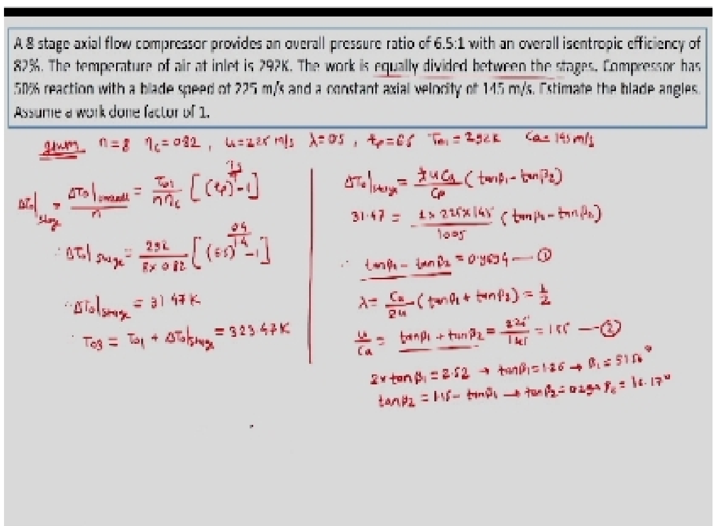
Aircraft Propulsion

Prof. Vinayak N. Kulkarni

Department of Mechanical Engineering
Indian Institute of Technology-Guwahati

Lecture-33
Examples of Axial Flow Compressor

Let us proceed with these some more examples practice.(refer time: 00:30)



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(refer time: 00:00) Let us proceed with these some more examples practice.(refer time: 00:30) We are seeing some examples here, first example states that 8 stage axial flow compressor provides an overall pressure ratio of 6.5:1 with an overall isentropic efficiency of 82%, a temperature drop of air at inlet temperature of air at inlet is 292 K, the work is equally divided between all the stages compressor has 50% reaction with a blade speed up to 25 m/s and constant axial velocity of 145 m/s.

Estimate the blade angles assume a work done factor to be 1. In this example, given things for us are number of stages 8 compressor's isentropic efficiency is 82% then, we are told that u = 225 m/s, λ = 0.5, pressure ratio is 6.5 and temperature T_{01} 292 K, we have u we have axial velocity 145 m/s ok, having said that we will proceed. So, we know Δ $T_0|_{overall}$ = $\frac{T_{01}}{\eta_c}\left((r_p)^{\frac{\gamma-1}{\gamma}}-1\right)$. This example we are solving for air.

So, γ will be taken as air, unless otherwise said. Further we are working for compressor. So, we should take γ as 1.4, the same γ will change to 1.33 in case of turbine, since we will have reacted products as gases flowing through the turbine. This is overall temperature ratio, temperature change, but this overall temperature change for that it is said that work is equally divided between the stages. So, temperature changes equally divided between the stages and this gives us $\Delta T_0|_s$.

