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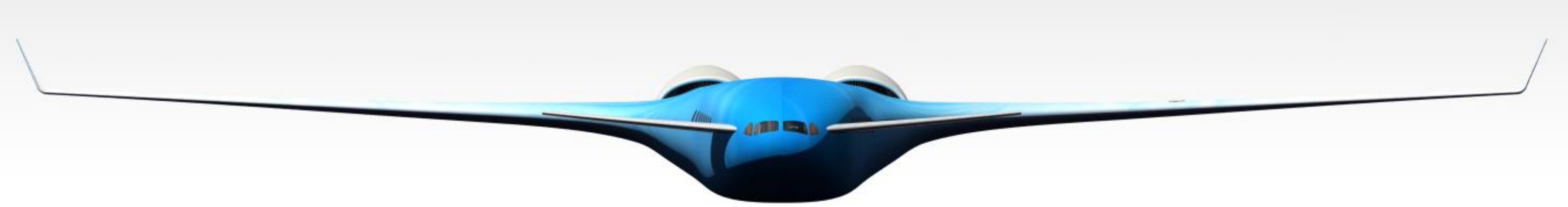

AE4238: Aero Engine Technology Assignment1 Sankey diagram

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LEAP-1A Turbofan

Known characteristics of LEAP-1A at cruise condition(Mach = 0.78 Altitude = 10668 meter) are as follows:

- Type: Twin spool turbofan Engine
- Inlet pressure ratio = 0.98
- Engine Air Mass flow rate = 173 kg/s
- Bypass ratio = 12
- Fan Pressure Ratio = 1.4
- LPC Pressure Ratio = 1.7
- HPC Pressure Ratio = 12.5
- Combustor Exit Temperature (T4) = 1400 K
- Fan isentropic efficiency = 0.90
- LPC & HPC isentropic efficiency = 0.92
- LPT & HPT isentropic efficiency = 0.90
- Mechanical efficiency = 0.99
- combustor efficiency = 0.995
- combustor pressure ratio = 0.96
- Nozzle= Convergent
- Nozzle efficiency = 0.98
- Ambient Temp. = 218.8 K
- Ambient Press. = 23842 Pa
- Gas constant= 287 J/kg K
- Fuel calorific value (LHV) = 43MJ/kg
- $c_{P,air}$ = 1000 J/kg.K; γ_{air} = 1.4
- $c_{P,gas}$ = 1150 J/kg.K; γ_{gas} = 1.33

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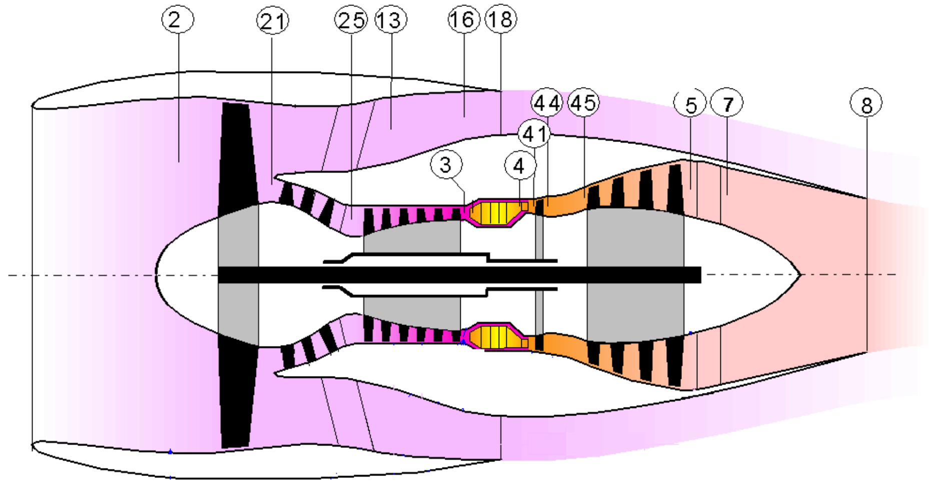
Part one-cycle calculation

- Calculate the pressure, temperature and mass flow at every section (2, 21, 13, 18, 25, 3, 4, 45, 5, 7 and 8)
- Calculate the thrust and SFC at cruise conditions
- Draw the T-S diagram of the cycle
- Draw relevant conclusions.



