**PROJECT-2**

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**Roll no –M22ME052**

1 matlab code:-

clear all;

close all;

clc;

%%

%joukowsky transformation

L=1;xmc=0.4\*L;ymc=0.02\*L;c=L/4;tm=0.12\*c;ro=1.225;U=100;alpha=[0:pi/180:12\*pi/180];n=160;

syms H

eqn=ymc==L\*sqrt(0.25\*(1+0.0625/H^2)-(xmc/L)^2)-0.125\*L/H;

s1=L\*double(solve(eqn,H));

n0=s1/2;

% n0=0;

g0=0.77\*tm\*c/L;

% g0=0;

delta=atan(n0/g0);

m=g0/cos(delta);

R=sqrt(m^2+c^2-2\*m\*c\*cos(delta));

theta=2\*pi/(n-1);

theta=0:theta:2\*pi;

T0=g0+i\*n0;

T=R\*exp(i\*theta)+T0;

Z=T+c^2./T;

x=(real(Z)+0.5\*L); %0.5\*L to shift airofoil to zero

y=(imag(Z));

for i=1:n-1

dx(i)=x(i+1)-x(i);

dy(i)=y(i+1)-y(i);

x\_cp(i)=(x(i+1)+x(i))/2;

y\_cp(i)=(y(i+1)+y(i))/2;

l(i)=sqrt((x(i+1)-x(i))^2+(y(i+1)-y(i))^2);

end

%%

for o=1:length(alpha)

[gamma,T\_vel]=naca(n,x,y,l,x\_cp,y\_cp,alpha,o,U);

%%

%cl cm\_le and cm\_qc by panel method

cl=0;

cm\_le=0;

for j=1:n-1

cl=cl+l(j)\*(gamma(j)+gamma(j+1))/(U\*L);

cm\_le=cm\_le-l(j)\*((2\*x(j)\*gamma(j)+x(j)\*gamma(j+1)+x(j+1)\*gamma(j)+2\*x(j+1)\*gamma(j+1))\*cos(alpha(o))+(2\*y(j)\*gamma(j)+y(j)\*gamma(j+1)+y(j+1)\*gamma(j)+2\*y(j+1)\*gamma(j+1))\*sin(alpha(o)))/(3\*U\*L^2);

end

cm\_qc=cm\_le+cl\*(0.25);

%%

%cl\_c cm\_le\_c and cm\_qc\_c by complex potential and by thin airofoil theory

cl\_c=2\*pi\*(sin(alpha(o))+n0\*cos(alpha(o))/sqrt(R^2-n0^2))/(1+g0/(sqrt(R^2-n0^2)-g0));

cm\_le\_c=-(0.25\*pi\*sin(2\*alpha(o))\*(R^2-n0^2-g0^2).^2/(R^2-n0^2).^2)-(0.25\*cl\_c\*((0.25-g0)\*cos(alpha(o))-n0\*sin(alpha(o)))\*(sqrt(R^2-n0^2)-g0)/(R^2-n0^2))-(0.0625\*cl\_c\*cos(alpha(o))\*(sqrt(R^2-n0^2)-g0)/(R^2-n0^2));

cm\_qc\_c=-0.25\*pi\*sin(2\*alpha(o))\*(R^2-n0^2-g0^2).^2/(R^2-n0^2).^2-0.25\*cl\_c\*((0.25-g0)\*cos(alpha(o))-n0\*sin(alpha(o)))\*(sqrt(R^2-n0^2)-g0)/(R^2-n0^2);

%%

%camber

Y=L\*sqrt(0.25\*(1+0.0625/s1^2)-((x(1:1+0.5\*n)-0.5\*L)./L).^2)-0.125\*L/s1;

