Scilab Textbook Companion for Gas Turbines by V. Ganesan[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 5

Ideal Cycles and their Analysis

Scilab code Exa 5.1 Calculation of MEP and Efficiency

```
clc;
p1=1; // Pressure before compression in bar
T1=350; // Temperature before compression in kelvin
T3=2000; // Temperature after combustion in kelvin
rp=1.3; // Pressure ratio
Cp=1.005; // Specific heat at constant pressure in
    kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

T2=T1*(rp)^((r-1)/r); // Temperature at the end of
    the compression
T4=T3*(1/rp)^((r-1)/r); // Temperature after
    expansion
Wc=Cp*(T2-T1); // Work done during compression
WT=Cp*(T3-T4); // Work done during expansion
WN=WT-Wc; // Net work done
p2=rp*p1; // Pressure at state 2
p3=p2; p4=p1; // Constant pressure process
V1=R*T1/(p1*10^5); // specific Volume at state 1
V2=R*T2/(p2*10^5); // specific Volume at state 2
```

```
V3=R*T3/(p3*10^5); // specific Volume at state 3
V4=R*T4/(p4*10^5); // specific Volume at state 4
imep=WN*10^3/(V4-V2); // Mean effective pressure
q=Cp*(T3-T2); // Heat supplied
eff=WN/q; // Efficiency of a Joule cycle
disp ("bar",imep*10^-5,"Mean effective pressure = ")
    ;
disp ("%",eff*100,"Efficiency of a Joule cycle = ");
```

Scilab code Exa 5.2 Calculation of Improvement in Efficiency

```
clc;
p1=1; // Pressure before compression in bar
T1=350; // Temperature before compression in kelvin
T3=2000; // Temperature after combustion in kelvin
rp=1.3; // Pressure ratio
Cp=1.005; // Specific heat at constant pressure in
    kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

T2=T1*(rp)^((r-1)/r); // Temperature at the end of
    the compression
T4=T3*(1/rp)^((r-1)/r); // Temperature after
    expansion
Wc=Cp*(T2-T1); // Work done during compression
WT=Cp*(T3-T4); // Work done during expansion
WN=WT-Wc; // Net work done
T5=T4; // For a perfect heat exchange
q=Cp*(T3-T5); // Heat added
eff2=WN/q; // Efficiency of a modified Joule cycle
eff1=0.072220534; // Efficiency of a joule cycle
disp ("%",eff2*100,"Efficiency of a modified Joule
    cycle = ");
disp (eff2/eff1,"Improvement in efficiency = ");
```

Scilab code Exa 5.3 calculation of net power output of the cycle

```
clc;
rp=6; // Pressure ratio
T1=300; // Inlet air temperature to the compressor in kelvin
T3=577+273; // Inlet temperature of air at turbine in kelvin
Vr=240; // Volume rate in m^3/s
Cp=1.005; // Specific heat at constant pressure in kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K
p1=1; // pressure at state 1 in bar

T2=T1*(rp)^((r-1)/r); // Temperature at the end of the compression
T4=T3*(1/rp)^((r-1)/r); // Temperature after expansion
Wc=Cp*(T2-T1); // Work done during compression
WT=Cp*(T3-T4); // Work done during expansion
WN=WT-Wc; // Net work done
q=Cp*(T3-T2); // Heat supplied
row1=p1*10^5/(R*T1); // Density of air at state 1
P=WN*Vr*row1; // Power output
eff=WN/q; // Efficiency of a cycle
disp ("MW  (roundoff error)",P/1000,"Power Output = ");
disp ("%",eff*100,"Efficiency of a cycle = ");
```

Scilab code Exa 5.4 Calculation of Efficiency and work of compression

```
clc;
T1=300; // Inlet air temperature to the compressor
    in kelvin
p1=1; // pressure at state 1 in bar
T2=475; // Temperature at discharge in kelvin
p2=5;// Pressure at state 2
T5=655; // Temperature after heat exchanger in
    kelvin
T3=870+273; // Temperature at he turbine inlet in
    kelvin
T4=450+273; // Temperature after turbine in kelvin
Cp=1.005; // Specific heat at constant pressure in
    kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

Wc=Cp*(T2-T1); // Work done during compression
WT=Cp*(T3-T4); // Work done during expansion
WN=WT-Wc; // Net work done
q=Cp*(T3-T5); // Heat supplied
eff=WN/q; // Efficiency of a cycle

disp ("kJ/kg",WN,"(i). The output per kg of air = ")
    ;
disp ("%",eff*100,"(ii).The efficiency of the cycle
    = ");
disp ("kJ/kg",Wc,"(iii). The work required to drive
    the compressor = ");
```

Scilab code Exa 5.5 Calculation of Thermal Efficiency

```
clc;
p1=1.4; // Pressure at state 1 in bar
T1=310; // Temperature at state 1 in kelvin
rp=5; // Pressure ratio
```

```
Tmax=1050; // Maximum temperatuer in kelvin
WN=3000; // Net output in kW
Cp=1.005; // Specific heat at constant pressure in
   kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

T3=Tmax;
T2=T1*(rp)^((r-1)/r); // Temperature at the state 2
T4=T3/(rp)^((r-1)/r); // Temperature at the state 4
T5=T4; // As regenerator effectiveness in 100 %
m=WN/(Cp*((T3-T4)-(T2-T1))); // mass flow rate of
   air
eff=(T3-T4-T2+T1)/(T3-T5); // Efficiency of a cycle
disp ("%",eff*100,"(i). Thermal efficiency of the
   cycle = ");
disp ("kg/min   (roundoff error)",m*60,"(ii). The
   mass flow rate of air per minute = ");
```

Scilab code Exa 5.6 Calculation of Pressure ratio of compressor and turbine

```
clc;
T1=290; // Compressor inlet temperature in kelvin
T2=460; // Compressor outlet temperature in kelvin
T3=900+273; // Turbine inlet temperature in kelvin
T4=467+273; // Turbine outlet temperature in kelvin
Cp=1.005; // Specific heat at constant pressure in
   kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

c=T2/T1; // Temperature ratio
rpc=c^(r/(r-1)); // Compression ratio
WN=(Cp*((T3-T4)-(T2-T1))); // Specific power
```

```
T5=T4; // Assuming regenerator effectiveness to be 100%
eff=WN/(Cp*(T3-T5)); // Overall efficiency of the cycle
Wc=Cp*(T2-T1); // Work required to drive the compressor
rpt=(T3/T4)^(r/(r-1)); // Turbine pressure ratio
disp (rpt," Turbine pressure ratio =  ",rpc," Compressor pressure ratio = ","(i).");
disp ("kJ/kg",WN,"(ii). Specific power output = ");
disp ("%",eff*100, "(iii). Overall efficiency of the cycle = ");
disp ("kJ/kg",Wc," (iv). Work required to drive the compressor = ");
```

Scilab code Exa 5.7 Calculation of temperature drop across the turbine

```
clc;
nW_WT=0.563; // Ratio of net work to turbine work
T1=300; // Inlet temperature to the compressor in kelvin
eff=0.35; // Thermal efficiency of the unit
m=10; // massflow rate in kg/s
Cp=1; // Specific heat at constant pressure in kJ/kg K
r=1.4; // Specific heat ratio

c=1/(1-eff); // For ideal simple cycle
T2=T1*c; // Temperature at state 2
Wc=Cp*(T2-T1); // Compressor work
WT=Wc/(1-nW_WT); // Turbine work
WN=WT-Wc; // Net work
q=WN/eff; // Net heat supplied per kg of air
T3=(q/Cp)+T2; // Temperature at state 3
T4=T3/c; // Temperature at state 4
```

```
T3_T4=T3-T4; // Temperature drop across the turbine
disp ("K",T3_T4,"Temperature drop across the turbine = ");
```

Scilab code Exa 5.8 Calculation of turbine pressure ratio

```
clc;
p=336.5; //specific power output of a turbine in kW/kg
T4=700; // Temperature at turbine outlet in kelvin
Cp=1; // Specific heat at constant pressure in kJ/kg K
Cv=0.717; // Specific heat at constant volume in kJ/kg K

r=Cp/Cv; // Specific heat ratio
T3=T4+(p/Cp); // Temperature at turbine inlet
p3_p4=(T3/T4)^(r/(r-1)); // Pressure ratio across the turbine
disp (round(p3_p4),"Pressure ratio across the turbine = ");
```

Scilab code Exa 5.9 Estimation of thermal efficiency of the plant

```
clc;
T1=300; // Minimum operating temperature in kelvin
T3=900; // Maximum operating temperature in kelvin
p1=1; // Minimum pressure in bar
p3=4; // Maximum pressure in bar
m=1600; // Mass flowrate in kg/min
r=1.4; // Specific heat ratio
Cp=1.005; // Specific heat at constant pressure in kJ/kg K
```

```
p2=p3; p4=p1; // Constant pressure process
c=(p2/p1)^((r-1)/r);
eff=(1-1/c); // The efficiency of the cycle
t=T3/T1; // ratio of maximum and minimum temperature
W=Cp*T1*(t*(1-1/c)-(c-1)); // Work output per kg of
    air
P=(m/60)*W; // Shaft power available
disp ("%",eff*100," Thermal efficiency of the plant
    = ");
disp ("kW   (roundoff error)",P,"Shaft power
    available for external Load = ");
```

Scilab code Exa 5.10 Determination of the cycle thermal efficiency

```
clc;
T1=15+273; // Inlet temperature of air at compressor
     inlet in kelvin
rp=6; // Compressor pressure ratio
T3=750+273; // Maximum permissible temperature in
    kelvin
T5=T3; // After reheat
Cp=1.005; // Specific heat at constant pressure in
    kJ/kg K
r=1.4; // Specific heat ratio

c=rp^((r-1)/r);
T2=T1*c; // Temperature at state 2
p3_p4=sqrt (rp); // For maximum expansion work
T4=T3/(p3_p4)^((r-1)/r); // Temperature at state 4
T6=T4; // As pressure ratio is same
Wc=Cp*(T2-T1); // Compressor work
WT=Cp*(T3-T4)+Cp*(T5-T6); // Turbine work
T7=T4; // Because of 100% regeneration
q=Cp*(T3-T7)+Cp*(T5-T4); // Heat supplied
```

```
WN=WT-Wc; // Net work done
eff=WN/q; // Efficiency of the plant
Wratio=WN/WT; // Work ratio
disp ("kJ/kg of air",q,"Heat supplied = ");
disp ("kW  (roundoff error)",WN,"Net shaft work = "
    );
disp ("%",eff*100,"The cycle thermal efficiency = ")
    ;
disp (Wratio,"Work ratio = ");
```

Scilab code Exa 5.11 Calculation of Efficiency under conditions giving maximum work

```
clc;
Tmin=5+273; // Minimum operating temperature in
    kelvin
Tmax=839+273; // Maximum operating temperature in
    kelvin
Cp=1.005; // Specific heat at constant pressure in
    kJ/kg K
r=1.4; // Specific heat ratio

eff_carnot=1-Tmin/Tmax; // Efficiency of the carnot
    cycle
c=1/(1-eff_carnot);
p2_p1=c^(r/(r-1)); // Pressure ratio
disp (p2_p1,"(i).Pressure ratio at which efficiency
    equals Carnot cycle efficiency = ");
t=Tmax/Tmin; // Temperature ratio
// Pressure ratio for maximum work is obtained when
c=sqrt (t);
p2_p1=c^(r/(r-1)); // Pressure ratio
eff=1-1/c;// Efficiency at maximum work output
disp (p2_p1,"(ii).Pressure ratio at which maximum
    work is obtained = ");
```

```
disp ("%",eff*100,"(iii).Efficiency at maximum work
    output = ");
```

