Scilab Textbook Companion for Turbines, Compressors And Fans by S. M. Yahya[1]

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Book Description

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Scilab numbering policy used in this document and the relation to the above book.

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

AP Appendix to Example(Scilab Code that is an Appednix to a particular Example of the above book)

For example, Exa 3.51 means solved example 3.51 of this book. Sec 2.3 means a scilab code whose theory is explained in Section 2.3 of the book.

Contents

List of Scilab Codes

Chapter 2

Thermodynamics

Scilab code Exa 2.1 Calculation on a Diffuser

```
// scilab Code Exa 2.1 Calculation on a Diffuser

p1=800; // Initial Pressure in kPa
T1=540;  // Initial Temperature in K
p2=580;  // Final Pressure in kPa
gamma=1.4; // Specific Heat Ratio
cp=1005; // Specific Heat at Constant Pressure in J
   /(kgK)
R=0.287; // Universal Gas Constant in kJ/kgK
g=9.81; // Gravitational acceleration in m/s^2
sg=13.6; // Specific Gravity of mercury
n=0.95; // Efficiency in %
AR=4; // Area Ratio of Diffuser
delp=(367)*(1e-3)*(g)*(sg); // Total Pressure Loss
   Across the Diffuser in kPa
pr=p1/p2; // Pressure Ratio
T2s=T1/(pr^((gamma-1)/gamma));
T2=T1-(n*(T1-T2s));
c2=sqrt(2*cp*(T1-T2));
```

```
ro2=p2/(R*T2);
c3=c2/AR;
m=0.5*1e-3*ro2*((c2^2)-(c3^2));
n_D=1-(delp/m);
disp ("%",n_D*1e2," Efficiency of the diffuser is")
p3=(p2+n_D*m)*1e-2;
disp("m/s",c2,"the velocity of air at diffuser entry is")
disp("m/s",c3,"the velocity of air at diffuser exit is")
disp("bar",p3,"static pressure at the diffuser exit is")
```

Scilab code Exa 2.2 Determining the infinitesimal stage efficiencies

```
// Exa 2.2 Determining the infinitesimal stage efficiencies
p1=1.02; // Initial Pressure in bar
T1=300;  // Initial Temperature in K

// part(a)
T2=315;  // Final Temperature in K
gamma=1.4; // Specific Heat Ratio
g=9.81; // Gravitational acceleration in m/s^2
sg=1; // Specific Gravity of air
delp=(1500)*(0.001)*(g)*(sg); // Total Pressure Loss Across the Diffuser in kPa
p2=p1+(0.01*delp);
pr=p2/p1; // Pressure Ratio
T2s=T1*(pr^((gamma-1)/gamma));
n_c=(T2s-T1)/(T2-T1); // Efficiency in %
n_p=((gamma-1)/gamma)*((log(p2/p1))/(log(T2/T1)));
disp ("%",n_c*100,"(a)Efficiency of the compressor
```

```
   is")
disp ("%",n_p*100,"and infinitesimal stage
   Efficiency or polytropic efficiency of the
   compressor is")

// part(b) Determining the infinitesimal stage
   efficiency

p2_b=2.5;  // Final pressure in bar
n_b=0.75; // Efficiency
pr_b=p2_b/p1; // Pressure Ratio
T2s_b=T1*(pr_b^((gamma-1)/gamma));
T2_b=T1+((T2s_b-T1)/n_b);
n_p_b=((gamma-1)/gamma)*((log(p2_b/p1))/(log(T2_b/T1
   )));
disp ("%" ,n_p_b*100,"(b)infinitesimal stage
   Efficiency or polytropic efficiency of the
   compressor is")
```

Scilab code Exa 2.3 Calculations on air compressor

```
// scilab Code Exa 2.3 Calculation on a compressor
p1=1.0; // Initial Pressure in bar
t1=40;  // Initial Temperature in degree C
T1=t1+273; // in Kelvin
s=8; // number of stages
m=50; // mass flow rate through the compressor in kg
   /s
pr=1.35; // equal Pressure Ratio in each stage
opr=pr^s; // Overall Pressure Ratio
gamma=1.4; // Specific Heat Ratio
cp=1.005; // Specific Heat at Constant Pressure in
   kJ/(kgK)
```

```
n=0.82; // Overall Efficiency

// part(a) Determining state of air at the compressor exit
p9=opr*p1;
delTc=T1*(opr^((gamma-1)/gamma)-1)/n;
T9=T1+delTc;
disp("bar",p9,"(a)Exit Pressure is")
disp("K",T9,"and Exit Temperature is")

// part(b) Determining the polytropic or small stage efficiency
n_p=((gamma-1)/gamma)*((log(p9/p1))/(log(T9/T1)));
disp("%",n_p*100,"(b)small stage Efficiency or polytropic efficiency of the compressor is")

// part(c) Determining efficiency of each stage
n_st=(pr^((gamma-1)/gamma)-1)/(pr^(((gamma-1)/gamma)/n_p)-1);
disp ("%",n_st*100,"(c)Efficiency of each stage is")

// part(d) Determining power required to drive the compressor
n_d=0.9; // Overall efficiency of the drive
P=m*cp*delTc/n_d;
disp ("MW" ,P/1e3,"(d)Power required to drive the compressor is")
```

Scilab code Exa 2.4 compressor with same temperature rise

```
// Exa 2.4 compressor with same temperature rise

p1=1.0; // Initial Pressure in bar
```

```
t1=40;  // Initial Temperature in degree C
T1=t1+273; // in Kelvin
s=8; // number of stages
pr=1.35;
opr=pr^s; // Overall Pressure Ratio
n=0.82; // Overall Efficiency
p9=opr*p1;
gamma=1.4;
delTc=(T1*(opr^((gamma-1)/gamma)-1)/n);
delTi=delTc/s;
T9=T1+delTc;
n_p=((gamma-1)/gamma)*((log(p9/p1))/(log(T9/T1)));
    // small stage Efficiency or polytropic
    efficiency
m=8;
T(1)=T1;
for i=1:m
    T(i+1)=T(i)+delTi;
    pr(i)=(1+(delTi/T(i)))^(n_p/((gamma-1)/gamma));
    n_st(i)=(pr(i)^((gamma-1)/gamma)-1)/(pr(i)^(((
        gamma-1)/gamma)/n_p)-1);
disp(T(i),"T is");
disp(pr(i),"pressure ratio is")
disp(n_st(i),"efficiency is" )
end
```

Scilab code Exa 2.5 Calculations on three stage gas turbine

```
// scilab Code Exa 2.5 Calculation on three stage
    gas turbine

p1=1.0; // Initial Pressure in bar
gamma=1.4;
```

```
T1=1500;  // Initial Temperature in K
s=3; // number of stages
opr=11; // Overall Pressure Ratio

// part(a)Determining pressure ratio of each stage
pr=opr^(1/s); // equal Pressure Ratio in each stage
disp (pr,"(a)Pressure ratio of each stage is")

// part(b)Determining the polytropic or small stage
   efficiency
n_o=0.88; // Overall Efficiency
delT=T1*(1-opr^(-((gamma-1)/gamma)))*n_o;
T2=T1-delT;
n_p=(log(T1/T2))/(((gamma-1)/gamma)*(log(opr)));
disp ("%",n_p*100,"(b)small stage Efficiency or
   polytropic efficiency of the turbine is")

// part(c) Determining mass flow rate
P=30000; // Power output of the Turbine in kW
n_d=0.91; // Overall efficiency of the drive
cp=1.005; // Specific Heat at Constant Pressure in
   kJ/(kgK)
m=P/(cp*delT*n_d);
disp ("kg/s",m,"(c)mass flow rate is")

// part(d) Determining efficiency of each stage
n_st=(1-pr^(n_p*(-((gamma-1)/gamma))))/(1-pr^(-((
   gamma-1)/gamma)));
disp ("%",n_st*100,"(d)Efficiency of each stage is")
d=3;
T(1)=T1;
for i=1:d
    delT(i)=T(i)*(1-pr^(n_p*(-((gamma-1)/gamma))));
    T(i+1)=T(i)-delT(i);
    P(i)=m*cp*delT(i);
printf("\n P(%d)=%f MW",i,P(i)*1e-3)
end
```

Scilab code Exa 2.6 Calculations on a Gas Turbine

```
// scilab Code Exa 2.6 calculation on a gas turbine

funcprot(0);
p1=5; // Inlet Pressure in bar
p2=1.2; // Exit Pressure in bar
T1=500;  // Initial Temperature in K
gamma=1.4;
m=20; // mass flow rate of the gas in kg/s
cp=1.005; // Specific Heat at Constant Pressure in kJ/(kgK)
n_T=0.9; // Overall Efficiency
pr=p1/p2; // Pressure Ratio
// part(a)
T2s=T1/(pr^((gamma-1)/gamma));
T2=T1-(n_T*(T1-T2s));
n_p=(log(T1/T2))/(log(T1/T2s));
disp("%",n_p*100,"(a)small stage Efficiency or polytropic efficiency of the expansion is")
P=m*cp*(T1-T2);
disp("kW",P,"and Power developed is")

// part(b)
AR=2.5; // Area Ratio of Diffuser
R=0.287; // Universal Gas Constant in kJ/kgK
p3=1.2; // Exit Pressure for diffuser in bar
c2=75; // Velocity of gas at turbine exit in m/s
c3=c2/AR;
n_d=0.7; // Efficiency of the diffuser
ro2=p2/(R*T2);
delp=n_d*(0.5*0.001*ro2*((c2^2)-(c3^2))); // delp=p3
```

```
-p2d
disp("mm W.G.",delp*100000/9.81,"(b)static pressure across the diffuser is")
p2d=p3-delp;
prd=p1/p2d;
T2sd=T1/(prd^((gamma-1)/gamma));
T2d=T1-(n_T*(T1-T2sd));
Pd=m*cp*(T1-T2d);
disp("kW",Pd-P,"and Increase in the power output of the turbine is")

disp("Comment: Error in Textbook, Answers vary due to Round-off Errors")
```

Chapter 3

Gas Turbine Plants

Scilab code Exa 3.1 Constant Pressure Gas Turbine Plant

```
// scilab Code Exa 3.1 Constant Pressure Gas Turbine
    Plant

t1=50;  // Minimum Temperature in degree C
T1=t1+273; // in Kelvin
t3=950;  // Maximum Temperature in degree C
T3=t3+273; // in Kelvin
n_c=0.82; // Compressor Efficiency
n_t=0.87; // Turbine Efficiency
gamma=1.4; // Specific Heat Ratio
cp=1.005; // Specific Heat at Constant Pressure in
   kJ/(kgK)
beeta=T3/T1;
alpha=beeta*n_c*n_t;
T_opt=sqrt(alpha); // For maximum power output, the
   temperature ratios in the turbine and compressor

// part(a) Determining pressure ratio of the turbine
    and compressor
```

```
pr=T_opt^(gamma/(gamma-1));
disp(pr,"(a)Pressure Ratio is")

// part(b) Determining maximum power output per unit
    flow rate
wp_max=cp*T1*((T_opt-1)^2)/n_c;
disp("kW/(kg/s)",wp_max,"(b)maximum power output per
    unit flow rate is")

// part(c) Determining thermal efficiency of the
   plant for maximum power output
n_th=(T_opt-1)^2/((beeta-1)*n_c-(T_opt-1));
disp("%",n_th*100,"(c)thermal efficiency of the
   plant for maximum power output is")
```

Scilab code Exa 3.2 Gas Turbine Plant with an exhaust HE

```
// scilab Code Exa 3.2 Gas Turbine Plant with an
   exhaust HE
T1=300;  // Minimum  cycle Temperature in Kelvin
funcprot(0);
pr=10; // pressure ratio of the turbine and
   compressor
T3=1500;  // Maximum cycle Temperature in Kelvin
m=10; // mass flow rate through the turbine and
   compressor in kg/s
e(1)=0.8; // thermal ratio of the heat exchanger
e(2)=1;
n_c=0.82; // Compressor Efficiency
n_t=0.85; // Turbine Efficiency
gamma=1.4; // Specific Heat Ratio
cp=1.005; // Specific Heat at Constant Pressure in
   kJ/(kgK)
```

```
beeta=T3/T1;
T2s=T1*(pr^((gamma-1)/gamma));
T2=T1+((T2s-T1)/n_c);
T4s=T3*(pr^(-((gamma-1)/gamma)));
T4=T3-((T3-T4s)*n_t);

for i=1:2
T5=T2+e(i)*(T4-T2);
T6=T4-(T5-T2);
Q_s=cp*(T3-T5);
Q_r=cp*(T6-T1);
// part(a) Determining power developed
w_p=Q_s-Q_r;
P=m*w_p;
printf("for effectiveness=%f, \n (a)the power
   developed is %f kW",e(i),P)

// part(b) Determining thermal efficiency of the
   plant
n_th=1-(Q_r/Q_s);
disp ("%",n_th*100,"(b)thermal efficiency of the
   plant is")
end

// part(c) Determining efficiencies of the ideal
   Joules cycle
n_Joule=1-(pr^((gamma-1)/gamma)/beeta);
disp("%",n_Joule*100,"(c)efficiency of the ideal
   Joules cycle with perfect heat exchange is")
n_Carnot=1-(T1/T3);
disp("%",n_Carnot*100,"and the Carnot cycle
   efficiency is")
```

Scilab code Exa 3.3 ideal reheat cycle Gas Turbine Plant

```
// scilab Code Exa 3.3 ideal reheat cycle gas
   turbine
T1=300;  // Minimum  cycle Temperature in Kelvin
r=25; // pressure ratio of the turbine and
   compressor
gamma=1.4;
T3=1500;  // Maximum cycle Temperature in Kelvin
cp=1.005; // Specific Heat at Constant Pressure in
   kJ/(kgK)
beeta=T3/T1;
n=(gamma-1)/gamma;
t=(r^n);
d=1/sqrt(t);
// part(a) Determining mass flow rate through the
   turbine and compressor
c=2*beeta*[1-d];
wp_max=cp*T1*(c+1-t);
m=1000/wp_max;
disp ("kg/s",m,"(a)mass flow rate through the
   turbine and compressor is")

// part(b) Determining thermal efficiency of the
   plant
n_th=(c+1-t)/(2*beeta-t-(beeta/sqrt(t)));
disp ("%",n_th*100,"(b)thermal efficiency of the
   plant is")
```

Scilab code Exa 3.4 Calculations on Gas Turbine Plant

```
// scilab Code Exa 3.4 Calculations on Gas Turbine
   Plant for an ideal reheat cycle with optimum
```

```
reheat pressure and perfect exhaust heat exchange
T1=300;  // Minimum  cycle Temperature in Kelvin
r=25; // pressure ratio of the turbine and compressor
T3=1500;  // Maximum cycle Temperature in Kelvin
gamma=1.4; // Specific Heat Ratio
cp=1.005; // Specific Heat at Constant Pressure in kJ/(kgK)
beeta=T3/T1;
n=(gamma-1)/gamma;
t=(r^n);
d=1/sqrt(t);
// part(a) Determining mass flow rate through the turbine and compressor
c=2*beeta*[1-d];
wp_max=cp*T1*(c+1-t);
m=1000/wp_max;
disp ("kg/s" ,m," mass flow rate through the turbine and compressor is")


// part(b) Determining thermal efficiency of the plant
c=sqrt(t)*(sqrt(t)+1)/(2*beeta);
n_th=1-c;
disp ("%",n_th*100," thermal efficiency of the plant is")
```

Scilab code Exa 3.5 Calculations on Gas Turbine Plant

```
// scilab Code Exa 3.5 Calculations on Gas Turbine Plant

```

```
P=10e4; // Power Output in kW
T1=310;  // Minimum  cycle Temperature in Kelvin
p1=1.013; // Compressor Inlet Pressure in bar
pr_c=8; // Compressor pressure ratio
gamma=1.4;
gamma_g=1.33;
R=0.287;
p2=pr_c*p1; // Compressor Exit Pressure in bar
T3=1350;  // Maximum cycle Temperature(Turbine inlet
    temp) in Kelvin
n_c=0.85; // Compressor Efficiency
p3=0.98*p2; // turbine inlet pressure
p4=1.02; // turbine exit pressure in bar
CV=40*10e2; // Calorific Value of fuel in kJ/kg;
n_B=0.98; // Combustion Efficiency
n_m=0.97; // Mechanical efficiency
n_t=0.9; // Turbine Efficiency
n_G=0.98; // Generator Efficiency
cp_a=1.005; // Specific Heat of air at Constant
   Pressure in kJ/(kgK)

// Air Compressor
T2s=T1*(pr_c^((gamma-1)/gamma));
T2=T1+((T2s-T1)/n_c);
w_c=cp_a*(T2-T1);

// Gas Turbine
n_g=(gamma_g-1)/gamma_g;
cp_g=1.157; // Specific Heat of gas at Constant
   Pressure in kJ/(kgK)
pr_t=p3/p4;
T4s=T3/(pr_t^((gamma_g-1)/gamma_g));
T4=T3-(n_t*(T3-T4s));
w_t=cp_g*(T3-T4);
w_net=w_t-w_c;
w_g=n_m*n_G*w_net;

// part(a) Determining Gas Flow Rate
```

```
m_g=P/w_g;
disp ("kg/s",m_g,"(a)Gas flow rate is")

// part(b) Determining Fuel-Air Ratio
F_A=((cp_g*T3)-(cp_a*T2))/((CV*n_B)-(cp_g*T3));
disp(F_A,"(b)Fuel-Air Ratio is")

// part(c) Air flow rate
m_a=m_g/(1+F_A);
disp("kg/s",m_a,"(c)Air flow rate is")

// part(d) Determining thermal efficiency of the
    plant
m_f=m_g-m_a;
n_th=m_g*w_net/(m_f*CV);
disp ("%",n_th*100,"(d)thermal efficiency of the
    plant is")

// part(e) Determining Overall efficiency of the
    plant
n_o=n_m*n_G*n_th;
disp ("%",n_o*100,"(e)overall efficiency of the
    plant is")

// part(f) Determining ideal Joule cycle efficiency
n_Joule=1-(1/(pr_c^((gamma-1)/gamma)));
disp ("%",n_Joule*100,"(f)efficiency of the ideal
    Joule cycle is")
```

Chapter 4

Steam Turbine Plants

Scilab code Exa 4.1 Calculations on Steam Turbine Plant

```
// scilab Code Exa 4.1 Calculations on Steam Turbine
    Plant

p1=25; // Turbine Inlet Pressure in bar
p2=0.065;  // Condenser Pressure in bar
n_B=0.82; // Boiler efficiency
delp=p1-p2;
v_w=0.001; // Specific Volume at condenser Pressure
    in m3/kg

h1=160.6; // from steam tables at p1=0.065 bar
h2=h1+(delp*100*v_w);

//part(a) Determining exact and approximate Rankine
    efficiency of the plant
h3=2800; // from steam table vapour enthalpy at 25
    bar
h4=1930; // from steam table
n_rankine_ex=(h3-h4-(h2-h1))/(h3-h1-(h2-h1));
```

```
disp ("%",n_rankine_ex*100,"(a)(i) Exact Rankine
    efficiency is")

n_rankine_app=(h3-h4)/(h3-h1);
disp ("%",n_rankine_app*100," (a)(ii)Approximate
    Rankine efficiency is")

//part(b) Determining thermal and relative
    efficiencies of the plant
n_t=0.78; // Turbine Efficiency
CV=26.3*10e2; // Calorific Value of fuel in kJ/kg;
n_th=(n_t*(h3-h4))/(h3-h1);
disp("%",n_th*100,"(b)(i)thermal efficiency of the
    plant is")
n_rel=n_th/n_rankine_app;
disp("%",n_rel*100,"(ii)relative efficiency of the
    plant is")

//part(c) Determining Overall efficiency of the
    plant
n_o=n_th*n_B;
disp("%",n_o*100,"(c)overall efficiency of the plant
     is")

//part(d) Turbine and Overall heat rates
hr_t=3600/n_th;
disp("kJ/kWh",hr_t,"(d)(i)Turbine Heat Rate is")
hr_o=3600/n_o;
disp("kJ/kWh",hr_o,"(d)(ii)overall Heat Rate is")

//part(e) Steam Consumption per kWh
m_s=3600/(n_t*(h3-h4));
disp("kg/kWh" ,m_s,"(e)Steam Consumption is")

//part(f) Fuel Consumption per kWh
m_f=3600/(CV*n_o);
disp("kg/kWh" ,m_f,"(f)Fuel Consumption is")
```

Scilab code Exa 4.2 Steam Turbine Plant for different reheat cycles

```

// scilab Code Exa 4.2 Steam Turbine Plant for different reheat cycles

p1=160; // Turbine Inlet Pressure in bar
T1=500;  // Turbine Entry Temperature in Degree Celsius
p2=0.06;  // Condenser Pressure in bar

// from steam tables at p1=0.06 bar,
h1=147; // Specific Enthalpy of water in kJ/kg
h2=2567; // Specific Enthalpy of steam in kJ/kg

h3=3295; // from steam table
h4=1947; // from steam table
q_n=h3-h1;
n_N=(h3-h4)/(q_n);
x=(h4-h1)/(h2-h1);
disp("%",n_N*100,"for non reheat cycle plant efficiency is")
disp ("kJ/kWh",3600/n_N,"Turbine Heat Rate is")
disp(x,"final dryness fraction is")
// for reheat cycle

p(1)=70;
h5(1)=3412; // in kJ/kg
h7(1)=3065; // in kJ/kg
h6(1)=2094; // in kJ/kg
p(2)=50;
h5(2)=3433; // in kJ/kg
```

```
h7(2)=2981; // in kJ/kg
h6(2)=2144; // in kJ/kg
p(3)=25;
h5(3)=3475; // in kJ/kg
h7(3)=2826; // in kJ/kg
h6(3)=2249; // in kJ/kg
for i=1:3
 q_r(i)=h5(i)-h7(i);
a(i)=(h6(i)-h4)/(q_r(i));
n_r(i)=1-a(i); // exact Rankine efficiency
b(i)=q_r(i)*n_r(i)/n_N;
n_th(i)=(q_n+b(i))*n_N/(q_n+q_r(i));
hr_t(i)=3600/n_th(i);
x(i)=(h6(i)-h1)/(h2-h1);
disp("bar",p(i),"for reheat pressure" )
disp("kJ",q_r(i),"q_R=")
disp("kJ",h6(i)-h4,"H6-H4= ")
disp("%",n_r(i)*100,"Rankine efficiency of the plant
    is")
disp("%",n_th(i)*100,"thermal efficiency of the
   plant is")
disp("kJ/kWh",hr_t(i),"Heat Rate is")
disp(x(i),"final dryness fraction is")

end

disp("Comment: Error in Textbook, Answers vary due
   to Round-off Errors")
```