%cl\_t cm\_le\_t and cm\_qc\_t by thin airofoil theory

for i=1:80

dyc\_dx(i)=-(Y(i+1)-Y(i))/(x(i+1)-x(i));

end

% cl\_t=2\*pi\*(alpha(o)-(1/pi)\*trapz(theta(1:80),dyc\_dx.\*(1-cos(theta(1:80)))));

cl\_t=2\*pi\*(sqrt(R^2-n0^2)-g0)\*(alpha(o)-atan(-n0/sqrt(R^2-n0^2)))/sqrt(R^2-n0^2);

cm\_le\_t=-0.25\*cl\_t+0.5\*trapz(theta(1:80),dyc\_dx.\*(cos(2\*theta(1:80))-cos(theta(1:80))));

cm\_qc\_t=cm\_le\_t+0.25\*cl\_t/L;

figure(1)

plot(180\*alpha(o)/pi,cl,'-o');

hold on;

plot(180\*alpha(o)/pi,cl\_c,'-p');

hold on;

plot(180\*alpha(o)/pi,cl\_t,'-s');

hold on;

xlabel('---- alpha(in degree) ---->');

ylabel('---- lift coefficient ---->');

legend('panel','joukowsky','thin airfoil');

figure(2)

plot(180\*alpha(o)/pi,cm\_le,'-o');

hold on;

plot(180\*alpha(o)/pi,cm\_le\_c,'-p');

hold on;

plot(180\*alpha(o)/pi,cm\_le\_t,'-s');

hold on;

xlabel('---- alpha(in degree) ---->');

ylabel('---- leading edge moment coefficient ---->');

legend('panel','joukowsky','thin airfoil');

figure(3)

plot(180\*alpha(o)/pi,cm\_qc,'-o');

hold on;

plot(180\*alpha(o)/pi,cm\_qc\_c,'-p');

hold on;

plot(180\*alpha(o)/pi,cm\_qc\_t,'-s');

hold on;

xlabel('---- alpha(in degree) ---->');

ylabel('---- quater chord moment coefficient ---->');

legend('panel','joukowsky','thin airfoil');

end

%%

% joukowsky profile

% alpha=pi\*input('enter the value of alpha = ')/180;

alpha=0\*pi/180;o=1;

[gamma,T\_vel]=naca(n,x,y,l,x\_cp,y\_cp,alpha,o,U);

%camber

Y=L\*sqrt(0.25\*(1+0.0625/s1^2)-((x(1:1+0.5\*n)-0.5\*L)./L).^2)-0.125\*L/s1;

figure(4)

plot(x,y);

hold on;

plot(x(1:1+0.5\*n),Y);

xlabel('---- x/c ---->');

ylabel('---- y/c ---->');

title('profile with camber');

%%

%cl cm\_le and cm\_qc by panel method

cl=0;

cm\_le=0;

for j=1:n-1

cl=cl+l(j)\*(gamma(j)+gamma(j+1))/(U\*L);

cm\_le=cm\_le-l(j)\*((2\*x(j)\*gamma(j)+x(j)\*gamma(j+1)+x(j+1)\*gamma(j)+2\*x(j+1)\*gamma(j+1))\*cos(alpha(o))+(2\*y(j)\*gamma(j)+y(j)\*gamma(j+1)+y(j+1)\*gamma(j)+2\*y(j+1)\*gamma(j+1))\*sin(alpha(o)))/(3\*U\*L^2);

end

cm\_qc=cm\_le+cl\*(0.25);

%%

%cl\_c cm\_le\_c and cm\_qc\_c by complex potential and by thin airofoil theory

cl\_c=2\*pi\*(sin(alpha(o))+n0\*cos(alpha(o))/sqrt(R^2-n0^2))/(1+g0/(sqrt(R^2-n0^2)-g0));

cm\_le\_c=-(0.25\*pi\*sin(2\*alpha(o))\*(R^2-n0^2-g0^2).^2/(R^2-n0^2).^2)-(0.25\*cl\_c\*((0.25-g0)\*cos(alpha(o))-n0\*sin(alpha(o)))\*(sqrt(R^2-n0^2)-g0)/(R^2-n0^2))-(0.0625\*cl\_c\*cos(alpha(o))\*(sqrt(R^2-n0^2)-g0)/(R^2-n0^2));

cm\_qc\_c=-0.25\*pi\*sin(2\*alpha(o))\*(R^2-n0^2-g0^2).^2/(R^2-n0^2).^2-0.25\*cl\_c\*((0.25-g0)\*cos(alpha(o))-n0\*sin(alpha(o)))\*(sqrt(R^2-n0^2)-g0)/(R^2-n0^2);

