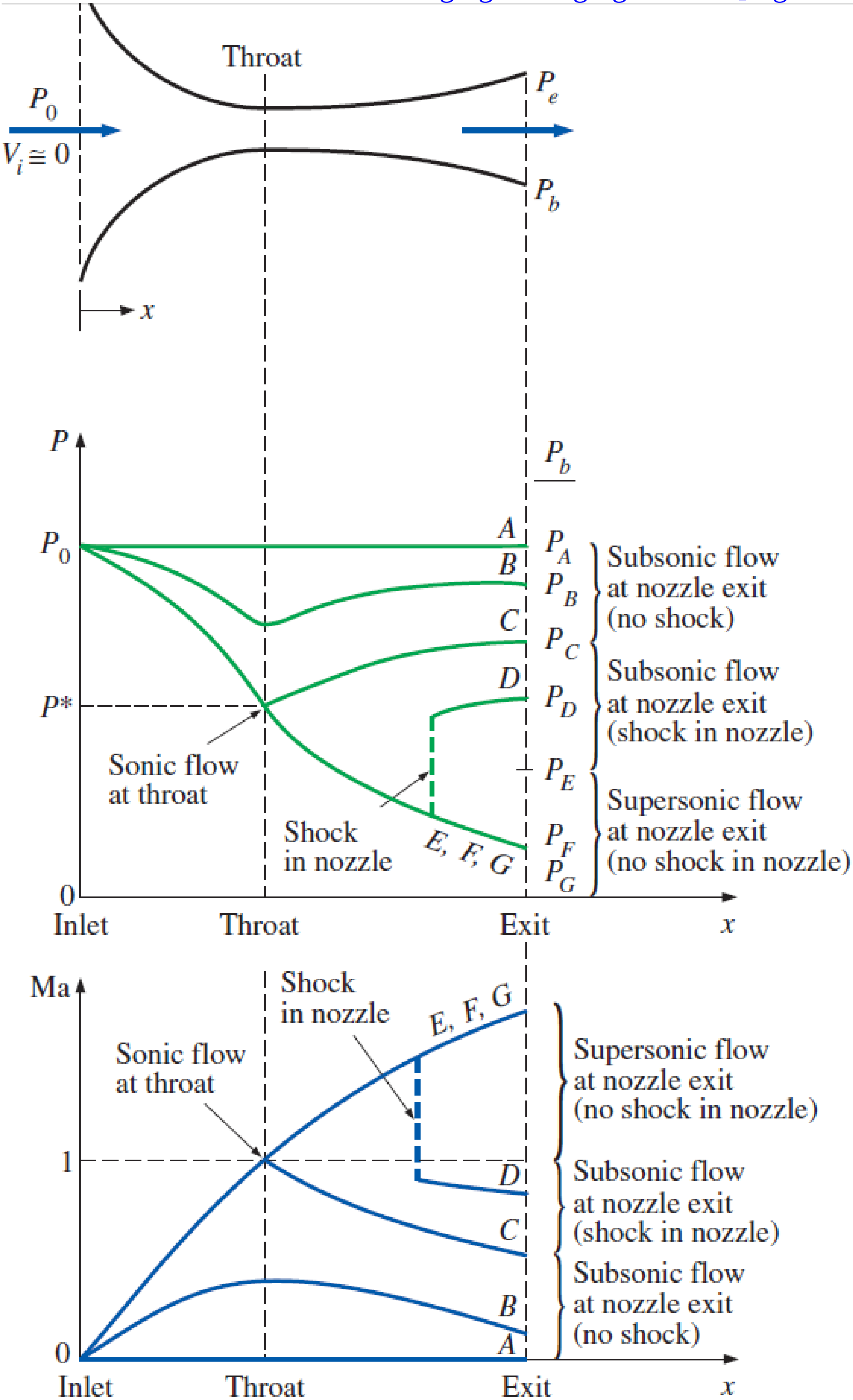
Today [last day of class ☺], we will:

- Finish our discussion about shock waves; converging-diverging nozzles
- Do some example problems

Effect of Back Pressure in a Converging-Diverging Nozzle: [Fig. 12-22 in Ed 2 of textbook]



Overexpanded nozzles:

Example – High speed jet aircraft

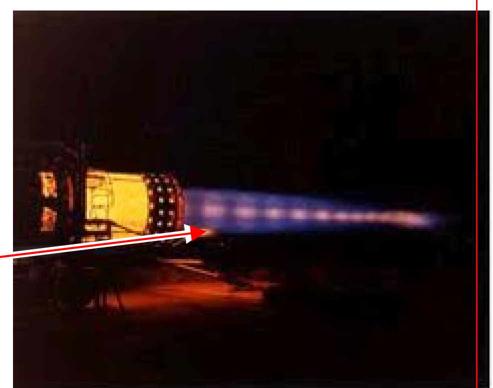
Given: The SR-71 travels at Ma = 3.2 at 24 km altitude (80,000 ft).