Scilab code Exa 5.12 Comparison of basic cycle with modified cycles

```
clc;
rp=4;// Overall pressure ratio
T1=300; // Temperature at state 1 in kelvin
T3=1000; // Temperature at state 3 in kelvin
Cp=1; // Specific heat at constant pressure in kJ/kg
     K
Cv=0.717; // Specific heat at constant volume in kJ/
    kg K

// Basic cycle
r=Cp/Cv; // Specific heat ratio
c=rp^((r-1)/r);
t=T3/T1; // Temperature ratio
WN=Cp*T1*(t*(1-1/c)-(c-1)); // Net work output
eff=(1-1/c)*100;  // Efficiency of the cycle

// Basic cycle with heat exchanger
WN_he=WN;
eff_he=(1-c/t)*100; // Efficiency of the cycle with
    heat exchanger
dev_WN1=(WN_he-WN)*100/WN; //Percentage deviation of
     Net work from basic cycle
dev_eff1=(eff_he-eff)*100/eff; // Percentage
    deviation of efficiency from basic cycle

// Basic cycle with intercooled compressor
WN_ic=(Cp*T1)*(t*(1-1/c)-2*(sqrt(c)-1));
eff_ic=(1-(((t/c)+sqrt(c)-2)/(t-sqrt(c))))*100;
dev_WN2=(WN_ic-WN)*100/WN; //Percentage deviation of
     Net work from basic cycle
```

```
dev_eff2=(eff_ic-eff)*100/eff; // Percentage deviation of efficiency from basic cycle

// Basic cycle with heat exchanger and intercooled compressor
WN_iche=WN_ic;
eff_iche=(1-((2*(sqrt(c)-1))/(t*(1-1/c))))*100;
dev_WN3=(WN_iche-WN)*100/WN; //Percentage deviation of Net work from basic cycle
dev_eff3=(eff_iche-eff)*100/eff; // Percentage deviation of efficiency from basic cycle

printf ("Cycle \t\t\t\t\t\t   WN(kJ/kg) \t\tefficiency (in percentage)\t\t  percentage Change in WN \t\tpercentage change in efficiency");
printf("\n\t\t\t\t\t\t(roundoff error)    \t(roundoff error)   \t\t\t (roundoff error)\t\t\t\t (roundoff error)");
printf ("\n\nBasci cycle \t\t\t\t\t %f \t\t\t %f\t\t\t\t\t - \t\t\t\t\t -",WN,eff);
printf ("\n\nWith Heat Exchanger \t\t\t\t %f \t\t\t %f\t\t\t\t\t %f \t\t\t %f",WN_he,eff_he,dev_WN1,dev_eff1);
printf ("\n\nWith intercooling \t\t\t\t %f \t\t\t %f \t\t\t\t\t %f \t\t\t %f",WN_ic,eff_ic,dev_WN2,dev_eff2);
printf ("\n\nWith Heat Exchanger & Intercooling \t\t %f \t\t\t %f\t\t\t\t\t %f \t\t\t %f",WN_iche,eff_iche,dev_WN3,dev_eff3);
```

Scilab code Exa 5.13 Comparison of Carnot efficiency with Brayton efficiency

```
clc;
```

```
T1=27+273; // Temperature at state 1 in kelvin
T3=827+273; // Temperature at state 3 in kelvin
Cp=1.005; // Specific heat at constant pressure in kJ/kg K
r=1.4; // Specific heat ratio

t=T3/T1; // Temperature ratio
Wmax=Cp*((T3*(1-1/sqrt(t)))-T1*(sqrt(t)-1)); // Maximum work
eff_wmax=(1-1/sqrt(t)); // Efficiency of brayton cycle
Tmax=T3; Tmin=T1;
eff_carnot=(Tmax-Tmin)/Tmax; // Carnot efficiency
disp ("kJ/kg of air",Wmax,"Maximum net work per kg of air = ");
disp ("%",eff_wmax*100,"Brayton cycle efficiency = ");
disp ("%",eff_carnot*100,"Carnot cycle efficiency = ");
```

Scilab code Exa 5.15 Calculation of Improvement in Efficiency

```
clc;
p1=1; // Pressure at state 1 in bar
T1=300; // Temperature at state 1 in kelvin
p4=5; // Pressure at state 4 in bar
T5=1250; // Temperature at state 5 in kelvin
Cp=1.005; // Specific heat at constant pressure in kJ/kg K
r=1.4; // Specific heat ratio

rp=p4/p1; // pressure ratio
p2=sqrt (rp); // Because of perfect intercooling
c1=p2^((r-1)/r);
T2=T1*c1; // Temperature at state 2
```

```
T4=T2; T3=T1;

Wc1=Cp*(T2-T1); // Work of compressor 1
Wc=2*Wc1; // net work of compressor
WT1=Wc;
T6=T5-(WT1/Cp); // Temperature at state 6
p5_p6=(T5/T6)^(r/(r-1)); // Pressure ratio
p6=rp/p5_p6; // Pressure at state 6
p7=p1; T7=T5;p8=p6;
T8=T7*(p7/p8)^((r-1)/r); // Temperature in state 8
WT2=Cp*(T7-T8); // Turbine 2 work
q=Cp*(T5-T4)+Cp*(T7-T6); // Heat supplied
eff=WT2/q; // Efficiency of the cycle
// With regenerator
T9=T8;
q_withregen=Cp*((T5-T9)+(T7-T6)); // Heat supplied with regenerator
eff_withregen=WT2/q_withregen; // Efficiency of the cycle with regenerator
I_eff=(eff_withregen-eff)/eff_withregen; // Percentage improvement in efficiency

disp ("%",eff*100,"Efficiency of the cycle = ","kJ/kg",q,"Heat supplied = ","kJ/kg",WT2,"Work of turbine = ","(i). Without regenerator ");
disp ("%",eff_withregen*100,"Efficiency of the cycle = ","kJ/kg   (roundoff error)",q_withregen,"Heat supplied = ","(ii). With regenerator" );

disp ("%",I_eff*100,"Percentage improvement in efficiency = ");
```

Scilab code Exa 5.16 Calculation of Efficiency ratio of the power plants

```
clc;
```

```
p1=1; // pressure at inlet in bar
T1=27+273; // Temperature at inlet in kelvin
T4=1200; // Maximum temperature in kelvin
t=T4/T1; // Temperature ratio
r=1.4; // Specific heat ratio

rp=t;
c=rp^((r-1)/r);
x=(1-sqrt(c)/rp)/(1-c/rp);
eff2_1=x;
r1=sqrt(rp);
r2=r1; r3=r1; r4=r1;

disp (eff2_1,"Efficiency ratio of power plants = ");
disp (r4,"pressure ratio of LPT = ",r3,"pressure
   ratio of HPT = ",r2,"pressure ratio of HPC = ",r1
   ,"pressure ratio of LPC = ");
```

Scilab code Exa 5.19 Determination of Net power output

```
clc;
m=30; // Mass flow rate in kg/s
p1=1; // pressure of air at compressor inlet in bar
T1=273+15; // Temperature of air at compressor inlet
    in kelvin
p2=10.5; // Pressure of air at compressor outlet
T_R=420; // Temperature rise due to combustion in
   kelvin
p4=1.2; // Pressure at turbine outlet in bar
Cp=1.005; // Specific heat at constant pressure in
   kJ/kg K
r=1.4; // Specific heat ratio

T2=T1*(p2/p1)^((r-1)/r); // Temperature at state 2
T3=T2+T_R; // Temperature at state 3
```

```
p3=p2;
T4=T3/(p3/p4)^((r-1)/r);
Wc=m*Cp*(T2-T1); // Compressor work
WT=m*Cp*(T3-T4); // Turbine work
WN=WT-Wc; // Net work output
Q=m*Cp*(T3-T2); // Heat supplied
eff_th=WN/Q; // Thermal efficiency

disp("%",eff_th*100,"Thermal efficiency = ","kW (roundoff error)",WN,"Power output = ","kW",Q,"Heat supplied = ");
```

Chapter 6

Practical Cycles and their Analysis

Scilab code Exa 6.1 Calculation of Net power and overall efficiency of installation

```
clc;
p01=1; // Pressure at state 1 in bar
T01=30+273; // Temperature at state 1 in kelvin
p02=6; // Pressure of air after compressed in bar
eff_c=0.87; // Isentropic efficiency of compressor
T03=700+273; // Temperature at state 3 in kelvin
eff_T=0.85; // Isentropic efficiency of the turbine
CV=43.1; // calorific value of fuel in MJ/kg
ma=80; // Mass flow rate of air in kg/min

Cpa=1.005;// Specific heat of air  at constant
   pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
   pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
T_02=T01*(p02/p01)^((r-1)/r); // from T-S diagram
T02=T01+(T_02-T01)/eff_c; // Temperature after
```

```
    compression
// Neglecting the addition of fuel in the combustion
     chamber we have mf+ma=ma
mf=(ma/60)*Cpg*(T03-T02)/(CV*10^3);
ma_mf=(ma/60)*(1/mf); // Air fuel ratio
A_F=ma_mf;
p04=p01;p03=p02;
T_04=T03*(p04/p03)^((rg-1)/rg);
T04=T03-eff_T*(T03-T_04);
WN=(ma/60)*Cpg*(T03-T04)-(ma/60)*Cpa*(T02-T01); //
    The net power of installation
eff_th=WN/(mf*CV*10^3); // The overall thermal
    efficiency

disp (A_F,"(i).Air fuel ratio of the turbine gases =
     ");
disp ("K",T04,"(ii).The final temperature of exhaust
     gases = ");
disp ("kW",WN,"(iii).The net power of installation =
     ");
disp ("%",eff_th*100,"(iv).The overall thermal
    efficiency = ");
```

Scilab code Exa 6.2 Calculation of ratio of compressor to turbine work

```
clc;
p01=1; // Air inlet pressure in bar
T01=7+273;// Air inlet temperature in kelvin
p02=4; // Pressure at state 2 in bar
eff_c=0.82;// Isentropic efficiency of compressor
T03=800+273; // Maximum temperature at the turbine
    inlet in kelvin
eff_T=0.85; // Isentropic efficiency of the turbine
CV=43.1; // calorific value of fuel in MJ/kg
Cpa=1.005;// Specific heat of air  at constant
```

```
pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
LS=0.85;
mf=1; // Let assume mass of fuel to be 1 kg

T_02=T01*(p02/p01)^((r-1)/r); // from T-S diagram
T02=T01+(T_02-T01)/eff_c; // Temperature after compression
Wc=Cpa*(T02-T01); // Work of compression
Q=Cpg*(T03-T02); // Heat supplied
p04=p01;p03=p02;
T_04=T03*(p04/p03)^((rg-1)/rg);
T04=T03-eff_T*(T03-T_04);
WT=Cpg*(T03-T04); // Turbine work
WN=WT-Wc; // Net work done
eff_th=WN/(Q/LS); // The thermal efficiency
ma_mf=(LS*CV*10^3/Q)-1; // AIR FUEL ratio
ma=mf*ma_mf;
sfc=(3600/(ma_mf*WN)); // specific fuel consumption
Wc_WT=(Wc*ma)/(WT*(ma+mf)); // work ratio

disp ("kJ/kg of air",Wc,"(i).Compressor work = ");
disp ("kJ/kg of air",Q,"(ii).Heat supplied = ");
disp ("kJ/kg of air",WT,"(iii).Turbine work = ");
disp ("kJ/kg of air",WN,"(iv).Net work = ");
disp ("%",eff_th*100,"(v).Thermal Efficiency = ");
disp (ma_mf,"(vi).Air/Fuel ratio = ")
disp ("kg/kWh",sfc,"(vii).Specific fuel consumption =");
disp (Wc_WT,"(viii).Ratio of compressor work to turbine work = ");
```

Scilab code Exa 6.3 Calculation of effect of pressure loss

```
clc;
eff_c=0.82; // Isentropic efficency of the
    compressor
eff_T=0.85; // Isentropic efficency of the turbine
eff_m=0.99; // Mechanical transmission efficiency
rp=7; // Pressure ratio
T03=1000; // Maximum cycle temperature in kelvin
eff_comb=0.97; // Combustion efficiency
CV=43.1; // Calorific value in MJ/kg
ma=20; // Air mass flow rate in kg/s
eff_reg=0.75; // Regenerator effectiveness
del_P=0.1; // Regenerator gas side pressure loss in
    bar
T01=327; // Ambient temperature in kelvin
p01=1; // Ambient pressure in bar
Cpa=1.005;// Specific heat of air  at constant
    pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
    pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air

//(i).With Regeneration and pressure loss
T_02=T01*(rp)^((r-1)/r);
T02=T01+(T_02-T01)/eff_c;
p04=p01+del_P;
p03=rp/p01;
T_04=T03*(p04/p03)^((rg-1)/rg);
T04_1=T03-eff_T*(T03-T_04);
T05=T02+eff_reg*(T04_1-T02);
mf1=(ma*Cpg*(T03-T05))/(CV*10^3*eff_comb); // By
    neglecting the effect of change in mass flow rate
     due to mf in combustion chamber
p03_p04_1=p03/p04;
WT1=(ma+mf1)*Cpg*(T03-T04_1); // Turbine work
WN1=(ma+mf1)*Cpg*(T03-T04_1)-(ma*Cpa*(T02-T01)/eff_m
```

```
); // Net work output
sfc1=mf1*3600/WN1; // Specifc fuel consumption
eff_th1=WN1/(mf1*CV*10^3); // Thermal efficiency



//(ii).Without Regenerator and without pressure loss

p04=p01;
T_04=T03*(p04/p03)^((rg-1)/rg);
T04_2=T03-eff_T*(T03-T_04);
mf2=(ma*Cpg*(T03-T02))/(CV*10^3*eff_comb);
WT2=(ma*Cpg*(T03-T04_2));
WN2=(ma*Cpg*(T03-T04_2))-(ma*Cpa*(T02-T01)/eff_m); // Net work output
p03_p04_2=p03/p04;
sfc2=mf2*3600/WN2; // Specific fuel consumption
eff_th2=WN2/(mf2*CV*10^3); // Thermal efficiency


//(iii).With Regenerator and without pressure loss
T_02=T01*(rp)^((r-1)/r);
T02=T01+(T_02-T01)/eff_c;
p04=p01;
p03=rp/p01;
T_04=T03*(p04/p03)^((rg-1)/rg);
T04_3=T03-eff_T*(T03-T_04);
T05=T02+eff_reg*(T04_3-T02);
WT3=(ma*Cpg*(T03-T05));
mf3=(ma*Cpg*(T03-T05))/(CV*10^3*eff_comb); // By neglecting the effect of change in mass flow rate due to mf in combustion chamber
p03_p04_3=p03/p04;
WN3=(ma+mf3)*Cpg*(T03-T04_3)-(ma*Cpa*(T02-T01)/eff_m); // Net work output
sfc3=mf3*3600/WN3; // Specifc fuel consumption
eff_th3=WN3/(mf3*CV*10^3); // Thermal efficiency