%%

% cl\_t cm\_le\_t and cm\_qc\_t by thin airofoil theory

for i=1:80

dyc\_dx(i)=-(Y(i+1)-Y(i))/(x(i+1)-x(i));

end

% cl\_t=2\*pi\*(alpha(o)-(1/pi)\*trapz(theta(1:80),dyc\_dx.\*(1-cos(theta(1:80)))));

cm\_le\_t=-0.25\*cl\_t+0.5\*trapz(theta(1:80),dyc\_dx.\*(cos(2\*theta(1:80))-cos(theta(1:80))));

cm\_qc\_t=cm\_le\_t+0.25\*cl\_t/L;

cl\_t=2\*pi\*(sqrt(R^2-n0^2)-g0)\*(alpha(o)-atan(-n0/sqrt(R^2-n0^2)))/sqrt(R^2-n0^2);

%%

%cp variation

cp=1-(T\_vel.^2./U^2);

figure(5)

plot(x\_cp,cp(1:n-1));

xlabel('---- x/c ---->');

ylabel('---- cp ---->');

title("cp on upper and lower surface");

set(gca, 'YDir','reverse');

%%

% % cp variation by complex potential method

% for j=1:n-1

% T\_cp(j)=(T(j+1)+T(j))/2;

% end

% w\_z=(exp(-i\*alpha)+(2\*i\*(sqrt(R^2-n0^2)\*sin(alpha)+n0\*cos(alpha))./(T\_cp-T0))-(R^2\*exp(i\*alpha)./(T\_cp-T0).^2))./(1-c^2./T\_cp.^2);

% cp\_c=(1-w\_z.^2);

% figure(4)

% plot(x\_cp,abs(cp\_c(1:n-1)));

% set(gca, 'YDir','reverse');

%%

a=[x(0.5\*n-1),0,x(0.5\*n+1)];

b=[y(0.5\*n-1),0,y(0.5\*n+1)];

vt=zeros(3,1);

for i=1:3

h=zeros(2,1);

[h]=global\_vel(x,y,l,a(i)+10^(-4),b(i)+10^(-4),h,gamma,n,alpha,U);

vt(i)=[(x(0.5\*n-1+i)-a(i))/sqrt((x(0.5\*n-1+i)-a(i))^2+(y(0.5\*n-1+i)-b(i))^2),(y(0.5\*n-1+i)-b(i))/sqrt((x(0.5\*n-1+i)-a(i))^2+(y(0.5\*n-1+i)-b(i))^2)]\*h;

end

d\_u\_vt=-(vt(3)-vt(2))/(a(3)-a(2));

d\_l\_vt=(vt(2)-vt(1))/(a(2)-a(1));

%%

%search stagnation point

vt\_le=vt(2);

N\_R=0;

u\_vt\_n=0;

l\_vt\_n=0;

while (u\_vt\_n<10^(-3)\*U || l\_vt\_n<10^(-3)\*U)

if (vt\_le<0)%search upper

N\_R=N\_R-vt\_le/d\_u\_vt;

else%search lower

N\_R=N\_R-vt\_le/d\_l\_vt;

end

xl\_g=0;yl\_g=0;xu\_g=0;yu\_g=0;