To do: Calculate its air speed.

Solution:

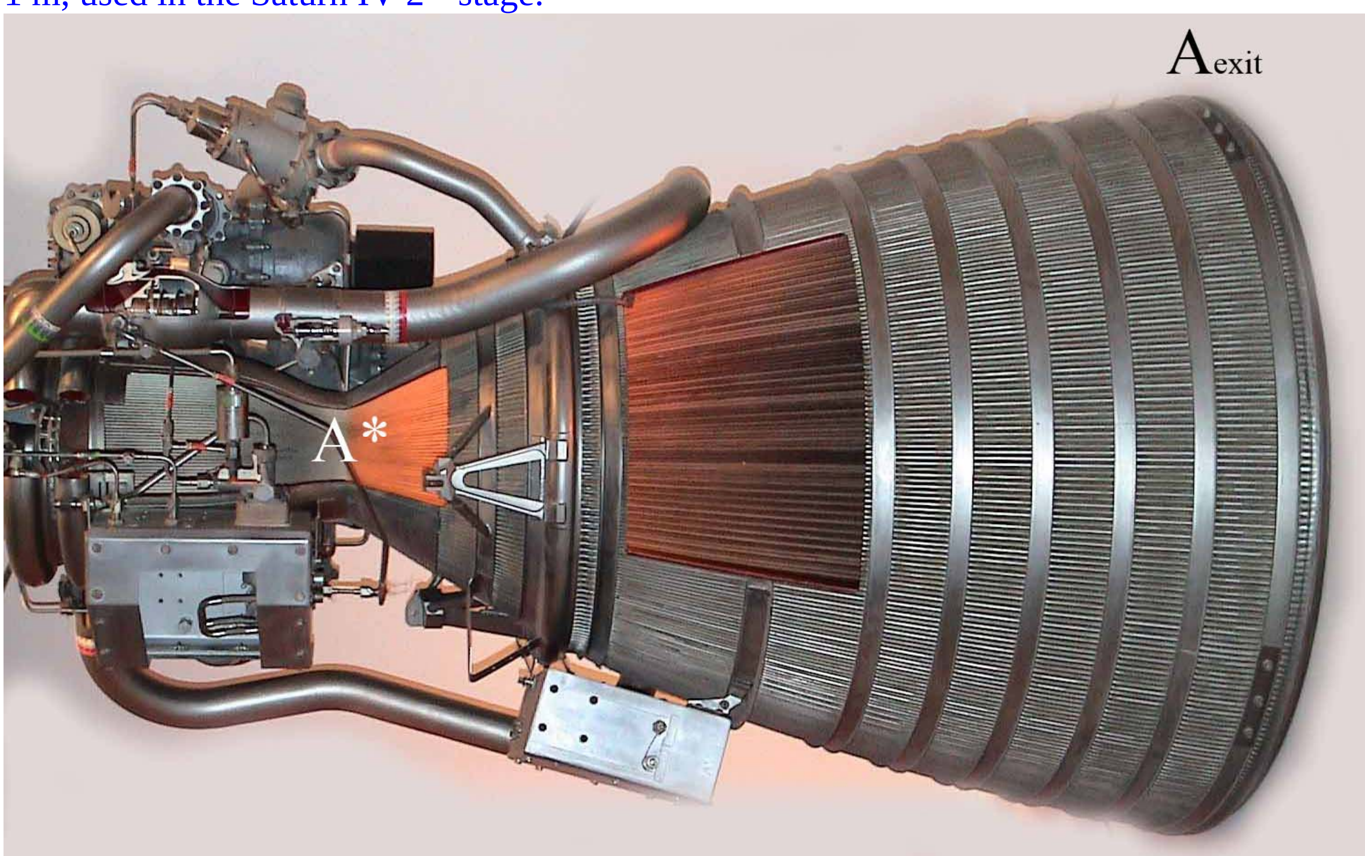
- From Table A-11E, T at 24 km altitude is -69.7ºF = 217 K.
- Using $k = 1.4$ and $R_{air} = 287\ m^2/(s^2 \cdot K)$, $c = (kRT)^{1/2} = 295$ m/s.
- Thus, $V = Ma \cdot c = 3.2(295\ m/s) =$ 944 m/s (= 2110 mph).

