University of Diyala
College of Engineering
Mechanical Engineering Dep
Class: Third Class

Lecture-3

Turbomachinery

Energy Transfer in Terms of lift & Drag coefficients

By
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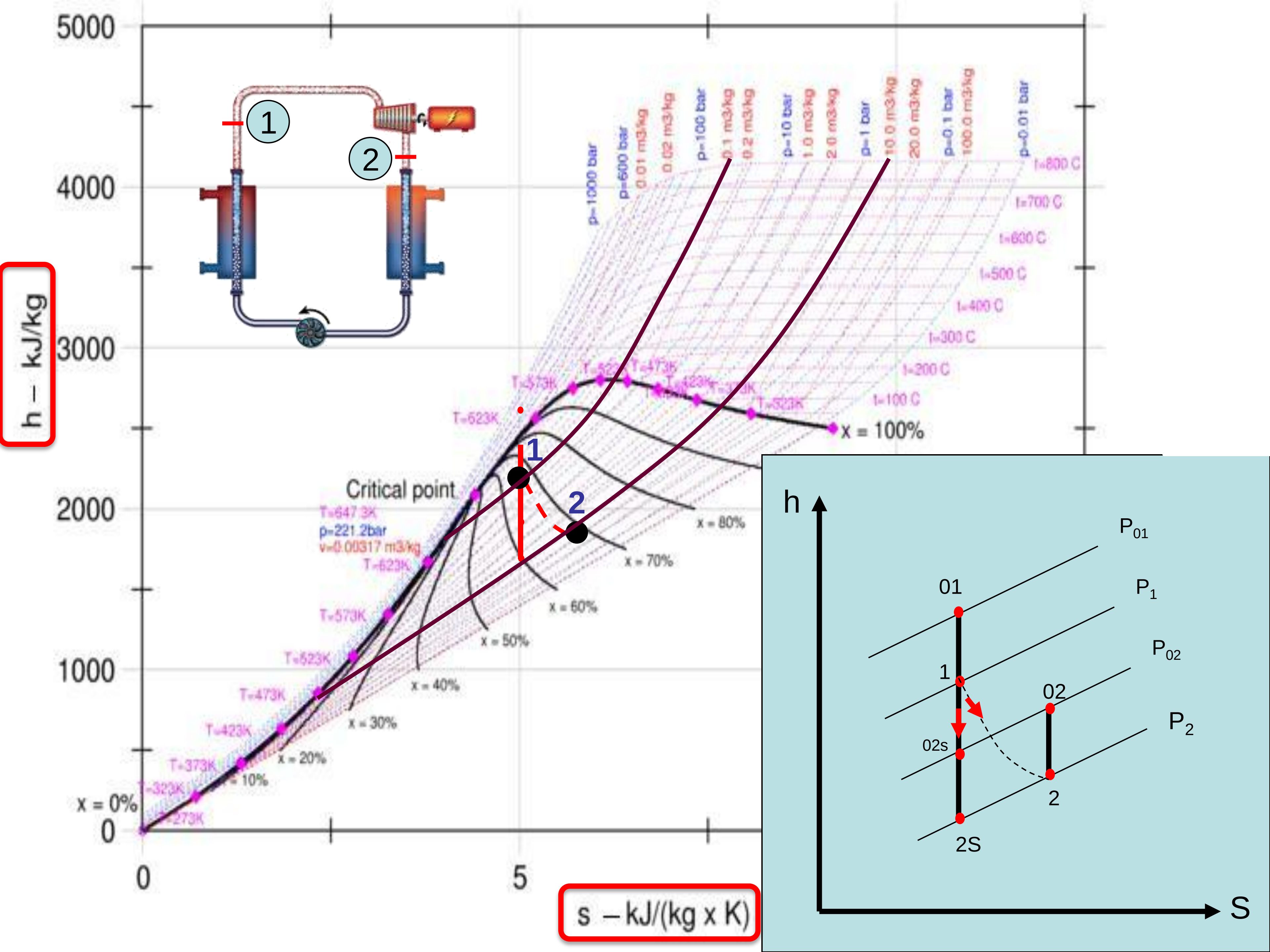
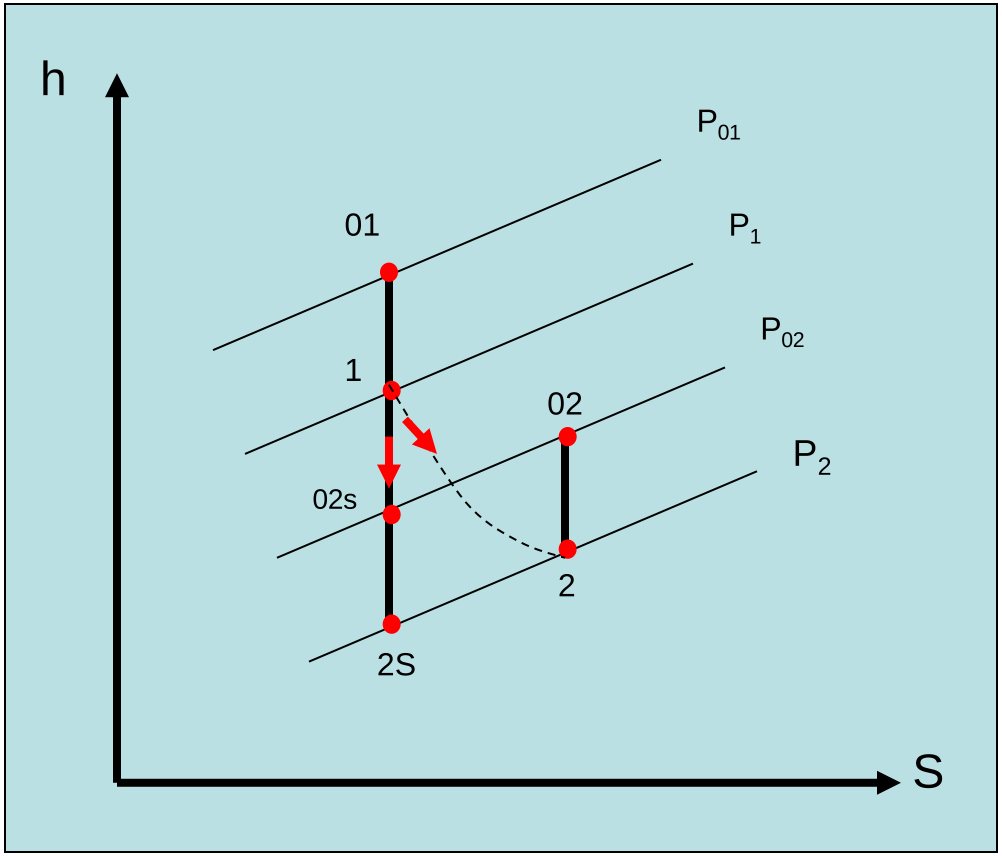


