Jet Aircraft Propulsion

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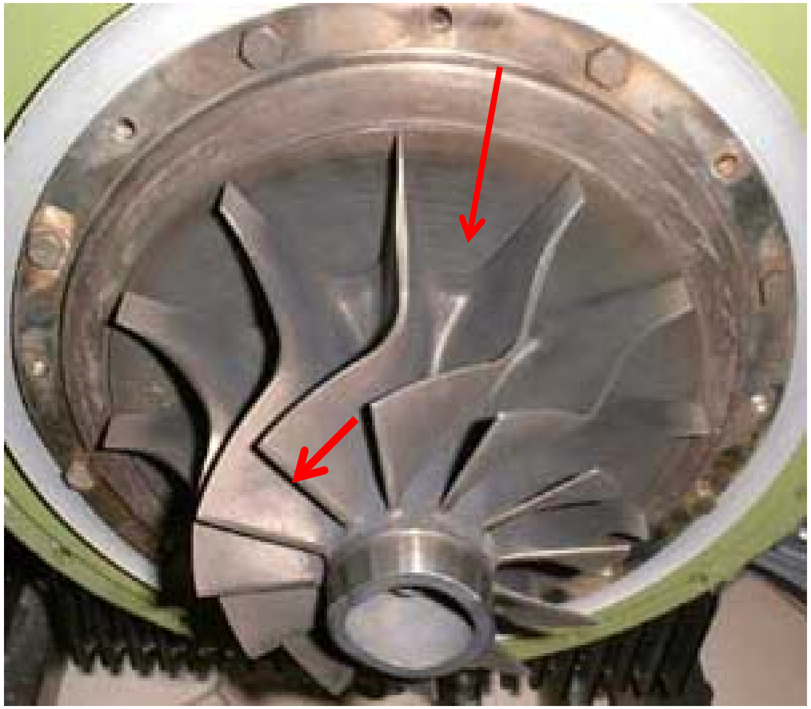
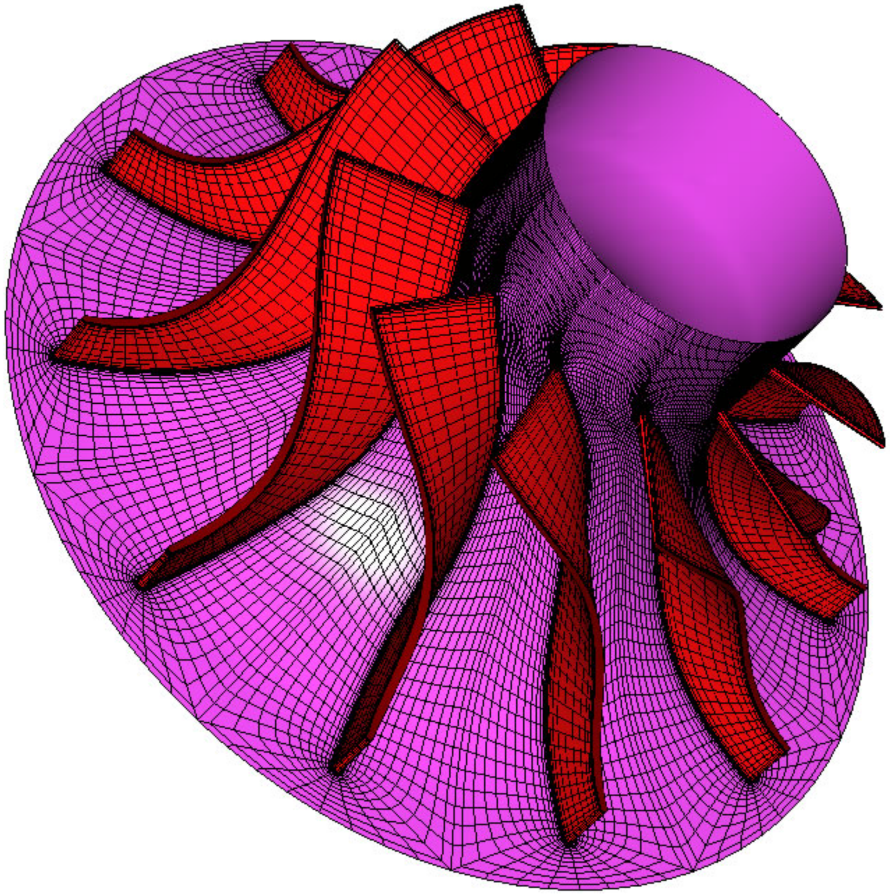
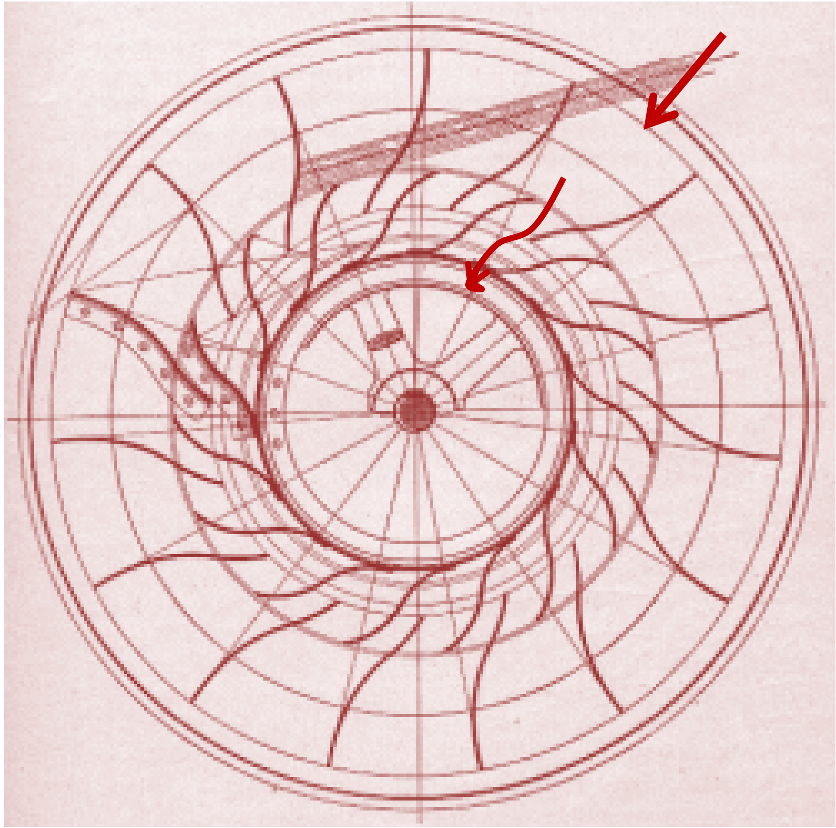
Lecture 22