% [xl\_n,yl\_n,xu\_n,yu\_n]=surface\_coordinate(tm,xmc\_c,ymc\_c,L,N\_R);

geta=acos(N\_R/(R+c^2/R));

xl\_n=N\_R;

xu\_n=N\_R;

yu\_n=(R-c^2/R)\*sin(geta);

yl\_n=(R-c^2/R)\*sin(pi+geta);

h\_u=zeros(2,1);

h\_l=zeros(2,1);

[h\_u]=global\_vel(x,y,l,xu\_n,yu\_n,h\_u,gamma,n,alpha,U);

[h\_l]=global\_vel(x,y,l,xl\_n,yl\_n,h\_l,gamma,n,alpha,U);

xl\_n=[xl\_g,xl\_n];yl\_n=[yl\_g,yl\_n];xu\_n=[xu\_g,xu\_n];yu\_n=[yu\_g,yu\_n];

u\_vt\_n=[(xu\_n(2)-xu\_n(1))/sqrt((xu\_n(2)-xu\_n(1))^2+(yu\_n(2)-yu\_n(1))^2),(yu\_n(2)-yu\_n(1))/sqrt((xu\_n(2)-xu\_n(1))^2+(yu\_n(2)-yu\_n(1))^2)]\*h\_u;

l\_vt\_n=[(xl\_n(2)-xl\_n(1))/sqrt((xl\_n(2)-xl\_n(1))^2+(yl\_n(2)-yl\_n(1))^2),(yl\_n(2)-yl\_n(1))/sqrt((xl\_n(2)-xl\_n(1))^2+(yl\_n(2)-yl\_n(1))^2)]\*h\_l;

xl\_g=xl\_n(2);yl\_g=yl\_n(2);xu\_g=xu\_n(2);yu\_g=yu\_n(2);

end

if u\_vt\_n<l\_vt\_n

xs=xu\_g;

ys=yu\_g;

v\_s=h\_u;

else

xs=xl\_g;

ys=yl\_g;

v\_s=h\_l;

end

%%

%plot

%from trailing edge

[t\_T,s\_T]=sl\_by\_point(x,y,l,gamma,n,alpha,U,1.001,0,0.001,25);

%from leading edge

[t\_L,s\_L]=sl\_by\_point(x,y,l,gamma,n,alpha,U,xs,ys+0.006,-0.001,25);

figure(6)

plot(x,y);

xlabel('---- x/c ---->');

ylabel('---- y/c ---->');

title("streamline");

hold on;

plot(t\_T,s\_T);

hold on;

plot(t\_L,s\_L);

hold on;

%other streamlines

for i=-21:2:21

[m,o]=sl\_by\_point(x,y,l,gamma,n,alpha,U,t\_L(end),s\_L(end)+0.03\*i,0.001,60);

plot(m,o);

hold on;

end

**FUNCTIONS USED**

**global\_vel.m**

function [v]=global\_vel(a,b,e,f,g,v,gamma,n,alpha,U)

for j=1:n-1

[P]=influence\_matrix\_vortex(a(j),a(j+1),b(j),b(j+1),e(j),f,g);

v=v+P\*[gamma(j),gamma(j+1)]';

end

v=[U\*cos(alpha),U\*sin(alpha)]'+v;

**influence\_matrix\_vortex.m**

function [P]=influence\_matrix\_vortex(x1,x2,y1,y2,l,x\_cp,y\_cp)

dx=x2-x1;

dy=y2-y1;

geta=(1/l)\*[dx,dy;-dy,dx]\*[x\_cp-x1;y\_cp-y1];

g=geta(1,1);

n=geta(2,1);

A=atan2(n\*l,g^2+n^2-l\*g);

B=0.5\*log((n^2+g^2)/((g-l)^2+n^2));

T=(1/l)\*[dx,-dy;dy,dx];

p=[(l-g)\*A+n\*B,g\*A-n\*B;n\*A-(l-g)\*B-l,-n\*A-g\*B+l];

P=(1/(2\*pi\*l))\*T\*p;