Scilab code Exa 4.3 Calculations on Steam Turbine Plant

```
// scilab Code Exa 4.3 Calculations on Steam Turbine
    Plant
```

```
p1=82.75; // Turbine Inlet Pressure in bar
T1=510;  // Turbine Entry Temperature in Degree Celsius
pc=0.042;  // Condenser Pressure in bar
H=3420;
n_e=0.85;
gamma=1.4;
n_st1=0.85;

p2=22.75;
// for regenerative cycle
hs(1)=121.4; // from steam tables and mollier chart
p(6)=p2; // pressure at bleed point 1
Hs(6)=3080; // Enthalpy of steam at bleed point 1
h1s=931;
hs(6)=h1s; // Enthalpy of water at bleed point 1
H_22=H-(n_st1*(H-h1s));

p(5)=10.65; // pressure at bleed point 2
Hs(5)=2950; // Enthalpy of steam at bleed point 2
hs(5)=772; // Enthalpy of water at bleed point 2

p(4)=4.35; // pressure at bleed point 3
Hs(4)=2730; // Enthalpy of steam at bleed point 3
hs(4)=612; // Enthalpy of water at bleed point 3

p(3)=1.25; // pressure at bleed point 4
Hs(3)=2590; // Enthalpy of steam at bleed point 4
hs(3)=444; // Enthalpy of water at bleed point 4

p(2)=0.6; // pressure at bleed point 5
Hs(2)=2510; // Enthalpy of steam at bleed point 5
hs(2)=360; // Enthalpy of water at bleed point 5

m=1;
h_c=121.4;
x=0.875;
```

```
disp(x,"(a)the final state at point C is")
for i=2:6
alpha(i)=(Hs(i)-hs(i-1))/(Hs(i)-hs(i));
m=m*alpha(i);
end
disp("kg",m,"(b)The mass of steam raised per kg of steam reaching the condenser is")
// part(c) thermal efficiency with feed heating
H_c=2250;
h_n=hs(6);
n_th=1-((H_c-h_c)/(m*(H-h_n)));
hr_t=3600/n_th;
//(c) the improvement in thermal efficiency and heat rate
c=H-H_c;
d=H-h_c;
n_R=(H-H_c)/(H-h_c);
hr_R=3600/n_R;
deln_th=(n_th-n_R)/n_R;
disp ("%",deln_th*100,"(c)therefore, the improvement in efficiency is")
delhr_t=(hr_R-hr_t)/hr_R;
disp ("%",delhr_t*100," and, the improvement in heat rate is")

// part(d) decrease of steam flow to the condenser per kWh due to feed heating
q_s=m*(H-h_n);
q_r=H_c-h_c;
w_t=q_s-q_r;
wt_m=w_t/m;
sf_r=3600/wt_m;
s_c=sf_r/m;
// without feed heating
wt_f=H-H_c;
m_wf=3600/wt_f;
sr_c=(m_wf-s_c)/m_wf;
disp ("%",sr_c*100,"(d)the decrease in steam
```

```
    reaching the condenser is")
disp("comment: the calculation for the improvement
    in efficiency is wrong in the book.")
```

Chapter 5

Combined Cycle Plants

Scilab code Exa 5.1 Calculation on combined cycle power plant

```
// scilab Code Exa 5.1. Calculation on combined
   cycle power plant

P_gt=1e5; // Power Output in kW
m_g=400; // mass flow rate of the exhaust gas in kg/
   s
cp_g=1.157; // Specific Heat of gas at Constant
   Pressure in kJ/(kgK)
x=0.9; // dryness fraction of steam at the turbine
   exit

// part(a) Determining capacity of the boiler in kg
   of steam per hour
p1=90; // steam Pressure at the entry of steam
   turbine in bar
// from steam tables
t_6s=303.3; // saturation temperature at 90 bar in
   degree C
t_5s=t_6s;
```

```
h_fg=1380.8; // from steam table liquid vapour
   enthalpy at 90 bar
pp=20; // pinch point in degree C
t_6=t_6s+pp;
h_5s=2744.6;
h_6s=1363.8;

t4=592.6;  // Exhaust gas temperature at gas turbine
    end in degree C
T4=t4+273; // in Kelvin
p_c=0.1; // Condenser pressure in bar
t7=176;  // Exhaust gas temperature at stack in
   degree C
T7=t7+273; // in Kelvin
h_7s=191.8; // Specific Enthalpy of water in kJ/kg

m_st=(m_g*cp_g*(t_6-t7))/(h_6s-h_7s);
disp ("tonnes/hr" ,m_st*3.6,"(a)capacity of the
   boiler in kg of steam per hour is")

// part(b) temperature of steam at turbine entry
t_5=t_6+((m_st*(h_5s-h_6s))/(m_g*cp_g)); // energy
   balance for the evaporator

h_4s=h_5s+(m_g*cp_g*(t4-t_5)/m_st);
t_4s=540; // in degree C from steam table at p=90
   bar
disp("degree celsius",t_4s,"(b)temperature of steam
   at turbine entry is")

// part(c)steam turbine plant output and thermal
   efficiency
h_5=2350;
h_6=2150;
w_st_s=h_4s-h_5;
w_st_g=w_st_s*(m_st/m_g);
P_st=m_st*w_st_s;
disp("MW",P_st/10e02,"(c)Power output of the steam
```

```
turbine plant is")
q_st=h_4s-h_7s;
n_st=w_st_s/q_st;
disp ("%" ,n_st*100,"thermal Efficiency of staem turbine plant is")

// part(d) thermal efficiency of the combined cycle plant
n_gt=0.2666; // Gas turbine plant Efficiency
w_gt=P_gt/m_g;
q_gt=w_gt/n_gt;
n_c=(w_gt+w_st_g)/q_gt;
disp ("%" ,n_c*100,"(d)thermal Efficiency of combined cycle plant is")
disp("Comment: Error in Textbook, Answers vary due to Round-off Errors")
```

Scilab code Exa 5.2 combined gas and steam cycle power plant

```
// scilab Code Exa 5.2 combined gas and steam cycle power plant
P_gt=10e03; // Power Output in kW
n_st=0.32; // Steam turbine power plant Efficiency

// part(a)steam turbine plant output
n_gt=0.2; // Gas turbine plant Efficiency
q_gt=P_gt/n_gt;
q_st=(1-n_gt)*q_gt;
P_st=n_st*q_st;
disp("MW",P_st/10e02,"(a)Power output of the steam turbine plant is")

// part(b) thermal efficiency of the combined cycle
```

```
    plant
n_c=n_gt+n_st-(n_gt*n_st);
disp ("%" ,n_c*100,"(b)thermal Efficiency of
    combined cycle plant is")

// part(c) the heat rate of the combined cycle plant
hr_c=3600/n_c;
disp ("kJ/kWh",hr_c," (c)Heat Rate of the combined
    cycle plant is")
```

Chapter 6

Fluid dynamics

Scilab code Exa 6.1 inward flow radial turbine 32000rpm

```
// scilab Code Exa 6.1 inward flow radial turbine
   32000rpm
P=150; // Power Output in kW
N=32e3; // Speed in RPM
d1=20/100; // outer diameter of the impeller in m
d2=8/100; // inner diameter of the impeller in m
V1=387; // Absolute Velocity of gas at entry in m/s
V2=193; // Absolute Velocity of gas at exit in m/s

// part(a) determining mass flow rate
u1=%pi*d1*N/60;
u2=d2*u1/d1;
w_at=u1^2/10e2;
m=P/w_at;
disp ("kg/s" ,m,"(a)mass flow rate is")

// part (b) determining the percentage energy
   transfer due to the change of radius
n=((u1^2-u2^2)/2e3)/w_at;
```

```
disp ("%",n*100,"(b)percentage energy transfer due
    to the change of radius is")
```

Scilab code Exa 6.2 radially tipped Centrifugal blower 3000rpm

```
// scilab Code Exa 6.2 radially tipped Centrifugal
    blower 3000rpm
P=150; // Power Output in kW
N=3e3; // Speed in RPM
d2=40/100; // outer diameter of the impeller in m
d1=25/100; // inner diameter of the impeller in m
b=8/100; // impeller width at entry in m
n_st=0.7; // stage efficiency
V1=22.67; // Absolute Velocity at entry in m/s
ro=1.25; // density of air in kg/m3

// part(a) determining the pressure developed
u2=%pi*d2*N/60;
u1=d1*u2/d2;
w_ac=u2^2;
delh_s=n_st*w_ac;
delp=ro*delh_s;
disp ("mm W.G." ,delp/9.81,"(a)the pressure
    developed is")

// part (b) determining the power required
A1=%pi*d1*b;
m=ro*V1*A1;
P=m*w_ac/10e2;
disp("kW",P,"(b)Power required is")
```

Scilab code Exa 6.3 Calculation on an axial flow fan

```
// scilab Code Exa 6.3 Calculation on an axial flow
    fan
N=1.47e3; // Speed in RPM
d=30/100; // Mean diameter of the impeller in m
ro=1.25; // density of air in kg/m3

// part(b) determining the pressure rise across the
    fan
u=%pi*d*N/60;
w_c=u^2/3;
delp=ro*w_c;
disp("mm W.G." ,delp/9.81,"(b)the pressure rise
    across the fan is")
```

Chapter 7

Dimensional Analysis and Performance Parameters

Scilab code Exa 7.1 Calculation for the specific speed

```
// scilab Code Exa 7.1 Calculation for the specific
   speed
funcprot(0)
//part(a)specific speed of gas turbine
P=2e3; // Gas Turbine Power Output in kW
N=16e3; // Speed in RPM
T1=1e3;  // Entry Temperature in Kelvin
p1=50; //  Entry Pressure in bar
p2=25; //  Exit Pressure in bar
cp=1.15e3; // Specific Heat at Constant Pressure in
   J/(kgK)
gamma_g=1.3;
omega=%pi*2*N/60;
ro=p1*1e5/(((gamma_g-1)/gamma_g)*cp*T1);
pr=p2/p1; //  pressure ratio
T2s=T1*(pr^((gamma_g-1)/gamma_g));
delh_s=cp*(T1-T2s);
```

```
NS=omega*sqrt(P*10e2/ro)*delh_s^(-5/4)
disp(NS,"(a)the specific speed of gas turbine is")

// part(b)the specific speed of a centrifugal
   compressor
pr_b=2; // Compressor pressure ratio
N_b=24e3; // Speed in RPM
m=1.5; //  in kg/s
cp_a=1.005e3; // Specific Heat of air at Constant
   Pressure in kJ/(kgK)
R=0.287;
gamma=1.4;
T1_b=300;  // Entry Temperature in Kelvin
p1_b=1; //  Entry Pressure in bar
ro_b=p1_b*1e2/(R*T1_b);
omega_b=%pi*2*N_b/60;
Q=m/ro_b;
T2=T1_b*(pr_b^((gamma-1)/gamma));
delh_s_b=cp_a*(T2-T1_b);
NS_b=omega_b*sqrt(Q)*delh_s_b^(-3/4);
disp(NS_b,"(b)the specific speed of a centrifugal
   compressor is")

// part(c)the specific speed of an axial compressor
pr_c=1.4; // Compressor pressure ratio
N_c=6e3; // Speed in RPM
m_c=15; //  in kg/s
omega_c=%pi*2*N_c/60;
Q_c=m_c/ro_b;
T2_c=T1_b*(pr_c^((gamma-1)/gamma));
delh_s_c=cp_a*(T2_c-T1_b);
NS_c=omega_c*sqrt(Q_c)*delh_s_c^(-3/4)
disp(NS_c,"(c)the specific speed of an axial
   compressor is")
```

Scilab code Exa 7.2 Calculating the discharge and specific speed

```

// scilab Code Exa 7.2 Calculating the discharge of
   a geometrically similar blower and specific speed
    of the fan
pr=2; // Compressor pressure ratio
N1=1.47e3; // fan Speed in RPM
N2=0.36e3; // blower Speed in RPM
Q1=2; // discharge in m3/s
h=10e-3; // in m W.G.
ro_w=10e2;
ro_a=1.25; // density of air in kg/m3
omega1=%pi*2*N1/60;
g=9.81; // in m/s2
p=ro_w*g*h
H=p/(ro_a*g);
delh_s=g*H;
NS=omega1*sqrt(Q1)*delh_s^(-3/4)
disp(NS,"the specific speed is")
// for the same specific speed of two geometrically
   similar fans
a=N1/N2;
Q2=a^2*Q1;
disp("m3/s",Q2," and the discharge of a
   geometrically similar blower is")
```

Scilab code Exa 7.3 Calculation on a small compressor

```
// scilab Code Exa 7.3 Calculation on a small
    compressor
pr=1.6; // Compressor pressure ratio
N1=54e3; // Speed in RPM
n_c=0.85; // efficiency
m_a=1.5778; //  in kg/s
cp_a=1.009; // Specific Heat of air at Constant
    Pressure in kJ/(kgK)
gamma=1.4;
// part (a) determining the power required to drive
    the compressor
T01=300;  // Entry Temperature in Kelvin
p01=1.008; //  Entry Pressure in bar
n=(gamma-1)/gamma;
T2s=T01*(pr^n);
delh_s=cp_a*(T2s-T01)/n_c;
P=m_a*delh_s;
disp("kW",P,"(a)Power required to drive the
    compressor is")

// part (b) determining the speed, mass flow rate,
    pressure ratio and power required of a
    geometrically similar compressor
// geometrically similar compressor of 3 times the
    size of small compressor is constructed
N2=N1/3;
disp("rpm",N2,"(b)(i)speed of a geometrically
    similar compressor is")
m2=9*m_a;
disp("kg/s",m2,"(b)(ii)mass flow rate of a
    geometrically similar compressor is")
disp(pr,"(b)(iii)pressure ratio of a geometrically
    similar compressor is")
P2=9*P;
disp("kW",P2,"(b)(iv)Power required is")
```

Scilab code Exa 7.4 Calculation on design of a single stage gas turbine

```
// scilab Code Exa 7.4 Calculation on a single stage gas turbine

gamma_g=1.33;
gamma=1.4
R_g=284.1;
R=287;
P=1e3; // Power Output in kW
N1=3e3; // Speed in RPM
n_t=0.87; // efficiency
cp_g=1.145; // Specific Heat of gas at Constant Pressure in kJ/(kgK)
cp_a=1.0045; // Specific Heat of air at Constant Pressure in kJ/(kgK)

// part (a)mass flow rate of the gas through the turbine
T01=1000;  // Entry Temperature in Kelvin
p01=2.5; //  Entry Pressure in bar
T01a=500;  // Entry Temperature of air in Kelvin
p01a=2; //  Entry Pressure of air in bar
p02=1; //  Exit Pressure in bar
pr0=p01/p02;
T02=T01*(pr0^(-((gamma_g-1)/gamma_g)));
delh_s1=cp_g*(T01-T02)*n_t;
m_g=P/delh_s1;
disp("kg/s",m_g,"(a)mass flow rate of the gas through the turbine is")

// part (b)speed, mass flow rate, pressure ratio and
```

```
    power required
N2=sqrt(1/2)*5*N1;
disp("rpm",N2,"(b)(i)speed of a geometrically
   similar compressor is")
a=0.2; // a=D2/D1;
m2=(a^2)*sqrt(R_g/R)*sqrt(T01/T01a)*(p01a/p01)*m_g;
disp("kg/s",m2,"(b)(ii)mass flow rate of a
   geometrically similar turbine is")
delh_s2=0.5*delh_s1;
P2=m2*delh_s2;
disp("kW",P2,"(b)(iii)Power developed is")
pr=(1-(delh_s2/(cp_a*T01a*n_t)))^(-1/((gamma-1)/
   gamma));
disp(pr,"(b)(iv)pressure ratio of a geometrically
   similar turbine is")
```

Chapter 8

Flow Through Cascades

Scilab code Exa 8.1 Calculation on a compressor cascade

```
// scilab Code Exa 8.1 Calculation on a compressor
   cascade

V1=75; // Absolute Velocity of air at entry in m/s
alpha1=48; // air angle at entry
alpha2=25; // air angle at exit
p=1.1; // pitch-chord ratio
delps=11; // stagnation pressure loss in mm W.G.
ro=1.25; // density of air in kg/m3
g=9.81;
a=0.5*(tand(alpha1)+tand(alpha2));
alpham=atand(a);
b=0.5*ro*(V1^2);
Y=delps*g/b;
disp (Y,"the loss coefficient is")
c=(cosd(alpham)^3)/(cosd(alpha1)^2);
C_D=p*Y*c;
disp (C_D,"the drag coefficient is")
d=2*p*(tand(alpha1)-tand(alpha2))*cosd(alpham);
```

```
e=C_D*tand(alpham);
C_L=d-e;
disp (C_L,"the Lift coefficient is")
f=(cosd(alpha1)^2)/(cosd(alpha2)^2);
C_ps=1-f;
disp (C_ps,"the Ideal pressure recovery coefficient is")
C_pa=C_ps-Y;
disp (C_pa,"the Actual pressure recovery coefficient is")
n_D=C_pa/C_ps;
disp (n_D,"the Diffuser efficiency is")
n_dmax=1-(2*C_D/C_L);
disp (n_dmax,"the Maximum Diffuser efficiency is")
```

Scilab code Exa 8.2 Calculation on a turbine blade row cascade

```
// scilab Code Exa 8.2 Calculation on a turbine blade row cascade

beta1=35; //  blade angle at entry
beta2=55; // blade angle at exit
i=5; // incidence
delta=2.5; // deviation
alpha1=beta1+i; // air angle at entry
alpha2=beta2-delta; // air angle at exit
t_c=0.3; // maximum thickness-chord ratio(t/l)
a_r=2.5; // aspect ratio

//part(a)optimum pitch-chord ratio from Zweifels relation
C_z=0.8; // from Zweifel's relation
p_c=C_z/(2*(cosd(alpha2)^2)*(tand(alpha1)+tand(
```

```
    alpha2)));
disp (p_c,"(a)the optimum pitch-chord ratio from
    Zweifels relation is")

//part(b) loss coefficient from Soderbergs and
    Hawthorne relations
ep=alpha1+alpha2; // deflection angle
Zeeta=0.075;
b=(1+Zeeta)*(0.975+(0.075/a_r))
zeeta=b-1;
disp (zeeta,"(b)(i)the loss coefficient from
    Soderbergs relation is")
z_p=0.025*(1+((ep/90)^2)); // Hawthorne's relation
disp (z_p,"(b)(ii)the loss coefficient from
    Hawthorne relation is")
z=(1+(3.2/a_r))*z_p; // the total cascade loss
    coefficient
Y=0.5*(z+zeeta);

// part(c)drag coefficient
alpham=atand(0.5*(tand(alpha2)-tand(alpha1)));
C_D=p_c*Y*(cosd(alpham)^3)/(cosd(alpha2)^2);
disp (C_D,"(c)the drag coefficient is")

// part(d)Lift coefficient
C_L=(2*p_c*(tand(alpha1)+tand(alpha2))*cosd(alpham))
    +(C_D*tand(alpham));
disp (C_L,"(d)the Lift coefficient is")
```

Scilab code Exa 8.3 Calculation on a compressor cascade

```
// scilab Code Exa 8.3 Calculation on a compressor
    cascade
```

```
theta=25; // Camber angle
gamma_a=30; // stagger angle
i=5; // incidence
t_c=0.031; // momentum thickness-chord ratio(t/l)
p_c=1; // pitch-chord ratio

//part(a)cascade blade angles
beta1=((2*gamma_a)+theta)*0.5; //  blade angle at
    entry
beta2=((2*gamma_a)-theta)*0.5; // blade angle at
    exit
disp ("(a)therefore , the blade angles are")
disp ("degree",beta1,"beta1=")
disp ("degree",beta2,"beta2=")

//part(b) the nominal air angles
alpha1=beta1+i; // air angle at entry
alpha2=atand(tand(alpha1)-(1.55/(1+(1.5*p_c)))); //
    air angle at exit
disp ("(b)therefore , the air angles are")
disp ("degree",alpha1,"alpha1=")
disp ("degree",alpha2,"alpha2=")

//part(c) stagnation pressure loss coefficient
Y=2*t_c*p_c*(cosd(alpha1)^2)/(cosd(alpha2)^3);
disp (Y,"(c)the stagnation pressure loss coefficient
     is")

// part(d)drag coefficient
alpham=atand(0.5*(tand(alpha1)+tand(alpha2)));
C_D=p_c*Y*(cosd(alpham)^3)/(cosd(alpha1)^2);
disp (C_D,"(d)the drag coefficient is")

// part(e)Lift coefficient
C_L=(2*p_c*(tand(alpha1)-tand(alpha2))*cosd(alpham))
    -(C_D*tand(alpham));
disp (C_L,"(e)the Lift coefficient is")
```

Scilab code Exa 8.4 Calculation on a blower type annular cascade tunnel

```
// scilab Code Exa 8.4 blower type annular cascade
   tunnel

t=35;
T=t+273;  // test Temperature in Kelvin
p=1.02; //  test Pressure in bar
dm=50/100; // mean diameter of the impeller blade in
    m
b=15/100; // blade length in m
n_o=0.6; // stage efficiency
R=287;
c=100; // Maximum Velocity upstream of the cascade
   in m/s
ro=p*10e4/(R*T); // density of air in kg/m3

// part(a) determining the total pressure developed
   by the blower
d_h=0.5*ro*(c^2);
loss=0.1*d_h;
delp=d_h+loss;
disp ("mm W.G." ,delp/9.81,"(a)the pressure
   developed is")

// part (b) determining the discharge
A=%pi*dm*b; // the annulus cross-sectional area
Q=c*A;
disp ("m3/min" ,Q*60,"(b)the discharge is")

// part (c) determining the power required to drive
   the blower
```

```
P=Q*delp/(n_o*10e2);
disp("kW",P,"(c)Power required to drive the blower
   is")
```

Scilab code Exa 8.5 Calculation on a compressor type radial cascade tunnel

```
// scilab Code Exa 8.5 compressor type radial
   cascade tunnel

M=0.7; // Mach Number
pr=0.721; // pr=pt/p0 From isentropic gas tables
t_opt=0.911; // t_opt=Tt/T0
pa=1.013; //  Atmospheric Pressure in bar
Ta=306; // in K
n_c=0.65; // efficiency
R=288;
gamma=1.4;
alpha=30;
dm=45/100; // mean diameter of the impeller blade in
    m
b=10/100; // blade width in m
cp_a=1.008; // Specific Heat of air at Constant
   Pressure in kJ/(kgK)

// part(a) pressure ratio of the compressor
pr_c=1/pr;
disp(pr_c,"(a)pressure ratio of the compressor is")

// part(b) stagnation pressure in the settling
   chamber
p02=pa*pr_c;
disp("bar",p02,"(b)stagnation pressure in the
```

```
settling chamber is")

// part(c)test section conditions(static pressure, temperature and velocity)
n=(gamma-1)/gamma;
T02s=Ta*(pr_c^((gamma-1)/gamma));
T02=Ta+((T02s-Ta)/n_c);
T_t=t_opt*T02;
p_t=pr*p02;
c_t=M*sqrt(gamma*R*T_t);
disp("(c)test section conditions are given by: ")
disp("bar",p_t,"static pressure of air in the test section is")
disp("K",T_t,"static temperature of air in the test section is")
disp("m/s",c_t,"velocity of air in the test section is")

// part(d) determining mass flow rate
c_r=c_t*sind(alpha);
ro_t=p_t*1e5/(R*T_t); // density of air in kg/m3
A_t=%pi*dm*b;
m=ro_t*A_t*c_r;
disp("kg/s",m,"(d) mass flow rate of compressor is")

// part (e) determining the power required to drive the air compressor
delh_s=cp_a*(T02-Ta);
P=m*delh_s;
disp("kW",P,"(e)Power required to drive the air compressor is")
```