Radial Flow Turbines

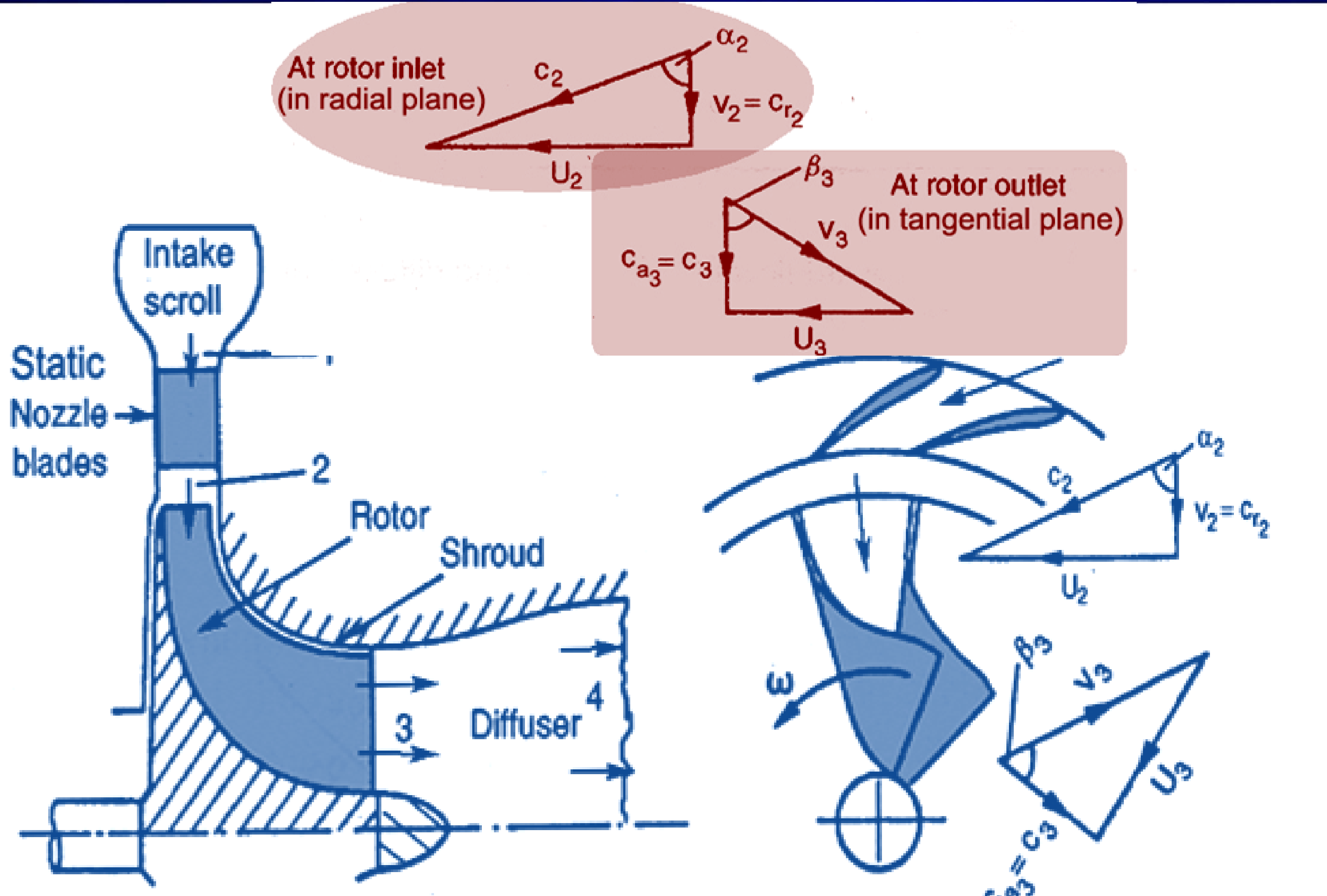


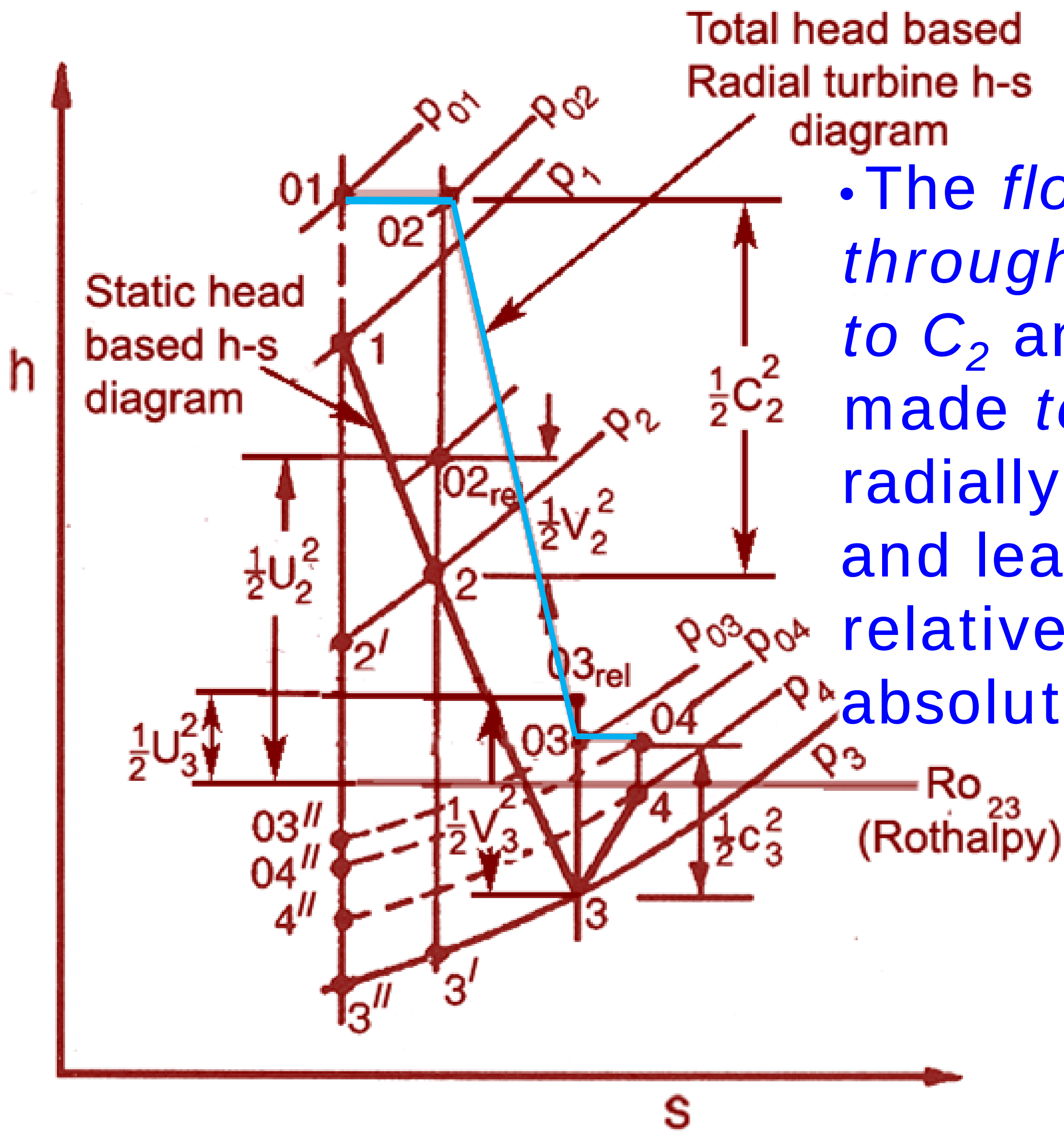
- Radial inflow turbines, which look similar to centrifugal compressor, are considered suitable for