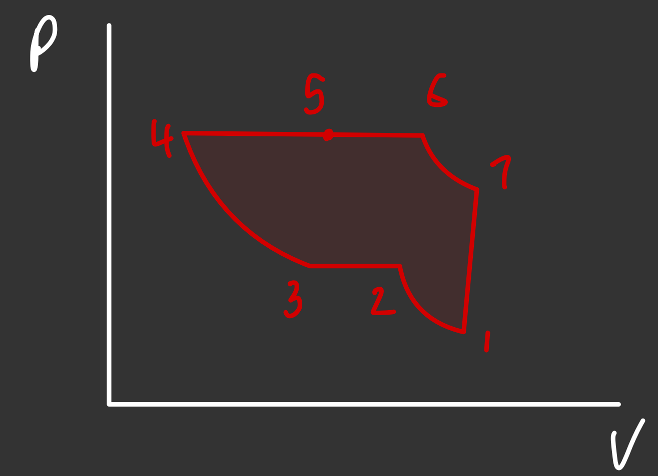
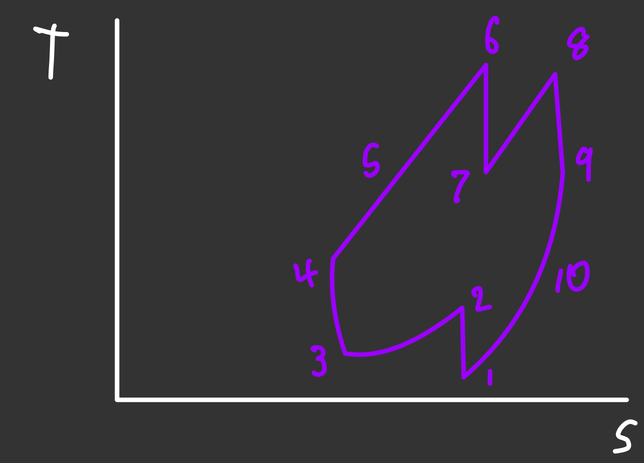
9-123 Air enters a gas turbine with two stages of compression and two stages of expansion at 100 kPa and 17°C. This system uses a regenerator as well as reheating and intercooling. The pressure ratio across each compressor is 4. And 300 kJ/kg of heat is added to the air in each combustion chamber; and the regenerator operates perfectly while increasing the temperature of the cold air by 20°C. Determine this system's thermal efficiency

Constant Cp, CV





add $q_{in} = 300$ (5→6), add $q_{in} = 300$ (7→8)

Isentropic | P const | Isentropic | P const | P const | Isentropic | P const | Isentropic | P const | P const

1	2	3	4	5	6	7	8	9	10
$P_1 = 100$ kPa	$P_2 = 400$ kPa	$P_3 = 400$ kPa	$P_4 = 1600$ kPa	$P_5 = 1600$ kPa	$P_6 = 1600$ kPa	$P_7 = 400$ kPa	$P_8 = 400$ kPa	$P_9 = 100$ kPa	$P_{10} = 100$ kPa
$T_1 = 290$ °K	$T_2 = 431$ °K	$T_3 = 290$ °K	$T_4 = 431$ °K	$T_5 = 451$ °K	$T_6 = 751$ °K	$T_7 = 505.4$ °K	$T_8 = 805.4$ °K	$T_9 = 542$ °K	$T_{10} = 522$ °K

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

Assume $T_3 = T_1$

100K at graph

$T_5 = T_4 + 20\,°K$

$$q = C_p \Delta T \rightarrow T_6 = \frac{q_{in\,5\text{-}6}}{C_p} + T_5$$

open system

$T_6 = 451 + 300/1 = 751$

use a Pressure ratio :