Chapter 9

Axial Turbine Stages

Scilab code Exa 9.1 Calculation on multi stage turbine

```
// scilab Code Exa 9.1 Calculation on multi stage
   turbine

d=1; // mean diameter of the impeller blade in m
T1=500;  // Initial Temperature in degree C
t1=T1+273; // in Kelvin
p1=100; //  Initial Pressure in bar
N=3e3; // Speed in RPM
m=100; //  in kg/s
alpha2=70; // exit angle of the first stage nozzle
   blades

// part(a) single stage impulse
nsti=0.78;
u=%pi*d*N/60;
sigma=0.5*(sind(alpha2)); // maximum utilization
   factor
c2=u/sigma;
cx=c2*(cosd(alpha2));
```

```
beta2=atand(0.5*(tand(alpha2))); // beta2=beta3
wst=2*(u^2)*1e-3;
P=m*wst;
disp("(a)for single stage impulse")
disp("degree",beta2,"blade angles are beta2=beta3= ")
disp("MW",P*1e-3,"Power developed is")

sv=0.04; // specific volume of steam after expansion in m3/kg
h=(m*sv)/(cx*%pi*d); // h2=h3=h
disp("cm",h*1e2,"blade height is")
delhs=wst/nsti;
disp("final state of the steam is")
p=81.5; // from enthalpy-entropy diagram
T=470;
disp("bar",p,"p=")
disp("degree C",T,"T=")

// part(b) Two-stage Curtis wheel
nstc=0.65;
u=%pi*d*N/60;
sigma2=0.25*(sind(alpha2));
c2_2=u/sigma2;
cx2=c2_2*(cosd(alpha2));
beta2_2=atand((3*u)/cx2); // beta2=beta3
alpha3=atand((2*u)/(c2_2*cosd(alpha2))); // alpha2'=alpha3
beta2_s=atand((u)/cx2); // beta2'=beta3'
wI=6*(u^2)*1e-3;
wII=2*(u^2)*1e-3;
wst2=wI+wII;
P2=m*wst2;
disp("(b)for Two-stage Curtis wheel")
disp("degree",alpha3,"air angles are alpha2s=alpha3= ")
disp("degree",beta2_2,"for first stage blade angles are beta2=beta3= ")
```

```
disp("degree",beta2_s,"for second stage blade angles are beta2s=beta3s= ")

disp("MW",P2*1e-3,"Power developed is")

delhs2=wst2/nstc;
// from enthalpy-entropy diagram for the expansion
disp("final state of the steam is")
p2=27;
T2=365;
v2=0.105; // specific volume of steam after expansion in m3/kg
disp("bar",p2,"p=")
disp("degree C",T2,"T=")
disp("m3/kg",v2,"v=")
h2=(m*v2)/(cx2*%pi*d);
disp("cm",h2*1e2,"blade height is")

// part(c) Two-stage Reateau wheel
nst1=0.78;
wI3=2*(u^2)*1e-3;
wII3=2*(u^2)*1e-3;
wst3=wI3+wII3;
P3=m*wst3;
disp("(c)for Two-stage Reateau wheel")
disp("degree",beta2,"blade angles are beta2=beta3= ")
disp("MW",P3*1e-3,"Power developed is")
delhs3=wst3/nst1;
disp("final state of the steam is")
p3=65; // from enthalpy-entropy diagram
T3=445;
v3=0.05; // specific volume of steam after expansion in m3/kg
disp("bar",p3,"p=")
disp("degree C",T3,"T=")
disp("m3/kg",v3,"v=")
h3=(m*v3)/(cx*%pi*d);
```

```
disp("cm",h3*1e2,"blade height for the second stage
    is")

// part(d) single stage 50% reaction
nstr=0.85;
sigma4=sind(alpha2); // maximum utilization factor
c2_4=u/sigma4; // c2_4=w_3
cx4=c2_4*(cosd(alpha2)); // alpha2=beta3;
beta2_4=0; // beta2=alpha3
wst4=(u^2)*1e-3;
P4=m*wst4;
disp("(d)for single stage 50% reaction")
disp("degree",beta2_4,"blade angles are beta2=alpha3
    = ")
disp("degree",alpha2,"and beta3=alpha2= ")
disp("MW",P4*1e-3,"Power developed is")
delhs4=wst4/nstr;
// from enthalpy-entropy diagram
disp("final state of the steam is")
p4=90;
T4=485;
v4=0.035;
disp("bar",p4,"p=")
disp("degree C",T4,"T=")
disp("m3/kg",v4,"v=")
h4=(m*v4)/(cx4*%pi*d);
disp("cm",h4*1e2,"the rotor blade height at exit is"
    )
```

Scilab code Exa 9.2 Calculation on an axial turbine stage

```
// scilab Code Exa 9.2 Calculation on an axial
    turbine stage
```

```
dh=0.450; // hub diameter in m
dt=0.750; // tip diameter in m
d=0.5*(dt+dh); // mean diameter of the impeller
   blade in m
r=d/2;
T1=500;  // Initial Temperature in degree C
t1=T1+273; // in Kelvin
p1=100; //  Initial Pressure in bar
N=6e3; // rotor Speed in RPM
m=100; //  in kg/s
alpha2m=75; //  air angle at nozzle exit
beta2m=45; //  air angle at rotor entry
beta3m=76; //  air angle at rotor exit
u=%pi*d*N/60;
uh=%pi*dh*N/60;
ut=%pi*dt*N/60;
// for mean section
c2m=(cosd(beta2m)/sind(alpha2m-beta2m))*u;
cx2m=c2m*cosd(alpha2m);
ct2m=c2m*sind(alpha2m);
ct3m=(cx2m*tand(beta3m))-u;
C2=r*ct2m;
C3=r*ct3m;

// part(a) the relative and absolute air angles
disp("for mean section")
disp("(a) the relative and absolute air angles are")
disp("degree",beta2m," air angle at rotor entry is
   beta2m= ")
disp("degree",beta3m," air angle at rotor exit is
   beta3m= ")
disp("degree",alpha2m," air angle at nozzle exit is
   alpha2m= ")
// part(b) degree of reaction
cx=cx2m;
R=cx*(tand(beta3m)-tand(beta2m))*100/(2*u);
disp("%",R,"(b)degree of reaction is")
```

```
// part(c) blade-to-gas speed ratio
sigma=u/c2m;
disp(sigma,"(c)blade-to-gas speed ratio is")
// part(d) specific work
omega=2*%pi*N/60;
w=omega*(C2+C3);
disp("kJ/kg",w*1e-3,"(d)specific work is")
// part(e) the loading coefficient
z=w/(u^2);
disp(z,"(e)the loading coefficient is")

// for hub section
rh=dh/2;
alpha2h=atand(C2/(rh*cx));
disp("for hub section")
disp("(a) the relative and absolute air angles are")
disp("degree",alpha2h,"air angle at nozzle exit is
    alpha2h= ")
beta2h=atand(tand(alpha2h)-(uh/cx));
disp("degree",beta2h,"air angle at rotor entry is
    beta2h= ")
beta3h=atand((C3/(rh*cx))+(uh/cx));
disp("degree",beta3h,"air angle at rotor exit is
    beta3h= ")
// part(b) degree of reaction
Rh=cx*(tand(beta3h)-tand(beta2h))*100/(2*uh);
disp("%",Rh,"(b)degree of reaction is")
// part(c) blade-to-gas speed ratio
c2h=cx/(cosd(alpha2h));
sigmah=uh/c2h;
disp(sigmah,"(c)blade-to-gas speed ratio is")
// part(d) specific work
wh=uh*cx*(tand(beta3h)+tand(beta2h));
disp("kJ/kg",wh*1e-3,"(d)specific work is")
// part(e) the loading coefficient
zh=wh/(uh^2);
disp(zh,"(e)the loading coefficient is")

```

```
// for tip section
rt=dt/2;
alpha2t=atand(C2/(rt*cx));
disp("for tip section")
disp("(a) the relative and absolute air angles are")
disp("degree",alpha2t,"air angle at nozzle exit is
    alpha2t= ")
beta2t=atand(tand(alpha2t)-(ut/cx));
disp("degree",beta2t,"air angle at rotor entry is
    beta2t= ")
beta3t=atand((C3/(rt*cx))+(ut/cx));
disp("degree",beta3t,"air angle at rotor exit is
    beta3t= ")
// part(b) degree of reaction
Rt=cx*(tand(beta3t)-tand(beta2t))*100/(2*ut);
disp("%",Rt,"(b)degree of reaction is")
// part(c) blade-to-gas speed ratio
c2t=cx/(cosd(alpha2t));
sigmat=ut/c2t;
disp(sigmat,"(c)blade-to-gas speed ratio is")
// part(d) specific work
wt=ut*cx*(tand(beta3t)+tand(beta2t));
disp("kJ/kg",wt*1e-3,"(d)specific work is")
// part(e) the loading coefficient
zt=wt/(ut^2);
disp(zt,"(e)the loading coefficient is")
```

Scilab code Exa 9.3 Calculation on an axial turbine stage

```
// scilab Code Exa 9.3 Calculation on an axial
    turbine stage

dh=0.450; // hub diameter in m
```

```
dt=0.750; // tip diameter in m
d=0.5*(dt+dh); // mean diameter of the impeller blade in m
r=d/2;
R_m=0.5; // degree of reaction for mean section
T1=500;  // Initial Temperature in degree C
t1=T1+273; // in Kelvin
p1=100; //  Initial Pressure in bar
N=6e3; // rotor Speed in RPM
m=100; //  in kg/s
alpha2m=75; //  air angle at nozzle exit
beta_2m=0; //  air angle at rotor entry
beta_3m=75; //  air angle at rotor exit
// assuming radial equillibrium and free vortex flow in the stage , axial velocity is constant throughout
u_m=%pi*d*N/60;
uh=%pi*dh*N/60;
ut=%pi*dt*N/60;
// for mean section
c_xm=u_m*cotd(alpha2m);
c_2m=(1/sind(alpha2m))*u_m;
c_t2m=u_m;

disp("for mean section")
// part(c) blade-to-gas speed ratio
sigma_m=u_m/c_2m;
disp(sigma_m,"(c)blade-to-gas speed ratio is")
// part(d) specific work
w_m=u_m*c_t2m;
disp("kJ/kg",w_m*1e-3,"(d)specific work is")
// part(e) the loading coefficient
shi_m=w_m/(u_m^2);
disp(shi_m,"(e)the loading coefficient is")

// for hub section
rh=dh/2;
n=(sind(alpha2m)^2);
```

```
c_x2h=c_xm*((r/rh)^n);
c_t2h=c_t2m*((r/rh)^n);
c_2h=c_2m*((r/rh)^n);
disp("for hub section")
disp("(a) the relative air angles are")
beta2h=atand((c_t2h-uh)/c_x2h);
disp("degree",beta2h,"air angle at rotor entry is
    beta2h= ")
beta3h=atand(uh/c_x2h);
disp("degree",beta3h,"air angle at rotor exit is
    beta3h= ")
// part(b) degree of reaction
Rh=c_x2h*(tand(beta3h)-tand(beta2h))*100/(2*uh);
disp("%",Rh,"(b)degree of reaction is")
// part(c) blade-to-gas speed ratio
sigmah=uh/c_2h;
disp(sigmah,"(c)blade-to-gas speed ratio is")
// part(d) specific work
wh=uh*c_t2h;
disp("kJ/kg",wh*1e-3,"(d)specific work is")
// part(e) the loading coefficient
shi_h=wh/(uh^2);
disp(shi_h,"(e)the loading coefficient is")

// for tip section
rt=dt/2;
c_x2t=c_xm*((r/rt)^n);
c_t2t=c_t2m*((r/rt)^n);
c_2t=c_2m*((r/rt)^n);
disp("for tip section")
disp("(a) the relative air angles are")
beta2t=atand((c_t2t-ut)/c_x2t);
disp("degree",beta2t,"air angle at rotor entry is
    beta2t= ")
beta3t=atand(ut/c_x2t);
disp("degree",beta3t,"air angle at rotor exit is
    beta3t= ")
// part(b) degree of reaction
```

```
Rt=c_x2t*(tand(beta3t)-tand(beta2t))*100/(2*ut);
disp("%",Rt,"(b)degree of reaction is")
// part(c) blade-to-gas speed ratio
sigmat=ut/c_2t;
disp(sigmat,"(c)blade-to-gas speed ratio is")
// part(d) specific work
wt=ut*c_t2t;
disp("kJ/kg",wt*1e-3,"(d)specific work is")
// part(e) the loading coefficient
shi_t=wt/(ut^2);
disp(shi_t,"(e)the loading coefficient is")
```

Scilab code Exa 9.4 axial turbine stage 3000 rpm

```
// scilab Code Exa 9.4 axial turbine stage 3000 rpm

d=1; // mean diameter of the impeller blade in m
r=d/2;
N=3e3; // rotor Speed in RPM
a_r(1)=1; // aspect ratio
a_r(2)=2;
a_r(3)=3;
alpha2=70; //  air angle at nozzle exit
alpha3=0;
beta_2=54; //  air angle at rotor entry
sigma=0.5*(sind(alpha2)); // blade to gas speed
   ratio
u=%pi*d*N/60;
c2=u/sigma;
cx=c2*(cosd(alpha2));
beta_3=beta_2;  //  air angle at rotor exit
phi=cx/u;
e_R=beta_2+beta_3; // Rotor deflection angle
```

```
zeeta_p_N=0.025*(1+((alpha2/90)^2)); // profile loss
    coefficient for nozzle
zeeta_p_R=0.025*(1+((e_R/90)^2)); // profile loss
    coefficient for rotor
for i=1:3
disp(a_r(i),"when Aspect ratio=")
zeeta_N=(1+(3.2/a_r(i)))*zeeta_p_N; // total loss
    coefficient for nozzle
zeeta_R=(1+(3.2/a_r(i)))*zeeta_p_R; // total loss
    coefficient for rotor
a=(zeeta_R*(secd(beta_3)^2))+(zeeta_N*(secd(alpha2)
    ^2));
b=phi*(tand(alpha2)+tand(beta_3))-1;
c=(zeeta_R*(secd(beta_3)^2))+(zeeta_N*(secd(alpha2)
    ^2))+(secd(alpha3)^2);
n_tt=inv(1+(0.5*(phi^2)*(a/b)));
disp("%",n_tt*1e2,"total-to-total efficiency is")
n_ts=inv(1+(0.5*(phi^2)*(c/b)));
disp("%",n_ts*1e2,"total-to-static efficiency is")
end
```

Scilab code Exa 9.5 Calculation on a gas turbine stage

```
// scilab Code Exa 9.5 Calculation on a gas turbine
    stage

Rm=0.5; // Degree of reaction
funcprot(0);
T1=1500;  // in Kelvin
p1=10; //  Initial Pressure in bar
N=12e3; // rotor Speed in RPM
m=70; //  in kg/s
pr=2; // Pressure Ratio
```

```
n_st=0.87; // Stage Efficiency
alpha_2=60; //  Fixed Blade exit angle
cp=1005; // Specific Heat at Constant Pressure in J
    /(kgK)
R=287;
gamma=1.4;
n=(gamma-1)/gamma;
T3ss=T1/(pr^n);
delh1_3=cp*(T1-T3ss)*n_st;
delh1_2=0.5*delh1_3;
c2=sqrt(2*delh1_2);
sigma_opt=sind(alpha_2);
u=sigma_opt*c2;
// part(a) Flow coefficient
cx=c2*cosd(alpha_2);
phi=cx/u;
disp(phi,"(a)Flow coefficient is")

// part(b) mean diameter of the stage
d=u*60/(%pi*N);
disp("m",d,"(b)mean diameter of the stage is")

// part(c) power developed
P=m*delh1_3;
disp("MW",P*1e-6,"(c)power developed is")

// part(d) pressure ratio across the fixed and rotor
     blade rings
delh1_3ss=delh1_3/n_st;
delT1_3=delh1_3/cp;
delT1_3ss=delh1_3ss/cp;
stage_loss=delT1_3ss-delT1_3;
delT1_2=delh1_2/cp;
delT1_2s=delT1_2+(0.5*stage_loss)
pr_stator=((1-(delT1_2s/T1))^(-1/n));
disp(pr_stator,"(d)pressure ratio across the fixed
    blade rings is")
pr_rotor=pr/pr_stator;
```

```
disp(pr_rotor,"and pressure ratio across the rotor
    blade rings is")

// part(e) hub-tip ratio of the rotor
p2=p1/pr_stator;
T2=T1-delT1_2;
ro2=(p2*1e5)/(R*T2);
l2=m/(ro2*cx*%pi*d);
p3=p2/pr_rotor;
T3=T1-delT1_3;
ro3=p3*1e5/(R*T3);
l3=m/(ro3*cx*%pi*d);
l=0.5*(l2+l3);
rm=d/2;
rh=rm-(l/2);
rt=rm+(l/2);
disp(rh/rt,"(e)hub-tip ratio of the rotor is")

// part(f) degree of reaction at the hub and tip
Rh=1-((1-Rm)*(rm^2/rh^2));
Rt=1-((1-Rh)*(rh^2/rt^2));
disp("%",Rh*1e2,"(f)degree of reaction at the hub is
    ")
disp("%",Rt*1e2,"(f)degree of reaction at the tip is
    ")
```

Chapter 11

Axial Compressor Stages

Scilab code Exa 11.1 Calculation on an axial compressor stage

```
// scilab Code Exa 11.1 Calculation on an axial
   compressor stage

Rm=0.5; // Degree of reaction
funcprot(0);
T1=300;  // in Kelvin
p1=1; //  Initial Pressure in bar
gamma=1.4;
N=18e3; // rotor Speed in RPM
d=36/100; // Mean Blade ring diameter in m
h=6/100; // blade height at entry in m
cx=180; // Axial velocity in m/s
alpha_1=25;  //  air angle at rotor and stator exit
wdf=0.88; // work-done factor
m=70; //  in kg/s
pr=2; // Pressure Ratio
n_st=0.85; // Stage Efficiency
n_m=0.967; // Mechanical Efficiency
cp=1005; // Specific Heat at Constant Pressure in J
```

```
/(kgK)
R=287;
u=%pi*d*N/60;
n=(gamma-1)/gamma;

// part(a) air angles at rotor and stator entry
cy1=cx*tand(alpha_1);
wy1=u-cy1;
beta1=atand(wy1/cx);
disp("degree",beta1,"air angles at rotor and stator entry are beta1=alpha2= ")
phi=cx/u;

// part(b) mass flow rate of the air
ro1=(p1*1e5)/(R*T1);
A1=%pi*d*h;
m=ro1*cx*A1;
disp("kg/s",m,"(b) mass flow rate of the air is")

// part(c) Determining power required to drive the compressor
beta2=alpha_1;
w=wdf*u*cx*(tand(beta1)-tand(beta2))
P=m*w/n_m;
disp ("kW" ,P/1000,"(c)Power required to drive the compressor is")

// part(d) Loading coefficient
shi=w/(u^2);
disp (shi,"(d)Loading coefficient is")

// part(e) pressure ratio developed by the stage
delTa=w/cp;
delTs=n_st*delTa;
pr=((1+(delTs/T1))^(1/n));
disp(pr,"(e)pressure ratio developed by the stage is")

```

```
// part(f) Mach number at the rotor entry
w1=cx/(cosd(beta1));
Mw1=w1/sqrt(gamma*R*T1);
disp(Mw1,"(f)Mach number at the rotor entry is")
```

Scilab code Exa 11.2 Calculation on an axial compressor stage

```
// scilab Code Exa 11.2 Calculation on an axial
   compressor stage

T1=314;  // in Kelvin
p1=768; //  Initial Pressure in mm Hg
N=18e3; // rotor Speed in RPM
d=50/100; // Mean Blade ring diameter in m
u=100; // peripheral speed in m/s
h=6/100; // blade height at entry in m
beta1=51;
beta2=9;
alpha_1=7;  //  air angle at rotor and stator exit
wdf=0.95; // work-done factor
m=25; //  in kg/s
n_st=0.88; // Stage Efficiency
n_m=0.92; // Mechanical Efficiency
cp=1005; // Specific Heat at Constant Pressure in J
   /(kgK)
R=287;
gamma=1.4;
n=(gamma-1)/gamma;

// part(a) air angle at stator entry
cx=u/(tand(alpha_1)+tand(beta1));
disp(cx,"cx=")
alpha2=atand(tand(alpha_1)+tand(beta1)-tand(beta2))
```

```
disp("degree",alpha2,"air angle at stator entry is alpha2= ")

// part(b) blade height at entry and hub-tip diameter ratio
ro1=(p1/750*1e5)/(R*T1);
h1=m/(ro1*cx*%pi*d);
disp("cm",h1*1e2,"(b)blade height at entry is")
dh=d-h1;
disp(dh,"dh=")
dt=d+h1;
disp(dt,"dt=")
disp(dh/dt,"and hub-tip diameter ratio is")

// part(c) stage Loading coefficient
w=wdf*u*cx*(tand(beta1)-tand(beta2));
shi=w/(u^2);
disp (shi,"(d)Loading coefficient is")

// part(d) stage pressure ratio
delTa=w/cp;
delTs=n_st*delTa;
pr=((1+(delTs/T1))^(1/n));
disp(pr,"(e)pressure ratio developed by the stage is")

// part(e) Determining power required to drive the compressor
P=m*w/n_m;
disp ("kW" ,P/1000,"(e)Power required to drive the compressor is")
```

Scilab code Exa 11.3 Calculation on an axial compressor stage

```
// scilab Code Exa 11.3 Calculation on an axial compressor stage

// part(c) Verification of stage efficiency of exa 11.1
beta1=54.82;
alpha_1=25;
beta2=alpha_1;
alpha_2=beta1;
phi=0.53; // Flow coefficient
YR=0.09; // loss coefficient for the blade rows
n_st=1-((phi*YR*(secd(beta1)^2))/(tand(beta1)-tand(beta2)))
disp("%",n_st*1e2,"stage efficiency n_st=")
// part(d) Determining efficiencies of the rotor and Diffuser blade rows
n_D=1-(YR/(1-((secd(alpha_1)^2)/(secd(alpha_2)^2))))
disp ("%",n_D*100," Efficiency of the diffuser n_D=n_R=")
```

Scilab code Exa 11.4 Calculation on hub mean and tip sections

```
// scilab Code Exa 11.4 Calculation on hub,mean and tip sections

dm=50/100; // Mean Blade ring diameter in m
rm=dm/2;
dh=0.3098354; // from results of exa 11.2
dt=0.6901646;
um=100; // peripheral speed in m/s
beta_1m=51;
beta_2m=9;
alpha_1m=7;  //  air angle at rotor and stator exit
```

```
alpha_2m=50.177922;
omega=um/rm;
rh=dh/2;
rt=dt/2;
uh=omega*rh;
ut=omega*rt;

// part(a) rotor blade air angles
cx=73.654965;
c_theta1m=cx*tand(alpha_1m);
C1=rm*c_theta1m;
c_theta1h=C1/rh;
c_theta1t=C1/rt;
c_theta2m=cx*tand(alpha_2m);
C2=rm*c_theta2m;
c_theta2h=C2/rh;
c_theta2t=C2/rt;
disp("(a) the rotor blade air angles are")
// for hub section
alpha1h=atand(C1/(rh*cx));
alpha2h=atand(C2/(rh*cx));
disp("for hub section")
disp("degree",alpha1h,"alpha1h=")
disp("degree",alpha2h,"alpha2h=")
beta1h=atand((uh/cx)-tand(alpha1h));
beta2h=atand((uh/cx)-tand(alpha2h));
disp("degree",beta1h,"beta1h=")
disp("degree",beta2h,"beta2h=")

// for tip section
alpha1t=atand(C1/(rt*cx));
alpha2t=atand(C2/(rt*cx));
disp("for tip section")
disp("degree",alpha1t,"alpha1t= ")
disp("degree",alpha2t,"alpha2t= ")
beta1t=atand((ut/cx)-tand(alpha1t));
beta2t=atand((ut/cx)-tand(alpha2t));
disp("degree",beta1t,"beta1t= ")
```

```
disp("degree",beta2t,"beta2t= ")

// part(b)Flow coefficients
disp("(b)Flow coefficients are")
phi_h=cx/uh;
disp(phi_h,"phi_h=")
phi_m=cx/um;
disp(phi_m,"phi_m=")
phi_t=cx/ut;
disp(phi_t,"phi_t=")
// part(c) degrees of reaction
disp("(c)Degrees of reaction are")
Rh=cx*(tand(beta1h)+tand(beta2h))*100/(2*uh);
disp("%",Rh,"Rh=")
Rm=cx*(tand(beta_1m)+tand(beta_2m))*100/(2*um);
disp("%",Rm,"Rm=")
Rt=cx*(tand(beta1t)+tand(beta2t))*100/(2*ut);
disp("%",Rt,"Rt=")

// part(d) specific work
w=omega*(C2-C1);
disp("kJ/kg",w*1e-3,"(d)specific work is")
// part(e) the loading coefficients
disp("(e)the loading coefficients are")
shi_h=w/(uh^2);
disp(shi_h,"shi_h=")
shi_m=w/(um^2);
disp(shi_m,"shi_m=")
shi_t=w/(ut^2);
disp(shi_t,"shi_t=")
```

