MET350 : Thermo Apps | Test 1 | 19-02-2019
Carter Fishback

1.) Purpose: Calculate the net work, heat addition and rejection, thermal efficiency, and heat exchanger for the following scenarios:

Case a.) The Original Design
Case b.) The original design without regeneration
Case c.) The original design with a pressure ratio of 8.58
Case d.) The original design with max cycle temp of 895.48°C
Case e.) The original design with a two stage compressor with Intercooling

Then determine the best design option.

Sources. Boles M. A., Gengel Y. A., Thermodynamics: An Engineering Approach. 8th Edition. Pearson 2016.

Design Considerations

- Open system with constant Specific heat and volume
- follows the Brayton Cycle
  - with regenerator
  - without Regenerator (Ideal)
  - with a two-stage Compressor and Intercooling
- Consider Isentropic for work processes

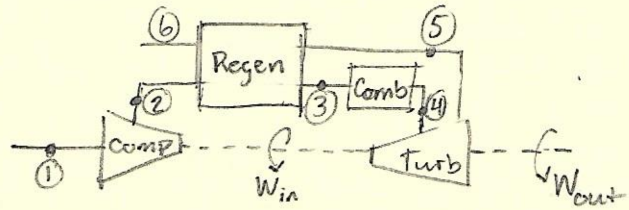
- regenerator $\omega = .59$ or 59%

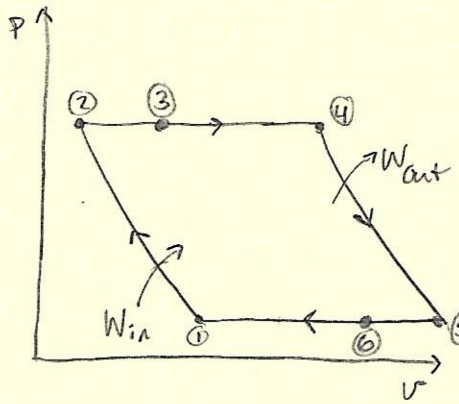
- $W_c = W_T$

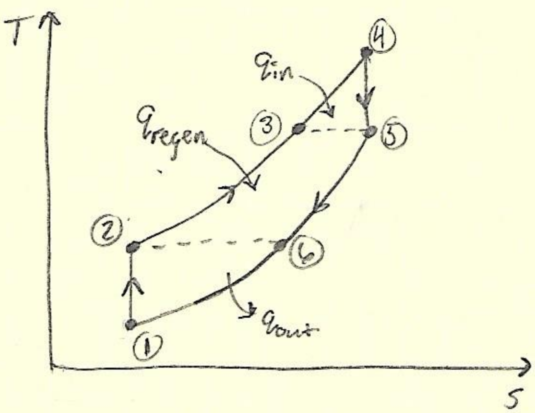
Effectivness

Drawings/Diagrams

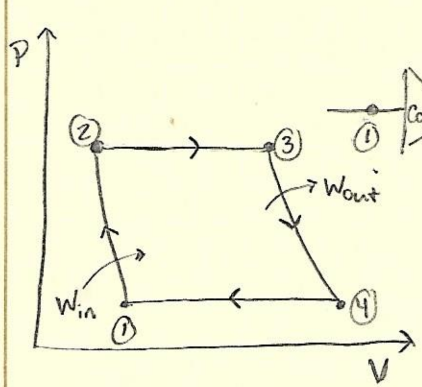
Case A:

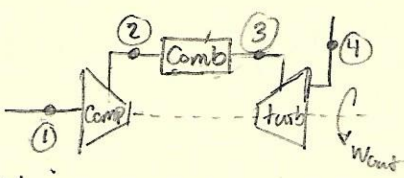


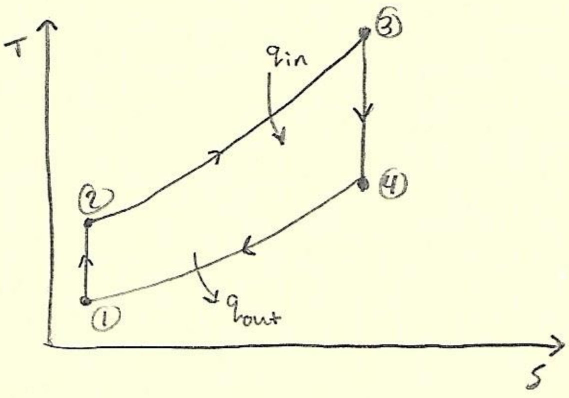




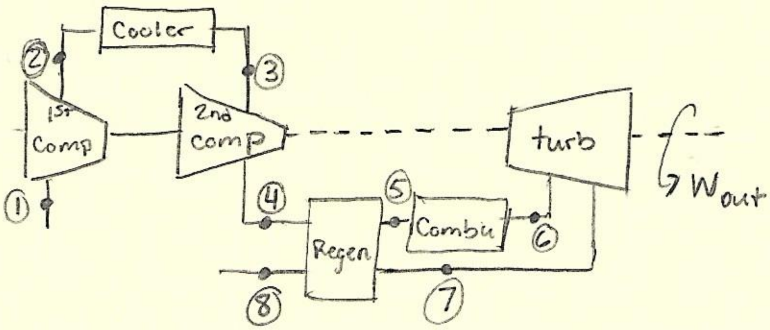
Case B:

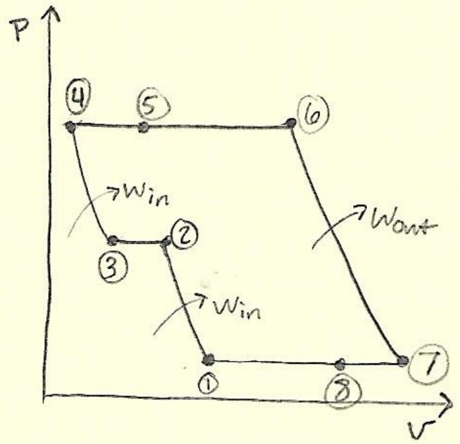


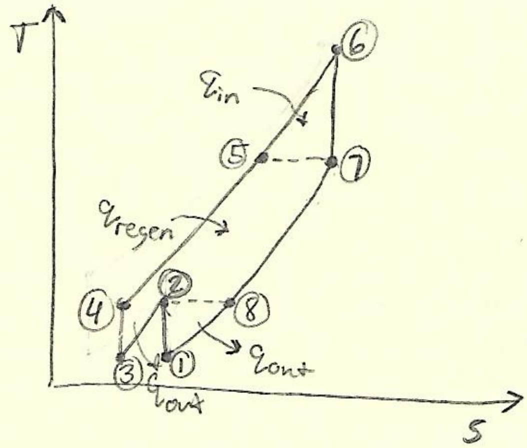




1.) Case e:







Data & Variables

T = Temperature

r_p = Compression ratio

v = specific volume

P = Pressure

q_{in} = heat in q_{out} = heat out q_{regen} = heat regenerated

W_{in} = Work in W_{out} = work out

η_{TH} = Thermal Efficiency

$P_1 = 100\ kPa$	$T_{max_1} = 800°C$
$T_1 = 30°C$	$T_{max_2} = 895.48°C$
$r_{p_1} = 10$	$r_{p_2} = 8.58$

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1.) Procedure

1. Find the Processes for case A (8 total Processes):

a. Given P_1 and T_1, $v_1 = \frac{RP_1}{T_1}$

b. Find State 2

- given $r_{p1} = 10$ then find $P_2 = r_{p1} P_1$
- $T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{1}}$

c. Find State 3

- $P_3 = P_2$
- $T_3 = T_5 - 10°$

$2 \xrightarrow{\text{Regenerator}} 3 \xrightarrow{q_{in}} 4$

d. find State 4

- $P_4 = P_2$
- $T_4 = T_{max_1}$

e. find State 5

- $P_5 = \frac{P_4}{r_{p1}}$
- $T_5 = T_4 \left(\frac{P_5}{P_4}\right)^{\frac{k-1}{1}}$

$5 \xrightarrow{\text{Regenerator}} 6$

f. Find State 6

- $P_6 = P_5 = P_1$
- T_6: $h_6 - h_5 = h_3 - h_2$

$$\cancel{c_p}(T_5 - T_6) = \cancel{c_p}(T_3 - T_2)$$

$$T_6 = T_5 - (T_3 - T_2)$$

g. $W_{net} = W_{out} - W_{out} = (h_4 - h_5) - (h_2 - h_1) = c_p[(T_4 - T_5) - (T_2 - T_1)]$

h. $q_{out} = C_p(T_6 - T_1)$ $\quad q_{in} = C_p(T_4 - T_3)$

I. $\eta_{TH} = \frac{W_{net}}{q_{in}}$

J. $\varepsilon = \frac{q_{regen_{act}}}{q_{regen,max}} = \frac{(h_3 - h_2)}{(h_5 - h_2)} = \frac{\cancel{c_p}(T_3 - T_2)}{\cancel{c_p}(T_5 - T_2)} = \frac{(T_3 - T_2)}{(T_5 - T_2)}$

2. find the States for Case B but do not use regeneration. Follow same steps.