$r_p = \sqrt{P_6 / P_9}$

$r_p = \frac{P6}{P7} = \frac{P8}{P9}$

$T_7 = T_6 \left(\frac{1}{P_r}\right)^{\frac{k-1}{k}}$

$T_7 = 751 \left(\frac{1}{4}\right)^{\frac{0.4}{1.4}}$

$T_7 = 505.4\,°K$

Because The 20° K added Between T_4 and T_5 is from T_9 to T_{10}

$T_5 - T_4 = T_9 - T_{10}$

$T_{10} = T_9 - 20\,°K$

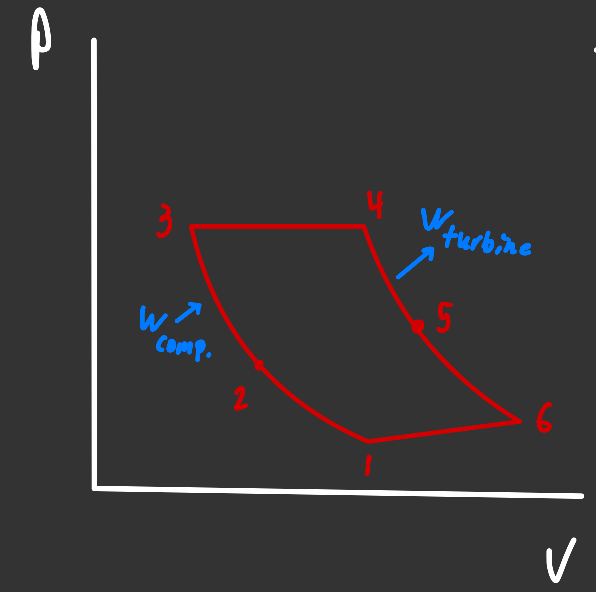
$T_{10} = 522\,°K$

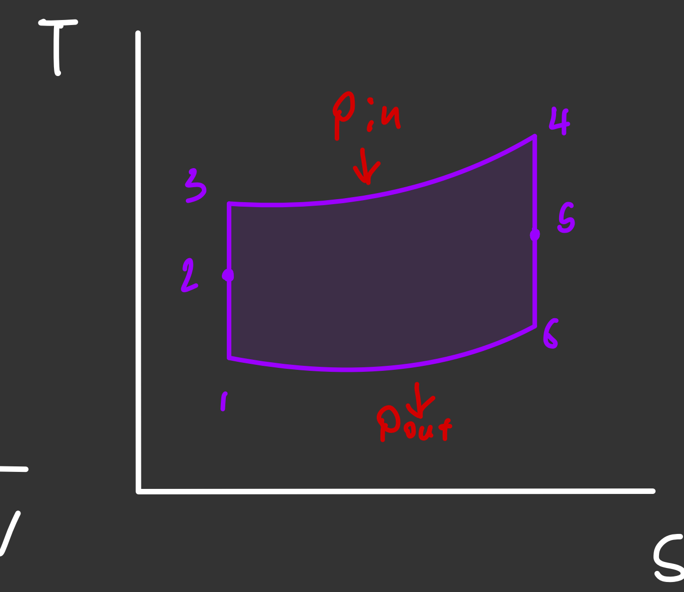
$P_{out} = (522 - 290 + 431 - 290) = 373 \text{ KJ/kg}$

$P_{in} = 600 \text{ KJ/kg}$

$\eta_{th} = \frac{373}{600} = 62\,\%$

9–129E A turbojet is flying with a velocity of 900 ft/s at an altitude of 20,000 ft, where the ambient conditions are 7 psia and 10°F. The pressure ratio across the compressor is 13, and the temperature at the turbine inlet is 2400 R. Assuming ideal operation for all components and constant specific heats for air at room temperature, determine (a) the pressure at the turbine exit, (b) the velocity of the exhaust gases, and (c) the propulsive efficiency.





