Ideal Rotor without wake rotation

a'=0, Cd=0 & a=1/3

Assume,

Tip speed ratio = 7
Number of Blades = 3
Airfoil used: NACA 63215

It can be seen that the max (Cl/Cd) occurs at an angle of attack of 5. Hence for the current airfoil design "Cl" is taken to be 0.722, corresponding to α =5.

Hence Cl_α = 0.722

The axial velocity at the rotor is given by U(1-a).

Where U is the free stream velocity and "a" the axial induction factor.

The tangential component of velocity is Ωr(1+a').

When a= 1/3 and a'= 0, λ= Ωr/U

Now the flow angle, $\phi=\tan^{-1}(2/3\lambda)$

At a=1/3 and without wake rotation the chord is given by

$$c= [8*\pi*r*\sin(\phi)] / [3*N*C_l*\lambda_r]$$

The above formula is implemented in MATLAB using the following code and for different radius the chord is found out.

CODE

The code given below finds the chord and the section pitch along the radius of the blade. It also finds the "a" value at each radius for different TSRs. Using this information the "Cp" for the given turbine at different tip speeds is calculated.

```
clear all; close all;clc;
tic
lambda=7;                   %design tip speed ratio
R=10;                       %Total Radius
r=1:0.5:10;                 %local Radius
rr=[r(1:length(r)-1)+0.25 R];    %Control points
r_bar=rr/R;
lamda_r=r_bar*lambda;       %local speed ratio
N=3;                        %number of blades
alpha=5;                    %design alpha
phi=2*radtodeg(atan(1./lamda_r))/3;
Cl_alpha=0.722;             %design Cl
theta=phi-alpha;
chord=16*pi().*r_bar.*sin(degtorad(phi/2)).^2./(N*Cl_alpha);
sig=N.*chord./(2*pi().*r_bar);       %solidity
sectionpitch=theta-theta(length(theta));
Output= [r_bar' lamda_r' phi' theta' chord' sectionpitch'];
```

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```
figure(1)
subplot(2,1,1)
plot(r_bar,sectionpitch)
title('section pitch vs rbar')
xlabel('rbar')
ylabel('section pitch degrees')
subplot(2,1,2)
plot(r_bar,chord)
title('chord vs rbar')
xlabel('rbar')
ylabel('chord')

TSRrange=3:1:9;

for TSR = TSRrange
    LTSR(TSR,:)=r_bar*TSR;
    for i=1:1:length(r_bar)
    k=1;
    a(TSR,length(r_bar),k)=0;
    err=1;
    while err>0.01
        phi(TSR,i)=radtodeg(atan((1-a(TSR,i,k))./LTSR(TSR,i)));
        alp(TSR,i)=phi(TSR,i)-theta(i);
        %cl(TSR,:)= 0.1105*alp(TSR,:) + 0.2031;
        [cl(TSR,i) cd(TSR,i)]=clcdcalc('naca63215',alp(TSR,i));

a(TSR,i,k+1)=chord(i)*N.*cl(TSR,i).*LTSR(TSR,i)./(8*pi().*r_bar(i).*sin(deg
torad(phi(TSR,i))));
        err=abs( a(TSR,i,k+1)- a(TSR,i,k))./ a(TSR,i,k);
        k=k+1;
        if k>2000
            break;
        end
    end
    a_stor(TSR,i)=a(TSR,i,k);
    end
    Cp(TSR)= 8/TSR^2*trapz([0 a_stor(TSR,:).*(1-
a_stor(TSR,:)).^2.*LTSR(TSR,:) ],[0 LTSR(TSR,:) ] );

end
toc
aa=mean(a_stor,2);

