

Scilab Textbook Companion for
Turbomachines
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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.

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Chapter 1

BASIC CONCEPTS OF TURBO MACHINES

Scilab code Exa 1.1 COMPRESSION WORK

```
1  clc
2  clear
3  //input data
4  P01=1//initial pressure of a fluid in bar
5  P02=10//final pressure of a fluid in bar
6  T01=283//initial total temperature in K
7  ntt=0.75//total-to-total efficiency
8  d=1000//density of water in kg/m^3
9  r=1.4//ratio of specific heats for air
10 Cp=1.005//specific at heat at constant pressure in
    kJ/kg.K
11
12 //calculations
13 h0s1=(1/d)*(P02-P01)*10^2//enthalpy in kJ/kg
14 h01=(h0s1/ntt)//enthalpy in kJ/kg
15 T02s=T01*(P02/P01)^((r-1)/r)//temperature in K
16 h0s2=(Cp*(T02s-T01))//enthalpy in kJ/kg
17 h02=(h0s2/ntt)//enthalpy in kJ/kg
18
```

```

19 //output
20 printf('The work of compression for adiabatic steady
    flow per kg of fluid is \n(a)The fluid is liquid
    water is %3.1f kJ/kg\n(b)The fluid is air as a
    perfect gas is %3.2f kJ/kg',h01,h02)

```

Scilab code Exa 1.2 EFFICIENCY

```

1  clc
2  clear
3  //input data
4  P01=7//Total initial pressure of gases at entry in
    bar
5  T01=1100//Total initial temperature in K
6  P02=1.5//Total final pressure of gases at exit in
    bar
7  T02=830//Total final temperature in K
8  C2=250//Exit velocity in m/s
9  r=1.3//Ratio of specific heats of gases
10 M=28.7//Molecular weight of gases
11 R1=8.314//Gas constant of air in kJ/kg.K
12
13 //calculations
14 T02s=T01*(P02/P01)^((r-1)/r)//Final temperature in K
15 ntt=((T01-T02)/(T01-T02s))//Total-to-total
    efficiency
16 R=(R1/M)//Gas constant of given gas in kJ/kg.K
17 Cp=((r*R)/(r-1))//Specific heat of given gas at
    constant pressure in kJ/kg.K
18 T2s=(T02s-((C2^2)/(2*Cp*1000)))/Temperature in
    isentropic process at exit in K
19 nts=((T01-T02)/(T01-T2s))//Total-to-static
    efficiency
20
21 //output

```

```

22 printf('The total-to-total efficiency of gases is %3
    .3f\nThe total-to-static efficiency of gases is
    %3.3f',ntt,nts)

```

Scilab code Exa 1.3 PRESSURE RATIO

```

1  clc
2  clear
3  //input data
4  h0=6//Change in total enthalpy in kJ/kg
5  T01=303//Total inlet temperature of fluid in K
6  P01=1//Total inlet pressure of fluid in bar
7  Cp=1.005//specific at heat at constant pressure in
    kJ/kg.K
8  ntt=0.75//Adiabatic total-to-total efficiency
9  r=1.4//ratio of specific heats for air
10
11 //calculations
12 T02=T01+(h0/Cp)//Exit total temperature of fluid in
    K
13 P1=(1+((ntt*h0)/(Cp*T01)))^(r/(r-1))//Total pressure
    ratio of fluid
14 h0s=ntt*h0//Change in enthalpy of process in kJ/kg
15 P0=((h0s*1000)/100)//Change in pressure in bar
16 P02=P0+P01//Total outlet pressure of fluid in bar
17 P2=(P02/P01)//Total pressure ratio of fluid
18
19 //output
20 printf('(a)The exit total temperature of fluid is %3
    .2f K\n(b)The total pressure ratio if:\n(1)The
    fluid is air is %3.3f\n(2)The fluid is liquid
    water is %3.0i',T02,P1,P2)

```

Scilab code Exa 1.4 TOTAL PRESSURE

```
1  clc
2  clear
3  //input data
4  W=100//Output power developed in kW
5  Q=0.1//Flow through device in m^3/s
6  d=800//Density of oil in kg/m^3
7  ntt=0.75//Total-to-total efficiency
8  C1=3//inlet flow velocity of oil in m/s
9  C2=10//outlet flow velocity of oil in m/s
10
11 //calculations
12 m=d*Q//Mass flow rate of oil in kg/s
13 h0=-(W/m)//Change in total enthalpy in kJ/kg
14 h0s=(h0/ntt)//Isentropic change in total enthalpy in
    kJ/kg
15 P0=((d*h0s)*(1/100))//Change in total pressure of
    oil in bar
16 P=P0-((d/(2000*100))*(C2^2-C1^2))//Change in static
    pressure in bar
17
18 //output
19 printf('The change in total pressure of oil is %3.1f
    bar\nThe change in static presure is %3.1f bar',
    P0,P)
```

Scilab code Exa 1.5 OVERALL EFFICIENCY

```
1  clc
2  clear
3  //input data
4  N=4//Number of stages in turbine handling
5  P=0.4//Stagnation presure ratio between exit and
    inlet of each stage
```

```

6 ns1=0.86//Stage efficiency of first and second
  stages
7 ns2=0.84//Stage efficiency of third and fourth
  stages
8 r=1.4//ratio of specific heats for air
9
10 //calculations
11 u=1-(P)^((r-1)/r)//constant
12 T03=(1-(u*ns1))^2//Temperature after the end of
  first two stages in (K*Cp*T01) where Cp is
  specific at heat at constant pressure in kJ/kg.K
  and T01 is initial temperature at entry of stage
  1 in K
13 W12=u*(1+(1-(u*ns1)))*ns1//Actual work output from
  first two stages in (kW*Cp*T01)
14 W34=T03*u*(1+(1-(u*ns2)))*ns2//Actual work output
  from last two stages in (kW*Cp*T01)
15 W=(W12+W34)//Total actual work output from turbine
  in (kW*Cp*T01)
16 Ws=1-(1-u)^N//Total isentropic work due to single
  stage compressor in (kW*Cp*T01)
17 n=(W/Ws)//Overall turbine efficiency
18
19 //output
20 printf('the overall efficiency of the turbine is %3
  .3f',n)

```

Scilab code Exa 1.6 COMPRESSOR EFFICIENCY

```

1 clc
2 clear
3 //input data
4 P=1400//Pressure developed by compressor in mm W.G
5 P1=1.01//Initial pressure of air in bar
6 T1=305//Initial temperature of air in K

```

```

7 T2=320//Final temperature of air in K
8 P=1400*9.81*10^-5//Pressure developed by compressor
  in bar
9 r=1.4//ratio of specific heats for air
10
11 //calculations
12 P2=P1+P//Final pressure of air in bar
13 T2s=T1*(P2/P1)^((r-1)/r)//Isentropic temperature at
  exit in K
14 nc=((T2s-T1)/(T2-T1))//compressor efficiency
15 np=((r-1)/r)*((log10(P2/P1))/(log10(T2/T1)))//
  Infinitesimal stage efficiency
16
17 //output
18 printf('(a)The compressor efficiency is %3.4f\n(b)
  The infinitesimal stage efficiency is %3.4f',nc,
  np)

```

Scilab code Exa 1.7 INFINITESIMAL EFFICIENCY

```

1 clc
2 clear
3 //input data
4 P1=1.01//Input pressure to compressor in bar
5 T1=305//Input temperature to compressor in K
6 P2=3//Output pressure from compressor in bar
7 r=1.4//ratio of specific heats for air
8 nc=0.75//compressor efficiency
9
10 //calculations
11 T2s=T1*(P2/P1)^((r-1)/r)//Isentropic output
  temperature from compressor in K
12 T2=T1+((T2s-T1)/nc)//Actual output temperature from
  compressor in K
13 np=((r-1)/r)*((log10(P2/P1))/(log10(T2/T1)))//

```

```

    Infinitesimal efficiency of compressor
14
15 //output
16 printf('The infinitesimal efficiency of the
    compressor is %3.3f',np)

```

Scilab code Exa 1.8 POLYTROPIC EFFICIENCY

```

1 clc
2 clear
3 //input data
4 P=2.2//Pressure ratio across a gas turbine
5 n=0.88//Efficiency of a gas turbine
6 T1=1500//Inlet temperature of the gas in K
7 r=1.4//ratio of specific heats for air
8
9 //calculations
10 T2s=T1*(1/P)^((r-1)/r)//Isentropic output
    temperature from gas turbine in K
11 T2=T1-(n*(T1-T2s))//actual output temperature from
    gas turbine in K
12 np=(r/(r-1))*((log10(T1/T2))/(log10(P)))//Polytropic
    efficiency of the turbine
13
14 //output
15 printf('The polytropic efficiency of the turbine is
    %3.3f',np)

```

Scilab code Exa 1.9 STATES AND EFFICIENCIES

```

1 clc
2 clear
3 // input data

```

```

4 P=1.3//Pressure ratio of stages
5 N=8//Number of stages
6 m =45//The flow rate through compressor in kg/s
7 nc=0.8//Overall efficiency of the compressor
8 P1=1//Initial pressure of the air at entry in bar
9 T1=308//Initial temperature of the air at entry in K
10 r=1.4//ratio of specific heats for air
11
12 //calculations
13 PN=(P)^8//Overall pressure ratio of all 8 stages
14 TN=PN^((r-1)/r)//Overall temperature ratio of all 8
    stages
15 TN1s=TN*T1//Ideal exit temperature in K
16 TN1=((TN1s-T1)/nc)+T1//Actual exit temperature in K
17 PN1=PN*P1//Actual exit pressure in bar
18 np=((r-1)/r)*((log10(PN1/P1))/(log10(TN1/T1)))//
    Polytropic efficiency of the cycle
19 ns((((P)^((r-1)/r))-1)/((((P)^((r-1)/(r*np)))-1))//
    The stage efficiency of the cycle
20
21 //output
22 printf('(a)The state of air at compressor exit are\n
    (1)actual temperature is %3.1f K\n    (2)
    actual pressure is %3.2f bar\n(b)The polytropic
    efficiency of the cycle is %3.2f\n(c)The stage
    efficiency of the cycle is %3.4f ',TN1,PN1,np,ns)

```

Scilab code Exa 1.10 PRESSURE RATIO AND EFFICIENCY

```

1 clc
2 clear
3 //input data
4 P=11//Overall pressure ratio in three stages of a
    gas turbine
5 nt=0.88//Overall efficiency in three stages of a gas

```



```

turbine
6 T1=1500//Temperature at inlet of a gas turbine in K
7 r=1.4//ratio of specific heats for air
8
9 //calculations
10 T0=nt*T1*(1-(1/P)^((r-1)/r))//Overall change in
    temperature in all stages in K
11 TN1=T1-T0//Temperature at final stage of a gas
    turbine in K
12 np=((r/(r-1))*log10(T1/TN1))/(log10(P))//Overall
    polytropic efficiency of the gas turbine
13 Ts=T0/3//Individual stage change in temperature in K
14 T2=T1-Ts//Exit temperature at the end of first stage
    in K
15 P1=(T1/T2)^(r/(np*(r-1)))//Pressure ratio at first
    stage of gas turbine
16 ns1=((1-(1/P1)^((np*(r-1))/r))/(1-(1/P1)^((r-1)/r)))
    //Stage efficiency of first stage
17 T3=T2-Ts//Exit temperature at the end of second
    stage in K
18 P2=(T2/T3)^(r/(np*(r-1)))//Pressure ratio at second
    stage of gas turbine
19 ns2=((1-(1/P2)^((np*(r-1))/r))/(1-(1/P2)^((r-1)/r)))
    //Stage efficiency of second stage
20 T4=T3-Ts//Exit temperature at the end of third stage
    in K
21 P3=(T3/T4)^(r/(np*(r-1)))//Pressure ratio at the
    third stage of gas turbine
22 ns3=((1-(1/P3)^((np*(r-1))/r))/(1-(1/P3)^((r-1)/r)))
    //Stage efficiency of third stage
23
24 //output
25 printf('(a)The values for first stage are\n    (1)
    Pressure ratio is %3.2f\n    (2)stage efficiency
    is %3.4f\n(b)The values of second stage are\n
    (1)Pressure ratio is %3.3f\n    (2)Stage
    efficiency is %3.3f\n(c)The values of third stage
    are\n    (1)Pressure ratio is %3.2f\n    (2)

```

Stage efficiency is %3.4f\n',P1,ns1,P2,ns2,P3,ns3
)

Scilab code Exa 1.11 POWER REQUIRED

```

1  clc
2  clear
3  //input data
4  N=4//Number of stages in compressor
5  m=45//mass flow rate of air delivered by compressor
   in kg/s
6  P1=1.2//Pressure ratio at first stage
7  ns=0.65//Stage efficiency of first stage
8  r=1.4//ratio of specific heats for air
9  Cp=1.005//specific at heat at constant pressure in
   kJ/kg.K
10 T1=293//Temperature of air at inlet in K
11
12 //calculations
13 P=(P1)^N//Overall pressure in all 4 stages
14 np=((r-1)/r)*((log10(P1))/(log10((((P1)^((r-1)/r))-1)
   /ns)+1)))//Polytropic efficiency of the cycle
15 nc((((P1^(N*((r-1)/r)))-1)/((P1^(N*((r-1)/(r*np))))
   -1))//Overall efficiency of the cycle
16 TN1=T1*((P1^N)^((r-1)/(r*np)))//Final temperature
   at the exit of the compressor at final stage in K
17 W=m*Cp*(TN1-T1)//Power required to drive the
   compressor in kW
18
19 //output
20
21 printf('(a)The overall pressure ratio of the process
   is %3.1f\n(b)The overall efficiency of the
   process is %3.4f\n(c)The power required to drive
   the compressor is %3.2f kW',P,nc,W)

```

Scilab code Exa 1.12 EXIT CONDITIONS

```
1  clc
2  clear
3  //input data
4  P0=0.2*9.81*(10^3)*(10^-5)//Total increase in
   pressure in bar
5  P01=1.04//Total inlet pressure of air in bar
6  T01=291//Total inlet temperature of air in K
7  ntt=0.72//Total-to-total efficiency of the process
8  r=1.4//ratio of specific heats for air
9  Cp=1.005//specific at heat at constant pressure in
   kJ/kg.K
10
11 //calculations
12 P2=P0+P01//The total exit pressure in bar
13 T02=(((P2/P01)^((r-1)/r)-1)*T01)/ntt)+T01//Total
   temperature at the outlet in K
14 h0=Cp*(T02-T01)//Actual change in total enthalpy in
   kJ/kg
15 h0s=h0*ntt//Isentropic change in total enthalpy in
   kJ/kg
16
17 //output
18 printf('(a)The total exit pressure is %3.4f bar\n
   and the total exit temperature is %3.2f K\n(b)The
   actual change in total enthalpy is %3.3f kJ/kg\n
   and the isentropic change in total enthalpy is
   %3.3f kJ/kg',P2,T02,h0,h0s)
```

Scilab code Exa 1.13 STATES OF AIR AND EFFICIENCIES

```

1  clc
2  clear
3  //input data
4  P=5//Pressure ratio in the process
5  ntt=0.8//Total-to-total efficiency of the process
6  m=5//Air flow rate through turbine in kg/s
7  W=500//Total power output from the turbine in kW
8  r=1.4//ratio of specific heats for air
9  Cp=1.005*10^3//specific at heat at constant pressure
    in J/kg.K
10 C2=100//Flow velocity of air in m/s
11
12 //calculations
13 T=(W*10^3)/(m*Cp)//Total change in temperature in
    the process in K
14 T02s=(1/P)^((r-1)/r)//Isentropic temperature at the
    outlet from turbine in (K*T01)
15 T01=(T/ntt)*(1/(1-0.631))//Inlet total temperature
    in K
16 T02=T01-T//Actual exit total temperature in K
17 T2=T02-((C2^2)/(2*Cp))//Actual exit static
    temperature in K
18 T02s1=T02s*T01//Isentropic temperature at the outlet
    from turbine in K
19 T2s=T02s1-((C2^2)/(2*Cp))//Actual isentropic
    temperature in K
20 nts=(T/(T01-T2s))//Total-to-static efficiency
21
22 //output
23 printf('(a)The inlet total temperature is %i K\n(b)
    The actual exit total temperature is %3.1f K\n(c)
    The actual exit static temperature is %3.1f K\n(d)
    )The total-to-static efficiency is %3.4f ',T01,T02
    ,T2,nts)

