Jet Aircraft Propulsion

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Lecture 20

Axial Flow Turbine Aerothermodynamic Fundamentals

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- For centuries water fall with a large drop (or head) has been used for converting the incipient potential energy to kinetic energy
- The basic mechanical principle, that if a fluid with large kinetic energy content is allowed to hit a set of blades free to rotate, certain amount of shaft work can be extracted from the passing fluid, has been known for long.
- This energy is available in the form of rotating shaft power and can be used for various purposes.
- Wind turbines also use naturally available wind kinetic energy to extract power out of it

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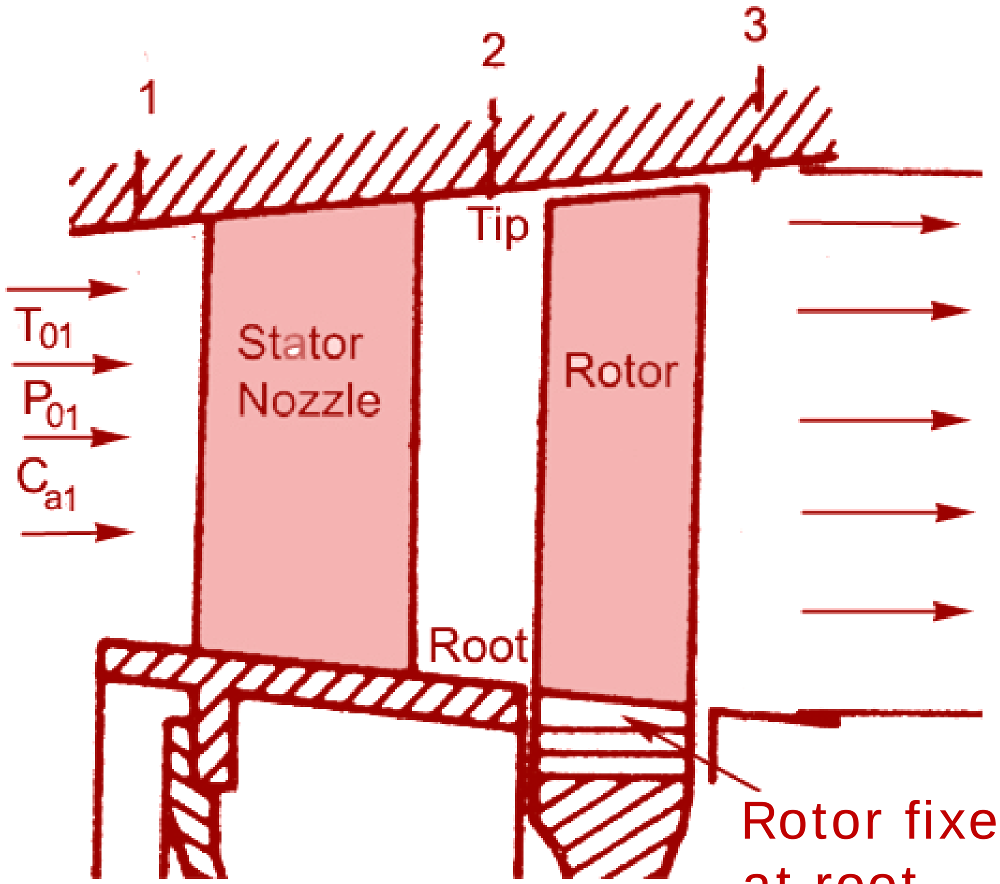
- It was also understood that for a gas turbine engine to go on an aircraft it must be compact in size and must weigh as less as possible.
- This requirement translates to the need for a turbine which produces high energy extraction per unit mass (*energy density*) of gas it is working on.
- The graduation of gas turbine based engines to jet engines (in all its variants) comes from the basic fact that the working fluid, i.e. air enters and exits almost parallel to the axis of the engine.
- Thus the gas, if it contains sufficient residual energy after the turbine, can be exited through a jet nozzle to create direct engine jet thrust.

Aerothermodynamics and basic theories of axial turbine



Rotor fixed at root

- Flow comes from the combustor with high internal energy (T_{01}, P_{01}, C_{a1}), and is made to go through the stator - where a large part of its internal energy is converted to kinetic energy.
- The transfer of energy occurs in rotor as the high kinetic energy flow, impinging on the rotor blade, is also made to take huge flow turning through the passage between the blades.