$P_r = 13 \qquad P_3 = 13 \cdot P_2$

const P → (1) → Isentropic → (2) → Isentropic → (3) → const. P → (4) → Isentropic → (5) → Isentropic → (6) → P const

(1)	(2)	(3)	(4)	(5)	(6)
$T_1 = 470\ °R$	$T_2 = 537.4\ °R$	$T_3 = 1118\ °R$	$T_4 = 2400\ °R$	$T_5 = 1819.4\ °R$	$T_6 = 1008.6\ °R$
$P_1 = 7\ psi$	$P_2 = 11.19\ psi$	$P_3 = 145.5\ psi$	$P_4 = 145.5\ psi$	$P_5 = 55.2\ psi$	$P_6 = 7\ psi$
$V_1 = 900\ ft/s$	$V_2 = 0\ ft/s$	$V_3 = 0\ ft/s$	$V_4 = 0\ ft/s$	$V_5 = 0\ ft/s$	$V_6 = 3120.7\ ft/s$

$$T_2 = T_1 + \frac{V_1^2}{2\,C_P}$$

$$T_2 = 470 + \frac{900}{2 \cdot 6.67} = 537.4\ °R$$

$$P_2 = P_1\left(\frac{T_2}{T_1}\right)^{k/k-1} \qquad P_2 = 7\left(\frac{537.4}{470}\right) = 11.19\ psia$$