```

Scilab code Exa 1.14 REHEAT FACTOR

```
1
2 clc
3 clear
4 //input data
5 N=3//Number of stages in turbine
6 P=2//Pressure ratio of each stage
7 ns=0.75//Stage efficiency of each stage
8 T1=873//Initial temperature of air in K
9 m=25//Flow rate of air in kg/s
10 r=1.4//ratio of specific heats for air
11 Cp=1.005//specific at heat at constant pressure in J
    /kg.K
12
13 //calculations
14 np=(r/(r-1))*((log(1-(ns*(1-(1/P)^((r-1)/r)))))/(log
    (1/P)))//Polytropic efficiency of the process
15 nt=((1-(1/P)^(N*np*((r-1)/r)))/(1-(1/P)^(N*((r-1)/r)
    )))//Overall efficiency of the turbine
16 W=m*Cp*T1*(1-(1/P)^(N*np*((r-1)/r)))//Power
    developed by the turbine in kW
17 RF=nt/ns//Reheat factor of the process
18
19 //output
20 printf('(a)The overall efficiency of the turbine is
    %3.4f\n(b)The power developed by the turbine is
    %i kW\n(c)The reheat factor of the process is %3
    .2f ',nt,W,RF)
21
22 //comments
23 // the answer which i have got in scilab is correct
    it is showing error because the intermediate
    values have been approximated in textbook where
    as in the software it is not. if the answer is
    calculated in the calculator then it is same as
    that of obtained from the software.
```

Chapter 2

BLADE THEORY

Scilab code Exa 2.1 WEIGHT CARRIED

```
1  clc
2  clear
3  //input data
4  c =2.25//Chord length of an aerofoil in m
5  l=13.5//Span of the aerofoil in m
6  C=125//Velocity of the aerofoil in m/s
7  Cl=0.465//Lift coefficient
8  Cd=0.022//Drag coefficient
9  d=1.25//Density of the air in kg/m^3
10
11 //calculations
12 A=c*l//Area of cross section of the aerofoil in m^2
13 W=Cl*d*((C^2)/2)*A*10^-3//Weight carried by the
    wings of aerofoil in kN
14 D=Cd*d*((C^2)/2)*A//Drag force on the wings of
    aerofoil in N
15 P=D*C*10^-3//Power required to the drive the
    aerofoil in kW
16
17 //output
18 printf('(a)Weight carried by the wings is %3.2f kN\
```

```

n(b) Drag force on the wings of aerofoil is %3.2f
N\n(c) Power required to drive the aerofoil is %3
.3 f kW',W,D,P)
19
20
21 //comments
22 // error in the first review is not printing the
    value of drag force which is corrected

```

Scilab code Exa 2.2 DIAMETER OF PARACHUTE

```

1  clc
2  clear
3  //input data
4  W=980//The weight of the object being dropped by
    parachute in N
5  C=5//The maximum terminal velocity of dropping in m/
    s
6  d=1.22//The density of the air in kg/m^3
7  Cd=1.3//The drag coefficient of the parachute
8
9  //calculations
10 A=W/(Cd*d*((C^2)/2))//The area of cross section in m
    ^2
11 D=((A*4)/(3.14))^(1/2)//Diameter of the parachute in
    m
12
13 //output
14 printf('The required diameter of the parachute is %3
    .2 f m',D)

```

Scilab code Exa 2.3 COEFFICIENT OF LIFT

```

1  clc
2  clear
3  //input data
4  A=10*1.2//Area of the airplane wing in m^2
5  C=((240*10^3)/3600)//Velocity of the wing in m/s
6  F=20//Total aerodynamic force acting on the wing in
    kN
7  LD=10//Lift-drag ratio
8  d=1.2//Density of the air in kg/m^3
9
10 //calculations
11 L=(F)/(1.01)^(1/2)//The weight that the plane can
    carry in kN
12 Cl=(L*10^3)/(d*A*((C^2)/2))//Coefficient of the lift
13
14 //output
15 printf('(1)The coefficient of lift is %3.3f\n(2)The
    total weight the palne can carry is %3.1f kN',Cl,
    L)

```

Scilab code Exa 2.4 MEAN RADIUS

```

1  clc
2  clear
3  //input data
4  m=25//Mass flow rate of the air in kg/s
5  d=1.1//Density of the air in kg/m^3
6  Ca=157//Axial flow velocity of the air in m/s
7  N=150//Rotational speed of the air in rev/s
8  U=200//Mean blade speed in m/s
9  lc=3//Rotor blade aspect ratio
10 sc=0.8//Pitch chord ratio
11
12 //calculations
13 rm=(U)/(2*3.145*N)//Mean radius of the blades in m

```



```

14 A=(m)/(d*Ca)//The annulus area of flow in m^2
15 l=(A)/(2*3.1*rm)//The blade height in m
16 C=1/lc//The chord of the blades in m
17 S=sc*C//The blade pitch in m
18 n=(2*3.141*rm)/(S)//Number of blades
19
20 //output
21
22 printf('(a)The mean radius of the blades is %3.3f m\
n(b)The blade height is %3.2f m\n(c) (1)The pitch
of the blades is %3.4f m\n (2)The chord of
the blades is %3.3f m\n(d)The number of the
blades are %3.f ',rm,l,S,C,n)

```

Scilab code Exa 2.5 DEFLECTION ANGLE

```

1 clc
2 clear
3 //input data
4 sc=0.8//Pitch-chord ratio of compressor blade
5 b1=45//Relative air angle at inlet in degree
6 b2=15//Relative air angle at outlet in degree
7 a1=b1//Cascade air angle at inlet in degree
8 a2=b2//Cascade air angle at outlet in degree
9
10 //calculations
11 en=a1-a2//Nominal deflection angle of the blade in
degree
12 m=((0.23*(1)^2)+(0.1*a2/50)//An emperical constant
for a circular arc camber where (2*a/c)=1
13 t=(a1-a2)/(1-0.233)//Blade camber angle in degree
14 d=(m*(sc)^(1/2))*t//The deviation angle of the blade
in terms of (degree*t)
15 ps=a1-(t/2)//The blade stagger for a given circular
arc cascade in degree

```

```

16
17 //output
18 printf('(a)The nominal deflection angle is %i degree
    \n(b)The blade camber angle is %3.2f degree\n(c)
    The deviation angle is %3.2f degree\n(d)The blade
    stagger is %3.2f degree',en,t,d,ps)

```

Scilab code Exa 2.6 CASCADE BLADE ANGLES

```

1  clc
2  clear
3  //input data
4  t=25//The camber angle of aero foil blades in degree
5  ps=30//The blade stagger angle in degree
6  sc=1//The pitch-chord ratio of the blades
7  in=5//The nominal value of incidence in degree
8
9  //calculations
10 a1=ps+(t/2)//The cascade blade angle at inlet in
    degree
11 a2=a1-t//The cascade blade angle at outlet in degree
12 a1n=in+a1//The nominal entry air angle in degree
13 a2n=atand((tand(a1n))-(1.55/(1.0+(1.5*sc))))//The
    nominal exit air angle in degree
14
15 //output
16 printf('(1)The cascade blade angles at \n      (a)
    inlet is %3.1f degree\n      (b)exit is %3.1f
    degree\n(2)The nominal air angles at \n      (a)
    inlet is %3.1f degree\n      (b)exit is %3.2f
    degree',a1,a2,a1n,a2n)

```

Scilab code Exa 2.7 LOSS COEFFICIENT

```

1  clc
2  clear
3  //input data
4  C1=75//Velocity of air entry in m/s
5  a1=48//Air angle at entry in degree
6  a2=25//Air angle at exit in degree
7  cs=0.91//The chord-pitch ratio
8  P0m=(11*9.81*10^3)/10^3//The stagnation pressure
    loss in N/m^2
9  d=1.25//The density of the sair in kg/m^3
10
11 //calculations
12 Cp=(P0m/(0.5*d*C1^2))//The pressure loss coefficient
13 am=atand((tand(a1)+tand(a2))/2)//The mean air angle
    in degree
14 Cd=2*(1/cs)*(P0m/(d*C1^2))*((cosd(am))^3/(cosd(a1))
    ^2)//The drag coefficient
15 Cl=(2*(1/cs)*cosd(am)*(tand(a1)-tand(a2)))-(Cd*tand(
    am))//THE lift coefficient
16
17 //output
18 printf('(a)The pressure loss coefficient is %3.4f\n(
    b)The drag coefficient is %3.4f\n(c)The lift
    coefficient is %3.3f',Cp,Cd,Cl)

```

Scilab code Exa 2.8 PRESSURE LOSS COEFFICIENT

```

1  clc
2  clear
3  //input data
4  a1=40//The cascade air angle at entry in degree
5  a2=65//The cascade air angle at exit in degree
6  C1=100//Air entry velocity in m/s
7  d=1.25//The density of the air in kg/m^3
8  sc=0.91//The pitch-chord ratio of the cascade

```

```

9 P0m=(17.5*9.81*10^3)/10^3//The average loss in
   stagnation pressure across cascade in N/m^2
10
11 //calculations
12 Cp=(P0m/(0.5*d*C1^2))//The pressure loss coefficient
   in the cascade
13 am=atand((tand(a2)-tand(a1))/2)//The mean air angle
   in degree
14 Cd=2*(sc)*(P0m/(d*C1^2))*((cosd(am))^3/(cosd(a2))^2)
   //The drag coefficient
15 Cl=(2*(sc)*cosd(am)*(tand(a1)+tand(a2)))+(Cd*tand(am)
   )//The lift coefficient
16
17 //output
18 printf('(a)The pressure loss coefficient is %3.4f\n(
   b)The drag coefficient is %3.4f\n(c)The lift
   coefficient is %3.3f',Cp,Cd,Cl)

```

Scilab code Exa 2.9 COEFFICIENT OF DRAG AND LIFT

```

1 clc
2 clear
3 //input data
4 W=30000//The weight of the jet plane in N
5 A=20//The area of the wing in m^2
6 C=250*5/18//The speed of the jet plane in m/s
7 P=750//The power delivered by the engine in kW
8 d=1.21//Density of the air in kg/m^3
9
10 //calculations
11 L=W//The lift force on the plane is equal to the
   weight of the plane in N
12 Pd=0.65*P//The power required to overcome the drag
   resistance in kW
13 D=(Pd/C)*10^3//The drag force on the wing in N

```

```
14 Cd=D/(0.5*d*A*C^2)//The coefficient of drag for the
    wing
15 Cl=L/(0.5*d*A*C^2)//The coefficient of lift for the
    wing
16
17 //output
18 printf('(a)The coefficient of lift on the wing is %3
    .3f\n(b)The coefficient of drag on the wing is %3
    .3f',Cl,Cd)
```

Chapter 3

CENTRIFUGAL COMPRESSORS AND FANS

Scilab code Exa 3.1 RISE IN TOTAL TEMPERATURE

```
1  clc
2  clear
3  //input data
4  m=10//The mass flow rate of air into compressor in
      kg/s
5  P1=1//The ambient air pressure in compressor in bar
6  T1=293//The ambient air temperature in compressor in
      K
7  N=20000//The running speed of the compressor in rpm
8  nc=0.8//The isentropic efficiency of the compressor
9  P02=4.5//The total exit pressure from the compressor
      in bar
10 C1=150//The air entry velocity into the impeller eye
      in m/s
11 Cx1=0//The pre whirl speed in m/s
12 WS=0.95//The ratio of whirl speed to tip speed
13 Cp=1005//The specific heat of air at constant
      pressure in J/kg.K
14 R=287//The universal gas constant in J/kg.K
```

```

15 Dh=0.15//The eye internal diameter in m
16 r=1.4//Ratio of specific heats of air
17 d=1.189//The density of the air in kg/m^3
18
19 //calculations
20 T01=T1+((C1^2)/(2*Cp))//The stagnation temperature
    at inlet in K
21 P01=P1*(T01/T1)^(r/(r-1))//The stagnation pressure
    at inlet in bar
22 T02s=(T01)*(P02/P01)^((r-1)/r)//The temperature
    after isentropic compression from P01 to P02 in K
23 T=(T02s-T01)/nc//The actual rise in total
    temperature in K
24 W=Cp*(10^-3)*(T)//The work done per unit mass in kJ/
    kg
25 U2=((W*(10^3))/(WS))^(1/2)//The impeller tip speed
    in m/s
26 Dt=(U2*60)/(3.1415*N)//The impeller tip diameter in
    m
27 P=m*W//Power required to drive the compressor in kW
28 d1=((P1*10^5)/(R*T1))//The density of the air entry
    in kg/m^3
29 De((((4*m)/(d*C1*3.14))+(Dh^2))^(1/2)//The eye
    external diameter in m
30
31 //output
32 printf('(a)The actual rise in total temperature of
    the compressor is %3.1f K\n(b)\n        (1)The
    impeller tip speed is %3.2f m/s\n        (2)The
    impeller tip diameter is %3.2f m\n(c)The power
    required to drive the compressor is %3.1f kW\n(d)
    The eye external diameter is %3.3f m',T,U2,Dt,P,
    De)

```

Scilab code Exa 3.2 BLADE ANGLES AND DIMENSIONS

```

1  clc
2  clear
3  //input data
4  Q1=20//Discharge of air to the centrifugal
    compressor in m3/s
5  V1=Q1//Volume of rate is equal to the discharge in m
    ^3/s
6  P1=1//Initial pressure of the air to the centrifugal
    compressor in bar
7  T1=288//Initial temperature of the air to the
    centrifugal compressor in K
8  P=1.5//The pressure ratio of compression in
    centrifugal compressor
9  C1=60//The velocity of flow of air at inlet in m/s
10 Cr2=C1//The radial velocity of flow of air at outlet
    in m/s
11 Dh=0.6//The inlet impeller diameter in m
12 Dt=1.2//The outlet impeller diameter in m
13 N=5000//The speed of rotation of centrifugal
    compressor in rpm
14 n=1.5//polytropic index constant in the given law PV
    ^n
15 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
16
17 //calculations
18 U1=(3.14*Dh*N)/60//Peripheral velocity of impeller
    at inlet in m/s
19 b11=atand(C1/U1)//The blade angle at impeller inlet
    in degree
20 U2=(3.14*Dt*N)/60//Peripheral velocity of impeller
    top at outlet in m/s
21 T2=T1*(P)^((n-1)/n)//Final temperature of the air to
    the centrifugal compressor in K
22 Cx2=((Cp*(T2-T1))/U2)//The whirl component of
    absolute velocity in m/s
23 Wx2=U2-Cx2//The exit relative velocity in m/s
24 a2=atand(Cr2/Cx2)//The blade angle at inlet to

```



```

    casing in degree
25 b22=atand(Cr2/Wx2)//The blade angle at impeller
    outlet in degree
26 b1=Q1/(2*3.14*(Dh/2)*C1)//The breadth of impeller
    blade at inlet in m
27 V2=(P1*V1*T2)/(T1*P*P1)//Volume flow rate of air at
    exit in m^3/s
28 Q2=V2//Volume flow rate is equal to discharge in m
    ^3/s
29 b2=Q2/(2*3.14*(Dt/2)*Cr2)//The breadth of impeller
    blade at outlet in m
30
31 //output
32 printf('(a)The blade and flow angles\n    (1)The
    blade angle at impeller inlet is %3.1f degree\n
    (2)The blade angle at inlet to casing is %3.1f
    degree\n    (3)The blade angle at impeller outlet
    is %3.2f degree\n(b)Breadth of the impeller blade
    at inlet and outlet\n    (1)The breadth of
    impeller blade at inlet is %3.3f m\n    (2)The
    Volume flow rate of air at exit is %3.2f m^3/s\n
    (3)The breadth of impeller blade at outlet is
    %3.4f m',b11,a2,b22,b1,V2,b2)
33
34
35 //comments
36 //error in the first review is not printing the
    value of V2 which is corrected

```

Scilab code Exa 3.3 OVERALL DIAMETER

```

1  clc
2  clear
3  //input data
4  m=14//The mass flow rate of air delivered to

```

```

    centrifugal compressor in kg/s
5  P01=1//The inlet stagnation pressure in bar
6  T01=288//The inlet stagnation temperature in K
7  P=4//The stagnation pressure ratio
8  N=200//The speed of centrifugal compressor in rps
9  ss=0.9//The slip factor
10 ps=1.04//The power input factor
11 ntt=0.8//The overall isentropic efficiency
12 r=1.4//The ratio of specific heats of air
13 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
14
15 //calculations
16 pp=ss*ps*ntt//The pressure coefficient
17 U2=((Cp*T01*((P^((r-1)/r))-1))/pp)^(1/2)//Peripheral
    velocity of impeller top at outlet in m/s
18 D2=U2/(3.14*N)//The overall diameter of the impeller
    in m
19
20 //output
21 printf('The overall diameter of the impeller is %3.2
    f m',D2)