Scilab code Exa 11.5 Forced Vortex axial compressor stage

```
// scilab Code Exa 11.5 Forced Vortex axial compressor stage

dm=50/100; // Mean Blade ring diameter in m
rm=dm/2;
dh=0.3098354; // from results of exa 11.2
dt=0.6901646;
um=100; // peripheral speed in m/s
beta_1m=51;
beta_2m=9;
alpha_1m=7;  //  air angle at rotor and stator exit
alpha_2m=50.177922;
omega=um/rm;
rh=dh/2;
rt=dt/2;
uh=omega*rh;
ut=omega*rt;
// part(a) rotor blade air angles
cx=73.654965;
c_theta1m=cx*tand(alpha_1m);
C1=c_theta1m/rm;
c_theta1h=C1*rh;
c_theta1t=C1*rt;
K1=cx^2+(2*(C1^2)*(rm^2));
cx1h=sqrt(K1-(2*(C1^2)*(rh^2)));
cx1t=sqrt(K1-(2*(C1^2)*(rt^2)));
c_theta2m=cx*tand(alpha_2m);
C2=c_theta2m/rm;
c_theta2h=C2*rh;
c_theta2t=C2*rt;
K2=cx^2-(2*(C2-C1)*omega*(rm^2))+(2*(C2^2)*(rm^2));
cx2h=sqrt(K2+(2*(C2-C1)*omega*(rh^2))-(2*(C2^2)*(rh^2)));
cx2t=sqrt(K2+(2*(C2-C1)*omega*(rt^2))-(2*(C2^2)*(rt^2)));
disp("(a) the rotor blade air angles are")
// for hub section
alpha1h=atand(C1*rh/cx1h);
```

```
alpha2h=atand(C2*rh/cx2h);
disp("for hub section")
beta1h=atand((uh/cx1h)-tand(alpha1h));
beta2h=atand((uh/cx2h)-tand(alpha2h));
disp("degree",beta1h,"beta1h=")
disp("degree",beta2h,"beta2h=")

// for tip section
alpha1t=atand(C1*rt/cx1t);
alpha2t=atand(C2*rt/cx2t);
disp("for tip section")
beta1t=atand((ut/cx1t)-tand(alpha1t));
beta2t=atand((ut/cx2t)-tand(alpha2t));
disp("degree",beta1t,"beta1t= ")
disp("degree",beta2t,"beta2t= ")

// part(b) specific work
wh=omega*(C2-C1)*(rh^2);
wm=omega*(C2-C1)*(rm^2);
wt=omega*(C2-C1)*(rt^2);
disp("kJ/kg",wh*1e-3,"(b)specific work at hub is")
disp("kJ/kg",wm*1e-3,"specific work at mean section
    is")
disp("kJ/kg",wt*1e-3,"specific work at tip is")
// part(c) the loading coefficients
disp("(c)the loading coefficients are")
shi_h=wh/(uh^2);
disp(shi_h,"shi_h=")
shi_m=wm/(um^2);
disp(shi_m,"shi_m=")
shi_t=wt/(ut^2);
disp(shi_t,"shi_t=")

// part(c) degrees of reaction
disp("(d)Degrees of reaction are")
Rh=((cx1h^2)*(secd(beta1h)^2)-(cx2h^2)*(secd(beta2h)
    ^2))*100/(2*wh);
Rm=((cx^2)*(secd(beta_1m)^2)-(cx^2)*(secd(beta_2m)
```

```
    ^2))*100/(2*wm);
Rt=((cx1t^2)*(secd(beta1t)^2)-(cx2t^2)*(secd(beta2t)
    ^2))*100/(2*wt);
disp("%",Rh,"Rh=")
disp("%",Rm,"Rm=")
disp("%",Rt,"Rt=")
```

Scilab code Exa 11.6 General Swirl Distribution axial compressor

```
// scilab Code Exa 11.6 General Swirl Distribution
    axial compressor

Rm=0.5; // Degree of reaction
dm=36/100; // Mean Blade ring diameter in m
rm=dm/2;
N=18e3; // rotor Speed in RPM
h=6/100; // blade height at entry in m
dh=dm-h;
dt=dm+h;
cx=180; // Axial velocity in m/s
alpha_1m=25;  //  air angle at rotor and stator exit
alpha_2m=54.820124;
um=%pi*dm*N/60;
omega=um/rm;
rh=dh/2;
rt=dt/2;
uh=omega*rh;
ut=omega*rt;

// part(a) rotor blade air angles
c_theta1m=cx*tand(alpha_1m);
c_theta2m=cx*tand(alpha_2m);
a=0.5*(c_theta1m+c_theta2m)
```

```
b=rm*(c_theta2m-c_theta1m)*0.5;
c_theta1h=a-(b/rh);
c_theta1t=a-(b/rt);
K1=cx^2+(2*(a^2)*((b/(a*rm))+log(rm)));
cx1h=sqrt(K1-(2*(a^2)*((b/(a*rh))+log(rh))));
cx1t=sqrt(K1-(2*(a^2)*((b/(a*rt))+log(rt))));

c_theta2h=a+(b/rh);
c_theta2t=a+(b/rt);
K2=cx^2+(2*(a^2)*(log(rm)-(b/(a*rm))));
cx2h=sqrt(K2-(2*(a^2)*(log(rh)-(b/(a*rh)))));
cx2t=sqrt(K2-(2*(a^2)*(log(rt)-(b/(a*rt)))));
disp("(a) the rotor blade air angles are")
// for hub section
alpha1h=atand(c_theta1h/cx1h);
alpha2h=atand(c_theta2h/cx2h);
disp("for hub section")
beta1h=atand((uh/cx1h)-tand(alpha1h));
beta2h=atand((uh/cx2h)-tand(alpha2h));
disp("degree",beta1h,"beta1h=")
disp("degree",beta2h,"beta2h=")

// for tip section
alpha1t=atand(c_theta1t/cx1t);
alpha2t=atand(c_theta2t/cx2t);
disp("for tip section")
beta1t=atand((ut/cx1t)-tand(alpha1t));
beta2t=atand((ut/cx2t)-tand(alpha2t));
disp("degree",beta1t,"beta1t= ")
disp("degree",beta2t,"beta2t= ")

// part(b) specific work
w=2*omega*b;
disp("kJ/kg",w*1e-3,"(b)specific work is")

// part(c) the loading coefficients
disp("(c)the loading coefficients are")
shi_h=w/(uh^2);
```

```
disp(shi_h,"shi_h=")
shi_m=w/(um^2);
disp(shi_m,"shi_m=")
shi_t=w/(ut^2);
disp(shi_t,"shi_t=")

// part(c) degrees of reaction
disp("(d)Degrees of reaction are")
Rh=((cx1h^2)*(secd(beta1h)^2)-(cx2h^2)*(secd(beta2h)
    ^2))*100/(2*w);
Rt=((cx1t^2)*(secd(beta1t)^2)-(cx2t^2)*(secd(beta2t)
    ^2))*100/(2*w);
disp("%",Rh,"Rh=")
disp("%",Rm*100,"Rm=")
disp("%",Rt,"Rt=")
disp("Comment: book contains wrong calculation for
    Rt value")
```

Scilab code Exa 11.7 flow and loading coefficients

```
// scilab Code Exa 11.7 flow and loading
    coefficients
u=339.29; // in m/s
cx=180; // Axial velocity in m/s
alpha_1m=25;  //  air angle at rotor and stator exit
phi(1)=0.2;
phi(2)=0.4;
phi(3)=cx/u;
phi(4)=0.6;
phi(5)=0.8;
n=5;
for i=1:n
    shi(i)=1-phi(i)*(2*tand(alpha_1m));
```

```
    disp(phi(i),"when flow coefficient phi=")
    disp(shi(i),"then loading coefficient shi=")
end
```

Chapter 12

Centrifugal Compressor Stage

Scilab code Exa 12.1 Calculation on a centrifugal compressor stage

```
// scilab Code Exa 12.1 Calculation on a centrifugal
    compressor stage
T01=335;  // in Kelvin
funcprot(0);
p01=1.02; //  Initial Pressure in bar
dh=0.10; // hub diameter in m
dt=0.25; // tip diameter in m
m=5; //  in kg/s
gamma=1.4;
N=7.2e3; // rotor Speed in RPM
d1=0.5*(dt+dh); // Mean Blade ring diameter
cp=1005; // Specific Heat at Constant Pressure in J
   /(kgK)
A=%pi*((dt^2)-(dh^2))/4;
R=287;
// I trial
ro1=(p01*1e5)/(R*T01);
cx0=m/(ro1*A);
T0=T01-((cx0^2)/(2*cp));
```

```
n=(gamma-1)/gamma;
p1=p01*((T0/T01)^(1/n));
ro=(p1*1e5)/(R*T0);
cx=m/(ro*A);
// II Trial
cx2=123;
T1=T01-((cx2^2)/(2*cp));
p2=p01*((T1/T01)^(1/n));
ro2=(p2*1e5)/(R*T1);
cx1=m/(ro2*A);
u1=%pi*d1*N/60;
beta1=atand(cx1/u1);
disp("degree",beta1,"air angle at inducer blade
    entry beta1=")
w1=cx1/(sind(beta1));
a1=sqrt(gamma*R*T1);
Mw1=w1/a1;
disp(Mw1,"the Relative Mach number at inducer blade
    entry Mw1=")
alpha1=atand(cx1/u1);
disp("degree",alpha1,"air angle at IGVs exit alpha1=
    ")
c1=cx1/(sind(alpha1));
T1_new=T01-((c1^2)/(2*cp));
a1_new=sqrt(gamma*R*T1_new);
Mw1_new=cx1/a1_new;
disp(Mw1_new,"the new value of Relative Mach number
    Mw1_new=")
```

Scilab code Exa 12.2 Calculation on a centrifugal air compressor

```
// scilab Code Exa 12.2 Calculation on a centrifugal
    air compressor
```

```
T01=288;   // in Kelvin
p01=1.02; //  Initial Pressure in bar
dh=0.10; // hub diameter in m
dt=0.25; // tip diameter in m
m=5; //  in kg/s
gamma=1.4;
n=(gamma-1)/gamma;
N=7.2e3; // rotor Speed in RPM
d2=0.45; // Impeller diameter in m
cp=1005; // Specific Heat at Constant Pressure in J
    /(kgK)
u2=%pi*d2*N/60;
pr0=((1+(u2^2/(cp*T01)))^(1/n));
disp(pr0,"pressure ratio developed pr0=")
w=u2^2;
disp("kW/(kg/s)",w*1e-3,"Power required to drive the
     compressor P=")
```

Scilab code Exa 12.3 centrifugal compressor stage 17000 rpm

```
// scilab Code Exa 12.3 Calculation on a centrifugal
     compressor stage

funcprot(0)
T01=306;   // Entry Temperature in Kelvin
p01=1.05; //  Entry Pressure in bar
dh=0.12; // hub diameter in m
dt=0.24; // tip diameter in m
m=8; //  in kg/s
mu=0.92; // slip factor
n_st=0.77; // stage efficiency
gamma=1.4;
N=17e3; // rotor Speed in RPM
```

```
d_it=0.48; // Impeller tip diameter in m
d1=0.5*(dt+dh); // Mean Blade ring diameter
rm=d1/2;
cp=1005; // Specific Heat at Constant Pressure in J/(kgK)
A=%pi*((dt^2)-(dh^2))/4;
R=287;
n=86; // number of iterations
ro01=(p01*1e5)/(R*T01);
cx(1)=m/(ro01*A);
for i=1:n
    T1=T01-((cx(i)^2)/(2*cp));
    p1=p01*((T1/T01)^(1/((gamma-1)/gamma)));
ro1=(p1*1e5)/(R*T1);
cx(i+1)=m/(ro1*A);
if cx(i+1)==cx(i) then
    disp("m/s",cx(i+1),"cx=")
    disp(T1,"T1")
disp(p1,"p1")
disp(ro1,"ro1")
end
end
cx1=cx(i+1);
u1m=%pi*d1*N/60;
omega=u1m/rm;
rh=dh/2;
rt=dt/2;
uh=omega*rh;
ut=omega*rt;
u2=d_it*u1m/d1;
beta1h=atand(cx1/uh);
beta1m=atand(cx1/u1m);
beta1t=atand(cx1/ut);
disp("(a) Without IGVs")
disp("degree",beta1h,"air angle at hub section beta1h=")
disp("degree",beta1m,"air angle at mean section beta1m=")
```

```
disp("degree",beta1t,"air angle at tip section beta1t=")
w1t=cx1/(sind(beta1t));
a1=sqrt(gamma*R*T1);
M1t=w1t/a1;
disp(M1t,"the maximum Mach number at inducer blade entry M1t=")
pr0=((1+(mu*n_st*(u2^2)/(cp*T01)))^(1/((gamma-1)/gamma)));
disp(pr0,"total pressure ratio developed is")
P=m*mu*(u2^2);
disp ("kW",P/1000,"Power required to drive the compressor without IGVs is")

// part(b) with IGVs
alpha1h=beta1h;
alpha1m=beta1m;
alpha1t=beta1t;
disp("(b)With IGVs")
disp("degree",alpha1h,"air angle at hub section alpha1h=")
disp("degree",alpha1m,"air angle at mean section alpha1m=")
disp("degree",alpha1t,"air angle at tip section alpha1t=")
c1t=cx1/(sind(alpha1t));
T1t=T01-((c1t^2)/(2*cp));
a1t=sqrt(gamma*R*T1t);
Mw1t=cx1/a1t;
disp(Mw1t,"the maximum Mach number at inducer blade entry Mw1t=")
pr0_w=((1+(n_st*(mu*(u2^2)-(u1m^2))/(cp*T01)))^(1/((gamma-1)/gamma)));
disp(pr0_w,"total pressure ratio developed is")
P_w=m*(mu*(u2^2)-(u1m^2));
disp ("kW",P_w/1000,"Power required to drive the compressor is")
disp("Comment: here the solution is found out using
```

```
    programming, so this gives slightly small
    variation from tha answers given in hte book, but
     answers from the present solution are exact.")
```

Scilab code Exa 12.4 Radially tipped blade impeller

```
// scilab Code Exa 12.4.b Radially tipped blade
   impeller
phi2=0.268; // Flow coefficient
T01=293;  // in Kelvin
p01=1; //  Initial Pressure in bar
dr=2.667; // diameter ratio(d2/d1)
gamma=1.4;
R=287;
N=8e3; // rotor Speed in RPM
d1=0.18; // Mean diameter at the impeller entry in m
u1=%pi*d1*N/60;
a1=sqrt(gamma*R*T01);
Mb1=u1/a1;
disp(Mb1,"the Mach number at inducer blade entry Mb1
   =")
M2=sqrt(((dr^2)*(Mb1^2)*(1+(phi2^2)))/(1+(0.5*(gamma
   -1)*(dr^2)*(Mb1^2)*(1-(phi2^2)))));
disp(M2,"the flow Mach number at impeller exit M2=")
```

Scilab code Exa 12.5 Radially tipped blade impeller

```
// scilab Code Exa 12.5 Radially tipped blade
   impeller
```

```
// part(a) free vortex flow
r3=0.25; // volute base circle radius in m
c_theta3=177.5; // tangential velocity component of
   air in m/s
K=r3*c_theta3;
b=0.12; // width in m
Q=5.4; // discharge in m3/s
n=8;
disp("part(a)")
theta(1)=%pi/4;
theta(2)=%pi/2;
theta(3)=3*%pi/4;
theta(4)=%pi;
theta(5)=5*%pi/4;
theta(6)=3*%pi/2;
theta(7)=7*%pi/4;
theta(8)=2*%pi;
disp("the volute radii at eight angular positions
   are given below:")
for i=1:n
    r4(i)=r3*exp(theta(i)*Q/(2*%pi*K*b))
    disp("radian",theta(i),"at theta=")
    disp("cm",r4(i)*100,"r4=")
end
L=r4(8)-r3;
disp(L/(2*r3),"(a)throat-to-diameter ratio (L/d3)=")

// part(b) constant mean velocity of 145 m/s
cm=145; // constant mean velocity in m/s
disp("part(b)")
for i=1:n
    r4b(i)=r3+(Q/(cm*b)*(theta(i)/(2*%pi)));
    disp("radian",theta(i),"at theta=")
    disp("cm",r4b(i)*100,"r4=")
end
L_b=r4b(8)-r3;
disp(L_b/(2*r3),"(b)throat-to-diameter ratio (L/d3)=
   ")
```

Chapter 13

Radial Turbine Stages

Scilab code Exa 13.1 ninety degree IFR turbine

```
// scilab Code Exa 13.1 ninety degree IFR turbine
t=650; // in degree C
T01=t+273; // in Kelvin
p3=1; //  Exit Pressure in bar
gamma=1.4;
sigma=0.66; // blade-to-isentropic speed ratio
N=16e3; // rotor Speed in RPM
b2=5/100; // blade height at entry in m
alpha_2=20;  //  air angle at nozzle exit
d_r=0.45; // rotor diameter ratio(d3/d2)
p01_3=3.5; // total-to-static Pressure Ratio(p01/p3)
n_N=0.95; // Nozzle Efficiency
cp=1005; // Specific Heat at Constant Pressure in J
   /(kgK)
R=287;
n=(gamma-1)/gamma;

// part(a) the rotor diameter
c_0=sqrt(2*cp*T01*(1-(p01_3^(-n))))
```

```
u_2=sigma*c_0;
d2=60*u_2/(%pi*N);
disp("cm",d2*1e2,"(a)the rotor diameter is")

// part(b) air angle at rotor blade exit
d3=d2*d_r;
c_r2=u_2*tand(alpha_2);
u3=%pi*d3*N/60;
beta3=atand(c_r2/u3);
disp("degree",beta3,"(b) air angle at rotor blade
    exit beta3=")

// part(c) mass flow rate
T03=T01-((u_2^2)/cp);
T3=T03-((c_r2^2)/(2*cp));
T2=T3+((0.5*(u_2^2))/cp);
c2=u_2/(cosd(alpha_2));
p01_2=(1-(((0.5*(c2^2))/(cp*n_N))/T01))^(-1/n);
p01=p3*p01_3;
p2=p01/p01_2;
ro2=(p2*1e5)/(R*T2);
m=ro2*c_r2*%pi*d2*b2;
disp("kg/s",m,"(c) mass flow rate is")

// part(d) hub and tip diameters at the rotor exit
ro3=(p3*1e5)/(R*T3);
b3=m/(ro3*c_r2*%pi*d3);
dh=d3-b3;
disp("cm",dh*1e2,"(d)hub diameter at the rotor exit
    is")
dt=d3+b3;
disp("cm",dt*1e2,"(d)tip diameter at the rotor exit
    is")

// part(e) Determining the power developed
P=m*(u_2^2);
disp ("kW",P/1000,"(e)Power developed is")

```

```
// part(f) the total-to-static Efficiency of the
   stage
n_ts=(u_2^2)/(cp*T01*(1-((p3/p01)^n)));
disp("%",n_ts*1e2,"(f)the total-to-static Efficiency
    of the stage is")
```

Scilab code Exa 13.2 Mach Number and loss coefficient

```
// scilab Code Exa 13.2 Mach Number and loss
   coefficient
t=650; // in degree C
T01=t+273; // in Kelvin
p3=1; //  Exit Pressure in bar
gamma=1.4;
sigma=0.66; // blade-to-isentropic speed ratio
N=16e3; // rotor Speed in RPM
b2=5/100; // blade height at entry in m
alpha_2=20;  //  air angle at nozzle exit
d_r=0.45; // rotor diameter ratio(d3/d2)
p01_3=3.5; // total-to-static Pressure Ratio(p01/p3)
n_N=0.95; // Nozzle Efficiency
cp=1005; // Specific Heat at Constant Pressure in J
   /(kgK)
R=287;
n=(gamma-1)/gamma;
c_0=sqrt(2*cp*T01*(1-(p01_3^(-n))))
u_2=sigma*c_0;
Mb0=u_2/sqrt(gamma*R*T01);

// part(a) Mach number at nozzle exit
M2=Mb0/(cosd(alpha_2)*sqrt(1-(0.5*(gamma-1)*(Mb0^2)
   *(secd(alpha_2)^2))));
disp(M2,"(a)the flow Mach number at nozzle exit M2="
```

```
    )

// part(b)rotor exit Relative Mach number
d2=60*u_2/(%pi*N);
d3=d2*d_r;
c_r2=u_2*tand(alpha_2);
u3=%pi*d3*N/60;
beta3=atand(c_r2/u3);
w3=u3/(cosd(beta3));
T03=T01-((u_2^2)/cp);
T3=T03-((c_r2^2)/(2*cp));
a3=sqrt(gamma*R*T3);
M3_rel=w3/a3;
disp(M3_rel,"(b)the Relative Mach number at rotor
    exit is")

// part(c) Nozzle enthalpy loss coefficient
T2=T3+((0.5*(u_2^2))/cp);
c2=u_2/(cosd(alpha_2));
T2s=T01-((0.5*(c2^2))/(cp*n_N));
c2=u_2/(cosd(alpha_2));
zeeta_N=cp*(T2-T2s)/(0.5*(c2^2));
disp(zeeta_N,"(c)the Nozzle enthalpy loss
    coefficient is")

// part(d)rotor enthalpy loss coefficient

p01_2=(1-(((0.5*(c2^2))/(cp*n_N))/T01))^(-1/n);
p01=p3*p01_3;
p2=p01/p01_2;
T3s=T2/((p2/p3)^n);
zeeta_R=cp*(T3-T3s)/(0.5*(w3^2));
disp(zeeta_R,"(d)the rotor enthalpy loss coefficient
     is")
disp("comment: Nozzle enthalpy loss coefficient
    value is not correctly calculated in the textbook
    . the above value is correct.")
```

Scilab code Exa 13.3 IFR turbine with Cantilever Blades

```
// scilab Code Exa 13.3 IFR turbine with Cantilever
   Blades
phi=0.4; // flow coefficient
funcprot(0);
P=100; // Power developed in kW
n_tt=0.9; // total-to-total Efficiency
N=12e3; // rotor Speed in RPM
m=1; // in kg/s
T01=400;  // in Kelvin
gamma=1.4;
d_r=0.8; // rotor diameter ratio(d3/d2)
u2=sqrt(P*1000/(2*m));
d2=60*u2/(%pi*N);
disp("cm",d2*1e2,"the rotor diameter at entry is")
d3=d2*d_r;
disp("cm",d3*1e2,"the rotor diameter at exit is")
beta2=atand(phi);
disp("degree",beta2,"air angle at rotor entry is
   beta2=")
d3=d2*d_r;
u3=%pi*d3*N/60;
c_r2=u2*phi;
beta3=atand(c_r2/u3);
disp("degree",beta3,"air angle at rotor exit is
   beta3=")
cp=1005;
n=(gamma-1)/gamma;
alpha_2=atand(c_r2/(2*u2));
disp("degree",alpha_2,"air angle at nozzle exit is
   alpha_2=")
```

```
p01_03=(1-((2*(u2^2))/(n_tt*cp*T01)))^(-1/n);
disp(p01_03,"stagnation pressure ratio across the
    stage is")
```

Chapter 14

Axial Fans and Propellers

Scilab code Exa 14.1 Axial fan stage 960 rpm

```
// scilab Code Exa 14.1 Axial fan stage 960 rpm
beta3=10; // rotor blade air angle at exit in degree
dh=0.3; // hub diameter in m
dt=0.6; // tip diameter in m
N=960; // rotor Speed in RPM
P=1; // Power required in kW
phi=0.245; // flow coefficient
T1=316;  // in Kelvin
p1=1.02; //Initial Pressure in bar
R=287;
A=%pi*((dt^2)-(dh^2))/4;
d=0.5*(dt+dh);
u=%pi*d*N/60;
cx=phi*u;
Q=cx*A;
ro=(p1*1e5)/(R*T1);
delp0_st=ro*(u^2)*(1-(phi*(tand(beta3))));
disp("mm W.G.",delp0_st/9.81,"stage pressure rise is
  ")
```

```
IP=Q*delp0_st/1000; // ideal power required to drive
    the fan in kW
n_o=IP/P;
disp("%",n_o*1e2,"the overall Efficiency of the fan
   is")
beta2=atand(u/cx);
disp("degree",beta2,"the blade air angle at the
   entry beta2=")
delp_st=0.5*ro*(u^2)*(1-(phi^2*(tand(beta3)^2)));
DOR=delp_st/delp0_st;
disp("%",DOR*1e2,"the degree of reaction is")
omega=2*%pi*N/60;
gH=delp0_st/ro;
NS=omega*sqrt(Q)/(gH^(3/4));
disp(NS,"the dimensionless specific speed is")
```