```

```

printf("Quantities \t\t\t \t\tRegenerator \t\t\t\t\t\t Without");
printf ("\n\t\t\t\twith Del_P\t\twithout Del_P\t\t\t\tregenerator and Del_P");
printf ("\n\t\t\t\t(roundoff error)\t(roundoff error)\t\t\t(roundoff error)");
printf("\n\n P03/P04\t\t\t%f\t\t%f\t\t\t\t\t%f",p03_p04_1,p03_p04_3,p03_p04_2);
printf ("\n\nT04 (K)\t\t\t\t%f\t\t%f\t\t\t\t\t%f",T04_1,T04_3,T04_2);
printf ("\n\nmf (kg/s)\t\t\t%f\t\t%f\t\t\t\t\t%f",mf1,mf3,mf2);
printf ("\n\nWT (kW)\t\t\t\t%f\t\t%f\t\t\t\t\t%f",WT1,WT3,WT2);
printf ("\n\nsfc (kg/kW h)\t\t\t%f\t\t%f\t\t\t\t\t%f",sfc1,sfc3,sfc2);
printf ("\n\nefficiency (in percentage)\t%f\t\t%f\t\t\t\t\t%f",eff_th1*100,eff_th3*100,eff_th2*100);

printf ("\n\nAs can be seen from the table that pressure loss plays a major role in the efficiency than the regenerator. \n\nHence,more care should be taken in the design to have minimum pressure loss.");
```

Scilab code Exa 6.4 Calculation of net power out SFC and overall Efficiency

```
clc;
eff_c=0.8; // Isentropic efficiency of compression each stage
eff_CT=0.88; // Isentropic efficiency of compressor turbine
eff_PT=0.88; // Isentropic efficiency of power
```

```
turbine
eff_trans=0.98; // Turbine to compressor transmission efficiency
rp=3; // Pressure ratio in each stage of compression
T08=297; // Temperature after intercooler in kelvin
ma=15; // Air mass flow in kg/s
eff_reg=0.8; // Regenerator effectiveness
del_P=0.1; // Regenerator gas side pressure loss in bar
T01=327; // Ambient temperature in kelvin
p01=1; // Ambient pressure in bar
T03=1000; // Maximum cycle temperature in kelvin
CV=43.1; // Calorific value in MJ/kg
Cpa=1.005;// Specific heat of air  at constant pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
p03=rp^2; // Pressre at state 3 in bar
T_07=T01*(rp)^((r-1)/r);
T07=T01+(T_07-T01)/eff_c;
WLPC=ma*Cpa*(T07-T01); //  Work of low pressue compressor
T_02=T08*(rp)^((r-1)/r);
T02=T08+(T_02-T08)/eff_c;
WHPC=ma*Cpa*(T02-T08);
WC=WLPC+WHPC; // Compressor work
WCa=WC/eff_trans; // Actual compressor work
// Neglecting effect of mf
T09=T03-(WCa/(ma*Cpg));
T_09=T03-(T03-T09)/eff_PT;
p09=p03/(T03/T_09)^(rg/(rg-1));
p04=p01+del_P;
T_04=T09*(p04/p09)^((rg-1)/rg);
T04=T09-eff_PT*(T09-T_04);
WTP=ma*Cpg*(T09-T04); // Work output of power turbine
```

```
T05=T02+eff_reg*(T04-T02);
mf=(ma*Cpg*(T03-T05))/(CV*10^3);
sfc=mf*3600/(WTP);//Specifc fuel consumption
eff_th=WTP/(mf*CV*10^3); // Thermal efficiency


disp ("kW   (roundoff error)",WTP,"Work output of
   power turbine = ");
disp ("kg/kW h",sfc,"Specifc fuel consumption = ");
disp ("%",eff_th*100,"Thermal efficiency = ");
```

Scilab code Exa 6.5 Calculation of the thermal efficiency and air rate

```
clc;
Wplant=1850; // Plant work output in KW
p01=1; // Ambient pressure in bar
T01=27+273; // Ambient temperature in kelvin
T03=720+273; // Maximum cycle temperature in kelvin
rp=2.5; // Pressure ratio
eff_T=0.80; // Turbine and compressor efficiency
eff_reg=0.75; // Regenerator effectiveness
eff_comb=0.98; // Combustion efficiency
CV=43.1; // Calorific value in MJ/kg
del_p=0.03; // Pressure drop
p02=6.25; // Pressure in bar
Cpa=1.005;// Specific heat of air  at constant
   pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
   pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air

T_07=T01*rp^((r-1)/r);
T07=T01+(T_07-T01)/eff_T;
T02=T07;
```

```
WLPC=Cpa*(T07-T01); // Work of low pressure
    compressor
WHPT=WLPC;
T09=T03-WHPT/Cpg;
T_09=T03-(T03-T09)/eff_T;
p03=(1-del_p)^2*p02
p09=p03/(T03/T_09)^(rg/(rg-1));
p10=p09*(1-del_p);
T10=T03;
p04=p01+del_p;
T_04=T10*(p04/p10)^((rg-1)/rg);
T04=T10-eff_T*(T10-T_04);
Wlpt=Cpg*(T10-T04);
WN=Wlpt-WHPT;
ma=Wplant/WN;
T05=T02+eff_reg*(T04-T02);
Q=Cpg*(T03-T05+T10-T09);
eff_th=WN/Q;
WHPT_1=ma*WHPT;
Wlpt_1=ma*Wlpt;
mf=ma*Q*3600/(eff_comb*CV*10^3);
sfc=mf/Wplant;

disp ("K",T_07,"T_07 = ");
disp ("K",T07,"T07 = ");
disp ("K",T09,"T09 = ");
disp ("K",T_09,"T_09 = ");
disp ("K",T_04,"T_04 = ");
disp ("K",T04,"T04 = ");
disp ("K",T05,"T05 = ");
disp ("bar",p03,"P03 = ");
disp ("bar",p09,"P09 = ");
disp ("bar",p10,"P10 = ");
disp ("kg/s",ma,"Mass flow rate = ");
disp ("%",eff_th*100,"The overall efficiency = ");
disp ("kg of fuel/kW h",sfc,"Specific fuel
    consumption = ");
```

Scilab code Exa 6.6 Calculation of Compressor efficiency and the temperature ratio

```
clc;
rp=11.3137; // Pressure ratio
WN=0; // Net work output
Q=476.354; // Heat added per kg of air mass in kJ
T01=300; // Inlet air total temperature in kelvin
eff_T=0.71; // turbine efficiency
Cpa=1.005;// Specific heat of air  at constant
    pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
    pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air

T_02=T01*rp^((r-1)/r);
T03_T02=Q/Cpa;
T03_T_04=rp^((r-1)/r);
T04_T03=1-(eff_T*(1/T03_T_04)*(T03_T_04-1));
T04=T01+(T03_T02);
T03=T04/T04_T03;
t=T03/T01; //Temperature ratio
T02=T03-T03_T02;
eff_C=(T_02-T01)/(T02-T01); // Compressor efficiency

disp ("%",eff_C*100,"Compressor Efficiency = ",);
disp (t,"Temperature ratio = ");
```

Scilab code Exa 6.7 Calculation of suitable pressure ratio

```
clc;
```

```
eff_C=0.7042; // Efficiency of the compressor
eff_T=0.71; // Efficiency of the turbine
Q=476.354; // Head added in kJ/kg
WR=0.0544; // Work ratio
T01=300;// Total inlet temperature in kelvin
Cpa=1.005;// Specific heat of air  at constant
   pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
   pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air

c_t=(1-WR)*(eff_T*eff_C);
t=((Q/(Cpg*T01))+1-1/eff_C)/(1-c_t/eff_C); //
   Temperature ratio
c=c_t*t;
rp=c^(r/(r-1)); // Pressure ratio

disp (rp,"Pressure ratio = ");
disp (t,"Temperature ratio = ");
```

Scilab code Exa 6.8 Calculation of minimum temperature ratio

```
clc;
WR=0.3; // Work ratio
rp=12; // Pressure ratio
t=4; // Temperature ratio
Cpa=1.005;// Specific heat of air  at constant
   pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
   pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air

c=rp^((r-1)/r);
```

```
eff_C_T=1/((1-WR)*t/c);
tmin=c/eff_C_T;
eff=1-1/c;

disp (tmin,"Minimum Temperature ratio = ");
disp ("%",eff*100,"Efficiency = ");
```

Scilab code Exa 6.9 Calculation of Isentropic efficiency of Turbine

```
clc;
eff_pe=0.85; // Polytropic efficiency of the compressor
T_02_T01=2;
Cpa=1.005;// Specific heat of air  at constant pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air

rc=(T_02_T01)^(r/(r-1));
eff_C=(T_02_T01-1)/(((rc^(((r-1)/r)*(1/eff_pe)))-1)); // Compressor efficiency
eff_T=(1-(1/rc)^(eff_pe*(r-1)/r))/(1-(1/rc)^((r-1)/r)); // Turbine efficiency


disp ("%",eff_C*100," Isentropic compressor efficiency = ");
disp ("%",eff_T*100," Isentropic Turbine efficiency = ");
```

Scilab code Exa 6.10 Plotting variation of Isentropic efficiency over a range of pressure ratio

```
clc;
eff_C=0.85; // Isentropic efficiency of the compressor
rp=4; // Pressure ratio
r=1.4; // specific heat ratio
eff_pc=(((r-1)/r)*log (rp))/log (((rp^((r-1)/r)-1)/eff_C)+1);
disp ("%",eff_pc*100,"Polytropic efficiency = ");
disp ("variation of compressor efficiency with compression ratio is shown in window1");
xset('window',1);
function eff_c=f(rc)
    eff_c=(rc^0.286-1)/(rc^0.326-1);
endfunction
rc=linspace (2,10,4);
plot(rc,f);
title ("variation of compressor efficiency with compression ratio","fontsize",4,"color","blue");
xlabel("compression ratio (rc)","fontsize",4,"color","blue");
ylabel ("Compressor efficiency","fontsize",4,"color","blue");
```

Scilab code Exa 6.11 Calculation of the power output thermal efficiency and the heat exchanger effectiveness

```
clc;
eff_pe=0.88; // Compressor and turbine polytropic efficiencies
T01=310; // Temperature at LP compressor inlet in kelvin
p01=14; // Pressure at LP compressor inlet in bar
```

```
rp=2; // Compressor pressure ratio
T03=300;// Temperature at HP compressor inlet in kelvin
m=180; // Mass flow of Helium in kg/s
Q=500; // Heat input to gas turbine in MW
T07=700; // Helium Temperature at entry to reactor channels in kelvin
P_precoller=0.34; // Pressure loss in pre-cooler and intercooler in bar
P_loss_HE=0.27; // Pressure loss in heat exchanger in bar
P_loss_RC=1.03; // Pressure loss in reactor channel in bar
eff_pc=0.88; // Polytropiic efficiency
Cp=5.19;// Specific heat  at constant pressure in kJ/kg K
r=1.66; // Specific heat ratio

n_1_n=((r-1)/r)*(1/eff_pc);
T02=T01*rp^n_1_n;
T04=T03*rp^n_1_n;
T05=((Q*10^3)/(m*Cp))+T07;
T_press_loss=P_precoller+P_loss_HE+P_loss_RC; // Total pressure loss
p05=56-T_press_loss;
p06=p01+P_precoller+P_loss_HE;
n__1_n=eff_pc*((r-1)/r);
T06=T05/(p05/p06)^n__1_n;
WC=m*Cp*((T02-T01)+(T04-T03)); // Work of compressor
WT=m*Cp*(T05-T06); // Work of Turbine
WN=WT-WC; // Net work output
eff_th=WN/(Q*10^3); // Efficiency
eff=(T07-T04)/(T06-T04); // Effectiveness

disp ("MW  (roundoff error)",WN/1000,"Power output = ");
disp ("%  (roundoff error)",eff_th*100,"Thermal efficiency = ");
```

```
disp ("%    (roundoff  error)",eff*100,"Effectiveness
    = ");
```