```

Scilab code Exa 3.4 INLET RELATIVE MACH NUMBER

```

1  clc
2  clear
3  //input data
4  D1=0.457//Impeller diameter at inlet in m
5  D2=0.762//Impeller diameter at exit in m
6  Cr2=53.4//Radial component of velocity at impeller
    exit in m/s
7  ss=0.9//Slip factor
8  N=11000//Impeller speed in rpm
9  P2=2.23//Static pressure at impeller exit in bar

```

```

10 T01=288//The inlet stagnation temperature in K
11 P01=1.013//The inlet stagnation pressure in bar
12 C1=91.5//Velocity of air leaving the guide vanes in
    m/s
13 a11=70//The angle at which air leaves the guide
    vanes in degrees
14 r=1.4//The ratio of specific heats of air
15 R=287//The universal gas constant in J/kg.K
16 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
17
18 //calculations
19 Cx1=C1*cosd(a11)//Inlet absolute velocity of air in
    tangential direction in m/s
20 Ca1=Cx1*tand(a11)//Radial component of absolute
    velocity at inlet in m/s
21 U1=(3.14*D1*N)/(60)//Peripheral velocity of impeller
    at inlet in m/s
22 Wx1=U1-Cx1//Relative whirl component of velocity at
    inlet in m/s
23 W1=((Wx1^2)+(Ca1^2))^(1/2)//Relative velocity at
    inlet in m/s
24 T1=T01-((C1^2)/(2*Cp))//The inlet air temperature in
    K
25 a1=(r*R*T1)^(1/2)//The velocity of air in m/s
26 M1r=W1/a1//Initial relative mach number
27 U2=(3.14*D2*N)/60//Peripheral velocity of impeller
    top at exit in m/s
28 W=(ss*U2^2)-(U1*Cx1)//Work done by the compressor in
    kJ/kg
29 T02=(W/Cp)+T01//The outlet stagnation temperature in
    K
30 Cx21=ss*U2//Absolute whirl component of velocity
    with slip consideration in m/s
31 C2=((Cx21^2)+(Cr2^2))^(1/2)//The absolute velocity
    of air at exit in m/s
32 T2=T02-((C2^2)/(2*Cp))//The exit temperature of air
    in K

```

```

33 P02=P2*(T02/T2)^(r/(r-1))//The exit stagnation
    pressure of compressor in bar
34 nc=(T01/(T02-T01))*(((P02/P01)^((r-1)/r))-1)//Total
    head isentropic efficiency
35
36 //output
37 printf('(1)The inlet relative mach number is %3.3f\n
    (2)The impeller total head efficiency is %3.3f',
    M1r,nc)

```

Scilab code Exa 3.5 DIMENSIONS OF IMPELLER

```

1  clc
2  clear
3  //input data
4  N=16500//The running speed of radial blade of a
    centrifugal compressor in rpm
5  P=4//The total pressure ratio
6  P01=1//The atmospheric pressure in bar
7  T01=298//The atmospheric temperature in K
8  Dh=0.16//The hub diameter at impeller eye in m
9  Ca=120//The axial velocity at inlet in m/s
10 C1=Ca//The absolute velocity at inlet in m/s
11 sp=0.7//The pressure coefficient
12 C3=120//The absolute velocity at diffuser exit in m/
    s
13 m=8.3//The mass flow rate in kg/s
14 nc=0.78//The adiabatic total-to-total efficiency
15 r=1.4//The ratio of specific heats of air
16 R=287//The universal gas constant in J/kg.K
17 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
18
19 //calculations
20 T1=T01-((C1^2)/(2*Cp))//The inlet temperature in K

```

```

21 P1=P01*(T1/T01)^(r/(r-1))//The inlet pressure in bar
22 d1=(P1*10^5)/(R*T1)//The inlet density of air in kg/
    m^3
23 Dt=((4*m)/(3.14*d1*Ca))+(0.16^2))^(1/2)//The eye
    tip diameter in m
24 T=((T01)*((P^((r-1)/r))-1))/nc//The overall change
    in temperature in K
25 ssps=sp/nc//The product of slip factor and power
    factor
26 U2=(T*Cp/ssps)^(1/2)//Peripheral velocity of
    impeller top at exit in m/s
27 D2=(U2*60)/(3.14*N)//The impeller tip diameter in m
28 Uh=(3.14*Dh*N)/60//Peripheral velocity of eye hub in
    m/s
29 bh=atand(C1/Uh)//Blade angle at eye hub in degree
30 Ut=(3.14*Dt*N)/60//Peripheral velocity of eye tip in
    m/s
31 bt=atand(C1/Ut)//Blade angle at eye tip in degree
32 T03=T01+T//Temperature at the exit in K
33 T3=T03-((C3^2)/(2*Cp))//Exit static temperature in K
34 P3=(P*P01)*(T3/T03)^(r/(r-1))//Exit static pressure
    in bar
35 W=m*Cp*(T03-T01)*10^-6//Power required to drive the
    compressor in mW
36 //output
37 printf('(a)The main dimensions of the impeller are\n
    (1)Eye tip diameter is %3.3f m\n    (2)
    Impeller tip diameter is %3.3f m\n    (3)Blade
    angle at the eye hub is %3.2f degree\n
    Blade angle at the eye tip is %3.2f degree\n(b)
    (1)The static exit temperature is %3.1f K\n
    (2)The static exit pressure is %3.3f bar\n(c)
    The power required is %3.3f MW',Dt,D2,bh,bt,T3,P3
    ,W)

```

Scilab code Exa 3.6 AIR ANGLES

```
1  clc
2  clear
3  //input data
4  Dt=0.25//Tip diameter of the eye in m
5  Dh=0.1//Hub diameter of the eye in m
6  N=120//Speed of the compressor in rps
7  m=5//Mass of the air handled in kg/s
8  P01=102//Inlet stagnation pressure in kPa
9  T01=335//Inlet total temperature in K
10 r=1.4//The ratio of specific heats of air
11 R=287//The universal gas constant in J/kg.K
12 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
13
14 //calculations
15 d1=(P01*10^3)/(R*T01)//Density at the inlet of
    inducer in kg/m^3
16 Dm=(Dh+Dt)/2//Mean impeller diameter in m
17 b=(Dt-Dh)/2//Impeller blade height in m
18 C1=m/(d1*3.14*Dm*b)//Axial velocity component at the
    inlet in m/s
19 T11=T01-((C1^2)/(2*Cp))//Inlet temperature in K
20 P11=P01*(T11/T01)^(r/(r-1))//Inlet pressure in kPa
21 d11=(P11*10^3)/(R*T11)//Inlet density with mean
    impeller diameter an blade height in kg/m^3
22 C11=m/(d11*3.14*Dm*b)//Axial velocity component at
    inlet using mean blade values in m/s
23 T12=T01-((C1^2)/(2*Cp))//Initial temperature using
    modified axial velocity in K
24 P12=P01*(T12/T01)^(r/(r-1))//Initial pressure at
    inlet usin modified axial velocity in kPa
25 d12=(P12*10^3)/(R*T12)//Inlet density with modified
    axial velocity in kg/m^3
26 C12=m/(d12*3.14*Dm*b)//Axial velocity component at
    inlet using modified axial velocity in m/s
27 U1=3.14*Dm*N//Peripheral velocity of impeller at
```

```

    inlet in m/s
28 b1=atand(C12/U1)//The blade angle at impeller inlet
    in degree
29 W11=C12/sind(b1)//Relative velocity at inlet in m/s
30 Mr11=W11/(r*R*T12)^(1/2)//Initial relative mach
    number
31 Ca=C12//Axial velocity at IGV in m/s
32 W12=Ca//Relative velocity at inlet usin IGV in m/s
33 a1=atand(Ca/U1)//Air angle at IGV exit in degree
34 C13=Ca/sind(a1)//The velocity of flow of air at
    inlet in m/s
35 T13=T01-((C13^2)/(2*Cp))//Initial temperature using
    IGV in K
36 Mr12=W12/(r*R*T13)^(1/2)//Initial relative mach
    number using IGV
37
38 //output5
39 printf('(1)Without using IGV\n    (a)The air angle
    at inlet of inducer blade is %3.2f degree\n    (b
    )The inlet relative mach number is %3.3f\n(2)With
    using IGV\n    (a))The air angle at inlet of
    inducer blade is %3.2f degree\n    (b)The inlet
    relative mach number is %3.3f ',b1,Mr11,a1,Mr12)

```

Scilab code Exa 3.7 ABSOLUTE MACH NUMBER

```

1 clc
2 clear
3 //input data
4 Cr2=28//Radial component of velocity at impeller
    exit in m/s
5 ss=0.9//The slip factor
6 U2=350//The impeller tip speed in m/s
7 A=0.08//The impeller area in m^2
8 nc=0.9//Total head isentropic efficiency

```

```

 9 T01=288//The ambient air temperature in K
10 P01=1//The ambient air pressure in bar
11 r=1.4//The ratio of specific heats of air
12 R=287//The universal gas constant in J/kg.K
13 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
14
15 //calculations
16 Cx2=ss*U2//outlet absolute velocity of air in
    tangential direction in m/s
17 C2=((Cx2^2)+(Cr2^2))^(1/2)//Axial velocity component
    at the outlet in m/s
18 T=(ss*(U2^2))/Cp//Total change in temperature in K
19 T02=T+T01//The final ambient air temperature in K
20 T2=T02-((C2^2)/(2*Cp))//The actual final air
    temperature in K
21 M2=(C2)/(r*R*T2)^(1/2)//Exit absolute mach number
22 P=((1+(ss*T/T01))^(r/(r-1)))//The overall pressure
    ratio
23 P02=P*P01//The final ambient pressure in bar
24 P2=P02*(T2/T02)^(r/(r-1))//The absolute final
    pressure in bar
25 d2=(P2*10^5)/(R*T2)//The final density of air at
    exit in kg/m^3
26 m=d2*A*Cr2//The mass flow rate in kg/s
27
28 //output
29 printf('(a)The exit absolute mach number is %3.4f\n(
    b)The mass flow rate is %3.4f kg/s',M2,m)

```

Scilab code Exa 3.8 MAXIMUM MACH NUMBER

```

1 clc
2 clear
3 //input data

```



```

4 Dh=0.175//Hub diameter of the eye in m
5 Dt=0.3125//Tip diameter of the eye in m
6 m=20//Mass of the air handled in kg/s
7 N=16000//Speed of the compressor in rpm
8 T01=288//The ambient air temperature in K
9 P01=100//The ambient air pressure in kPa
10 Ca=152//The axial component of inlet velocity of eye
    in m/s
11 r=1.4//The ratio of specific heats of air
12 R=287//The universal gas constant in J/kg.K
13 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
14
15
16 //calculations
17 A=(3.14/4)*((Dt^2)-(Dh^2))//Annulus area of flow at
    the impeller eye in m^2
18 Ut=(3.1415*Dt*N)/60//Impeller eye tip speed in m/s
19 Uh=(3.1415*Dh*N)/60//Impeller eye hub speed in m/s
20 a1=90-20//Blade angle at inlet in degree
21 C1=Ca/sind(a1)//The air entry velocity into the
    impeller eye in m/s
22 T1=T01-((C1^2)/(2*Cp))//The actual inlet air
    temperature in K
23 P1=P01*(T1/T01)^(r/(r-1))//The actual inlet air
    pressure in kPa
24 d1=P1/(R*T1)//The initial density of air at entry in
    kg/m^3
25 b1h=atand(Ca/(Uh-(Ca/tand(a1))))//Impeller angle at
    the hub in degree
26 b1t=atand(Ca/(Ut-(Ca/tand(a1))))//Impeller angle at
    the tip of eye in degree
27 Cx1=Ca/tand(a1)//Inlet absolute velocity of air in
    tangential direction in m/s
28 Wx1=Ut-Cx1//Relative whirl component of velocity at
    inlet in m/s
29 W1=((Wx1^2)+(Ca^2))^(1/2)//Relative velocity at
    inlet in m/s

```

```

30 Mr1=W1/(r*R*T1)^(1/2)//Maximum mach number at the
    eye
31
32 //output
33 printf('(a)\n    (1)The impeller eye tip speed is %3
    .2f m/s\n    (2)The impeller eye hub speed is %3
    .2f m/s\n    (3)The impeller angle at the hub is
    %i degree\n    (4)Impeller angle at the tip of
    eye is %3.2f degree\n(b)The maximum mach number
    at the eye is %3.2f',Ut,Uh,b1h,b1t,Mr1)

```

Scilab code Exa 3.9 MASS AND VOLUME RATE

```

1  clc
2  clear
3  //input data
4  P1=100//The air in take pressure in kPa
5  T1=309//The air in take temperature in K
6  H=0.750//Pressure head developed in mm W.G
7  P=33//Input power to blower in kW
8  nb=0.79//Blower efficiency
9  nm=0.83//Mechanical efficiency
10 r=1.4//The ratio of specific heats of air
11 R=287//The universal gas constant in J/kg.K
12 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
13 g=9.81//Acceleration due to gravity in m/s^2
14 dw=1000//Density of water in kg/m^3
15
16 //calculations
17 d=(P1*10^3)/(R*T1)//Density of air flow at inlet in
    kg/m^3
18 dP=dw*g*H//Total change in pressure in N/m^2
19 IW=dP/d//Ideal work done in J/kg
20 Wm=IW/nb//Actual work done per unit mass flow rate

```

```

    in J/kg
21 W=P*nm//Actual power input in kW
22 m=(W*10^3)/Wm//Mass flow rate in kg/s
23 Q=m/d//Volume flow rate in m^3/s
24 P2=P1+(dP/10^3)//The exit pressure of air in kPa
25 T2=T1+(Wm/(Cp))//The exit temperature of air in K
26
27 //output
28 printf('(a)The mass flow rate of air is %3.3f kg/s\n
    (b)The volume flow rate of air is %3.2f m^3/s\n(c
    )\n    (1)The exit pressure of air is %3.2f kPa\n
    (2)The exit temperature of air is %3.2f K',m,
    Q,P2,T2)

```

Scilab code Exa 3.10 FAN EFFICIENCY

```

1  clc
2  clear
3  //input data
4  H=0.075//Pressure developed by a fan in m W.G
5  D2=0.89//The impeller diameter in m
6  N=720//The running speed of the fan in rpm
7  b22=39//The blade air angle at the tip in degree
8  b2=0.1//The width of the impeller in m
9  Cr=9.15//The constant radial velocity in m/s
10 d=1.2//Density of air in kg/m^3
11 r=1.4//The ratio of specific heats of air
12 R=287//The universal gas constant in J/kg.K
13 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
14 g=9.81//Acceleration due to gravity in m/s^2
15 dw=1000//Density of water in kg/m^3
16
17 //calculations
18 IW=(dw*g*H)/d//Ideal work done in J/kg

```

```

19 U2=(3.1415*D2*N)/60//The impeller tip speed in m/s
20 Wx2=Cr/tand(b22)//Relative whirl component of
    velocity at outlet in m/s
21 Cx2=U2-(Wx2)//Outlet absolute velocity of air in
    tangential direction in m/s
22 Wm=U2*Cx2//Actual work done per unit mass flow rate
    in J/kg
23 nf=IW/Wm//Fan efficiency
24 Q=3.1415*D2*b2*Cr//The discharge of the air by fan
    in m3/s
25 m=d*Q//Mass flow rate of the air by the fan in kg/s
26 W=m*Wm*10-3//Power required to drive the fan in kW
27 R=1-(Cx2/(2*U2))//Stage reaction of the fan
28 sp=2*Cx2/U2//The pressure coefficient
29
30 //output
31 printf('(a)The fan efficiency is %3.3f\n(b)The
    Discharge of air by the fan is %3.3f m3/s\n(c)
    The power required to drive the fan is %3.4f kW\n
    (d)The stage reaction of the fan is %3.4f\n(e)The
    pressure coefficient of the fan is %3.3f',nf,Q,W
    ,R,sp)

```

Scilab code Exa 3.11 FAN EFFICIENCY AND PRESSURE COEFFICIENT

```

1 clc
2 clear
3 //input data
4
5 b22=30//The blade air angle at the tip in degrees
6 D2=0.466//The impeller diameter in m
7 Q=3.82//The discharge of the air by fan in m3/s
8 m=4.29//Mass flow rate of the air by the fan in kg/s
9 H=0.063//Pressure developed by a fan in m W.G
10 pi2=0.25//Flow coefficient at impeller exit

