Lecture 23

Review for Test 2

Key things to focus on

- Lectures 14-22 (but have to remember some older definitions)
- Meaning and Calculation of Thrust, Specific Thrust, Specific Impulse (Isp), Thrust Specific Fuel Consumption (TSFC)
- Turbojet, Turbofan, Turboprop, configurations, benefits, disadvantages
- Turbojets: Inlet, Compressor pressure ratios, Thrust, Peak Temperature Issues, Manipulation of thrust equation
- Turbofans: Bypass Ratio, Thrust, Manipulation of thrust equation
- Stage analysis of ideal Turbojet and Turbofan Engines
- Meaning of adiabatic efficiency for diffusers, combustors, nozzles, compressors and turbines using T-S diagrams
- Nozzles, subsonic and supersonic
- Subsonic Inlet behavior under different flight conditions
- Normal and Oblique Shock Inlets
- Combustion chamber basics – fuel-air ratio requirements, flame out limits for fuel and air. Chemical Kinetics and Emissions.
- Stoichiometric fuel air ratio, fuel-air equivalence ratio

Key equations to remember

- Mach Number, M = u/a, where u is flight speed and a is speed of sound.
- Speed of sound $a = \sqrt{\gamma R T}$
- Fuel equivalency ratio = actual fuel-air-ratio/stoichiometric fuel-air-ratio
- Thrust =mdote* Ue - mdota * Ua + (Pe-Pa) * Ae
- TSFC = mdotf/Thrust
- Isp = Thrust/(mdotf*g) (Note g = 9.8 m/s^2)
- Specific Thrust = Thrust/mdota
- Isentropic static to stagnation relations and pressure temperature relations (from compressible flow)
- Enthalpy balance across engine:
  - Inlet : KE converted to stagnation enthalpy
  - Compressor: Stgn. Enthalpy increase equals work done on fluid
  - Combustor: Stgn. Enthalpy increase equals heat input
  - Turbine: Stgn. Enthalpy decrease equals work removed from fluid
  - Nozzle: Stgn. Enthalpy converts to KE
- Note: Any other equations outside of these basic equations will be provided on the test.

Example 1

- Assuming the exit velocity of the core flow is the same as the bypass flow, $f_b << 1$, and Bypass ratio > 0, show that the TSFC of a turbofan engine is always lower than a turbojet engine at the same fuel flow rate.

Example 1 solution

$$\Im = \dot{m}_a \left\{ \left[\left(1 + f_b \right) u_{e,p} - u \right] + B \left[u_{e,f} - u \right] \right\}$$

- For fb <<1, and $u_{e,f} = u_{e,p} = u_e$
- $\Im = \dot{m}_a(1 + B)(u_e - u)$
- For a turbojet B = 0, so $\Im = \dot{m}_a(u_e - u)$
- $TSFC_{turbofan}/TSFC_{turbojet} = 1+B > 1$ for $B > 0$

Example #2

- You are given a fuel with a formula C_8H_{16}, write its equation for complete combustion in air. Its heat of combustion is 50MJ/kg

- What is the stoichiometric fuel-air molar ratio?
- What is the stoichiometric fuel-air mass ratio?

- To produce 200MJ/s of energy, what is airflow rate of the engine?

Part #1 Solution

- You are given a fuel with a formula $C_8H_{16,}$ write its equation for complete combustion in air.

- C_8H_{16} + _12__ (O_2 + 3.76 N_2) →_8___CO_2 + _8____H_2O + _45.1____N_2

- What is the stoichiometric fuel-air molar ratio?
  - 1/12
- What is the stoichiometric fuel-air mass ratio?
  - C8H16 has molar mass of 8*12+16*1=112gms
  - O2 has a molar mass of 32, N2 has a molar mass of 28, therefore, air mass is 12*(32+3.76*28) ~ 1647

- Therefore fuel-air mass ratio is 112/1647 = 0.068

Part #2: Solution

- To produce 200MJ/s of energy, how much airflow is required at stoichiometric conditions?
- $m_{dotf}\, Q_r = Q_{dot}$ (Rate of energy production by combustion, $Q_r = 50$, $Q_{dot} = 200$)
- $m_{dotf\ (required)} = 200/50 = 4$ kg/s
- $f = m_{dotf}/m_{dota} = 0.068$,
- Therefore, $m_{dota} = 4/0.068 = 58.8$ kg/s

Example 3

- Given an exit Mach No of 2 and an exit velocity of 900 m/s, and a turbine inlet temperature of 2000K, compute the power extracted by the turbine for an airflow rate of 50kg/s

Example 3 solution

- Given an exit Mach No of 2 and an exit velocity of 900 m/s, exit speed of sound = 450 m/s.
- Therefore, $T_e = a^2/\gamma.R$ = 450*450/(1.4*287) = 503K
- Assume isentropic expansion in nozzle, T05 = Te * (1+0.2*2*2) = 503 * 1.8 = 907K

- Power extracted by turbine = mdot-air * Cp (T04-T05) = 50* 1005 * (2000-907)
- 54.9 MW.