application in small aircraft engines.
- In many applications a radial turbine is used as an ideal companion to a centrifugal compressor.
- Because of its shape, it is generally not feasible to employ cooling technology





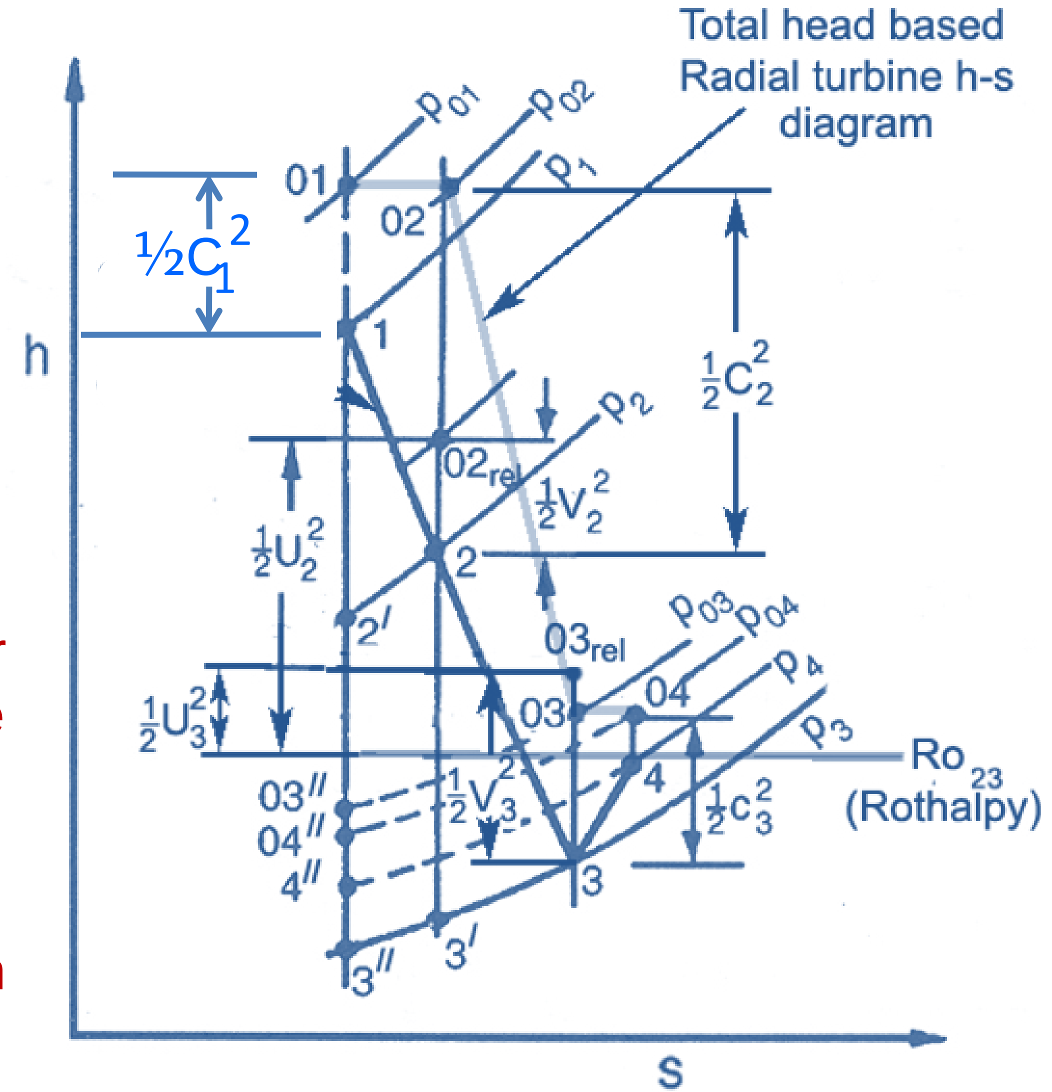
• Such turbines are sturdy by shape / construction, show good performance and show higher efficiency with advanced fabrication technology.


