TOPIC V - Gas Cycles

The Turbojet Cycle (Lecture 4/4)

Thrust from gas cycles.

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9. The Turbojet Cycle – "modified Brayton (Joule)"- worked example to estimate thrust
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Objectives

Identify specific processes that are in addition to Brayton – diffuser, nozzle, thrust.

Application

Turbojet – oldest type of jet engine (Whittle). Messerschmidt ME262, De Havilland Comet, Concord

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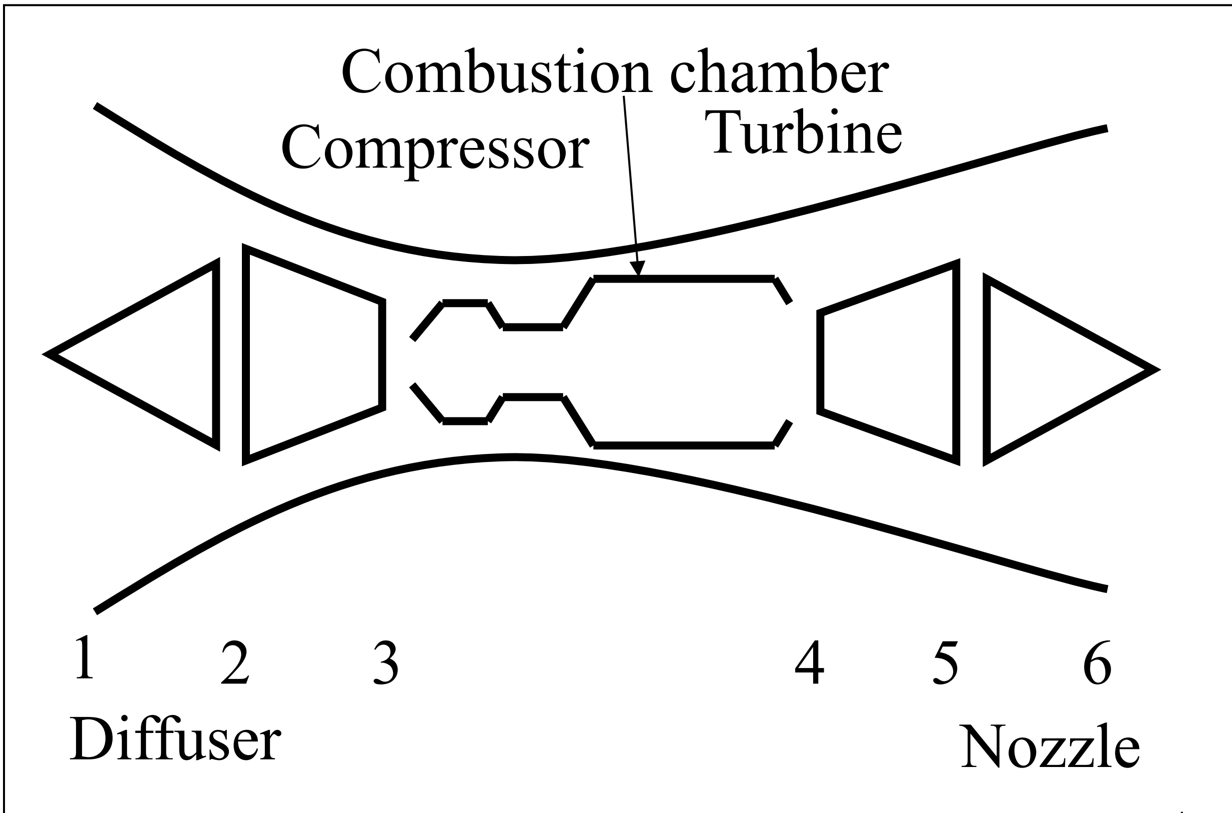
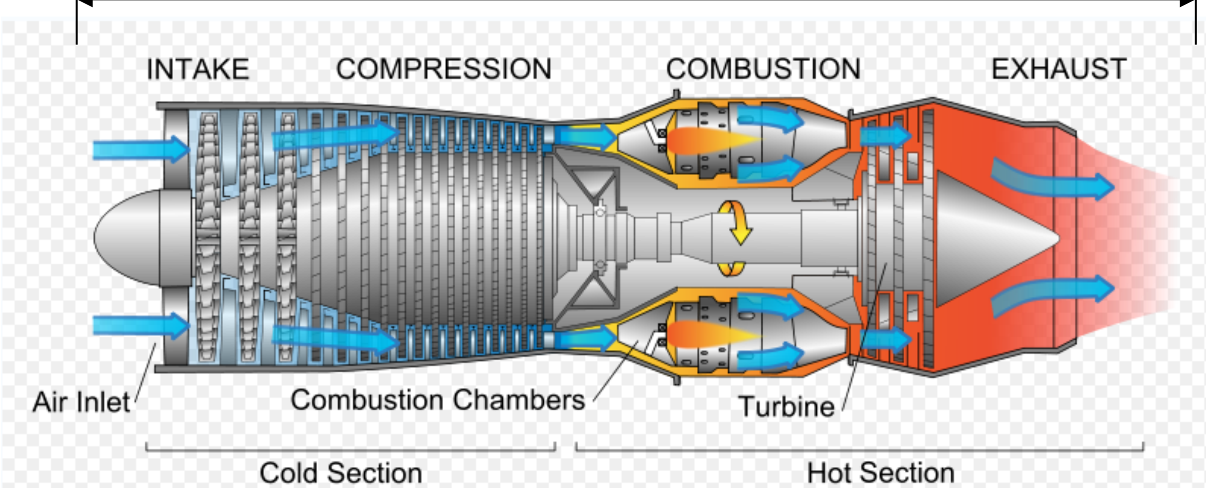
<u>Sketch and graphic (from Wikipedia!)</u>