5000
4000
3000
2000
1000
0
h – kJ/kg
0
5
s – kJ/(kg x K)
1
2
Critical point
T=647.3K
p=221.2bar
v=0.00317 m3/kg
x = 0%
x = 10%
x = 20%
x = 30%
x = 40%
x = 50%
x = 60%
x = 70%
x = 80%
x = 100%
p=1000 bar
p=600 bar
p=100 bar
p=10 bar
p=1 bar
p=0.1 bar
p=0.01 bar
t=800 C
t=700 C
t=600 C
t=500 C
t=400 C
t=300 C
t=200 C
t=100 C
h
S
P01
P1
P02
P2
01
1
02s
02
2
2S

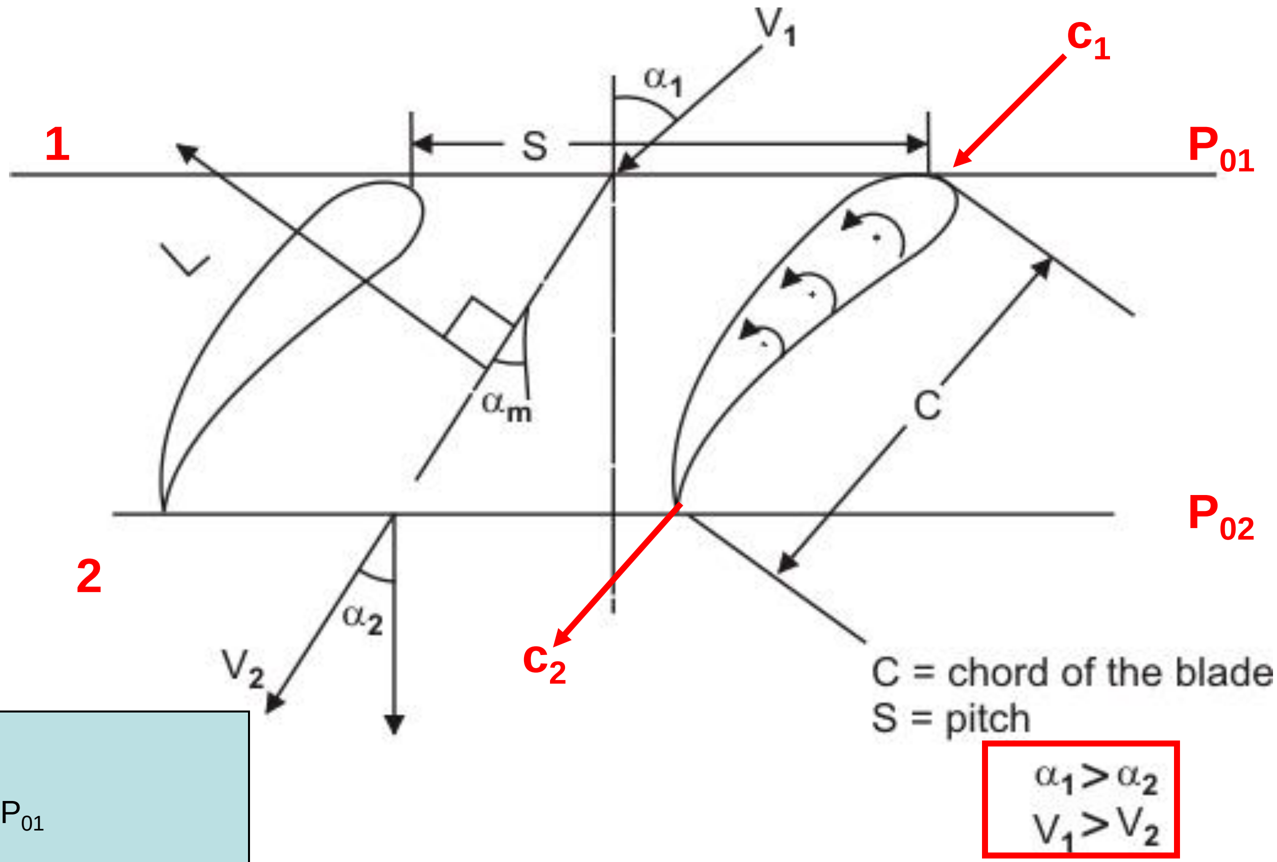
the static condition of the fluid at inlet is determined by state 1 with state (01 as the corresponding stagnation state) . the final static properties are determined by the state 2 with (02 as the corresponding stagnation state) .If the process were reversible , the fluid static state would be 2s and the stagnation state be 02s .

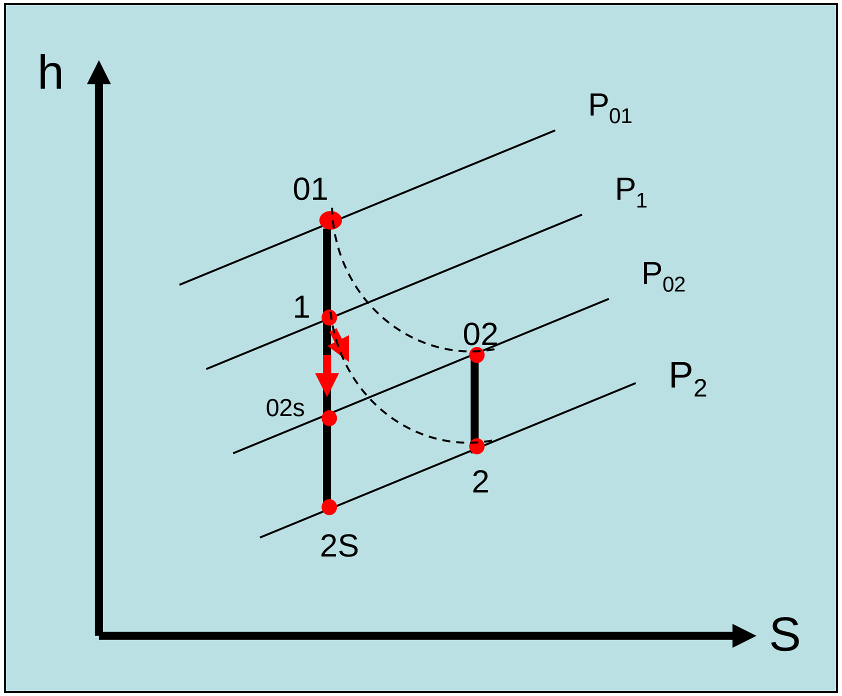


Process 1-2 : is the actual expansion process .
Process 1-2s : is the isentropic or ideal expansion process.