**Naca.m**

function [gamma,T\_vel]=naca(n,x,y,l,x\_cp,y\_cp,alpha,o,U)

A=zeros(n,n);

Tn=zeros(n,n);

B=zeros(n,1);

v\_in\_t=zeros(n,1);

for i=1:n-1

for j=1:n-1

[P]=influence\_matrix\_vortex(x(j),x(j+1),y(j),y(j+1),l(j),x\_cp(i),y\_cp(i));

A(i,j)=A(i,j)+(-P(1,1)\*(y(i+1)-y(i))/l(i)+P(2,1)\*(x(i+1)-x(i))/l(i));

A(i,j+1)=A(i,j+1)+(-P(1,2)\*(y(i+1)-y(i))/l(i)+P(2,2)\*(x(i+1)-x(i))/l(i));

end

end

for i=1:n-1

for j=1:n-1

[P]=influence\_matrix\_vortex(x(j),x(j+1),y(j),y(j+1),l(j),x\_cp(i)+0.001\*(-(y(i+1)-y(i))/l(i)),y\_cp(i)+0.001\*((x(i+1)-x(i))/l(i)));

Tn(i,j)=Tn(i,j)+(P(1,1)\*(x(i+1)-x(i))/l(i)+P(2,1)\*(y(i+1)-y(i))/l(i));

Tn(i,j+1)=Tn(i,j+1)+(P(1,2)\*(x(i+1)-x(i))/l(i)+P(2,2)\*(y(i+1)-y(i))/l(i));

end

end

A(n,[1,end])=1;

Tn(n,[1,end])=1;

for i=1:n-1

B(i,1)=U\*((y(i+1)-y(i)).\*cos(alpha(o))-(x(i+1)-x(i)).\*sin(alpha(o)))./l(i);

v\_in\_t(i,1)=U\*((x(i+1)-x(i))\*cos(alpha(o))+(y(i+1)-y(i))\*sin(alpha(o)))/l(i);

end

gamma=A\B;

T\_vel=Tn\*gamma+v\_in\_t;

**sl\_by\_point.m**

function [t\_T,s\_T]=sl\_by\_point(x,y,l,gamma,n,alpha,U,a,b,dx,N)

t\_T(1)=a;

s\_T(1)=b;

% v=zeros(2,1);

k=[a;b];

for i=2:N

v=zeros(2,1);

[v]=global\_vel(x,y,l,t\_T(i-1),s\_T(i-1),v,gamma,n,alpha,U);

%euler method

k=k+dx\*v;

t\_T(i)=k(1);

s\_T(i)=k(2);

end

**RESULT:-**

cl = panel lift coefficient

cl\_c = joukowsky lift coefficient

cl\_t = thin airfoil lift coefficient

cm\_le = panel moment coefficient at leading edge

cm\_le\_c = joukowsky moment coefficient at leading edge

cm\_le\_t = thin airfoil moment coefficient at leading edge

cm\_qc = panel moment coefficient at quarter chord

cm\_qc\_c = joukowsky moment coefficient at quarter chord

cm\_qc\_t = thin airfoil moment coefficient at quarter chord

**At angle of attack = 0**

**cl=0.7084 cl\_c=0.7009 cl\_t =0.6978**

**cm\_le = -0.3499 cm\_le\_c = -0.3462 cm\_le\_t = -0.3231**

**cm\_le = -0.1718 cm\_le\_c = -0.1711 cm\_le\_t = -0.1618**

**Variation of coefficient of lift with angle of attack from 0 to 12 degree with different methods**

**Example :-**

cl = panel lift coefficient

cl\_c = joukowsky lift coefficient

cl\_t = thin airfoil lift coefficient

**at angle of attack = 0**

**cl=0.7084 , cl\_c=0.7009 , cl\_t =0.6978**

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****

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**At center shift (0.0058 , 0.0279 ) and radius = 0.2458**

**Joukowsky profile**

****

**At angle of attack =0**

****

**Angle of attack = 0**

****