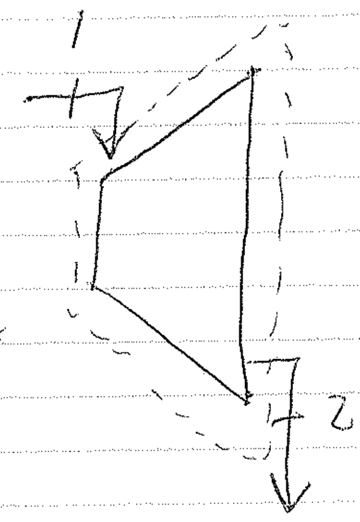
Example – air turbine w/Air Tables

Air expands in an air turbine from a pressure of 450 kPa and a temperature of 550 K to an exhaust pressure of 150 kPa. Assume the process is reversible and adiabatic, with negligible changes in kinetic and potential energy.

a) Sketch the system & boundary and classify the system.
b) Show initial state and final state isobars on both Pv and Ts diagrams. Sketch this process on both diagrams. Visualize and forecast sign of work as well as heat transfer.
c) Use the air tables to find initial and final state conditions.
d) Write the conservation of energy for this process.
e) Write the entropy balance for this process.
f) What is the specific work of air flowing through the turbine?
g) What is the specific entropy production for this turbine?

AIR TURBINE PROBLEM



$T_1 = 550\ K$

$P_1 = 450\ kPa$

$Q = 0$

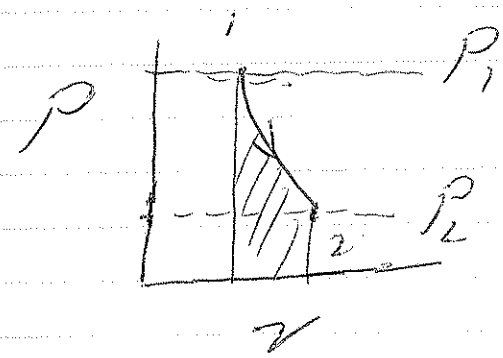
OPEN SYSTEM
STEADY FLOW

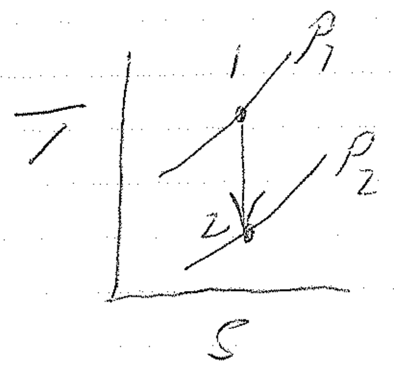
$W = ?\ (kJ/kg)$

$s = ?\ (kJ/kg)$

$P_2 = 150\ kPa$

FLUID MODEL: IDEAL GAS, AIR TABLES





W is +ve

$Q = 0$

PROPERTIES: TABLE C.16 b

$T_1 = 550\ K \quad h_1 = 555\ kJ/kg \quad P_{r_1} = 11.86$

$P_{r_2} = P_{r_1}\left(P_2/P_1\right) = 11.86\left(150/450\right) = 3.95$

$T_2 \approx 405\ K \quad h_2 \approx 405\ kJ/kg$

1ST LAW

$$\dot{q}^{0} - w + (h_i + V_i^2/2g_c + g z_i/g_c) - (h_e + V_e^2/2g_c + g z_e/g_c) = \frac{dE}{dt}$$

ON SPECIFIC ENERGY BASIS

SO $w = h_i - h_e = 555 - 405 = 150$ KJ/Kg

ENTROPY BALANCE

$s_i = s_e$

$$\sum \dot{q}_k/T_k + \sum s_i - \sum s_e + s_p = 0$$

ON SPECIFIC ENTROPY BASIS

SO $s_p = 0$ WHICH IT SHOULD FOR A REVERSIBLE PROCESS!

```
"AIR TURBINE PROBLEM"

"Initial State"
f$='air'
T[1] = 550[K]
P[1] = 450[kPa]
s[1] = Entropy(f$, T=T[1], P=P[1])
h[1] = Enthalpy(f$, T=T[1])

hs[1] = h[1]
ss[1] = s[1]
Ts[1] = T[1]

"Final State (Isentropic Process)"
P[2] = 140[kPa]
ss[2] = ss[1]
Ts[2] = Temperature(f$, P=P[2], s=ss[2])
hs[2] = Enthalpy(f$, T=Ts[2])

"Isentropic Process Analysis"
q = 0[kJ/kg]
q - ws + hs[1] - hs[2] = 0      "Energy Conservation"

Tb= 300[K]
Sps = -q/Tb + (ss[2]-ss[1])  "Entropy Balance"

"Analysis with nt = 80%"
nt = .80[dim]
nt = wa/ws
q-wa + h[1]- h[2] = 0
T[2] = Temperature(f$, h=h[2])
s[2] = Entropy(f$, T=T[2], P=P[2])
Sp = -q/Tb + (s[2] - s[1])
```

