MET 350

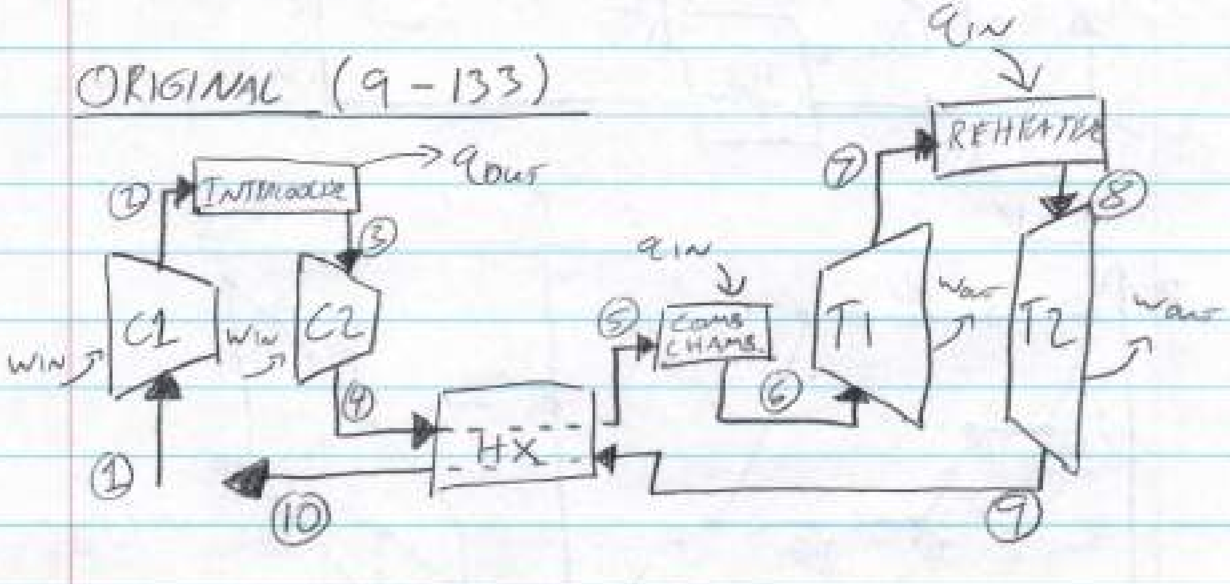
GOLDMAN TEST 1 Q1

Q1.1 PURPOSE

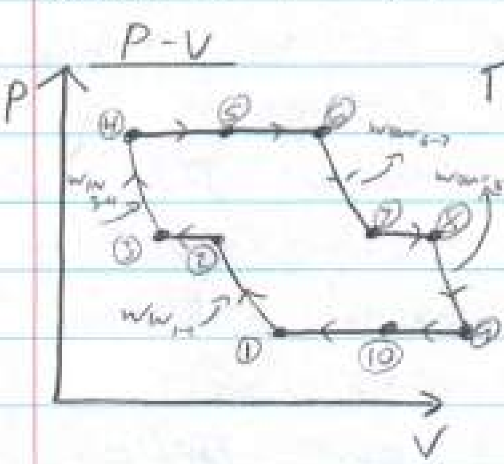
IN Q1, THE PURPOSE IS TO EXTEND PROBLEM 9-133, FINDING REGENERATOR EFFECTIVENESS (ε). ALSO, FINDING HOW A REDUCTION IN HEAT INPUT (q_{in}) IMPACTS MAX POWER OUTPUT. A SPECIAL NOTE IS MADE TO CONVEY THAT HX ε IS DEPENDENT ON DESIGN RATHER THAN TEMPERATURE. DIFFERENT EFFICIENCIES AND MAX POWER OUTPUTS ARE FOUND FOR DIFFERING SYSTEM CONFIGURATIONS.

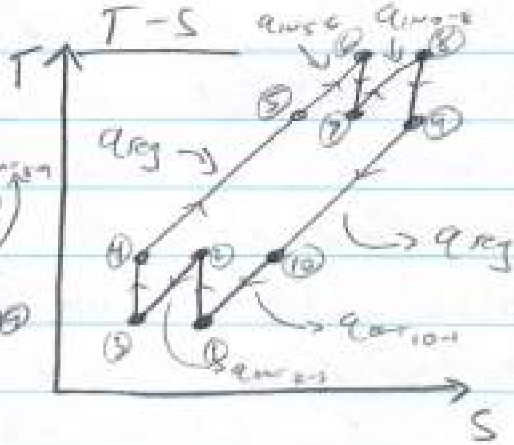
Q1.2 DRAWINGS AND DIAGRAMS

ORIGINAL (9-133)

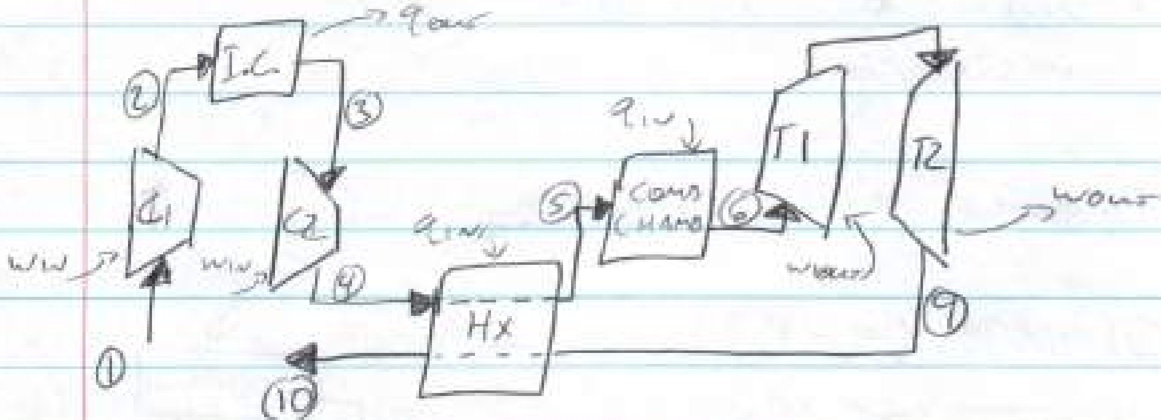


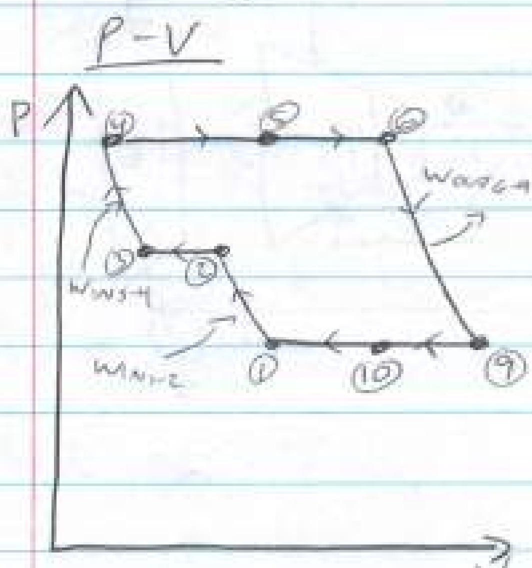
ORIGINAL P-V, T-S DIAGRAMS.