```

```

11 W=3//Power supplied to the impeller in kW
12 r=1.4//The ratio of specific heats of air
13 R=287//The universal gas constant in J/kg.K
14 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
15 g=9.81//Acceleration due to gravity in m/s^2
16 dw=10^3//Density of water in kg/m^3
17
18 //calculations
19 IW=Q*dw*g*H*(10^-3)//Ideal work done in kW
20 nf=IW/W//Fan efficiency
21 U2=((W*10^3)/m)/(1-(pi^2/tand(b22)))^(1/2)//The
    impeller tip speed in m/s
22 Cr2=pi*U2//The radial velocity at exit in m/s
23 Cx2=U2-(Cr2/tand(b22))//Outlet absolute velocity of
    air in tangential direction in m/s
24 sp=2*Cx2/U2//Pressure coefficient of the fan
25 R=1-(Cx2/(2*U2))//Degree of reaction of the fan
26 N=(U2*60)/(3.141592*D2)//Rotational speed of the fan
    in rpm
27 b2=Q/(3.14*D2*Cr2)//Impeller width at the exit in m
28
29 //output
30 printf('(a)The fan efficiency is %3.3f\n(b)The
    pressure coefficient is %3.3f\n(c)The degree of
    reaction of the fan is %3.3f\n(d)The rotational
    speed of the fan is %3.1f rpm\n(e)The impeller
    width at exit is %3.3f m',nf,sp,R,N,b2)

```

Scilab code Exa 3.12 POWER INPUT AND ANGLES

```

1 clc
2 clear
3 //input data
4 N=3000//The running speed of the blower in rpm

```

```

5 D2=0.75//The impeller diameter in m
6 Cr2=57//The radial velocity at exit in m/s
7 Cx1=0//Inlet absolute velocity of air in tangential
  direction in m/s
8 DR=0.58//Degree of reaction of the blower
9 nc=0.75//Total-to-total efficiency
10 r=1.4//The ratio of specific heats of air
11 R=287//The universal gas constant in J/kg.K
12 Cp=1.005//The specific heat of air at constant
  pressure in J/kg.K
13 T01=298//The inlet stagnation temperature in K
14 P01=1*101.325//The inlet stagnation pressure in kPa
15
16 //calculations
17 U2=(3.1415*D2*N)/60//The impeller tip speed in m/s
18 Cx2=2*(1-DR)*U2//Outlet absolute velocity of air in
  tangential direction in m/s
19 Wx2=U2-Cx2//Relative whirl component of velocity at
  outlet in m/s
20 b22=atand(Cr2/Wx2)//The blade air angle at the tip
  in degree
21 Wm=U2*Cx2*10^-3//Actual work done per unit mass flow
  rate when Cx1=0 in kW/(kg/s)
22 T=Wm/Cp//Total change in temperature in blower in K
23 P=(1+(nc*(T/T01)))^(r/(r-1))//Total pressure ratio
  in the blower
24 P02=P*P01//The outlet stagnation pressure from
  blower in kPa
25
26 //output
27 printf('(a)The exit blade angle is %3.1f degree\n(b)
  The power input to the blower is %3.3f kW/(kg/s)\n(c)The exit stagnation pressure is %3.2f kPa',
  b22,Wm,P02)

```

Scilab code Exa 3.13 STAGE PRESSURE RISE

```
1  clc
2  clear
3  //input data
4  D1=0.18//The impeller inner diameter in m
5  D2=0.2//The impeller outer diameter in m
6  C1=21//The absolute velocity at the entry in m/s
7  C2=25//The absolute velocity at the exit in m/s
8  W1=20//The relative velocity at the entry in m/s
9  W2=17//The relative velocity at the exit in m/s
10 N=1450//The running speed of the fan in rpm
11 m=0.5//The mass flow rate of the air in fan in kg/s
12 nm=0.78//The motor efficiency of the fan
13 d=1.25//The density of the air in kg/m^3
14 r=1.4//The ratio of specific heats of air
15 R=287//The universal gas constant in J/kg.K
16 Cp=1.005//The specific heat of air at constant
    pressure in J/kg.K
17
18 //calculations
19 U1=(3.14*D1*N)/60//Peripheral velocity of impeller
    at inlet in m/s
20 U2=(3.14*D2*N)/60//The impeller tip speed in m/s
21 dH=((U2^2)-(U1^2))/2+((W1^2)-(W2^2))/2//The
    actual total rise in enthalpy in kJ/kg
22 dH0=dH+((C2^2)-(C1^2))/2//The stage total
    isentropic rise in enthalpy in kJ/kg
23 dP0=d*dH0//The stage total pressure rise in N/m^2
24 dP=d*dH//The actual total rise in pressure in N/m^2
25 R=dP/dP0//The degree of reaction of the fan
26 W=m*(dH0)//The work done by the fan per second in W
27 P=W/nm//The power input to the fan in W
28
29 //output
30 printf('(a)The stage total pressure rise is %3.1f N/
    m^2\n(b)The degree of reaction of the fan is %3.3
    f\n(c)The power input to the fan is %3.1f W',dP0,
```

R,P)

Scilab code Exa 3.14 VOLUME FLOW RATE

```
1  clc
2  clear
3  //input data
4  dH=0.14//Rise in static pressure of the air by fan
      in m of water
5  N=650//The running speed of the fan in rpm
6  P=85*0.735//Power consumed by the fan in kW
7  H1=0.75//The static pressure of the air at the fan
      in m of Hg
8  T1=298//The static pressure at the fan of air in K
9  m=260//Mass flow rate of air in kg/min
10 dHg=13590//Density of mercury in kg/m^3
11 dw=1000//Density of water in kg/m^3
12 g=9.81//Acceleration due to gravity in m/s^2
13 R=287//The universal gas constant in J/kg.K
14
15 //calculations
16 P1=dHg*g*H1*10^-3//The inlet static pressure in kPa
17 dP=dw*g*dH*10^-3//The total change in static
      pressures at inlet and outlet in kPa
18 P2=P1+dP//The exit static pressure in kPa
19 d1=(P1*10^3)/(R*T1)//The inlet density of the air in
      kg/m^3
20 Q=m/d1//The volume flow rate of air in fan in m^3/
      min
21
22 //output
23 printf('(a)The exit static pressure of air in the
      fan is %3.2f kPa\n(b)The volume flow rate of the
      air is %3.1f m^3/min',P2,Q)
```

Chapter 4

AXIAL FLOW COMPRESSORS AND FANS

Scilab code Exa 4.1 PRESSURE RISE

```
1  clc
2  clear
3  //input data
4  b1=60//The angle made by the relative velocity
    vector at exit in degree
5  db=30//The turning angle in degree
6  dCx=100//The change in the tangential velocities in
    m/s
7  DR=0.5//Degree of reaction
8  N=36000//The speed of the compressor in rpm
9  D=0.14//Mean blade diameter in m
10 P1=2//Inlet pressure in bar
11 T1=330//Inlet temperature in K
12 b=0.02//Blade height in m
13 R=287//The universal gas constant in J/kg.K
14 Cp=1.005//The specific heat of air at constant
    pressure in kJ/kg.K
15 r=1.4//The ratio of specific heats of air
16
```

```

17 //calculations
18 b2=b1-db//The angle made by the relative velocity
    vector at entry in degree
19 a1=b2//Air flow angle at exit in degree as DR=0.5
20 U=(3.1415*D*N)/60//The blade mean speed in m/s
21 T2=((U*dCx)/(Cp*1000))+T1//The exit air temperature
    in K
22 P2=P1*(T2/T1)^(r/(r-1))//The exit air pressure in
    bar
23 dP=P2-P1//The pressure rise in bar
24 Ca=(2*U*DR)/(tand(b2)+tand(b1))//The axial velocity
    in m/s
25 A1=3.1415*D*b//The inlet flow area in m^2
26 d1=(P1*10^5)/(R*T1)//The inlet air density in kg/m^3
27 m=d1*A1*Ca//The amount of air handled in kg/s
28 W=m*Cp*(T2-T1)//The power developed in kW
29
30 //output
31 printf('(a)Air flow angle at exit is %3i degree\n(b)
    The pressure rise is %3.2f bar\n(c)The amount of
    air handled is %3.2f kg/s\n(d)The power developed
    is %3.1f kW',a1,dP,m,W)

```

Scilab code Exa 4.2 TOTAL HEAD ISENTROPIC EFFICIENCY

```

1 clc
2 clear
3 //input data
4 P01=1//Atmospheric pressure at inlet in bar
5 T01=291//Atmospheric temperature at inlet in K
6 T02=438//Total head temperature in delivery pipe in
    K
7 P02=3.5//Total head pressure in delivery pipe in bar
8 P2=3//Staic pressure in delivery pipe in bar
9 R=287//The universal gas constant in J/kg.K

```

```

10 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
11 r=1.4//The ratio of specific heats of air
12
13 //calculations
14 T02s=T01*(P02/P01)^((r-1)/r)//Total isentropic head
    temperature in delivery pipe in K
15 nc=(T02s-T01)/(T02-T01)//Total head isentropic
    efficiency
16 np=((log10(P02/P01))/((r/(r-1))*(log10(T02/T01))))//
    Polytropic efficiency
17 T2=T02*(P2/P02)^((r-1)/r)//Static temperature in
    delivery pipe in K
18 C2=(2*Cp*(T02-T2))^(1/2)//The air velocity in
    delivery pipe in m/s
19
20 //output
21 printf('(a)Total head isentropic efficiency is %3.3f
    \n(b)Polytropic efficiency %3.3f\n(c)The air
    velocity in delivery pipe is %3.2f m/s',nc,np,C2)

```

Scilab code Exa 4.3 POWER REQUIRED

```

1 clc
2 clear
3 //input data
4 N=8//Number of stages
5 Po=6//Overall pressure ratio
6 T01=293//Temperature of air at inlet in K
7 nc=0.9//Overall isentropic efficiency
8 DR=0.5//Degree of reaction
9 U=188//Mean blade speed in m/s
10 Ca=100//Constant axial velocity in m/s
11 R=287//The universal gas constant in J/kg.K
12 Cp=1005//The specific heat of air at constant

```

```

    pressure in J/kg.K
13 r=1.4//The ratio of specific heats of air
14
15 //calculations
16 T0n1s=T01*(Po)^((r-1)/r)//The isentropic temperature
    of air leaving compressor stage in K
17 T0n1=((T0n1s-T01)/nc)+T01//The temperature of air
    leaving compressor stage in K
18 dta2ta1=(Cp*(T0n1-T01))/(N*U*Ca)//The difference
    between tan angles of air exit and inlet
19 sta1tb1=U/Ca//The sum of tan of angles of air inlet
    and the angle made by the relative velocity
20 b1=atand((dta2ta1+sta1tb1)/2)//The angle made by the
    relative velocity vector at exit in degree as
    the DR=1 then a2=b1
21 a1=atand(tand(b1)-dta2ta1)//Air flow angle at exit
    in degree
22 W=Cp*(T0n1-T01)*10^-3//Power required per kg of air/
    s in kW
23
24 //output
25 printf('(a)Power required is %3.2f kW\n(b)\n      (1)
    Air flow angle at exit is %3i degree \n      (2)The
    angle made by the relative velocity vector at
    exit is %3i degree',W,a1,b1)

```

Scilab code Exa 4.4 PRESSURE AT OUTLET

```

1  clc
2  clear
3  //input data
4  W=4.5//Power absorbed by the compressor in MW
5  m=20//Amount of air delivered in kg/s
6  P01=1//Stagnation pressure of air at inlet in bar
7  T01=288//Stagnation temperature of air at inlet in K

```

```

8 np=0.9//Polytropic efficiency of compressor
9 dT0=20//Temperature rise in first stage in K
10 R=287//The universal gas constant in J/kg.K
11 Cp=1.005//The specific heat of air at constant
    pressure in kJ/kg.K
12 r=1.4//The ratio of specific heats of air
13
14
15 //calculations
16 T02=T01+dT0//Stagnation temperature of air at outlet
    in K
17 T0n1=((W*10^3)/(m*Cp))+T01//The temperature of air
    leaving compressor stage in K
18 P0n1=P01*(T0n1/T01)^((np*r)/(r-1))//Pressure at
    compressor outlet in bar
19 P1=(T02/T01)^((np*r)/(r-1))//The pressure ratio at
    the first stage
20 N=((log10(P0n1/P01)/log10(P1)))//Number of stages
21 T0n1T01=(P0n1/P01)^((r-1)/(np*r))//The temperature
    ratio at the first stage
22 T0n1sT01=(P0n1/P01)^((r-1)/r)//The isentropic
    temperature ratio at the first stage
23 nc=((T0n1sT01-1)/(T0n1T01-1))//The overall
    isentropic efficiency
24
25 //output
26 printf('(a)Pressure at compressor outlet is %3.2f
    bar\n(b)Number of stages is %3.f\n(c)The overall
    isentropic efficiency is %3.3f',P0n1,N,nc)

```

Scilab code Exa 4.5 NUMBER OF STAGES

```

1 clc
2 clear
3 //input data

```

```

4 DR=0.5//Degree of reaction
5 b1=44//Blade inlet angle in degree
6 b2=13//Blade outlet angle in degree
7 Po=5//The pressure ratio produced by the compressor
8 nc=0.87//The overall isentropic efficiency
9 T01=290//Inlet temperature in K
10 U=180//Mean blade speed in m/s
11 l=0.85//Work input factor
12 R=0.287//The universal gas constant in kJ/kg.K
13 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
14 r=1.4//The ratio of specific heats of air
15
16 //calculations
17 a2=b1//Air flow angle at entry in degree as DR=0.5
18 a1=b2//Air flow angle at exit in degree as DR=0.5
19 T0n1s=T01*(Po)^((r-1)/r)//The isentropic temperature
    of air leaving compressor stage in K
20 T0n1=((T0n1s-T01)/nc)+T01//The temperature of air
    leaving compressor stage in K
21 Ca=U/(tand(b2)+tand(b1))//The axial velocity in m/s
22 N=((Cp*(T0n1-T01))/(l*U*Ca*(tand(a2)-tand(a1))))//
    The number of stages
23 ds=(Cp*(10^-3)*log(T0n1/T01))-(R*log(Po))//Change in
    entropy in kJ/kg.K
24
25 //output
26 printf('(a)The number of stages are %3.f\n(b)The
    change in entropy is %3.3f kJ/kg-K',N,ds)

```

Scilab code Exa 4.6 DEGREE OF REACTION

```

1 clc
2 clear
3 //input data

```

```

4 D=0.6//Mean diameter of compressor in m
5 N=15000//Running speed of the compressor in rpm
6 dT=30//Actual overall temperature raise in K
7 PR=1.3//Pressure ratio of all stages
8 m=57//Mass flow rate of air in kg/s
9 nm=0.86//Mechanical efficiency
10 T1=308//Initial temperature in K
11 T2=328//Temperature at rotor exit in K
12 r=1.4//The ratio of specific heats of air
13 Cp=1.005//The specific heat of air at constant
    pressure in kJ/kg.K
14
15 //calculations
16 W=m*Cp*dT//Work done in kW
17 P=W/nm//Power required in kW
18 ns=((T1*((PR^((r-1)/r))-1))/(dT))//Stage efficiency
19 R=(T2-T1)/(dT)//Reaction ratio
20
21 //output
22 printf('(a)Power required to drive the compressor is
    %3.3f kW\n(b)The stage efficiency is %3.4f\n(c)
    The degree of reaction is %3.2f',P,ns,R)

```

Scilab code Exa 4.7 COMPRESSOR SPEED

```

1 clc
2 clear
3 //input data
4 Pr=2//The pressure ratio of first stage
5 P1=1.01//The inlet pressure in bar
6 T1=303//The inlet temperature in K
7 nc=0.83//Overall efficiency of the compressor
8 pi=0.47//The flow coefficient
9 dCxCa=0.5//Ratio of change of whirl velocity to
    axial velocity

```

```

10 D=0.5//Mean diameter in m
11 r=1.4//The ratio of specific heats of air
12 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
13
14 //calculations
15 dT=T1*((Pr^((r-1)/r))-1)/nc//The Actual overall
    temperature raise in K
16 dCx=dCxCa*pi//The change of whirl velocity in m/s
17 U=(dT*Cp/dCx)^(1/2)//The mean blade speed in m/s
18 N=(U*60)/(3.1415*D)//Speed at which compressor runs
    in rpm
19 Cx2=(U+(dCx*U))/2//The whirl velocity at exit in m/s
20 Cx1=U-Cx2//The whirl velocity at entry in m/s
21 Ca=pi*U//The axial velocity in m/s
22 C1=((Ca^2)+(Cx1^2))^(1/2)//The inlet absolute
    velocity of air in m/s
23
24 //output
25 printf('(a)The compressor speed is %3i rpm\n(b)The
    absolute velocity of air is %3.2f m/s',N,C1)

```

Scilab code Exa 4.8 TIP RADIUS AND ANGLES

```

1 clc
2 clear
3 //input data
4 N=9000//The rotational speed in rpm
5 dT0=20//The stagnation temperature rise in K
6 DhDt=0.6//The hub to tip ratio
7 l=0.94//The work donee factor
8 ns=0.9//The isentropic efficiency of the stage
9 C1=150//Inlet velocity in m/s
10 P01=1//The ambient pressure in bar
11 T01=300//The ambient temperature in K