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Inlet

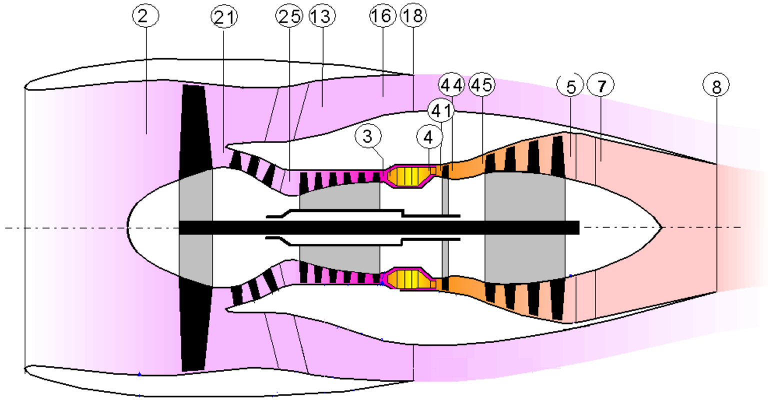
$$Tt_2 = Tt_a$$

$$P_{t2} = Pt_a * PRinl_{et}$$

$$\frac{T_{ta}}{T_a} = 1 + \frac{\gamma_a - 1}{2} M^2$$

$$\frac{p_{ta}}{p_a} = \left(1 + \frac{\gamma_a - 1}{2} M^2\right)^{\frac{\gamma_a}{\gamma_a - 1}}$$

$$\frac{p_{t,2}}{p_a} = \left(1 + \eta_{is_{inlet}} \frac{\gamma_a - 1}{2} M^2\right)^{\frac{\gamma_a}{\gamma_a - 1}}$$



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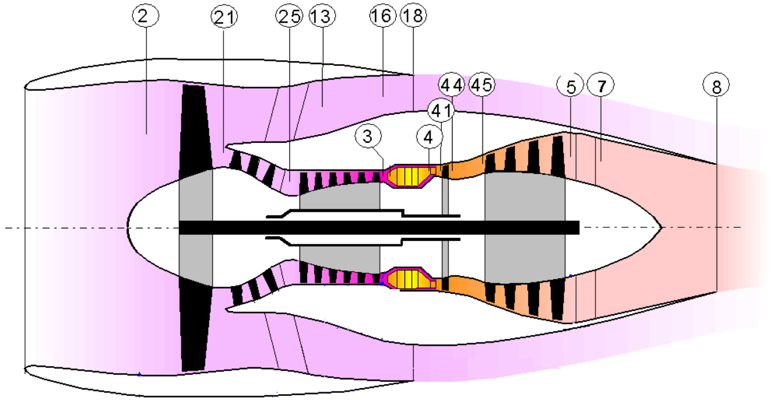
Fan

$$\frac{T_{t,2}}{T_{t,1}} = 1 + \frac{1}{\eta_{is}}\left[\left(\frac{p_{t,2}}{p_{t,1}}\right)^{\left(\frac{\gamma_a - 1}{\gamma_a}\right)} - 1\right]$$