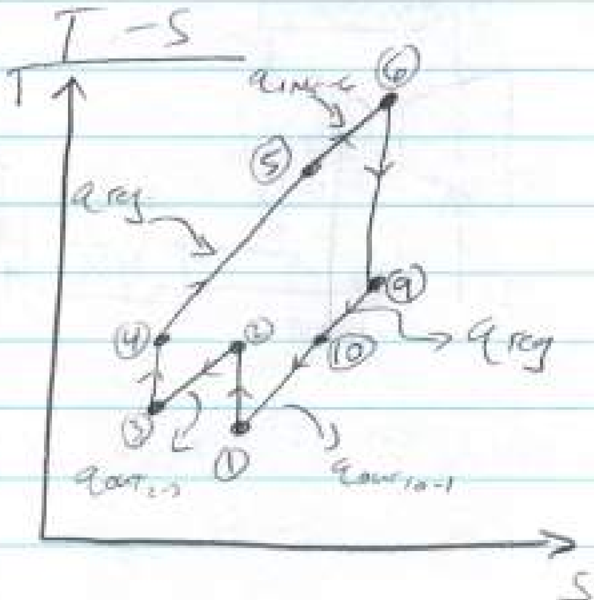




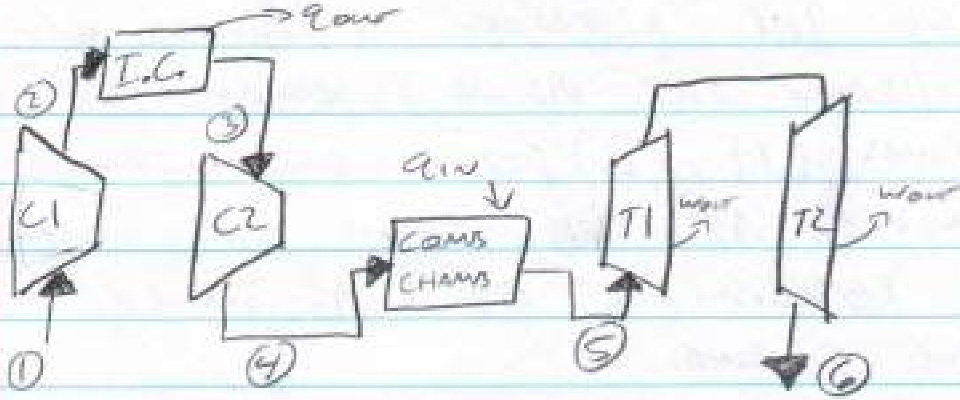
W/OUT REHEATER



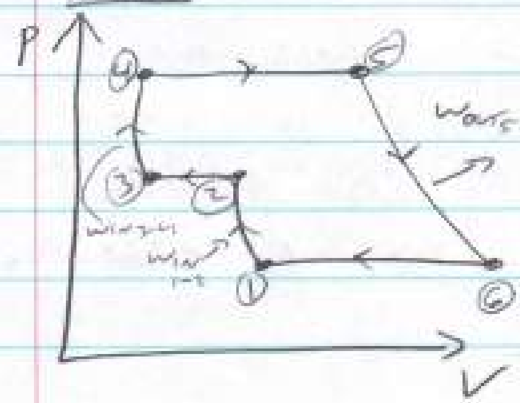




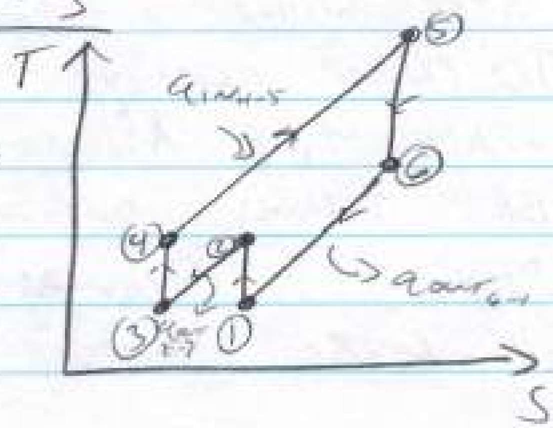
W/OUT REHEATER AND HX.



P-V



T-S



Q1. 3 SOURCES

THERMODYNAMICS, AN ENGINEERING APPROACH
BY YUNUS A. ÇENGEL AND MICHAEL A. BOLES
6TH EDITION

JOHNDCOOK.COM INTERPOLATION
CALCULATOR.

ODU LECTURE MATERIALS

Q1.4 DESIGN CONSIDERATIONS

WHILE THE REHEATER IS TURNED OFF, I DRAW THE PIPING INBETWEEN 2 TURBINES ($T1$, $T2$) FOR CONTINUITY, HOWEVER AT THIS POINT THEY COULD BE REPRESENTED BY A SINGLE LARGE TURBINE.

LATER, WHILE I "BYPASS" THE HX TO PREVENT COOLING TO FLUID AT STATE 4, I ASSUME THIS WILL NOT BE TERRIBLY DIFFICULT TO ACHIEVE PHYSICALLY, COMPARED TO RE ORGANIZING THE ENTIRE STRUCTURE

Q1.5. DATA AND VARIABLES

ALL SYSTEM ITERATIONS: $P_1 = 100kPa$, $T_1 = 290.15K$, $r_p = 4$, $q_{IN} = 300 kJ/kg$ / HEATER SOURCE, C_p, C_v CONST, $C_p = 1.005 kJ/kg \cdot K$ $C_v = .718 kJ/kg \cdot K$, $R = .287 kJ/kg \cdot K$, FULL LOAD: 800kW

ORIGINAL DESIGN (9-133): $T_4 + 20 = T_5$

Q1-7. CALCULATIONS

ORIGINAL (9-133)

$\xrightarrow{P} ① \xrightarrow{ISEN} ② \xrightarrow{P} ③ \xrightarrow{ISEN} ④ \xrightarrow{P} ⑤ \xrightarrow{P}$

$P_1 = 100kPa$	$P_2 = 400kPa$	$P_3 = 400kPa$	$P_4 = 1600kPa$	$P_5 = 1600kPa$
$T_1 = 290.15k$	$T_2 = 431.16k$	$T_3 = 290.15k$	$T_4 = 431.15k$	$T_5 = 451.15k$
$V_1 = .833 m^3/kg$	$V_2 = .309 m^3/kg$	$V_3 = .208 m^3/kg$	$V_4 = .077 m^3/kg$	$V_5 = .081 m^3/kg$