The figure shows two blades of a cascade having chord C, and Pitch S. At sections 1 and 2.

The total pressures are P_{01} and P_{02} respectively with corresponding velocities of C_1 and C_2





The static pressure change across the cascade is given by :-

$$(P1- P2)=\Delta P=\frac{\rho\,(c^2{}_1 - c^2{}_2)}{2\text{-}(P_{01} - P_{02})\ m}$$

$$(P1-P2)=\Delta P=\frac{\rho\,(c^2_1 - c^2_2)}{2-(P_{01} - P_{02})\,m}$$

Where the difference $(P_{01} - P_{02})$ is obtained from cascade test , it should be noted that $P_{01} > P_{02}$, Because no work is in the cascade and the flow is proceeded irreversible.

$(P_{01} - P_{02})m = P_0\,m$

$$(P1-P2)=\Delta P=\frac{\rho\,(c^2_1 - c^2_2)}{2-P_o\,m}$$

Pressure loss coefficient $= (P_{o\ m}) / (0.5\,\rho\,C^2_1)$

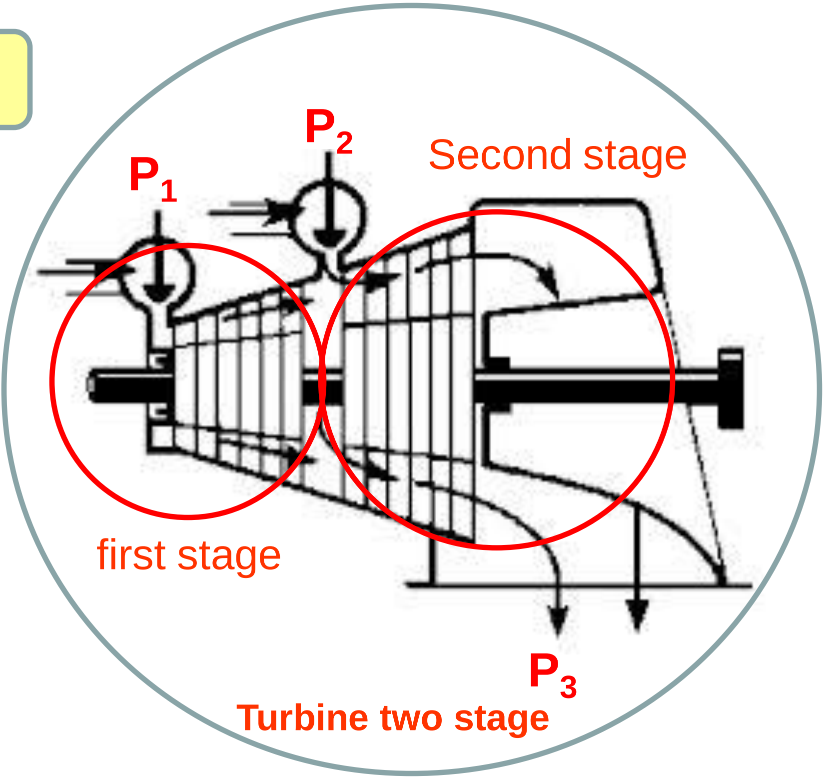
$P_{o\ m} =$ stagnation pressure loss = mmHG

$P_{o\ m} = N/m^2$.

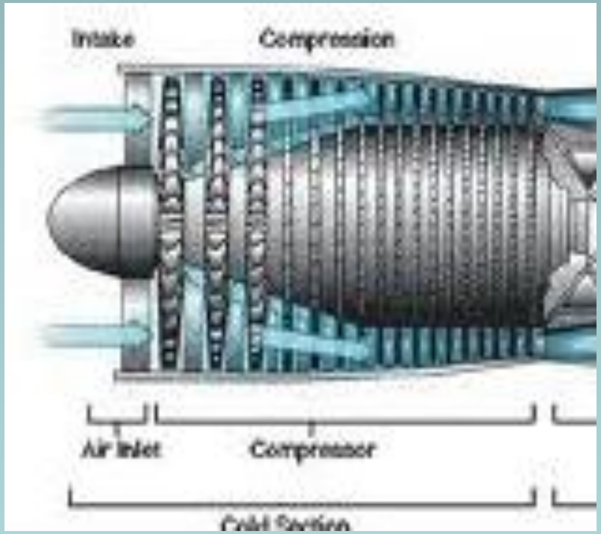
To convert from mmHG to N/m^2

$10^3 * 9.81 * (P_{o\ m} / 10^3)$

$= 9.81 * P_{o\ m}$



COMPRESSOR



Going back to the main law to force of (Lift and drag)

$$C_D = \frac{D}{(0.5\ \rho W^2_m A)}$$

- $D = S * P_o m * \cos \alpha_m$
- S= Pitch
- $\alpha_m = \tan^{-1} [(\tan \alpha_1 + \tan \alpha_2)] / 2)$
- $P_o m = = (P_{01} - P_{02})m$, m=Kg/s
- m=0.23(2a/c) +0.1(α2/50)