3. Find States for Case C and follow same steps 1a. – 1j. Substitute for $r_p = 8.58$.

4. Find States for Case D and follow same steps 1a – 1j. Substitute for $T_{max_2} = 895.48°C$

5. Include the extra steps for intercooling in Case E and make the necessary changes.

6. Compare and contrast each design solution and determine the most effective and cost friendly case.

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Calculations $C_p = 1.005\ kJ/kg$ $C_v = .718\ kJ/kg$ $k = 1.4$ $R = .287\ kJ/kg$

Case A: Original Design

$$① \xrightarrow[W_{in}]{Isent} ② \xrightarrow[Regenerator]{P\ const} ③ \xrightarrow[q_{in}]{P\ const} ④ \xrightarrow[W_{out}]{Isent} ⑤ \xrightarrow[regenerator]{P\ const} ⑥ \xrightarrow[q_{out}]{P\ const}$$

$T_1 = 303.15°K$, $P_1 = 100\ kPa$

$P_2 = 1000\ kPa$, $T_2 = 585.29°K$

$P_3 = P_2 = 1000\ kPa$, $T_3 = 545.84°K$

$T_4 = 1073.15°K$, $P_4 = P_2 = 1000\ kPa$

$T_5 = 555.84°K$, $P_5 = 100\ kPa$

$T_6 = 595.29°K$, $P_6 = P_1 = 100\ kPa$

$P_2 = r_{P_1} P_1 = 10(100\ kPa) = 1000\ kPa$

$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = T_1 \left(r_{P_1}\right)^{\frac{k-1}{k}} = 303.15(10)^{\frac{.4}{1.4}} =$

$T_3 = T_5 - 10° = 555.84 - 10 = 545.84°K$

$P_5 = \frac{P_4}{r_{P_1}} = \frac{1000\ kPa}{10} = 100\ kPa$

$T_5 = T_4 \left(\frac{100}{1000}\right)^{\frac{k-1}{k}} = 1073.15\left(\frac{1}{10}\right)^{\frac{.4}{1.4}} = 555.84°K$

$W_C = W_T \longrightarrow (h_6 - h_5) = (h_3 - h_2) \longrightarrow \cancel{C_p}(T_5 - T_6) = \cancel{C_p}(T_3 - T_2) \longrightarrow T_6 = -(T_3 - T_2) + T_5$

$T_6 = -(545.84 - 585.29) + 555.84$ $T_6 = 595.29°K$

$W_{net} = C_p[(T_4 - T_5) - (T_2 - T_1)] = 1.005[(1073.15 - 555.84) - (585.28 - 303.15)]$

$\boxed{W_{net} = 236.34\ kJ/kg}$

$q_{out} = C_p(T_6 - T_1) = 1.005(595.29 - 303.15)$

$\boxed{q_{out} = 293.6007\ kJ/kg}$

$q_{in} = C_p(T_4 - T_3) = 1.005(1073.5 - 545.85)$

$\boxed{q_{in} = 529.94\ kJ/kg}$

$\eta_{TH} = \frac{W_{net}}{q_{in}} = \frac{236.34}{529.94}$

$\boxed{\eta_{TH} = .446}$

$\varepsilon = \frac{T_3 - T_2}{T_5 - T_2} = \frac{545.84 - 585.29}{555.821 - 585.29}$ $\boxed{\varepsilon = 1.31 \text{ (IMPOSSIBLE EFFECTIVENESS)}}$

Case B: No Regenerator

$$① \xrightarrow[W_{in}]{Isent} ② \xrightarrow[q_{in}]{P\ const} ③ \xrightarrow[W_{out}]{Isent} ④ \xrightarrow[q_{out}]{P\ const}$$

$P_1 = 100\ kPa$, $T_1 = 303.15°K$

$P_2 = 1000\ kPa$, $T_2 = 585.29°K$

$T_3 = 1073.15°K$, $P_3 = P_2 = 1000\ kPa$

$P_4 = P_1 = 100\ kPa$, $T_4 = 555.84\ K$

$P_2 = 10(100\ kPa) = 1000\ kPa$

$T_4 = T_3 \left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}}$ $T_4 = 555.84$

$W_{net} = C_p[(T_3 - T_4) - (T_2 - T_1)] \longrightarrow 1.005[(1073.15 - 555.84) - (585.29 - 303.15)]$

$\boxed{W_{net} = 236.35\ kJ/kg}$

$q_{out} = 1.005(1073.15 - 585.29°K)$

$\boxed{q_{out} = 490\ kJ/kg}$

$q_{in} = 1.005(555.84 - 303.15)$

$\boxed{q_{in} = 253.95\ kJ/kg}$

$\eta_{TH} = \frac{236.35}{253.95}$ $\boxed{\eta_{TH} = .931}$

No Regenerator so no ε

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Calculations Continued

Case C : $r_{P2} = 8.58$

$$① \xrightarrow[\text{Win}]{\text{Isent}} ② \xrightarrow[\text{Regenerator}]{\text{P const}} ③ \xrightarrow{\text{P const}} ④ \xrightarrow[\text{Wout}]{\text{Isent}} ⑤ \xrightarrow[\text{Regenerator}]{\text{Pconst}} ⑥ \xrightarrow{\text{Pconst}}$$