Scilab code Exa 14.2 Downstream guide vanes

```
// scilab Code Exa 14.2 Downstream guide vanes

beta3=10; // rotor blade air angle at exit in degree
dh=0.3; // hub diameter in m
dt=0.6; // tip diameter in m
N=960; // rotor Speed in RPM
phi=0.245; // flow coefficient
d=0.5*(dt+dh);
u=%pi*d*N/60;
cx=phi*u;
cy3=u-(cx*tand(beta3));
alpha3=atand(cy3/cx);
disp("the rotor blade air angles, overall efficiency
   , flow rate, power required and degree of
   reaction are the same as calculated in Ex14_1")
```

```
disp("degree",alpha3,"the guide vane air angle at
    the entry alpha3=")
```

Scilab code Exa 14.3 upstream guide vanes

```
// scilab Code Exa 14.3 upstream guide vanes
beta2=86; // rotor blade air angle at inlet in
    degree
dh=0.3; // hub diameter in m
dt=0.6; // tip diameter in m
N=960; // rotor Speed in RPM
phi=0.245; // flow coefficient
T1=316;  // in Kelvin
p1=1.02; //Initial Pressure in bar
R=287;
n_o=0.647; // overall Efficiency of the drive
A=%pi*((dt^2)-(dh^2))/4;
d=0.5*(dt+dh);
u=%pi*d*N/60;
cx=phi*u;
Q=cx*A;
ro=(p1*1e5)/(R*T1);

// part(i) static pressure rise in the rotor and
    stage
delh0_st=(u^2)*((phi*(tand(beta2)))-1);
delp0_st=ro*delh0_st;
disp("mm W.G.",delp0_st/9.81,"(i)static pressure
    rise in the stage is")
beta3=atand(u/cx);
w2=cx/(cosd(beta2));
w3=cx/(cosd(beta3));
delp_r=0.5*ro*((w2^2)-(w3^2));
```

```
disp("mm W.G.",delp_r/9.81,"and the static pressure
    rise in the rotor is")

// part(ii) the stage pressure coefficient and
    degree of reaction
shi=2*((phi*(tand(beta2)))-1);
disp(shi,"(ii)stage pressure coefficient is")
DOR=0.5*((phi*(tand(beta2)))+1);
disp("%",DOR*1e2,"and the degree of reaction is")

// part(iii) the blade air angle at the rotor exit
    and the air angle at the UGV exit
disp("degree",beta3,"(iii)the blade air angle at the
     rotor exit beta3=")
cy2=(cx*tand(beta2))-u;
alpha2=atand(cy2/cx);
disp("degree",alpha2,"and the air angle at the UGV
    exit alpha2=")

// part(iv) Power required to drive the fan
m=ro*Q;
P=m*delh0_st/n_o;
disp("kW",P/1000,"(iv)Power required to drive the
    fan is")
```

Scilab code Exa 14.4 rotor and upstream guide blades

```
// scilab Code Exa 14.4 rotor and upstream guide
    blades
beta2=30; // rotor blade air angle at inlet in
    degree
beta3=10; // rotor blade air angle at exit in degree
dh=0.3; // hub diameter in m
```

```
dt=0.6; // tip diameter in m
N=960; // rotor Speed in RPM
phi=0.245; // flow coefficient
T1=316;  // in Kelvin
p1=1.02; //Initial Pressure in bar
R=287;
n_d=0.88; // Efficiency of the drive
n_f=0.8; // Efficiency of the fan
A=%pi*((dt^2)-(dh^2))/4;
d=0.5*(dt+dh);
u=%pi*d*N/60;
cx=phi*u;
Q=cx*A;
ro=(p1*1e5)/(R*T1);
delh0_st=(u^2)*phi*(tand(beta2)-tand(beta3));
n_o=n_f*n_d;
delp0_st=n_f*ro*delh0_st;
disp("mm W.G.",delp0_st/9.81,"static pressure rise
   in the stage is")
shi=2*phi*(tand(beta2)-tand(beta3));
disp(shi,"stage pressure coefficient is")
m=ro*Q;
P=m*delh0_st/n_d;
disp("kW",P/1000,"Power required to drive the fan is
   ")
```

Scilab code Exa 14.5 DGVs and upstream guide vanes

```
// scilab Code Exa 14.5 DGVs and upstream guide
   vanes
beta2=86; // rotor blade air angle at inlet in
   degree
beta3=10; // rotor blade air angle at exit in degree
```

```
dh=0.3; // hub diameter in m
dt=0.6; // tip diameter in m
N=960; // rotor Speed in RPM
phi=0.245; // flow coefficient
T1=316;  // in Kelvin
p1=1.02; //Initial Pressure in bar
R=287;
n_d=0.8; // Efficiency of the drive
n_f=0.85; // Efficiency of the fan
A=%pi*((dt^2)-(dh^2))/4;
d=0.5*(dt+dh);
u=%pi*d*N/60;
cx=phi*u;
Q=cx*A;
ro=(p1*1e5)/(R*T1);
delh0_st=2*(u^2)*((phi*(tand(beta2)))-1);
delp0_st=n_f*ro*delh0_st;
disp("mm W.G.",delp0_st/9.81,"static pressure rise
    in the stage is")
shi=4*((phi*(tand(beta2)))-1);
disp(shi,"stage pressure coefficient is")
m=ro*Q;
P=m*delh0_st/n_d;
disp("kW",P/1000,"Power of the electric motor is")
```

Scilab code Exa 14.6 open propeller fan

```
// scilab Code Exa 14.6 open propeller fan
c_u=5; // upstream velocity in m/s
c_s=25; // downstream velocity in m/s
t=37; // in degree C
T=t+273; // in Kelvin
d=0.5;
```

```
p=1.02; // Initial Pressure in bar
R=287;
n_o=0.4; // overall Efficiency of the fan
A=%pi*(d^2)/4;
c=0.5*(c_u+c_s);
Q=c*A;
ro=(p*1e5)/(R*T);
m=ro*c*A;
disp("kg/s",m,"(a) flow rate through the fan is")
delh_0=0.5*((c_s^2)-(c_u^2));
delp_0=ro*delh_0;
disp("mm W.G.",delp_0/9.81,"(b)static pressure rise
    in the stage is")
P=m*delh_0/n_o;
disp("kW",P/1000,"(c)Power required to drive the fan
     is")
```

Chapter 15

Centrifugal Fans and Blowers

Scilab code Exa 15.1 Centrifugal fan stage 1450 rpm

```
// scilab Code Exa 15.1 Centrifugal fan stage 1450
   rpm

d1=0.18; // inner diameter of the impeller in m
d2=0.2; // outer diameter of the impeller in m
N=1450; // rotor Speed in RPM
c1=21; // Absolute velocity at entry in m/s
w1=20; // relative velocity at entry in m/s
c2=25; // Absolute velocity at exit in m/s
w2=17; // relative velocity at exit in m/s
m=0.5; // flow rate in kg/s
n_m=0.78; // overall Efficiency of the motor
ro=1.25; // density of air in kg/m3

u1=%pi*d1*N/60;
u2=%pi*d2*N/60;
delp_r=0.5*ro*((w1^2)-(w2^2))+(0.5*ro*((u2^2)-(u1^2)
   ));
delp0_st=0.5*ro*(((w1^2)-(w2^2))+((u2^2)-(u1^2))+((
```

```
c2^2)-(c1^2)));
disp("mm W.G.",delp0_st/9.81,"(a)stage pressure rise is")
DOR=delp_r/delp0_st;
disp(DOR,"(b)the degree of reaction is")
w_st=delp0_st/ro;
P=m*w_st/n_m;
disp("W",P,"(c)the motor Power required to drive the fan is")
```

Scilab code Exa 15.2 Centrifugal blower 3000 rpm

```
// scilab Code Exa 15.2 Centrifugal blower 3000 rpm

beta2=90; // rotor blade air angle at inlet in degree
N=3e3; // rotor Speed in RPM
T1=310;  // in Kelvin
p1=0.98; //Initial Pressure in bar
R=287;
n_d=0.88; // Efficiency of the drive
n_f=0.82; // Efficiency of the fan
Q=200/60; // discharge in m3/s
h=1000; // mm column of water
delp0=h*9.81;
Pi=Q*delp0/1000; // ideal power
P=Pi/(n_d*n_f);
disp("kW",P,"(a)Power required by the electric motor is")

// part(b) impeller diameter
ro=(p1*1e5)/(R*T1);
u2=sqrt(delp0/(ro*n_f));
```

```
d2=u2*60/(%pi*N);
disp("cm",d2*1e2,"(b)the impeller diameter is")

// part(c) inner diameter of the blade ring
c_r2=0.2*u2;
c_i=0.4*u2;
d1=sqrt(Q*4/(%pi*c_i));
disp("cm",d1*1e2,"(c)the inner diameter of the blade
    ring is")

// part(d) air angle at the entry
u1=u2*d1/d2;
beta1=atand(c_r2/u1);
disp("degree",beta1,"(d)the air angle at the entry
   beta1=")

// part(e) impeller widths at entry and exit
b1=Q/(c_r2*%pi*d1);
disp("cm",b1*1e2,"(e)the impeller width at entry is"
   )
b2=b1*d1/d2;
disp("cm",b2*1e2,"and the impeller width at exit is"
   )

// part(f) number of impeller blades
z=8.5*sind(beta2)/(1-(d1/d2));
disp(z,"(f)the number of impeller blades is")

// part(g) the specific speed
gH=u2^2;
omega=2*%pi*N/60;
NS=omega*sqrt(Q)/(gH^(3/4));
disp(NS,"(g)the dimensionless specific speed is")
```

Chapter 16

Wind Turbines

Scilab code Exa 16.1 Wind turbine output 100 kW

```
// scilab Code Exa 16.1 Wind turbine output 100 kW

c_u=48*5/18; // wind upstream velocity in m/s
n=0.95; // overall Efficiency of the drive
P=100; // aerogenerator power output in kW
n_m=0.9; // mechanical Efficiency of the drive
n_a=0.7; // aerodynamic Efficiency
ro=1.125; // density of air in kg/m3
cp_max=0.593; // power coefficient for the windmill(Pi/Pu)

// part(a) propeller diameter of the windmill
A=2*P*1e3/(ro*(c_u^3)*n*n_m*n_a*cp_max);
d=sqrt(4*A/%pi);
disp("m",d,"(a)the propeller diameter of the windmill is")

// part(b)
disp("(b)corresponding to maximum power")
```

```
c=2*c_u/3;
disp("m/s",c,"the wind velocity through the
    propeller disc is")
delp1_a=5*ro*(c^2)/8;
disp("mm W.G.",delp1_a/9.81,"the gauge pressure just
    before the disc is")
delp2_a=-3*ro*(c^2)/8;
disp("mm W.G.",delp2_a/9.81,"the gauge pressure just
    after the disc is")
Fx=(delp1_a-delp2_a)*A;
disp("kN",Fx*1e-3,"and the axial thrust is")
```

Chapter 18

Miscellaneous Solved Problems in Turbomachines

Scilab code Exa 18.1 Gas Turbine nozzle row

```
// scilab Code Exa 18.1 Gas Turbine nozzle row

T1=600;  // Entry Temperature of the gas in Kelvin
p1=10; // Inlet Pressure in bar
gamma_g=1.3;
delT=32; // Temperature drop of the gas(T1-T2) in K
cp_g=1.23*1e3; // Specific Heat of gas at Constant
   Pressure in kJ/(kgK)
pr1_2=1.3; // pressure ratio(p1/p2)
T2s=T1/(pr1_2^((gamma_g-1)/gamma_g));
delTs=T1-T2s;

// part(a) nozzle efficiency
n_N=delT/delTs;
disp("%",n_N*100,"(a) nozzle efficiency is")

// part(b)
```

```
disp("(b)(i)for ideal flow:")
p2=p1/pr1_2;
h_01=cp_g*T1;
h2s=cp_g*T2s;
c_2s=sqrt((h_01-h2s)/0.5);
disp("m/s",c_2s,"the nozzle exit velocity is")
R_g=cp_g*((gamma_g-1)/gamma_g);
M_2s=c_2s/(sqrt(gamma_g*R_g*T2s));
disp(M_2s,"and the Mach number is")
disp("(b)(ii)for actual flow:")
T2=T1-delT;
a2=sqrt(gamma_g*R_g*T2);
c_2=sqrt((cp_g*delT)/0.5);
disp("m/s",c_2,"the nozzle exit velocity is")
M2=c_2/a2;
disp(M2,"and the Mach number is")

// part(c) stagnation pressure loss across the
   nozzle
p01=p1;
p02=p2/0.79; // from isentropic gas tables p2/p02
   =0.79 at gamma=1.3 and M2=0.613
delp0=p01-p02;
disp("bar",delp0,"(c)the stagnation pressure loss
   across the nozzle is")

// part(d) nozzle efficiency based on stagnation
   pressure loss
delp=p1-p2;
n_N_a=1-(delp0/delp);
disp("%",n_N_a*100,"(d)the nozzle efficiency based
   on stagnation pressure loss is")
```

Scilab code Exa 18.2 Steam Turbine nozzle

```
// scilab Code Exa 18.2 Steam Turbine nozzle

t1=550;   // Entry Temperature in Kelvin
p1=170; // Inlet Pressure in bar
p2=120.7; // Exit Pressure in bar
d=1; // Mean Blade ring diameter in m
alpha_2=70;  // nozzle angle in degree
gamma_g=1.3; // for superheated steam
R=0.5*1e3; // in J/kgK
m=280; // in kg/s

// part(a) exit velocity c2 of steam
h1=3440; // from superheated steam tables at p1 and
   t1
h2=3350; // at p2
t2=503; // at p2 in degree C
v_s2=0.0268; // Specific Volume at p2 in m3/kg
c_2=sqrt((h1-h2)*1e3/0.5);
disp("m/s",c_2,"(a)the nozzle exit velocity is")

// part(b)
T2=t2+273;
a2=sqrt(gamma_g*R*T2);
M2=c_2/a2;
disp(M2,"(b)and the exit Mach number is")

// part(c)
cx=c_2*cosd(alpha_2);
h=m*v_s2/(%pi*cx*d);
disp("cm",h*1e2,"(c)nozzle blade height at exit is")

T2s=0.87*(t1+273); // T2s/T1=0.87 from gas tables
p2s=0.546*p1; // p2s/p1=0.546 from gas tables
vs_s=0.031; // from steam tables
a_s=sqrt(gamma_g*R*T2s);
disp("m/s",a_s,"the corresponding nozzle exit
```

```
   velocity is")
cx_s=a_s*cosd(alpha_2);
m_max=cx_s*%pi*d*h/(vs_s);
disp("kg/s",m_max,"the maximum possible mass flow
   rate is")
```

Scilab code Exa 18.3 Irreversible flow in nozzles

```
// scilab Code Exa 18.3 Irreversible flow in nozzles
pr=0.843; // pr=p/p0
n_n=0.95; // nozzle efficiency
gamma=1.4;
Ms=0.5; // from gas tables for gammma and pr value
Ma=sqrt((2/(gamma-1))*(n_n/(1-n_n+(2/((gamma-1)*(Ms
   ^2))))));
disp(Ma,"actual value of the Mach number is")
```

Scilab code Exa 18.4 Calculation on a Diffuser

```
// scilab Code Exa 18.4 Calculation on a Diffuser

pe=35; // Initial Pressure in mm W.G.
pa=1.0135; // ambient pressure in bar
c1=100; // entry velocity in m/s
C_pa=0.602; // actual pressure recovery coefficient
ro=1.25; // density in kg/m3
g=9.81; // Gravitational acceleration in m/s^2
Ar=1.85; // Area Ratio of Diffuser

```

```
// part(a)
C_ps=1-(1/(Ar^2));
disp(C_ps,"(a)ideal value of the pressure recovery coefficient is")

// part(b)
n_D=C_pa/C_ps;
disp ("%",n_D*1e2,"(b)Efficiency of the diffuser is")

// part(c)
p1=pa+(pe*g*1e-5);
p01=p1+(0.5*ro*(c1^2)*1e-5);
delp_0=(C_ps-C_pa)*(0.5*ro*(c1^2)*1e-5);
disp("mm W.G.",delp_0*1e5/g,"(c)the stagnation pressure loss across the diffuser is")

// part(d)
p02=p01-delp_0;
c2=c1/Ar;
p2=p02-(0.5*ro*(c2^2)*1e-5);
disp("mm W.G.",(p2-pa)*1e5/g,"(d)the gauge pressure at the diffuser exit is")
```

Scilab code Exa 18.5 Calculation on a Draft Tube

```
// scilab Code Exa 18.5 Calculation on a Draft Tube

c2=6.25; // exit velocity in m/s
ro=1e3; // density in kg/m3
g=9.81; // Gravitational acceleration in m/s^2
AR=1.6; // Area Ratio of Diffuser
Q=100; // discharge in m3/s
```

```
n_D=0.82; // Efficiency of the Draft Tube

// part(a)
c1=c2*AR;
A1=Q/c1;
disp("m2",A1,"(a)area of cross-section at entry is")
A2=A1*AR;
disp("m2",A2,"and the area of cross-section at exit
    is")

// part(b)
delHi=((c1^2)-(c2^2))/(2*g);
delH_a=delHi*n_D;
disp("m",delH_a,"(b)actual head gained by the Draft
    Tube is")

// part(c)
m=ro*Q;
delP_a=m*g*delH_a;
disp("MW",delP_a*1e-6,"(c)the additional power
    generated is")

// part(d)
Loss=delHi-delH_a;
disp("m",Loss,"(d)the loss of head due to losses in
    the draft tube is")
```

Scilab code Exa 18.6 Calculations on a Gas Turbine

```
// scilab Code Exa 18.6 Calculations on a Gas
    Turbine

m=472; // flow rate of hot gases in kg/s
```

```
T01=1335;  // Turbine inlet temp in Kelvin
p01=10; // Turbine Inlet Pressure in bar
c2=150; // exit velocity in m/s
pr0=10; // Turbine pressure ratio
gamma_g=1.67;
T2=560;  // Temperature of gases at exit in Kelvin
cp_g=1.157; // Specific Heat of gas at Constant Pressure in kJ/(kgK)

// part(a) Determining total to total efficiency
T02=T2+(0.5*(c2^2)/(cp_g*1e3));
T02s=T01/(pr0^((gamma_g-1)/gamma_g));
n_tt=(T01-T02)/(T01-T02s);
disp("%",n_tt*100,"(a)total to total efficiency is")


// part(b) Determining total to static efficiency
T2s=T02s-(0.5*(c2^2)/(cp_g*1e3));
n_ts=(T01-T02)/(T01-T2s);
disp("%",n_ts*100,"(b)total to static efficiency is")

// part(c) Determining the polytropic efficiency
n_p=((gamma_g)/(gamma_g-1))*((log(T01/T02))/(log(pr0)));
disp("%",n_p*100,"(c)polytropic efficiency is")

// part(d) Determining power developed by the turbine
P=m*cp_g*(T01-T02);
disp("MW",P/1e3,"(d)Power developed by the turbine is")
```

Scilab code Exa 18.7 RHF of a three stage turbine

```
// scilab Code Exa 18.7 RHF of a three stage turbine

p1=1.0; // Initial Pressure in bar
gamma=1.4;
T1=1500;  // Initial Temperature in K
s=3; // number of stages
opr=11; // Overall Pressure Ratio
pr=opr^(1/s); // equal Pressure Ratio in each stage
n_T=0.88; // Overall Efficiency
delTa=T1*(1-opr^(-((gamma-1)/gamma)))*n_T;
T2=T1-delTa;
n_p=(log(T1/T2))/(((gamma-1)/gamma)*(log(opr))); //
    polytropic or small stage efficiency
cp=1.005; // Specific Heat at Constant Pressure in
    kJ/(kgK)
n_st=(1-pr^(n_p*(-((gamma-1)/gamma))))/(1-pr^(-((
    gamma-1)/gamma))); // stage efficiency
T(1)=T1;
for i=1:3
    delT(i)=T(i)*(1-pr^(n_p*(-((gamma-1)/gamma))));
    delw_s(i)=delT(i)*cp/n_st;
    T(i+1)=T(i)-delT(i);
end
w_a=cp*delTa;
w_s=w_a/n_T;
RHF=(delw_s(1)+delw_s(2)+delw_s(3))/w_s;
disp(RHF,"the reheat factor is")
```

Scilab code Exa 18.8 Calculation on an air compressor

```
// scilab Code Exa 18.8 Calculation on an air
```

```
compressor

funcprot(0)
p1=1.0; // Initial Pressure in bar
T1=305;  // Initial Temperature in degree K
k=16; // number of stages
m=400; // mass flow rate through the compressor in
    kg/s
p_rc=10; // overall Pressure Ratio
gamma=1.4; // Specific Heat Ratio
cp=1.005; // Specific Heat at Constant Pressure in
    kJ/(kgK)
n_p=0.88; // polytropic efficiency

// part(a) Determining stage Pressure Ratio
pr=p_rc^(1/k);
disp(pr,"(a)stage Pressure Ratio is")

// part(b) Determining the stage efficiency
T2s=T1*(pr^((gamma-1)/gamma));
T2=T1*(pr^((gamma-1)/(gamma*n_p)));
n_st=(T2s-T1)/(T2-T1);
disp("%",n_st*100,"(b)stage Efficiency of the
    compressor is")

// part(c) Determining power required for the first
    stage
P1=m*cp*(T2-T1);
disp ("MW",P1/1e3,"(c)Power required for the first
    stage is")

// part(d)Overall Compressor Efficiency
T17=T1*exp(((gamma-1)/(gamma*n_p))*(log(p_rc))); //
    k+1=17;
T17s=T1*(p_rc^((gamma-1)/gamma));
n_C=(T17s-T1)/(T17-T1);
disp ("%",n_C*100,"(d)Overall Compressor Efficiency
    is")
```

```

// part(e) Determining power required to drive the compressor
P=m*cp*(T17-T1);
disp ("MW",P/1e3,"(e)Power required to drive the compressor is")
```

Scilab code Exa 18.9 Constant Pressure Gas Turbine Plant

```
// scilab Code Exa 18.9 Constant Pressure Gas Turbine Plant

T1=298; // Minimum Temperature in Kelvin
beeta=4.5; // Maximum to Minimum Temperature ratio(T_max/T_min)
m=115; // mass flow rate through the turbine and compressor in kg/s
n_C=0.79; // Compressor Efficiency
n_T=0.83; // Turbine Efficiency
gamma_g=1.33;
R=0.287;
cp=(gamma_g/(gamma_g-1))*R; // Specific Heat at Constant Pressure in kJ/(kgK)
alpha=beeta*n_C*n_T;
t_opt=sqrt(alpha); // For maximum power output, the temperature ratios in the turbine and compressor

// part(a) Determining optimum pressure ratio of the plant
r=t_opt^(gamma_g/(gamma_g-1));
disp(r,"(a)optimum pressure ratio of the plant is")

// part(b)Carnot's efficiency
```

```
n_Carnot=1-(1/beeta);
disp("%",n_Carnot*100,"(b)Carnot efficiency of the
    plant is")

// part(c) Determining Joule's cycle efficiency
n_Joule=1-(1/t_opt);
disp("%",n_Joule*100,"(c)efficiency of the Joule
    cycle is")

// part(d) Determining thermal efficiency of the
    plant for maximum power output
n_th=(t_opt-1)^2/((beeta-1)*n_C-(t_opt-1));
disp("%",n_th*100,"(d)thermal efficiency of the
    plant for maximum power output is")

// part(e) Determining power output
wp_max=cp*T1*((t_opt-1)^2)/n_C; // maximum work
    output
P_max=m*wp_max;
disp ("MW",P_max/1e3,"(e)Power output is")

// part(f) Determining power generated by the
    turbine required to drive the compressor
T3=beeta*T1;  // Maximum Temperature in degree K
T4s=T3*(r^(-((gamma_g-1)/gamma_g)));
T4=T3-((T3-T4s)*n_T);
P_T=m*cp*(T3-T4);
disp ("MW",P_T/1e3,"(f)Power generated by the
    turbine is")

// part(g) Determining power absorbed by the
    compressor
T2s=T1*(r^((gamma_g-1)/gamma_g));
T2=T1+((T2s-T1)/n_C);
P_C=m*cp*(T2-T1);
disp ("MW",P_C/1e3,"(g)Power absorbed by the
    compressor is")

