ME EN 5830/6830: Aerospace Propulsion
Problem Set #1: Thermodynamics Review
Due date: 01/16/2024 by 3:40pm

Submission

Assignments can only be submitted on Gradescope, which can be accessed through Canvas. If you are unsure of how to use Gradescope, please read the two links below *first*. If questions remain, please email the class TA, John Gardner at u0763966@utah.edu. Do not wait until the last minute to figure out Gradescope. Submissions will be automatically locked at the due date given above.

Using Gradescope with Canvas: https://help.gradescope.com/article/5d3ifaeqi4-student-canvas
Mobile submission: https://help.gradescope.com/article/0chl25eed3-student-scan-mobile-device

Introduction

This problem set primarily covers the material from Lecture 2. The goal is to remind students of fundamental concepts learned in Thermodynamics that are critical to Aerospace Propulsion. By the end of the problem set, students should be able to:

- Determine state variables (T, p, v, h, s) in a thermodynamic cycle
- Use the JANAF tables to look up the enthalpy and entropy
- Calculate the efficiency of a cycle

JANAF Tables

Recall that computing variables like enthalpy and entropy involves complex integrals:

$$h(T) = \int_{T_{ref}}^{T} c_p dT' + h(T_{ref})$$

$$s(T,p) = s(T_{ref}, P_{ref}) + \int_{T_{ref}}^{T} c_p \frac{dT'}{T'} - R\, ln \frac{P}{P_{ref}}$$

Without knowing the functional form of c_p, this integral is impossible. Assuming a constant value of c_p is a simple, but often inaccurate way to calculate states. Instead, we will use the JANAF tables which contain accurately calculated values for these integrals. The tables are accessible from https://janaf.nist.gov/. We can find the molecule we're interested in by searching (e.g., "N2") and selecting (e.g., "N2, Nitrogen (ref)). By selecting the molecule, we get the table shown on the following page. The table provides values of key quantities as a function of temperature.

Nitrogen (N_2) N_2(ref)

Enthalpy Reference Temperature = T_r = 298.15 K Standard State Pressure = p° = 0.1 MPa

		J·K^{-1} mol^{-1}		kJ·mol^{-1}			
***T*/K**	**C_p°**	**S°**	**-[G°-H°(T_r)]/T**	**H-H°(T_r)**	**$\Delta_f H^\circ$**	**$\Delta_f G^\circ$**	**log K_f**
0	0.	$\boxed{0.}$	$\bar{s}(T_{ref}, P_{ref})$		0.	0.	0.
100	29.104	159.811			0.	0.	0.
200	29.107	179.985	194.272	-2.857	0.	0.	0.
250	29.111	186.481	192.088	-1.402	0.	0.	0.
298.15	29.124	191.609	191.609	$\boxed{0.}$	$\bar{h}(T_{ref})$		0.
300	29.125	191.789	191.610	0.054	0.	0.	0.
350	29.165	196.281	191.964	1.511	0.	0.	0.
400	29.249	200.181	192.753	2.971	0.	0.	0.
450	29.387	203.633	193.774	4.437	0.	0.	0.
500	29.580	206.739	194.917	5.911	0.	0.	0.

The most important quantities in the table for this assignment are:

Table column	Equivalent mathematical term
T/K	Temperature in Kelvin
$H - H^O(T_r)$	$\int_{T_{ref}}^{T} c_p dT'$
S^o	$\int_{T_{ref}}^{T} c_p \frac{dT'}{T'}$

Pay careful attention to the units of these quantities, which are given above the column titles. Note that JANAF quantities are given as units per mole, whereas this assignment requests units per mass. Conversions will be necessary (e.g., $h = \bar{h}/\bar{m}$). Note that because temperatures in the JANAF tables are only given in 100 K intervals, **linear interpolation may be necessary for intermediate temperatures**.

Assignment

Problem #1: Consider a three-process thermodynamic cycle with Nitrogen (N_2), assumed to be an ideal gas, as the working fluid. Do **not** assume that specific heats are constant for this problem.

- Initial Conditions (state 1): $T_1 = 298.15$ K $p_1 = 1$ bar $= 100.0$ kPa
- Process 12 (state 1 -> state 2): Isochoric heat addition to $T_2 = 2270\ K$
- Process 23 (state 2 -> state 3): Isentropic/adiabatic expansion to $p_3 = 100.0$ kPa
- Process 31 (state 3 -> state 1): Isobaric return to initial state

a) Draw the pV diagram for this cycle.

b) Determine the state variables (T, p, v, h, s) at state 1, 2, and 3. Fill these variables into a table like the one given below.

c) Compute the overall cycle thermodynamic efficiency

State	**T (K)**	**p (kPa)**	**h (kJ/kg)**	**v (m3/kg)**	**s (kJ/kg-K)**
1	298.15	100			
2	2270				
3					