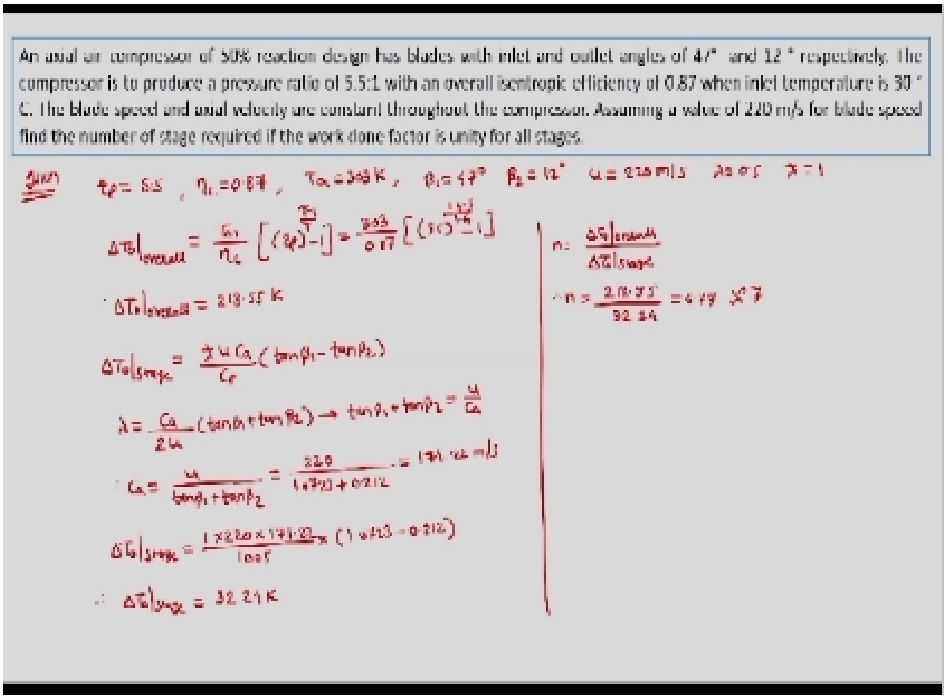
So, $\Delta T_0|_s$, Δ $T_0|_{overall}$/n. So we can find out Δ $T_0|_s$ and it is equal to 292 divided by 8 stages, compressor efficiency point 0.82, pressure ratio is $(6.5)^{\frac{0.4}{1.4}}$ - 1. So, Δ $T_0|_s$ = 31.47 K. Hence, we can get T_{03} = T_{02} + Δ $T_0|_s$. ΔT_{01} + Δ $T_0|_s$ hence it is 323.47 K, we are expected to find out blade angles. So, for that we can make use of new formula which is Δ $T_0|_s$ and that is equal to work done factor $\frac{uC_a}{C_p}$(tan β_1 - tan β_2).

So, we know Δ $T_0|_s$ is 31.47, work done factor is 1, u is 225 and C_a is 145, C_p is 1005 $\times$ (tan β_1 - tan β_2). So, we get (tan β_1 - tan β_2) = 1.55 we do not know both tan of β_1 and β_2. So we name it as equation number 1. Further we can make use of the expression for degree of reaction which is λ = $\frac{C_a}{2u}$ (tan β_1 + tan β_2) but we are working with degree of reaction 1/2. So, it turns out to be $\frac{u}{C_a}$ = (tan β_1 + tan β_2).

We know u and u is 225, C_a is 145. So, u/C_a is 1.55 we'll name it as equation number 1. So, we have tan β_1 + tan β_2 we have tan β_1 minus, tan β_1 - tan β_2 = 0.9694. So, we have tan β_1 - tan β_2, we have tan β_1 + β_2. So we can solve these equations simultaneously and we can get 2 $\times$ tan β_1 is 2.52 which gives us tan β_1 = 1.26. So, we have β_1 = 51.56°. Similarly, we can get tan β_2 = 1.55 - tan β_1, so this gives us tan β_2 = 0.29 and hence β_2 = 16.17°. So, we got the required thing from the example.(refer time: 07:49)

We move on to the next example it reads that an axial air compressor of 50% reaction has blades with inlet and outlet angles of 47° and 12° respectively. The compressor is to produce a pressure ratio of 5.5:1 with an overall efficiency isentropic efficiency of 0.87, when inlet temperature is 30°C. The inlet the blades speed and axial velocity are constant throughout the compressor.

Assume a value of 220 m/s for blade speed, find out number of stages required. If work done factor is unity. So for all this sake whatever we are given with we can make use of we are given that pressure ratio is 5.5 isentropic efficiency is 0.87, T_{01}, we are told that that is 303 Kelvin, then we are told that β_1 = 47° and β_2 is 12°, u is 220 m/s, λ = 0.5, work done factor unity.