C_D = Drag coefficient = $2(s/c) * (P_{om} / \rho C^2_m) * (\cos \alpha_m)$

compressor

$C_m = C_a / \cos \alpha_m$

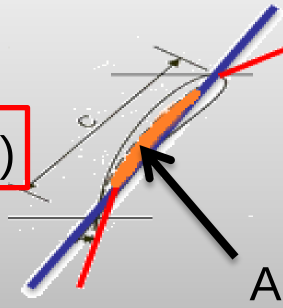
$C_a = c_1 * \cos \alpha_1$

Inlet Absolute velocities m/s

D= Drag force = $C_D * \rho * (c/2) * A$

A = (Chord length * span of moves @ velocity)

C (meter) (meter)



Q: How can we calculate:

The power required to drive the aerofoil = ?

Power required = D *C

- $D = S * P_{om} * \cos \alpha_m$

$$C_D = \frac{D}{(0.5\ \rho W^2 m A)}$$

$$D = C_D * \rho * (c^2 / 2) * A$$

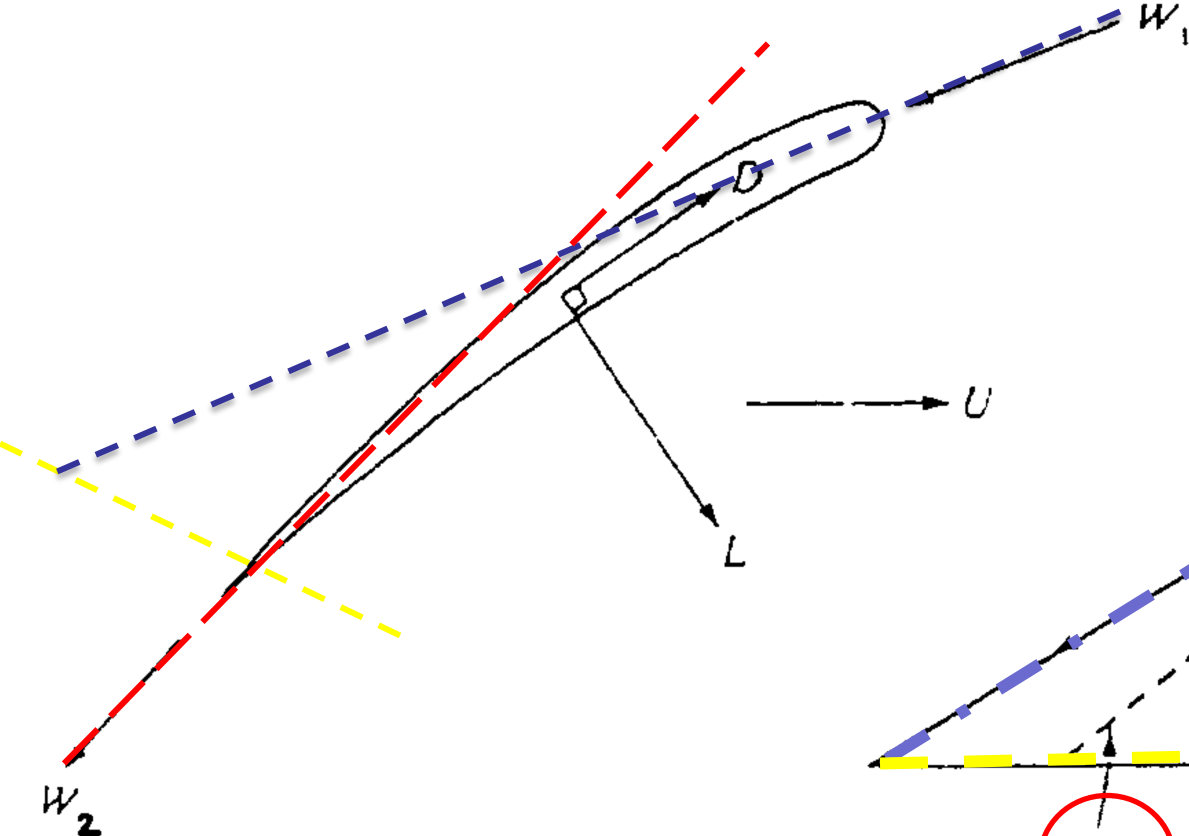
$$c^2 = W^2_m = W^2_\alpha \text{ m/s}$$

