Aero 417 **Name:** **Benjamin Tollison**

1. A jet engine is traveling through the air with the forward velocity of 300 m/s. The exhaust gases leave the nozzle with an exit velocity of 800 m/s with respect to the nozzle. If the mass flow rate through the engine is 10 kg/s, determine the jet engine thrust. The exit plane static pressure is 80 kPa, inlet plane static pressure is 20 kPa, ambient pressure surrounding the engine is 20 kPa, and the exit plane area is 4.0 m^2.

Solution:

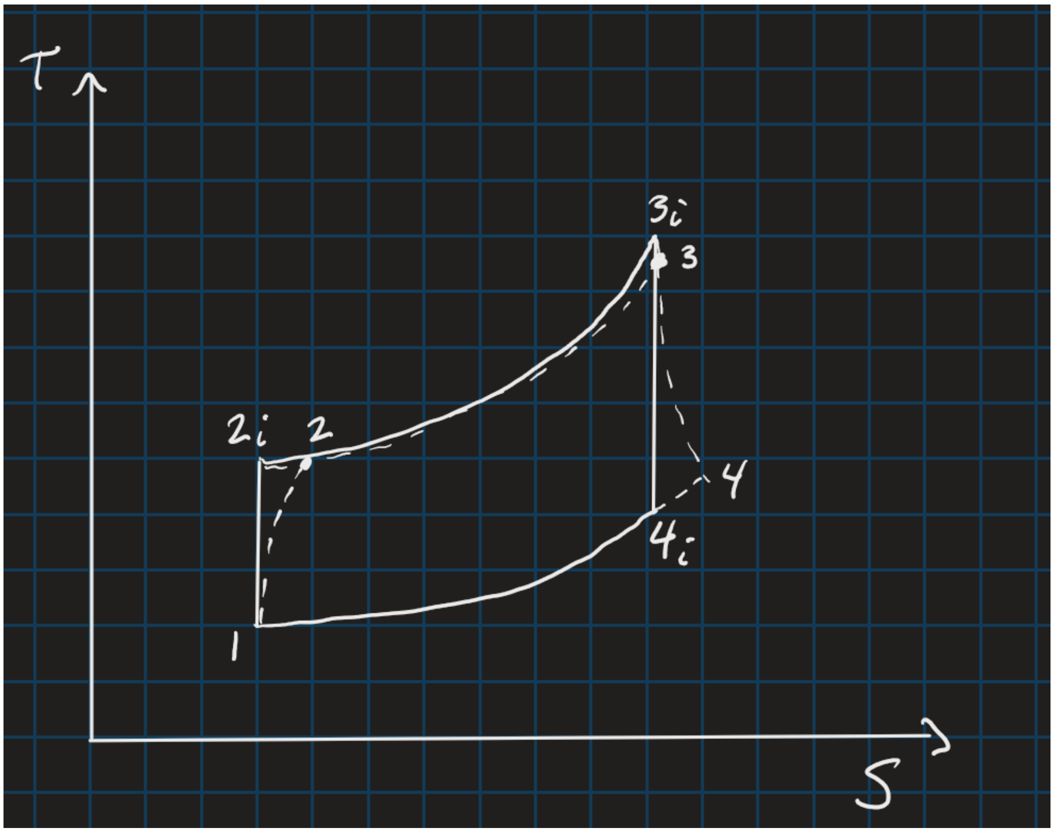
$$\begin{cases} V_\infty = 300\frac{m}{s} \\ V_e = 800\frac{m}{s} \\ P_e = 80\text{kPa} \\ P_{\text{atm}} = 20\text{kPa} \\ A_e = 4\,m^2 \\ \dot{m} = 10\frac{kg}{s} \end{cases}$$

$$T = \dot{m}V_e - \dot{m}V_\infty + A_e(P_e - P_{\text{atm}})$$

$$\therefore T = 245\text{kN}$$

2. Describe the differences between Brayton Cycle and a Real Gas Turbine Cycle. Make diagrams to explain the losses associated with a real engine.