Scilab code Exa 6.12 Calculation of the isentropic efficiency of the turbine and the mass flow of air

```
clc;
rp=4; // Pressure ratio
WN=1500; // Net work output in kW
T01=25+273; // Inlet temperature in kelvin
p01=1; // Inlet pressure in bar
p03=4; // Turbine inlet pressure in bar
T03=700+273;// turbine inlet temperature in kelvin
eff_c=0.85; // Compressor efficiency
eff_over=0.21; // Overall efficiency
Cp=1.005;// Specific heat of air  at constant
    pressure in kJ/kg K
r=1.4; // Specific heat ratio of air

T02=T01+T01*(rp^((r-1)/r)-1)/eff_c;
Q=WN/eff_over;
m=Q/(Cp*(T03-T02));
Wn=WN/m; // Net work per kg
T04=T03-T02+T01-(Wn/Cp);
T_04=T03/rp^((r-1)/r);
eff_T=(T03-T04)/(T03-T_04);

disp ("kg/s",m,"Mass flow rate = ");
disp ("%",eff_T*100,"Isentropic efficiency  of the
    Turbine = ");
```

Scilab code Exa 6.13 Determination of pressure of the gas entering the low pressure turbine

```
clc;
rp=4; // Pressure ratio
eff_c=0.86; // Compressor efficiency
eff_Thp=0.84;// High pressure turbine efficiency
eff_Tlp=0.8;// Low pressure turbine efficiency
eff_M=0.92; // Mechanical efficiency
T03=660+273; // in kelvin
T05=625+273; // In kelvin
T01=15+273; // Inlet temperature in kelvin
p01=1; // Inlet pressure in bar
Cp=1.005;// Specific heat of air  at constant
    pressure in kJ/kg K
r=1.4; // Specific heat ratio of air
eff= 0.75; // Heat exchanger effectiveness

T_02=T01*(rp)^((r-1)/r);
T02=((T_02-T01)/eff_c)+T01;
T04=T03-((T02-T01)/eff_M);
// In HP turbine
T_04=T03-((T03-T04)/eff_Thp);
p_04=rp/(T03/T_04)^(r/(r-1));
// In LP turbine
p05=p_04;p_06=p01;
T_06=T05/(p05/p_06)^((r-1)/r);
T06=T05-(eff_Tlp*(T05-T_06));
T07=T02+eff*(T06-T02);
Q=Cp*(T03-T07+T05-T04);
Wc=Cp*(T02-T01);
WT=Cp*(T03-T04+T05-T06);
eff_th=(WT-Wc)/Q;

disp ("bar",p_04,"(i).Pressure of gas entering low
    pressure turbine = ");
disp ("%",eff_th*100,"Overall efficiency = ");
```

Scilab code Exa 6.14 Calculation of pressure ratio and cycle efficiency

```
clc;
T01=38+273; // Inlet temperature of compressor in kelvin
eff_c=0.82; // Compressor efficiency
T03=650+273; // Turbine inlet temperature in kelvin
eff_T=0.8; // Turbine efficiency
Cpa=1.005;// Specific heat of air  at constant pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air

t=T03/T01;
// For maximun specific work we know that
ropt=(sqrt (t*eff_c*eff_T))^(r/(r-1));
T_02=T01*ropt^((r-1)/r);
T02=T01+(T_02-T01)/eff_c;
T_04=T03/ropt^((rg-1)/rg);
T04=T03-eff_T*(T03-T_04);
eff_th=((Cpg*(T03-T04))-(Cpa*(T02-T01)))/(Cpg*(T03-T02));

disp (ropt,"Optimum pressure ratio = ");
disp ("%",eff_th*100, "Overall efficiency = ");
```

Scilab code Exa 6.15 Estimation of the temperature of the gases at entry to the turbine

```
clc;
p01=1; // Stagnation pressure at entry in bar
pa=0.93; // Static pressure at entry in bar
T1=10+273;// Static temperature in entry in kelvin
```

```
p02=6; // Pressure at state 2 in bar
T02=230+273; // Temperature at state 2 in kelvin
P=5100; // Turbine output power in kW
A=0.1; // Compressor entry area in m^2
Cpa=1.005;// Specific heat of air  at constant
    pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
    pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
R=287; // Characteristic constant in J/kg K
T04=460+273; // Exhaust pipe temperature in kelvin

M=sqrt (((p01/pa)^((r-1)/r)-1)/((r-1)/2));
T01=T1*(1+(r-1)/2*M^2);
T_02=T01*(p02/p01)^((r-1)/r);
eff_c=(T_02-T01)/(T02-T01);
row_s=(pa*10^5)/(R*T1);
a=sqrt (r*R*T1);
V=M*a;
m=row_s*A*V;
T03=(P/(m*Cpg))+T04;

disp ("%",eff_c*100,"Compressor efficiency = ");
disp ("kg/s",m,"Mass flow rate = ");
disp ("K  (roundoff error)",T03,"Turbine inlet
    stagnation temperature = ");
```

Scilab code Exa 6.16 Calculation of efficiency and work ratio of modern turbines and old turbines

```
clc;
T01=27+273; // Inlet temperature in kelvin
p01=1; // Inlet pressure in bar
rp=3; // Pressure ratio
```

```
Cpa=1.005;// Specific heat of air  at constant pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
R=287; // Characteristic constant in J/kg K

T_02=T01*rp^((r-1)/r);
// Turbines 70 years ago
eff_c=0.65; // Compressor efficiency
eff_T=0.7; // Turbine efficiency
T03=700+273; // in kelvin
T02=T01*(1+((rp^((r-1)/r)-1)/eff_c));
T04=T03*(1-eff_T*(1-(1/rp^((rg-1)/rg))));
eff_th=(Cpg*(T03-T04)-Cpa*(T02-T01))/(Cpg*(T03-T02));
WR=(Cpg*(T03-T04)-Cpa*(T02-T01))/(Cpg*(T03-T04));

disp (WR,"Work ratio = ",eff_th*100,"The Efficiency = ","(i).70 years ago");

//Modern turbines
eff_c=0.85; // Compressor efficiency
eff_T=0.9; // Turbine efficiency
T03=1000+273; // in kelvin
T02=T01+(T_02-T01)/eff_c;
T_04=T03/rp^((rg-1)/rg);
T04=T03-eff_T*(T03-T_04);
Wc=Cpa*(T02-T01);
WT=Cpg*(T03-T04);
WN=WT-Wc;
eff_th=WN/(Cpg*(T03-T02));
WR=WN/WT;

disp (WR,"Work ratio = ","%",eff_th*100,"The Efficiency = ","(ii).Modern turbines");
```

Scilab code Exa 6.17 Determination of necessary mass flow rate

```
clc;
rp=7; // Pressure ratio
T03=1000; // Maximum temperature in kelvin
eff_c=0.85; // Compressor efficiency
eff_T=0.9; // Turbine efficiency
T01=288; // Air entering temperature in kelvin
PN=750; // Power output in kW
Cpa=1.005;// Specific heat of air  at constant
    pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
    pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
R=287; // Characteristic constant in J/kg K

// Actual cycle
T02=T01*(1+((rp^((r-1)/r)-1)/eff_c));
T04=T03*(1-(eff_T*(1-(1/rp^((r-1)/r)))));
WN_a=(Cpa*(T03-T04)-Cpa*(T02-T01));
eff_th=WN_a/(Cpa*(T03-T02));
disp ("%",eff_th*100,"The Efficiency = ","kJ/kg",
    WN_a,"Net work = ","(i).Actual cycles");

// Ideal cycle
WN=Cpa*((T03*(1-(1/rp^((r-1)/r))))-T01*((rp^((r-1)/r
    )-1)));
eff_th=1-(1/rp^((r-1)/r));
ma=PN/WN_a;

disp ("kg/s",ma,"Mass flow rate  = ","%",eff_th*100,
    "The Efficiency = ","kJ/kg",WN,"Net work = ","(ii
    ).Ideal cycles");
```

Scilab code Exa 6.18 Estimation of intermediate pressure and temperature between the two turbine stages

```
clc;
m=5; // Mass flow rate in kg/s
p01=1; // Pressure at state 1 in bar
p02=5; // Pressure at state 2 in bar
eff_c=0.85;// Compressor efficiency
eff_Thp=0.87; // High pressure turbine efficiency
eff_Tlp=0.82; // Low pressure turbine efficiency
T03=675+273; // HP turbine inlet temperature in kelvin
eff=0.7; // Effectiveness of the heat exchanger
T01=15+273; // Temperature at state 1 in kelvin
Cpa=1.005;// Specific heat of air  at constant pressure in kJ/kg K
r=1.4; // Specific heat ratio of air
R=287; // Characteristic constant in J/kg K
p03=p02;

T_02=T01*(p02/p01)^((r-1)/r);
T02=T01+(T_02-T01)/eff_c;
T04=T01-T02+T03;
T_04=T03-(T03-T04)/eff_Thp;
p04=p03/(T03/T_04)^(r/(r-1));
p05=p01;
T_05=T04/(p04/p05)^((r-1)/r);
T05=T04-eff_Tlp*(T04-T_05);
T0x=eff*(T05-T02)+T02;
Wlpt=Cpa*(T04-T05);
Plpt=Wlpt*m;
Q=Cpa*(T03-T0x);
eff_th=Wlpt/Q;

```

```
disp ("Intermediate pressure p04 and temperature T04
    between the two turbine stages ");
disp ("K",T04,"To4 = ","bar",p04,"P04 = ");
disp ("kW",Plpt,"Power output of LP turbine = ");
disp ("kJ/kg",Q,"Heat supplied = ");
disp ("%",eff_th*100,"The Overall efficiency = ");
```

Scilab code Exa 6.19 Determination of the percentage of the total air intake that passes to the turbine and the thermal efficiency of the plant

```
clc;
rlp=3; // Pressure ratio
rhp=rlp;
eff_c=0.82; // Compressor efficiency
T04=650+273; // Temperature at state 4 in kelvin
T05=540+273; // Temperature at state 5 in kelvin
eff_T=0.87; // Efficiency of turbine
T01=15+273; // Temperature at compressor inlet in
    kelvin
Cpa=1.005;// Specific heat of air  at constant
    pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
    pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air

T02=T01*(1+(rlp^((r-1)/r)-1)/eff_c);
T03=T02*(1+(rhp^((r-1)/r)-1)/eff_c);
T_06=T05/(rlp)^(2*(rg-1)/rg);
T06=T05-eff_T*(T05-T_06);
x1=1-((T02-T01)/(((Cpg/Cpa)*(T05-T06)-(T03-T02))));
x=abs (x1);
T07=T04*(1-(eff_T*(1-(1/rhp^((rg-1)/rg)))));
eff_th=(x*Cpg*(T04-T07))/((1-x)*Cpg*(T05-T03)+x*Cpg
    *(T04-T02));
```

```
disp ("%",(x)*100,"Percentage of the total air
    intake that passes to the power turbine = ");
disp ("%  (Roundoff error)",(eff_th)*100,"The
    overall efficiency = ");
```

Scilab code Exa 6.20 Calculation of the Thermal efficiency

```
clc;
rp=2; // Pressure ratio
T01=15+273; // Inlet temperature in kelvin
p01=1; // Inlet pressure in bar
T05=700+273; // Temperature at state 5 in kelvin
T07=T05;
eff_c=0.85; // compressor efficiency
eff_T=0.85; // Turbine efficiency
eff=0.5; // Effectiveness of heat exchanger
Cp=1.147;// Specific heat at constant pressure in kJ
    /kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air

T03=T01;
// p02/p01=p04/p03=rp
//p04/p01=p05/p08=rp^2
T_02=T01*(rp)^((r-1)/r);
T02=T01+(T_02-T01)/eff_c;
T04=T02;
T_06=T05/rp^((rg-1)/rg);
T06=T05-eff_T*(T05-T_06);
T08=T06;
T09=T04+eff*(T08-T04);
WN=Cp*(T07-T08);
Q=Cp*(2*T05-T06-T09);
eff_th=WN/Q;
```

```

disp ("kJ/kg",WN,"Net work done = ");
disp ("%",eff_th*100,"The overall efficiency = ");
```

Scilab code Exa 6.21 Calculation of cycle thermal efficiency

```
clc;
T01=270+273; // Temperature at state 1 in kelvin
T03=T01;
p01=1; // Inlet pressure in bar
rp=6; // Pressure ratio
eff_c=0.85; // Compressor efficiency
T05=1150+273; // Temperature at inlet to expansion in kelvin
eff_T=0.9; // Turbine efficiency
n=1.24; // Polytropic index
R=10.05; // in kJ/kg K

T_02=T01*rp^((n-1)/n);
T02=T01+(T_02-T01)/eff_c;
Cv=R/(n-1);
Cp=R+Cv;
Wc=2*Cp*(T02-T01);
T_06=T05/rp^((n-1)/n);
T06=T05-eff_T*(T05-T_06);
WT=2*Cp*(T05-T06);
Q=Cp*(T05-T02)+Cp*(T05-T06);
WN=WT-Wc;
eff_th=WN/Q;

disp ("%",eff_th*100,"The Cycle efficiency = ");
```