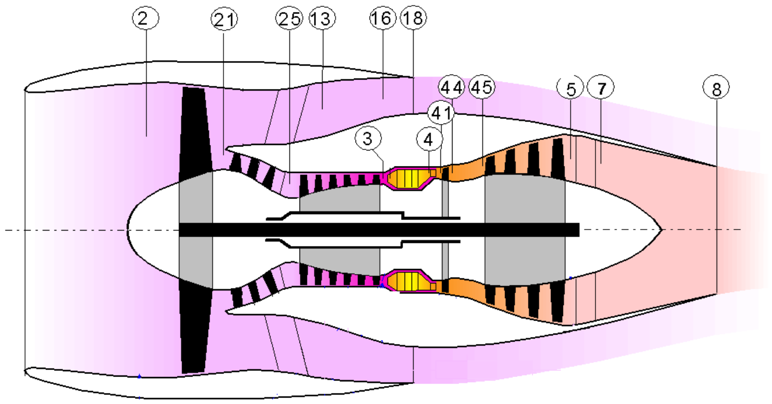
$$P_{t21} = Pt_2 * PRf_{an}$$

$$P_{t13} = Pt_{21}$$

$$W_{fan} = \dot{m}_2 c_{p,air}(T_{t21} - T_{t2})$$



LPC + HPC



$$W_{LPC} = \dot{m}_{25} c_{p,air} (T_{t25} - T_{t21})$$

$$W_{HPC} = \dot{m}_{3} c_{p,air} (T_{t3} - T_{t25})$$

$$P_{t25} = Pt_{21} * PRL_{PC}$$

$$P_{t3} = Pt_{25} * PRH_{PC}$$

Temperature follows the same as fan calculation

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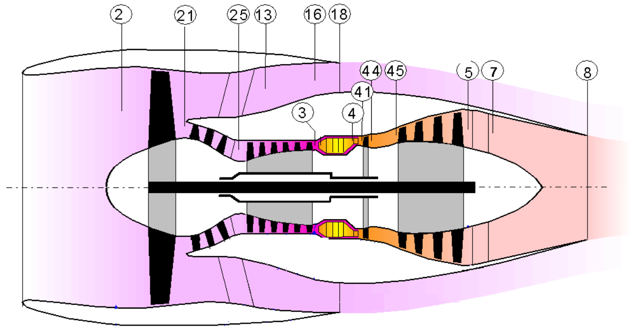
Combustion chamber

$$\text{Heat added} = \dot{m} * (h_{out} - h_{in})$$
$$= \dot{m} * c_p\,(T_{out} - T_{in})$$
$$= \dot{m}_f * LHV * \eta_{cc}$$

$$\rightarrow \dot{m}_f = \frac{\dot{m}_3 * c_p * \left(T_{t,4} - T_{t,3}\right)}{\eta_{cc} * LHV}$$

$$\dot{m}_4 = \dot{m}_3 + \dot{m}_f$$

$$p_{t,4} = 0.96 * p_{t,3}$$



HPT

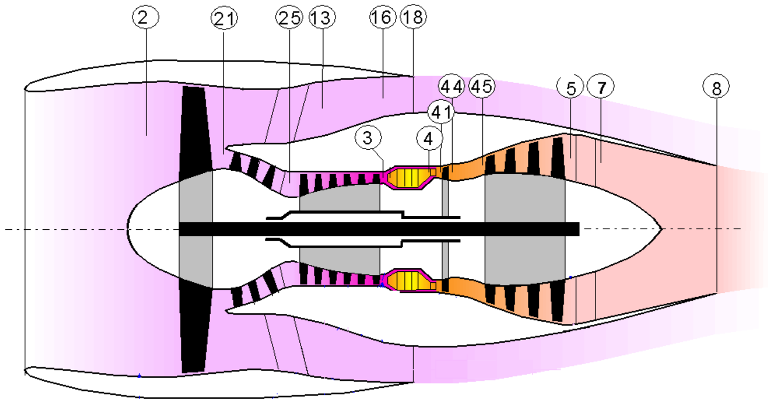
$$\text{Work done} = \dot{m} * \Delta h$$
$$= \dot{m} * c_p\,(\Delta T)$$

$$\frac{T_{t,2}}{T_{t,1}} = 1 - \eta_{is}\left[1 - \left(\frac{p_{t,2}}{p_{t,1}}\right)^{\left(\frac{\gamma_g - 1}{\gamma_g}\right)}\right]$$

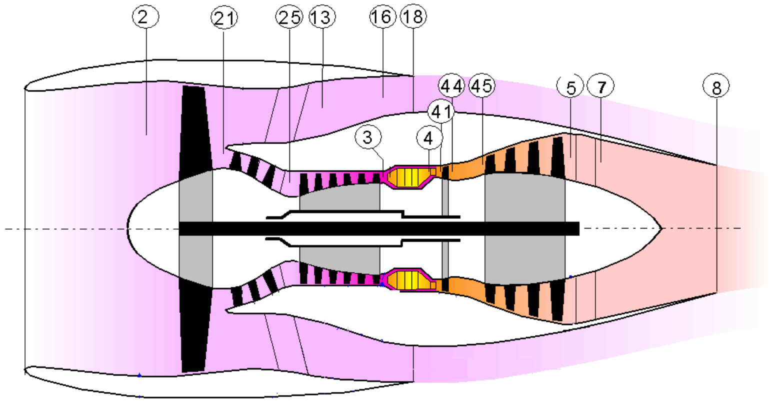
$$W_{HPT} = \frac{W_{HPC}}{\eta_{mech}}$$

$$Tt_{45} = Tt_4 - \frac{W_{HPT}}{\dot{m}_4 c_{p,gas}}$$

$$pt_{45} = pt_4\left(1 - \frac{1}{\eta_{is}}\left(1 - \frac{Tt_{45}}{Tt_4}\right)\right)^{\frac{\gamma_{gas}}{\gamma_{gas}-1}}$$