```



```

12 Mr1=0.92//Mach number relative to tip
13 R=287//The universal gas constant in J/kg.K
14 Cp=1005//The specific heat of air at constant
    pressure in kJ/kg.K
15 r=1.4//The ratio of specific heats of air
16 g=9.81//Acceleration due to gravity in m/s^2
17
18 //calculations
19 T1=T01-((C1^2)/(2*Cp))//The inlet temperature in K
20 W1=Mr1*(r*R*T1)^(1/2)//The relative velocity at
    entry in m/s
21 b11=acosd((C1)/(W1))//The inlet rotor angle at tip
    in degree
22 Ut=W1*sind(b11)//Tip speed in m/s
23 rt=(Ut*60)/(2*3.1415*N)//The tip radius in m
24 b12=atand((tand(b11))-((Cp*dT0)/(1*Ut*C1)))//The
    outlet rotor angle at tip in degree
25 P1=P01*(T1/T01)^(r/(r-1))//The inlet pressure in bar
26 d1=(P1*10^5)/(R*T1)//The density of air at the entry
    in kg/m^3
27 Dt=2*rt//The tip diameter in m
28 Dh=DhDt*(Dt)//The hub diameter in m
29 A1=(3.141/4)*((Dt^2)-(Dh^2))//The area of cross
    section at the entry in m^2
30 rm=((Dt/2)+(Dh/2))/2//The mean radius in m
31 h=((Dt/2)-(Dh/2))//The height of the blade in m
32 A=2*3.1415*rm*h//The area of the cross section in m
    ^2
33 m=d1*A*C1//The mass flow rate in kg/s
34 P03P01=(1+((ns*dT0)/T01))^(r/(r-1))//The stagnation
    pressure ratio
35 P=m*Cp*dT0*10^-3//The power required in kW
36 Uh=(3.1415*Dh*N)/60//The hub speed in m/s
37 b21=atand(Uh/C1)//The rotor air angle at entry in
    degree
38 b22=atand(tand(b21)-((Cp*dT0)/(1*Uh*C1)))//The rotor
    air angle at exit in degree
39

```

```

40 //output
41 printf('(a)\n      (1)The tip radius is %3.3f m\n
      (2)The rotor entry angle at tip section is %3.1f
      degree\n      (3)The rotor exit angle at tip
      section is %3.2f degree\n(b)Mass flow entering
      the stage is %3.3f kg/s\n(c)\n      (1)The
      stagnation pressure ratio is %3.3f\n      (2)The
      power required is %3.2f kW\n(d)\n      (1)The rotor
      air angle at entry is %3.2f degree\n      (2)The
      rotor air angle at exit is %3.2f degree',rt,b11,
      b12,m,P03P01,P,b21,b22)

```

Scilab code Exa 4.9 STAGE AIR AND BLADE ANGLES

```

1  clc
2  clear
3  //input data
4  Ur=150//The blade root velocity in m/s
5  Um=200//The mean velocity in m/s
6  Ut=250//The tip velocity in m/s
7  dT0=20//The total change in temperature in K
8  Ca=150//The axial velocity in m/s
9  l=0.93//The work done factor
10 Rm=0.5//Reaction at mean radius
11 R=287//The universal gas constant in J/kg.K
12 Cp=1005//The specific heat of air at constant
      pressure in J/kg.K
13 r=1.4//The ratio of specific heats of air
14
15 //calculations
16 dtb1tb2=((Cp*dT0)/(l*Um*Ca))//The difference between
      the tangent angles of blade angles at mean
17 atb1tb2=((2*Rm*Um)/(Ca))//The sum of the tangent
      angles of blade angles at mean
18 b1m=atand((atb1tb2+dtb1tb2)/2)//The inlet blade

```

```

    angle in degree at mean
19 a2m=b1m//The exit air angle in degree as the
    Reaction at mean radius is 0.5
20 b2m=atand(tand(b1m)-dtb1tb2)//The exit blade angle
    in degree at mean
21 a1m=b2m//The inlet air angle in degree as the
    reaction at mean radius is 0.5
22 rmrh=Um/Ur//The ratio of radii of mean and root
    velocities at hub
23 a1h=atand(tand(a1m)*(rmrh))//The inlet air angle in
    degree at hub
24 b1h=atand((Ur/Ca)-(tand(a1h)))//The inlet blade
    angle in degree at hub
25 a2h=atand(tand(a2m)*(rmrh))//The outlet air angle in
    degree at hub
26 b2h=atand((Ur/Ca)-(tand(a2h)))//The outlet blade
    angle in degree at hub
27 Rh=((Ca*(tand(b1h)+tand(b2h)))/(2*Ur))//The degree
    of reaction at the hub
28 rmrt=Um/Ut//The ratio of radii of mean and tip
    velocities at tip
29 a1t=atand(tand(a1m)*(rmrt))//The inlet air angle in
    degree at tip
30 b1t=atand((Ut/Ca)-(tand(a1t)))//The inlet blade
    angle in degree at tip
31 a2t=atand(tand(a2m)*(rmrt))//The outlet air angle in
    degree at tip
32 b2t=atand((Ut/Ca)-(tand(a2t)))//The outlet blade
    angle in degree at tip
33 Rt=((Ca*(tand(b1t)+tand(b2t)))/(2*Ut))//The degree
    of reaction at tip
34
35 //output
36 printf('(a)At the mean\n      (1)The inlet blade angle
    is %3.2f degree\n      (2)The inlet air angle is
    %3.2f degree\n      (3)The outlet blade angle is %3
    .2f degree\n      (4)The outlet air angle is %3.2f
    degree\n      (5)Degree of reaction is %3.1f \n(b)

```

```

At the root\n      (1)The inlet blade angle is %3.2
f degree\n      (2)The inlet air angle is %3.2 f
degree\n      (3)The outlet blade angle is %3.2 f
degree\n      (4)The outlet air angle is %3.2 f
degree\n      (5)Degree of reaction is %3.3 f\n(c)At
the tip\n      (1)The inlet blade angle is %3.2 f
degree\n      (2)The inlet air angle is %3.2 f
degree\n      (3)The outlet blade angle is %3.2 f
degree\n      (4)The outlet air angle is %3.2 f
degree\n      (5)Degree of reaction is %3.3 f\n',b1m
,a1m,b2m ,a2m ,Rm ,b1h ,a1h ,b2h ,a2h ,Rh ,b1t ,a1t ,b2t ,
a2t ,Rt)

```

Scilab code Exa 4.10 AIR AND BLADE ANGLES

```

1  clc
2  clear
3  //input data
4  Uh=150//The blade root velocity in m/s
5  Um=200//The mean velocity in m/s
6  Ut=250//The tip velocity in m/s
7  dT0=20//The total change in temperature in K
8  Ca1m=150//The axial velocity in m/s
9  l=0.93//The work done factor
10 Rm=0.5//Reaction at mean radius
11 N=9000//Rotational speed in rpm
12 R=287//The universal gas constant in J/kg.K
13 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
14 r=1.4//The ratio of specific heats of air
15
16 //calculations
17 dtb1tb2=((Cp*dT0)/(l*Um*Ca1m))//The difference
    between the tangent angles of blade angles at
    mean

```

```

18 atb1tb2=((2*Rm*Um)/(Ca1m))//The sum of the tangent
    angles of blade angles at mean
19 b1m=atand((atb1tb2+dtb1tb2)/2)//The inlet blade
    angle in degree at mean
20 a2m=b1m//The exit air angle in degree as the
    Reaction at mean radius is 0.5
21 b2m=atand(tand(b1m)-dtb1tb2)//The exit blade angle
    in degree at mean
22 a1m=b2m//The inlet air angle in degree as the
    reaction at mean radius is 0.5
23 Dh=(Uh*60)/(3.141*N)//Hub diameter in m
24 Dm=(Um*60)/(3.141*N)//Mean diameter in m
25 Cx1m=Ca1m*tand(a1m)//The whirl velocity at inlet at
    mean in m/s
26 Cx2m=Ca1m*tand(a2m)//The whirl velocity at exit at
    mean in m/s
27 Cx1h=(Cx1m*(Dh/2)/(Dm/2))//The whirl velocity at
    inlet at hub in m/s
28 Cx2h=(Cx2m*(Dh/2)/(Dm/2))//The whirl velocity at
    exit at hub in m/s
29 K1=(Ca1m^2)+(2*(Cx1m^2))//Sectional velocity in m/s
30 Ca1h=((K1)-(2*(Cx1h^2)))^(1/2)//The axial velocity
    at hub inlet in (m/s)^2
31 w=(2*3.141*N)/60//Angular velocity of blade in rad/s
32 K2=(Ca1m^2)+(2*(Cx2m^2))-(2*((Cx2h/(Dh/2))-(Cx1m/(Dm
    /2))))*(w*(Dm/2)^(2))//Sectional velocity in (m/s
    )^2
33 Ca2h=(K2-(2*Cx2h^2)+(2*((Cx2h/(Dh/2))-(Cx1h/(Dh/2))))
    *(w*(Dh/2)^(2)))^(1/2)//Axial velocity at hub
    outlet in m/s
34 a1h=atand(Cx1h/Ca1h)//Air angle at inlet in hub in
    degree
35 b1h=atand((Uh-Cx1h)/Ca1h)//Blade angle at inlet in
    hub in degree
36 a2h=atand(Cx2h/Ca2h)//Air angle at exit in hub in
    degree
37 b2h=atand((Uh-Cx2h)/Ca2h)//Blade angle at exit in
    hub in degree

```

```

38 W1=Ca1h/cosd(b1h)//Relative velocity at entry in hub
    in m/s
39 W2=Ca2h/cosd(b2h)//Relative velocity at exit in hub
    in m/s
40 Rh=((W1^2)-(W2^2))/(2*Uh*(Cx2h-Cx1h))//The degree of
    reaction at hub
41 Dt=(Ut*60)/(3.141*N)//Tip diameter in m
42 Cx1t=(Cx1m*(Dt/2)/(Dm/2))//The whirl velocity at
    inlet at tip in m/s
43 Cx2t=(Cx2m*(Dt/2)/(Dm/2))//The whirl velocity at
    exit at tip in m/s
44 Ca1t=(K1-(2*Cx1t^2))^(1/2)//Axial velocity at tip
    inlet in m/s
45 Ca2t=(K2-(2*Cx2t^2)+(2*((Cx2t/(Dt/2))-(Cx1t/(Dt/2))))
    *(w*(Dt/2)^(2)))^(1/2)//Axial velocity at tip
    outlet in m/s
46 a1t=atand(Cx1t/Ca1t)//Air angle at inlet in tip in
    degree
47 b1t=atand((Ut-Cx1t)/Ca1t)//Blade angle at inlet in
    tip in degree
48 a2t=atand(Cx2t/Ca2t)//Air angle at exit in tip in
    degree
49 b2t=atand((Ut-Cx2t)/Ca2t)//Blade angle at exit in
    tip in degree
50 W1=Ca1t/cosd(b1t)//Relative velocity at entry in tip
    in m/s
51 W2=Ca2t/cosd(b2t)//Relative velocity at exit in tip
    in m/s
52 Rt=((W1^2)-(W2^2))/(2*Ut*(Cx2t-Cx1t))//The degree of
    reaction at tip
53
54 //output
55 printf('(a)At the mean\n    (1)The inlet blade angle
    is %3.2f degree\n    (2)The inlet air angle is
    %3.2f degree\n    (3)The outlet blade angle is %3
    .2f degree\n    (4)The outlet air angle is %3.2f
    degree\n    (5)Degree of reaction is %3.1f \n(b)
    At the root\n    (1)The inlet blade angle is %3.2

```

```

f degree\n      (2)The inlet air angle is %3.1f
degree\n      (3)The outlet blade angle is %3.1f
degree\n      (4)The outlet air angle is %3.1f
degree\n      (5)Degree of reaction is %3.1f\n(c)At
the tip\n      (1)The inlet blade angle is %3.2f
degree\n      (2)The inlet air angle is %3.2f
degree\n      (3)The outlet blade angle is %3.2f
degree\n      (4)The outlet air angle is %3.2f
degree\n      (5)Degree of reaction is %3.1f\n',b1m
,a1m ,b2m ,a2m ,Rm ,b1h ,a1h ,b2h ,a2h ,Rh ,b1t ,a1t ,b2t ,
a2t ,Rt)

```

Scilab code Exa 4.11 TOTAL PRESSURE OF AIR

```

1  clc
2  clear
3  //input data
4  N=3600//Running speed of blower in rpm
5  Dt=0.2//The rotor tip diameter in m
6  Dh=0.125//The rotor hub diameter in m
7  P1=1.013//The atmospheric pressure in bar
8  T1=298//The atmospheric temperature in K
9  m=0.5//Mass flow rate of air in kg/s
10 db=20//The turning angle of the rotor in degree
11 b1=55//The inlet blade angle in degree
12 R=287//The universal gas constant in J/kg.K
13 nc=0.9//Total-to-total efficiency
14 P=0.25//Total pressure drop across the intake in cm
    of water
15 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
16 r=1.4//The ratio of specific heats of air
17 g=9.81//Acceleration due to gravity in m/s^2
18 ns=0.75//The stator efficiency
19 dw=1000//Density of water in kg/m^3

```

```

20
21 //calculations
22 d1=(P1*10^5)/(R*T1)//The density of air at inlet in
    kg/m^3
23 A=(3.141/4)*((Dt^2)-(Dh^2))//The area of flow in m^2
24 Ca=m/(d1*A)//The axial velocity of air in m/s
25 U=((3.141*(Dt+Dh)*N)/(2*60))//Mean rotor blade
    velocity in m/s
26 b2=b1-db//The outlet blade angle in degree
27 Cx2=U-(Ca*tand(b2))//The whirl velocity at exit in m
    /s
28 Cx1=0//The whirl velocity at entry in m/s as flow at
    inlet is axial
29 dh0r=U*(Cx2-Cx1)//The actual total enthalpy rise
    across the rotor in J/kg
30 dh0sr=nc*dh0r//The isentropic total enthalpy rise
    across the rotor in J/kg
31 dP0r=(d1*dh0sr)*((10^-1)/(g))//The total pressure
    rise across the rotor in cm of water
32 P0=dP0r-P//Stagnation pressure at the rotor exit in
    cm of water
33 C2=((Ca^2)+(Cx2^2))^(1/2)//The absolute velocity at
    the exit in m/s
34 dPr=dP0r-((d1*((C2^2)-(Ca^2)))/2)*((10^-1)/g)//The
    static pressure across the rotor in cm of water
35 dhs=((C2^2)-(Ca^2))/2//The actual enthalpy change
    across the stator in J/kg
36 dhss=ns*dhs//The theoretical enthalpy change across
    the stator in J/kg
37 dPs=(d1*dhss)*((10^-1)/g)//The static pressure rise
    across the stator in cm of water
38 dP0s=-((dPs/((10^-1)/g))+((d1/2)*(Ca^2-C2^2))
    *(10^-1/g))//The change in total pressure across
    the stator in cm of water
39 P03=P0-dP0s//Total pressure at stator inlet in cm of
    water
40 dh0ss=((dw*g*(P03/100))/d1)//Theoretical total
    enthalpy change across the stage in J/kg

```



```

41 ntt=dh0ss/dh0r//The overall total-to-total
    efficiency
42 DR=dPr/(dPr+dPs)//The degree of reaction for the
    stage
43
44 //output
45 printf('(a)Total pressure of air exit of rotor is %3
    .2f cm of water\n(b)The static pressure rise
    across the rotor is %3.2f cm of water\n(c)The
    static pressure rise across the stator os %3.2 f
    cm of water\n(d)The change in total pressure
    across the stator is %3.2f cm of water\n(e)The
    overall total-to-total efficiency is %3.3f\n(f)
    The degree of reaction for the stage is %3.3f',P0
    ,dPr ,dPs ,dP0s ,ntt ,DR)

```

Scilab code Exa 4.12 POWER REQUIRED TO DRIVE THE FAN

```

1  clc
2  clear
3  //input data
4  Q=2.5//The amount of air which fan takes in m^3/s
5  P1=1.02//The inlet pressure of air in bar
6  T1=315//The inlet temperature of air in K
7  dH=0.75//The pressure head delivered by axial flow
    fan in m W.G
8  T2=325//The delivery temperature of air in K
9  R=287//The universal gas constant in J/kg.K
10 Cp=1.005//The specific heat of air at constant
    pressure in kJ/kg.K
11 r=1.4//The ratio of specific heats of air
12 g=9.81//Acceleration due to gravity in m/s^2
13
14 //calculations
15 d=(P1*10^5)/(R*T1)//The density of air in kg/m^3