At rotor inlet
(in radial plane)
c_2
α_2
$V_2 = c_{r_2}$
U_2
β_3
At rotor outlet
(in tangential plane)
V_3
$c_{a_3} = c_3$
U_3
Intake scroll
Static Nozzle blades
2
Rotor
Shroud
3
Diffuser
4
ω
α_2
c_2
$V_2 = c_{r_2}$
U_2
β_3
V_3
U_3
$c_{a_3} = c_3$



- The *flow is* <u>*accelerated*</u> *through the stator from C_1 to C_2* and normally is made *to* enter the rotor radially with velocity V_2 and leaves the rotor with relative velocity V_3 and absolute velocity C_3 axially

- The tip of the rotor the vanes are usually radial and straight. Immediately thereafter the vanes are given 3-D curvature to guide the flow, in an accelerated manner, to a lower radial station and finally let it out at an angle β_3 with velocity V_3.
- The rotational speed of rotor imparted by the gas has gone down from U_2 to U_3. The flow now assumes an absolute velocity C_3 (which by design is made axial i.e. C_{a3}) and in many turbines is then axially diffused to a lower exit velocity C_4.



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At the beginning the hot gas flow is accelerated from C_1 to C_2 through the outer ring-nozzle blade passages. No work is intended to be done during this fluid flow.

Thus, *total enthalpy* across the ring-nozzle remains constant,

$$h_{01} = h_{02}$$

However, *static enthalpy change* is shown as ,

$$h_1 - h_2 = \frac{1}{2}\left(C_2^2 - C_1^2\right)$$

In an *ideal flow* with no losses, $P_{01} = P_{02}$. In an ideal flow static point in the diagram would fall to 2', which would have resulted in a flow velocity of $C'_2 > C_2$. Due to the losses suffered by the flow the nozzle exit velocity is less than the ideal.

At rotor entry, a *relative total enthalpy* is defined,

$$h_{02-rel} = h_2 + \frac{1}{2}V_2^2 \neq h_{02}$$

Where, *total enthalpy at rotor entry* is

$$h_{02} = h_2 + C_2^2$$

The gas flow is guided to move from radial entry to axial exit. Thus using the theory of rate of change of tangential momentum, specific work done by the gas (per unit mass) may be given as :

$$\frac{W}{\dot{m}} = H_{023} = U_2.C_{w2} - U_3.C_{w3}$$

Where, C_{w2} & C_{w3} are the tangential components of absolute velocities C_2 & C_3.