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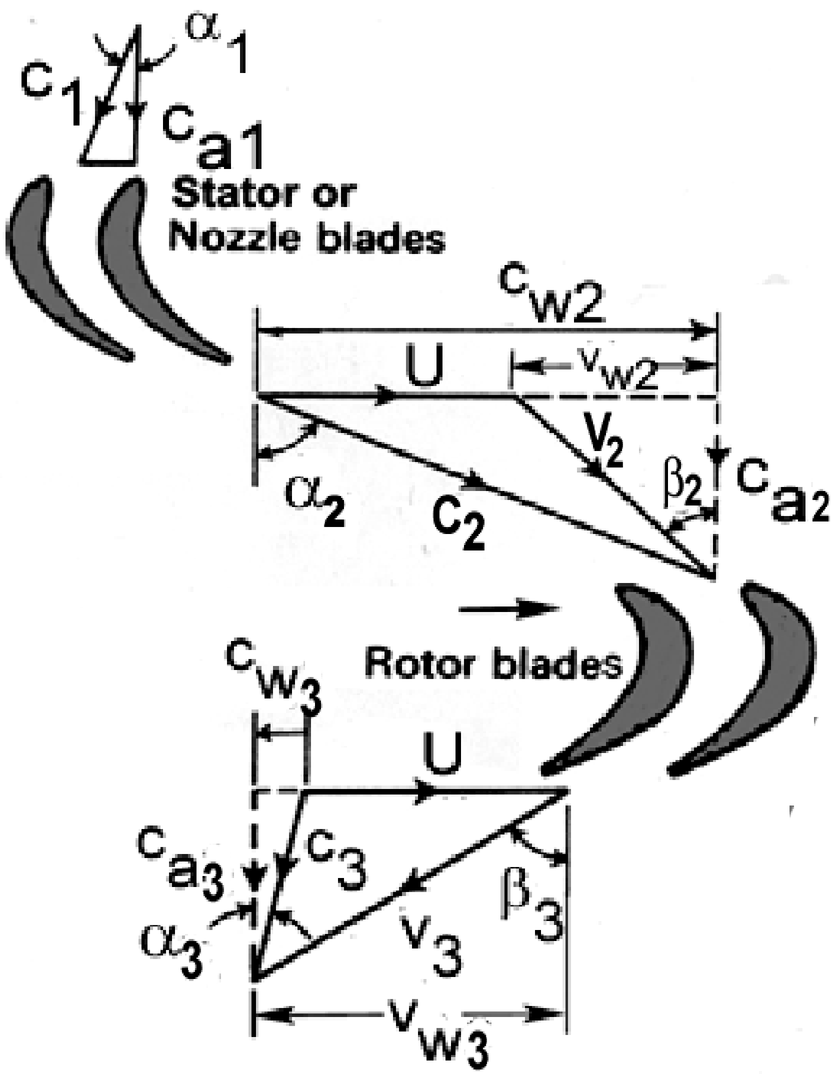

- Turbines use fundamental principles for making blades rotate to create mechanical rotation - are called *impulse turbines*.
- The amount of energy given up by passing gas is decided (i) by the energy level of the incoming gas, and (ii) by amount of turning executed by the gas in the bladed passages.
- The energy transfer occurs as per the Newton's laws of motion so that rate of change of momentum of the gas is in the direction in which the blades rotate

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- Development of gas turbines, especially for aircraft engines, required even more energy to be transferred *per unit mass flow* than is possible with impulse turbines.
- This was achieved by making the flow also accelerate through the rotor blades by making an expanding (and converging) curved nozzle passage, in addition to the large turning.
- Jet effect of the flow exiting from the rotors creates a reaction as per Newton's 3rd law of motion.
- This reaction force, or rather its component along the plane of rotation, adds to the angular momentum created by the impulse effects of the gas.
- These turbines are called *reaction turbines*. The gas turbines in aircraft engines are reaction turbines.