 figure(2)
plot(TSRrange,Cp((length(aa)-length(TSRrange)+1):length(aa)))
title('Cp vs TSR')
xlabel('TSR')
ylabel('Cp')
```

Output:

r	chord	section pitch
0.125	0.23	27.12
0.175	0.21	20.73
0.225	0.18	16.19
0.275	0.16	12.88
0.325	0.14	10.40
0.375	0.13	8.48
0.425	0.11	6.97
0.475	0.10	5.74
0.525	0.10	4.73
0.575	0.09	3.88
0.625	0.08	3.16
0.675	0.08	2.55
0.725	0.07	2.01
0.775	0.07	1.54
0.825	0.06	1.13
0.875	0.06	0.76
0.925	0.06	0.43
0.975	0.05	0.14
1	0.05	0.00

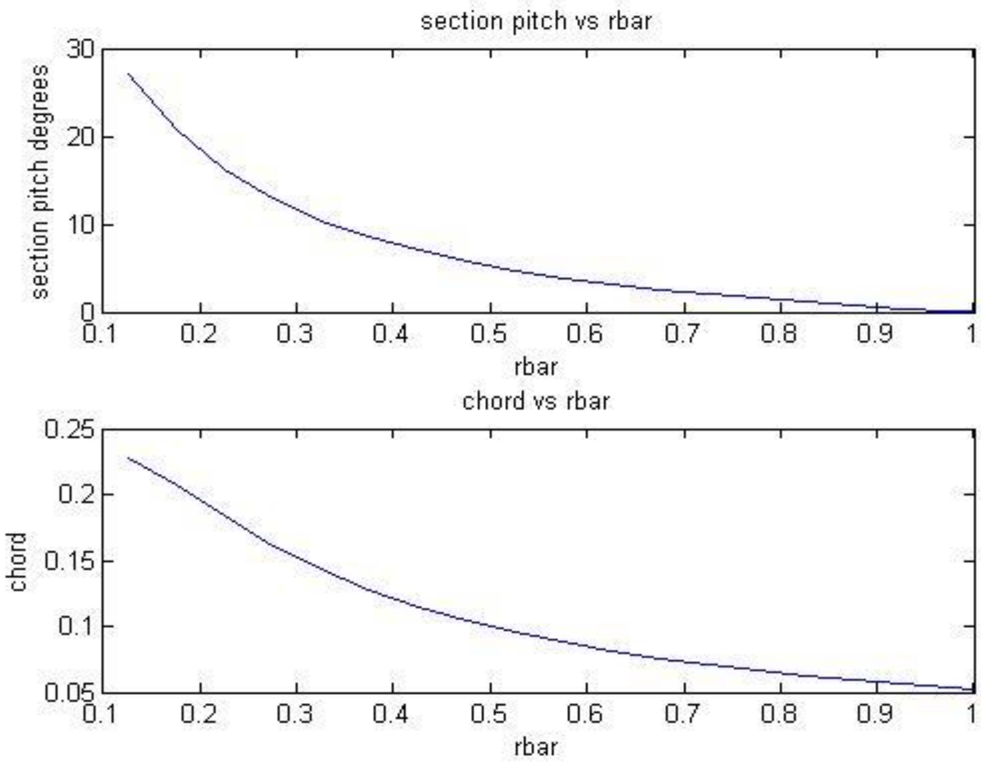

Figure 1

From the output and the graphs in figure 1, it can be seen that near to the root the chord length requirement is high. However practically the root portion of the blade is designed keeping into consideration the strength required rather than the aerodynamics.

The variation of Cp with TSR is shown below

TSR	Cp
3	0.29
4	0.35
5	0.45
6	0.57
7	0.59
8	0.56
9	0.41

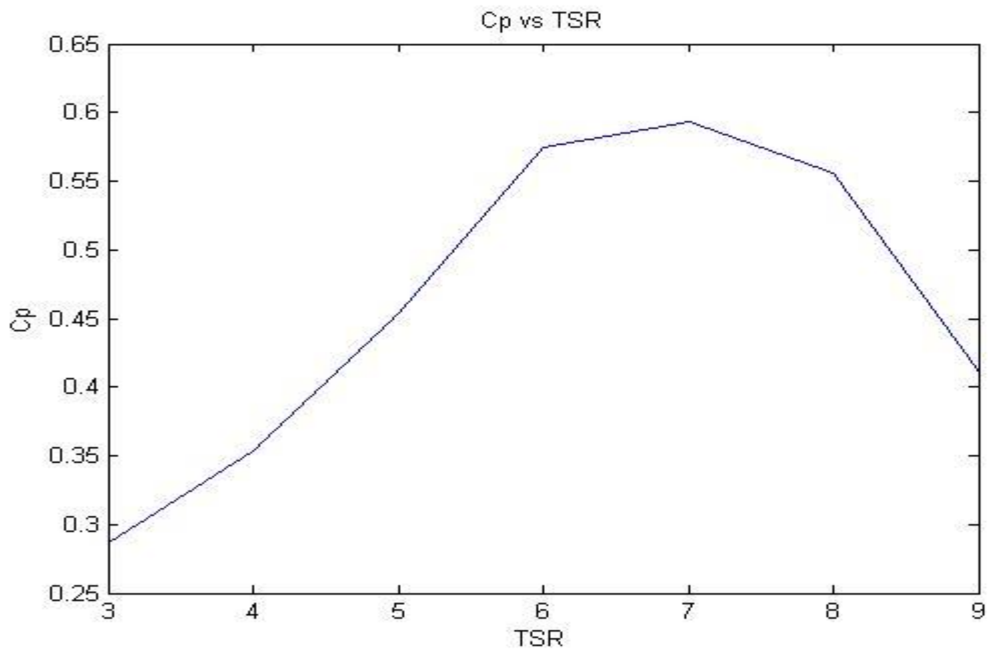

Figure 2

The "a" value is found by iterating at each radius for each tip speed. First value for "a" is assumed. Then "phi", the flow angle is calculated using the formula below

Φ=atan((1-a)/λ_r), and then "a" is calculated using the below formula.

a = (cNC$_l$ λ_r)/(8πr*sin ϕ), The iterations are repeated until a converged value of "a" is obtained.

The "Cp"is then calculated from the below formula.

Cp = 8/ $\lambda^2 \int a(1-a)^2 \lambda_r \, d\lambda_r$

The variation of "Cp vs TSR" is shown in figure 2

From the graph it can be seen that the maximum "Cp" occurs at TSR = 7, as expected.

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