In the most usual *normal design* case shown in slide 5, $C_{w2}=U_2$ and $C_{w3}=0$. Thus, $H_{023} = U_2^2$ is the max work.

Energy transfer in the rotor can be written as the enthalpy change between the entry and exit of the rotor, as $H_{023} = h_{02} - h_{03}$.

$$H_{023} = h_{02} - h_{03} = h_2 - h_3 + \frac{1}{2}\left(C_2^2 - C_3^2\right)$$

Assuming that the flow in the rotor is adiabatic and there has been no heat / energy exchange with any external body

$$H_{023} = \frac{1}{2}\left[\left(U_2^2 - U_3^2\right) - \left(V_2^2 - V_3^3\right) + \left(C_2^2 - C_3^3\right)\right]$$

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$$H_{023} = \frac{1}{2}\left[\left(U_2^2 - U_3^2\right) - \left(V_2^2 - V_3^3\right) + \left(C_2^2 - C_3^3\right)\right]$$

- Depending on the size and rotor rpm, the deference between U_2 and U_3 could be large and the first term could be a major contributor to the work transfer.
- In most cases V_2 and V_3 are either same or there could be flow acceleration in the relative frame of reference, $V_3 > V_2$. Thus, the second term could be either zero or could be a positive contributor to the work transfer.
- The third term, kinetic energy differential between entry and exit of turbine, is always a small contributor to the work done.

- In case of axial machines it has been found that relative total enthalpy terms across the rotor may be considered to remain constant.
- However, in case of radial flow machines because of significant change in radius between the entry and exit the relative total parameters need to be modified. The concept of *Rothalpy* is introduced as the modified parameter.

Across the rotor, $\mathbf{Ro_{023}}$ = $h_2 + \frac{V_2{}^2}{2} - \frac{U_2^2}{2} = h_3 + \frac{V_3^2}{2} - \frac{U_3^2}{2}$

Across the Rotor static enthalpy drop,

$$h_2 - h_3 = \left(\frac{V_3^{\,2}}{2} - \frac{V_2^2}{2}\right) + \left(\frac{U_2^2}{2} - \frac{U_3^2}{2}\right) = \frac{1}{2}\left[\left(U_2^2 - U_3^2\right) + \left(V_3^{\,2} - V_2^2\right)\right]$$

Across the *exit duct*, (a diffuser) again since no work is transacted,

$$h_{03} = h_{04}$$

The static enthalpy change at the exhaust duct

$$h_4 - h_3 = \frac{1}{2}\left(C_3^2 - C_4^2\right)$$

Losses and efficiency

Nozzle enthalpy loss coefficient is defined

$$\xi_N = \frac{(h_2 - h_2^{/})}{\frac{1}{2} C_2^2}$$

Nozzle exit velocity coefficient is defined $\phi_N = \frac{C_2}{C_2^{/}}$

using conservation of energy, $h_2 - h_2^{/} = \frac{1}{2}(C_2^{/2} - C_2^2)$

Nozzle loss coefficient : $\xi_N = \frac{1}{\phi_N^2} - 1$

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Rotor exit velocity coefficient $$\phi_R = \frac{V_3}{V_3^{/}}$$

Rotor loss coefficient : $$\xi_R = \frac{1}{\phi_R^2} - 1$$

For most normal designs, $\phi_N \approx 0.97$ for subsonic,
≈ 0.95 for sonic,
and ≈ 0.90 for supersonic