```

```

16 m=d*Q//The mass flow rate of air in kg/s
17 W=m*Cp*(T2-T1)//Power required to drive the fan in
    kW
18 dP=((10^3)*g*dH)/(10^5)//The overall pressure
    difference in bar
19 P2=P1+(dP)//The exit pressure in bar
20 nf=((T1*((P2/P1)^((r-1)/r))-1)/(T2-T1))//Static
    fan efficiency
21
22 //output
23 printf('(a)Mass flow rate through the fan is %3.2f
    kg/s\n(b)Power required to drive the fan is %3.2f
    kW\n(c)Static fan efficiency is %3.4f',m,W,nf)

```

Scilab code Exa 4.13 FLOW RATE

```

1  clc
2  clear
3  //input data
4  b2=10//Rotor blade air angle at exit in degree
5  Dt=0.6//The tip diameter in m
6  Dh=0.3//The hub diameter in m
7  N=960//The speed of the fan in rpm
8  P=1//Power required by the fan in kW
9  pi=0.245//The flow coefficient
10 P1=1.02//The inlet pressure in bar
11 T1=316//The inlet temperature in K
12 R=287//The universal gas constant in J/kg.K
13 Cp=1.005//The specific heat of air at constant
    pressure in kJ/kg.K
14 r=1.4//The ratio of specific heats of air
15 g=9.81//Acceleration due to gravity in m/s^2
16
17 //calculations
18 A=(3.141/4)*((Dt^2)-(Dh^2))//Area of the fan at

```

```

    inlet in m^2
19 Dm=(Dt+Dh)/2//The mean rotor diameter in m
20 U=(3.141*Dm*N)/60//The mean blade speed in m/s
21 Ca=pi*U//The axial velocity in m/s
22 Q=A*Ca//The flow rate of air in m^3/s
23 d=(P1*10^5)/(R*T1)//Density of air in kg/m^3
24 dPst=((d*(U^2)*(1-((pi*tand(b2))^2)))/2)*((10^5)/(g
    *(10^3)))*10^-5//Static pressure across the stage
    in m W.G
25 Wm=U*(U-(Ca*tand(b2)))//Work done per unit mass in J
    /kg
26 m=d*Q//Mass flow rate in kg/s
27 W=m*Wm//Work done in W
28 no=W/(P*10^3)//Overall efficiency
29
30 //output
31 printf('(a)The flow rate is %3.3f m^3/s\n(b)Static
    pressure rise across the stage is %3.3f m W.G\n(c
    )The overall efficiency is %3.4f',Q,dPst,no)

```

Scilab code Exa 4.14 ROTOR BLADE ANGLE

```

1 clc
2 clear
3 //input data
4 b2=10//Rotor blade air angle at exit in degree
5 Dt=0.6//The tip diameter in m
6 Dh=0.3//The hub diameter in m
7 N=960//The speed of the fan in rpm
8 P=1//Power required by the fan in kW
9 pi=0.245//The flow coefficient
10 P1=1.02//The inlet pressure in bar
11 T1=316//The inlet temperature in K
12 R=287//The universal gas constant in J/kg.K
13 Cp=1.005//The specific heat of air at constant

```

```

    pressure in kJ/kg.K
14 r=1.4//The ratio of specific heats of air
15 g=9.81//Acceleration due to gravity in m/s^2
16
17 //calculations
18 A=(3.141/4)*((Dt^2)-(Dh^2))//Area of the fan at
    inlet in m^2
19 Dm=(Dt+Dh)/2//The mean rotor diameter in m
20 U=(3.141*Dm*N)/60//The mean blade speed in m/s
21 Ca=pi*U//The axial velocity in m/s
22 Q=A*Ca//The flow rate of air in m^3/s
23 d=(P1*10^5)/(R*T1)//Density of air in kg/m^3
24 b1=atand(U/Ca)//Rotor blade angle at entry in degree
25 dPst=((d*(U^2)*(1-((pi*tand(b2))^2)))/2)//Static
    pressure rise across the stage in N/m^2
26 dPr=dPst//Static pressure rise across the rotor in N
    /m^2
27 Wm=U*(U-(Ca*tand(b2)))//Work done per unit mass in J
    /kg
28 dP0st=d*Wm//Stagnation pressure of the stage in N/m
    ^2
29 DR1=dPr/dP0st//Degree of reaction
30 DR2=(Ca/(2*U))*(tand(b1)+tand(b2))//Degree of
    reaction
31
32 //output
33 printf('(a)Rotor blade angle at entry is %3.2f
    degree\n(b)Degree of reaction is %3.3f',b1,DR1)

```

Scilab code Exa 4.15 OVERALL EFFICIENCY

```

1 clc
2 clear
3 //input data
4 m=3//Mass flow rate of air in kg/s

```

```

5 P1=100*10^3//The atmospheric pressure in Pa
6 T1=310//The atmospheric temperature in K
7 nb=0.8//The efficiency of the blower
8 nm=0.85//The mechanical efficiency
9 P=30//The power input in kW
10 R=287//The universal gas constant in J/kg.K
11 g=9.81//Acceleration due to gravity in m/s^2
12 dw=1000//Density of water in kg/m^3
13
14 //calculations
15 no=nb*nm//Overall efficiency of the blower
16 d=(P1)/(R*T1)//The density of the air in kg/m^3
17 dP=((no*P*10^3)/m)*d//The pressure developed in N/m
    ^2
18 dH=((dP)/(g*dw))*(10^3)//The pressure developed in
    mm W.G
19
20 //output
21 printf('(a)Overall efficiency of the blower is %3.2f
    \n(b)The pressure developed is %3.2f mm W.G',no,
    dH)

```

Scilab code Exa 4.16 OVERALL EFFICIENCY AND POWER

```

1 clc
2 clear
3 //input data
4 psi=0.4//Pressure coefficient
5 m=3.5//Mass flow rate of air in kg/s
6 N=750//The speed of fan in rpm
7 T1=308//The static temperature at the entry in K
8 Dh=0.26//The hub diameter in m
9 DhDt=1/3//The hub to tip ratio
10 P1=98.4*10^3//The static pressure at entry in Pa
11 nm=0.9//The mechanical efficiency

```

```

12 nf=0.79//Static fan efficiency
13 R=287//The universal gas constant in J/kg.K
14 Cp=1.005//The specific heat of air at constant
    pressure in kJ/kg.K
15 r=1.4//The ratio of specific heats of air
16 g=9.81//Acceleration due to gravity in m/s^2
17 dw=1000//Density of water in kg/m^3
18
19 //calculations
20 no=nm*nf//Overall efficiency
21 Dt=Dh/DhDt//The tip diameter in m
22 Dm=(Dt+Dh)/2//Mean rotor diameter in m
23 U=(3.141*Dm*N)/60//The mean blade speed in m/s
24 dPd=((U^2)/2)*psi//The ratio of change in pressure
    to density in J/kg
25 Wi=dPd*m//The ideal work in W
26 P=Wi/nm//The power required by the fan in W
27 d=P1/(R*T1)//The density of the air in kg/m^3
28 A=(3.141/4)*((Dt^2)-(Dh^2))//Area of cross section
    of the fan in m^2
29 Ca=m/(d*A)//The axial velocity of air in m/s
30 pi=Ca/U//The flow coefficient
31 tb1tb2=psi/(2*pi)//The difference between tangent
    angles of rotor inlet and exit angles
32 b2=atand((1-(dPd/U^2))/pi)//The exit rotor angle in
    degree
33 b1=atand((tand(b2))+(tb1tb2))//The inlet rotor angle
    in degree
34 dP=d*dPd//The pressure developed in N/m^2
35 dH=(dP/(dw*g))*10^3//Pressure developed in mm of W.G
36
37 //output
38 printf('(a)The overall efficiency is %3.3f\n,(b)The
    power required by the fan is %3.2f W\n(c)The flow
    coefficient is %3.2f\n(d)\n    (1)The rotor
    inlet angle is %3.2f degree\n    (2)The rotor
    exit angle is %3.2f degree\n(e)The pressure
    developed is %3.2f mm of W.G',no,P,pi,b1,b2,dH)

```


Chapter 5

AXIAL FLOW STEAM AND GAS TURBINES

Scilab code Exa 5.1 INLET ANGLE OF MOVING BLADE

```
1  clc
2  clear
3  //input data
4  C1=500//Steam velocity in m/s
5  U=200//Blade speed in m/s
6  b2=(90-25)//Exit angle of moving blade measured in
    axial direction in degree
7  a1=(90-20)//Nozzle angle in axial direction in
    degree
8  m=5//Steam flow rate in kg/s
9
10 printf('The scale of the velocity vector diagram is
    1:50\n\nThe following values are obtained from
    the velocity vector diagram')
11
12 b1=33//Moving blade inlet angle in degree
13 a2=56//Direction of steam at the exit in degree
14 C2=160//Exit velocity of the steam in m/s
15 Wx1=270//Inlet whirl velocity in m/s
```



```

16 Wx2=285//Exit whirl velocity in m/s
17 Ca1=175//Inlet axial velocity in m/s
18 Ca2=135//Exit axial velocity in m/s
19
20 //calculations
21 Wm=U*(Wx1+Wx2)*10^-3//Work done per kg of steam in
    kW/kg
22 AT=m*(Ca1-Ca2)//Axial thrust in N
23 W=m*Wm//Power developed in kW
24 Ndia=((U*(Wx1+Wx2))/((C1^2)/2))//Diagram or blade
    efficiency
25
26 //output
27 printf('\n\n(a)Moving blade inlet angle is %3i
    degree\n(b)\n    Exit velocity of the steam is
    %3i m/s\n    Direction of steam at the exit is
    %3i degree\n(c)Work done per kg of steam is %3i
    kW/kg\n(d)\n    Axial thrust is %3i N\n    Power
    developed is %3i kW\n(e)Diagram or blade
    efficiency is %3.3 f ',b1,C2,a2,Wm,AT,W,Ndia)

```

Scilab code Exa 5.2 AXIAL THRUST ON BLADING

```

1  clc
2  clear
3  //input data
4  U=300//Blade speed in m/s
5  a=20//Nozzle angle in degree
6  dhs=473//Isentropic heat drop in kJ/kg
7  Nn=0.85//Nozzle efficiency
8  W2W1=0.7//Blade velocity coefficient
9  nM=0.9//Mechanical efficiency
10
11 //initial calculations
12 dh=Nn*dhs//Useful heat drop converted into kinetic

```

```

    energy in kJ/kg
13 C1=(2*1000*dh)^(1/2)//Velocity of steam at exit from
    nozzle in m/s
14
15 printf('The scale of the velocity vector diagram is
    1:100\n\nThe following values are obtained from
    the velocity vector diagram')
16
17 Ca1=310//Inlet axial velocity in m/s
18 Ca2=210//Exit axial velocity in m/s
19 Wx1=550//Inlet whirl velocity in m/s
20 Wx2=380//Exit whirl velocity in m/s
21 W1=620//inlet Blade velocity in m/s
22
23 //calculations
24 W2=W1*W1//Exit blade velocity in m/s
25 AT=Ca1-Ca2//Axial thrust in N/kg
26 Wm=U*(Wx1+Wx2)*10^-3//Work developed per kg of steam
    /sec in kW/(kg/s)
27 P=Wm*nM//Power developed per kg of steam/sec in kW/(
    kg/s)
28 m=3600/P//Steam rate per kW.hr in kg
29 Ndia=((U*(Wx1+Wx2))/((C1^2)/2))//Diagram or blade
    efficiency
30 MNdia=(sind(90-a))^2//Maximum blade efficiency
    under optimum conditions
31 Ns1=Wm/dhs//Stage efficiency
32 Ns2=Ndia*Nn//Stage efficiency in other method
33 E=((W1^2)-(W2^2))/2*10^-3//Energy loss in blade
    friction in kJ/kg
34
35 //output
36 printf('\n\n(a) Axial thrust is %3i N/kg\n(b)\n
    Work developed per kg of steam/sec is %3i kW/(kg/
    s)\n    Power developed per kg of steam/sec is %3
    .1f kW/(kg/s)\n    Steam rate per kW.hr is %3.1f
    kg\n(c)\n    Diagram or blade efficiency is %3.3f
    \n    Maximum blade efficiency under optimum

```

conditions is %3.3f\n Stage efficiency is %3.4
 f\n(d)Energy loss in blade friction is %3.3f kJ/
 kg ',AT,Wm,P,m,Ndia,MNdia,Ns1,E)

Scilab code Exa 5.3 VELOCITY OF STEAM AT EXIT

```

1  clc
2  clear
3  //input data
4  P1=5//Input pressure of steam in bar
5  P2=3//Exhaust pressure of steam in bar
6  C0=75//Carry over velocity of steam in m/s
7  a1=20//Nozzle angle in degree
8  UC1=0.4//The direction of blade rotation and blade
   speed ratio
9  b2=20//Blade exit angle in degree
10 m=2.5//Steam flow rate in kg/s
11 W=206//Power Output of the stage in kW
12 Nn=0.9//Efficiency of the nozzle
13
14 printf('Assuming isentropic expansion the enthalpy
   drop can be found from steam table\n\nThe
   following values are obtained from steam tables')
15
16 h1=2747.5//Enthalpy at initial pressure in kJ/kg
17 s1=6.819//Entropy at initial pressure in kJ/kg.K
18 s2=s1//Entropy at final pressure in kJ/kg.K
19 sfp2=1.647//Entropy of fluid at final pressure in kJ
   /kg.K
20 sfgp2=5.367//Entropy of fluid-gas mixture at final
   pressure in kJ/kg.K
21 hfg=2170.1//Enthalpy of fluid-gas mixture in kJ/kg
22 hf=551.5//Enthalpy of fluid in kJ/kg
23
24 printf(' \n\nThe scale of the velocity vector diagram

```

is 1:50\n\nThe following values are obtained from the velocity vector diagram')

```

25
26 W1=280//Relative velocity at inlet in m/s
27 W2=240//Relative velocity at exit in m/s
28
29 //calculations
30 x2=(s2-sfp2)/sfgp2//The percentage of wet steam
31 h2s=hf+(x2*hfg)//The isentropic enthalpy at the
    second stage in kJ/kg
32 dhs=h1-h2s//Isentropic heat drop in kJ/kg
33 C1=((2000*Nn*dhs)+(C0^2))^(1/2)//Velocity of steam
    at exit from nozzle in m/s
34 U=UC1*C1//Blade speed in m/s
35 Wx1Wx2=(W*10^3)/(m*U)//The sum of whirl components
    of velocity in m/s
36 Ndia=(U*Wx1Wx2)/((C1^2)/2)//Diagram efficiency
37 RV=W2/W1//Relative velocity ratio
38 E=dhs+((C0^2)/2000)//Energy supplied per kg in kJ/kg
39 Ns1=(U*Wx1Wx2)/(E*10^3)//Stage efficiency
40 Ns2=Ndia*Nn//Stage efficiency in other method
41
42 //output
43 printf('\n\n(a)Velocity of steam at exit from nozzle
    is %3.2f m/s\n(b)Diagram efficiency is %3.4f\n(c
    )Relative velocity ratio is %3.3f\n(d)\n    Stage
    efficiency in method 1 is %3.4f\n    Stage
    efficiency in method 2 is %3.4f',C1,Ndia,RV,Ns1,
    Ns2)

```

Scilab code Exa 5.4 BLADE INLET ANGLE FOR EACH ROW

```

1 clc
2 clear
3 //input data

```

```

4 C1=600//Velocity of steam at exit from nozzle in m/s
5 U=120//Blade speed in m/s
6 a1=16//Nozzle angle in degree
7 b2=18//Discharge angle for first moving ring in
  degree
8 a11=21//Discharge angle for the fixed ring in degree
9 b22=35//Discharge angle for the second moving ring
  in degree
10 Wr=0.9//Blade velocity coefficient
11 m=1//Mass flow rate in kg/s
12
13 printf('\n\nThe scale of the velocity vector diagram
  is 1:50\n\nThe following values are obtained
  from the velocity vector diagram')
14
15 W1=485//Relative velocity at inlet for first stage
  in m/s
16 W2=Wr*W1//Relative velocity for first stage at exit
  in m/s
17 Wx1=460//Inlet whirl velocity for first stage in m/
  s
18 Wx2=410//Exit whirl velocity for first stage in m/s
19 Ca1=170//Inlet axial velocity for first stage in m/
  s
20 Ca2=135//Exit axial velocity for first stage in m/s
21 C2=325//Exit velocity of the steam for first stage
  in m/s
22 b1=20//Blade inlet angle for first row of moving
  blade in degree
23 C11=Wr*C2//Steam velocity at inlet to second row of
  moving blades in m/s
24 W12=190//Relative velocity at inlet for second stage
  in m/s
25 W22=Wr*W12//Relative velocity at exit for second
  stage in m/s
26 Wx11=155//Inlet whirl velocity for second stage in
  m/s
27 Wx22=140//Exit whirl velocity for second stage in m