Chapter 7

Jet Propulsion Cycles and Their Analysis

Scilab code Exa 7.1 Calculation of Thrust power and Heat Input

```
clc;
CV=43; // Calorific value of fuel in MJ/kg
mf=0.18*9000/3600; // Fuel consumption in kg/s
F=9; // Thrust in kN
ci=500; // Aircraft velocity in m/s
ma=27; // Mass of air passing through compressor in
   kg/s

A_F=ma/mf; // Air fuel ratio
PT=F*ci; // Thrust power
Q=mf*(CV*10^3); // Heat supplied
eff=PT/Q; // Overall efficiency
disp (A_F,"Air fuel ratio = ");
disp ("%",eff*100,"Overall efficiency = ");
```

Scilab code Exa 7.2 Calculation of The Total Design Thrust

```
clc;
T03=1200; // Maximum turbine inblet temperature in kelvin
rc=4.25; // Pressure ratio across compressor
ma=25; // Mass flow rate in kg/s
eff_C=0.87; // Isentropic efficiency of the compressor
eff_T=0.915; // Isentropic efficiency of turbine
eff_n=0.965; // Propelling nozzle efficiency
eff_Tr=0.985; // Transmission efficiency
del_pcomb=0.21; // Combustion chamber pressure loss in bar
Cpa=1.005; // Specific heat at constant pressure of air in kJ/kg K
ra=1.4; // Specific heat ratio of air
Cpg=1.147; // Specific heat of fuel in kJ/kg K
rg=1.33; // Specific heat of fuel
T01=293; // Ambient temperature in kelvin
p01=1; // Ambient pressure in bar
A_F=50; // Air Fuel ratio
p02=rc/p01;

T02=(T01*((rc)^((ra-1)/ra)-1)/eff_C)+T01; // Actual temperature at state 2
T04=T03-((Cpa*(T02-T01))/(eff_Tr*Cpg)); // Temperature at state 4
rt=(1/(1-((T03-T04)/(eff_T*T03))))^(1/((rg-1)/rg)); // Pressure ratio across turbine
p04=(p02-del_pcomb)/rt; // Pressure at 4
p5=p01;
T_5=T04/(p04/p5)^((rg-1)/rg); // Temperature at 5
T5=T04-eff_n*(T04-T_5);
c5=sqrt (2*Cpg*10^3*(T04-T5));
F=ma*c5; // Total design thrust
p04_pc=1/(1-((1/eff_n)*((rg-1)/(rg+1))))^(rg/(rg-1))
pc=p04*(1/p04_pc);
Tc=T04*(1/p04_pc)^((rg-1)/rg);
R=Cpg*10^3*(rg-1)/rg;
```

```
cj=sqrt (rg*R*Tc);
row_c=(pc*10^5)/(R*Tc);
A=ma/(row_c*cj); // Area of the propelling nozzle
d=sqrt (4*A/3.14); // Diameter of the nozzle
pa=p01;
Fp=(pc-pa)*10^5*A;// Pressure thrust
Fm=ma*cj;
Ft=Fp+Fm; // Total thrust
sfc=(ma/A_F)*3600/Ft;

disp ("N  (roundoff error)",F," Total design thrust
    /s = ");
disp ("N  (roundoff error)",Ft,"Total thrust /s = "
    );
disp ("kg/ N thrust h",sfc, "Specific fuel
    consumption = ");
```

Scilab code Exa 7.3 Calculation of the velocity leaving the nozzle

```
clc;
p03=4.5; // Pressure at turbine inlet in bar
T03=800+273; // Temperature at turbine inlet in
    kelvin
p04=1.75; // Pressure at turbine outlet in bar
eff_T=0.75; //Turbine efficiency
p05=1.03; // Pressure at state 5 in bar
Cp=1.05; // Specific heat at constant pressure  in
    kJ/kg K
r=1.38; // Specific heat ratio

T04=T03*(1-eff_T*(1-(1/(p03/p04)^((r-1)/r)))); //
    Temperature at state 4
cj=sqrt (2*Cp*10^3*T04*(1-(1/(p04/p05)^((r-1)/r))));
     // Velocity leaving nozzle

```

```
disp ("K",T04,"(i).Temperature of the gas entering
   the jet (nozzle) = ");
disp ("m/s",cj,"(ii).Velocity of gas leaving the jet
    = ");
```

Scilab code Exa 7.4 Calculation of propulsive efficiency

```
clc;
cj=2700; // The effective jet velocity from jet
   engine in m/s
ci=1350; // Flight velocity in m/s
ma=78.6; // Air flow rate in m/s

a=ci/cj;
F=ma*(cj-ci); // Thrust
P=F*ci; // Thrust power
eff_P=2*a/(a+1); // Propulsive efficiency

disp ("N",F,"(i).Thrust = ");
disp ("MN",P/10^6,"(ii). Thrust power = ");
disp ("%",eff_P*100,"(iii). Propulsive efficiency =
   ");
```

Scilab code Exa 7.5 Calculation of the thrust and Specific fuel consumption

```
clc;
pa=0.458; // Ambient pressure in bar
Ta=248; // Ambient temperature in kelvin
Ci=805*1000/3600; // Speed of the aircraft in m/s
rp=4;// Pressure ratio
DelP_comb=0.21; // Combustion chamber pressure loss
   in bar
```

```
T03=1100; // Turbine inlet temperature in kelvin
eff_ram=0.95; // Intake duct efficiency
eff_c=0.85; // Compressor efficiency
eff_T=0.90; // Turbine efficiency
eff_m=0.99; // Mechanical efficiency of transmission
eff_nozzle=0.95; // Nozzle efficiency
CV=43; // Low calorific value in MJ/kg
Ac=0.0935; // Nozzle outlet area in m^2
Cpa=1.005;// Specific heat of air  at constant pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
R=287; // Characteristic gas constant in J/kg K

p01=pa*(1+eff_ram*((1+Ci^2/(2*Cpa*Ta*10^3))^(r/(r-1))-1));
p02=p01*rp;
T01=Ta+Ci^2/(2*Cpa*10^3);
T02=T01+T01*(rp^((r-1)/r)-1)/eff_c;
T04=T03-(Cpa*(T02-T01))/(Cpg*eff_m);
p03=p02-DelP_comb;
T_04=T03-(T03-T04)/eff_T;
p04=p03*(T_04/T03)^(r/(r-1));
p04_pc=1/(1-(((rg-1)/(rg+1))/eff_nozzle))^(rg/(rg-1));
Tc=T04*(1/p04_pc)^((rg-1)/rg);
pc=p04/p04_pc;
row_c=(pc*10^5)/(R*Tc);
cj=sqrt (rg*R*Tc);
m=row_c*Ac*cj;
F=m*(cj-Ci)+Ac*(pc-pa)*10^5; // Total thrust
mf=(m*Cpg*(T03-T02))/(CV*10^3);
sfc=mf*3600/F; // specific fuel consumption

disp ("N  (roundoff error)",F,"Total thrust = ");
disp ("kg/N h  (roundoff error)",sfc,"specific fuel
```

```
consumption = ");
```

Scilab code Exa 7.6 Calculation of specific power output

```
clc;
ci=600*1000/3600; // Velocity in m/s
Cpa=1.005;// Specific heat of air  at constant pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
R=287; // Characteristic gas constant in J/kg K
pa=0.458; // Ambient pressure in bar
Ta=-15+273; // Ambient temperature in kelvin
rp=9; // pressure ratio
T03=1200; // Maximum temperature in kelvin
eff_ram=0.9; // Intake duct efficiency
eff_c=0.89; // Compressor efficiency
eff_T=0.93; // Turbine efficiency
eff_m=0.98; // Mechanical efficiency of transmission

cj=ci
T_01=Ta+(ci^2/(2*Cpa*10^3));
p_01=pa*(T_01/Ta)^(r/(r-1));
p01=eff_ram*(p_01-pa);
p02=rp*p01;
T01=T_01;
T_02=T01*rp^((r-1)/r);
T02=T01+(T_02-T01)/(eff_c);
T_04=T03*(1/rp)^((rg-1)/rg);
T04=T03-eff_T*(T03-T_04);
WN=Cpg*(T03-T04)-Cpa*(T02-T01)/eff_m;// net work done
eff_th=WN/(Cpg*(T03-T02)); // Thermal efficiency
```

```
disp ("kJ/kg   (roundoff error)",WN,"Net work done =
    ");
disp ("%",eff_th*100,"Thermal efficiency = ");
```

Scilab code Exa 7.7 Determination of rate of fuel consumption

```
clc;
pa=0.7; // Ambient pressure in bar
Ta=1+273; // Ambient temperature in kelvin
Ci=800*1000/3600; // Speed of the aircraft in m/s
rp=5;// Pressure ratio
eff_ram=1.00; // Intake duct efficiency
eff_c=0.85; // Compressor efficiency
eff_T=0.90; // Turbine efficiency
eff_comb=0.98; //Combustion efficiency
eff_nozzle=0.95; // Nozzle efficiency
rp_T=2.23;// Turbine pressure ratio
CV=43; // Low calorific value in MJ/kg
Cpa=1.005;// Specific heat of air  at constant
    pressure in kJ/kg K
Cpg=1.005;// Specific heat of fuel at constant
    pressure in kJ/kg K
rg=1.4;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
R=287; // Characteristic gas constant in J/kg K
F=25000; // Thrust in N

cj=2*Ci;
T_01=Ta+(Ci^2/(2*Cpa*10^3));
T01=T_01;
T02=T01+(T01*(((rp)^((r-1)/r))-1))/eff_c;
p_01=pa*(1+Ci^2/(2*Cpa*10^3*Ta))^(r/(r-1));
p01=eff_ram*(p_01-pa);
p02=rp*p01;
```

```
T03=(T02-T01)/(eff_T*(1-1/rp_T^((r-1)/r)));
ma=F/(cj-Ci);
// Neglecting the effect of the mass addition of
   fuel on the right hand side
mf=(ma*Cpa*(T03-T02))/(eff_comb*CV*10^3);

disp ("kg/s",ma,"Mass flow rate of air = ");
disp ("kg/s  (roundoff error)",mf,"Mass flow rate
   of fuel = ");
```

Scilab code Exa 7.8 Calculation of the take off thrust

```
clc;
Ta=288; // Ambient temperature in kelvin
pa=1.01; // Ambient pressure in bar
p04=2.4; // Stagnation pressure in bar
T04=1000;// Stagnation temperature in kelvin
m=23; // Mass flow rate in kg/s
rp=1.75; // Pressure ratio
eff_f=0.88 ; // Efficiency of the fan
eff_ft=0.9; // Efficiency of the fan turbine
Cpa=1.005;// Specific heat of air  at constant
   pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
   pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
R=284.6; // Characteristic gas constant in J/kg K
T01=Ta;
p01=pa;
pc=p04*(2/(r+1))^(r/(r-1));
// since pc>pa the nozzle will choke
Tc=T04*(2/(r+1));
row_c=pc*10^5/(R*Tc);
cj=sqrt (r*R*Tc);
```

```
A=m/(row_c*cj);
p1=pa;
F=m*cj+(A*(pc-p1)*10^5);
// For fan engine
T_02=T01*(rp)^((r-1)/r);
T02=T01+(T_02-T01)/eff_f;
// For cold nozzle
m_nozzle=2*m; // Flow through cold nozzle
pc1=p01*rp*(2/(r+1))^(r/(r-1));
F_cold=m_nozzle*sqrt (2*Cpa*10^3*(T02-T01));
// Fan Turbine
T05=T04-((m_nozzle*Cpa*(T02-T01))/(m*Cpg));
T_05=T04-(T04-T05)/eff_ft;
p_05=p04*(T_05/T04)^(rg/(rg-1));
pc=p_05*(2/(rg+1))^(rg/(rg-1));
F_hot=m*sqrt (2*Cpg*10^3*(T05-T01));
Takeoffthrust= F_cold + F_hot;

disp ("m^2  (roundoff error)",A,"Nozzle Exit area =
    ");
disp ("N  (roundoff error)",F,"Total Thrust = ");
disp ("N  (roundoff error)",Takeoffthrust,"Take-off
    Thrust = ");
```