①	②	③	④	⑤	⑥
$P_1 = 100$ kPa	$P_2 = 858$ kPa	$P_3 = 858$ kPa	$P_4 = 858$ kPa	$P_5 = 100$ kPa	$P_6 = 100$ kPa
$T_1 = 303.15$°k	$T_2 = 560.23$°k	$T_3 = 570.70$°	$T_4 = 1073.15$°k	$T_5 = 580.70$°k	$T_6 = 570.23$°k

$P_2 = 8.58\,(100) = 858$ kPa

$T_2 = T_1\,(r_{P2})^{\frac{k-1}{k}} \longrightarrow T_2 = 303.15°k\,(8.58)^{\frac{.4}{1.4}} = 560.23°k$

$T_3 = T_5 - 10° \longrightarrow T_3 = 570.70°k$

$P_5 = \dfrac{P_4}{r_{P2}} = \dfrac{858}{8.58} = 100$ kPa

$T_5 = T_4 \Big/ \left(\dfrac{P_4}{P_5}\right)^{\frac{.4}{1.4}} = 580.70°k$

$W_c = W_T \longrightarrow T_6 = T_5 - (T_3 - T_2) \longrightarrow T_6 = 580.70 - (570.7 - 560.23) \rightarrow T_6 = 570.23°k$

$W_{net} = 1.005\left[(1073.15 - 580.70) - (560.23 - 303.15)\right]$ $\boxed{W_{net} = 236.55 \text{ kJ/kg}}$

$q_{in} = 1.005\,(1073.15 - 570.7)$ $\boxed{q_{in} = 504.96 \text{ kJ/kg}}$

$q_{out} = 1.005\,(570.23 - 303.15)$ $\boxed{q_{out} = 268.415 \text{ kJ/kg}}$

$\eta_{TH} = \dfrac{236.55}{504.96}$ $\boxed{\eta_{TH} = .468}$

$\varepsilon = \dfrac{570.7 - 560.23}{580.7 - 560.23}$ $\boxed{\varepsilon = .511}$ ✓

Case D : $T_{max_2} = 895.48$°C

$$① \xrightarrow[\text{Win}]{\text{Isent}} ② \xrightarrow[\text{Regenerator}]{\text{P const}} ③ \xrightarrow[q_{in}]{\text{P const}} ④ \xrightarrow[\text{Wout}]{\text{Isent}} ⑤ \xrightarrow[\text{regenerator}]{\text{P const}} ⑥ \xrightarrow[q_{out}]{\text{Pconst}}$$

①	②	③	④	⑤	⑥
$P_1 = 100$ kPa	$P_2 = 1000$ kPa	$P_3 = 1000$ kPa	$T_4 = 1168.63$°k	$T_5 = 605.29$°k	$P_6 = 100$ kPa
$T_1 = 303.15$°k	$T_2 = 585.29$°k	$T_3 = 595.29$°k	$P_4 = 1000$ kPa	$P_5 = 100$ kPa	$T_6 = 595.29$

$T_3 = T_5 - 10°$

$T_5 = T_4 \Big/ \left(\dfrac{P_4}{P_5}\right)^{\frac{k-1}{k}} \longrightarrow T_5 = \dfrac{1168.63}{(10)^{\frac{.4}{1.4}}} = 605.29°k$

$T_6 = T_5 - (T_3 - T_2) \longrightarrow T_6 = 605.29 - (595.29 - 585.29) = 595.29$

$W_{net} = 1.005\left[(1168.63 - 605.29) - (585.29 - 303.15)\right]$ $\boxed{W_{net} = 282.61 \text{ kJ/kg}}$

$q_{in} = 1.005\,(1168.63 - 595.29)$ $\boxed{q_{in} = 576.21 \text{ kJ/kg}}$

$q_{out} = 1.005\,(595.29 - 303.15)$ $\boxed{q_{out} = 293.60 \text{ kJ/kg}}$

$\eta_{TH} = \dfrac{282.61}{293.60}$ $\boxed{\eta_{TH} = .963}$

$\varepsilon = \dfrac{595.29 - 585.29}{605.29 - 585.29}$ $\boxed{\varepsilon = .5}$