```

```
//part(h)heat supplied in the combustion chamber
Qs=m*cp*(T3-T2);
disp("MW",Qs/1e3,"(h)heat supplied in the combustion
    chamber is")
```

Scilab code Exa 18.10 Calculation on combined cycle power plant

```
// scilab Code Exa 18.10 Calculation on combined
   cycle power plant

P_gt=25.845; // Power Output of gas turbine plant in
    MW
P_st=21; // Power Output of steam turbine plant in
   MW
m_gt=115; // mass flow rate of the exhaust gas in kg
   /s
n_T=0.86; // Turbine Efficiency
gamma_g=1.33;
R=0.287;
cp=(gamma_g/(gamma_g-1))*R; // Specific Heat at
   Constant Pressure in kJ/(kgK)
T3=1341; // Maximum Temperature in gas turbine in
   degree K from Ex18.9
p1=84; // steam Pressure at the entry of steam
   turbine in bar
// from steam tables
t_6s=298.4; // saturation temperature at 84 bar in
   degree C
t_5s=t_6s;
h_6s=1336.1; // from steam table liquid vapour
   enthalpy at 84 bar
t6=535;  // steam temperature at the entry of steam
   turbine in degree C
```

```
T6=t6+273; // in Kelvin
h_4s=3460; // from mollier diagram at t=535 degree C
h_7=2050;
p_c=0.07; // Condenser pressure in bar
r=8.8502464; //optimum pressure ratio from Ex18.9
T4=875.92974; //from Ex 18.9
t4=T4-273; // in degree C
h_7s=163.4; // Specific Enthalpy of water in kJ/kg
m_st=P_st*1e3/((h_4s-h_7)*n_T); // mass flow rate of the steam in kg/s

// part(a)Exhaust gas temperature at stack
t_7=t4-((m_st*(h_4s-h_7s))/(m_gt*cp)); // energy balance for the economiser entry(7') to the superheater exit(4')
disp("degree celsius",t_7,"(a)Exhaust gas temperature at stack is")

// part(b)mass of steam per kg of gas
disp("kg",m_st/m_gt,"(b)mass of steam per kg of gas is")

// part(c) Pinch Point(PP)
t_6=t_7+((m_st*(h_6s-h_7s))/(m_gt*cp)); // energy balance for the economiser
PP=t_6-t_6s;
disp("degree celsius",PP,"(c)Pinch Point(PP) is")

// part(d)thermal efficiency of steam turbine plant
delh4s_7ss=(h_4s-h_7)*n_T;
n_st=delh4s_7ss/(h_4s-h_7s);
disp("%",n_st*100,"(d)thermal Efficiency of steam turbine plant is")

// part(e) thermal efficiency of the combined cycle plant
n_B=0.978; // Assuming Combustion chamber Efficiency
Qs=102.72554; // heat supplied in the combustion
```

```
    chamber from Ex 18.9
Qss=Qs/n_B; // power supplied to the combined cycle
n_gst=(P_gt+P_st)/Qss;
disp ("%" ,n_gst*100,"(e)thermal Efficiency of
    combined gas and steam power plant is")

// part(f)the dryness fraction of steam at the
    turbine exhaust
x=0.875; // from Mollier diagram at p=0.07 bar
disp(x,"(f)the dryness fraction of steam at the
    turbine exhaust is")
```

Scilab code Exa 18.11 Calculation on combined cycle power plant

```
// scilab Code Exa 18.11 Calculation on combined
    cycle power plant

P_gt=25.845; // Power Output of gas turbine plant in
     MW
P_st=21; // Power Output of steam turbine plant in
    MW
m_gt=115; // mass flow rate of the exhaust gas in kg
    /s
n_T=0.86; // Turbine Efficiency
gamma_g=1.33;
R=0.287;
cp=(gamma_g/(gamma_g-1))*R; // Specific Heat at
    Constant Pressure in kJ/(kgK)
T3=1341; // Maximum Temperature in gas turbine in
    degree K from Ex18.9
p1=84; // steam Pressure at the entry of steam
    turbine in bar
// from steam tables
```

```
t_6s=298.4; // saturation temperature at 84 bar in degree C
h_6s=1336.1; // from steam table liquid vapour enthalpy at 84 bar
pp(1)=20; // pinch point in degree C
pp(2)=28.2;
pp(3)=35;

for i=1:3
    printf("\nfor PP=%d degree C\n",pp(i))
t_6=t_6s+pp(i);
h_4s=3460; // from mollier diagram at t=535 degree C
h_7=2050;
p_c=0.07; // Condenser pressure in bar
T4=875.92974; //from Ex 18.9
t4=T4-273; // in degree C
h_7s=163.4; // Specific Enthalpy of water in kJ/kg

// part(a)steam flow per kg of gas
m_st_gt=cp*(t4-t_6)/(h_4s-h_6s); // steam flow per kg of gas
disp("kg",m_st_gt,"(a)steam flow per kg of gas is")

// part(b)Exhaust gas temperature at stack
t_7=t_6-((m_st_gt*(h_6s-h_7s))/(cp)); // energy balance for the economiser entry(7') to the superheater exit(4')
disp("degree celsius",t_7,"(b)Exhaust gas temperature at stack is")

// part(c)steam turbine plant output
h_7ss=2247;
P_st=m_st_gt*m_gt*(h_4s-h_7ss);
disp("MW",P_st/1e3,"(c)Power output of the steam turbine plant is")

// part(d)thermal efficiency of steam turbine plant
delh4s_7ss=(h_4s-h_7)*n_T;
```

```
n_st=delh4s_7ss/(h_4s-h_7s);
disp("%",n_st*100,"(d)thermal Efficiency of steam
   turbine plant is")

// part(e) thermal efficiency of the combined cycle
   plant
n_B=0.978; // Assuming Combustion chamber Efficiency
Qs=102.72554; // heat supplied in the combustion
   chamber from Ex 18.9
Qss=Qs/n_B; // power supplied to the combined cycle
n_gst=(P_gt+(P_st*1e-3))/Qss;
disp("%",n_gst*100,"(e)thermal Efficiency of
   combined gas and steam power plant is")
end

disp("Comment: Error in Textbook, Answers vary due
   to Round-off Errors")
```

Scilab code Exa 18.12 turbo prop Gas Turbine Engine

```
// scilab Code Exa 18.12 turbo prop Gas Turbine
   Engine

Ti=268.65; // in Kelvin
n_C=0.8; // Compressor Efficiency
c1=85; // entry velocity in m/s
m=50; // mass flow rate of air in kg/s
R=287;
gamma=1.4; // Specific Heat Ratio
cp=1.005; // Specific Heat at Constant Pressure in
   kJ/(kgK)
u=500/3.6; // speed of a turbo prop aircraft in m/s
delT=225; // temperature rise through the compressor
```

```
(T02−T01) in K
pi=.701; // Initial Pressure in bar
n_D=0.88; // inlet diffuser efficiency
a_i=sqrt(gamma*R*Ti);
Mi=u/a_i;
Toi_i=1/0.965; // (Toi/Ti)from isentropic flow gas tables at Mi and gamma values
T01=Ti*Toi_i;
T1=T01-(0.5*(c1^2)/(cp*1e3));

//part(a)
T1s_i=1+n_D*((T1/Ti)-1); // (T1s/Ti)isentropic temperature ratio through the diffuser
p1_i=T1s_i^(gamma/(gamma-1)); // (p1s/pi)isentropic pressure ratio
p1=p1_i*pi;
delp_D=p1-pi;
disp("bar",delp_D,"(a)isentropic pressure rise through the diffuser is")

// part(b) compressor pressure ratio
T02s=T01+(delT*n_C);
r_oc=(T02s/T01)^(gamma/(gamma-1)); //compressor pressure ratio(p02/p01)
disp(r_oc,"(b)compressor pressure ratio is")

// part(c)
P=m*cp*delT;
disp("MW",P*1e-3,"(c)power required to drive the compressor is")
```

Scilab code Exa 18.13 Turbojet Gas Turbine Engine

```
// scilab Code Exa 18.13 Turbojet Gas Turbine Engine

T1=223.15; // in Kelvin
n_C=0.75; // Compressor Efficiency
c1=85; // entry velocity in m/s
m=50; // mass flow rate of air in kg/s
R=287;
n_B=0.98; // Combustion chamber Efficiency
Qf=43*1e3; // Calorific Value of fuel in kJ/kg;
T03=1220;  // Turbine inlet stagnation temp in Kelvin
n_T=0.8; // Turbine Efficiency
gamma=1.4; // Specific Heat Ratio
n_m=0.98; // Mechanical efficiency
sigma=0.5; // flight to jet speed ratio(u/ce)
n_N=0.98; // exhaust nozzle efficiency
cp=1.005; // Specific Heat at Constant Pressure in kJ/(kgK)
u=886/3.6; // flight speed of a turbo prop aircraft in m/s
delT=200; // temperature rise through the compressor (T02-T01) in K
pi=.701; // Initial Pressure in bar
n_D=0.88; // inlet diffuser efficiency
a1=sqrt(gamma*R*T1);
M1=u/a1; // Mach number at the compressor inlet
T1_01=0.881; // (T1/T01)from isentropic flow gas tables at M1 and gamma values
T01=T1/T1_01;
T1=T01-(0.5*(c1^2)/(cp*1e3));

// part(a) compressor pressure ratio
T02s=T01+(delT*n_C);
r_oc=(T02s/T01)^(gamma/(gamma-1)); //compressor pressure ratio(p02/p01)
disp(r_oc,"(a)compressor pressure ratio is")

// part(b)
```

```
T02=T01+delT;
f=((cp*T03)-(cp*T02))/((Qf*n_B)-(cp*T03)); // f=(ma/mf);energy balance in the combustion chamber
disp(1/f,"(b)Air-Fuel Ratio is")

// part(c) turbine pressure ratio
// turbine power input P_T=n_m*(ma+mf)*cp*(T03-T01)
// power input to the compressor P_C=ma*cp*(T02-T01)
T04s=T03-(delT/(n_m*n_T*(1+f))); // from energy balance P_T=P_C
r_ot=(T03/T04s)^(gamma/(gamma-1)); //turbine pressure ratio(p03/p04)
disp(r_ot,"(c)turbine pressure ratio is")

// part(d)exhaust nozzle pressure ratio
ce=u/sigma; // jet velocity at the exit of the exhaust nozzle
T04=T03-(delT/(n_m*(1+f)));
Te=T04-(0.5*(ce^2)/(cp*1e3));
Tes=T04-((T04-Te)/n_N);
r_N=(T04/Tes)^(gamma/(gamma-1)); //exhaust nozzle pressure ratio(p04/pe)
disp(r_N,"(d)exhaust nozzle pressure ratio is")
ae=sqrt(gamma*R*Te);
Me=ce/ae; // Mach number
disp(Me,"and the Mach Number is")
```

Scilab code Exa 18.15 Impulse Steam Turbine 3000 rpm

```
// scilab code Exa 18.15 Impulse Steam Turbine 3000 rpm

P=500; // Power Output in kW
```

```
u=100; // peripheral speed of the rotor blades in m/
    s
cy2=200; // whirl component of the absolute velocity
     at entry of the rotor
cy3=0; // whirl component of the absolute velocity
    at exit of the rotor
alpha2=65; // nozzle angle at exit
n_st=0.69; // isentropic stage efficiency
p2=8; // steam pressure at the exit of the first
    stage in bar
t2=200; // steam temperature at the exit of the
    first stage in degree C
N=3e3; // rotor Speed in RPM

//part(a)Mean diameter of the stage
d=u*60/(%pi*N);
disp("m",d,"(a)Mean diameter of the stage is")

// part(b)mass flow rate of the steam
w_st=2*(u^2)*1e-3; // specific work
m=P/w_st;
disp("kg/s",m,"(b)mass flow rate of the steam is")

// part(c)isentropic enthalpy drop
delh_s=w_st/n_st;
disp("kJ/kg",delh_s,"(c)isentropic enthalpy drop is"
    )

// part(d)rotor blade angles
cx=cy2/(tand(alpha2));
beta3=atand(u/cx);
disp("degree",beta3,"(d)the rotor blade angles are
    beta2=beta3=")

// part(e)blade height at the nozzle exit
v_s2=0.2608; // from steam tables at p2=8bar and t2
    =200 degree C
Q=m*v_s2;
```

```
h=Q/(cx*%pi*d);
disp("m",h,"(e)blade height at the nozzle exit is")
```

Scilab code Exa 18.16 large Centrifugal pump 1000 rpm

```
// scilab Code Exa 18.16 large Centrifugal pump 1000
   rpm

N=1e3; // rotor Speed in RPM
H=45; // height in m
ro=1e3;
g=9.81; // Gravitational acceleration in m/s^2
n_o=0.75; // overall Efficiency of the drive
dr=2; // diameter ratio(d2/d1)
phi=0.35; // flow coefficient(cr2/u2)
Q=2.5; // discharge in m3/s

//part(a)Power required to drive the pump
P=(ro*Q*g*H)/(n_o);
disp("kW",P*1e-3,"(a)Power required to drive the
   pump is")

// part(b) impeller diameters at entry and exit
u2=sqrt(g*H);
w_p=u2^2;
d2=u2*60/(%pi*N);
disp("cm",d2*1e2,"(b)the impeller diameter at exit
   is")
d1=d2/2;
disp("cm",d1*1e2,"and the impeller diameter at entry
    is")

//part(c) impeller width
```

```
c_r2=phi*u2;
b=Q/(c_r2*%pi*d2);
disp("cm",b*1e2,"(c)the impeller width is")

// part(d)impeller blade angle at the entry
c_r1=Q/(b*%pi*d1);
u1=u2/dr;
beta1=atand(c_r1/u1);
disp("degree",beta1,"(d)the impeller blade angle at
   the entry beta1=")
```

Scilab code Exa 18.17 three stage steam turbine

```
// scilab Code Exa 18.17 three stage steam turbine

t1=250;  // Initial Temperature in degree C
n_T=0.75; // overall Efficiency of the turbine
p1=10; //Initial Pressure in bar
n_m=0.98; // Mechanical Efficiency
m=5;
N=1e3; // rotor Speed in RPM
H=45; // height in m
ro=1e3;
g=9.81; // Gravitational acceleration in m/s^2
Q=2.5; // discharge in m3/s

P=(ro*Q*g*H)/(n_T);
delh_T=P/(m*n_m*1e3);
delh_st=delh_T/3;
delh1_4ss=delh_T/n_T;

//part(a)steam conditions
h1=2940; // from Mollier diagram
```

```
disp("(a)steam conditions at the turbine exit are:")
h_4ss=h1-delh1_4ss;
p4=1.2; // in bar
disp("bar",p4,"pressure:")
h4=2640;
x4=0.98;
t4=104.8; // in degree C
disp("degree C",t4,"temperature:")
disp(x4,"the dryness fraction is:")

// part(b)stage Efficiencies
h2=h1-delh_st;
p2=5;
h3=h2-delh_st;
p3=2.5;
h4=h3-delh_st;
h2s=2795;
h3s=2705;
h4s=2605;
n_st1=delh_st/(h1-h2s);
n_st2=delh_st/(h2-h3s);
n_st3=delh_st/(h3-h4s);
disp ("%",n_st1*100,"(b)Efficiency of the first stage is")
disp ("%",n_st2*100,"Efficiency of the second stage is")
disp ("%",n_st3*100,"Efficiency of the third stage is")
```

Scilab code Exa 18.18 Ljungstrom turbine 3600 rpm

```
// scilab Code Exa 18.18 Ljungstrom turbine 3600 rpm

```

```
d1=0.92; // inner diameter of the impeller in m
d2=1; // outer diameter of the impeller in m
N=3.6e3; // rotor Speed in RPM
aplha_1=20; // blade exit angle in degree
p2=0.1; //exit Pressure of steam in bar
x2=0.88; // dryness fraction at exit
n_st=0.83; // stage Efficiency
u1=%pi*d1*N/60;
u2=%pi*d2*N/60;

//part(a)power developed
sigma=cosd(aplha_1)/2;
w_st=u1^2+u2^2;
disp("kW/(kg/s)",w_st*1e-3,"(a)power developed per unit flow rate is")

//part(b) isentropic enthalpy drop
delh_s=w_st/n_st;
disp("kJ/kg",delh_s*1e-3,"(b)isentropic enthalpy drop is")

// part(c)steam conditions at entry
disp("(c)steam conditions at entry are:")
p1=0.18; // in bar
disp("bar",p1,"pressure:")
x1=0.9;
disp(x1,"the dryness fraction is:")
```

Scilab code Exa 18.19 blower type wind tunnel

```
// scilab Code Exa 18.19 blower type wind tunnel

T01=310;  // in Kelvin
```

```
p01=1.013; //  Initial Pressure in bar
n_n=0.96; // nozzle efficiency
n_c=0.78; // compressor efficiency
Ma(1)=0.5;
Ma(2)=0.9;
pi(1)=0.837; // from isentropic flow gas tables
pi(2)=0.575;
gamma=1.4; // Specific Heat Ratio
R=287;
cp=1.005; // Specific Heat at Constant Pressure in
    kJ/(kgK)

for i=1:2
printf("when Ma=%f",Ma(i))
//part(a)
Ms=((n_n/(Ma(i)^2))-(((gamma-1)/2)*(1-n_n)))^(-1/2);
disp(Ms,"(a)Mach number for isentropic flow is")

// part(b)
p0e=1;
p_r0(i)=p0e/pi(i);
disp(p_r0(i),"(b)pressure ratio of the compressor is
    ")

// part(c)
delT0e_0i=((p_r0(i)^((gamma-1)/gamma))-1)/n_c;
T0e=T01+(T01*delT0e_0i);
delT0e_t=n_n*(1-(p_r0(i)^((1-gamma)/gamma)))*T0e;
T_t=T0e-delT0e_t;
disp("K",T_t,"(c)the test section temperature is")
a_t=sqrt(gamma*R*T_t);
c_t=Ma(i)*a_t;
disp("m/s",c_t,"and the test section velocity is")

// part(d)
ro_t=p01*1e5/(R*T_t);
A_t=0.17*0.15;
m=ro_t*A_t*c_t;
```

```
disp("kg/s",m,"(d)mass flow rate is")

// part(e)
P(1)=m*cp*(T0e-T01);
P(2)=m*cp*(T_t-T01);
disp("kW",P(i),"(e)power required for the compressor
    is")
end
```

Scilab code Exa 18.20 Calculation on an axial turbine cascade

```
// scilab Code Exa 18.20 Calculation on an axial
   turbine cascade

beta1=35; //  blade angle at entry
beta2=55; // blade angle at exit
i(1)=5; // incidence
i(2)=10;
i(3)=15;
i(4)=20;
delta=2.5; // deviation
alpha2=beta2-delta; // air angle at exit
a_r=2.5; // aspect ratio(h/l)

n=4;
for m=1:n
//part(a)
printf("\nfor incidence=%d\n",i(m))
alpha1=beta1+i(m); // air angle at entry
ep=alpha1+alpha2; // deflection angle
disp("degree",ep,"(a)flow deflection is")
p_c=0.505; //(s/l)

```

```
//part(b) loss coefficient from Hawthorne relations

z_p=0.025*(1+((ep/90)^2)); // Hawthorne's relation
disp (z_p,"(b)the profile loss coefficient from Hawthorne relation is")
z=(1+(3.2/a_r))*z_p; // the total cascade loss coefficient
disp (z,"and the total loss coefficient is")
Y=z;

// part(c)drag and lift coefficients
alpham=atand((0.5*(tand(alpha2)-tand(alpha1))));
C_D=p_c*Y*((cosd(alpham)^3)/(cosd(alpha2)^2));
disp (C_D,"(c)the drag coefficient is")

C_L=(2*p_c*(tand(alpha1)+tand(alpha2))*cosd(alpham))+(C_D*tand(alpham));
disp (C_L,"and the Lift coefficient is")
end
```

Scilab code Exa 18.21 low reaction turbine stage

```
// scilab Code Exa 18.21 low reaction turbine stage

Beta2=35; // rotor blade air angle in degree
alpha1=0; // fixed blade air angle in degree
alpha2=65;
beta3=52.5;
I(1)=0; // incidence angle
I(2)=5;
I(3)=10;
I(4)=15;
I(5)=20;
```

```
a_r=2.5; // aspect ratio(h/l)

for i=1:5
disp("degree",I(i),"when incidence=")
beta2(i)=Beta2+I(i); // beta2 varies with incidence

//part(a)
phi=cosd(alpha2)*cosd(beta2(i))/(sind(alpha2-beta2(i)));
ep=alpha1+alpha2; // deflection angle
disp(phi,"(a)flow coefficient is")
p_c=0.505; //pitch-chord ratio(s/l)

//part(b)blade to gas speed ratio
sigma=sind(alpha2-beta2(i))/(cosd(beta2(i)));
disp(sigma,"(b)blade to gas speed ratio is")
z_N=2.28*0.025*(1+((ep/90)^2)); // Hawthorne's relation

// part(c)degree of reaction
R=0.5*phi*(tand(beta3)-tand(beta2(i)));
disp("%",R*1e2,"(c)the degree of reaction is")

// part(d)total-to-total efficiency
e_R=beta2(i)+beta3; // Rotor deflection angle
zeeta_p_R=0.025*(1+((e_R/90)^2)); // profile loss coefficient for rotor
zeeta_R=(1+(3.2/a_r))*zeeta_p_R; // total loss coefficient for rotor
a=(zeeta_R*(secd(beta3)^2))+(z_N*(secd(alpha2)^2));
b=phi*(tand(alpha2)+tand(beta3))-1;
n_tt=inv(1+(0.5*(phi^2)*(a/b)));
disp("%",n_tt*1e2,"(d)total-to-total efficiency is")

end
```

Scilab code Exa 18.22 Isentropic or Stage Terminal Velocity for Turbines

```
// scilab Code Exa 18.22 Isentropic or Stage Terminal Velocity for Turbines

T01=1273;  // in Kelvin
funcprot(0);
p01=5; //  Initial Pressure in bar
p02=3.5; //  exit gas Pressure in bar
cp=1.005; // Specific Heat at Constant Pressure in kJ/(kgK)
gamma=1.4; // Specific Heat Ratio
m=28; // mass flow rate of the gas in kg/s
n_tt=0.84; // stage efficiency
shi=1.7; // stage loading coefficient
pr_0=p01/p02;
delh01_03ss=cp*T01*(1-(pr_0^((1-gamma)/gamma)));

//part(a)stage terminal velocity
c0=sqrt(2*delh01_03ss*1e3);
disp("m/s",c0,"(a)stage terminal velocity is")

// part(b)isentropic blade to gas speed ratio
sigma_s=sqrt(0.5*n_tt/shi);
disp(sigma_s,"(b)the isentropic blade to gas speed ratio is")

//part(c) peripheral speed of the rotor
u=sigma_s*c0;
disp("m/s",u,"(c)peripheral speed of the rotor is")

//part(d) the power developed
```

```
P=m*n_tt*delh01_03ss;
disp("MW",P*1e-3,"(d) the power developed is")
```

Scilab code Exa 18.23 axial compressor stage efficiency

```
// scilab Code Exa 18.23 axial compressor stage
   efficiency

R=0.5; // Degree of reaction
n_R=0.849; // efficiency of rotor blade row
n_D=0.849; // efficiency of diffuser blade row
n_st=R*n_R+(1-R)*n_D;
disp("%",n_st*1e2,"the value of stage efficiency is"
   )
```

