AME 436	Assigned: Friday 4/15/2016
Problem Set #5	• Due Friday 4/22/2016 at 4:30 pm in drop-off box in OHE 430N (back room of the OHE 430 suite of offices, where the Xerox machine is located) • Hard copies are preferred but you can email your assignment to the graders at ame436usc@gmail.com if you're off campus. Emailed files **must be a single .pdf file**, not 20 .jpg images! Multiple files or "hybrid" paper + electronic assignments will **not** be accepted. • DEN students submit through the usual channels.

Problem #1 (20 Points)

For each of the following equations (a) – (c) used frequently in this course, state whether or not each of the following restrictions (i) – (x) are necessary to derive or use these equations

i. steady
ii. one-dimensional flow
iii. ideal gas
iv. constant specific heats
v. reversible
vi. adiabatic
vii. no work transfer
viii. negligible change in kinetic energy
ix. constant area
x. inviscid flow

a) Thrust equation: $T = \dot{m}[(1+FAR)u_9-u_1] + (P_9-P_1)A_9$

b) Constant stagnation temperature between states 1 and 2: $T_1\left(1+\frac{\gamma-1}{2}M_1^2\right)=T_2\left(1+\frac{\gamma-1}{2}M_2^2\right)$

c) Compression/expansion law: $\frac{T_2}{T_1}=\left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}$

Problem #2 (gas turbine performance) (20 points)

The following performance parameters were measured in a turbojet-powered aircraft (no fan or afterburner):

- Flight velocity u_1 = 250 m/s; air mass flow $\dot{m}_a$ = 10 kg/s; fuel mass flow $\dot{m}_f$ = 0.3 kg/s
- Compressor pressure ratio π_c = 30
- Thrust = 10650 N
- Ambient pressure P_1 = exit pressure P_9 = 0.5 atm = 5.07×10^4 N/m^2
- Ambient temperature T_1 = 250K
- Gas constant R = 300 J/kgK, gas specific heat ratio γ = 1.35
- Fuel heating value $Q_R = 4.3 \times 10^7$ J/kg

From this information compute:

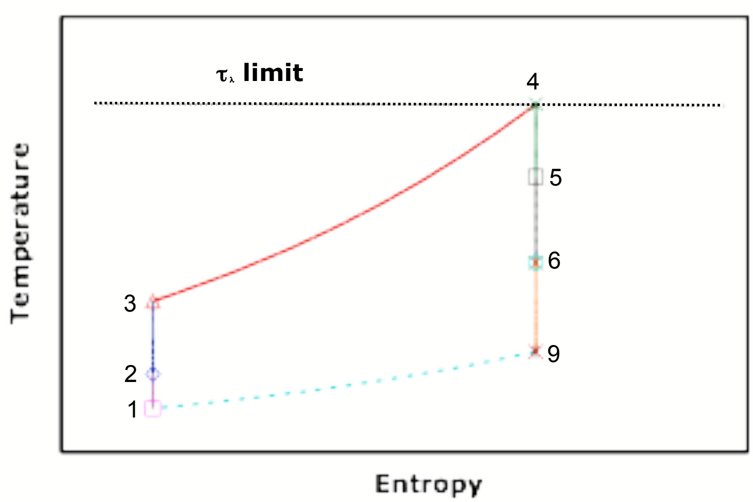
a) Flight Mach number (M_1) and recovery temperature ratio (τ_r)
b) Specific Thrust
c) Exhaust velocity (u_9)
d) Overall efficiency (η_o)
e) Propulsive efficiency (η_{prop})
f) Turbine inlet temperature T_4 (assuming an ideal cycle with no heat losses or irreversibilities)

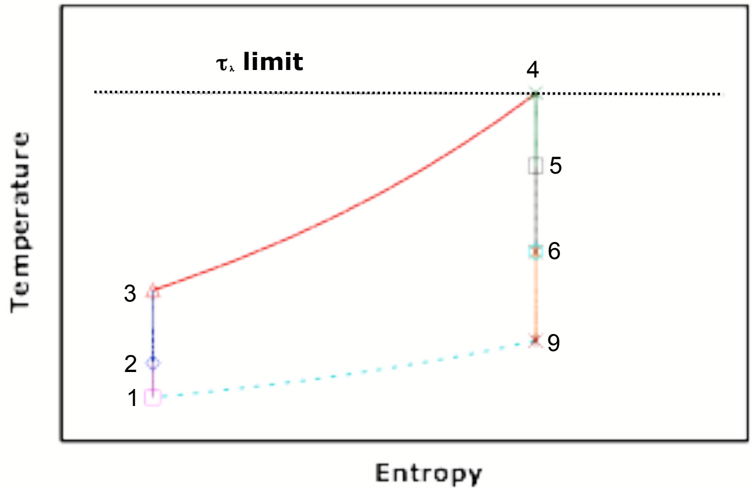
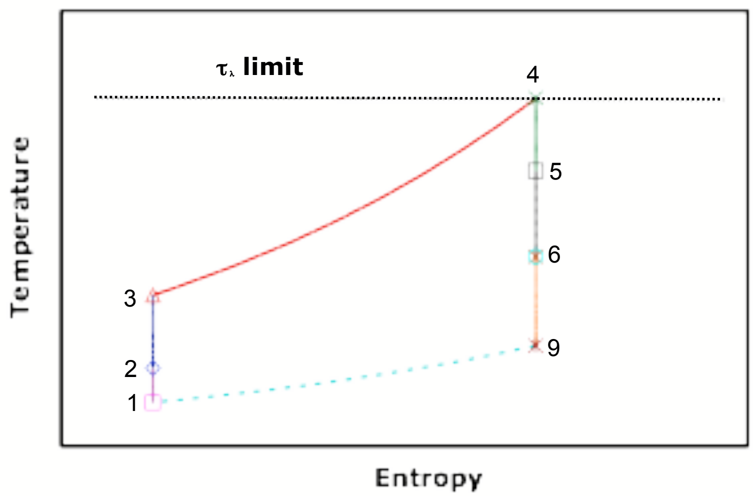
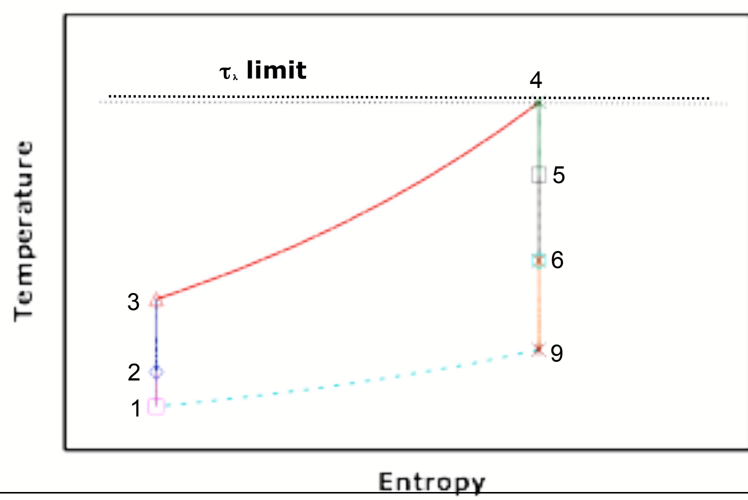
Problem #3 (10 points)