LPT



$$W_{LPT} = \frac{W_{LPC} + W_{fan}}{\eta_{mech}}$$

Pressure and temperature follow the same as HPT calculation

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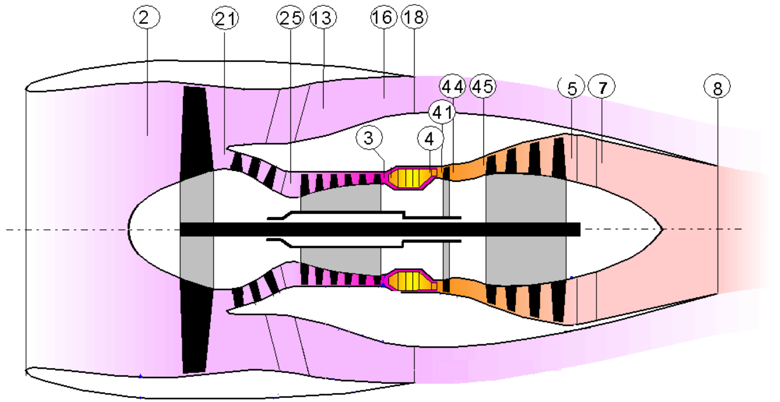
Nozzle

$$T_{t8} = Tt_7 = Tt_5$$

Compare for choked/unchoked

Critical Pressure for Core Nozzle

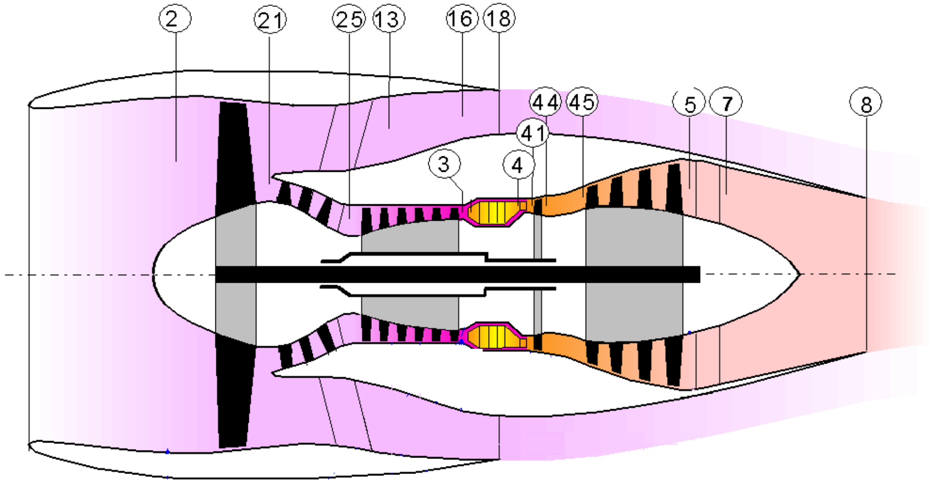
$$\frac{p_{t,7}}{p_{critcal}} = \left[1 - \frac{1}{\eta_j}\left(\frac{\gamma_g - 1}{\gamma_g + 1}\right)\right]^{\left(\frac{-\gamma_g}{\gamma_g - 1}\right)}$$



Part two-cycle calculation

Based on the original cycle parameters of LEAP-1A

- Varying the bypass ratio from [9,11,13] with FPR of 1.4 and 1.5 respectively
- Varying the HPC pressure ratio from [11, 13, 15]
- Varying the turbine inlet temperature from [1400K, 1500,1600K]
- Calculate the thrust and SFC for each variation
- Plot the variation of thrust and SFC vs. FPR, BPR, OPR, TIT
- Draw relevant conclusions.



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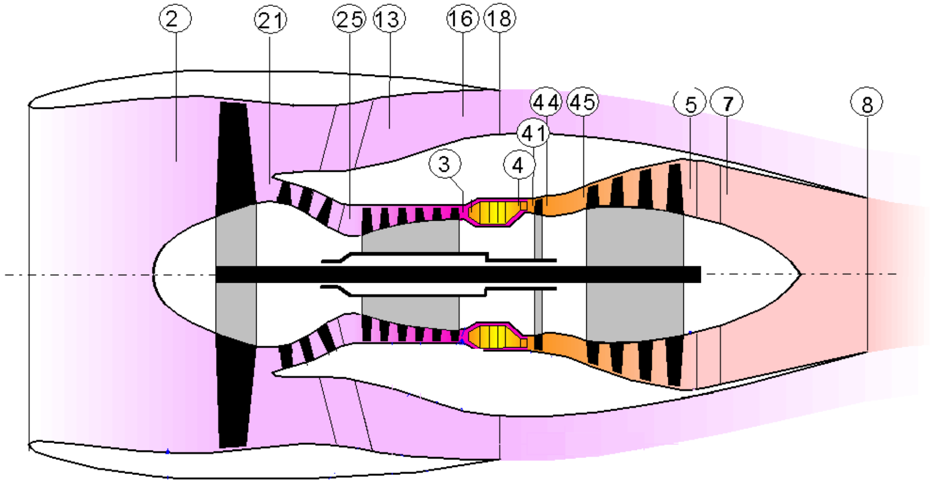
Part three-Sankey diagram