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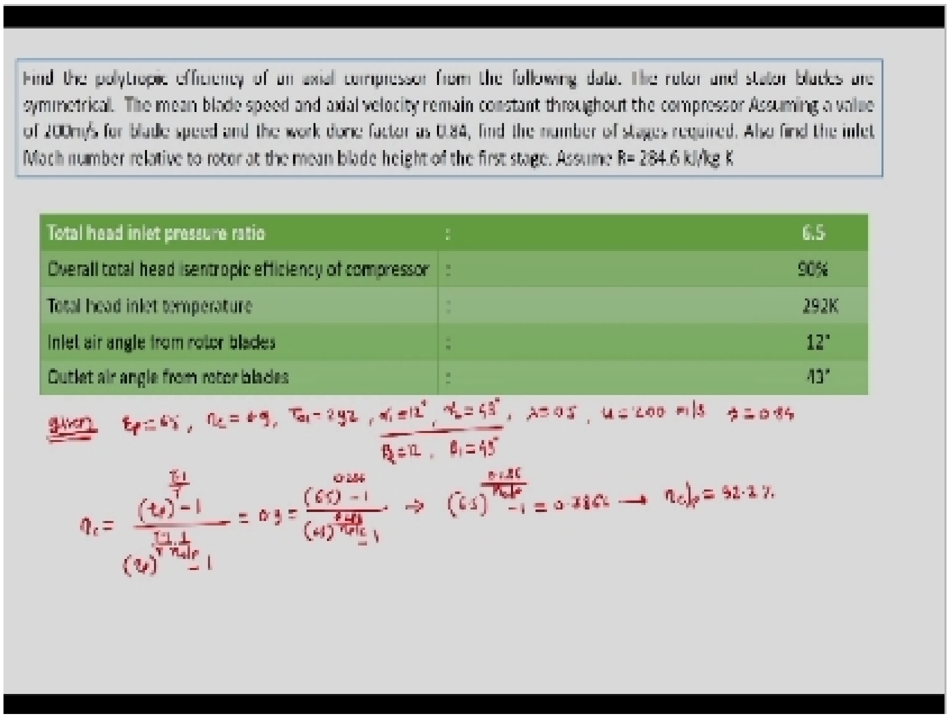
So, these are the things which are given, now we first find out overall temperature change from the efficiency formula. So, $\frac{T_{01}}{\eta_c}\left((r_p)^{\frac{\gamma-1}{\gamma}}-1\right)$. So T_{01} is 303, isentropic efficiency 0.87, so c, so we can find out overall temperature change in the compressor and that turns out to be 218.55 K. Now, we are supposed to find out the stage temperature change.

And then we can devide them and find out number of stages, the formula for stage temperature change is $\frac{\lambda u C_a}{C_p}$ (tan β_1 - tan β_2). But in this formula, we are not aware about C_{a1}. So, to find out C_{a1} we can make use of degree of reaction, which says that λ = $\frac{C_a}{2u}$ (tan β_1 + tan β_2). So, we will have tan β_1 + tan β_2 = u/C_a.

So, Ca = u/(tan β_1 + tan β_2), we know u it is 220 m/s, tan β_1 which is tan of 47° and it is 1.0723 + tan of β_2 which is tan 12° which is 0.212 and then it gives us C_a as 171.22 m/s, this helps us find out $\Delta T_0|_s$. So, we know work done factor is unity u is 220, C_a is just now found out as 171.22 divided by C_p which is 1005 into tan β_1 is 1.0723 - 0.212 which is tan β_2.

$\Delta T_0|_s$ = 32.24 K, thus we can find out number of stages as $\Delta T_0|_{overall}$/ $\Delta T_0|_s$. So, n = 218.55/32.24 and this is 6.77. So, we have to use 7 stages to achieve this required pressure rise of 5.5 total pressure ratio.(refer time: 13:31)



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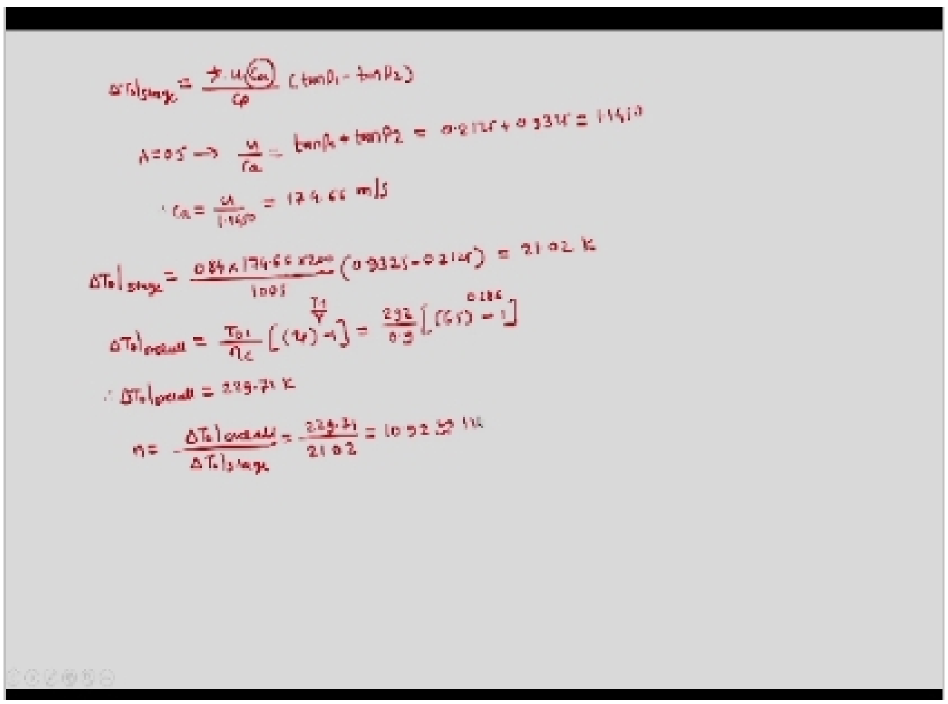
We will move on to the next example and this example says that find the polytrophic efficiency of an axial compressor from the following data. The rotor and stator are symmetrical, we know that when it is said the rotor and stator blades are symmetrical it means that degree of reaction is 50%. The mean blade speed and axial velocity remain constant throughout the compressor. Assume a value 100 m/s blade speed and work done factor of 0.84, find number of stages required, also find the inlet Mach number related to the rotor at mean blade height.