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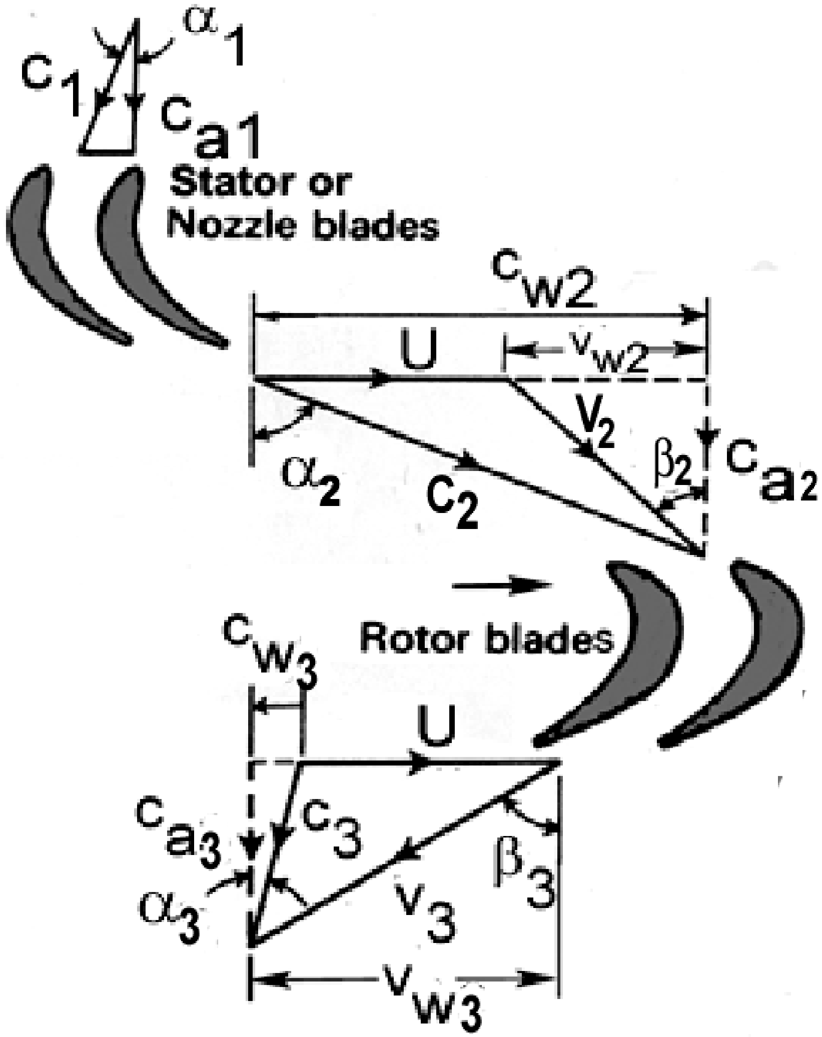
Impulse turbines

High energy flow is first accelerated and made to impinge on the rotor blade with high momentum and then made to take huge turn through the passage between the blades.

Reaction turbines

The flow is accelerated through the rotor blades by making an expanding (converging) curved nozzle passage, in addition to the large turning. Jet effect creates a reaction as per Newton's 3rd law of motion.



- In the *Impulse turbines* described earlier, $\mathbf{V_2 = V_3}$
- In *reaction turbines* $\mathbf{V_3 > V_2}$
- In the aircraft gas turbines the exit Mach number from stator-nozzle $\mathbf{M_2 = 1.0}$
- On the other hand, relative exit Mach number from the rotor $\mathbf{M_{3\text{-}rel} = V_3 / a_3 < 1.0}$
- The work done in a gas turbines may be increased by increasing entry temp T_{01}.

Work done in a gas turbine rotor

$$H_{Th} = U\left(C_{W_2} + C_{W_3}\right)$$

Degree of Reaction through a stage provides the split of acceleration between the rotor and stator

$$D.R = \frac{h_{rotor}}{h_{rotor} + h_{stator}} = \frac{h_{rotor}}{h_T} = \frac{V_3^2 - V_2^2}{2h_T}$$

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Total-to-Total efficiency of gas turbine engine is given as

$$\eta_{0T} = \frac{H_{0T}}{H_{0T}^{/}} = \eta_T \frac{H_T^{/}}{H_{0T}^{/}} = \eta_T \frac{1}{1 - \left(\frac{C_3^2}{C_3^{/2}}\right)\left(\frac{T_3^{/}}{T_3}\right)}$$