Solution:



The first losses occur in the compressor from stage 1->2 due to the flow not being reversible. The combustion process is not completely isobaric. The process in the turbine is also not reversible.

3. Draw the T-s diagram and determine the turbine shaft power, and the air-fuel ratio

Solution: With all the given infomation the only equations used to find the shaft power were:

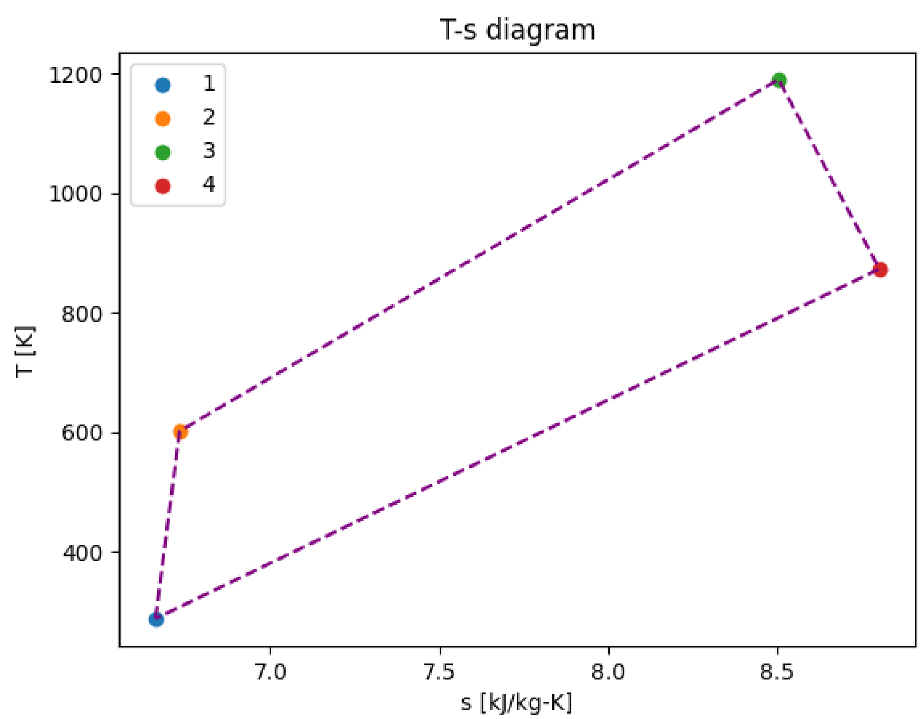
$$P_{02} = rP_{01}$$
$$T_{02} = T_{01}\left[1 + \frac{1}{\eta_c}\left(r^{\frac{\gamma-1}{\gamma}} - 1\right)\right]$$
$$W_* = \frac{1}{\eta_*}cp_*(T_i - T_j)$$
$$P = \dot{m}_{gas}(W_T - W_C)$$

$\therefore P_{shaft} = 5740.3282$ [kW]

The entropy starting values were pulled from Dr.Cizmas' textbook from the air tables for s_1 and stoichiometric tables for s_3. The following equation was used to find the other two values:

$$s_i - s_j = cp_* \ln\frac{T_i}{T_j} - R\ln\frac{P_i}{P_j}$$

which then produces the following T-s graph.



The ideal fuel to air ratio was pulled from the 5th set of lecture slides:

$$\Delta t_c = 588.4864 \rightarrow f \approx 0.014$$

$$\therefore f^{-1} \approx 71.429$$

In [1]:

```python
### Benjamin Tollison ###
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import scipy
import sympy as sp
from IPython.display import Latex, Math, display
from sympy import (
    Eq,
    Function,
    Matrix,
    cos,
    cosh,
    exp,
    integrate,
    lambdify,
    pi,
    sin,
    sinh,
    symbols,
)
from decimal import Decimal
from sympy.solvers.pde import pdsolve
from sympy.solvers.solveset import linsolve
def displayEquations(LHS,RHS):
    left = sp.latex(LHS)
    right = sp.latex(RHS)
    display(Math(left + '=' + right))
    np.set_printoptions(suppress=True)
def displayVariable(variable:str,RHS):
    left = sp.latex(symbols(variable))
    right = sp.latex(RHS)
    display(Math(left + '=' + right))
def displayVariableWithUnits(variable:str,RHS,units):
    left = sp.latex(symbols(variable))
    right = sp.latex(RHS)
    latexUnit = sp.latex(symbols(units))
    display(Math(left + '=' + right + '\\;' +'\\left['+ latexUnit + '\\right]'))
def format_scientific(number:float):
    a = '%E' % number
    return a.split('E')[0].rstrip('0').rstrip('.') + 'E' + a.split('E')[1]
deg2rad = np.pi/180
rad2deg = 180/np.pi
```

In [2]:

```python
thrust = 10*(800-300) + 4*(80-20)*1000
displayVariableWithUnits('T',thrust,'N')
```

$T = 245000\;\left[N\right]$

3)

In [3]:

```python
T01 = 288 # K
P01 = 101325 # Pa
compressor_ratio = 10.3
compressor_isentropic_efficiency = 0.87
mechanical_efficiency = 0.99
combustion_pressure_loss = 0.05
LHV_kerosene = 41 # J/kg
combustion_efficiency = 0.99
```

```
combustion_efficiency = 0.99
T03 = 1190 # K
turbine_efficiency = 0.88
T4 = 873 # K
massflow_rate = 108 # kg/s
cp_air = 1005 # J/kg-K
cp_gas = 1150 # J/kg-K
cycle_dict = {
  '1':{'T0': T01,'P0':P01}
}
gamma_air = 1.4
gamma_gas = 1.33
display(pd.DataFrame(cycle_dict))
```

	1
T0	288
P0	101325

In [4]:

```
P02 = compressor_ratio*P01
T02 = T01 * (1 + (1/compressor_isentropic_efficiency)*(compressor_ratio**((gamma_air-1)
displayVariableWithUnits('P_{02}',P02,'Pa')
displayVariableWithUnits('T_{02}',T02,'K')
compressor_work = cp_air*(T02-T01)
displayVariableWithUnits('W_c',compressor_work,'J')
```

$P_{02} = 1043647.5 \ [Pa]$

$T_{02} = 601.513567990099 \ [K]$

$W_c = 315081.135830049 \ [J]$

In [5]:

```
turbine_work = cp_gas*(T03-T4)/mechanical_efficiency
displayVariableWithUnits('W_T',turbine_work,'J')
```

$W_T = 368232.323232323 \ [J]$

In [6]:

```
shaft_power = massflow_rate*(turbine_work-compressor_work)
displayVariableWithUnits('P_{shaft}',shaft_power,'W')
```

$P_{shaft} = 5740328.23944558 \ [W]$

In [7]:

```
S01 = 6.6608
S02 = cp_air*np.log(T02/T01)/1000 - .287*np.log(compressor_ratio) + S01
displayVariableWithUnits('s_{02}',round(S02,4),'\\frac{kJ}{kgK}')
S03 = ((8.5067-8.4956)/(1193.16-1183.16))*(1190-1183.16) + 8.4956
displayVariableWithUnits('s_{03}',round(S03,4),'\\frac{kJ}{kgK}')
S04 = cp_gas*np.log(T4/T03)/1000 - .287*np.log(P01/(P02*0.95)) + S03
displayVariableWithUnits('s_{04}',round(S04,4),'\\frac{kJ}{kgK}')
```