- 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
- Draw Sankey Diagram to indicate losses through the engine cycle
- Draw relevant conclusions.



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Further assumptions

- We assume no turbine cooling and bleed air
- We consider a real Brayton cycle partially, meaning non-isentropic process are considered in the calculation.
- Please use the suggested value for Cp and gamma as given.
- T-S diagram should contain the inlet and exit conditions for all the engine core components, including inlet, inner fan, LPC, HPC, combustion chamber, HPT, LPT, core nozzle are required.

Products/deliverables

- Individual/Team work with max. two students: state the tasks per person in case of collaboration
- Create codes for engine cycle and efficiency calculation, any programming language is ok
- Make a report including the following sections:
  - Brief introduction
  - Methodology: details in calculation procedure, e.g., equations, constants, assumptions, etc.
  - Results of temperature, pressure, mass flow rate, thrust and fuel consumption
  - Results of efficiencies and Sankey Diagram
  - Conclusions and discussions: Implication of the results beyond what is observed
  - Appendix with code
  - References if applicable
- Format: Both doc/pdf format in A4 size are ok.
- Submission time: 30th Sep, 2022 to Brightspace
- Please do not plagiarise. Cases with plagiarism will directly be reported to the Board of Examiners

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Resources

In case of any questions, please refer to the following materials:

- Reader chapter 5 on an example calculation of engine cycle efficiency
- Lecture tutorial on cycle calculation
- Lecture 3 & 4 recording

Or contact the TAs and Lecturers:

- TAs: opening office hours? + email exchange
- Lecturer: opening office hours every Wednesday 16:00-17:00, LR3.21

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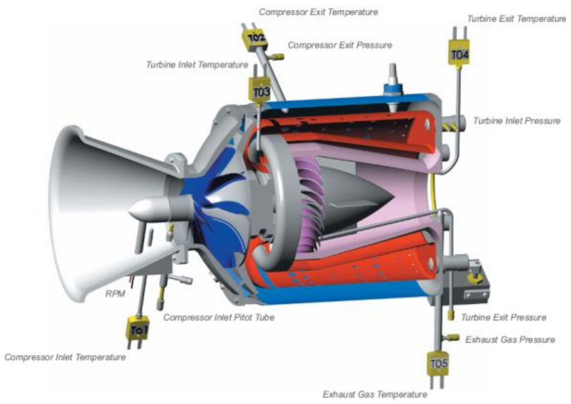

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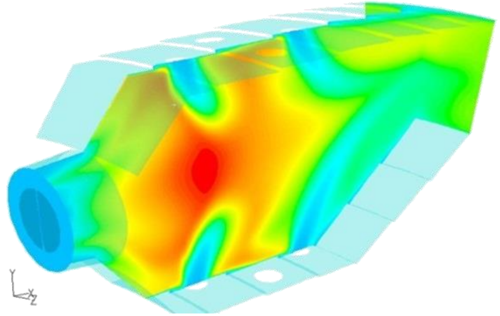

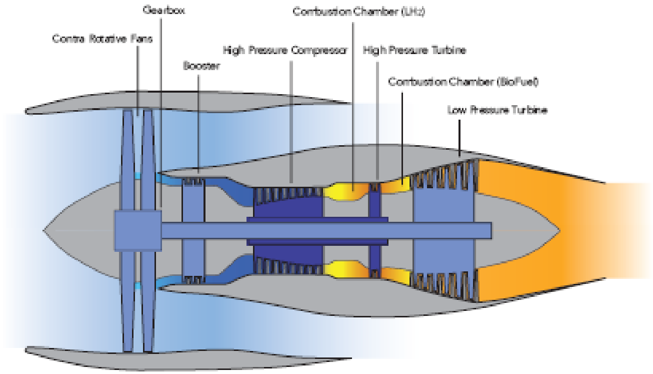

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