The parameters with ()' refer to isentropic process in the turbine

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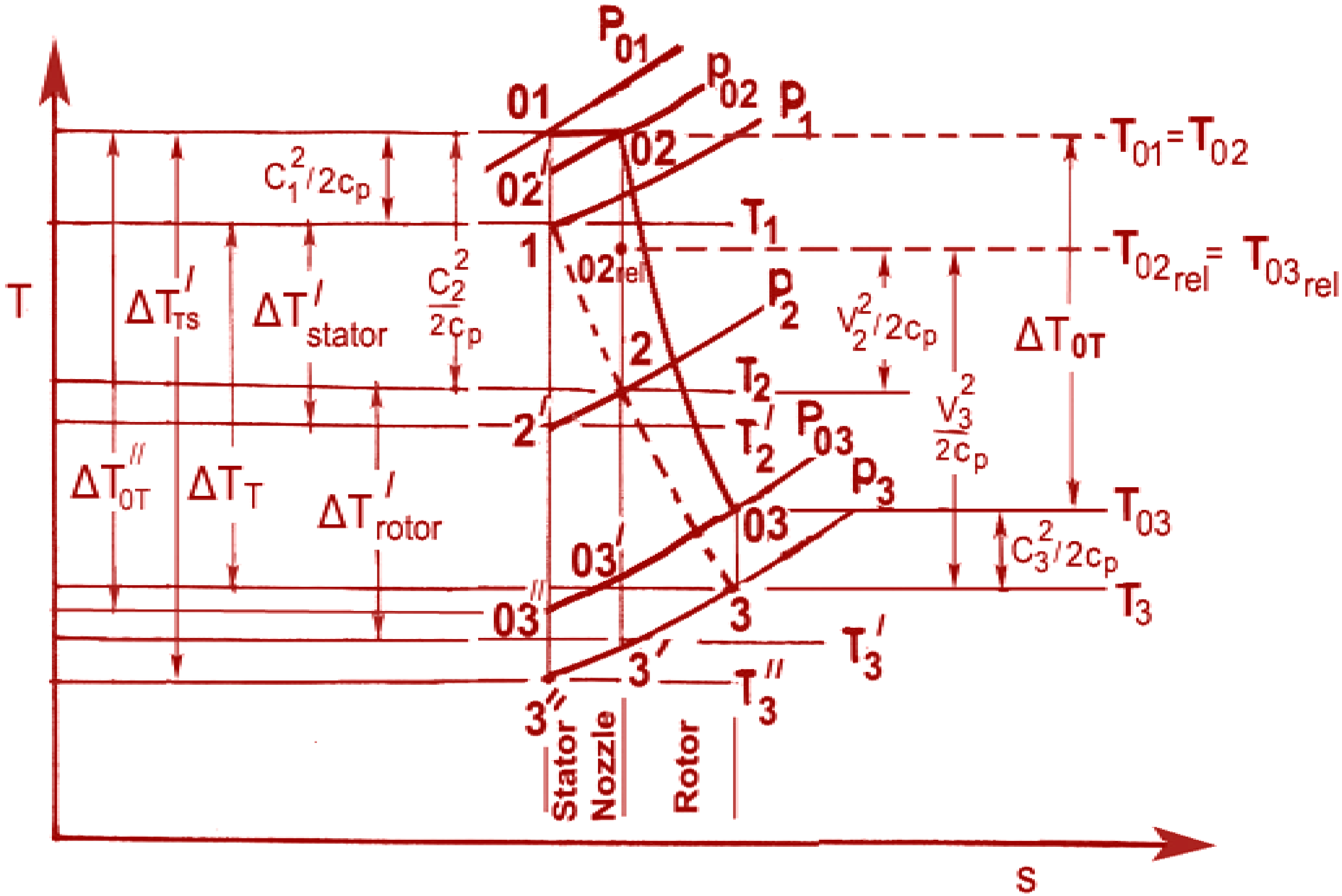

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Total-to-total efficiency,

$$\eta_{0T} = \frac{\Delta T_{0T}}{\Delta T_{0T}^{/}}$$

Static-to-static efficiency,

$$\eta_{T} = \frac{\Delta T_{T}}{\Delta T_{T}^{/}} = \frac{\Delta T_{T}}{\Delta T_{Stator}^{/} + \Delta T_{Rotor}^{/}}$$