$\xrightarrow{P} ⑥ \xrightarrow{ISEN} ⑦ \xrightarrow{P} ⑧ \xrightarrow{ISEN} ⑨ \xrightarrow{P}$

$P_6 = 1600kPa$	$P_7 = 400kPa$	$P_8 = 400kPa$	$P_9 = 100kPa$
$T_6 = 749.66k$	$T_7 = 504.49k$	$T_8 = 803k$	$T_9 = 540.39k$
$V_6 = .1345 m^3/kg$	$V_7 = .362 m^3/kg$	$V_8 = .576 m^3/kg$	$V_9 = 1.551 m^3/kg$

$\xrightarrow{P} ⑩ \xrightarrow{P}$

$P_{10} = 100kPa$

$T_{10} = 520.39k$

$V_{10} = 1.49 m^3/kg$

V_1 $\quad P_1 V_1 = RT_1$

$$V_1 = \frac{RT_1}{P_1} = \frac{(.287 kJ/kg \cdot k)(290.15k)}{100kPa}$$

$V_1 = .833 m^3/kg$

P_2 $\quad r_p = 4 = P_2/P_1 \Rightarrow P_2 = 4(P_1) = 4(100kPa)$

$P_2 = 400kPa = P_3$

T_2 $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \Rightarrow T_2 = (r_p)^{\frac{k-1}{k}}(T_1) = (4)^{\frac{1.4-1}{1.4}}(290.15k)$

$T_2 = 431.16k$

V_2 $P_2V_2 = RT_2 \Rightarrow V_2 = RT_2/P_2 = (.287kJ/kg\cdot k)(431.16k)/400kPa$

$V_2 = .309 m^3/kg$

T_3 $T_3 = T_1$

$T_3 = 290.15k$

V_3 $P_3V_3 = RT_3 \Rightarrow V_3 = RT_3/P_3 = (.287kJ/kg\cdot k)(290.15k)/400kPa$

$V_3 = .208 m^3/kg$

P_4 $r_p = P_4/P_3 \Rightarrow P_4 = r_pP_3 = 4(400kPa)$

$P_4 = 1600kPa = P_5 = P_6$

$P_{9,10}$ $P_9 = P_{10} = P_1 = 100kPa$

T_4 $\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}} \Rightarrow T_4 = (r_p)^{\frac{k-1}{k}} T_3 = (4)^{\frac{1.4-1}{1.4}} 290.15k$

$T_4 = 431.15k$

V_4 $P_4V_4 = RT_4 \Rightarrow V_4 = RT_4/P_4 = (.287kJ/kg\cdot k)(431.15k)/1600kPa$

$V_4 = .077 m^3/kg$

T_5 $T_5 = T_4 + 20 = 431.15k + 20$

$T_5 = 451.15k$

V_5 $P_5 V_5 = RT_5 \Rightarrow V_5 = RT_5 / P_5 = (.287 kJ/kg \cdot k)(451.15k) / 1600 kPa$

$V_5 = .081 m^3/kg$

T_6 $q_{IN} = h_6 - h_5 = C_p(T_6 - T_5) \Rightarrow q_{IN}/C_p + T_5 = T_6$

$T_6 = 300 kJ/kg / 1.005 kJ/kg \cdot k + 451.15k$

$T_6 = 749.66k$

V_6 $P_6 V_6 = RT_6 \Rightarrow V_6 = RT_6 / P_6 = \dfrac{(.287 kJ/kg \cdot k)(749.66k)}{1600 kPa}$

$V_6 = .1345 m^3/kg$

P_7 $r_p = P_6 / P_7 \Rightarrow P_7 = P_6 / r_p = 1600 kPa / 4$

$P_7 = 400 kPa = P_8$

T_7 $\dfrac{T_7}{T_6} = \left(\dfrac{P_7}{P_6}\right)^{\frac{k-1}{k}} \Rightarrow T_7 = (1/r_p)^{\frac{k-1}{k}} T_6 = (.25)^{\frac{1.4-1}{1.4}} 749.66k$

$T_7 = 504.49k$

V_7 $P_7 V_7 = RT_7 \Rightarrow V_7 = RT_7 / P_7 = (.287 kJ/kg \cdot k)(504.49k) / 400 kPa$

$V_7 = .362 m^3/kg$

T_8 $q_{in} = h_8 - h_7 = C_p(T_8 - T_7)$

$T_8 = q_{in}/c_p + T_7 = 300\,kJ/kg / 1.005\,kJ/kg\cdot K + 504.49\,K$

$T_8 = 803\,K$

V_8 $P_8 V_8 = R T_8 \Rightarrow V_8 = R T_8 / P_8 = (.287\,kJ/kg\cdot K)(803\,kPa)/(400\,kPa)$

$V_8 = .576\,m^3/kg$

T_9 $\frac{T_9}{T_8} = \left(\frac{P_9}{P_8}\right)^{\frac{k-1}{k}} \Rightarrow T_9 = (1/r_p)^{\frac{k-1}{k}} T_8 = (.25)^{\frac{1.4-1}{1.4}} 803\,K$

$T_9 = 540.39\,K$

V_9 $P_9 V_9 = R T_9 \Rightarrow V_9 = R T_9 / P_9 = \frac{(.287\,kJ/kg\cdot K)(540.39\,K)}{100\,kPa}$

$V_9 = 1.551\,m^3/kg$

T_{10} $q_{regin} = q_{regout}$

$h_5 - h_4 = h_9 - h_{10} \Rightarrow T_5 - T_4 = T_9 - T_{10}$

$T_{10} = T_9 - T_5 + T_4 = 540.39\,K - 451.15\,K + 431.15\,K$

$T_{10} = 520.39\,K$

V_{10} $P_{10} V_{10} = R_{10} \Rightarrow V_{10} = R T_{10} / P_{10} = \frac{(.287\,kJ/kg\cdot K)(520.39\,K)}{100\,kPa}$

$V_{10} = 1.49\,m^3/kg$

$W_{NET} = W_{OUT\,6-7} + W_{OUT\,8-9} - W_{IN\,1-2} - W_{IN\,3-4}$

$W_{OUT\,6-7} = h_6 - h_7 = C_P(T_6 - T_7) = 1.005\,kJ/kg\cdot K(749.66 - 504.49)K$

$W_{OUT\,6-7} = 246.4\,kJ/kg$

$W_{OUT\,8-9} = h_8 - h_9 = C_P(T_8 - T_9) = 1.005\,kJ/kg\cdot K(803 - 540.39)K$

$W_{OUT\,8-9} = 263.92\,kJ/kg$

$W_{IN\,1-2} = h_2 - h_1 = C_P(T_2 - T_1) = 1.005\,kJ/kg\cdot K(431.16 - 290.15)K$