$$T_3 = T_2\left(\frac{P_3}{P_2}\right)^{\frac{k-1}{k}}$$

$$T_3 = 537.4\,(13)^{0.4/1.4}$$

$$T_3 = 1118\ °R$$

$$T_5 = T_4 - T_3 + T_2$$

$$T_5 = 2400 - 1118 + 537.4 = 1819.4\ °R$$

$$P_5 = 145.5\left(\frac{1819.4}{2400}\right)^{0.4/1.4} = 55.2\ psi$$

$$T_6 = 1819.4\left(\frac{7}{55.2}\right)^{0.4/1.4} = 1008.6\ °R$$

$$V_6^2 = 2\left(c_p \cdot \left(T_6 - T_5\right)\right)$$

$$V_6 = \sqrt{2(6008.8)(1614 - 1008.6)}$$

$$\boxed{V_6 = 3120.7 \ ft/s}$$

$$W_p = \left(V_{exit} - V_{inlet}\right) V_{aircraft}$$

$$W_p = \frac{(3120.7 - 900)\,900}{25037} = 79.8 \ Btu/lbm$$

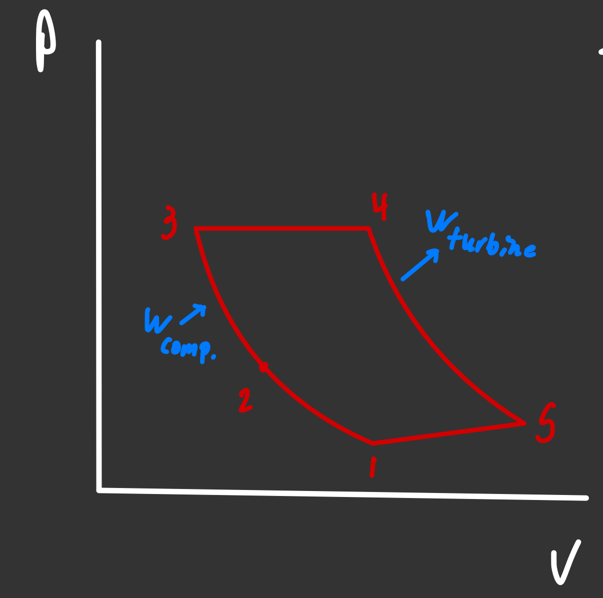
$$Q_{in} = c_p\left(T_4 - T_3\right)$$

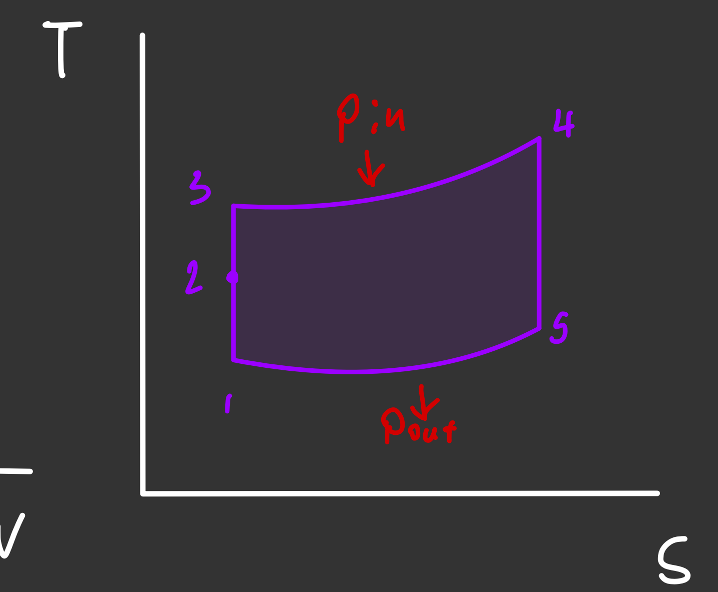
$$Q_{in} = 0.24\left(2400 - 1118\right) = 307.7 \ Btu/lbm$$

$$\eta_{th} = \frac{W_p}{Q_{in}}$$

$$\eta_{th} = \frac{79.8}{307.7} = 0.26 \quad \boxed{26\%}$$

9–135 Consider an aircraft powered by a turbojet engine that has a pressure ratio of 9. The aircraft is stationary on the ground, held in position by its brakes. The ambient air is at 7°C and 95 kPa and enters the engine at a rate of 20 kg/s. The jet fuel has a heating value of 42,700 kJ/kg, and it is burned completely at a rate of 0.5 kg/s. Neglecting the effect of the diffuser and disregarding the slight increase in mass at the engine exit as well as the inefficiencies of engine components, determine the force that must be applied on the brakes to hold the plane stationary.
Answer: 19,370 N





$P_r = 9$

$\dot{Q}_{in} = 21{,}350$ kJ/s

const P → (1) Isentropic → (2) Isentropic → (3) const. P → (4) Isentropic → (5) P const

State 1

$T_1 = 290$ °K

$P_1 = 95$ kPa

$h_1 = 290.16$

$Pr_1 = 1.2311$

State 2

$T_2 = 540$ °K

$P_2 = 10.5$ kPa

$h_2 = 544.35$

$Pr_2 = 11.08$

State 3

$T_3 = 1480$ °K

$P_3 = 855$ kPa

$h_3 = 1611.85$

$Pr_3 = 568.8$

State 4

$T_4 = 1268$ °K

$P_4 = 855$ kPa

$h_4 = 1357.66$

State 5

$T_5 = 860$ °K

$P_5 = 95$ kPa

$h_5 = 888.56$

$$Pr_5 = Pr_3 \left(\frac{P_5}{P_3} \right)$$

$$Pr_5 = 568.8 \left(1/9 \right)$$

$$Pr_5 = 63.2$$

$$Pr_2 = \left(\frac{P_2}{P_1} \right) Pr_1$$

$$Pr_2 = (9)\, 0.2311$$

$$Pr_2 = 11.08$$

$$q_{in} = \frac{21{,}350}{20} = 1067.5$$

$$h_3 = h_2 + q_{in}$$

$$h_3 = 544.35 + 1067.5$$

$$h_3 = 1611.85$$

$$h_4 = h_3 - h_2 + h_1$$

$$h_4 = 1611.85 - 544.35 + 290.16$$

$$h_4 = 1357.66$$

$$V_5 = \sqrt{2(h_4 - h_5)}$$

$$V_5 = \sqrt{2(1357.66 - 888.56)\cdot 1000}$$

$$V_5 = 968.6 \text{ m/s}$$

$$F = \dot{m}(V_{exit} - V_{inlet})$$

$$F = 20(968.6 - 0)$$

$$F = 19.37 \text{ kN}$$