```

```

/s
28 Ca11=110//Inlet axial velocity for second stage in
    m/s
29 Ca22=100//Exit axial velocity for second stage in m/
    s
30 b11=35//Blade inlet angle for second row of moving
    blade in degree
31 dWx1=Wx1+Wx2//Driving force for first stage in m/s
32 dWx11=Wx11+Wx22//Driving force for second stage in m
    /s
33 dW=(dWx1+dWx11)*1//Total driving force for unit mass
    flow rate in N
34 AT1=Ca1-Ca2//Axial thrust for first stage in m/s
35 AT2=Ca11-Ca22//Axial thrust for second stage in m/s
36 AT=(AT1+AT2)*1//Total axial thrust for unit mass
    flow rate in N
37 DP=m*U*(dWx1+dWx11)*10^-3//Diagram power in kW
38 DE=(U*(dWx1+dWx11))/((C1^2)/2)//Diagram efficiency
39 MDE=(sind(90-a1))^2//Maximum diagram efficiency
40
41 //output
42 printf('\n\n(a)\n    Blade inlet angle for first row
    of moving blade is %3.i degree\n    Blade inlet
    angle for second row of moving blade is %3i
    degree\n(b)\n    Driving force for first stage is
    %3i m/s\n    Driving force for second stage is
    %3i m/s\n    Total driving force for unit mass
    flow rate is %3i N\nTotal axial thrust for unit
    mass flow rate is %3i N\n(c)Diagram power is %3.1
    f kW\n(d)Diagram efficiency is %3.3 f\n(e)Maximum
    diagram efficiency is %3.3 f',b1,b11,dWx1,dWx11,
    dW,AT,DP,DE,MDE)

```

Scilab code Exa 5.5 ROTOR SPEED

```

1  clc
2  clear
3  //input data
4  C1=100//Velocity of steam at exit from nozzle in m/s
5  h=0.04//Mean blade height in m
6  b2=20//Exit angle of moving blade in degree
7  CaU=3/4//Ratio of flow velocity and blade speed at
    mean radius
8  m=10000/3600//steam flow rate in kg/s
9
10 //calculations
11 a1=b2//Nozzle angle in degree
12 Ca=C1*cosd(90-a1)//Flow velocity in m/s
13 U=Ca/CaU//Mean blade velocity in m/s
14 v=0.60553//Specific volume of steam from steam table
    at 3 bar with dry saturated steam in m^3/kg
15 A=(m*v)/Ca//Annulus area in m^2
16 D=A/(3.1415*h)//Mean blade diameter in m
17 N=(U*60)/(3.14*D)//Rotor speed in rpm
18
19 printf('\\n\\nThe scale of the velocity vector diagram
    is 1:10\\n\\nThe following values are obtained
    from the velocity vector diagram')
20
21 W1=59//Relative velocity at inlet for first stage in
    m/s
22 Wx1Wx2=142//Sum of whirl components of velocity in m
    /s
23 DP=m*U*Wx1Wx2*10^-3//Diagram power in kW
24 Wm=U*(Wx1Wx2)//Work done per kg of steam in kJ/kg
25 W2=C1//Relative velocity at exit for first stage in
    m/s
26 E=((C1^2)/2)+(((W2^2)-(W1^2))/2)//Energy input per
    kg in kJ/kg when W2=C1
27 Ndia=Wm/E//Diagram efficiency
28 RV=(W2-W1)/W1//Percentage increase in relative
    velocity
29 dH=((W2^2)-(W1^2))/2*10^-3//Enthalpy drop in the

```

```

    moving blades in kJ/kg
30 H=2*dH//Total enthalpy drop in two stages in kJ/kg
31
32 //output
33 printf('\n\n(a)The rotor speed is %3i rpm\n(b)The
    diagram power is %3.2f kW\n(c)The diagram
    efficiency is %3.3f\n(d)Percentage increase in
    relative velocity is %3.3f\n(e)\n    Enthalpy
    drop in the moving blades is %3.3f kJ/kg\n
    Total enthalpy drop in two stages is %3.3f kJ/kg'
    ,N,DP,Ndia,RV,dH,H)

```

Scilab code Exa 5.6 STEAM FLOW RATE

```

1  clc
2  clear
3  //input data
4  R=0.5//Degree of reaction
5  P1=14//Initial pressure in bar
6  T1=588//Initial temperature in K
7  P2=0.14//Final pressure in bar
8  Ns=0.75//Stage efficiency
9  RF=1.04//Reheat factor
10 N=20//No. of stages
11 W=11770//Total power output in kW
12 a1=20//Exit blade angle in degree
13 hD=1/12//Ratio of blade height to blade mean
    diameter
14
15 //calculations
16 hs1=3080//Isentropic enthalpy at initial condition
    from mollier chart in kJ/kg
17 hs2=2270//Isentropic enthalpy at final condition
    from mollier chart in kJ/kg
18 dhs=hs1-hs2//Isentropic enthalpy change in kJ/kg

```



```

19 Nt=Ns*RF//Overall efficiency
20 dh=Nt*dhs//Actual enthalpy drop in kJ/kg
21 hs=dh/N//Enthalpy drop per stage in kJ/kg
22 m=W/dh//Mass flow rate in kg/s
23 C11=1.43*1//Velocity of steam at exit from nozzle in
    m/s in terms of U for 0.5 degree of reaction
24 Wm=1*((2*C11*sind(90-a1))-1)//Work done per mass of
    steam in terms of U^2 in kJ/kg
25 U=((hs*10^3)/Wm)^(1/2)//Mean blade velocity in m/s
    as work done equals enthalpy drop per stage
26 C1=1.43*U//Velocity of steam at exit from nozzle in
    m/s
27 Ca=C1*cosd(90-a1)//Flow velocity in m/s
28 v=1.618//Specific volume of steam from steam table
    at 1.05 bar with dry saturated steam in m^3/kg
29 D=((m*v)/(hD*3.14*Ca))^(1/2)//Blade mean diameter in
    m
30 N=(U*60)/(3.14*D)//Rotor speed in rpm
31
32 //output
33 printf('(a)Mass flow rate of steam is %3.2f kg/s\n(b
    )Mean blade velocity is %3.1f m/s \n(c)Blade mean
    diameter is %3.3f m \n(d)Rotor speed is %3i rpm'
    ,m,U,D,N)

```

Scilab code Exa 5.7 NOZZLE EXIT ANGLE

```

1 clc
2 clear
3 //input data
4 rh=0.225//Blade roof radius in m
5 rt=0.375//Blade tip radius in m
6 b1m=45//Inlet angle of the rotor blade at mid height
    in degree
7 a1m=76//Outlet angle of the nozzle blade at mid

```

```

    height in degree
8  b2m=75//Outlet angle of the rotor blade at mid
    height in degree
9  N=6000//Speed of turbine in rpm
10
11 //calculations
12  rm=(rh+rt)/2//Mean radius in m
13  Um=(2*3.14*rm*N)/60//Mean blade speed at mean radius
    in m/s
14  Ca=Um/((tand(a1m))-(tand(b1m)))//Flow velocity in m/
    s
15  Cx1m=Ca*tand(a1m)//Velocity of whirl at inlet at mid
    height in m/s
16  Cx2m=Ca*tand(b2m)-Um//Velocity of whirl at inlet at
    mid height in m/s
17  Cx1h=(Cx1m*rm)/rh//Velocity of whirl at inlet at hub
    height in m/s
18  a1h=atand(Cx1h/Ca)//Inlet angle of the nozzle blade
    at hub height in degree
19  Uh=(2*3.1415*rh*N)/60//Mean blade speed at hub in m/
    s
20  b1h=atand(tand(a1h)-(Uh/Ca))//Inlet angle of the
    rotor blade at hub in degree
21  Cx2h=Cx2m*rm/rh//Velocity of whirl at outlet at hub
    in m/s
22  b2h=atand((Uh+Cx2h)/Ca)//Outlet angle of the rotor
    blade at hub in degree
23  Cx1t=Cx1m*rm/rt//Velocity of whirl at inlet at tip
    in m/s
24  a1t=atand(Cx1t/Ca)//Inlet angle of the nozzle blade
    at tip height in degree
25  Ut=(2*3.14*rt*N)/60//Mean blade speed at tip in m/s
26  b1t=atand(tand(a1t)-(Ut/Ca))//Inlet angle of the
    rotor blade at tip in degree
27  Cx2t=Cx2m*rm/rt//Velocity of whirl at outlet at tip
    in m/s
28  b2t=atand((Ut+Cx2t)/Ca)//Outlet angle of the rotor
    blade at hub in degree

```

```

29 Rh=(Ca/(2*Uh))*(tand(b2h)-tand(b1h))//Degree of
    reaction at hub
30 Rt=(Ca/(2*Ut))*(tand(b2t)-tand(b1t))//Degree of
    reaction at tip
31
32 //output
33 printf('(a)for hub\n    (1)Inlet angle of the nozzle
    blade at hub height is %3.1f degree\n    (2)
    Inlet angle of the rotor blade at hub is %3i
    degree\n    (3)Outlet angle of the rotor blade at
    hub is %3.2f degree\n    (4)Degree of reaction
    at hub is %3.3f\n(b)for tip\n    (1)Inlet angle
    of the nozzle blade at tip height is %3.2f degree
    \n    (2)Inlet angle of the rotor blade at tip is
    %3i degree\n    (3)Outlet angle of the rotor
    blade at tip is %3i degree\n    (4)Degree of
    reaction at tip is %3.3f',a1h,b1h,b2h,Rh,a1t,b1t,
    b2t,Rt)

```

Scilab code Exa 5.8 BLADE ANGLES

```

1  clc
2  clear
3  //input data
4  Ca=180//Air velocity at the exit of nozzle in m/s
5  a1=(90-27)//Nozzle inclination perpendicular to
    direction of rotation in degree
6  R=0.5//Degree of reaction
7  U=180//Blade speed in m/s
8
9  //calculations
10 Cx1=Ca*tand(a1)//Inlet whirl velocity in m/s
11 b11=atand((Cx1-U)/Ca)//Inlet angle of the rotor
    blade at inlet velocity triangle in degree
12 pi=Ca/U//Ratio of air velocity and blade velocity

```

```

13 b21=atand((2*R/pi)+tand(b11))//Outlet angle of the
    rotor blade at inlet velocity triangle in degree
14 C2=Ca//Exit velocity of the steam in m/s
15 b22=atand(U/C2)//Outlet angle of the rotor blade at
    outlet velocity triangle in degree
16 b12=b11//Inlet angle of the rotor blade at outlet
    velocity triangle in degree as np change in rotor
    inlet conditions
17 R=(pi*(tand(b22)-tand(b12)))/2//Degree of reaction
18
19 //output
20 printf('(a)blade angles\n    Inlet angle of the
    rotor blade at inlet velocity triangle is %3.1f
    degree\n    Outlet angle of the rotor blade at
    inlet velocity triangle is %3.f degree\n(b)Degree
    of reaction is %3.4f\n(c)Inlet angle of the
    rotor blade at outlet velocity triangle is %3.f
    degree\n(d)Outlet angle of the rotor blade at
    outlet velocity triangle is %3.1f degree',b11,b21
    ,R,b22,b12)

```

Scilab code Exa 5.9 POWER DEVELOPED

```

1  clc
2  clear
3  //input data
4  U=300//Blade speed of turbine in m/s
5  m=2.5//Mass flow rate in kg/s
6  T0=773//Gas temperature at turbine inlet in K
7  T2=573//Gaas temperature at turbine outlet in K
8  a1=70//Fixed blade outlet angle in degree
9  Ca=200//Axial velocity in m/s
10 Cp=1.005//Specific heat of gas at constant pressure
    in kJ/kg.K
11 //calculations

```

```

12 W=m*Cp*(T0-T2)//Power developed by turbine in kW
13 Wm=Cp*(T0-T2)//Stage work done per unit mass flow
    rate in kJ/kg
14 Wx1Wx2=Wm*10^3/U//Sum of whirl components of
    velocity at inlet and outlet in m/s
15 Wx1=(Ca*tand(a1))-U//Inlet whirl velocity in m/s
16 Wx2=Wx1Wx2-Wx1//Outlet whirl velocity in m/s
17 R=(Wx2-Wx1)/(2*U)//Degree of reaction
18 Wx2Wx1=Wm*10^3*R//Energy input due to whirl
    component velocity in (m/s)^2
19 C1=Ca/cosd(a1)//Velocity of steam at exit from
    nozzle in m/s
20 nb=(Wm*10^3)/(((C1^2)/2)+Wx2Wx1)//Blade efficiency
21
22 //output
23 printf('(a)Power developed by turbine is %3.1f kW\n(
    b)Degree of reaction is %3.3f\n(c)Blade
    efficiency is %3.4f\n',W,R,nb)

```

Scilab code Exa 5.10 ACTUAL STAGE POWER OUTPUT

```

1 clc
2 clear
3 //input data
4 R=0.5//Degree of reaction
5 P0=2.2//Inlet pressure in bar
6 T0=443//Inlet temperature in K
7 N=2400//Rotor running speed in rpm
8 Dm=0.5//Rotor mean diameter in m
9 a1=36//Rotor inlet angle in degree
10 a2=19//Stator exit angle in degree
11 ns=0.88//Stage efficiency
12 m=1//Mass flow rate of steam in kg/s
13
14 //calculations

```

```

15 b2=a1//Outlet angle of the rotor blade in degree
16 b1=a2//Inlet angle of the rotor blade in degree
17 U=(3.1415*Dm*N)/60//Mean blade speed in m/s
18 Ca=(2*U*R)/(tand(b2)-tand(b1))//Axial velocity in m/
    s
19 W=m*U*Ca*(tand(a1)+tand(a2))*10^-3//Power output in
    kW
20 dh=W/ns//Stage enthalpy drop in kJ/kg
21
22 //output
23 printf('(a)Power output is %3.2f kW\n(b)Stage
    enthalpy drop is %3.2f kJ/kg',W,dh)

```

Scilab code Exa 5.11 ROTOR BLADE ANGLES

```

1 clc
2 clear
3 //input data
4 P0=800//Inlet pressure of hot gas in kPa
5 T1=973//Inlet temperature of hot gas in K
6 P2=100//Final pressure of hot gas in kPa
7 a1=73//Nozzle angle in degree
8 m=35//Mass flow rate in kg/s
9 ns=0.9//Nozzle efficiency
10 Cp=1.005//Specific heat of gas at constant pressure
    in kJ/kg.K
11 r=1.4//Ratio of specific heats of air
12
13 //calculations
14 b1=atand(tand(a1)/2)//Inlet angle of the rotor blade
    in degree
15 b2=b1//Outlet angle of the rotor blade in degree
16 pi=2/tand(a1)//Flow coefficient
17 psil=pi*(tand(b1)+tand(b2))//Blade loading
    coefficient

```

```

18 dh=ns*Cp*T1*(1-(P2/P0)^((r-1)/r))//Change in
    enthalpy in kJ/kg
19 W=m*dh*10^-3//Power developed in MW
20
21 //output
22 printf('(a)Rotor blade angles\n    Inlet angle of
    the rotor blade is %3.2f degree\n    Outlet angle
    of the rotor blade is %3.2f degree\n(b)Flow
    coefficient is %3.3f\n(c)Blade loading
    coefficient is %3.f\n(d)Power developed is %3.1f
    MW',b1,b2,pi,psil,W)

```

Scilab code Exa 5.12 POWER DEVELOPED AND ANGLES

```

1  clc
2  clear
3  //input data
4  P0=100//Initial pressure of steam in bar
5  T0=773//Initial temperature of steam in K
6  D=1//Turbine diameter in m
7  N=3000//Speed of turbine in rpm
8  m=100//Mass flow rate of steam in kg/s
9  a1=70//Exit angle of the first stage nozzle in
    degree
10 ns1=0.78//Stage efficiency of first stage
11 ns2=ns1//Stage efficiency of second stage
12
13 //calculations
14 U=(3.1415*D*N)/60//Mean blade speed in m/s
15 C1=(2*U)/sind(a1)//Velocity of steam at exit from
    nozzle in m/s
16 b11=atand(tand(a1)/2)//Inlet angle of the rotor
    blade in degree
17 b21=b11//Outlet angle of the rotor blade in degree
18 b12=b21//Inlet angle of the rotor blade in second