$W_{IN\,1-2} = 141.715\,kJ/kg$

$W_{IN\,3-4} = h_4 - h_3 = C_P(T_4 - T_3) = 1.005\,kJ/kg\cdot K(431.15 - 290.15)K$

$W_{IN\,3-4} = 141\,kJ/kg$

$W_{NET} = (246.4 + 263.92 - 141.715 - 141)\,kJ/kg$

$W_{NET} = 227.605\,kJ/kg$

$q_{IN} = 600\,kJ/kg$

$$\eta_{TH} = \frac{227.605\,kJ/kg}{600\,kJ/kg}$$

$$\boxed{\eta_{TH} = 37.9\%}$$

$$\varepsilon = \frac{\text{ACTUAL ENERGY GAIN}}{\text{MAX ENERGY GAIN}} = \frac{h_5 - h_4}{h_9 - h_4}$$

$$\varepsilon = \frac{C_P(T_5 - T_4)}{C_P(T_9 - T_4)} = \frac{(451.15 - 431.15)K}{(540.39 - 431.15)K}$$

$$\boxed{\varepsilon = 18.3\%}$$

W/OUT REHEATER.

CHANGES: NO $q_{IN\,7-8}$, $(T_4+20=T_5)$ IS NO LONGER VALID. STATES $\overleftrightarrow{I-4}$, THEREFORE I WILL REFRAIN FROM RECALCULATING THEM.

$\overleftrightarrow{E}$

$$(4) \xrightarrow{\overleftrightarrow{P}} (5) \xrightarrow{\overleftrightarrow{P}} (6) \xrightarrow{ISEN} (9) \xrightarrow{\overleftrightarrow{P}} (10) \xrightarrow{\overleftrightarrow{P}}$$

$P_4=1600kPa$	$P_5=1600kPa$	$P_6=1600kPa$	$P_9=100kPa$	$P_{10}=100kPa$
$T_4=451.15K$	$T_5=428.97K$	$T_6=727.48K$	$T_9=329.55K$	$T_{10}=351.73K$
$V_5=.081m^3/kg$	$V_5=.073m^3/kg$	$V_6=.1305m^3/kg$	$V_9=.943m^3/kg$	$V_{10}=1.01m^3/kg$

$q_{IN\,5-6}=h_6-h_5$

$q_{IN\,5-6}=c_p(T_6-T_5)$

$300kJ/kg=1.005kJ/kg\cdot K(T_6-T_5)$

* $T_6-T_5=298.51K$

$$18.3\%=\frac{T_5-T_4}{T_9-T_4}=\frac{T_5-451.15K}{T_9-451.15K}$$

$T_9(.183)-82.56=T_5-451.15K$

* $T_5=T_9(.183)+368.59K$

$T_5=T_6-298.51K$

$T_9(.183)+368.59K=T_6-298.51K$

* $T_6=T_9(.183)+667.1K$

$$\frac{T_9}{T_6} = \left(\frac{P_9}{P_6}\right)^{\frac{k-1}{k}} \Rightarrow \frac{T_9}{T_6} = \left(\frac{100kPa}{1600kPa}\right)^{\frac{1.4-1}{1.4}}$$

$\cdot\ T_9 = .453\,T_6$

$T_9 = .453(T_9(.183) + 667.1k)$

$T_9 = T_9(.083) + 302.2k$

$T_9 = 329.55k$

V_9 $\quad P_9 V_9 = RT_9 \Rightarrow V_9 = RT_9 / P_9 = (.287kJ/kg\cdot k)(329.55k)/100kPa$

$V_9 = .94 m^3/kg$

T_6 $\quad T_6 = T_9 / .453 = 329.55k / .453$

$T_6 = 727.48k$

V_6 $\quad P_6 V_6 = RT_6 \Rightarrow V_6 = RT_6 / P_6 = (.287kJ/kg\cdot k)(727.48k)/1600kPa$

$V_6 = .1305 m^3/kg$

T_5 $\quad T_6 - T_5 = 298.51k$

$T_5 = T_6 - 298.51k = 727.48k - 298.51k$

$T_5 = 428.97k$

V_5 $\quad P_5 V_5 = RT_5 \Rightarrow V_5 = RT_5 / P_5 = (.287kJ/kg\cdot k)(428.97k)/1600kPa$

$V_5 = .077 m^3/kg$

T_{10} $q_{regin} = q_{regout}$

$h_5 - h_4 = h_9 - h_{10}$

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

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

$T_{10} = (329.55 - 428.97 + 451.15K)$

$T_{10} = 351.73K$

($T_{10} > T_9$, $T_5 < T_4$, THE HX IS WORKING BACKWARDS!)

(THIS IS COUNTERPRODUCTIVE, AND AS AN ENGINEER I WOULD RECOMMEND REMOVAL OF THE HX, AND REEVALUATE)

V_{10} $P_{10}V_{10} = RT_{10} \Rightarrow V_{10} = RT_{10}/P_{10} = (.287 kJ/kg \cdot K)(351.73K)/100kPa$

$V_{10} = 1.01 m^3/kg$

η_{TH} $\eta_{TH} = \frac{W_{net}}{q_{IN}} = \frac{W_{net}}{300 kJ/kg}$ (600 W/ REHEATER, 300 W/OUT)

$W_{net} = W_{out6-9} - W_{in1-2} - W_{in3-4}$

$W_{net} = (h_6 - h_9) - (h_2 - h_1) - (h_4 - h_3)$

$W_{net} = Cp((T_6 - T_9) - (T_2 - T_1) - (T_4 - T_3))$

$W_{net} = 1.005 kJ/kg \cdot K ((727.48 - 329.55)K - (431.16 - 290.15)K$
$- (451.15K - 290.15K))$

$W_{net} = 96.4 kJ/kg$

$\eta_{TH} = 96.4 kJ/kg / 300 kJ/kg$

$\boxed{\eta_{TH} = 32.1\%}$

ORIGINALLY: $\eta_{TH} = \frac{\dot{W}_{NET}}{\dot{Q}_{IN}} \Rightarrow 37.9\% = \frac{800\,kW}{\dot{Q}_{IN}}$

$\dot{Q}_{IN} = 2110.82\,kW$

BY REMOVING THE REHEATER, I ASSUME $\dot{Q}_{IN}$ IS CUT IN HALF.