SOLUTION

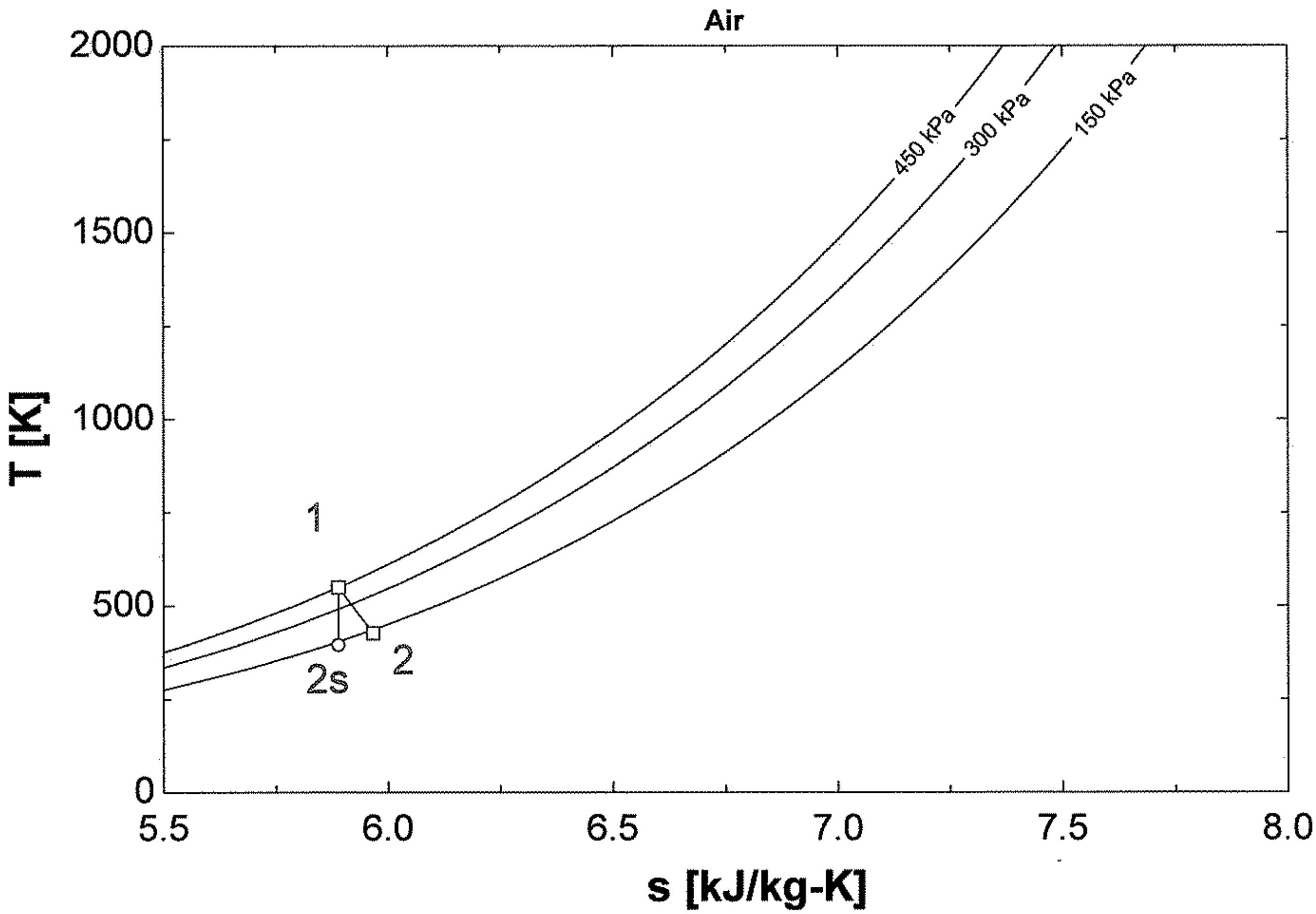
Unit Settings: SI K kPa kJ mass deg

f$ = 'air'	nt = 0.8 [dim]	q = 0 [kJ/kg]
Sp = 0.0764 [kJ/kg-K]	Sps = 0 [kJ/kg-K]	Tb = 300 [K]
wa = 126 [kJ/kg]	ws = 157.5 [kJ/kg]	

No unit problems were detected.

Arrays Table: Main

	P_i [kPa]	s_i [kJ/kg-K]	T_i [K]	h_i [kJ/kg]	Ts_i [K]	hs_i [kJ/kg]	ss_i [kJ/kg-K]
1	450	5.889	550	555.1	550	555.1	5.889
2	140	5.966	427.4	429	396.3	397.5	5.889


Air
2000
1500
1000
500
0
T [K]
5.5
6.0
6.5
7.0
7.5
8.0
s [kJ/kg-K]
450 kPa
300 kPa
150 kPa
1
2
2s

REFLECTION:

1) Note slight difference between hand calculations with Air Tables and EES ideal gas model.

2) Create Ts Property Plot, specifying initial pressure, intermediate pressure, and final pressure.

3) Overlay Ts versus ss and T versus s to show ideal expansion and real expansion processes.

4) Click on each axis to modify min and max values, making it easier to distinguish between ideal and real processes.