Calculations Continued

Case E: Two stage compressor with intercooling

$$① \xrightarrow[W_{in}]{\text{Isent}} ② \xrightarrow[q_{out}]{\text{P const}} ③ \xrightarrow[W_{in}]{\text{Isent}} ④ \xrightarrow[\text{Regenerator}]{\text{P const}} ⑤ \xrightarrow[q_{in}]{\text{P const}} ⑥ \xrightarrow[W_{out}]{\text{Isent}} ⑦ \xrightarrow[\text{Regenerator}]{\text{P const}} ⑧ \xrightarrow[q_{out}]{\text{P const}}$$

①	②	③	④	⑤	⑥	⑦	⑧
$T_1 = 303.15°K$	$T_2 = 585.29°K$	$P_3 = 1000\ kPa$	$P_4 = 10000\ kPa$	$P_5 = 10000\ kPa$	$P_6 = 10000\ kPa$	$P_7 = 1000\ kPa$	$P_8 = 1000\ kPa$
$P_1 = 100\ kPa$	$P_2 = 1000\ kPa$	$T_3 = 303.15°K$	$T_4 = 585.29°K$	$T_5 = 545.84°K$	$T_6 = 1073.15°K$	$T_7 = 555.84°K$	$T_8 = 595.29$

$P_4 = r_{p_1} P_3$

$= 10\,(1000\ kPa)$

$T_4 = T_3 \left(\frac{P_4}{P_3}\right)^{\frac{k-1}{.4}}$

$= (303.15)(10)^{\frac{.4}{1.4}}$

$T_5 = T_7 - 10°$

$P_7 = \frac{P_6}{r_{p_1}}$

$T_7 = \frac{T_6}{\left(\frac{P_6}{P_7}\right)^{\frac{k-1}{k}}}$

$\frac{1073.15°K}{\left(\frac{10000}{1000}\right)^{\frac{k-1}{k}}} = T_7$

$W_c = W_T$

$(T_5 - T_4) = (T_7 - T_8)$

$T_8 = T_7 - (T_5 - T_4)$

$T_8 = 555.84 - (545.84 - 585.29)$

$T_8 = 595.29$

$W_{net} = c_p\left[(T_6 - T_7) - \left((T_2 - T_1) + (T_4 - T_3)\right)\right]$

$= 1.005(1073.15 - 555.84) - 1.005\,(585.29 - 303.15 + 585.29 - 303.15)$

$\boxed{W_{net} = -47.20\ kJ/kg}$

$q_{in} = c_p\,(T_6 - T_5) = 1.005\,(1073.15 - 545.84)$

$\boxed{q_{in} = 529.95\ kJ/kg}$

$q_{out} = c_p\,(T_2 - T_3) = 1.005(585.29 - 303.15)$

$\boxed{q_{out} = 283.55\ kJ/kg}$

$\eta_{TH} = \frac{-47.20\ kJ/kg}{283.55}$

$\boxed{\eta_{TH} = -.166}$

$\varepsilon = \frac{T_5 - T_4}{T_7 - T_4} = \frac{545.85 - 585.29}{555.84 - 585.29}$

$\boxed{\varepsilon = 1.34 \text{ IMPOSSIBLE EFFECTIVENESS}}$

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Matericals

1. Air is the Primary Gas for combustion in this cycle

Summary

Case	A	B	C	D	E
W_{net}	236.34 kJ/kg	236.35 kJ/kg	236.55 kJ/kg	282.61 kJ/kg	-47.20 kJ/kg
q_{in}	529.44 kJ/kg	253.95 kJ/kg	504.96 kJ/kg	576.21 kJ/kg	529.95 kJ/kg
q_{out}	293.60 kJ/kg	490 kJ/kg	268.415 kJ/kg	293.6 kJ/kg	283.55 kJ/kg
η_{TH}	.446	.931	.468	.963	-.166
ε	1.31	None	.511	.5	1.34

Analysis

Cases A and E are not possible due to the effectiveness, ε, being too high. It violates the rule for $C_{min}/C_{max} \approx 1.00$ which corelates with an an $\varepsilon \approx .59$. This means that the cycles cannot exceed a ε of .59. Case B, the system without regeneration, is theoretically possible but the thermal efficiency is far too great for practical Application. Case D is also affected by this theoretical η_{TH} being too great. The final Design, Case C fits all requirements of a practical design. Both the Thermal Efficiency and regenerator effectiveness can be found in modern design.

