From the given data, the mass flow rate can be determines easily using the one-dimensional mass flow equation and the perfect gas equation. Thus

$$\dot{m} = \rho_1 A_1 V_1 = \frac{P_1 A_1}{R T_1} M_1 \sqrt{\gamma R g_c T_1} = P_1 A_1 M_1 \sqrt{\frac{\gamma g_c}{R T_1}}$$

$$T_1 = 0.7519 \times 518.7 = 390.0^\circ R \text{ and } P_1 = 0.1151 \times 2116 = 243.55 \text{ lb/ft}^2$$

$$\dot{m} = P_1 A_1 M_1 \sqrt{\frac{\gamma g_c}{R T_1}} = 243.55 \times 4.235 \times 3 \sqrt{\frac{1.4 \times 32.174}{53.34 \times 390}} = 144.0 \frac{\text{lbm}}{\text{sec}}$$

3

b. We first determine the total temperature and pressure at station 1.

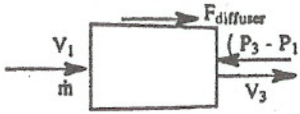
$$T_{t1} = T_1\left(1+\frac{\gamma-1}{2}M_1^2\right) = 0.7519\times 518.7\,(1+0.2\times 3^2) = 1092.0^{\circ}R$$

$$P_{t1} = P_1\left(1+\frac{\gamma-1}{2}M_1^2\right)^{\frac{\gamma}{\gamma-1}} = 0.1151\times 2116\,(1+0.2\times 3^2)^{3.5} = 8946.3\ \text{lb/ft}^2$$

The total pressure is 8946.3 lb/ft² for all stations and the total temperature equals 1092°R for stations 1, 2, and 3 and equals 4000°R for stations 4, 5, and 6. The properties at flow stations are as follows:

Station:	1	2	3	4	5	6
Area (ft²)	4.235	1.00	3.910	7.483	1.914	8.105
Mach	3	1	0.15	0.15	1	3
P (psia)	1.691	32.84	61.16	61.16	32.84	1.691
T (°R)	390.0	910.0	1087.1	3982.1	3333.3	1428.6
V (ft/sec)	2904	1479	242.4	464.0	2830	5580

c. Thrust (magnitude and direction) of diffuser, combustor, and nozzle. We assume that the outside of each component is subjected to the atmospheric pressure (P_1). For the diffuser we have

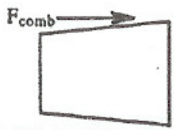


$$F_{diffuser} - (P_3 - P_1)A_3 = \frac{\dot{m}}{g_c}(V_3 - V_1)$$

$$F_{diffuser} = \frac{\dot{m}}{g_c}(V_3 - V_1) + (P_3 - P_1)A_3$$

$$F_{diffuser} = \frac{144.0}{32.174}(242.4 - 2904) + (61.16 - 1.69)\times 144\times 3.91 = 21{,}570\ \text{lbf}$$

Thus the diffuser has a thrust of 21,570 lbf to the left.
For the combustor we have

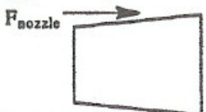


$$F_{comb} + (P_3 - P_1)A_3 - (P_4 - P_1)A_4 = \frac{\dot{m}}{g_c}(V_4 - V_3)$$

$$F_{comb} = \frac{\dot{m}}{g_c}(V_4 - V_3) + (P_4 - P_1)A_4 - (P_3 - P_1)A_3$$

$$F_{comb} = \frac{144}{32.174}(464 - 242.4) + (61.16 - 1.69)\,144\,(7.483 - 3.910) = 31{,}590\ \text{lbf}$$

Thus the combustor has a thrust of 31,590 lbf to the left.
For the nozzle we have



$$F_{nozzle} + (P_4 - P_1)A_4 = \frac{\dot{m}}{g_c}(V_6 - V_4)$$

$$F_{nozzle} = \frac{\dot{m}}{g_c}(V_6 - V_4) - (P_4 - P_1)A_4$$

$$F_{nozzle} = \frac{144}{32.174}(5590 - 464) - (61.16 - 1.69)\,144\times 7.483 = -41{,}140\ \text{lbf}$$

Thus the nozzle has a thrust of 41,140 lbf to the right (a drag).

d. Thrust (magnitude and direction) of ramjet. The thrust can easily be determined by summing the thrust of the diffuser, combustor, and nozzle. Thus the thrust of the ramjet is 12,020 lbf.

2.

(3) $\dot{W}_t = \dot{m}\,(h_{t_4} - h_{t_5}) = \dot{m}\,C_p\,(T_{t_4} - T_{t_5})$

$C_p = \frac{\gamma R}{\gamma - 1} = \frac{(1.31)\left(\frac{1716}{32.174}\right)}{(778.16)(0.31)} = 0.29\ \frac{Btu}{lbm\ {}^\circ R}$

$W_t = (251)(0.29)(1970-850) = 81,525\ \left(\frac{Btu}{s}\right)$

$= 115,345\ hp.$

$= 6.337\times10^{7}\ \frac{ft\cdot lbf}{s}$

3-8 An ideal ramjet (see Fig. P3-8) is operated at 50,000 ft altitude with a flight Mach number of