And for Rotors $\phi_R \approx 0.85$

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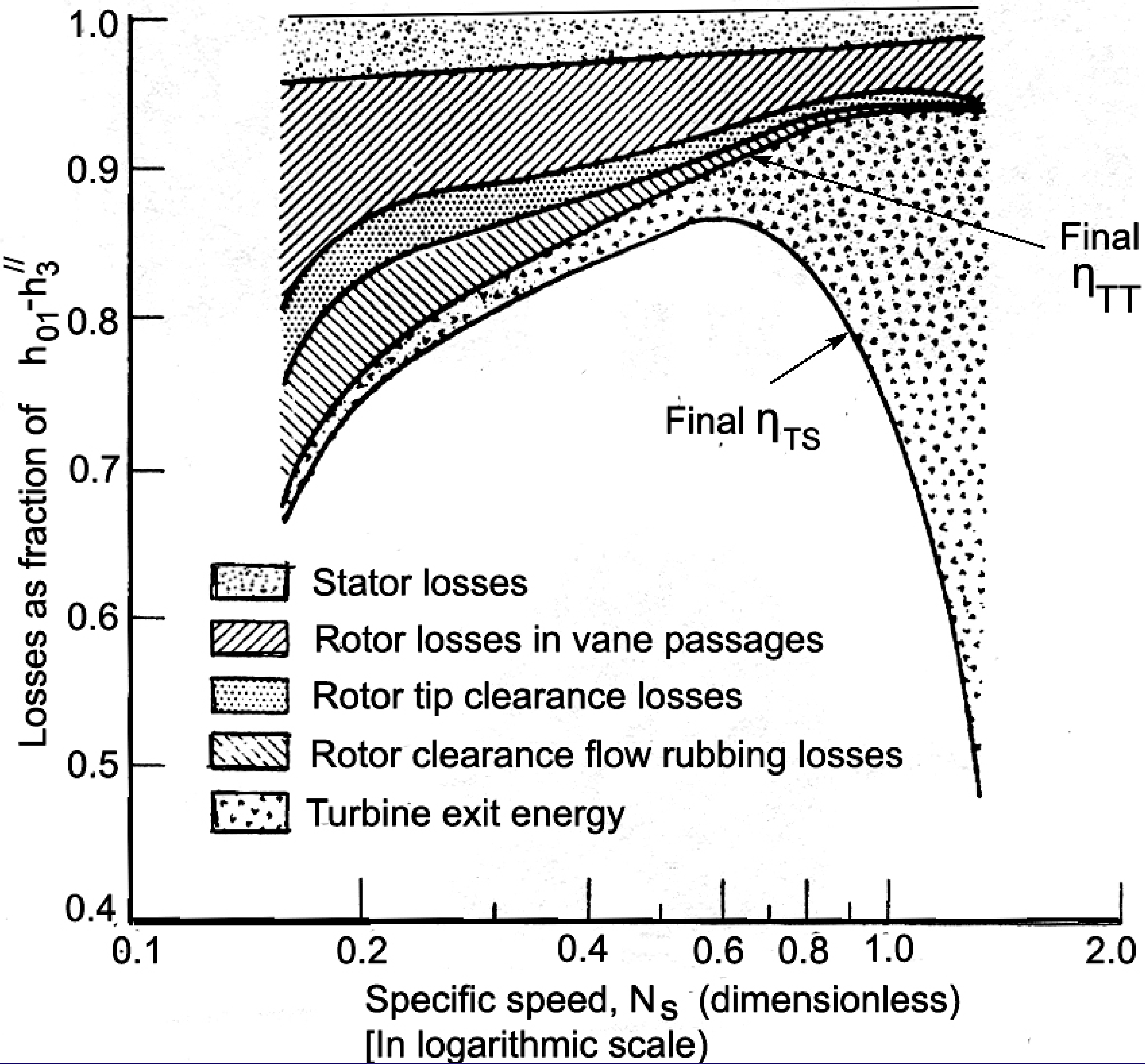