$\Rightarrow$ NOW $\dot{Q}_{IN} = 1055.41\,kW$

W/OUT REHEATING, $\eta_{TH} = \frac{\dot{W}_{NET}}{\dot{Q}_{IN}}$

$\dot{W}_{NET} = \eta_{TH}\dot{Q}_{IN} = (.321)(1055.41\,kW)$

$\boxed{\dot{W}_{NET} = 339.1\,kW}$

NOW, I WILL CALCULATE STATES, η_{TH}, AND $\dot{W}_{NET}$ IF I REMOVE THE REHEATER, AND HX(REGENERATOR

$\longrightarrow (4) \xrightarrow{P} (5) \xrightarrow{ISEN} (6) \xrightarrow{P}$

$P_4 = 1600\,kPa$ $\quad P_5 = 1600\,kPa$ $\quad P_6 = 100\,kPa$

$T_4 = 451.15\,K$ $\quad T_5 = 749.68\,K$ $\quad T_6 = 339.5\,K$

$V_5 = .081\,m^3/kg$ $\quad V_5 = .134\,m^3/kg$ $\quad V_6 = .061\,m^3/kg$

T_5 $\quad q_{IN\,4\text{-}5} = h_5 - h_4 = C_p(T_5 - T_4)$

$300\,kJ/kg = 1.005\,kJ/kg\cdot K\,(T_5 - 451.15\,K)$

$T_5 = 749.68\,K$

V_5 $P_5 V_5 = RT_5 \Rightarrow V_5 = RT_5/P_5 = (.287\,kJ/kg\cdot K)(749.68\,K)/1600\,kPa$

$V_5 = .134\,m^3/kg$

T_6 $\frac{T_6}{T_5} = \left(\frac{P_6}{P_5}\right)^{\frac{k-1}{k}} \Rightarrow T_6 = \left(\frac{P_6}{P_5}\right)^{\frac{k-1}{k}} T_5$

$T_6 = \left(\frac{100\,kPa}{1600\,kPa}\right)^{\frac{1.4-1}{1.4}} (749.68\,K)$

$T_6 = 339.5\,K$

V_6 $P_6 V_6 = RT_6 \Rightarrow V_6 = RT_6/P_6 = (.287\,kJ/kg\cdot K)(339.5\,K)/1600\,kPa$

$V_6 = .061\,m^3/kg$

η_{TH} $\eta_{TH} = W_{NET}/q_{IN} = (W_{OUT\,5-6} - W_{IN\,1-2} - W_{IN\,3-4})/300\,kJ/kg$

$W_{OUT\,5-6} = h_5 - h_6 = C_p(T_5 - T_6) = 1.005\,kJ/kg\cdot K(749.68 - 339.5)K$

$W_{OUT\,5-6} = 412.2\,kJ/kg$

$W_{IN\,1-2}$ AS PREV STATED $= 141.72\,kJ/kg$

$W_{IN\,3-4}$ AS PREV STATED $= 141.71\,kJ/kg$

$\eta_{TH} = \frac{(412.2 - 141.72 - 141.71)\,kJ/kg}{300\,kJ/kg}$

$\boxed{\eta_{TH} = 42.9\%}$

AS PREV. STATED:

$\dot{Q}_{IN} = 1055.41\,kW$, $\dot{W}_{NET} = \eta_{TH} \dot{Q}_{IN}$

$\dot{W}_{NET} = (.429)(1055.41\,kW)$

$\boxed{\dot{W}_{NET} = 452.77\,kW}$

Q1.8 SUMMARY

HERE, I WILL RECAP AND ANSWER THE QUESTIONS ASKED IN THE TEST.
FIRST, HERE IS A CHART SUMMARIZING THE MATHEMATICAL UNKNOWNS WE SOLVED FOR:

	ε	η_{TH}	$\dot{W}_{net}$
ORIGINAL (9-133)	18.3%	37.9%	800kW
NO REHEATER	18.3%	32.1%	339.1kW
NO REHEATER AND HX	N/A	42.9%	452.77kW

- THIS EFFECTIVENESS VALUE (18.3%) OF THE REGENERATOR (HX), IS RELATIVELY LOW. THIS MEANS THAT ONLY ABOUT 20% OF THE TEMP IS TRANSFERRED.

- WHAT IS THE POWER IF THE REHEATER IS TURNED OFF?
339.1kW. THIS IS A LARGE DROP, AND IN REAL LIFE WOULD BE UNDESIRABLE.

- DOES η_{TH} CHANGE? WHY?
YES, FROM 37.9% $\rightarrow$ 32.1%

I BELIEVE THIS DECREASES DUE TO THE INTERACTIONS CONCERNING THE HX. W/OUT THE REHEATER, THE EXHAUST TEMP OUT OF THE TURBINES DOES NOT GET HOT ENOUGH TO HEAT THE INCOMING FLUID FROM THE SECOND COMPRESSOR. INFACT, THE INCOMING FLUID HEATS UP THE EXHAUST! THIS IS WHAT CAUSES A DROP IN EFFICIENCY, ALSO RESULTING IN A LOSS OF POWER.

AS AN ENGINEER, I DECIDED TO REMOVE THE TROUBLESOME HX, AND REEVALUATE THE STATES, η_{TH}, AND $\dot{W}_{NET}$. DOING THIS RESULTED IN THE INCREASE IN η_{TH} DUE TO NOT HEATING EXHAUST FLUID IN THE REGENERATOR ANYMORE, HOWEVER, WE CAN STILL NOT REACH THE 800 kW ANYMORE, CAPPING OUT AT ABOUT 453 kW.

Q1. 9. MATERIALS: NO SPECIFIC CONSIDERATIONS FOR MATERIALS WERE MADE

Q1.10. ANALYSIS: BY ONLY LOSING THE Q_{IN} FROM THE REHEATER WE LOST MORE THAN HALF OF OUR $\dot{W}_{NET}$. BY SIMPLY DIVERTING / DUMPING THE STEAM AFTER TURBINE 2, WE GAINED BACK MORE THAN 100 kW AND 10% EFFICIENCY. THE MARKED DECREASE IN η_{TH} AND $\dot{W}_{NET}$ FROM REMOVING THE REHEATER IS INFLUENCED BY HX PROPERTIES, SUCH AS EFFECTIVENESS NOT BEING DEPENDENT ON TEMPERATURES OF THE FLUIDS.

Q2 GOLDMAN

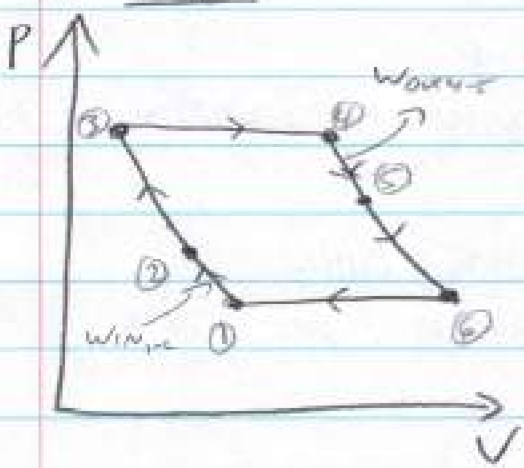
Q2.1 PURPOSE:

AFTER FINDING PROPULSIVE EFFICIENCY OF THE PROBLEM 9-142, WE ADD EFFICIENCIES OF THE TURBINE AND COMPRESSOR, AND THEN RECALCULATE PROPULSIVE EFFICIENCY AND SEE HOW IT CHANGES.