Scilab code Exa 7.9 Calculation of thrust provided by the engine and the thrust power developed

```
clc;
ma=18.2; // Massflow rater in m/s
Mi=0.6; // Mach number
pa=0.55; // Ambient pressure in bar
Ta=255; // Ambient temperature in kelvin
rp=5; // Pressure ratio
T03=1273; // Maximum temperature in kelvin
eff_c=0.81; // Compressor efficiency
```

```
eff_T=0.85; // Turbine efficiency
eff_nozzle=0.915; // Nozzle efficiency
eff_ram=0.9; // Intake duct efficiency
CV=45870; // Low calorific value in kJ/kg
Cpa=1.005;// Specific heat of air  at constant pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
R=284.6; // Characteristic gas constant in J/kg K

ci=Mi*sqrt(r*R*Ta);
T_01=Ta+ci^2/(2*Cpa*10^3);
T01=T_01;
p_01=pa*(T01/Ta)^(r/(r-01));
p01=eff_ram*(p_01-pa)+pa;
p02=rp*p01;
T02=T01*(1+((rp^((r-1)/r))-1)/eff_c);
Wc=ma*Cpa*(T02-T01);
WT=Wc;
mf=ma/((CV/(Cpg*(T03-T02)))-1);
f1=mf/ma;
T04=T03-(WT/((ma+mf)*Cpg));
rp_T=(1/(1-((1-(T04/T03))/eff_T)))^(r/(r-1));
p03=p02;
p04=p03/rp_T;
p04_pc=1/(1-((rg-1)/((rg+1)*eff_nozzle)))^(rg/(rg-1));
pc=p04_pc/p04;
Tc=T04*(1/p04_pc)^((rg-1)/rg);
cj=sqrt (r*R*Tc);
row_c=pc*10^5/(R*Tc);
An=(ma+mf)/(row_c*cj);
F=(ma+mf)*cj-ma*ci+An*(pc-pa);
Fp=F*ci;

disp ("kW   (roundoff error)",Wc,"Work of
```

```
    compression = ");
disp ("kW  (roundoff error)",WT,"Power output of
    the turbine = ");
disp (f1,"Fuel-Air ratio = ");
disp ("N  (roundoff error)",F,"Thrust = ");
disp ("kW  (roundoff error)",Fp/1000,"Thrust power
    = ");
```

Scilab code Exa 7.10 Calculation of exit speed of the gases and the thrust developed

```
clc;
ma=(12*10^4)/3600; // Air flow rate in kg/s
T01=15+273; // Temperature in kelvin
rp=4; // pressure ratio
p01=1.03; // Pressure in bar
T02=182+273; // Temperature in kelvin
T03=815+273; // Temperature in kelvin
T04=650+273; // Temperature in kelvin
ci=800*1000/3600; // Velocity in m/s
eff_nozzle=0.90; // Nozzle efficiency
Cpa=1.005;// Specific heat of air  at constant
    pressure in kJ/kg K
Cpg=1.147;// Specific heat of fuel at constant
    pressure in kJ/kg K
rg=1.33;// Specific heat ratio of fuel
r=1.4; // Specific heat ratio of air
p03=4.12; // in bar

eff_c=1/((T02-T01)/(T01*((rp^((r-1)/r))-1)));
eff_T=eff_c;
Wc=ma*Cpa*(T02-T01);
rp_T=(1/(1-((T03-T04)/(eff_T*T03))))^((r/(r-1)));
p04=p03/rp_T;
p04_pc=1/(1-((rg-1)/((rg+1)*eff_nozzle)))^(rg/(rg-1)
```

```
);
p5=p01;
T_5=T04*(p5/p04)^((rg-1)/rg);
T5=T04-eff_nozzle*(T04-T_5);
cj=sqrt(2*Cpg*10^3*(T04-T5));
F=ma*(cj-ci);

disp ("%",eff_c*100,"Efficiency of the compressor = ");
disp ("%",eff_T*100,"Efficiency of the Turbine = ");
disp ("kW",Wc,"Compressor work = ");
disp ("m/s  (roundoff error)",cj,"The exit speed of gases = ");
disp ("N  (roundoff error)",F,"Thrust developed = ");
```

Chapter 8

Centrifugal Compressors

Scilab code Exa 8.1 Calculation of compressor efficiency

```
clc;
N=11500; // Speed in rpm
T01=21+273; // Inlet total temperature in kelvin
p01=1;// Inlet total pressure in bar
p02=4;// Outlet total pressure in bar
D=0.75; // impeller diameter in m
mu=0.92;// slip factor
Cp=1.005; // specific heat at constant pressure in
   kJ/kg K
r=1.4; // Specific heat ratio

u=3.14*D*N/60;
W=mu*u^2;
T02=W/(Cp*10^3)+T01;
T_02=T01*(p02/p01)^((r-1)/r);
eff_c=(T_02-T01)/(T02-T01);

disp ("%",eff_c*100,"Efficiency of the compressor =
   ");
```

Scilab code Exa 8.2 Estimation of the probable axial width of the impeller

```
clc;
m=35; // mass flow rate of air in kg/s
D=0.76; // Impeller diameter in m
N=11500; // speed in rpm
eff_c=0.8; // Efficiency of the compressor
rp=4.2; // Pressure ratio
cr=120; // Radial velocity in m/s
p01=1; // Inlet pressure in bar
T01=47+273; // Inlet temperature in kelvin
Cp=1.005; // specific heat at constant pressure in kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

T_02=T01*rp^((r-1)/r);
T02=T01+(T_02-T01)/eff_c;
// ignoring the effects of the velocity of flow
p02=rp/p01;
row2=p02*10^5/(R*T02);
Atip=m/(row2*cr);
AW=Atip/(3.14*D); // Axial width

disp ("cm",AW*100,"Axial Width = ");
```

Scilab code Exa 8.3 Calculation of theoretical blade angles

```
clc;
D=0.15; // Inlet eye diameter in m
N=20000; // Speed in rpm
ca1=107; // Axial velocity in m/s
```

```
T01=294; // Inlet temperature in kelvin
p01=1.03; // Inlet pressure in kg/cm^2
Cp=1.005; // specific heat at constant pressure in
    kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

u1=3.14*D*N/60;
beta_1=atand (ca1/u1);// Blade angle
cr=u1/cosd (beta_1);
a=sqrt (r*R*(T01-ca1^2/(2*Cp*10^3)));
M=cr/a; // Mach number at the tip

disp ("degree",beta_1,"(i).Theoretical angle of the
    blade at this point = ");
disp (M,"(ii).Mach number of the flow at the tip of
    the eye = ");
```

Scilab code Exa 8.4 Calculation of final temperature of the gases and the work done per kg of gas

```
clc;
T01=0+273; // Inlet gas temperature in kelvin
p01=0.7; // Inlet pressure in bar
p02=1.05; // Delivery pressure in bar
eff_c=0.83; // Compressor efficiency
Cp=1.005;// Specific heat  at constant pressure in
    kJ/kg K
Cv=0.717;// Specific heat  at constant volume in kJ
    /kg K
r=1.4; // Specific heat ratio

T_02=T01*(p02/p01)^((r-1)/r);
T02=T01+(T_02-T01)/eff_c; // Final temperature of
    the gas
```

```
Wc=Cp*(T02-T01); // Work of compression

// With additional compressor
T_03=T02*(p02/p01)^((r-1)/r);
T03=T02+(T_03-T02)/eff_c;
T_03=T01*(p02/p01)^(2*(r-1)/r);
eff_overall=(T_03-T01)/(T03-T01);

disp ("K",T02,"Final temperature of the gas = ");
disp ("kJ/kg",Wc," Work of compression = ");
disp ("%",eff_overall*100,"Overall efficiency = ");
```

Scilab code Exa 8.5 Calculation of impeller diameters and the width at the impeller exit

```
clc;
N=12500; // Speed in rpm
m=15; // Mass flow rate in kg/s
rp=4; // Pressure ratio
eff_c=0.75; // Isentropic efficiency
mu=0.9; // Slip factor
pi=0.3; // Flow coefficient at impeller exit
D=0.15; // Hub diameter in m
ca2=150; // Axial velocity in m/s
T01=275; // Inlet temperature in kelvin
p01=1; // Inlet pressure in bar
Cp=1.005;// Specific heat  at constant pressure in
   kJ/kg K
Cv=0.717;// Specific heat  at constant volume in kJ
   /kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

u2=ca2/pi;
P=m*mu*u2^2/1000; // Power output
```

```
D2=u2*60/(3.14*N);
T1=T01-ca2^2/(2*Cp*10^3);
p1=p01*(T1/T01)^(r/(r-1));
row1=p1*10^5/(R*T1);
A1=m/(row1*ca2);
D1=sqrt ((A1*4/(3.14))+D^2);
p3_p1=rp;
p2=2*p1;
T_2=T1*(p2/p1)^((r-1)/r);
T2=T1+(T_2-T1)/eff_c;
row2=p2*10^5/(R*T2);
W2=(m)/(row2*ca2*3.14*D2);

disp ("kW",P,"Power = ");
disp ("Impeller Diameters");
disp ("cm",D2*100,"D2 = ","cm   (roundoff error)",D1*100,"D1 = ");
disp ("Impeller width")
disp ("cm   (roundoff error)",W2*100,"W2 = ");
```

Scilab code Exa 8.6 Calculation of the minimum possible depth of the diffuser

```
clc;
m=14; // mass flow rate in kg/s
rp=4; // pressure ratio
N=12000; // Speed in rpm
T01=288; // Inlet temperature in kelvin
p01=1.033; // Inlet pressure in bar
Cp=1.005;// Specific heat   at constant pressure in kJ/kg K
Cv=0.717;// Specific heat   at constant volume in kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K
```

```
mu=0.9; // Slip factor
chi=1.04; // Power input factor
eff_c=0.8; // Compressor efficiency

T03=(((rp^((r-1)/r))-1)*T01/eff_c)+T01;;
U=sqrt ((T03-T01)*Cp*10^3/(chi*mu));
D=U*60/(3.14*N);

T3=T03/1.2;
c2=sqrt (r*R*T3);
ca2=sqrt (c2^2-(mu*U)^2);
T02=eff_c*(T03-T01)+T01;
Loss=T03-T02;
T2=T3-Loss/2
p2=p01*(T2/T01)^(r/(r-1));
row2=p2*10^5/(R*T2);
A=m/(row2*ca2);
Depth=A/(2*3.14*D/2);

disp ("cm",D*100,"Overall diameter of the Impeller
   = ");
disp ("cm  (roundoff error)",Depth*100,"Depth of
   the diffuser = ");
```

Scilab code Exa 8.7 Calculation of impeller and diffuser blade angles at inlet

```
clc;
N=10000; // Speed in rpm
Q=600; // Flow rate m^2/min
rp=4; // Pressure ratio
eff_c=0.82; // Compressor efficiency
T01=293; // Inlet temperature in kelvin
p01=1.0; // Inlet pressure in bar
Cp=1.005;// Specific heat  at constant pressure in
```

```
kJ/kg K
Cv=0.717;// Specific heat  at constant volume in kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K
ca=60; // Axial velocity in m/s
D2_D1=2 ;// Diameter ratio

T_03=T01*rp^((r-1)/r);
T03=T01+(T_03-T01)/eff_c;
u2=sqrt (Cp*10^3*(T03-T01));
Wc=u2^2; // Work of compression
D2=(u2*60/(3.14*N));
D1=D2/D2_D1;
T1=T01-(ca^2/(2-Cp*10^3));
p1=p01*(T1/T01)^(r/(r-1));
row1=p1*10^5/(R*T1);
Wroot=(Q/60)*(1/(ca*3.14*D1));
u1=3.14*N*D1/60;
alpha_root=atand (ca/u1);
alpha_tip= atand (ca/u2);

disp ("(i).Power input ");
disp ("kW/kg/s",Wc/1000,"Wc = ");
disp ("(ii).Impeller Diameters");
disp ("m",D2,"D2 = ","m",D1,"D1 = ");
disp ("(iii).Impeller and diffuser blade angles at inlet");
disp ("degree",alpha_tip,"alpha_tip = ","degree",alpha_root,"alpha_root = ");
```

Scilab code Exa 8.8 Calculation of slip factor

```
clc;
rp=4; // Pressure ratio
```

```
eff_c=0.8; // Compressor efficiency
N=15000; // Speed in rpm
T01=293; // Inlet temperature in kelvin
De=0.25; // Diameter of eye in m
C1=150; // Absolute velocity in m/s
Di=0.6; // Impeller diameter in m
a1=25; // in degree
Cp=1.005;// Specific heat  at constant pressure in
   kJ/kg K
Cv=0.717;// Specific heat  at constant volume in kJ
   /kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

T02=T01*rp^((r-1)/r);
DelT_actual=(T02-T01)/eff_c;
P=Cp*10^3*DelT_actual; // Power input
u1=3.14*De*N/60;
ct1=C1*sind (a1);
// At Exit
u2=3.14*Di*N/60;
ct2=(P+(u1*ct1))/u2;
mu=ct2/u2; // Slip factor

disp (mu,"Slip Factor = ");
```

Scilab code Exa 8.9 Determination of number of radial impeller vanes

```
clc;
P=180*10^3; // Power input in J
N=15000; // Speed in rpm
a1=25; // in degrees
De=0.25; // Mean dia of the eye in m
Di=0.6;// Impeller tip diameter in m
c1=150; // Absolute air velocity at inlet in m/s
```

```

u1=3.14*De*N/60;
u2=3.14*Di*N/60;
ct1=c1*sind (a1);
ct2=(P+(u1*ct1))/u2;
mu=ct2/u2;
z=(1.98)/(1-mu); // Number of impeller vanes
disp(z,"Number of impeller vanes using Stanitz
    formulae = ");
```