Scilab code Exa 18.24 Calculation on an axial compressor cascade

```
// scilab Code Exa 18.24 Calculation on an axial
   compressor cascade

beta1=51;
beta2=9;
alpha_1=7; // air angle at rotor and stator exit
u=100; // test section velocity of air in m/s
cx=u/(tand(alpha_1)+tand(beta1));
w1=cx/cosd(beta1);
alpha2=atand(tand(alpha_1)+tand(beta1)-tand(beta2))
c2=cx/cosd(alpha2);
```

```
Y_D=0.0367; // loss coefficient for diffuser blade
    row
Y_R=0.0393; // loss coefficient for rotor blade row
z_R=Y_R*((w1/u)^2);
z_D=Y_D*((c2/u)^2);
phi=cx/u;
n_st=1-(0.5*phi*(z_D*(secd(alpha2)^2)+z_R*(secd(
    beta1)^2))/(tand(beta1)-tand(beta2)));
disp("%",n_st*1e2,"the value of stage efficiency is"
    )
```

Scilab code Exa 18.25 Calculation on two stage axial compressor

```
// scilab Code Exa 18.25 Calculation on two stage
    axial compressor

T01=310;  // in Kelvin
funcprot(0);
gamma=1.4;
p01=1.02; //  Initial Pressure in bar
pr_o=2;
pr_o1=1.5;
N=7.2e3; // rotor Speed in RPM
d=65/100; // Mean Blade ring diameter in m
h=10/100; // blade height at entry in m
n_p=0.9; // polytropic efficiency
wdf=0.87; // work-done factor
m=25; //  in kg/s
cp=1.005; // Specific Heat at Constant Pressure in
    kJ/(kgK)
R=287;
T01(1)=T01;
// part(a) stage pressure ratio
```

```
pr_o2=pr_o/pr_o1;
disp(pr_o2,"(a)pressure ratio developed by the 2nd
    stage is")

//part(b) stage efficiency
n=(gamma-1)/gamma;
n_st1=((pr_o1^n)-1)/((pr_o1^(n/n_p))-1);
disp("%",n_st1*1e2,"(b)stage efficiency for the
    stage 1 is")
n_st2=((pr_o2^n)-1)/((pr_o2^(n/n_p))-1);
disp("%",n_st2*1e2,"and stage efficiency for the
    stage 2 is")
// part(c)power required to drive the compressor
T02=T01*(pr_o1^((gamma-1)/gamma));
P1=m*cp*(T02-T01)/n_st1;
disp("kW",P1,"(c) power required for the 1st stage
    is")
T02s=T01+(T01*(pr_o1^((gamma-1)/gamma)-1)/n_st1);
P2=m*cp*T02s*(pr_o2^((gamma-1)/gamma)-1)/n_st2;
disp("kW",P2,"and power required for the 2nd stage
    is")



// part(d) air angles of the rotors and stators
A1=%pi*d*h;
ro_01=(p01*1e5)/(R*T01);
cx=m/(ro_01*A1);
    T1=T01-((cx^2)/(2*cp*1e3));
    p1=p01*((T1/T01)^(1/((gamma-1)/gamma)));
ro1=(p1*1e5)/(R*T1);
cx_new=m/(ro1*A1);
c1=cx_new;
disp("for first stage")
u=%pi*d*N/60;
beta1=atand(u/c1);
disp("degree",beta1,"beta1=")
wst1=cp*(T02-T01)*1e3/n_st1;
```

```
cy2=wst1/(wdf*u);
alpha2=atand(cy2/cx_new);
disp("degree",alpha2,"alpha2=")
beta2=atand((u/cx_new)-tand(alpha2));
disp("degree",beta2,"beta2=")
R=cx_new*(tand(beta1)+tand(beta2))*100/(2*u);
disp("%",R,"degree of reaction for the first stage is")

T01_II=T02s;
disp("for second stage")
T02_II=T01_II*(pr_o2^((gamma-1)/gamma));
wst2=cp*1e3*(T02_II-T01_II)/n_st2;
alpha1s=beta2;
cy1s=cx_new*tand(alpha1s);
cy2s=(cy1s)+(wst2/(wdf*u));
alpha2s=atand(cy2s/cx_new);
disp("degree",alpha2s,"alpha2s=")
beta1s=atand((u-cy1s)/cx_new);
disp("degree",beta1s,"beta1s=")
beta2s=atand((u-cy2s)/cx_new);
disp("degree",beta2s,"beta2s=")
R_II=cx_new*(tand(beta1s)+tand(beta2s))*100/(2*u);
disp("%",R_II,"Degree of Reaction for the second stage is")
```

Scilab code Exa 18.26 Calculation on an axial compressor cascade

```
// scilab Code Exa 18.24 Calculation on an axial compressor cascade

R=0.5906; // Degree of reaction
beta1=66;
```

```
beta2=22;
alpha2=61;
p_R=0.865; // pitch-chord ratio(s/l) for rotor
p_S=0.963; // pitch-chord ratio(s/l) for stator
alpha_3=beta2; //  air angle at rotor and stator
    exit
u=100; // test section velocity of air in m/s
Y_D=0.077; // profile loss coefficient for stator
    blade row
Y_R=0.08; // loss coefficient for rotor blade row
beta_m=atand(0.5*(tand(beta1)+tand(beta2)));
C_D_R=p_R*Y_R*(cosd(beta_m)^3)/(cosd(beta1)^2);
C_L_R=(2*p_R*(tand(beta1)-tand(beta2))*cosd(beta_m))
    -(C_D_R*tand(beta_m));
n_R=1-(2*C_D_R/(C_L_R*sind(2*beta_m)));
disp("%",n_R*1e2,"the value of rotor cascade
    efficiency is")

alpham=atand(0.5*(tand(alpha2)+tand(alpha_3)));
C_D_S=p_S*Y_D*(cosd(alpham)^3)/(cosd(alpha2)^2);
C_L_S=(2*p_S*(tand(alpha2)-tand(alpha_3))*cosd(
    alpham))-(C_D_S*tand(alpham));
n_D=1-(2*C_D_S/(C_L_S*sind(2*alpham)));
disp("%",n_D*1e2,"the value of diffuser cascade
    efficiency is")

n_st=R*n_R+(1-R)*n_D;
disp("%",n_st*1e2,"the value of stage efficiency is"
    )
```

Scilab code Exa 18.27 Isentropic Flow Centrifugal Air compressor

```
// scilab Code Exa 18.27 Isentropic Flow-centrifugal
```

```
Air compressor

T01=335;  // in Kelvin
p01=1.02; //  Initial Pressure in bar
beta1=61.4; // air angle at the inlet of axial inducer blades
gamma=1.4;
d1=0.175; // Mean Blade ring diameter at entry
d2=0.5; // impeller diameter at exit
cp=1005; // Specific Heat at Constant Pressure in J/(kgK)
A1=0.0412; // Area of cross section at the impeller inlet
R=287;

N(1)=5700; // rotor Speed in RPM
N(2)=6200;
N(3)=6700;
N(4)=7200;
for i=1:4
printf("\n for N=%d rpm\n\n",N(i))
u1=%pi*d1*N(i)/60;
u2=%pi*d2*N(i)/60;
c1=u1*tand(beta1);
T1=T01-((c1^2)/(2*cp));
p1=p01*((T1/T01)^(gamma/(gamma-1)));
ro1=(p1*1e5)/(R*T1);
pr0=((1+(u2^2/(cp*T01)))^(gamma/(gamma-1)));
disp(pr0,"(a)pressure ratio is")
m=ro1*A1*c1;
disp("kg/s",m,"(b)mass flow rate of air is")
T02=T01*(pr0^((gamma-1)/gamma));
P=m*cp*(T02-T01);
disp("kW",P*1e-3,"(c)Power required to drive the compressor P=")
end
```

Scilab code Exa 18.28 centrifugal Air compressor

```
// scilab Code Exa 18.28 centrifugal Air compressor
T01=335;  // in Kelvin
p01=1.02; //  Initial Pressure in bar
beta1=61.4; // air angle at the inlet of axial
    inducer blades
gamma=1.4;
N=7200; // rotor Speed in RPM
d1=0.175; // Mean Blade ring diameter at entry
d2=0.5; // impeller diameter at exit
cp=1005; // Specific Heat at Constant Pressure in J
    /(kgK)
A1=0.0412; // Area of cross section at the impeller
    inlet
R=287;
b2=A1/(%pi*d2);
disp("cm",b2*1e2,"(a)width of the impeller at exit
    is")
u2=%pi*d2*N/60;
//for N=7200 rpm
p1=0.9444579; // from Ex18.27
pr=1.4206988; //pressure ratio
m=5.0061078; //mass flow rate of air in kg/s
T02=370.35381;
ro2=1.1; //trial and error
cr2(1)=m/(A1*ro2);
n=2;
for i=1:n
    c2(i)=sqrt(cr2(i)^2+(u2^2));
    T2=T02-((c2(i)^2)/(2*cp));
    p02=pr*p01;
```

```
    p2=p02*((T2/T02)^(1/((gamma-1)/gamma)));
ro2=(p2*1e5)/(R*T2);
cr2(i+1)=m/(ro2*A1);
end
cr=cr2(3);
disp(p2/p1,"(b)the static pressure ratio is")

//part(c)
alpha2=atand(cr/u2);
disp("degree",alpha2,"(c)the direction alpha2 of the
    absolute velocity vector(c2) or the diffuser
   angle at entry is")
```

Scilab code Exa 18.29 Centrifugal compressor with vaned diffuser

```
// scilab Code Exa 18.29 Centrifugal compressor with
    vaned diffuser
T01=310;  // in Kelvin
p01=1.103; //  Initial Pressure in bar
dh=0.10; // hub diameter in m
d2=0.55; // impeller diameter in m
c1=100; // Velocity of air at the entry of inducer
c3=c1; // Velocity of air at diffuser exit
shi=1.035; // power input factor
mu=0.9; // slip factor
m=7.5; //  in kg/s
gamma=1.4;
N=15e3; // rotor Speed in RPM
disp("(a)for radially tipped blades")
cp=1005; // Specific Heat at Constant Pressure in J
   /(kgK)
R=287;
n_tt=0.81; // total to total efficiency
```

```
T1=T01-((c1^2)/(2*cp));
p1=p01*((T1/T01)^(gamma/(gamma-1)));
ro1=(p1*1e5)/(R*T1);
A1=m/(ro1*c1);
dt=sqrt((A1*4/(%pi))+(dh^2));
disp("cm",dt*1e2,"(i)tip diameter of the inducer at
    entry is")
d1=0.5*(dt+dh); // Mean Blade ring diameter
u1=%pi*d1*N/60;
w1=sqrt((u1^2)+(c1^2));
a1=sqrt(gamma*R*T1);
M1_rel=w1/a1;
disp(M1_rel,"(ii)the Relative Mach number at inducer
    blade entry Mw1=")
u2=%pi*d2*N/60;
w_st=shi*mu*(u2^2);
T02=T01+(w_st/cp);
T02s=T01+(n_tt*(T02-T01));
pr_0=(T02s/T01)^(gamma/(gamma-1));
disp(pr_0,"(iii)stagnation pressure ratio developed
    is")
P=m*cp*(T02-T01);
disp("kW",P*1e-3,"(iv)the power required is")
disp("(b)for vaned diffuser")
c_theta2=mu*u2; // velocity of whirl(swirl component
    ) at the impeller exit
// vaneless space between the impeller exit and the
    vaned diffuser entry=0.1*impeller radius
//r2s=r2*1.1;
// width of the casing after the impeller exit=1.4*
    impeller passage width
c_theta2s=c_theta2/(1.1*1.4);
cr2=c1;
cr2s=cr2/(1.1*1.4);
c2s=sqrt((cr2s^2)+(c_theta2s^2));
alpha2s=atand(cr2s/c_theta2s);
disp("degree",alpha2s,"(i)the direction of flow at
    the diffuser entry is alpha2s=")
```

```
T2s=T02-((c2s^2)/(2*cp));
a2s=sqrt(gamma*R*T2s);
M2s=c2s/a2s;
disp(M2s,"(ii)the Mach number at the diffuser entry
    is")
Ar=c2s/c3;
d3_2s=1.16; // d3/d2s from last trial given in the
    book
alpha3=acosd(cosd(alpha2s)/d3_2s);
Ar_v=d3_2s*sind(alpha3)/(sind(alpha2s));
disp(Ar_v,"(iii)Area ratio of the vaned diffuser is"
    )
T03=T02;
T3=T03-((c3^2)/(2*cp));
pr3_1=(((T3*T01)/(T1*T03))^(gamma/(gamma-1)))*pr_0;
disp(pr3_1,"(iv)the static pressure ratio of the
    compressor is")
disp("comment: Calculations in the book are wrong in
     the beginning itself for p1. so the values
    slightly differs here only for part(a)")
```

Scilab code Exa 18.30 Inward Flow Radial Gas turbine

```
// scilab Code Exa 18.30 Inward Flow Radial Gas
    turbine

T1=873; // the gas entry temperature at nozzle in
    Kelvin
p1=4; // the gas entry pressure at nozzle in bar
n_T=0.85; // isentropic efficiency
d2=0.4; // rotor blade ring diameter at entry in m
d3=0.2; // rotor blade ring diameter at exit in m
pr_t=4; // static Pressure Ratio across the turbine(
```

```
    p3/p1)
pr_n=2; // static Pressure Ratio across the nozzles(
    p3/p1)
phi=0.3; // flow coefficient at impeller entry
gamma=1.4;
N=18e3; // rotor Speed in RPM
m=5; // mass flow rate of gas in kg/s
cp=1005; // Specific Heat at Constant Pressure in J
    /(kgK)
R=287;
u2=%pi*d2*N/60;
u3=%pi*d3*N/60;
cr2=phi*u2;
// part(a)
T3ss=T1/(pr_t^((gamma-1)/gamma));
T3=T1-n_T*(T1-T3ss);
T2s=T1/(pr_n^((gamma-1)/gamma));
T2=T2s+(0.5*(T3-T3ss)); // half of the losses(T3-
    T3ss) occur in the nozzles
p2=p1/pr_n;
rho2=(p2*1e5)/(R*T2);
b2=m/(rho2*cr2*%pi*d2);
disp("cm",b2*1e2,"(a)axial width of the impeller
    blade passage at entry is")
alpha2=atand(cr2/u2);
disp("degree",alpha2,"(b)nozzle exit air angle is")
cx3=cr2;
beta3=atand(cx3/u3);
disp("degree",beta3,"(c)impeller exit air angle is")
c_theta3=0;
c_theta2=u2;
P=m*(u2*c_theta2-u3*c_theta3);
disp("kW",P*1e-3,"(d)power developed is")
```

Scilab code Exa 18.31 Cantilever Type IFR turbine

```
// scilab Code Exa 18.31 Cantilever Type IFR turbine

P=150; // Power developed in kW
T01=960; // the gas entry temperature at nozzle in
    Kelvin
p01=3; // the gas entry pressure at nozzle in bar
beta2=45; // air angle at rotor blade entry (from
    radial direction)
beta3=65; // air angle at rotor blade exit (from
    radial direction)
d2=0.2; // rotor blade ring diameter at entry in m
d3=0.15; // rotor blade ring diameter at exit in m
gamma=1.4;
N=36e3; // rotor Speed in RPM
alpha_2=15;  //  air angle at nozzle exit(from
    tangential direction)
pr0=2.29; // total-to-static Pressure Ratio(p01/p3)
n_N=0.94; // Nozzle Efficiency
cp=1100; // Specific Heat at Constant Pressure in J
    /(kgK)
R=cp*((gamma-1)/gamma);
u2=%pi*d2*N/60;
u3=%pi*d3*N/60;

// part(a) mass flow rate of the gas
cr2_theta2=tand(alpha_2); // cr2_theta2=cr2/c_theta2
c_theta2=u2/(1-cr2_theta2); // c_theta2=cr2*tan(
    alpha2)+u2
cr2=c_theta2*cr2_theta2;
cr3=cr2;
c_theta3=(cr3*tand(beta3))-u3;
w_st=(u2*c_theta2)+(u3*c_theta3);
m=P/(w_st*1e-3);
disp("kg/s",m,"(a)mass flow rate of the gas is")

// part(b)rotor blade axial length at entry
```

```
c2=cr2/sind(alpha_2);
T2s=T01-((0.5*(c2^2))/(cp*n_N));
T2=T01-((T01-T2s)*n_N);
p_rn=(T2s/T01)^(gamma/(gamma-1));
p2=p01*p_rn;
rho2=(p2*1e5)/(R*T2);
b2=m/(rho2*cr2*%pi*d2);
disp("cm",b2*1e2,"(b)rotor blade axial length at
    entry is")

// part(c)total-to-total turbine efficiency
T03ss=T01*(pr0^((1-gamma)/gamma));
n_T=P/(m*cp*1e-3*(T01-T03ss));
disp("%",n_T*1e2,"(c)total-to-total turbine
    efficiency is")

//part(d)rotor blade length at exit
p03=p01/pr0;
T03=T01-(P/(m*cp*1e-3));
c3=sqrt((cr3^2)+(c_theta3^2));
T3=T03-((cr3^2)/(2*cp));
p3=p03*((T3/T03)^(gamma/(gamma-1)));
ro3=(p3*1e5)/(R*T3);
b3=m/(ro3*cr3*%pi*d3);
disp("cm",b3*1e2,"(d)rotor blade length at exit is")

// part(e) degree of reaction
DOR=(T2-T3)/(T01-T03);
disp("%",DOR*1e2,"(e)degree of reaction is")
```

Scilab code Exa 18.32 IFR turbine stage efficiency

```
// scilab Code Exa 18.32 IFR turbine stage
```

```
    efficiency

// part(b)
R=0.48;
sigma_s=0.6;
n_n=0.92;
alpha_2=15; //  air angle at nozzle exit(from
    tangential direction)
n_st=2*sigma_s*sqrt(n_n*(1-R))*cosd(alpha_2);
disp("%",n_st*100,"stage efficiency of the radial
    turbine is")
```

Scilab code Exa 18.33 Vertical Axis Crossflow Wind turbine

```
// scilab Code Exa 18.33 Vertical Axis Crossflow
    Wind turbine

c1=24/3.6; // wind speed in m/s
c2=30/3.6; // rotor speed in m/s
m1=25; // mass flow rate of air at wind side in kg/s
m2=31.25; // rotor  air mass flow rate in kg/s
d1=3; // rotor outer diameter in m
d2=2; // rotor inner diameter in m
gamma=1.4;
alpha=37;  //  air angle at rotor entry(from
    tangential direction)
c(1)=c1;
c(2)=c2;
m(1)=m1;
m(2)=m2;

for i=1:2
c_theta1=c(i)*cosd(alpha);
```

```
u1=c_theta1/2;
u2=u1*d2/d1;
disp("kmph",c(i)*3.6,"for speed=")

// part(a)optimum rotor speed
N=60*u1/(%pi*d1);
disp("rpm",N,"(a)optimum rotor speed is")

// part(b)blade to wind speed ratio
sigma=u1/c(i);
disp(sigma,"blade to wind speed ratio is")

// part(c)hydraulic powers and efficiencies
Ph=m(i)*((2*(u1^2))+(u2^2));
disp("Watts",Ph,"(c)hydraulic power is")
n_h=((2*(u1^2))+(u2^2))/(0.5*(c(i)^2));
disp("%",n_h*1e2,"and hydraulic efficiency is")
end
```

Scilab code Exa 18.34 Counter Rotating fan

```
// scilab Code Exa 18.34 Counter Rotating fan

n=0.809; // combined efficiency of the fans
phi=0.245; // flow coefficient
A=0.212; // data from Ex14.1
d=0.45; // data from Ex14.1
u=22.62; // data from Ex14.1
cx=phi*u;
Q=1.175; // in m3/s
delp0_I=550.755; // data from Ex14.1
delp0_II=delp0_I;
delp0=delp0_I+delp0_II;
```

```
disp("mm W.G.",delp0/9.81,"(a)the overall pressure rise obtained is")
IP=Q*delp0; // power required for isentropic flow in Watts
P=IP/n;
disp("kW",P*1e-3,"(b)the Power required is")
```

Scilab code Exa 18.35 Sirocco Radial fan 1440 rpm

```
// scilab Code Exa 18.35 Sirocco Radial fan 1440 rpm

d2=0.4; // outer diameter of the impeller in m
d1=0.36; // inner diameter of the impeller in m
b=0.5; // axial length of the impeller in m
rho=1.25; // density of air in kg/m3
N=1440; // rotor Speed in RPM
P=50; // Power required in kW

u1=%pi*d1*N/60;
u2=%pi*d2*N/60;

beta1=atand(d2/d1);
disp("degree",beta1,"(a)the blade air angle at the impeller entry beta1=")
beta2=90-beta1;
disp("degree",beta2,"and the blade air angle at the impeller exit beta2=")
delp0=2*rho*(u2^2);
disp("mm W.G.",delp0/9.81,"(b)the stagnation pressure rise across the fan is")
cr1=u1*tand(beta1);
m=rho*cr1*%pi*d1*b;
disp("kg/s",m,"(c)mass flow rate of the air through
```

```
    the fan is")
c_theta1=0; // for zero inlet swirl
w_st=2*(u2^2);
IP=m*w_st/1000; // ideal power required to drive the
     fan in kW
n=IP/P;
disp("%",n*1e2,"(d)the Efficiency of the fan is")
```

Scilab code Exa 18.37 Calculation for the specific speed

```
// scilab Code Exa 18.37 Calculation for the
    specific speed

//part(1)specific speed of Axial flow gas turbine
P1=0.5e3; // Gas Turbine Power Output in kW
N1=60; // Speed in RPS
omega1=%pi*2*N1;
ro1=2;
delh_1=30; // change of enthalpy in kJ
NS_1=omega1*sqrt(P1*10e2/ro1)*((delh_1*1e3)^(-5/4));
disp(NS_1,"1.the specific speed of Axial flow gas
    turbine is")

//part(2)specific speed of IFR gas turbine
P2=0.75e3; // Gas Turbine Power Output in kW
N2=300; // Speed in RPS
omega2=%pi*2*N2;
ro2=1;
delh_2=250; // change of enthalpy in kJ
NS_2=omega2*sqrt(P2*10e2/ro2)*((delh_2*1e3)^(-5/4));
disp(NS_2,"2.the specific speed of IFR gas turbine
    is")

```

```
// part(3)the specific speed of an axial compressor
N_c=120; // Speed in RPS
omega_c=%pi*2*N_c;
Q_c=25; // flow rate in m3/s
delh_3=40; // change of enthalpy in kJ
NS_c=omega_c*sqrt(Q_c)*((delh_3*1e3)^(-3/4));
disp(NS_c,"3.the specific speed of an axial
    compressor is")

// part(4)the specific speed of a centrifugal
    compressor
Q=5; // flow rate in m3/s
delh_4=35; // change of enthalpy in kJ
NS_4=omega_c*sqrt(Q)*((delh_4*1e3)^(-3/4));
disp(NS_4,"4.the specific speed of a centrifugal
    compressor is")

// part(5)the specific speed of an axial fan
N5=22; // Speed in RPS
omega_5=2*%pi*N5;
Q_5=3.5; // flow rate in m3/s
rho=1.25; // density in kg/m3
g=9.81; // gravitational acceleration in m/s2
H1=55/rho; // head in m
NS_5=omega_5*sqrt(Q_5)*((g*H1)^(-3/4));
disp(NS_5,"5.the dimensionless specific speed of an
    axial fan is")

// part(6)the specific speed of a Radial fan
N6=20; // Speed in RPS
omega_6=2*%pi*N6;
Q_6=1.4; // flow rate in m3/s

H2=52/rho; // head in m
NS_6=omega_6*sqrt(Q_6)*((g*H2)^(-3/4));
disp(NS_6,"6.the dimensionless specific speed of a
    Radial fan is")
```

Scilab code Exa 18.38 Kaplan turbine 70 rpm

```
// scilab Code Exa 18.38 Kaplan turbine 70 rpm

//part(a)flow rate and specific speed
P=8e3; // Gas Power Output in kW
N=70; // Speed in RPM
H=10; // net head in m
n_m=0.85; // efficiency
omega=%pi*2*N/60;
NS=omega*sqrt(P*10e2)*(H^(-5/4))/549.016;
disp(NS,"(a)the specific speed of turbine is")
rho=1000; // density in kg/m3
g=9.81; // gravitational acceleration in m/s2
Q=P*1e3/(n_m*rho*g*H);
disp("m3/s",Q,"and the flow rate is")

// part(b) determining the speed, flow rate and
   power for the model
Dp_m=12; // Dp_m=Dp/Dm
Np=N; // Speed for prototype
Hm=3; // head of the model
Hp=H; // head for prototype
Nm=Np*Dp_m*sqrt(Hm/Hp);
disp("rpm",Nm,"(b)speed for the model is")
Dm_p=1/Dp_m;
Qp=Q;
Qm=(Dm_p^2)*sqrt(Hm/Hp)*Qp;
disp("m3/s",Qm,"the flow rate for model is")
Pm=n_m*rho*g*Qm*Hm;
disp("kW",Pm*1e-3,"the power for the model is")
```