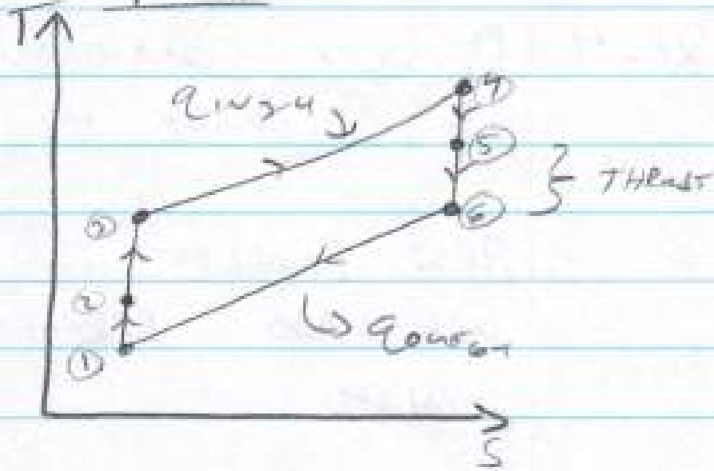
Q2.2. DRAWINGS AND DIAGRAMS.

9-142 P-V, T-S

P-V

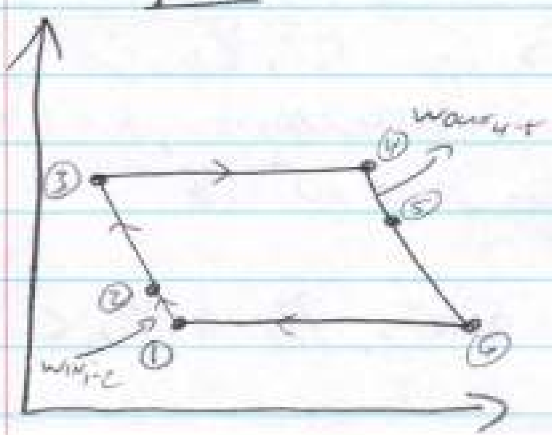


T-S

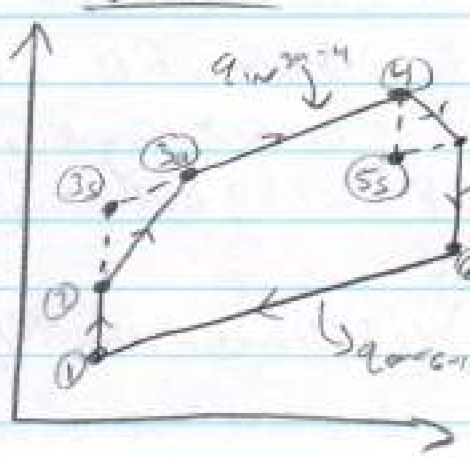


W/ η_C, η_T P-V, T-S

P-V



T-S



Q2.3 SOURCES:

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6TH EDITION.

JOHNDCOOK.COM INTEGRATION
CALCULATOR

ODU LECTURE MATERIAL

Q2.4. DESIGN CONSIDERATIONS

C_p, C_v VARY W/ TEMPERATURE. (NOT ON 9-142)

FIRST PROBLEM IS IDEAL, THEN I
WILL ADD IRREVERSIBILITIES TO THE
SYSTEM.

Q2.5. DATA AND VARIABLES:

9-142: $V_{AIRCRAFT} = 240\ m/s$, $T_1 = 260.15K$,
$P_1 = 45kPa$, $ID = 1.6m$, $r_{PC} = 13$, $\overleftrightarrow{C_p, C_v}$,
$C_p = 1.005\ kJ/kg\cdot K$, $C_v = .718\ kJ/kg\cdot K$, $k = 1.4$
$R = .287\ kJ/kg\cdot K$, $T_{TURBIN} = 830.15K$

W/ IRREVERSIBILITIES: $\eta_C = 80\%$, $\eta_T = 85\%$, $C_p, C_{v\ VAR}$

Q2.6. PROCEDURE:

FIRST, I WILL SOLVE 9-142 AND FIND η_P (PROPULSIVE EFFICIENCY)

THEN, I WILL ADD η_C (COMPRESSOR EFFICIENCY) AND η_T (TURBINE EFFICIENCY) AND SOLVE FOR η_P AGAIN. AFTER THIS, I WILL COMPARE AND DISCUSS.

Q2.7. CALCULATIONS

$$\rightarrow ① \xrightarrow{ISEN} ② \xrightarrow{ISEN} ③ \xrightarrow{\dot{q}} ④ \xrightarrow{ISEN}$$

①	②	③	④
$T_1 = 260.15K$	$V_2 \approx 0 m/s$	$V_3 \approx 0 m/s$	$V_4 \approx 0 m/s$
$P_1 = 45kPa$	$T_2 = 288.01K$	$P_3 = 842.92kPa$	$T_4 = 830.15K$
$V_1 = 240 m/s$	$P_2 = 64.84kPa$	$T_3 = 601.01K$	$P_4 = 842.92kPa$
$h_1 = 260.24 kJ/kg$	$h_2 = 288.46 kJ/kg$	$h_3 = 607.02 kJ/kg$	$h_4 = 855.2 kJ/kg$

$$\xrightarrow{ISEN} ⑤ \xrightarrow{ISEN} ⑥ \xrightarrow{\dot{q}}$$

⑤	⑥
$V_5 \approx 0 m/s$	$P_6 = 45kPa$
$T_5 = 517.95K$	$T_6 = 359.36K$
$h_5 = 537.14 kJ/kg$	$h_6 = 359.93 kJ/kg$
$P_5 = 161.77kPa$	$V_6 = 564.6 m/s$

h_1 FROM A-17, @ T_1, $h_1 = 260.24 kJ/kg$
USING INTERPOLATION CALCULATOR (I.C.)

T_2 1ST LAW: $h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$

$$C_p T_1 + \frac{V_1^2}{2} = C_p T_2 + \frac{\cancel{V_2^2}^{\,0}}{\cancel{2}}$$

$$T_2 = T_1 + V_1^2 / 2c_p$$

$$T_2 = 260.15K + \frac{240^2 m^2}{s^2}\left|\frac{}{2}\right|\frac{kg \cdot K}{1.005kJ}\left|\frac{kJ}{kg}\right|\frac{s^2}{1000m^2}$$

$$T_2 = 260.15K + 28.66K$$

$$T_2 = 288.81K$$

P_2 $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \Rightarrow \frac{288.81K}{260.15K} = \left(\frac{P_2}{45kPa}\right)^{\frac{1.4-1}{1.4}}$

$$\left(\sqrt[.2857]{1.11}\right) 45kPa = P_2$$

$$P_2 = 64.84kPa$$

h_2 USING A-17, I.C.

$$h_2 = 288.96 kJ/kg$$

P_3 $r_p = P_3/P_2 \Rightarrow P_3 = P_2 r_p = 64.84kPa(13)$

$$P_3 = 842.92kPa$$

T_3 $\frac{T_3}{T_2} = \left(\frac{P_3}{P_2}\right)^{\frac{k-1}{k}} \Rightarrow T_3 = (r_p)^{\frac{k-1}{k}} T_2 = (13)^{\frac{1.4-1}{1.4}}(288.81K)$

$$T_3 = 601.01K$$

h_3 USING A-17, DUE TO 601.01K AND 600K BEING .168% APART, I WILL USE $T_3 = 600K$ FOR A-17 VALUES.