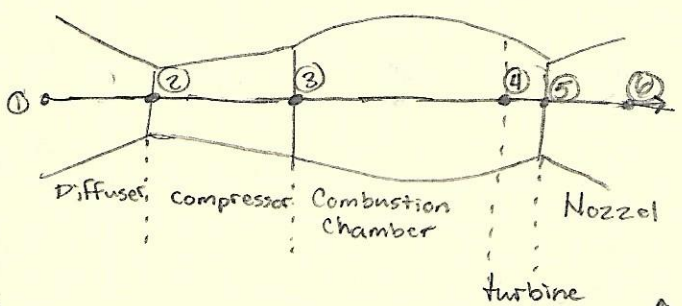
2.) Purpose Determine the pressure of combustion gases at the turbine exit, velocity of the gases at the nozzel exit, and thrust for this engine if the diffuser inlet diameter is 1.6m.

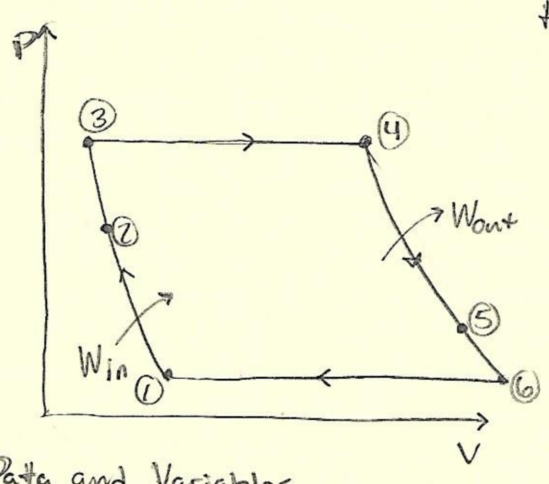
Sources Boles M. A., Gengel Y. A.. Thermodynamics: An Engineering Approach. 8th Edition. Pearson 2016.

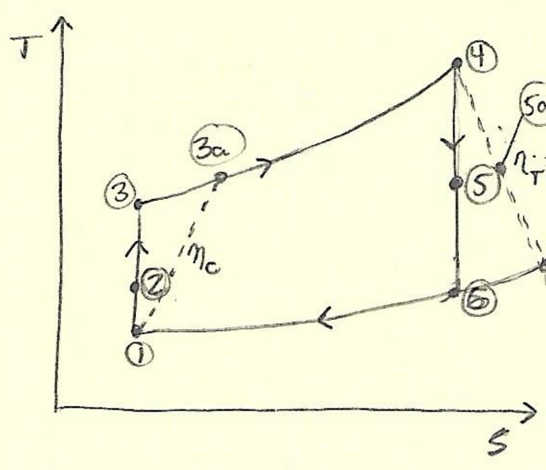
Design Considerations

- Follows turbojet Cycle
- Open System w/ variable C_p and C_v
- Consider Isentropic processes
- Compressor has isentropic efficiency 80%
- Turbine Isentropic efficiency 90%
- diffuser affects thrust

Drawings and Diagrams







Data and Variables

$V_1 = 900\,km/h$

$T_1 = -35°C$

$P_1 = 40\,kPa$

$T_4 = 950°C$

$W_{out_{5-6}} = 500\,kJ/kg$

$\eta_{comp} = 80\%$

$\eta_{Turb} = 90\%$

$V_2 \sim 0\,m/s$

$V_5 \sim 0\,m/s$

$W_c = W_T$

2.) Procedure

1. Find the states of the entire Ideal cycle.
   a. State 1:
      - $P_1 = 40\ kPa$
      - $T_1 = -35\ ^\circ C$
      - $V_1 = 900\ km/h$
      - h_1 = Table A-17 pg 924
      - P_{r_1} = Table A-17
   b. State 2:
      - h_2: $\frac{V_1^2}{2} + h_1 = \frac{V_2^2}{2} + h_2 \longrightarrow \frac{V_1^2}{2} = \cancel{\frac{V_2^2}{2}}^{\approx 0} (h_2 - h_1) \longrightarrow \frac{V_1^2}{2} + h_1 = h_2$
      - T_2: Interpolated from table A-17
      - P_{r2}: Interpolate from table A-17
      - $P_2 = \left(\frac{P_{r2}}{P_{r1}}\right) P_1$
   c. State 3:
      - h_3: $W_c = h_3 - h_2 \longrightarrow h_3 = W_c + h_2 \longrightarrow W_c = W_T$
      - $P_3 = P_1 \left(\frac{P_{r3}}{P_{r1}}\right)$
      - T_3: Interpolated from table A-17
      - P_{r3} = Found from A-17
   d. State 4:
      - $P_4 = P_3$
      - $T_4 = 950\ ^\circ C$
      - P_{r4} = found on A-17
   e. State 5:
      - $V_5 = 0\ m/s$
      - $W_T = h_4 - h_5 \longrightarrow h_5 = h_4 - W_T$
      - $T_5 = T_4 - (T_3 - T_2)$ or Interpolate from A-17
      - P_{r5} = interpolated from A-17
      - $\frac{P_4}{P_5} = \left(\frac{P_{r4}}{P_{r5}}\right) \longrightarrow P_5 = \left(\frac{P_{r5}}{P_{r4}}\right) P_4$
   f. State 6:
      - $P_6 = P_1$
      - $\frac{P_{r6}}{P_{r5}} = \frac{P_6}{P_5} \longrightarrow P_{r6} = \left(\frac{P_6}{P_5}\right) P_{r5}$
      - T_6: Interpolated from A-17
      - h_6: Interpolated from A-17
2. Calculate the Properties for states 3a and 6a
   a. State 3a.
      - $\eta_c = \frac{T_3 - T_1}{T_{3a} - T_1} \longrightarrow T_{3a} = \frac{T_3 - T_1}{\eta} + T_1$
      - Interpolate for h_{3a} and P_{3a}

