# Part 3: Sankey diagram

Using the station parameters calculated from part one (only consider the original LEAP-1A data), calculate the thermodynamic efficiency, gas generation efficiency, thermal efficiency, propulsive efficiency, and overall efficiency of the engine at cruise

# LEAP-1A Turbofan

Characteristics:

clear all

close all

clc

pi\_inlet = 0.98; %Inlet Pressure Ratio

m = 173;%Engine Air Mass flow rate [kg/s]

BPR = 12; %Bypass Ratio

FPR = 1.4; %Fan Pressure Ratio

pi\_LPC = 1.7; %LPC Pressure Ratio

pi\_HPC = 12.5; %HPC Pressure Ratio

TIT = 1400; %Turbine Inlet Temperature [K]

eta\_fan = 0.9; %Fan isentropic efficiency

eta\_comp = 0.92; %LPC & HPC isentropic efficiency

eta\_turb = 0.9; %LPT & HPT isentropic efficiency

eta\_mec = 0.99; %Mechanical efficiency

eta\_comb = 0.995; %Combustor efficiency

pi\_comb = 0.96; %Combustor pressure ratio

eta\_noz = 0.98; %Nozzle efficiency

M = 0.78; %Mach number

h = 10668; %Altitude [m]

T\_amb = 218.8; %Ambient Temperature [K]

P\_amb = 23842; %Ambient Pressure [Pa]

R = 287; %Gas constant [J/(Kg\*K)]

LHV = 43000000; %Fuel Calorific Value [J/Kg]

cp\_a = 1000; %Specific heat at constant pressure for air [J/(Kg\*K)]

g\_a = 1.4; %Specific heat ratio for air

cp\_gas = 1150; %Specific heat at constant pressure for combusted gases [J/(Kg\*K)]

g\_gas = 1.33; %Specific heat ratio for combusted gases

## Inlet:

First the total quantities are calculated at the station 0, then at the station 2

v\_0 = M\*sqrt(g\_a\*R\*T\_amb);

T\_ta = T\_amb\*(1+ ((g\_a-1)/2)\*M^2);

T\_t2 = T\_ta;

P\_ta = P\_amb\*(1+ ((g\_a-1)/2)\*M^2)^(g\_a/(g\_a-1));

P\_t2 = P\_ta\*pi\_inlet;

## Fan:

Here it is calculated the work required to move the fan, divided in a contribution from the cold flow and another from the hot flow

P\_t21 = P\_t2\*FPR;

P\_t13 = P\_t21;

T\_t21 = T\_t2\*(1 + (1/eta\_fan)\*(FPR^((g\_a-1)/g\_a) -1));

T\_t13 = T\_t21;

W\_fan = m\*cp\_a\*(T\_t21-T\_t2);

m\_hot = m/(BPR+1);

m\_cold = m\_hot\*BPR;

W\_fan\_hot = m\_hot\*cp\_a\*(T\_t21-T\_t2);

W\_fan\_cold = m\_cold\*cp\_a\*(T\_t21-T\_t2);

## Compressors:

Here it is calculated the work required to move the LPC and the HPC

P\_t25 = P\_t21\*pi\_LPC;

P\_t3 = P\_t25\*pi\_HPC;

T\_t25 = T\_t21\*(1 + (1/eta\_comp)\*(pi\_LPC^((g\_a-1)/g\_a) -1));

T\_t3 = T\_t25\*(1 + (1/eta\_comp)\*(pi\_HPC^((g\_a-1)/g\_a) -1));

W\_LPC = m\_hot\*cp\_a\*(T\_t25-T\_t21);

W\_HPC = m\_hot\*cp\_a\*(T\_t3-T\_t25);

## Combustion chamber:

In this part the total values of T and P are calculated at the station 4, adding fuel and the energy due to the combustion

m\_f = (m\_hot\*(cp\_gas\*TIT-cp\_a\*T\_t3))/(eta\_comb\*LHV);

m\_gas = m\_hot + m\_f;

P\_t4 = P\_t3\*pi\_comb;

## HPT:

Here it is calculated the work obtained moving the HPT, obtaining as a result also the total values at the station 45

W\_HPT = W\_HPC/eta\_mec;

T\_t45 = TIT-W\_HPT/(m\_gas\*cp\_gas);

P\_t45 = P\_t4\*(1- (1/eta\_turb)\*(1- T\_t45/TIT))^(g\_gas/(g\_gas-1));

## LPT:

Here it is calculated the work obtained moving the LPT, obtaining as a result also the total values at the station 5

W\_LPT = (W\_LPC+W\_fan)/eta\_mec;

W\_45g = (W\_LPC+W\_fan\_hot)/eta\_mec;

T\_tg = T\_t45- W\_45g/(m\_gas\*cp\_gas);

T\_t5 = T\_t45- W\_LPT/(m\_gas\*cp\_gas);

P\_t5 = P\_t45\*(1- (1/eta\_turb)\*(1- T\_t5/T\_t45))^(g\_gas/(g\_gas-1));

P\_tg = P\_t45\*(1- (1/eta\_turb)\*(1- T\_tg/T\_t45))^(g\_gas/(g\_gas-1));

P\_8is = P\_amb;

T\_8is = T\_tg\*(P\_8is/P\_tg)^((g\_gas-1)/g\_gas);

W\_gg = m\_gas\*cp\_gas\*(T\_tg-T\_8is);

## Core Nozzle:

It is now shown how the flow evolves through the core nozzle, until the end of the "open" cycle, that is station 8