Scilab code Exa 8.10 Calculation of the torque power required and the head developed

```
clc;
m=30; // mass flow rate in kg/s
N=15000; // Speed in rpm
r2=0.3; // Radius in m
D2=r2*2; // Diameter in m
w2=100; // Relative velocity in m/s
beta_1=80; // in degrees
p01=1; // Inlet pressure in bar
T01=300 // Inlet temperature in kelvin
Cp=1.005; // specific heat at constant pressure in
    kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

u2=3.14*D2*N/60;
ct2=u2-(w2*cosd (beta_1));
Fr=m*ct2*r2;
P=Fr*(2*3.14*N/60);
W=u2*ct2;
P02=p01*(1+(W*10^-3/(Cp*T01)))^(r/(r-1));

disp ("Nm",Fr,"Torque = ");
```

```
disp ("kW",P/1000,"Power = ");
disp ("bar",P02,"Head Developed = ");
```

Chapter 9

Axial Flow Compressors

Scilab code Exa 9.1 Estimation of blade angles

```
clc;
n=10; // No of stages in the axial flow compressor
rp=5; // Overall pressure ratio
eff_C=0.87; // Overall isentropic efficiency
T1=15+273; // Temperature of air at inlet in kelvin
u=210; // Blade speed in m/s
ca=170; // Axial velocity in m/s
wf=1; // Work factor
r=1.33; // Specific heat ratio
Cp=1.005; // Specific heat in kJ/kg K

Del_Tstage=(T1*(rp^((r-1)/r)-1))/(n*eff_C); // Temperature increase per stage
// By property relations and let us assume
// tan_beta1-tan_beta2=Del_Tstage*Cp/(wf*u*ca)
// tan_beta1+tan_beta2=u/ca    for 50% reaction
// To solve this above equations using matrix method
a=[1,-1;1,1]; c=[(Del_Tstage*Cp*10^3/(wf*u*ca));u/ca];
b=a\c;
beta1=atand(b(1));// Blade angles at inlet
```

```
beta2=atand(b(2)); // Blade angles at outlet

disp ("degree  (roundoff error)",beta2,"Blade angle
    at outlet = ","degree  (roundoff error)",beta1,
   "Blade angle at inlet = ");
```

Scilab code Exa 9.2 Calculation of mass flow rate and degree of reaction

```
clc;
P1=1.0132; // Inlet air pressure in bar
T01=288; // Inlet air temperature in kelvin
ca=150; // axial velocity in m/s
dtip=60; // Tip diameter of rotor in cm
dhub=50; // Hub diameter of rotor in cm
N=100; // Speed of rotor in rps
t_angle=30; // Deflected angle of air in degree (in
    question it is 30.2 but in solution it is 30)
P2_P1=1.2; // Stage pressure ratio
Cp=1005; // Specific heat in J/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

u=(3.142857*(dhub+dtip)*10^-2*N)/2; // Mean blade
    velocity
beta_1=atand(u/ca); // Blade angle at inlet
beta_2=beta_1-t_angle; // As air is deflected by 30
// from velocity triangle
x=ca*tand(beta_2);
alpha_2=atand ((u-x)/ca);
C1=ca;
T1=T01-(C1^2/(2*Cp)); // Static temperature at inlet
P2=P1*P2_P1; // Pressure at outlet
T2=T1*(P2/P1)^((r-1)/r); // Static temperature at
    outlet
row_2=(P2*10^5)/(R*T2); // Density at outlet
```

```
m=3.14*(dtip^2-dhub^2)*ca*row_2*10^-4/4; // Mass flow rate
wf=1; // Work factor
P=wf*u*ca*m*(tand(beta_1)-tand(beta_2))/1000; // Power developed
R=ca*(tand(beta_1)+tand(beta_2))/(2*u); // Degree of reaction

disp ("kg/s",m,"Mass flow rate = ");
disp("kW    (Error due to more decimal values in expression)",P,"Power developed = ");
disp (R,"Degree of Reaction = ");
```

Scilab code Exa 9.3 Estimation of number of stages of the compressors

```
clc;
beta_1=45; // Inlet blade angle in degree
beta_2=10; // Outlet blade angle in degree
rp=6; // Compressor pressure ratio
eff_C=0.85;// Overall isentropic efficiency
T1=37+273; // Inet static temperature in kelvin
u=200; // Blade speed in m/s
Cp=1005; // Specific heat in J/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

// (i). wf=1
wf=1; // Work factor
ca=u/(tand(beta_1)+tand(beta_2)); // Axial velocity
Del_Tstage=wf*u*ca*(tand(beta_1)-tand(beta_2))/Cp; // Stage temperature drop
Del_Toverall=(T1*(rp^((r-1)/r)-1))/eff_C; // Overall temperature drop
n=Del_Toverall/Del_Tstage; // No of stages

```

```
disp (n,"Number of stages required = ","(i).wf = 1")
   ;

// (ii).wf = 0.87
wf =0.87; // Work factor
ca=u/(tand(beta_1)+tand(beta_2)); // Axial velocity
Del_Tstage=wf*u*ca*(tand(beta_1)-tand(beta_2))/Cp;
   // Stage temperature drop
Del_Toverall=T1*(rp^((r-1)/r)-1)/eff_C; // Overall
   temperature drop
n=Del_Toverall/Del_Tstage; // No of stages

disp (n,"Number of stages required = ","(ii).wf =
   0.87");
```

Scilab code Exa 9.4 Determination of Mach number relative to Rotor

```
clc;
rp=4; // Total head pressure ratio
eff_O=0.85; // Overall total head isentropic
   efficiency
T01=290; // Total head inlet temperature in kelvin
alpha_1=10; // Inlet air angle in degree
alpha_2=45; // Outlet air angle in degree
u=220; // Blade velocity in m/s
wf=0.86; // Wok done factor
R=284.6; // Characteristic gas constant in kJ/kg K
Cp=1005; // Specific heat in J/kg K
r=1.4; // Specific heat ratio

eff_P=1/(log10(((rp^((r-1)/r)-1)/eff_O)+1)/(log10(rp
   )*((r-1)/r)));;
// From velocity triangle
ca=u/(tand(alpha_1)+tand(alpha_2)); // Axial
   velocity
```

```
Del_Tstage=wf*u*ca*(tand(alpha_2)-tand(alpha_1))/Cp; // Stage temperature rise
T02=T01*(rp)^((r-1)/(r*eff_P)); // Total head temperature
T02_T01=T02-T01; // Total temperature rise
n=T02_T01/Del_Tstage; // Total number of stages
// from velocty traingles
w1=ca/cosd(alpha_2);
c1=ca/cosd(alpha_1);
T1=T01-c1^2/(2*Cp); // Static temperature
M=w1/sqrt(r*R*T1); // Mach number at inlet

disp (eff_P*100,"Polytropic efficiency of the compressor = ");
disp (n,"Total number of stages = ");
disp (M,"Mach number at inlet = ");
```

Scilab code Exa 9.5 Calculation of pressure rise per blade ring and the power input per stage

```
clc;
Q=1000; // Flow rate of free air in m^3/min
P1=0.98; // Inlet pressure in bar
T1=15+273; // Inlet temperature in kelvin
Dm=0.6; // Mean diameter in m
h=6.75; // blade length in cm
CL=0.6; CD=0.05; // At zero angle of incidence
Cp=1.005; // Specific heat in kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K
k=1-0.1; //Blade occupys 10% of axial area
N=6000; // speed in rpm
Ac=19.25*10^-4; // Projected area in m^2
n=50;
eff_C=1; // Efficiency of compressor
```

```
row=(P1*10^5)/(R*T1); // Density
A=k*3.14*Dm*h*10^-2; // Area of axial
ca=Q/(60*A); // Axial velocity
u=3.14*Dm*N/60; // Blade velocity
beta_1=atand(u/ca); // Blade angle at inlet
w=sqrt (ca^2+u^2); // From velocity triangle
L=CL*row*w^2*Ac/2;
D=CD*row*w^2*Ac/2;
P=(L*cosd(beta_1)+D*sind (beta_1))*u*n*10^-3; //
    Power input / stage
m=Q*row/60;// mass flow rate
rp=((P*eff_C/(m*Cp*T1))+1)^(r/(r-1)); // pressure
    ratio
P2=rp*P1; // Pressure

disp ("kW  (Roundoff error )",P,"Power input/stage
    = ");
disp ("bar",P2,"Pressure at outlet = ");
```

Scilab code Exa 9.6 Determination of the direction of the air entry to and exit from the rotor

```
clc;
T1=290; // Temperature at inlet in kelvin
n=10; // Number of stages
rp=6.5; // Pressure ratio
m=3; // mass flow rate in kg/s
eff_C=0.9; // isentropic efficiency of the
    compression
ca=110; // Axial velocity in m/s
u=180; // Mean blade velocity in m/s
Cp=1.005; // Specific heat in kJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K
```

```
T_2=(rp)^((r-1)/r)*T1; // temperature after
    isentropic compression
T2=((T_2-T1)/eff_C)+T1; // Temperature after actual
    compression
P=m*Cp*(T2-T1); // Power given to the air
Del_Tstage=(T2-T1)/n; // Temperature rise per stage
Del_ct=Cp*10^3*Del_Tstage/u; // For work done per kg
     of air per second
// To find blade angles let solve the following
    equations
// Del_ct=ca(tan beta_1-tan beta_2) for symmetrical
    stages
// u=ca(tan beta_1=tan beta_2) for degree of
    reaction = 0.5
// Solving by matrix method
A=[1,-1;1,1]; C=[Del_ct/ca;u/ca];
B=A\C;
// Blade angles at entry and exit
beta_1=atand(B(1));
beta_2=atand(B(2));

disp ("kW   (roundoff error)",P,"Power given to the
    air = ");
disp ("degree",beta_2,"Blade angle at exit = ","
    degree",beta_1,"Blade angle at inlet = ");
```

Scilab code Exa 9.7 Calculation of the rotational speed and the length of the last stage

```
clc;
rp=4; // Overall pressure ratio
m=3; // mass flow rate in kg/s
eff_pc=0.88; // Polytropic efficiency
Del_Tstage=25; // The stagnation temperature
```

```
pressure rise in kelvin
c1=165; // Absolute velocity in m/s
alpha_1=20; // air angle from axial direction in degree
wf=0.83; // Workdone factor
D=18; // Mean diameter of the last stage rotor in cm
P01=1.01; // Ambient pressure in bar
T01=288; // Ambient temperature in kelvin
Cp=1005; // Specific heat in J/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

n=1/(1-(r-1)/(r*eff_pc));
T02=T01*(rp)^((n-1)/n); // Total pressure at stage 2
Del_Toverall= T02-T01; // Overall temperature difference
Ns=Del_Toverall/Del_Tstage; // Number of stages
eff_C=((rp^((r-1)/r)-1)/(rp^((r-1)/(r*eff_pc))-1)); // Efficiency of compressor
rp1=(1+(eff_C*Del_Tstage/T01))^(r/(r-1)); // Pressure ratio acrocc first stage
Del_Tstage1=Del_Toverall/Ns; // Temperature rise across stage 1
T0ls=T02-Del_Tstage1; // Temperature at inlet to last stage
rpls=(1+(eff_C*Del_Tstage1/T0ls))^(r/(r-1)); // Pressure ratio acrocc last stage
// For symmetrical blade, R=0.5
beta_2=alpha_1;
ca=c1*cosd (alpha_1); // Axial velocity
beta_1=atand(sqrt(((Cp*Del_Tstage1/(wf*ca))/ca)+(tand(beta_2))^2)); // blade angle
u=ca*(tand(beta_1)+tand(beta_2)); // mean velocity of blade
N=60*u/(3.14*D*10^-2*60); // Speed in rps
Po=rp/rpls; // Total pressure at inlet to the last stage
T0=T0ls; // Total temperature to the last stage
```

```
Tst=T0-c1^2/(2*Cp); // Static temperature
Pst=Po/(T0/Tst)^((r-1)/r); // Static pressure
row=(Pst*10^5)/(R*Tst); // Density
h=m/(ca*row*3.14*D*10^-2);// Length of last stage

disp (Ns,"Number of stages = ");
disp (rp1,"Pressure ratio across first stage = ");
disp ("   (roundoff error)",rpls,"Temperature at inlet to last stage = ");
disp ("degree   (roundoff error)",beta_1,"beta1=" );
disp ("rps   (roundoff error)",N,"Speed = ");
disp ("cm   (roundoff error)",h*100,"Length of last stage = ");
```