Losses in Radial Turbines

Sp. Speed

$$N_s = \frac{N.Q_3^{\frac{1}{2}}}{\Delta H_{013^{//}}^{//}}$$

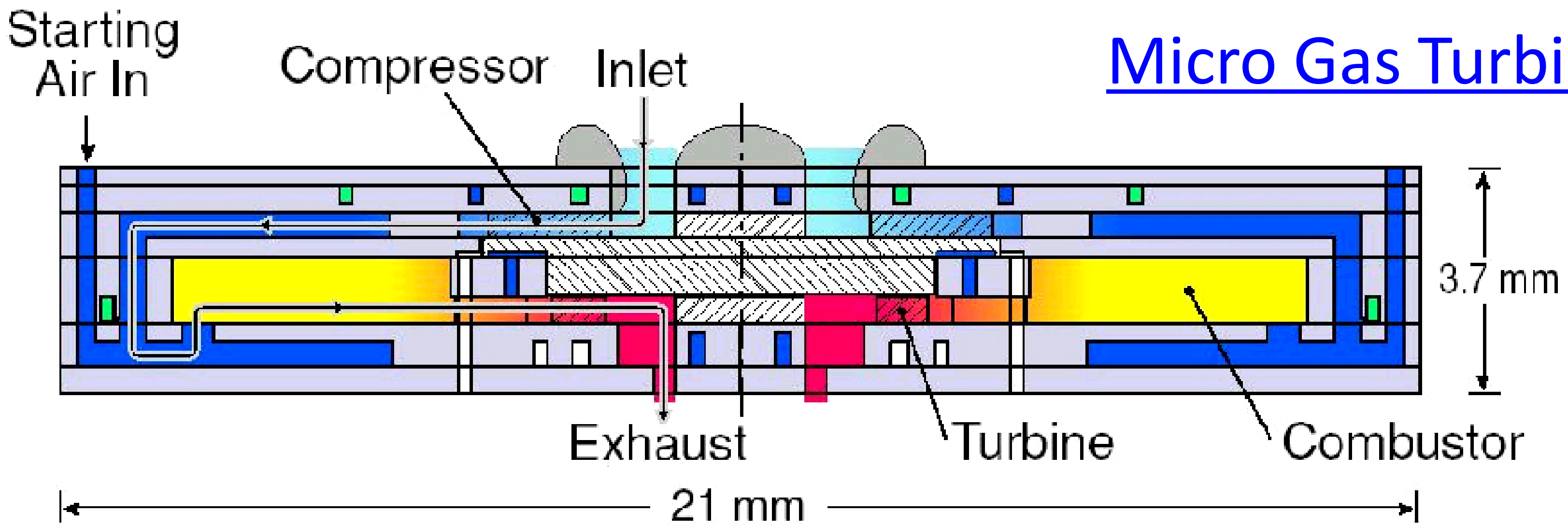
The efficiency of a radial turbine may be defined in two slightly different ways

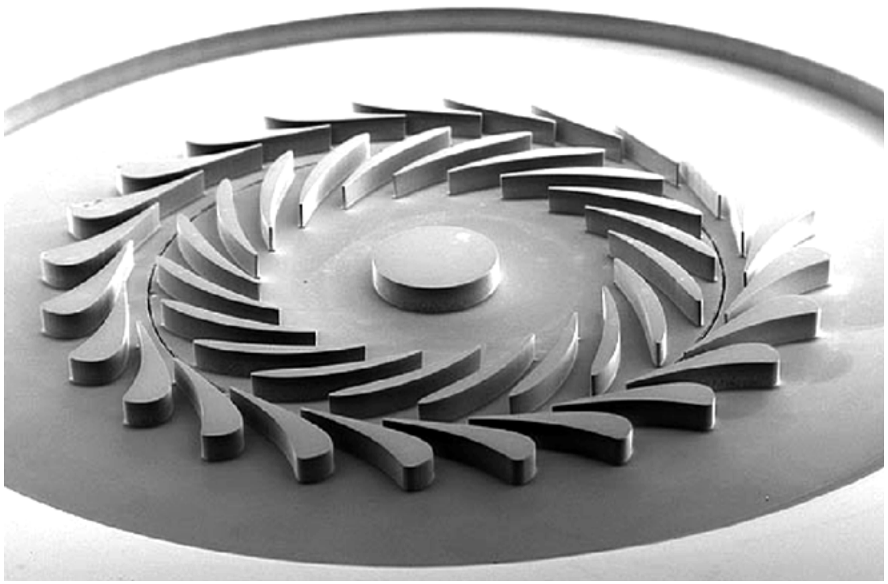
Total-to-Total efficiency : $$\eta_{TT} = \frac{h_{01} - h_{03}}{h_{01} - h_{03}^{//}}$$

Total-to-Static efficiency: $$\eta_{TS} = \frac{h_{01} - h_{03}}{h_{01} - h_{3}^{//}}$$

- In case the turbine exit energy is utilized either for propulsive purpose, the first definition $\boldsymbol{\eta_{TT}}$ is an for efficiency of the turbine.
- If however, the turbine is the last component, any energy content in the turbine exhaust would be a dead loss, and the second efficiency, $\boldsymbol{\eta_{TS}}$ would apply.

Micro Gas Turbine





- Radial turbine has become a serious contender for small, mini and micro gas turbine engines for micro air vehicles.

Next Class

Turbine Problems and Tutorials