So, for this data given is total pressure inlet head is 6.5, overall total head inlet pressure ratio is 6.5, overall head isentropic efficiency of compressor 90%, total head inlet temperature is 292 K, inlet air angle from the rotor blades is 12°, outlet air angle from the rotor blades is 43°. So, we can write down given things pressure ratio is 6.5, overall isentropic efficiency is 0.9, T_{01} is 292 K.

We are told that air angles as α_1 as 12° and α_2 as 43°, blades are symmetrical. So, lambda = 0.5. Hence, we can mention the same thing as β_2 = 12° and β_1 is = 43°. We arSo 292 divided by 0.9, 6.5 bracket raise to 0.286 - 1. So, overall temperature rise is 229.71 Kelvin, this helps us to find out number of stages which is delta T0 overall divided by delta T0 stage 229.71 divided by 174.66 divided by 21.02 and this gives us 10.92 which is 11 stages are required.(refer time: 21:45) e told that u is = 200 m/s and work done factor λ is 0.85, with this we will proceed we know isentropic efficiency of an axial compressor can be written as $\frac{r_p^{\frac{\gamma-1}{\gamma}}-1}{r_p^{\frac{\gamma-1}{\gamma}\cdot\frac{1}{\eta_c|_p}}-1}$. We know isentropic efficiency is 0.9, pressure ratio is $6.5^{0.286}$ - 1 divided by $6.5^{\frac{0.286}{\eta_c|_p}}$ - 1.

So, we will get from here $6.5^{\frac{0.286}{\eta_c|_p}}$ - 1 = 0.7866 from here we can find out compressors polytrophic efficiency and it turns out to be 92.2%. So, we first found out polytrophic efficiency, now we have to find out number of stages. Again, we have to find out stage temperature rise and overall temperature rise. So, we know for stage temperature rise we know the formula.(refer time: 17:55)