$h_3 = 607.02\ kJ/kg$

P_4 $P_4 = P_3$

$P_4 = 842.92\ kPa$

h_4 A-17, I.C.

$h_4 = 855.2\ kJ/kg$

P_6 $P_1 = P_6$

$P_6 = 45\ kPa$

T_5 $W_{comp} = W_{turb}$

$h_3 - h_2 = h_4 - h_5 \Rightarrow C_p(T_3 - T_2) = C_p(T_4 - T_5)$

$T_5 = T_4 - T_3 + T_2$

$T_5 = 830.15K - 601.01K + 288.81K$

$T_5 = 517.95K$

h_5 $h_3 - h_2 = h_4 - h_5$

$h_5 = h_4 - h_3 + h_2 = (855.2 - 607.02 + 288.96)\ kJ/kg$

$h_5 = 537.14\ kJ/kg$

P_5 $\frac{T_5}{T_4} = \left(\frac{P_5}{P_4}\right)^{\frac{k-1}{k}} \Rightarrow \left(\frac{517.95K}{830.15K}\right) = \left(\frac{P_5}{842.92kPa}\right)^{\frac{1.4-1}{1.4}}$

$P_5 = \left(\sqrt[.2857]{.624}\right) 842.92\,kPa$

$P_5 = 161.77\,kPa$

T_6 $\frac{T_6}{T_5} = \left(\frac{P_6}{P_5}\right)^{\frac{k-1}{k}} \Rightarrow T_6 = \left(\frac{P_6}{P_5}\right)^{\frac{k-1}{k}} T_5$

$T_6 = \left(\frac{45kPa}{161.77kPa}\right)^{\frac{1.4-1}{1.4}} 517.95K$

$T_6 = 359.36K$

h_6 I.C. + A-17

$h_6 = 359.93\,kJ/kg$

V_6 $h_5 + \frac{\cancel{V_5^2}^{\,0}}{\cancel{2}} = h_6 + \frac{V_6^2}{2}$

$V_6 = \sqrt{2(h_5 - h_6)} = \sqrt{2(c_p(T_5 - T_6))}$

$V_6 = \sqrt{2(1.005\,kJ/kg\cdot K(517.95 - 359.36)K \left|\frac{1000\,m^2/s^2}{1\,kJ/kg}\right.}$

$V_6 = 564.6\,m/s$

V_{exit} $V_{exit} = V_6$

$V_{exit} = 564.6\,m/s$

$F \quad F = \dot{m}(V_{EXIT} - V_{INLET})$

$F = \frac{V}{v} A (V_{EXIT} - V_{INLET})$

$Pv = RT \Rightarrow v = RT/P = (.287\,kJ/kg\cdot K)(260.15K)/45\,kPa$

$v_1 = 1.66\,m^3/kg$

$F = \frac{240\,m}{s} \left| \frac{kg}{1.66\,m^3} \right| \frac{\pi\, 1.6^2\,m^2}{4} \left| (564.6 - 240)\,m/s \right.$

$F = 94358.6\ kg\cdot m/s^2$

$F = 94358.6\,N$

$\eta_P \quad \eta_P = W_P / q_{IN} = (V_{EXIT} - V_{INLET}) V_{AIRCRAFT} / C_P (T_4 - T_3)$

$\eta_P = \dfrac{(564.6\,m/s - 240\,m/s)\, 564.6\,m/s}{1.005\,kJ/kg\cdot K\,(830.15K - 601.01K)}$

$\eta_P = \dfrac{183269.16\,m^2/s^2}{230.286\,kJ/kg} \left| \dfrac{1\,kJ/kg}{1000\,m^2/s^2} \right.$

$\boxed{\eta_P = 80\%}$

NOW, I WILL ADD IN η_C, η_T AND SOLVE AGAIN.

$① \xrightarrow{ISEN} ② \xrightarrow{ISEN} ③s ③a \xrightarrow{C_p} ④ \xrightarrow{ISEN}$

①	②	③s ③a	④
$T_1 = 260.15K$	$V_2 \approx 0m/s$	$V_3 \approx 0m/s$	$T_4 = 870.15K$
$P_1 = 45kPa$	$h_2 = 289.04kJ/kg$	$P_3 = 843.7kPa$	$V_4 \approx 0m/s$
$V_1 = 240m/s$	$T_2 = 288.88K$	$T_{3s} = 594.95K$	$P_4 = 843.7kPa$
$h_1 = 260.24kJ/kg$	$P_2 = 64.9kPa$	$h_{3s} = 601.72kJ/kg$	$h_4 = 855.2kJ/kg$
$v_1 = 1.659m^3/kg$		$h_{3a} = 679.89kJ/kg$	
		$T_{3a} = 668.83K$	

$⑤s ⑤a \xrightarrow{ISEN} ⑥ \xrightarrow{C_p}$

⑤s ⑤a	⑥
$V_5 \approx 0m/s$	$P_6 = 45kPa$
$h_{5s} = 542.52kJ/kg$	$T_6 = 371.7K$
$T_{5s} = 538.24K$	$h_6 = 372.39kJ/kg$
$h_{5a} = 589.42kJ/kg$	$V_6 = 658.83m/s$
$T_{5a} = 583.22K$	
$P_5 = 167.91kPa$	

P_6 $P_6 = P_1$

$P_6 = 45kPa$

h_1 h_1 IS THE SAME AS PART A (9-142)

$h_1 = 260.24 kJ/kg$

v_1 $P_1 v_1 = R_1 T_1 \Rightarrow R_1 = C_{p1} - C_{v1}$

USING I.C. + TABLE A-2.