Same pressure, $p_1 = p_6$



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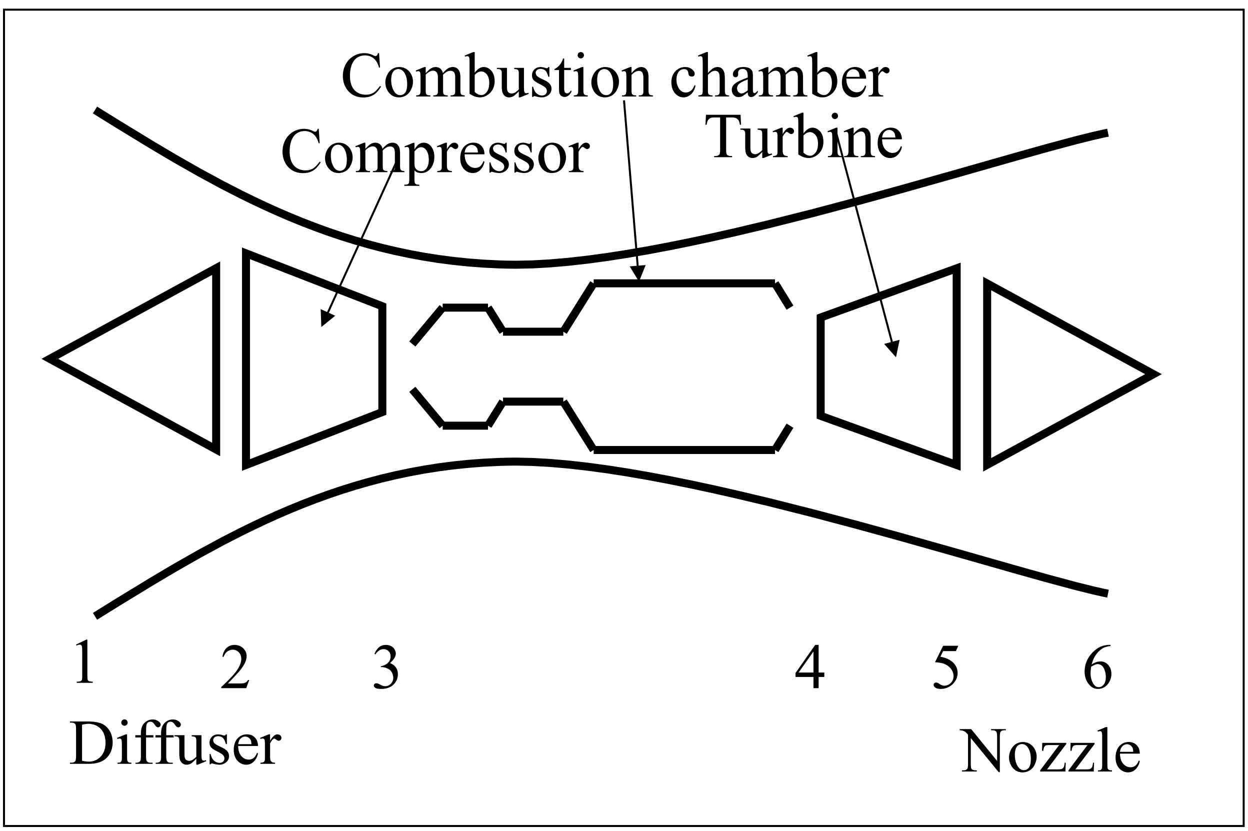
Resembles Brayton (Joule).