Scilab code Exa 9.8 Calculation of the stage stagnation pressure ratio and the power input

```
clc;
N=6000; // Speed in rpm
Del_rise=20; // Stagnation temperature rise in kelvin
wf=0.93; // Work done factor eff_c=0.89; // Isentropic efficiency of the state
c1=140; // Inlet velocity in m/s
p01=1.01; // Ambient pressure in bar
T01=288; // Ambient temperature in kelvin
M1=0.95; // Mach number
Cp=1.005; // Specific heat in J/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K
H_T_ratio=0.6; // Hub tip ratio in
eff_s=0.89; // Stage efficiency
T1=T01-c1^2/(2*Cp*10^3);
w1=M1*sqrt (r*R*T1);
beta_1=acosd (c1/w1);
```

```
u=w1*sind (beta_1);
beta_2=atand (tand(beta_1)-((Cp*10^3*Del_rise)/(u*wf
    *c1)));
p1=p01/(T01/T1)^(r/(r-1));
row_1=(p1*10^5)/(R*T1);
Rtip=60*u/(2*3.14*N);
Rroot=H_T_ratio*Rtip;
Rm=(Rtip+Rroot)/2;
h=Rtip-Rroot;
m=row_1*2*3.14*Rm*h*c1;
rp=(1+(eff_s*Del_rise)/(T01))^(r/(r-1));
P=m*Cp*Del_rise;
uroot=2*3.14*Rroot*N/60;
beta_1root=atand (uroot/c1);
beta_2root=atand (tand (beta_1root)-((Cp*10^3*
    Del_rise)/(wf*uroot*c1)));

disp ("degree",beta_2,"beta 2 = ","degree",beta_1,"
    beta 1 = ","Rotor air angles at tip:","m",Rtip,"
    Tip Radius = ","(i). ");
disp ("kg/s   (Roundoff error)",m,"Mass flow rate =
    ","(ii).");
disp ("kW",P,"Power input = ",rp,"Stagnation
    pressure ratio = ","(iii).");
disp ("degree",beta_2root,"beta 2 = ","degree",
    beta_1root,"beta 1 = ","Rotor air angles at root
    sections","(iv).");
```

Scilab code Exa 9.9 Determination of the stage efficiency and the work done factor of an axial flow compressor

```
clc;
rp=1.35; // Actual pressure ratio
DelT_rise=30; // Actual temperature rise in K
beta_1=47; // Inlet blade angle in degree
```

```
beta_2=15; // Outlet blade angle in degree
u=225; // Peripheral velocity in m/s
ca=180; // Axial velocity in m/s
T01=27+273; // Ambient temperature in kelvin
Cp=1.005; // Specific heat in KJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

eff_s=(rp^((r-1)/r)-1)*T01/DelT_rise;
wf=(DelT_rise*Cp*10^3)/(u*ca*(tand(beta_1)-tand(beta_2)));

disp ("%",eff_s*100,"Stage Efficiency = ");
disp (wf,"Work done factor = ");
```

Scilab code Exa 9.10 Determination of blade and air angle

```
clc;
u=250; // Mean blade speed in m/s
rp=1.3; // Pressure ratio
ca=200; // Axial velocity in m/s
p01=1; // Inlet pressure in bar
T01=300; // Inlet temperature in kelvin
R1=0.5; // Degree of reaction
Cp=1.005; // Specific heat in KJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

Del_T=(rp^((r-1)/r)-1)*T01;
//tan_beta1+tan_beta2=(R*2*u/ca);
//tan_beta1-tan_beta2=(Del_T*Cp*10^3/(u*ca));
A=[1 1;1 -1]; B=[(R1*2*u/ca) ;(Del_T*Cp*10^3/(u*ca))];
tan_beta=A\B;
beta_1=atand (tan_beta(1));
```

```
beta_2=atand (tan_beta(2));
alpha_1=beta_2; alpha_2=beta_1;

disp ("degree",beta_2,"beta2 = ","degree",beta_1,"beta1 = ");
disp ("degree",alpha_2,"alpha2 = ","degree",alpha_1,"alpha1 = ");
```

Scilab code Exa 9.11 Calculation of rotational speed

```
clc;
n=4; // Number of stage
rp=10; // Pressure ratio
eff_p_ac=0.92; // Ploytropic efficiency of axial compressor
eff_p_cc=0.83; // Polytropic efficiency of centrifugal compressor
Del_Trise=30; // Axial compressor stage temperature in kelvin
R=0.5; // Reaction stage
beta_2=20; // Outlet stator angle in degree
D=0.25; // Mean diameter of each stage in m
wf=0.8; // Work done factor
ca=150; // Axial velocity in m/s
Di=0.33; //Impeller diameter in m
mu=0.9; // Slip factor
p01=1.01; // Ambient pressure in bar
T01=288; // Ambient temperature in kelvin
pif=1.04; // Power input factor
Cp=1.005; // Specific heat in KJ/kg K
r=1.4; // Specific heat ratio
R=287; // Characteristic gas constant in J/kg K

beta_1=atand (sqrt ((Cp*10^3*Del_Trise/(wf*ca^2))+(tand(beta_2)^2)));
```

```
u=ca*(tand (beta_1)+tand(beta_2));
Nac=(u/(3.14*D));
r1=(1+n*Del_Trise/T01)^(eff_p_ac*r/(r-1)); // Total
    pressure ratio across the axial compressor

r2=rp/r1; // Pressure ratio across centrifugal
    compressor
T02=T01*r1^((r-1)/(eff_p_ac*r));
T03=T02*r2^((r-1)/(eff_p_cc*r));
Del_Tsc=T03-T02;
u=sqrt ((Del_Tsc*Cp*10^3)/(pif*mu));
Ncc=u/(3.14*Di);

disp ("rps  (roundoff error)",Nac,"Speed of the
    axial compressor = ");
disp ("rps  (roundoff error)",Ncc,"Speed of the
    centrifugal compressor = ");
```

Chapter 11

Impulse and Reaction Turbines

Scilab code Exa 11.1 Estimation of maximum number of stages required

```
clc;
p02=6; // Inlet pressure in bar
T02=900; // Inlet temperature in kelvin
p0fs=1; // Outlet pressure in bar
eff_isenT=0.85; // insentropic efficiency of turbine
alpha_2=75; // Nozzle outlet angle in degree
u=250; // Mean blade velocity in m/s
Cp=1.15*10^3; // Specific heat in J/ kg K
r=1.333; // Specific heat ratio

T0fs=T02/(p02/p0fs)^((r-1)/r); // Isentropic
    temperature at the exit of the final stage
Del_Toverall=eff_isenT*(T02-T0fs); // Actual overall
     temperature drop
c2=2*u/sind (alpha_2); // absolute velocity
c3= c2*cosd (alpha_2);// absolute velocity
c1=c3; // From velocity triangles
Del_Tstage=(c2^2-c1^2)/(2*Cp); // Stage temperature
    drop
n=Del_Toverall/Del_Tstage; // Number of stages

```

```
disp (round (n),"Number of stages n =");
```

Scilab code Exa 11.2 Determination of output power developed by the turbine shaft

```
clc;
N=10000; // Speed of gas turbine in rpm
T01=700+273.15; // Total head temperature at nozzle
    entry in kelvin
P01=4.5; //Total head pressure at nozzle entry in
    bar
P02=2.6; // Outlet pressure from nozzle in bar
p3=1.5;// Pressure at trbine outlet annulus in bar
M=0.5; // Mach number at outlet
alpha_2=70; // outlet nozzle angle in degrees
D=64; // Blade mean diameter in cm
m=22.5; // Mass flow rate in kg/s
eff_T=0.99; // turbine mechanical efficiency
Cp=1.147; // Specific heat in kJ/kg K
r=1.33; // Specific heat ratio
fl=0.03; // frictional loss
R=284.6; // characteristic gas constant in J/kg K

eff_N=1-fl; // Nozzle efficiency
T_02=(P02/P01)^((r-1)/r)*T01; // Isentropic
    temperature after expansion
T02=T01-eff_N*(T01-T_02); // Actual temperature
    after expansion
c2=sqrt (2*Cp*10^3*(T01-T02)); // Absolute velocity
u=(3.14*D*10^-2*N)/60; // Mean blade velocity
// From velocity triangles
wt2=c2*sind (alpha_2)-u;
ca=c2*cosd (alpha_2);
beta_2=atand((wt2)/ca);
T3=T02/(P02/p3)^((r-1)/r); // Assuming rotor losses
```

```
   are negligible
c3=M*sqrt (r*R*T3); // Absolute velocity
beta_3=atand(u/c3);
ct2=c2*sind(alpha_2);
P=eff_T*m*(ct2)*u/1000; // Power developed

disp ("degree",beta_3,"Gas angle at exit = ","degree
   ",beta_2,"Gas angle at entry","(i).");
disp ("kW  (roundoff error)",P,"Power developed = "
   ,"(ii).");
```

Scilab code Exa 11.3 Estimation of the blade angle and power produced

```
clc;
alpha_2=65; // Nozzle discharge angle in degree
c3=300; // Absolute velocity in m/s
alpha_3=30; // in degrees

ca2=c3*cosd (alpha_3); // Axial velocity
c2=ca2/cosd(alpha_2); //  Absolute velocity
// ca3=ca2=ca and equal blade angles then
ca=ca2;
beta_2=atand((c2*sind(alpha_2)+c3*sind(alpha_3))/(2*
   ca)); // Blade angle
beta_3=beta_2; // equal blade angles
u=c2*sind(alpha_2)-ca2*tand(beta_2); // Mean blade
   velocity
// From velocity triangles
ct2=c2*sind(alpha_2);
ct3=c3*sind(alpha_3);
WT=u*(ct2+ct3)/1000; // Work done
sigma=u/c2; // optimum speed ratio
eff_B=4*(sigma*sind(alpha_2)-sigma^2);

disp ("degree",beta_2,"Blade angle = beta_2= beta_3
```

```
   = ");
disp ("kJ/kg   (roundoff error)",WT,"Power Produced
   = ");
disp ("%",eff_B*100,"Blade efficiency = ");
```

Scilab code Exa 11.4 Calculation of blade angle used and the mass flow rate required

```
clc;
P01=7; // Pressure at inlet in bar
T01=300+273.15; // Temperature at inlet in kelvin
P02=3; // Pressure at outlet in bar
alpha_2=70; // Nozzle angle in degree
eff_N=0.9; // Isentropic efficiency of nozzle
WT=75; // Power Produced in kW
Cp=1.15; // Specific heat in kJ/kg K
r=1.33; // Specific heat ratio

T_02=T01*(P02/P01)^((r-1)/r); // Isentropic
   temperature after expansion
T02=T01-eff_N*(T01-T_02); // Actual temperature
   after expansion
c2=sqrt (2*Cp*10^3*(T01-T02)); // Absolute velocity
// For optimum blade speed ratio
u=(c2*sind (alpha_2)/2); // Mean blade velocity
beta_2=atand((c2*sind(alpha_2)-u)/(c2*cosd(alpha_2))
   ); // Blade angle
// From velocity triangles
ct2=c2*sind(alpha_2);
w2=c2*cosd(alpha_2)/cosd(beta_2);
w3=w2; // Equal inlet and outlet angles
beta_3=54; // in degrees
ct3=w3*sind(beta_3)-u;
m=(WT*10^3)/(u*(ct2+ct3)); // Gas mass flow rate

```

```
disp ("degree",beta_2,"Blade angle = ");
disp ("kg/s",m,"Gas Mass Flow Rate = ");
```

Scilab code Exa 11.5 Determination of gas temperature velocities and discharge angles at the blade root and tip radii

```
clc;
P01=4.6; // Total head inlet pressure in bar
T01=700+273.15; // Total head inlet temperature in
    kelvin
P2=1.6; // Static head pressure at mean radius in
    bar
Dm_h=10; // Mean blade diameter/blade height
lc=0.1; // Nozzle losses coefficient
alpha_2=60; // Nozzle outlet angle in degree
Cp=1.147; // Specific heat in kJ/kg K
r=1.33; // Specific heat ratio
m=20; // Mass flow rate in kg/s
R=284.6; // characteristic gas constant in J/kg K

T_2=T01*(P2/P01)^((r-1)/r); // Isentropic
    temperature after expansion
T2=(lc*T01+T_2)/(1+lc); // Actual temperature after
    expansion
c2=sqrt(2*Cp*10^3*(T01-T2)); // Absolute velocity
// From velocity triangles
ca=c2*cosd(alpha_2);
row=P2*10^5/(R*T2); // Density of gas
A=m/(ca*row); // Area
Dm=sqrt (A*Dm_h/3.14); // Mean Diameter
h=Dm/10; // Blade height
rm=Dm/2; // Mean radius
// At root
r_root=(Dm-h)/2;
//At the tip
```

```
r_tip=(Dm+h)/2;
// Free vorte flow
ct_mean=c2*sind (alpha_2);
// At the root
ct2_root=(ct_mean*rm)/r_root;
alpha2_root=atand(ct2_root/ca);
c2_root=ct2_root/sind (alpha2_root);
T2_root=T01-c2_root^2/(2*Cp*10^3);
// At the tip
ct2_tip=ct_mean*rm/r_tip;
alpha2_tip = atand (ct2_tip/ca);
c2_tip=ct2_tip/sind(alpha2_tip);
T2_tip=T01-c2_tip^2/(2*Cp*10^3);

disp ("degree",alpha2_root,"Discharge angle at the root = ","m/s",c2_root,"Gas velocity at the root = ","K",T2_root,"Gas Temperature at the root = ","A the Root");
disp ("degree",alpha2_tip,"Discharge angle at the tip = ","m/s",c2_tip,"Gas velocity at the tip = ","K",T2_tip,"Gas Temperature at the tip = ","A the tip");
```