$$W^2_m = (C_a / \cos \beta m)$$

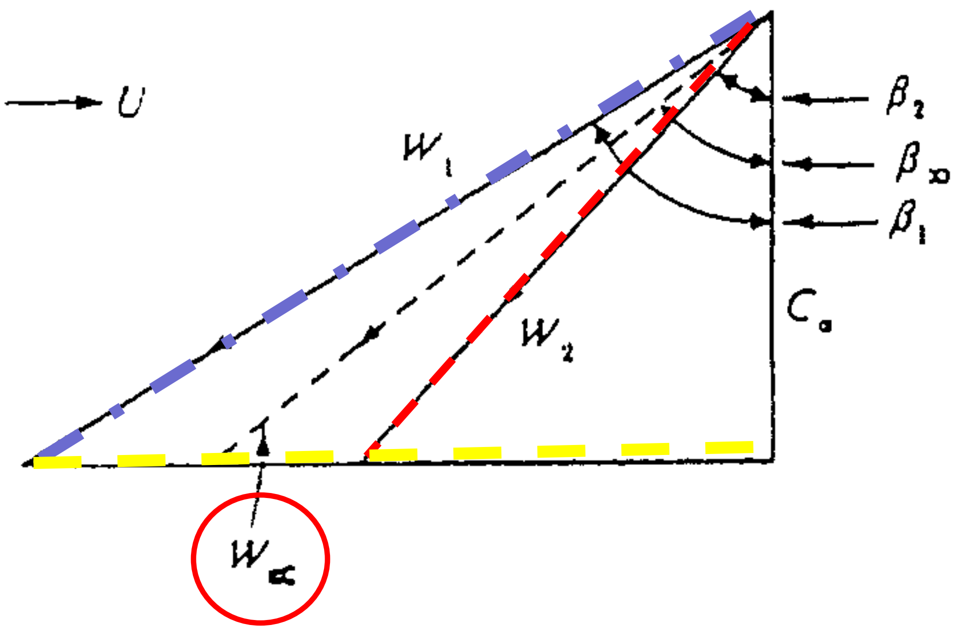
$$C_a = c_1 * \cos \alpha_1$$

c1 = Inlet or entry velocities m/s

- **c = velocity m/s of fluied**



Velocity triangle of rotor blade

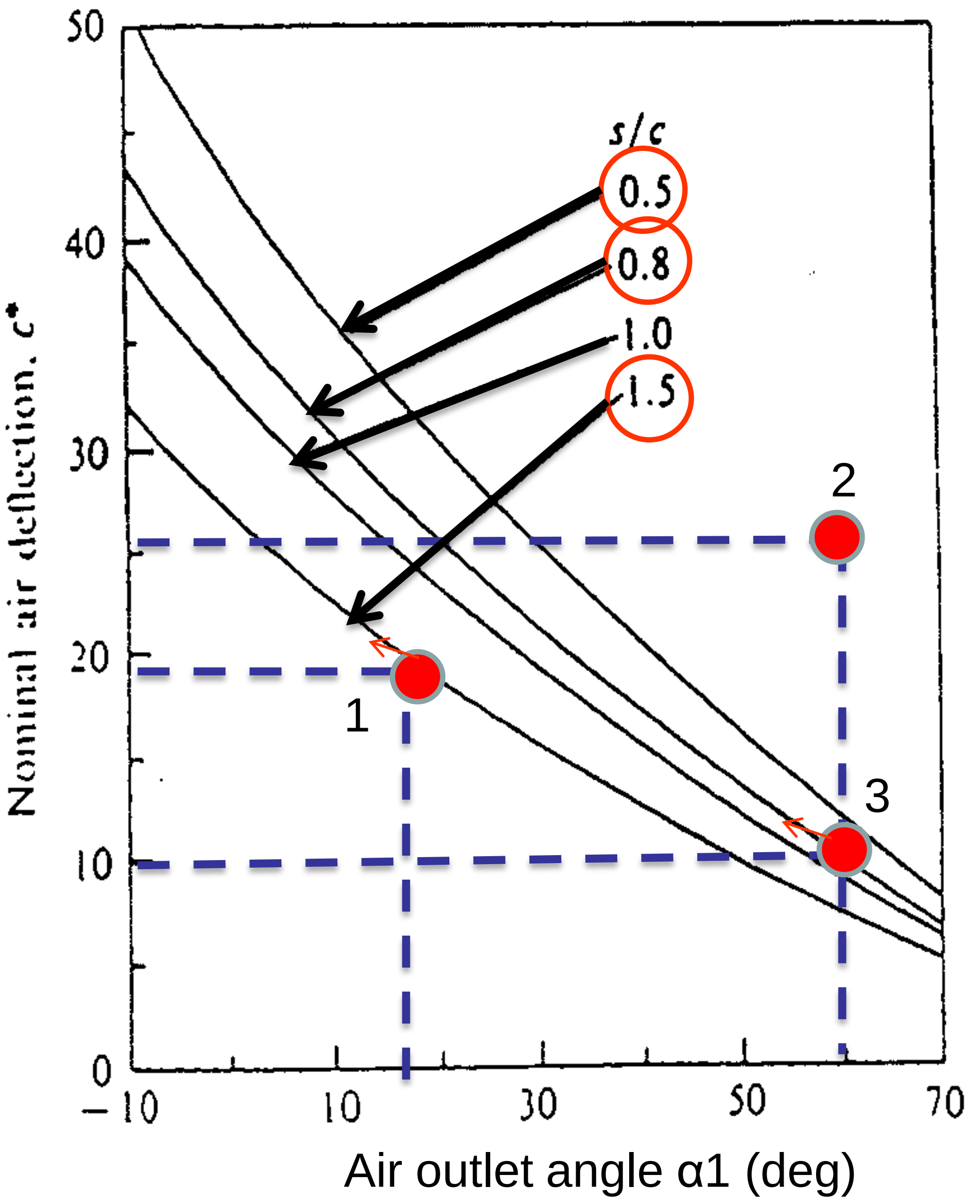


Consider a rotor blade shown in the figure with :

W1,W2 = relative velocity vectors at inlet & outlet , Wα = resultant velocity

β_1= relative inlet air angle , β_2= relative outlet air angle , βα = mean flow angle =45°

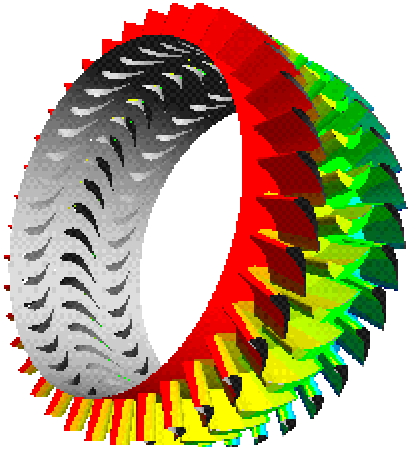
Ratio (s/c) can be calculated through the following chart (which gives in question)



in Figure can be find the value of (s/c)
s/c @ Point 1 = 1.5
@ Point 2 = 0.5
@ Point 3 = 0.8

C_D = Drag coefficient = $2(s/c) * (P_{om} / \rho C^2_1) * (\cos^3 \alpha_m / \cos^2 \alpha_1)$