Produces **thrust** (vs work)

- Diffuser (1-to-2) decellerates incoming air, $v_2 \sim 0 \text{ m s}^{-1}$
- Nozzle (5-to-6) accelerates exit air until $p_6 = p_1$. Assume $v_5 \sim 0 \text{ m s}^{-1}$.
- Turbine produces sufficient work to drive compressor – no more.



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The Turbojet Cycle (Lecture 4/4)

Thrust = rate of change of momentum (Newton #2), so

$$F = \dot{m} v_6 - \dot{m} v_1 = \dot{m}(v_6 - v_1) \quad (25)$$

Momentum flow, owing to air leaving the system boundary

Momentum flow, owing to air entering the system boundary

Quote all velocities relative to airframe. Term $v_1 \approx$ airframe velocity

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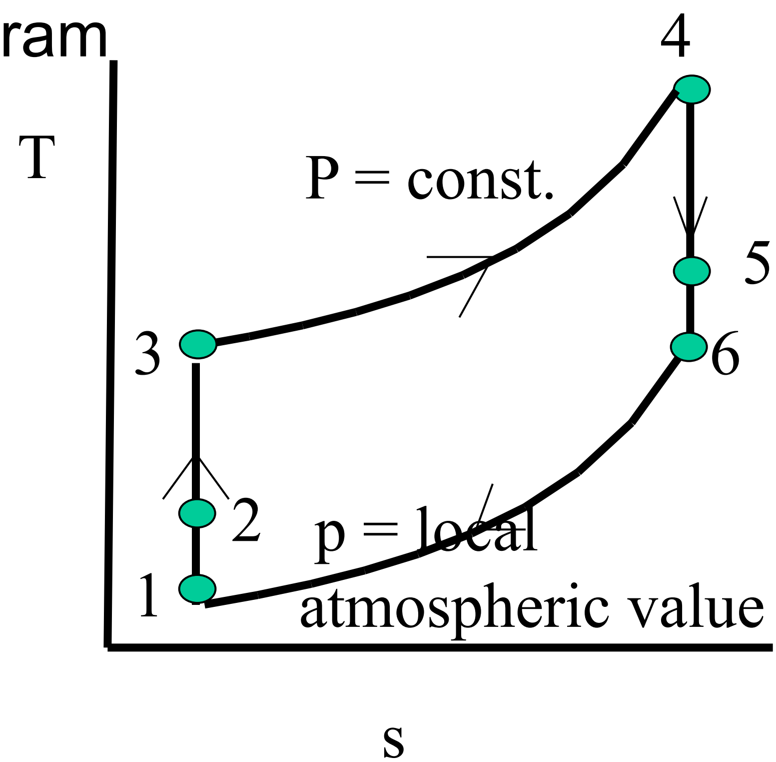
The Turbojet Cycle (Lecture 4/4)