Shock Diamonds ("tiger tail"):

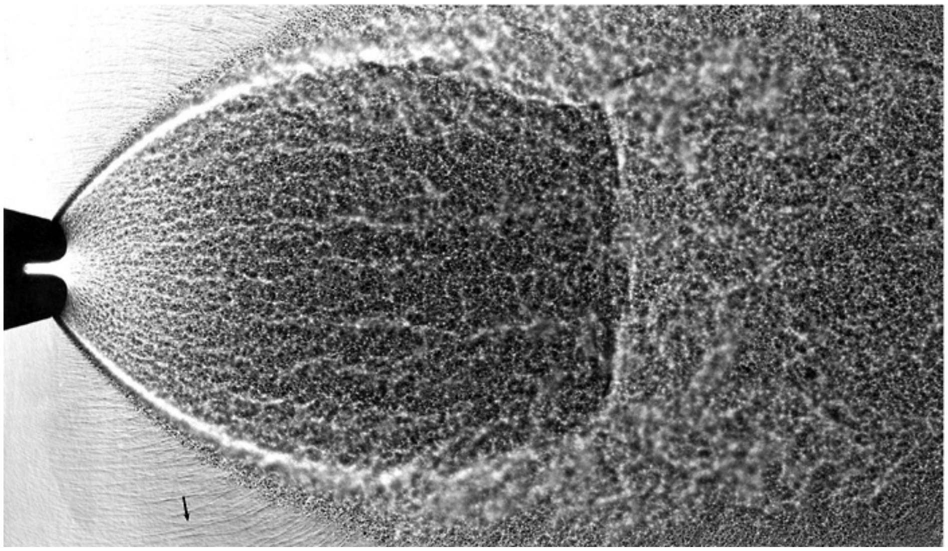


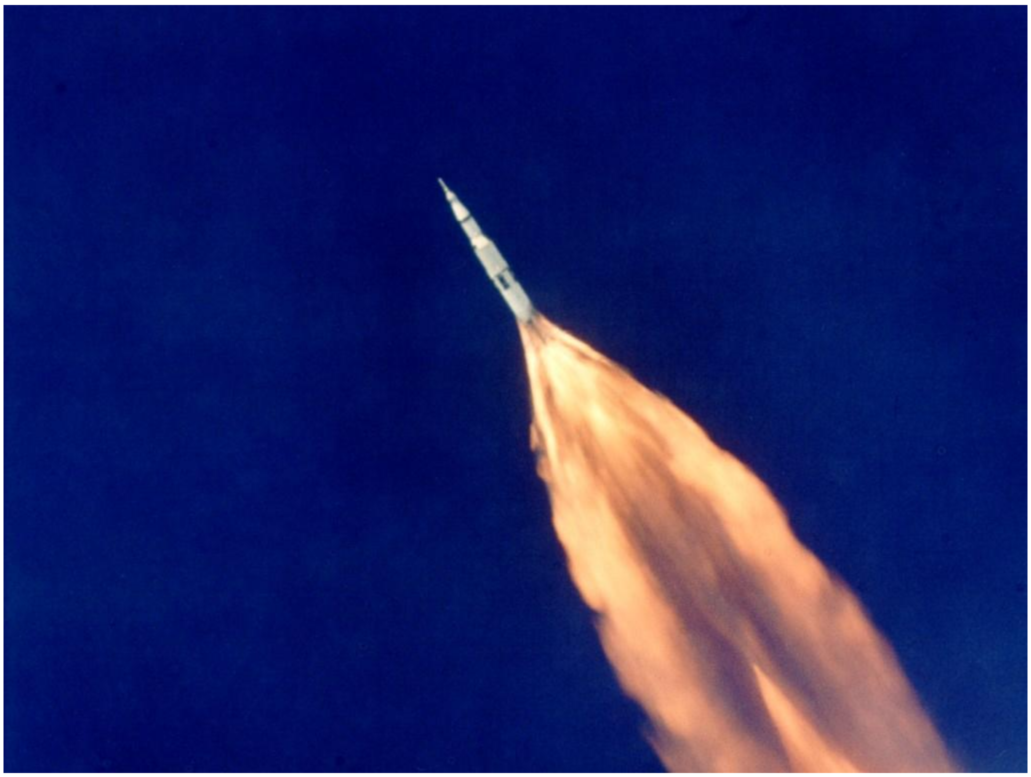
Example of a Rocket Engine:

Pratt &Whitney RL-10 rocket motor designed for a specific Ma_{exit} (photographed at the National Air & Space Museum). 1960-vintage, $Ma_{exit} = 5$, $k = 1.33$, thrust = 15,000 lbf, $D_e \sim 1$ m, used in the Saturn IV 2nd stage.



Underexpanded Nozzles:





Example – Normal shock at Ma = 3.0

Given: A converging/diverging nozzle accelerates air to Ma = 3.0 at the exit. The upstream stagnation properties are T_0 = 1000 K and P_0 = 1.00 MPa.

To do: If a normal shock occurs right at the exit plane, calculate the pressure, temperature, and density upstream (1) and downstream (2) of the shock.

Solution:

- From Table A-13 at Ma_1 = 3.0,
  A/A^* = 4.2346, P/P_0 = 0.0272, T/T_0 = 0.3571, and ρ/ρ_0 = 0.0760.
- From Table A-14 at Ma_1 = 3.0,
  Ma_2 = 0.4752, P_2/P_1 = 10.3333, T_2/T_1 = 2.679, and ρ_2/ρ_1 = 3.8571.
- The rest of the problem to be completed in class.