2.) Procedure Cont.

b. State 6a.

- $\eta = \frac{T_4 - T_6}{T_4 - T_{6a}} \longrightarrow T_{6a} = -\left(\frac{T_4 - T_6}{\eta}\right) + T_4$

- Interpolate for h_{6a} and P_{6a}

c. State 5a.

- $\eta = \frac{T_4 - T_5}{T_4 - T_{5a}} \longrightarrow T_{5a} = -\left(\frac{T_4 - T_6}{\eta}\right) + T_4$

- Interpolate for h_{5a}

3. Find the velocity of gasses at point 6

$$\cancel{\frac{V_{5a}^2}{2}}^{\,0} + h_{5a} = \frac{V_{6a}^2}{2} + h_{6a}$$

$$V_{6a} = \sqrt{2\left(h_{5a} - h_{6a}\right)}$$

4. Thrust of the engine w/ diffuser inlet = 1.6m

$$F = \dot{m}\left(V_{exit} - V_{inlet}\right) = \underline{\frac{V_1}{v_1}\frac{\pi}{4}D^2\left(V_{6a} - V_1\right) = F}$$

Material

1. Air is the primary gas for the combustion Process

Calculations

$$① \xrightarrow{\text{Isent}} ② \xrightarrow{\text{Isent}} ③ \xrightarrow[q_{in}]{P\text{ const}} ④ \xrightarrow{\text{Isent}} ⑤ \xrightarrow{\text{Isent}} ⑥ \xrightarrow[q_{out}]{P\text{ const}}$$

W_{in} $\qquad\qquad$ W_{out}

①	②	③	④	⑤	⑥
$T_1 = 238.15\,°K$	$h_2 = 269.42$	$h_3 = 769.42$	$P_4 = P_3$	$P_{r5} = 44.35$	$T_6 = 411.82\,°K$
$P_1 = 40$ kPa	$P_{r2} = .951$	$P_{r3} = 37.73$	$T_4 = 1223.15$	$T_5 = 784.56\,°K$	$h_6 = 412.91$ kJ/kg
$v_1 = 250$ m/s	$T_2 = 269.31$ K	$T_3 = 751.96$ K	$h_4 = 1305.03$	$h_5 = 805.03$ kJ/kg	$V_6 =$
$P_{r1} = .619$	$P_2 = 61.45$ kPa	$P_3 = 2437.97$ kPa	$P_{r4} = 257.47$	$V_5 \approx 0$ m/s	$P_6 = P_1$
$h_1 = 238.17\ \frac{kJ}{kg}$				$P_5 = 419.94$ kPa	$P_{r6} = 4.22$
$v_1 = 1.71\ m^3/kg$					

$$900\,km/h\left(\frac{1000\,m}{3600\,s}\right) = 250\,m/s$$

$$v_1 = \frac{RT_1}{P_1} = \frac{(.287)(238.15)}{40}$$

$$P_{r1} = \frac{(238.15-230)(.6355-.5477)}{(240-230)} + .5477 = .619$$

$$h_1 = \frac{(238.15-230)(240.02-230.02)}{(240-230)} + 230.02 = 238.17$$

$$h_2 = \frac{V_1^2}{2} + h_1 \longrightarrow h_2 = \frac{\left(\frac{(250)^2\,m^2/s^2}{2}\right)}{1000\,m^2/s^2} + 238.17\,kJ/kg = 269.42\,kJ/kg$$

$$P_{r2} = \frac{(269.42-260.09)(.959-.8405)}{(270.11-260.09)} + .8405 = .951$$

$$P_2 = \left(\frac{P_{r2}}{P_{r1}}\right)P_1 = \left(\frac{.951}{.619}\right)40 = 61.45$$