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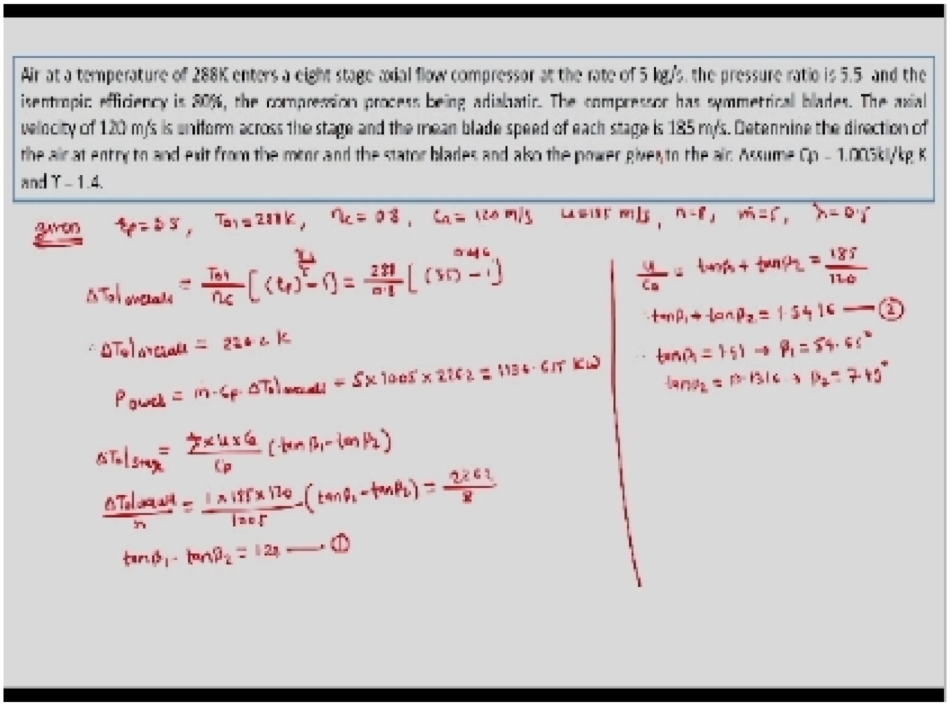
And that formula is $\Delta T_0|_s = \frac{\lambda u C_a}{C_p}$ (tan β_1 - tan β_2), we know $\alpha_1 = \beta_2$ and $\alpha_2 = \beta_1$, but here we are not aware about C_a. So, we have to first find out C_a, we will make use of the formula for degree of reaction which is 0.5 and this gives us u/C_a = tan β_1 + tan β_2 which is also tan α_2 = tan α_1 and then this we know this gives us 0.932125 + 0.9325 and it gives us 1.1450.

So, we can know C_a = u/1.450 and it comes out to be 174.66 m/s. So, $\Delta T_0|_s$ can be found out now and it is $\frac{0.84\times174.66\times200}{1005}$ (tan β_2 tan β_1 - tan β_2 tan β_1) is 0.9325 - 0.2125 and this gives us stage temperature rise as 21.02 K. We can as well find out overall temperature rise and that is $\frac{T_{01}}{\eta_c}\left((r_p)^{\frac{\gamma-1}{\gamma}}-1\right)$.

So 292/0.9, $(6.5)^{0.286}$ - 1. So, overall temperature rise is 229.71 K, this helps us to find out number of stages which is $\Delta T_0|_{overall}$ divided by $\Delta T_0|_s$, 229.71 divided by 174.66 divided by 21.02 and this gives us 10.92 which is 11 stages are required.(refer time: 21:45)



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We will move to next example, it states that air at a temperature of 288 K enters an 8 stage axial flow compressor at the rate of 5 kg/s, pressure ratio is 5.5 and isentropic efficiency is 80%, compression is adiabatic, the compressor has symmetrical blades, again degree of reaction is 50%. The axial velocity is 120 m/s which is uniform across the stage and the mean blade speed of each stage is 185 m/s.

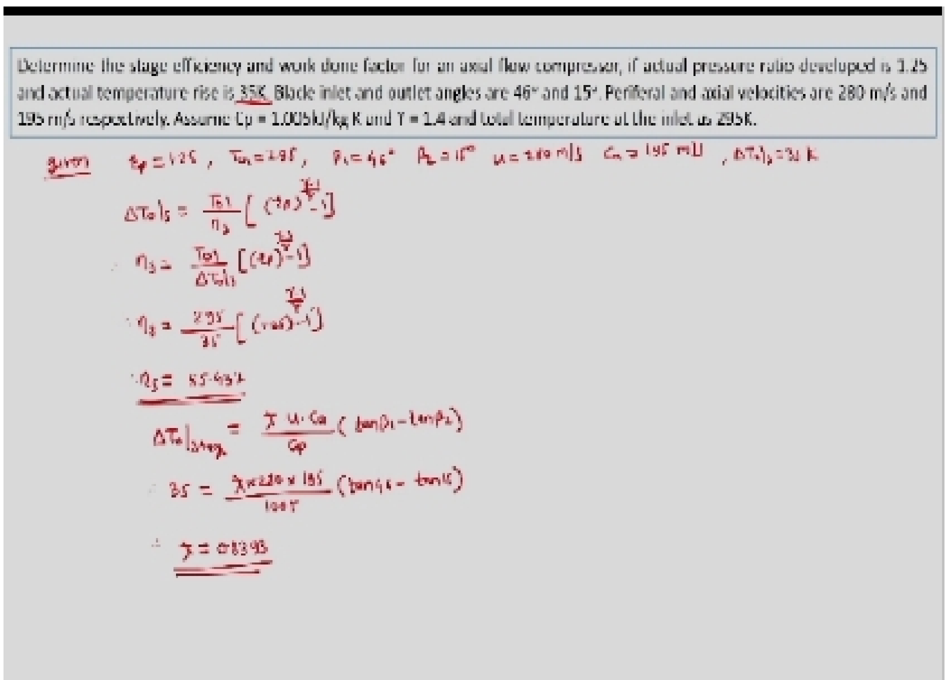
Determine the direction of air at entry and at entry to an exit from the rotor and stator blades and also power given to the air. Assume C_p as 1.005, γ as 1.4. Let us mention what are the given things, given things are pressure ratio is 5.5, T_{01} is 288 Kelvin, compressor's isentropic efficiency is 80%, it is told that C_a is 120 m/s and u is 185 m/s, number of stages are 8, mass flow rate is 5 and degree of reaction is 0.5.