Scilab code Exa 18.39 Calculation for Pelton Wheel prototype

```
// scilab Code Exa 18.39 Calculation for the Pelton
   Wheel

Nm=102; // Speed for the model in RPM
Hm=30; // net head for the model in m
n_m=1; // Assuming efficiency
Qm=0.345; // discharge in m3/s
rho=1000; // density in kg/m3
g=9.81; // gravitational acceleration in m/s2
omega_m=%pi*2*Nm/60;
Pm=n_m*rho*g*Qm*Hm;
NS=omega_m*sqrt(Pm)*(Hm^(-5/4))/549.016;
disp(NS,"the specific speed of turbine is")

// determining the speed, flow rate and power for
   the prototype
Hp=1500; // head for prototype
Pp=((Hp/Hm)^(3/2))*Pm;
disp("MW",Pp*1e-6,"the power for the prototype is")
omega_p=NS*549.016*(Hp^(5/4))/(sqrt(Pp));
Np=omega_p*60/(2*%pi);
disp("rpm",Np,"speed for the prototype is")
Qp=sqrt(Hp/Hm)*Qm;
disp("m3/s",Qp,"the flow rate for prototype is")
```

Scilab code Exa 18.40 Francis turbine 910 rpm

```
// scilab Code Exa 18.40 Calculation for the Francis
    turbine

// part(a) determining the speed, specific speed and
    power for the model
Qm=0.148; // discharge in m3/s
N=910; // Speed in RPM
Hm=25; // net head in m
n=0.9; // efficiency
omega=%pi*2*N/60;
NS=omega*sqrt(Qm)*(Hm^(-3/4))*0.1804;
disp(NS,"(a)the specific speed of turbine is")
Nu=N/(sqrt(Hm));
disp("rpm",Nu,"unit speed for the model is")
rho=1000; // density in kg/m3
g=9.81; // gravitational acceleration in m/s2
Pm=rho*g*Qm*Hm;
disp("kW",Pm*1e-3,"the power for the model is")

// part(b)determining the speed, flow rate and power
    for the prototype
Hp=250; // head for prototype
Dp_m=6; // Dp_m=Dp/Dm
Qp=sqrt(Hp/Hm)*Qm*(Dp_m^2);
disp("m3/s",Qp,"(b)the flow rate for prototype is")
Pp=rho*g*Qp*Hp*n;
disp("MW",Pp*1e-6,"the power for the prototype is")
omega_p=NS*(Hp^(3/4))/(0.1804*sqrt(Qp));
Np=omega_p*60/(2*%pi);
disp("rpm",Np,"speed for the prototype is")
```

Scilab code Exa 18.41 Calculation for the Pelton Wheel

```
// scilab Code Exa 18.41 Calculation for the Pelton Wheel
NS=0.1; //specific speed
H1=1000; // net head for the model in m
Q1=1; // discharge in m3/s
omega1=NS*(H1^(3/4))/(sqrt(Q1)*0.1804);
N1=omega1*60/(2*%pi);
disp("rpm",N1,"speed of the rotation is")
rho=1000; // density in kg/m3
g=9.81; // gravitational acceleration in m/s2
P1=rho*g*Q1*H1;

// determining the speed, flow rate and power for the prototype
H2=100; // head for prototype
N2=N1*sqrt(H2/H1);
disp("rpm",N2,"speed for the prototype is")
Q2=sqrt(H2/H1)*Q1;
disp("m3/s",Q2,"the discharge for the prototype is")
P2=((H2/H1)^(3/2))*P1;
disp("MW",P2*1e-6,"the power for the prototype is")
```

Scilab code Exa 18.42 Calculation for Tidal Power Plant

```
// scilab Code Exa 18.42 Calculation for Tidal Power Plant

T=50e6; // capacity of basin in cubic meters of sea water
N=60; // Speed for the model in RPM
NS=3; //specific speed
H=9.8; // net head for the model in m
n_o=0.78; // Assuming efficiency
```

```
rho=1000; // density in kg/m3
g=9.81; // gravitational acceleration in m/s2
n(1)=5; // number of turbines
n(2)=10;
omega=%pi*2*N/60;

P=(NS^2)*(H^(5/2))*(549.016^2)/(omega^2);
disp("MW",P*1e-6,"(a)the power for the turbines is")
Q=P/(n_o*rho*g*H);  // discharge in m3/s
disp("m3/s",Q,"(b)the discharge rate for the
    turbines is")
disp("(c)")
for i=1:2
    disp(n(i),"when number of turbines are:")
    t=T/(n(i)*Q*3600);
disp("hours",t,"duration of operation is")
end
```

Scilab code Exa 18.43 Francis turbine 250 rpm

```
// scilab Code Exa 18.43 Francis turbine 250 rpm

NS=0.4; //specific speed
N=250; // Speed in RPM
H=75; // net head in m
beta3=25; // exit angle of the runner blades
n_o=0.81; // overall efficiency
g=9.81; // gravitational acceleration in m/s2
rho=1000; // density in kg/m3
// part(a)
u2=0.6*sqrt(2*g*H);
cr2=0.21*sqrt(2*g*H);
omega=%pi*2*N/60;
```

```
Q=(NS^2)*(H^(3/2))/((0.1804^2)*(omega^2));
disp("m3/s",Q,"(a)the discharge rate for the turbine
    is")
// part(b)
d2=u2*60/(%pi*N);
disp("m",d2,"(b)outer diameter of the runner blade
   ring is")
cr3=cr2;
cx3=cr3;
//Euler work,w_ET=u2*c_theta2
c_theta2=((g*H)-(0.5*(cx3^2)))/u2;
u3=cx3/(tand(beta3));
d3=u3*60/(%pi*N);
disp("m",d3,"and inner diameter of the runner blade
   ring is")
// part(c)
alpha2=atand(cr2/c_theta2);
disp("degree",alpha2,"(c)the inlet guide vane exit
   angle is")
beta2=atand(cr2/(c_theta2-u2));
disp("degree",beta2,"and inlet angle of the runner
   blades is beta2= ")
// part(d)
n_h=(u2*c_theta2)/(g*H);
disp("%",n_h*1e2,"(d)the hydraulic efficiency is")
// part(e)
P=n_o*rho*g*Q*H;
disp("MW",P*1e-6,"(e)the output power is")
disp("comment: the calculation for c_theta2 is done
   wrongly in the book. hence the values of alpha2,
   beta2, n_h differs from the book.")
```

Scilab code Exa 18.44 Pelton Wheel 360 rpm

```
// scilab Code Exa 18.44 Pelton Wheel 360 rpm

d=2; // mean diameter in m
N=360; // Speed in RPM
theta=150; //deflection angle of water jet in degree
H=140; // net head for the model in m
q=45000; // discharge in litres/min
Q=q*1e-3/60; // in m3/s
rho=1000; // density in kg/m3
g=9.81; // gravitational acceleration in m/s2
// part(a)
u=%pi*d*N/60;
c2=sqrt(2*g*H);
sigma=u/c2;
disp(sigma,"(a)blade to jet speed ratio is")
// part(b)
w2=c2-u;
w3=w2;
beta2=0;
beta3=180-theta;
cy2=c2;
cy3=u-(w3*cosd(beta3));
w_T=u*(cy2-cy3);
m=rho*Q;
P_T=m*w_T;
disp("kW",P_T*1e-3,"(b)the power developed is")
// part(c)
n=w_T/(0.5*(c2^2));
disp("%",n*1e2,"(c)the efficiency is")
// part(d)
n_max=0.5*(1+cosd(beta3));
disp("%",n_max*1e2,"(d)the Maximum efficiency is")
P_max=m*g*H*n_max;
disp("kW",P_max*1e-3,"and the Maximum power
    developed is")
// part(e)
sigma_opt=0.5; // for Maximum efficiency
u_opt=sigma_opt*c2;
```

```
N_opt=u_opt*60/(d*%pi);
disp("rpm",N_opt,"(e)speed of the rotation
   corresponding to Maximum efficiency is")
// part(f)
omega=%pi*2*N/60;
NS=omega*sqrt(P_T)*(H^(-5/4))/549.016;
disp(NS,"(f)the specific speed of turbine is")
```

Scilab code Exa 18.45 Kaplan turbine 120 rpm

```
// scilab Code Exa 18.45 Kaplan turbine 120 rpm

N=120; // Speed in RPM
H=25; // net head in m
Q=120; // discharge in m3/s
dt=5; // runner diameter in m
dh_t=0.4; // hub-tip ratio of the runner
beta2=150; //inlet angle of the runner blades in
   degree
n_o=0.8; // overall efficiency
rho=1000; // density in kg/m3
g=9.81; // gravitational acceleration in m/s2
// part(a)
P=n_o*rho*g*Q*H;
disp("MW",P*1e-6,"(a)the output power is")
// part(b)
omega=%pi*2*N/60;
NS=omega*sqrt(P)*(H^(-5/4))/549.016;
disp(NS,"(b)the specific speed of turbine is")
// part(c)
dh=dh_t*dt;
d=0.5*(dt+dh); // mean diameter of the impeller
   blade in m
```

```
u=%pi*d*N/60;
cx=Q*4/(%pi*(dt^2-dh^2));
cy2=u-(cx*tand(90-(180-beta2)));
alpha2=atand(cx/cy2);
disp("degree",alpha2,"(c)the inlet guide vane exit
   angle is")
// part(d)
beta3=atand(cx/u);
disp("degree",beta3,"(d)the exit angle of the runner
    blades is beta3= ")
// part(e)
n_h=(u*cy2)/(g*H);
disp("%",n_h*1e2,"(e)the hydraulic efficiency is")
```

Scilab code Exa 18.46 Fourneyron Turbine 360 rpm

```
// scilab Code Exa 18.46 Fourneyron Turbine 360 rpm

d2=3; // outer diameter of the impeller in m
d1=1.5; // inner diameter of the impeller in m
H=50; // net head in m
rho=1000; // density in kg/m3
g=9.81; // gravitational acceleration in m/s2
N=360; // rotor Speed in RPM
n_o=0.785; // overall efficiency
P=4; // Power Output in MW
u1=%pi*d1*N/60;
u2=%pi*d2*N/60;
// part(a)
Q=P*1e6/(n_o*rho*g*H);
disp("m3/s",Q,"(a)the discharge is")
c2=9; // velocity of water at exit in m/s
// part(b)
```

```
w_ET=(g*H)-(0.5*(c2^2));
n_h=w_ET/(g*H);
disp("%",n_h*1e2,"(b)the hydraulic efficiency is")
// part(c)
cr2=c2;
b=Q/(cr2*%pi*d2); // axial length of the impeller in
    m
disp("cm",b*1e2,"(c)the runner passage width is")
// part(d)
beta2=atand(cr2/u2);
disp("degree",beta2,"(d) the blade air angle at the
   impeller exit beta2=")
c_theta1=w_ET/u1;
cr1=Q/(b*%pi*d1);
beta1=atand(cr1/(u1-c_theta1));
disp("degree",beta1,"and the blade air angle at the
   impeller entry beta1=")
// part(e)
alpha1=atand(cr1/c_theta1);
disp("degree",alpha1,"(e)the guide vane exit angle
   is")
```

Scilab code Exa 18.47 Crossflow Radial Hydro turbine

```
// scilab Code Exa 18.47 Crossflow Radial Hydro
   turbine

N=50; // Speed in RPM
H=25; // net head in m
Q=150; // discharge in m3/s
P=20; // Power Output in MW
d1=3.5; //  runner diameter in m
dr=1.3; // diameter ratio of the runner
```

```
rho=1000; // density in kg/m3
g=9.81; // gravitational acceleration in m/s2
u1=%pi*d1*N/60;
u2=u1/dr;
c_theta1=2*u1;
c_theta2=u2;
w_st1=(u1*c_theta1)-(u2*c_theta2);
u3=u2;
c_theta3=u2;
c_theta4=0;
w_st2=(u3*c_theta3)-(u1*c_theta4);
w_st=w_st1+w_st2;
// part(a)
n_h=w_st/(g*H);
disp("%",n_h*1e2,"(a)the hydraulic efficiency is")
Ph=rho*Q*w_st;
disp("MW",Ph*1e-6,"and the hydraulic power is")
n_o=P*1e6/(rho*Q*g*H);
disp("%",n_o*1e2,"and the overall efficiency is")
// part(b)
omega=%pi*2*N/60;
NS=omega*sqrt(P*1e6)*(H^(-5/4))/549.016;
disp(NS,"(b)the specific speed of turbine is")
// part(c)
disp("(c)Adopting the flow model of the crossflow
   wind turbine")
P_h=rho*Q*((2*(u1^2))+(u2^2));
disp("MW",P_h*1e-6,"the hydraulic power is")
nh=((2*(u1^2))+(u2^2))/(g*H);
disp("%",nh*1e2,"and hydraulic efficiency is")
```

Scilab code Exa 18.48 Calculation on a Draft Tube

```
// scilab Code Exa 18.48 Calculation on a Draft Tube

pa=1.013; // atmospheric pressure in bar
p3=0.4*pa; // turbine exit pressure in bar
rho=1e3; // density in kg/m3
g=9.81; // Gravitational acceleration in m/s^2
n_D=0.82; // Efficiency of the Draft Tube
delHi=3.1058869; // from Ex 18.5
// part(b)
Hd=delHi;
Hs=((pa-p3)*1e5/(rho*g))-(n_D*Hd); // Hs=Z3-Z4
disp("m",Hs,"(b)the suction head(height of the
    turbine exit above the tail race) is")
disp("comment: the calculation for Hs is done
    wrongly in the book. hence the value of Hs
    differs from the book.")
```

Scilab code Exa 18.49 Centrifugal pump 890 kW

```
// scilab Code Exa 18.49 Centrifugal pump 890 kW

H=50; // head developed in m
P=890; // Power required in kW
NS=0.75; //specific speed
rho=1e3;
g=9.81; // Gravitational acceleration in m/s^2
n_h=0.91; // hydraulic efficiency
f=0.925; // blockage factor for the flow
Q=1.5; // discharge in m3/s of water
u2=0.8*sqrt(2*g*H);
cr2=0.3*sqrt(2*g*H);
dr=0.5; // diameter ratio(d1/d2)
// part(a)
```

```
omega=NS*(H^(3/4))/(0.1804*sqrt(Q));
N=omega*60/(2*%pi);
disp("rpm",N,"(a)the speed of rotation is")
// part(b) impeller diameter
d2=u2*60/(%pi*N);
disp("m",d2,"(b)the impeller diameter is")
//part(c)
c_theta2=g*H/(u2*n_h);
beta2=atand(cr2/(u2-c_theta2));
disp("degree",beta2,"(c)the blade air angle at the impeller exit beta2=")
u1=u2*dr;
cr1=cr2;
beta1=atand(cr1/u1);
disp("degree",beta1,"and the blade air angle at the impeller entry beta1=")
//part(d)
b2=Q/(cr2*%pi*d2*f);
disp("m",b2,"(d)the impeller width at exit is")
//part(e)overall Efficiency
n_o=rho*Q*H*g/(P*1e3);
disp("%",n_o*1e2,"(e)overall efficiency is")
```

Scilab code Exa 18.50 Centrifugal pump 1500 rpm

```
// scilab Code Exa 18.50 Centrifugal pump 1500 rpm

N=1500; // rotor Speed in RPM
H=5.2; // head in m
b=2/100; // width in m
d1=2.5/100; // entry diameter of the blade ring in m
d2=0.1; // exit diameter of the blade ring in m
rho=1e3;
```

```
g=9.81; // Gravitational acceleration in m/s^2
n_o=0.75; // overall Efficiency of the drive
u2=%pi*d2*N/60;
u1=u2*d1/d2;
// part(a)impeller blade angle at the entry
c_r2=0.4*u2;
c_r1=c_r2*d2/d1;
beta1=atand(c_r1/u1);
disp("degree",beta1,"(a)the impeller blade angle at
    the entry beta1=")
//part(b) discharge
Q=c_r1*%pi*d1*b;
disp("litres/sec",Q*1e3,"(b)the discharge is")
//part(c)Power required
P=(rho*Q*g*H)/(n_o);
disp("kW",P*1e-3,"(a)Power required to drive the
    pump is")
// part(d)
omega=%pi*2*N/60;
NS=(H^(-3/4))*0.1804*(omega)*sqrt(Q);
disp(NS,"(d)the specific speed is")
```

Scilab code Exa 18.51 Axial pump 360 rpm

```
// scilab Code Exa 18.51 Axial pump 360 rpm

N=360; // rotor Speed in RPM
dh=0.30; // hub diameter of the impeller in m
beta2=48; // exit angle of the runner blades(from
    the tangential direction)
cx=5; // axial velocity of water through the
    impeller in m/s
n_h=0.87; // hydraulic efficiency
```

```
n_o=0.83; // overall Efficiency
Q=2.5; // discharge in m3/s
rho=1e3;
g=9.81; // Gravitational acceleration in m/s^2
//part(a)
dt=sqrt((4*Q/(cx*%pi))+(dh^2));
disp("m",dt,"(a)the impeller tip diameter is")
// part(b)impeller blade angle at the entry
d=0.5*(dt+dh); // mean diameter of the impeller
    blade in m
u=%pi*d*N/60;
beta1=atand(cx/u);
disp("degree",beta1,"(b)the impeller blade angle at
    the entry beta1=")
// part(c)
cy2=u-(cx/tand(beta2));
H=n_h*u*cy2/g;
disp("m",H,"(c)the head developed is")
//part(d)Power required
P=(rho*Q*g*H)/(n_o);
disp("kW",P*1e-3,"(d)Power required to drive the
    pump is")
// part(e)
omega=%pi*2*N/60;
NS=(H^(-3/4))*0.1804*(omega)*sqrt(Q);
disp(NS,"(e)the specific speed is")
```

Scilab code Exa 18.52 NPSH for Centrifugal pump

```
// scilab Code Exa 18.52 NPSH for Centrifugal pump

H=30; // head developed in m
ds=0.15; // suction pipe diameter in m
```

```
f=0.005; //Coefficient of friction for the suction pipe
pa=1.013; // atmospheric pressure in bar
As=%pi/4*(ds^2); // Cross-sectional Area of the suction pipe in m2
rho=1e3; // density of water in kg/m3
g=9.81; // Gravitational acceleration in m/s^2
t=30; // temperature of water in degree C
pv=0.0424; // vapour pressure of water at t value
Hv=pv*1e5/(rho*g);
Z(1)=0; // altitude in m
Z(2)=2500;
p(1)=pa; // at altitude Z=0
p(2)=0.747; // at Z=2500m
Q(1)=0.065; // discharge in m3/s of water
Q(2)=0.1;
Q(3)=0.15;
Hs(1)=3; // vertical length of the suction pipe in m
Hs(2)=5;
for i=1:3
    disp("m3/s",Q(i),"when Q=")
    cs=Q(i)/As;
    for k=1:2
        disp("m",Hs(k),"and Hs=")
        delHf=4*f*(Hs(k)/ds)*(cs^2/(2*g));
        for j=1:2
        disp("m",Z(j),"and Z=")
        Ha=p(j)*1e5/(rho*g);
    H1=Ha-(Hs(k)+(cs^2/(2*g))+delHf);
    NPSH=H1-Hv;
disp(NPSH,"NPSH=")
sigma=NPSH/H;
disp(sigma,"Cavitation Coefficient sigma=")
end
end
end
```

Scilab code Exa 18.53 NPSH and Thoma Cavitation Coefficient

```
// scilab Code Exa 18.53 NPSH and Thoma Cavitation
   Coefficient

H=60; // head developed in m
c1=8; // exit velocity in m/s
pa=1.0133; // ambient pressure in bar
rho=1e3;
n_d=0.8; // Efficiency of the Draft Tube
g=9.81; // Gravitational acceleration in m/s^2
ta=30; // ambient temperature of water in degree C
pv=0.0424; // vapour pressure of water at t value
Hv=pv*1e5/(rho*g);
//Q=c1*A1=c2*A2
Ar(1)=1.2; // draft tube area ratio(A2/A1=c1/c2)
Ar(2)=1.4;
Ar(3)=1.6;
Hs=2.5; // vertical length of the draft tube between
    the turbine exit and the tail race in m
Ha=pa*1e5/(rho*g);
for i=1:3
    Hsd=(c1^2)*(1-(1/(Ar(i)^2)))/(2*g); // ideal
       head gained by the draft tube
    Hd=n_d*Hsd; //Actual head gained by the draft
       tube
    disp(Ar(i),"for Area Ratio Ar=")
    disp("m",Hd,"(a)Actual head gained by the draft
       tube is")
    H1=Ha-(Hs+Hd);
    NPSH=H1-Hv;
disp(NPSH,"(b)NPSH=")
```

```
sigma=NPSH/H;
disp(sigma,"and Cavitation parameter(Thoma Number)
   sigma=")
end
```

Scilab code Exa 18.54 Maximum Height of Hydro Turbines

```
// scilab Code Exa 18.54 Maximum Height of Hydro
   Turbines

H=52; // head developed in m
c1=6.5; // exit velocity in m/s
pa=1.0133; // ambient pressure in bar
rho=1e3;
n_d=0.75; // Efficiency of the Draft Tube
g=9.81; // Gravitational acceleration in m/s^2
ta=20; // ambient temperature of water in degree C
sigma_cr=0.1;
pv=0.023; // vapour pressure of water at t value(
   from tables)
Hv=pv*1e5/(rho*g);
//Q=c1*A1=c2*A2
Ar=1.5; // draft tube area ratio(A2/A1=c1/c2)
Z(1)=0; // altitude in m
Z(2)=2500;
Z(3)=3000;
Z(4)=4000;
p(1)=pa; // at altitude Z=0
p(2)=0.747; // at Z=2500m
p(3)=0.701; // at altitude Z=3000m
p(4)=0.657; // at Z=4000m
 Hsd=(c1^2)*(1-(1/(Ar^2)))/(2*g); // ideal head
    gained by the draft tube
```

```
    Hd=n_d*Hsd; //Actual head gained by the draft tube
Ha=pa*1e5/(rho*g);
for i=1:4
        disp("m",Z(i),"For Z=")
        Ha=p(i)*1e5/(rho*g);
    H1=Ha-(Hsd+Hd);
    Hs=Ha-((sigma_cr*H)+Hd+Hv); // vertical length of the draft tube between the turbine exit and the tail race in m
    disp("m",Hs,"the maximum height of the turbine exit above the tail race is")
    NPSH=sigma_cr*H;
disp(NPSH,"NPSH=")
end
```

Scilab code Exa 18.55 Propeller Thrust and Power

```
// scilab Code Exa 18.55 Propeller Thrust and Power

c_u=5; // upstream velocity in m/s
c_s=10; // downstream velocity in m/s
rho=1e3; // density of water in kg/m3
c=0.5*(c_u+c_s); // velocity of water through the propeller in m/s
d(1)=0.5; // propeller diameter in m
d(2)=1;
d(3)=1.5;
delh_0=0.5*((c_s^2)-(c_u^2));
delp_0=rho*delh_0;
disp("bar",delp_0*1e-5,"(b)stagnation pressure rise across the propeller is")
for i=1:3
```

```
    disp("cm",d(i)*1e2,"for propeller diameter=")
A=%pi*(d(i)^2)/4;
Q=c*A;
m=rho*Q;
disp("m3/s",Q,"(a) flow rate through the propeller
   is")
Fx=A*delp_0;
disp("kN",Fx*1e-3,"(c) thrust exerted by the
   propeller on the boat is")
P=m*delh_0;
disp("kW",P/1000,"(d)the ideal Power required to
   drive the propeller is")
end
```