$$T_2 = \frac{(269.42-260.09)(270-260)}{(270.11-260.09)} + 260 = 269.31\,°K$$

$$P_3 = \left(\frac{P_{r3}}{P_{r2}}\right)P_2 = 2437.97$$

$$h_3 = W_c + h_2 \longrightarrow h_3 = 500\,kJ/kg + 269.42\,kJ/kg = 769.42\,kJ/kg$$

$$T_3 = \frac{(769.42-767.29)(760-750)}{(778.18-767.29)} + 750 = 751.96\,K$$

$$P_{r3} = \frac{(769.42-767.29)(39.27-37.35)}{(778.18-767.29)} + 37.35 = 37.73$$

$$h_4 = \frac{(1223.15-1220)(1324.93-1301.31)}{(1240-1220)} + 1301.31 = 1305.03$$

$$P_{r4} = \frac{(1223.15-1220)(272.3-254.7}{(1240-1220)} + 254.$$

$$P_{r4} = 257.47$$

$$h_5 = h_4 - W_T \longrightarrow h_5 = 1305.03 - 500 = 805.03\,kJ/kg$$

$$T_5 = \frac{(805.03-800.03)(800-780)}{(821.95-800.03)} + 780 = 784.56\,°K$$

$$P_{r5} = \frac{(784.56-780)(47.75-43.35)}{(800-780)} + 43.35 = 44.35$$

$$\frac{P_4}{P_5} = \frac{P_{r4}}{P_{r5}} \quad P_5 = \frac{P_4}{\left(\frac{P_{r4}}{P_{r5}}\right)} \quad P_5 = 419.9$$

$$\frac{P_5}{P_6} = \frac{P_{r5}}{P_{r6}} \longrightarrow P_{r6} = \frac{P_{r5}}{\left(\frac{P_5}{P_6}\right)} \longrightarrow P_{r6} = \frac{44.35}{\left(\frac{419.94}{40}\right)} = 4.22$$

$$T_6 = \frac{(4.22-4.153)(420-410)}{(4.522-4.153)} + 410 = 411.82\,°K$$

$$h_6 = \frac{(4.22-4.153)(421-411.12)}{(4.522-4.153)} + 411.12 = 412.91$$

Calculations Continued

State 3a:

$$\eta_c = \frac{T_3 - T_1}{T_{3a} - T_1} \longrightarrow T_{3a} = \frac{T_3 - T_1}{\eta_c} + T_1$$

$$T_{3a} = \frac{751.96 - 238.15}{.8} + 238.15 = \underline{880.41\,°k}$$

$$h_{3a} = \frac{(880.41 - 880)(932.93 - 910.56)}{(900 - 880)} + 910.56 = \underline{911.02\ kJ/kg}$$

State 5a:

$$\eta_T = \frac{T_4 - T_5}{T_4 - T_{5a}} \longrightarrow T_{5a} = T_4 - \frac{T_4 - T_5}{\eta_T} = 1223.15 - \frac{1223.15 - 784.56}{.9}$$

$$\underline{T_{5a} = 735.83\ k}$$

$$h_{5a} = \frac{(735.83 - 730)(756.44 - 745.62)}{(740 - 730)} + 745.62 = \underline{751.92\ kJ/kg}$$

State 6a:

$$T_{6a} = T_4 - \frac{T_4 - T_6}{\eta_T} \longrightarrow T_{6a} = 1223.15 - \frac{1223.15 - 411.82}{.9} = \underline{321.67\ k}$$

$$h_{6a} = \frac{(321.67 - 320)(325.31 - 320.29)}{(325 - 320)} + 320.29 = \underline{321.97\ kJ/kg}$$

Velocity @ turbin exit $= \boxed{V_5 = 0\ m/s}$

$$V_{6a} = \sqrt{2(h_{5a} - h_{6a})} = \sqrt{2\,(751.92 - 321.97)\left(\frac{1000\ m^2/s^2}{1\ kJ/kg}\right)} = \boxed{927.31\ m/s}$$

$$F = \frac{V_1}{v_1}\frac{\pi}{4}D^2(V_{6a} - V_1) = \left(\frac{250}{1.71}\right)\left(\frac{\pi}{4}\right)(1.6)^2(927.31 - 250) = \boxed{199095.4\ N}$$

$\boxed{F = 199.1\ kN}$

Summary

$$\boxed{\begin{aligned} V_{Turbine_{Exit}} &= 0\ m/s \\ V_{diff_{Exit}} &= 927.31\ m/s \\ F &= 199.1\ kN \end{aligned}}$$

Analysis

The turbojet engine is designed in such a way that the velocity of gases a The exit of the diffuser is greater than that of the inlet gases. This Provide a propulsive force that moves the aircraft forward. The design proposed in this problem does meet the previously made statement and yields an appropriate force that will move the Aircraft.