Shown as T-s diagram

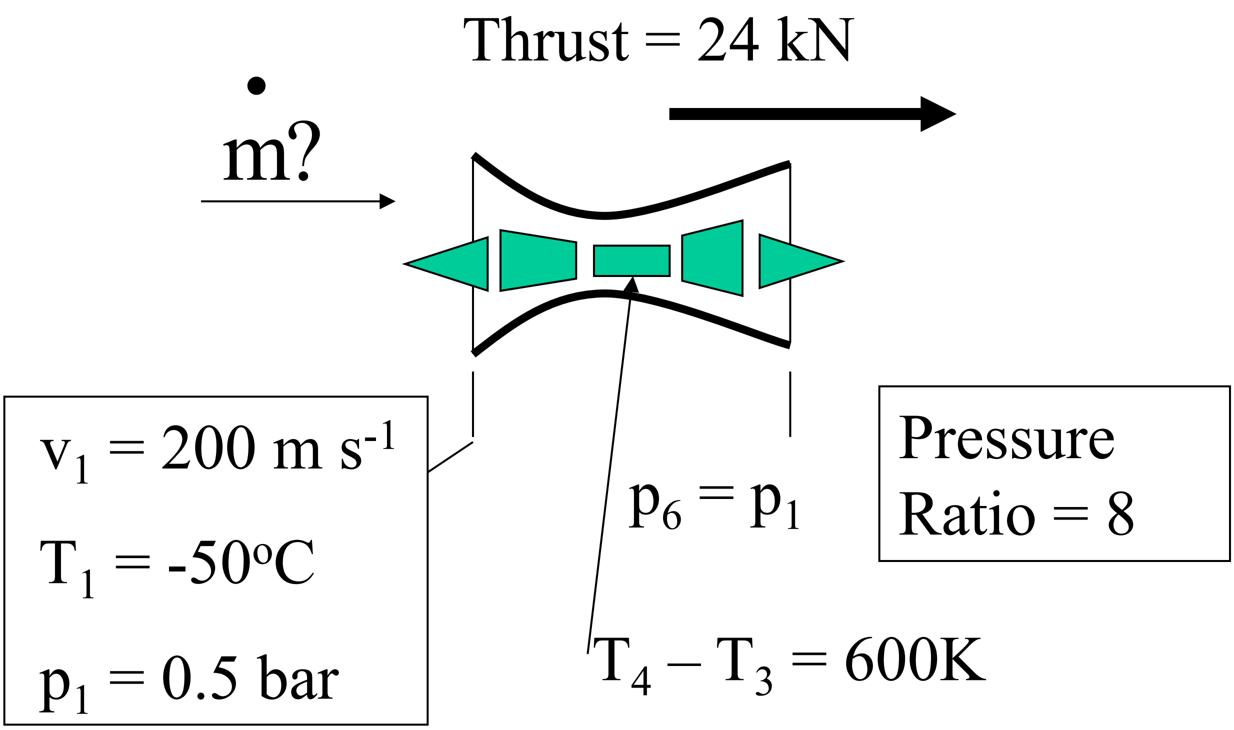


<u>Worked example</u>

<u>Statement</u>: Air throughput giving specified thrust .

<u>Schematic</u>: - Ts diagram plus …

The Turbojet Cycle (Lecture 4/4)



<u>Assumptions</u>: v_2, $v_5 \sim 0$. Internally reversible processes throughout. Adiabatic processes (other than "combustor"). Ignore KE and PE changes in turbine and compressor. Turbine transmits work perfectly.

Properties: $c_p = 1.005 \text{ kJ kg}^{-1} \text{ K}^{-1}$

Physical Laws: isentropic expansion/ compression in nozzle, diffuser, compressor, turbine so $p/T^{\gamma/\gamma-1}$ = constant. SFEE relates enthalpy change to KE change in nozzle and diffuser

Calculations:

Enthalpy and KE

$$T_2 = T_1 + \frac{v_1^2}{2c_p}$$

Diffuser – manipulate SFEE

$\Rightarrow T_2 = -30.1^oC = 243 \text{ K}$

$p_2 = p_1 (T_2/T_1)^{\gamma/\gamma-1} = \underline{1.351\ p_1}$

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The Turbojet Cycle (Lecture 4/4)

Given as 8

Compressor – $T_3 = (p_3 / p_2)^{(\gamma-1)/\gamma} T_2 = 440$ K

$p_3 = 8 p_2 = \underline{10.81 p_1}$

Given

Combustor - $T_4 = 440 + 600 = 1040$ K

$p_4 = p_3 = \underline{10.81 p_1}$

Turbine- same work as comp, const c_p

$T_3 - T_2 = T_4 - T_5 \Rightarrow \underline{T_5 = 843 \text{ K}}$

$p_5 = p_4 (T_5/T_4)^{\gamma/\gamma-1} = (843/1040)^{3.5} \times 10.81 p_1$
$= \underline{5.18 p_1}$

Nozzle - if $p_1 = p_6$

$T_6 = T_5 / (p_5/p_6)^{\gamma-1/\gamma} = 843/ 5.18^{1/3.5} = 527$ K

Apply SFEE, (assume $v_5 \sim 0$)

$$v_6 = \sqrt{2\, c_p \left(T_5 - T_6\right)} = \sqrt{2 \times 1005 \times \left(843 - 527\right)}$$

$$V_6 = 797 \text{ m s}^{-1}$$

Thrust

$$F = \dot{m}(v_6 - v_1) \Rightarrow$$

$$24000 = \dot{m}(797 - 200) \Rightarrow$$

$$\underline{\dot{m} = 40.2 \,\text{kg s}^{-1}}$$

10. Turbofan

Very simply, the fan drives by-pass air/
Can prove more effective/ economic.

Conclusions

Differences with Brayton (Joule)– nozzle, diffuser, less turbine work.

Analysis – thoughtful application of

SFEE ,e.g. $$0 = c_p\left(T_{end} - T_{start}\right) + \left(\frac{v_{end}^2}{2} - \frac{v_{start}^2}{2}\right)$$

$$\dot{W} \ or \ \dot{Q} = \dot{m}\, c_p\left(T_{end} - T_{start}\right)$$

Isentropic $$T = const.\ p^{(\gamma-1)/\gamma}$$