Using the Breguet range equation, estimate the range of a bar-tailed godwit, a bird that stores 55 percent of its body weight as fat to fuel its journey. When estimating the heating value of bird fat, note that 1 diet calorie = 1000 thermodynamic calories. (This question always throws students for a loop. The point is not to get an exact answer, but to estimate each of the terms in the Breguet range equation, and see if the result is reasonable or not.) Compare your prediction to the actual range (see for example the Wikipedia article on the bar-tailed godwit.)

Problem #4 (T-s diagrams) (20 points)

In an ideal τ_λ-limited turbofan, how would the T-s diagrams be affected if the following changes were made? In all cases, the compressor and fan pressure ratios are the same for the baseline and modified cycle. When useful, add statements like "this ΔT = that ΔT," "this area = that area," etc. In some cases there may be no change. *Please make your modifications clear; cycles that look like random scribbles and have no explanations don't get much credit!*

a)	
	The aircraft is taken to Planet X whose atmospheric pressure is twice that of earth, but the ambient temperature and all other properties of the atmosphere, fuel and engine are the same as on earth.

<table>
<tr><td>b)</td><td>
</td></tr>
<tr><td></td><td>The fan is removed and an afterburner with the same τ_λ limit as the turbine is added.</td></tr>
<tr><td>c)</td><td>
</td></tr>
<tr><td></td><td>Half way though the standard (constant pressure) burn, abnormal combustion occurs which results in constant volume combustion. The same total amount of fuel is burned as in the baseline cycle (τ_λ limit cannot be honored in this case). All other components operate normally.</td></tr>
<tr><td>d)</td><td>
</td></tr>
<tr><td></td><td>A new fuel is used that has 10% higher heating value.</td></tr>
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Problem #5 (15 points total)

The following 5 changes to a τ_λ-limited turbofan engine flying at subsonic conditions ($M_1 = 0.8$) are being considered:

1) Use a new fuel with twice the heating value per unit mass (Q_R)
2) Increase ambient pressure (P_1) by a factor of 2 (ambient temperature T_1 not changed)
3) Increase ambient temperature (T_1) by a factor of 2 (ambient pressure P_1 not changed)
4) Increase the flight Mach number M_1 from 0.8 to 1.6
5) Use a new wing with twice the lift to drag ratio (L/D) of the original wing

All other properties of the engine, e.g. bypass ratio (α), compressor pressure ratio (π_c), fan pressure ratio (π_c'), engine size, turbine inlet temperature limit (τ_λ), etc. are held constant.

Briefly answer the following questions **(no credit without explanation!)** In some cases there might be more than one potentially "correct" answer; if so, any one of those answers are acceptable. **Do not list more than one answer for each part.**

If **only one** of these 5 changes were implemented:

a) Which change would **increase specific thrust** (Thrust/$\dot{m}_a c_1$) the most?
b) Which change would **decrease thrust** (not specific thrust) the most?
c) Which change would **increase Thrust Specific Fuel Consumption (TSFC)** the most?
d) Which change would **increase propulsive efficiency** the most?
e) Which change would **increase aircraft range** the most?

Problem #6 (15 points)

For turbofan example at the end of Lecture 13, using aircycles4propulsion.xls, determine what combination of bypass ratio (α) and fan pressure ratio (π_c') (changing **nothing else)** gives the minimum thrust specific fuel consumption under the following 3 conditions:

a) Ideal cycle (all component efficiencies = 1) as in Lecture 13
b) Ideal cycle (all component efficiencies = 1) but with drag coefficient = 0.1

You don't have to show any calculations, just use the spreadsheet to find the optima under these conditions, but answer the following questions:

1) Why was the answer to (a) $\alpha \rightarrow \infty$, $\pi_c' \rightarrow 1$?
2) Why was the optimal α smaller for part (b) than (a)?