We can find out $\Delta T_0|_{overall}$ as $\frac{T_{01}}{\eta_c}\left((r_p)^{\frac{\gamma-1}{\gamma}}-1\right)$, 288 divided by 0.8 into $(5.5)^{0.286}$ - 1. So, now we have found out overall temperature rise as 226.2 K. So power required = $\dot{m}\ C_p \times \Delta T_0|_{overall}$, $\dot{m}$ is said as 5 kg per second C_p is 1005 × 226.2 and this gives us a number

1136.635 kW.

Now we can find out Δ $T_0|_s$ and delta T0 stage is $\frac{\lambda u C_a}{C_p}$ (tan β_1 - tan β_2). So, Δ $T_0|_s$ we can find out from Δ $T_0|_{overall}$/n = this is 1 work done factor u is 185, C_a is 120 divided by 1005 $\times$ tan β_1 - tan β_2, what we know overall is 226.2 divided by number of stages is 8.

So, we get tan β_1 - tan β_2 = 1.28, we will number this equation as equation number 1, from degree of reaction 5, u/C_a = tan β_1 + tan β_2. So u is 185 and C_a is 120. So we have tan β_1 + tan β_2 = 1.5416. So we can solve equation number 1 and equation number 2 simultaneously. So, that we can get tan β_1 = 1.41 and this gives us β_1 = 54.65° and tan β_2 is 1. 0.1316. So, β_2 = 7.49°. So, this is how we would solve this example.(refer time: 27:36)



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We will move on to the next example, it reads that determine the stage efficiency and work done factor for an axial flow compressor if actual pressure ratio developed is 1.25 and actual temperature rises 35 K, blade inlet and outlet angles are 46° and 15°. Peripheral and axial velocities are 280 m/s and 195 m/s respectively. C_p is 1.005 kJ/kg.K, γ is 1.4 and total temperature at inlet is 295 K.

So let us say what is given here and given here is actually it's a stage pressure rise, it is 1.25 T_{01} is 295, β_1 is 46°, β_2 is 15°, u peripheral speed is 280 m/s and the axial speed C_a is 195 m/s. Having said this we can find out the stage temperature rise basically using the formula which is the $\frac{T_{01}}{\eta_c}\left((r_p)^{\frac{\gamma-1}{\gamma}}-1\right)$.

Here we are given the stage temperature rise as 35 K, that is also given. So, we can say stage efficiency is $\frac{T_{01}}{\eta_c}\left((r_p)^{\frac{\gamma-1}{\gamma}}-1\right)$, so stage efficiency turns out to be 295/35 $\times$ (1.25)$\frac{\gamma-1}{\gamma}$ - 1 and directly we get stage efficiency as 55.43%. Then we are supposed to find out work done factor for that we can make use of the formula $\Delta T_0|_s$ = $\frac{\lambda u C_a}{C_p}$ (tan β_1 - tan β_2)

So, we have 35 = work done factor $\times$ u, u is 280 into C_a is 195 divided by 1005 and tan β_1 is tan of 46 - tan of 15. So we have work done factor as 0.8393. This is a simple example where we had to use straight formulas to find out the quantity thank you.