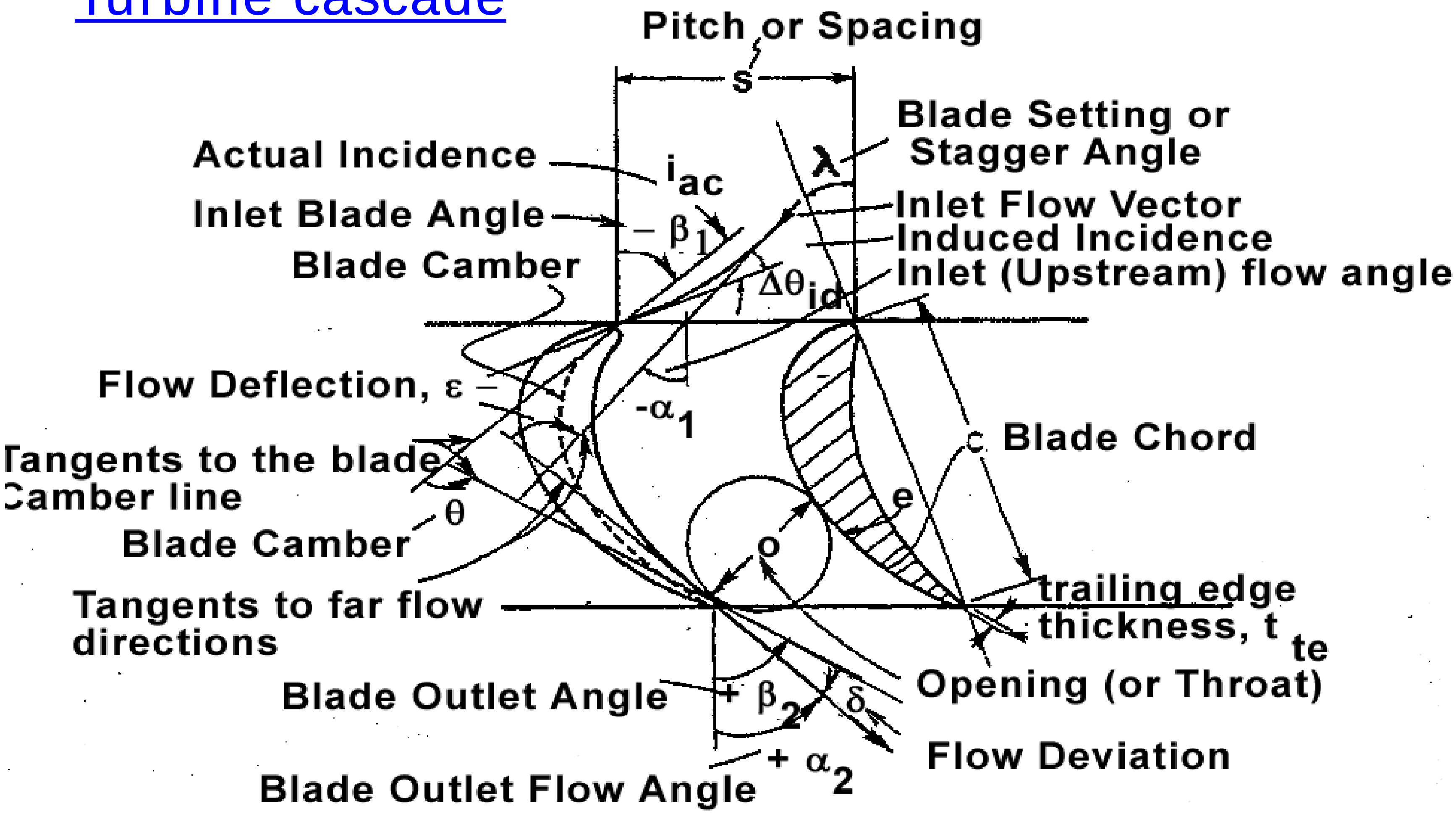
Total-to-static efficiency

$$\eta_{TS} = \frac{\Delta T_{0T}}{\Delta T_{T}^{/}} = \frac{\Delta T_{0T}}{\Delta T_{Stator}^{/} + \Delta T_{Rotor}^{/}}$$

Total-to-total isentropic efficiency of the *rotor only* is,

$$\eta_{0\text{-}Rotor} = \frac{\Delta T_{0\text{-}Rotor}}{\Delta T_{0\text{-}Rotor}^{/}} = \frac{T_{02} - T_{03}}{T_{02} - T_{03}^{/}}$$

Turbine cascade



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Next Class

Multi-staging of turbine

Turbine Cooling

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