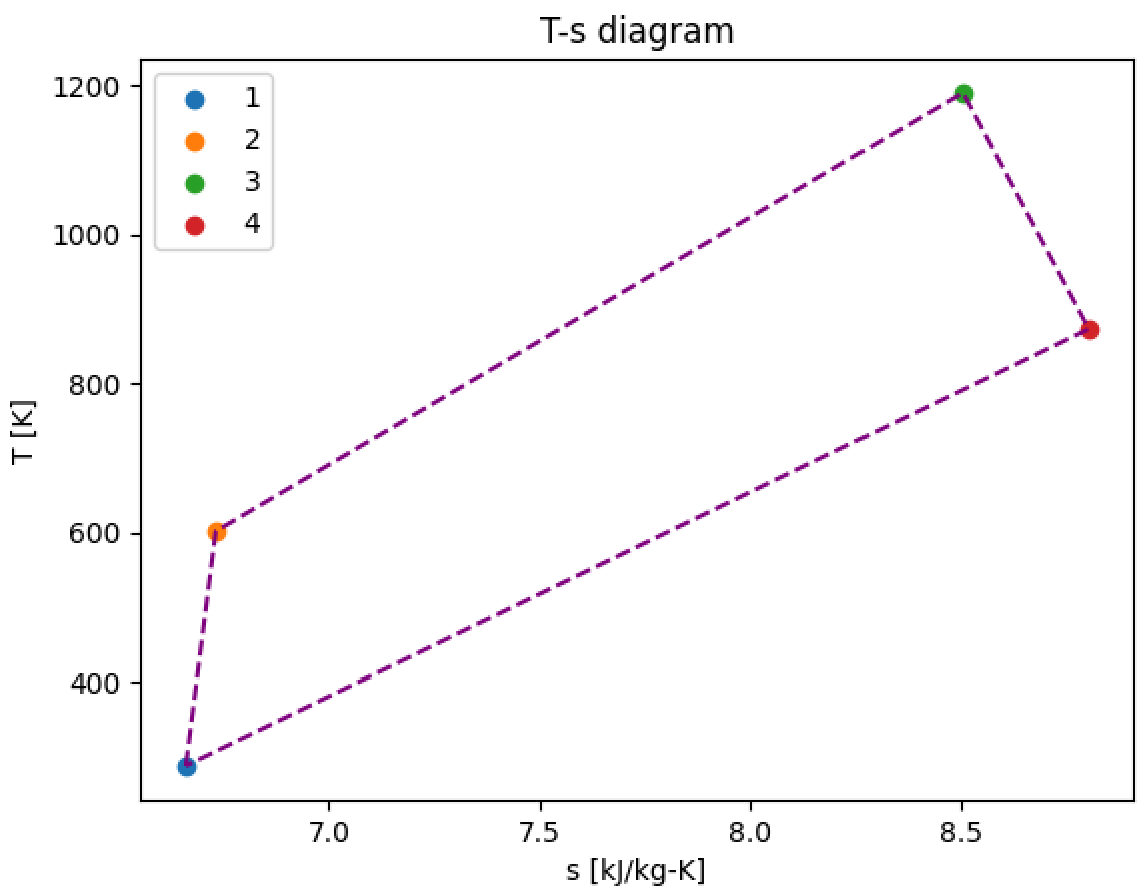
$s_{02} = 6.7316 \ \left[\frac{kJ}{kgK}\right]$

$s_{03} = 8.5032 \ \left[\frac{kJ}{kgK}\right]$

$$s_{04} = 8.8016 \left[\frac{kJ}{kgK}\right]$$

In [8]:

```
temperature_values = [T01,T02,T03,T4,T01]
entropy_values = [S01,S02,S03,S04,S01]
for i in range(len(temperature_values)-1):
  plt.scatter(entropy_values[i],temperature_values[i],label=f'{i+1}')
plt.plot(entropy_values,temperature_values,label=None,color='purple',linestyle='--')
plt.xlabel('s [kJ/kg-K]')
plt.ylabel('T [K]')
plt.legend()
plt.title("T-s diagram")
plt.show()
```



In [9]:

```
displayVariableWithUnits('\\Delta{t_{c}}',round(T03-T02,4),'K')
fuel_ratio_ideal = 0.014
air_to_fuel = fuel_ratio_ideal**-1
displayVariable('f^{-1}',air_to_fuel)
```

$$\Delta t_c = 588.4864 \; [K]$$

$$f^{-1} = 71.4285714285714$$