T\_t7 = T\_t5;

T\_t8 = T\_t7;

P\_t7 = P\_t5;

Crit\_ratioc = (1- (1/eta\_noz)\*((g\_gas-1)/(g\_gas+1)))^(-g\_gas/(g\_gas-1));

if P\_t7/P\_amb >= Crit\_ratioc %Critical nozzle or chocked nozzle

M\_8 = 1;

T\_8 = T\_t7\*(2/(g\_gas+1));

P\_8 = P\_t7/(Crit\_ratioc);

v\_8 = sqrt(g\_gas\*R\*T\_8);

r\_8 = P\_8/(R\*T\_8);

A\_8 = m\_gas/(r\_8\*v\_8);

else %unchocked nozzle

P\_8 = P\_amb;

T\_8 = T\_t8\*(1 -eta\_noz\*(1- (P\_8/P\_t7)^((g\_gas-1)/g\_gas)));

M\_8 = sqrt((T\_t8/T\_8 -1)\*(2/(g\_gas-1)));

v\_8 = M\_8\*sqrt(g\_gas\*R\*T\_8);

r\_8 = P\_8/(R\*T\_8);

A\_8 = m\_gas/(r\_8\*v\_8);

end

P\_t8 = P\_8\*(1 + ((g\_gas-1)/2)\*M\_8^2)^(g\_gas/(g\_gas-1));

## Bypass Nozzle:

It is now shown how the flow evolves through the bypass nozzle, until the end of the "open" cycle, that is station 18

T\_t16 = T\_t13;

P\_t16 = P\_t13;

Crit\_ratiobp = (1- (1/eta\_noz)\*((g\_a-1)/(g\_a+1)))^(-g\_a/(g\_a-1));

if P\_t16/P\_amb >= Crit\_ratiobp %Critical nozzle or chocked nozzle

M\_18 = 1;

T\_18 = T\_t16\*(2/(g\_a+1));

P\_18 = P\_t16/(Crit\_ratiobp);

v\_18 = sqrt(g\_a\*R\*T\_18);

r\_18 = P\_18/(R\*T\_18);

A\_18 = m\_cold/(r\_18\*v\_18);

else %unchocked nozzle

P\_18 = P\_amb;

T\_18 = T\_t18\*(1 -eta\_noz\*(1- (P\_18/P\_t16)^((g\_a-1)/g\_a)));

M\_18 = sqrt((T\_t18/T\_18 -1)\*(2/(g\_a-1)));

v\_18 = M\_18\*sqrt(g\_a\*R\*T\_18);

r\_18 = P\_18/(R\*T\_18);

A\_18 = m\_cold/(r\_18\*v\_18);

end

P\_t18 = P\_18\*(1 + ((g\_a-1)/2)\*M\_18^2)^(g\_a/(g\_a-1));

## Performance parameters:

Now the results obtained are used to calculate Thrust and SFC at cruise condition

F\_core = m\_gas\*v\_8 - m\_hot\*v\_0 + A\_8\*(P\_8-P\_amb);

v\_8eff = (m\_hot\*v\_0+F\_core)/m\_gas;

F\_bp = m\_cold\*(v\_18-v\_0) + A\_18\*(P\_18-P\_amb);

v\_18eff = v\_0+F\_bp/m\_cold;

F = F\_core+F\_bp;

TSFC = m\_f/F;

## Efficiencies:

eta\_thermodynamic = W\_gg/(m\_hot\*(cp\_gas\*TIT-cp\_a\*T\_t3))

eta\_thermodynamic\_err = W\_gg/(m\_gas\*cp\_gas\*TIT-m\_hot\*cp\_a\*T\_t3)

eta\_jetgen = (m\_cold\*(v\_18eff^2 -v\_0^2)/2 +m\_gas\*(v\_8eff^2 - v\_0^2)/2)/W\_gg

eta\_thermal = eta\_jetgen\*eta\_thermodynamic\*eta\_comb

eta\_prop = v\_0\*(m\_cold\*(v\_18eff -v\_0) +m\_gas\*(v\_8eff - v\_0))/(m\_cold\*(v\_18eff^2 -v\_0^2)/2 +m\_gas\*(v\_8eff^2 - v\_0^2)/2)

eta\_tot = eta\_prop\*eta\_thermal

# Draw Sankey Diagram to indicate losses through the engine cycle:

I am assuming that I start with a chemical energy, and for every step I make, there is a loss, until I reach the final result: thrust power.

chem\_energy = m\_f\*LHV

heat = chem\_energy\*eta\_comb

gas\_power = heat\*eta\_thermodynamic

prop\_power = gas\_power\*eta\_jetgen

thrust\_power = prop\_power\*eta\_prop

In the Sankey diagram the percentage shown are all referred to the chemical energy, so the losses are therefore shown:

loss\_comb = 100\*(chem\_energy-heat)/chem\_energy

loss\_thermodynamic = 100\*(heat-gas\_power)/chem\_energy

loss\_jetgen = 100\*(gas\_power-prop\_power)/chem\_energy

loss\_prop = 100\*(prop\_power-thrust\_power)/chem\_energy

tot\_loss = loss\_prop+loss\_jetgen+loss\_thermodynamic+loss\_comb

And finally it is checked if it is a good procedure using the total efficiency

thrust\_powercheck = chem\_energy\*eta\_tot

tot\_losscheck = 100\*(chem\_energy-thrust\_powercheck)/chem\_energy

efficiency = 100-tot\_loss