspeed?

2. A supersonic flow at Mach 2.4 passes over a convex corner, with a downstream Mach number of 3. Now an oblique shock is introduced that impinges directly on the corner, such that no expansion fan and no reflected shock are generated. What is the shock angle, β?



3. The purpose of the inlet of a ramjet engine is to slow the incoming air to subsonic conditions so that it can be mixed and reacted with the fuel. Often this is accomplished via a system of shocks that are stabilized in the inlet. As an example, consider the compression taking place in the inlet of the ramjet engine pictured below. Two oblique shocks followed by a normal shock decelerate the incoming Mach-3.5 flow to subsonic conditions. The aircraft is flying at an altitude of 10 km, where the static pressure and temperature are 26.5 kPa and 223 K respectively. Assume the flow is two-dimensional (NOT axisymmetric), and that conditions are uniform behind the normal shock.



   (a) Determine the Mach number, static temperature, static pressure, total temperature, and total pressure at each stage in the compression process (i.e., behind each of the three shocks).

   (b) Compare the final conditions with those behind a single normal shock with the same freestream Mach number.

(c) Temperature-entropy (T-s) diagrams are often used to visualize thermodynamic processes. Plot a T-s diagram for the entire ramjet compression (compute the entropy change through each shock, choosing an initial value equal to zero); include a line corresponding to the total temperature. Add contours showing the total pressure at each stage in the compression. Add the normal shock case to your diagram (computing the entropy and stagnation pressure change). Is the oblique shock system or the single normal shock preferable for the compression?

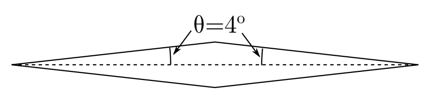
4. Early supersonic fighters, such as the Lockheed F-104 Starfighter, employed a very slender wing with a sharp leading edge (sharp enough that it was considered a hazard on the ground). In this problem, we will look at the flow over an idealized version of this wing.

(a) Consider a wing having a two-dimensional symmetric diamond-shaped profile, as shown in the figure below. Shocks form at the leading and trailing edges, and an expansion fan at the midpoint. Assuming an inviscid flow, calculate the two shock angles, β_1 and β_2, the leading and trailing angles (μ) of the expansion fan, and the Mach number and pressure behind the leading shock, the expansion fan, and the trailing shock.

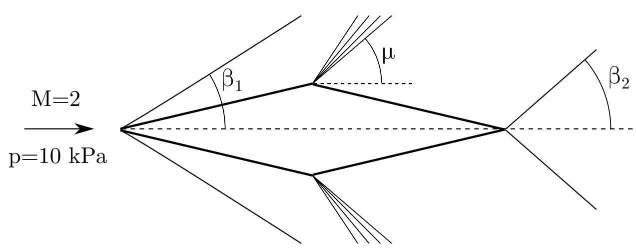
(b) As you might have noted, a symmetrical wing will not produce any lift, which is a somewhat undesirable property for a wing to have. One way to produce lift would be to change the half-angle θ on one of the halves (upper or lower) of the diamond. Assume the angle on one half is increased to 6° - to generate positive lift, should this be the upper or lower half? Calculate the lift coefficient (per unit depth) based on the wing chord.

(c) If one of the diamond angles is increased to 6°, as in part (b), a shear layer will form at the trailing edge, as the flow angle leaving the airfoil will no longer be horizontal. Which way will this shear layer tilt - towards the 4° side or the 6° side? *Hint*: first, assume that the shear layer is horizontal, and calculate the pressure behind the trailing-edge shock on the 6° side. Then deduce the answer based on comparing this pressure with the equivalent pressure on the other side (remembering that pressure must be constant across a shear layer).

Actual airfoil shape



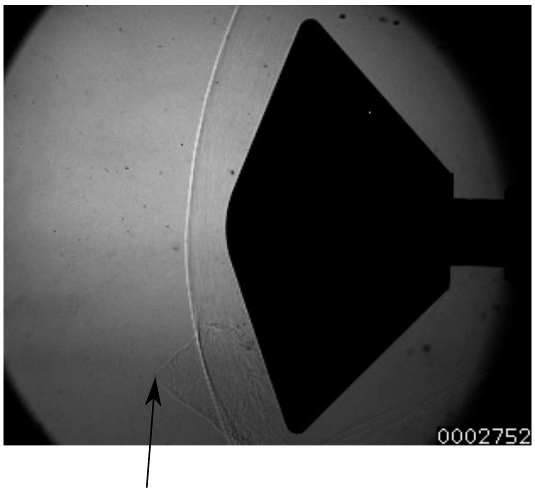
Idealized airfoil shape



5. In shock tunnels, particles from diaphragm burst etc. are sometimes visible in schlieren images by the flow disturbances they produce (if they are not travelling at the same speed as the flow). In such cases, it may be possible to estimate the particle velocities from the shock angle far away from the particle.

   (a) The air free stream in the picture below has a Mach number of 8 and a temperature of 220 K. A particle with accompanying bow-shock is seen in a schlieren image, with a shock angle in the farfield of 30°. What is the velocity of the particle?

   (b) What would the farfield shock angle be if the particle were stationary in the laboratory frame of reference? What would the minimum particle velocity be such that no shock were present?



Particle