compressor cascade

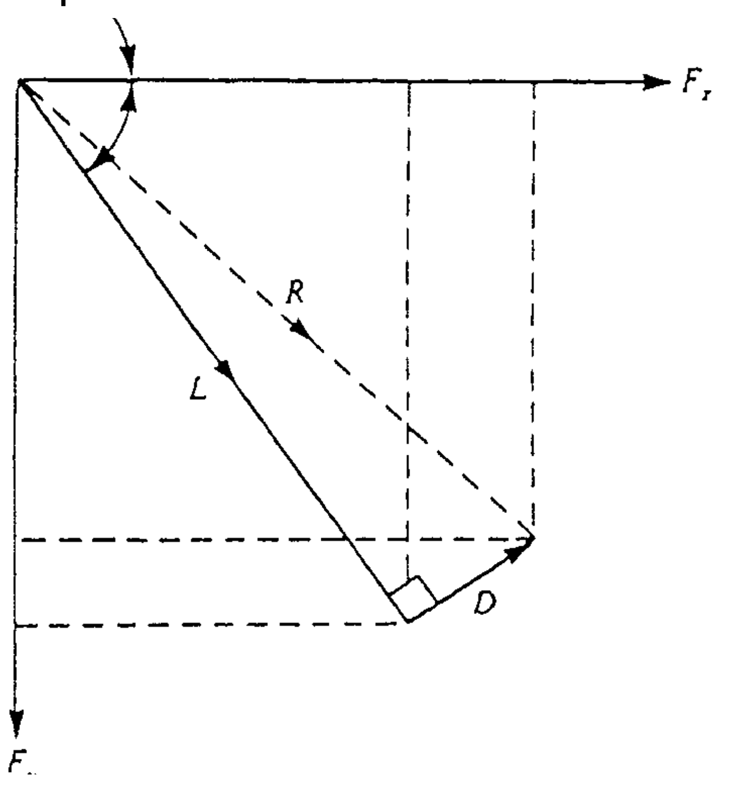


C_L = Lift coefficient = $2(s/c) * (\cos \alpha_m) * (\tan \alpha_1 - \tan \alpha_2) - C_D \tan \alpha_m$

compressor cascade

Q: How can we calculate:

weight carried by the aerofoil should be equal to the lift force =weight which the wing carries



Resolving blade forces into the direction of rotation

C_L **= Lift coefficient** $= L / 0.5\ \rho W_\alpha^2\ A$

$$W_\alpha = C_a / \cos\beta_\alpha$$

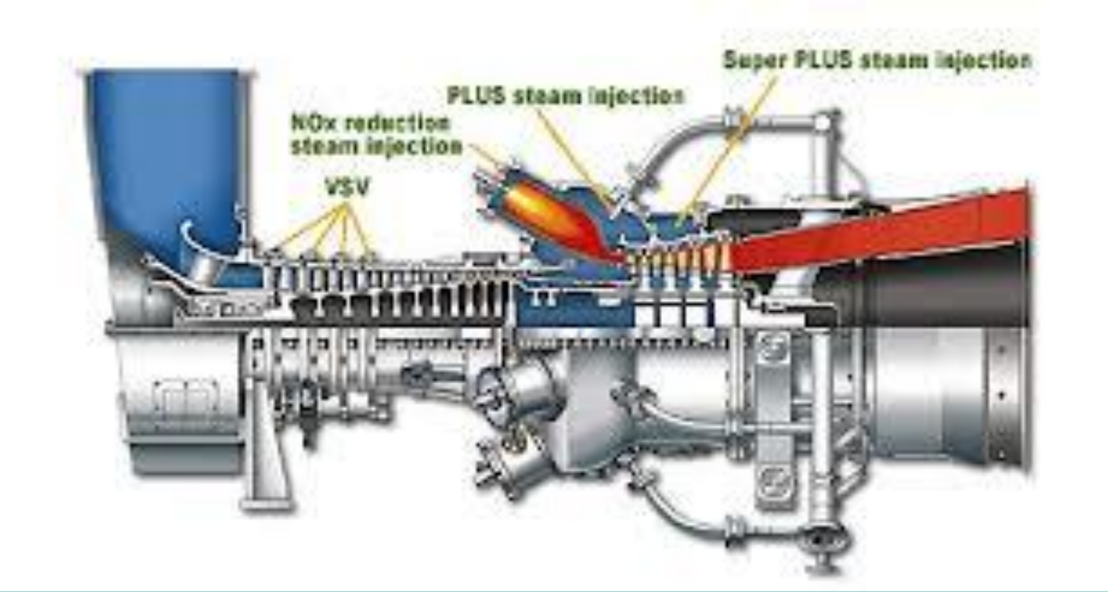
βα = mean flow angle =0°
Cos 0 = 1

$$W_\alpha = C_a$$

weight which the wing carries

$$L = C_L * \rho * (c^2/2) * A$$

TURBINE



Super PLUS steam injection
PLUS steam injection
NOx reduction
steam injection
VSV

cascade

C_L = Lift coefficient = $2(s/c) * (\cos \alpha_m) * (\tan \alpha_1 + \tan \alpha_2) + C_D \tan \alpha_m$

C_D = Drag coefficient = $2(s/c) * (P_{o\,m} / \rho C^2_1) * (\cos^3 \alpha_m / \cos^2 \alpha_2)$

$$\alpha_m = \tan^{-1} [(\tan \alpha_1 - \tan \alpha_2)] / 2)$$

C1= inlet or enters velocity @Cascade tunnel = m/s

The total drage cofficient is given by

$$C_{DT} = C_D + C_{DA} + C_{DS}$$

- **C_{DA} = Annulus drag coefficients**
  $C_{DA} = 0.002*(s/l)$

L=span of moves @ velocity = blade height

- **C_{Ds} = Secondary drag coefficients**
  $C_{Ds} = 0.018*C_L^2$

C_L = Lift coefficient