$C_{p1} = 1.00341 kJ/kg \cdot K$, $C_{v1} = .71641 kJ/kg \cdot K$

$\Rightarrow R_1 = .287 kJ/kg \cdot K$

$V_1 = R_1 T_1 / P_1 = (.287\,kJ/kg\cdot K)(260.15K)/45kPa$
$V_1 = 1.659\,m^3/kg$

h_2 $h_1 + \frac{V_1^2}{2} = h_2 \cancel{\frac{V_2^2}{2}}^{0}$

$h_2 = h_1 + \frac{V_1^2}{2} = 260.24\,kJ/kg + \frac{240^2\,m^2/s^2}{2}$

$h_2 = 260.24\,kJ/kg + \frac{240^2\,m^2/s^2}{2} \left| \frac{1\,kJ/kg}{1000\,m^2/s^2} \right.$

$h_2 = 289.04\,kJ/kg$

T_2 I.C. + A-17,
$T_2 = 288.88K$

P_2 $\frac{P_2}{P_1} = \frac{Pr_2}{Pr_1}$ USING I.C. + A-17,
$Pr_1 = .8423$
$Pr_2 = 1.21488$

$P_2 = \left(\frac{Pr_2}{Pr_1}\right) P_1 = \left(\frac{1.21488}{.8423}\right) 45kPa$
$P_2 = 64.9kPa$

P_3 $r_p = 13 = P_3/P_2 \Rightarrow P_3 = 13P_2$
$P_3 = 13(64.9kPa)$
$P_3 = 843.77kPa$

T_{3s} $\frac{P_3}{P_2} = \frac{Pr_3}{Pr_2} \Rightarrow Pr_3 = r_p Pr_2$

$Pr_3 = 13(1.21488)$

$Pr_3 = 15.79$

USING I.C. + A-17

$T_{3s} = 594.95K$

h_{3s} I.C. + A-17

$h_{3s} = 601.72\ kJ/kg$

h_{3a} $\eta_c = \frac{h_{3s} - h_2}{h_{3a} - h_2}$

$h_{3a} = \frac{h_{3s} - h_2}{\eta_c} + h_2$

$h_{3a} = \frac{(601.72 - 289.04)\ kJ/kg}{.8} + 289.04\ kJ/kg$

$h_{3a} = 679.89\ kJ/kg$

T_{3a} I.C. + A-17

$T_{3a} = 668.83K$

P_4 $P_3 = P_4$

$P_4 = 843.77kPa$

h_4 I.C. + A-17

$h_4 = 855.2\ kJ/kg$

h_{5s} $W_{comp} = W_{turb}$

$h_{3s} - h_2 = h_4 - h_{5s}$

$h_{5s} = h_4 - h_{3s} + h_2$

$h_{5s} = (855.2 - 601.72 + 289.04)\ kJ/kg$

$h_{5s} = 542.52\ kJ/kg$

T_{5s} I.C. + A-17

$T_{5s} = 538.24K$

h_{5a} $\eta_T = \dfrac{h_4 - h_{5a}}{h_4 - h_{5s}} \Rightarrow h_{5a} = h_4 - \eta_T (h_4 - h_{5s})$

$h_{5a} = 855.2\ kJ/kg - .85(855.2 - 542.52)\ kJ/kg$

$h_{5a} = 589.42\ kJ/kg$

T_{5a} I.C. + A-17

$T_{5a} = 583.22K$

P_5 $\dfrac{P_5}{P_4} = \dfrac{Pr_5}{Pr_4} \Rightarrow P_5 = \left(\dfrac{Pr_5}{Pr_4}\right) P_4$

I.C. + A-17, $Pr_5 = 10.97152$, $Pr_4 = 55.1326$

$P_5 = (10.97152 / 55.1326)(843.77\ kPa)$

$P_5 = 167.91\ kPa$

T_6 $\frac{P_6}{P_5} = \frac{Pr_6}{Pr_5} \Rightarrow Pr_6 = \left(\frac{P_6}{P_5}\right) Pr_5$

$Pr_6 = \frac{45\,kPa}{167.91\,kPa} (10.972)$

$Pr_6 = 2.9404$

I.C. + A-17

$T_6 = 371.7\,K$

h_6 I.C. + A-17

$h_6 = 372.39\,kJ/kg$

V_6 $h_5 + \cancel{\frac{V_5^2}{2}}^{\approx 0} = h_6 + \frac{V_6^2}{2}$

$V_6 = \sqrt{2(h_{5a} - h_6)}$.

$V_6 = \sqrt{\frac{(584.42 - 372.39)\,kJ/kg}{} \Big| 2 \Big| \frac{1000\,m^2/s^2}{1\,kJ/kg}}$

$V_6 = 658.83\,m/s$

V_{exit} $V_{exit} = V_6$

$V_{exit} = 658.83\,m/s$

F $F = \dot{m}(V_{exit} - V_{inlet}) = V/v A (V_{exit} - V_{inlet})$

$F = \frac{240\,m}{s} \Big| \frac{kg}{1.659\,m^3} \Big| \frac{\pi\, 1.6^2\,m^2}{4} \Big| \frac{(658.83 - 240)\,m}{s}$

$F = 121\,823.9\,kg\,m/s^2$

$F = 121\,823.9\,N$

η_P $\eta_P = \dfrac{W_P}{q_{IN}} = \dfrac{(V_{EXIT} - V_{INLET})V_{AIRCRAFT}}{h_4 - h_{5a}}$

$\eta_P = \dfrac{(658.83 - 240)\,m/s\ (240\,m/s)}{855.2\,kJ/kg - 679.89\,kJ/kg} \left| \dfrac{1\,kJ/kg}{1000\,m^2/s^2} \right.$

$\boxed{\eta_P = 57\%}$

Q2.8. SUMMARY

	IDEAL COMPRESSOR + TURBINE	η_C, η_T
η_P	80%	57%
V_{EXIT}	564.6 m/s	658.83 m/s
F	94358.6 N	121823.9 N

DUE TO INEFFICIENCIES IN THE TURBINE AND COMPRESSOR, THE EXHAUST TEMP / ENTHALPY WERE HIGHER, THIS RESULTED IN A HIGHER EXIT VELOCITY AND FORCE, BUT DROPPED THE EFFICIENCY OF THE SYSTEM (η_P) BY 23%!

ACCORDING TO THE TEXT, $W_{NET} = 0$, $\Rightarrow \eta_P$ IS USED TO DEFINE EFFICIENCY IN JET ENGINES. $\eta_P = \dfrac{\text{PROPULSIVE POWER}}{\text{ENERGY INPUT}}$

BY NOT CHANGING INPUT PARAMETERS, THIS RESULTED IN ENERGY INPUT DECREASING.

HOWEVER, DUE TO IRREVERSIBILITIES IN THE TURBINE, THE PRODUCTIVE POWER DECREASES MUCH GREATER THAN THE ENERGY INPUT THEREFORE RESULTING IN AN OVERALL LOWER EFFICIENCY.

Q2.9. MATERIALS:

MATERIALS WERE OF NO CONSEQUENCE IN THIS TEST.

Q2.10. ANALYSIS:

BY CHANGING THE FLOWPATH, CERTAIN EFFICIENCIES COULD BE BROUGHT UP TO INCREASE THE OVERALL EFFICIENCY. IN TOTAL, THE EFFICIENCY DROPPED BY 23%. THIS IS SIGNIFICANT AND SHOULD BE ACCOUNTED FOR WHEN DESIGNING AN ENGINE.