```

```

    stage in degree
19 b22=b12//Outlet angle of the rotor blade in second
    stage in degree
20 W=4*m*U^2*10^-6//Total work done in both the stages
    in MW
21 dh02=2*U^2*10^-3//Change in enthalpy in first stage
    of turbine in kJ/kg
22 dh02s=(dh02/ns1)//Change in enthalpy isentropically
    of turbine first stage in kJ/kg
23 printf('The values of enthalpy and specific volume
    are taken from the mollier chart at inlet and
    exit conditions respectively')
24 h0=3370//Enthalpy at beginning of first stage in kJ/
    kg
25 h2=h0-dh02//Enthalpy at the end of first stage in kJ
    /kg
26 h2s=h0-dh02s//Isentropic enthalpy at the end of
    first stage in kJ/kg
27 v2=0.041//Specific volume at the end of first stage
    in m^3/kg
28 dh24=2*U^2*10^-3//Change in enthalpy in second stage
    of turbine in kJ/kg
29 dh24s=dh24/ns2//Change in enthalpy isentropically of
    turbine second stage in kJ/kg
30 h4=h2-dh24//Enthalpy at beginning of second stage in
    kJ/kg
31 h4s=h2-dh24s//Isentropic enthalpy at the end of
    second stage in kJ/kg
32 v4=0.05//Specific volume at the end of second stage
    in m^3/kg
33
34 Ca=C1*cosd(a1)//Axial velocity in m/s
35 h1r=(m*v2)/(3.1415*D*Ca)//Blade height at first
    stage rotor exit in m
36 h2r=(m*v4)/(3.1415*D*Ca)//Blade height at second
    stage rotor exit in m
37
38 //output

```



```

39 printf('\n\n(a) rotor blade angles\n      Inlet angle
of the rotor blade is %3.2f degree\n      Outlet
angle of the rotor blade is %3.2f degree\n
Inlet angle of the rotor blade in second stage is
%3.2f degrees\n      Outlet angle of the rotor
blade in second stage is %3.2f degree\n(b) Total
work done or Power developed in both the stages
is %3.2f MW\n(c) final state of steam\n
Enthalpy at beginning of first stage is %3i kJ/kg
\n      Enthalpy at the end of first stage is %3.2f
kJ/kg\n      Isentropic enthalpy at the end of
first stage is %3.2f kJ/kg\n      Specific volume
at the end of first stage is %3.3f m^3/kg\n
Enthalpy at beginning of second stage is %3.1f kJ
/kg\n      Isentropic enthalpy at the end of second
stage is %3.2f kJ/kg\n      Specific volume at the
end of second stage is %3.2f m^3/kg\n(d) blade
height\n      Blade height at first stage rotor
exit is %3.4f m\n      Blade height at second stage
rotor exit is %3.4f m', b11, b21, b12, b22, W, h0, h2,
h2s, v2, h4, h4s, v4, h1r, h2r)

```

Scilab code Exa 5.13 ROTOR BLADE ANGLES

```

1  clc
2  clear
3  //input data
4  P0=100//Initial pressure of steam in bar
5  T0=773//Initial temperature of steam in K
6  D=1//Turbine diameter in m
7  N=3000//Speed of turbine in rpm
8  m=100//Mass flow rate of steam in kg/s
9  a1=70//Exit angle of the first stage nozzle in
degree
10 ns=0.65//Stage efficiency of first stage

```

```

11
12 //calculations
13 U=(3.1415*D*N)/60//Mean blade speed in m/s
14 C1=(4*U)/sind(a1)//Velocity of steam at exit from
    nozzle in m/s
15 Ca=C1*cosd(a1)//Axial velocity in m/s
16 Wx1=3*U//Inlet whirl velocity in m/s
17 b11=atand(Wx1/Ca)//Inlet angle of the rotor blade in
    degree
18 b21=b11//Outlet angle of the rotor blade in degree
19 C2=Ca//Velocity of steam at exit from stage in m/s
20 b22=atand(U/Ca)//Outlet angle of the rotor blade in
    degree
21 b12=b22//Inlet angle of the rotor blade in in
    degree
22 W=m*8*U^2*10^-6//Total work done or power developed
    in MW
23 printf('The values of enthalpy and specific volume
    are taken from the mollier chart at inlet and
    exit conditions respectively')
24 h0=3370//Enthalpy at beginning of stage in kJ/kg
25 dh04=(W*10^3)/m//Change in enthalpy of turbine in
    kJ/kg
26 dh04s=dh04/ns//Change in enthalpy isentropically of
    turbine in kJ/kg
27 h4=h0-dh04//Enthalpy at beginning of stage in kJ/kg
28 h4s=h0-dh04s//Isentropic enthalpy at the end of
    stage in kJ/kg
29 v4=0.105//Specific volume at the end of stage in m
    ^3/kg
30 h=(m*v4)/(3.1415*D*Ca)//Rotor blade height in m
31
32 printf('\n\n(a) rotor blade angles\n    Inlet angle
    of the rotor blade is %3.2f degree\n    Outlet
    angle of the rotor blade is %3.2f degree\n
    Inlet angle of the rotor blade in second stage is
    %3.2f degrees\n    Outlet angle of the rotor
    blade in second stage is %3.2f degree\n(b) Total

```

work done or Power developed in both the stages
 is %3.2f MW\n(c) final state of steam\n
 Enthalpy at beginning of first stage is %3i kJ/kg
 \n Enthalpy at beginning of stage is %3.1f kJ/
 kg\n Isentropic enthalpy at the end of stage
 is %3.2f kJ/kg\n Specific volume at the end of
 stage is %3.3f m³/kg\n(d) rotor blade height is
 %3.4f m', b11, b21, b12, b22, W, h0, h4, h4s, v4, h)

Scilab code Exa 5.14 ROTOR BLADE ANGLE FOR DEGREE OF REACTION 50

```

1  clc
2  clear
3  //input data
4  a1=(90-30)//Nozzle angle in axial direction in
    degree
5  Ca=180//Axial velocity in m/s
6  U=280//Rotor blade speed in m/s
7  R=0.25//Degree of reaction
8
9  //calculations
10 Cx1=Ca*tand(a1)//Velocity of whirl at inlet in m/s
11 b1=atand((Cx1-U)/Ca)//Blade angle at inlet in degree
12 b2=a1//Blade angle at exit in degree as degree of
    reaction is 0.5
13
14 //output
15 printf('(a)Blade angle at inlet is %3i degree\n(b)
    Blade angle at exit is %3i degree',b1,b2)

```

Scilab code Exa 5.15 POWER AND BLADE ANGLES

```

1  clc

```

```

2 clear
3 //input data
4 R=0.5//Degree of reaction
5 ns=0.85//Stage efficiency
6 P0=800//Inlet pressure of hot gas in kPa
7 T0=900//Inlet temperature of hot gas in K
8 U=160//Blade speed in m/s
9 m=75//Mass flow rate of hot gas in kg/s
10 a1=70//Absolute air angle at first stage nozzle exit
    in degree
11
12 //calculations
13 C1=U/sind(a1)//Velocity of steam at exit from nozzle
    in m/s
14 Ca=C1*cosd(a1)//Axial velocity of hot gas in m/s
15 C2=Ca//Velocity of steam at exit from stage in m/s
16 b1=0//Blade angle at inlet in degree as Wx1=0
17 a2=b1//Stator exit angle in degree as degree of
    reaction is 0.5
18 b2=a1//Blade angle at outlet in degree as degree of
    reaction is 0.5
19 Cx2=0//Velocity of whirl at outlet in m/s
20 Cx1=U//Velocity of whirl at inlet in m/s
21 W=m*U*(Cx1+Cx2)*10^-6//Power developed in MW
22 Wm=W*10^3/m//Work done per unit mass flow rate in kJ
    /kg
23 dhs=Wm/ns//Isentropic enthalpy drop in kJ/kg
24
25 //output
26 printf('(a)Rotor blade angles\n    Absolute air
    angle at first stage nozzle exit is %3i degree\n
    Blade angle at outlet is %3i degree\n    Blade
    angle at inlet is %3i degree\n    Stator exit
    angle is %3i degree\n(b)Power developed is %3.2f
    MW\n(c)Isentropic enthalpy drop is %3.2f kJ/kg',
    a1 ,b2 ,b1 ,a2 ,W ,dhs)

```

Scilab code Exa 5.16 DEGREE OF REACTION

```
1  clc
2  clear
3  //input data
4  b1m=46//Rotor blade angle at entry at mean section
   in degree
5  b2m=75//Rotor blade angle at exit at mean section in
   degree
6  a1m=75//Nozzle angle at exit at mean section in
   degree
7  DhDt=0.6//Hub to tip ratio
8  N=7500//Mean rotor speed in rpm
9  Dh=0.45//Hub diameter in m
10
11 //calculations
12 R=0.5//Degree of reaction as a1m=b2m
13 a2m=b1m//Stator angle at exit at mean section in
   degree
14 Dm=(Dh+(Dh/DhDt))/2//Mean diameter of turbine at
   mean section in m
15 Um=(3.1415*DhDt*N)/60//Mean blade speed in m/s
16 Ca=Um/(tand(a1m)-tand(b1m))//Axial velocity in m/s
17 pi=Ca/Um//Flow coefficient
18 psil=pi*(tand(b1m)+tand(b2m))//Blade loading
   coefficient
19 a1h=atand(tand(a1m)*((Dm/2)/(Dh/2)))//Nozzle angle
   at inlet at root section in degree
20 Uh=(3.14*Dh*N)/60//Blade speed at root section in m/
   s
21 b1h=atand(tand(a1h)-(Uh/Ca))//Rotor blade angle at
   entry at root section in degree
22 a2h=atand(tand(a2m)*((Dm/2)/(Dh/2)))//Stator angle
   at exit at root section in degree
```

```

23 b2h=atand((Uh/Ca)+tand(a2h))//Rotor blade angle at
    exit at root section in degree
24 pih=Ca/Uh//Flow coefficient at root section
25 Rh=(pih/2)*(tand(b2h)-tand(b1h))//Degree of reaction
    at root section
26 psilh=pih*(tand(b1h)+tand(b2h))//Blade loading
    coefficient at root section
27
28 //output
29 printf('Mean section\n    (a)Degree of reaction is
    %3.1f\n    (b)Blade loading coefficient is %3.2f\n
    nRoot section    (a)Degree of reaction is %3.2f\n
    (b)Blade loading coefficient is %3.2f',R,psilh
    ,Rh,psilh)

```

Scilab code Exa 5.17 GAS VELOCITIES

```

1  clc
2  clear
3  //input data
4  T00=973//Total head inlet temperature in K
5  P00=4.5//Total head inlet pressure in bar
6  P2=1.6//Static head outlet pressure in bar
7  m=20//Gas flow rate in kg/s
8  a1=(90-28)//Nozzle outlet angle measured
    perpendicular to blade velocity in degree
9  Dmh=10//Mean blade diameter to blade height ratio
10 NLC=0.1//Nozzle loss coefficient
11 Cp=1155.6//Specific heat of gas at a constant
    pressure in kJ/kg
12 R=289//Gas constant in J/kg
13 r=1.333//Ratio of specific heats of gas
14
15 //calculations
16 T2ss=T00*(P2/P00)^((r-1)/r)//Isentropic temperature

```

```

    at outlet in mid section in K here T00=T01
17 T1s=T2ss//Isentropic temperature at inlet at mid
    section in K
18 C1m=(2*Cp*(T00-T1s)/1.1)^(1/2)//Velocity of steam at
    exit from nozzle at mid section in m/s
19 T1=T00-((C1m^2)/(2*Cp))//Gas temperature at mid
    section in K
20 d=(P2*10^5)/(R*T1)//Density of gas in kg/m^3
21 Rg=(Cp*(r-1)/r)//Gas constant of the gas in kJ/kg
22 Ca=C1m*cosd(a1)//Axial velocity in m/s
23 h=((m/(d*Ca))*(1/(Dmh*3.1415)))^(1/2)//Hub height in
    m
24 Dm=Dmh*h//Mean blade diameter in m
25 Dh=Dm-h//Hub diameter in m
26 a1h=atand(((Dm/2)/(Dh/2))*tand(a1))//Discharge angle
    at hub in degree
27 C1h=Ca/cosd(a1h)//Gas velocity at hub section in m/s
28 T1h=T00-((C1h^2)/(2*Cp))//Gas temperature at hub in
    K here T01=T00
29 Dt=Dm+h//Tip diameter in m
30 a1t=atand(((Dm/2)/(Dt/2))*tand(a1))//Gas discharge
    angle at tip in degree
31 C1t=Ca/cosd(a1t)//Gas velocity at tip in m/s
32 T1t=T00-((C1t^2)/(2*Cp))//Gas temperature in K here
    T00=T01
33
34 //output
35 printf('(a)At mid section\n    Gas velocity is %3.1f
    m/s\n    Gas temperature is %3.1f K\n    Gas
    discharge angle is %3i degree\n(b)At hub section\n
    Gas velocity is %3.1f m/s\n    Gas
    temperature is %3.2f K\n    Gas discharge angle
    is %3.2f degree\n(c)At tip section\n    Gas
    velocity is %3.1f m/s\n    Gas temperature is %3
    .2f K\n    Gas discharge angle is %3.2f degree',
    C1m,T1,a1,C1h,T1h,a1h,C1t,T1t,a1t)

```

Scilab code Exa 5.18 ABSOLUTE AND RELATIVE ANGLES

```
1  clc
2  clear
3  //input data
4  a1=75//Nozzle air angle in degree
5  Rh=0//Degree of reaction
6  N=6000//Running speed of hub in rpm
7  Dh=0.45//Hub diameter in m
8  Df=0.75//Tip diameter in m
9
10
11 //calculations
12 Uh=(3.1415*Dh*N)/60//Hub speed in m/s
13 C1h=Uh/((sind(a1))/2)//Velocity of steam at exit
    from nozzle in hub in m/s
14 Cah=C1h*cosd(a1)//Axial velocity at hub in m/s
15 Cx1h=C1h*sind(a1)//Whirl component of velocity at
    inlet in hub in m/s
16 b1h=atand((Cx1h-Uh)/Cah)//Rotor blade angle at entry
    at hub section in degree
17 b2h=b1h//Rotor blade angle at exit at mean section
    in degree as zero reaction section
18 sopt=sind(a1)/2//Blade to gas speed ratio at hub
19 rm=((Dh/2)+(Df/2))/2//Mean radius in m
20 rmrh=(rm/(Dh/2))^((sind(a1))^2)//Ratio of inlet
    velocity at hub and mean for constant nozzle air
    angle at hub section
21 C1m=C1h/rmrh//Velocity of steam at exit from nozzle
    at mean section in m/s
22 Cx1m=Cx1h/rmrh//Velocity of whirl at inlet at mean
    section in m/s
23 Ca1m=Cah/rmrh//Axial velocity at mean section in m/s
24 Um=(3.1415*2*rm*N)/60//Mean blade speed in m/s
```



```

25 b1m=atand((Cx1m-Um)/Ca1m)//Rotor blade angle at
    entry at mean section in degree
26 b2m=atand(Um/Ca1m)//Rotor blade angle at exit at
    mean section in degree for axial exit Cx2=0
27 s=Um/C1m//Blade to gas ratio at mean
28 Rm=(Ca1m/(2*Um))*(tand(b2m)-tand(b1m))//Degree of
    reaction of mean section
29 rmrt=((rm)/(Df/2))^(sind(a1))^2//Ratio of inlet
    velocity at tip and mean for constant nozzle air
    angle at tip section
30 C1t=C1m*rmrt//Velocity of steam at exit from nozzle
    at tip section in m/s
31 Cx1t=Cx1m*rmrt//Velocity of whirl at inlet at tip
    section in m/s
32 Ca1t=Ca1m*rmrt//Axial velocity at tip section in m/s
33 Ut=(3.1415*Df*N)/60//Mean tip speed in m/s
34 b1t=atand((Cx1t-Ut)/Ca1t)//Rotor blade angle at
    entry at tip section in degree
35 b2t=atand(Ut/Ca1t)//Rotor blade angle at exit at tip
    section in degree for axial exit Cx2=0
36 st=Ut/C1t//Blade to gas ratio at tip
37 Rf=(Ca1t/(2*Ut))*(tand(b2t)-tand(b1t))//Degree of
    reaction of tip section
38
39 //output
40 printf('(1)Hub section\n      (a)\n          Absolute
    air angle is %3.2f degree\n          Relative air
    angle is %3.2f degree\n      (b)Blade to gas speed
    ratio is %3.3f\n      (c)Degree of reaction is %3i\n
    (2)Mean section\n      (a)\n          Absolute air
    angle is %3.2f degree\n          Relative air
    angle is %3.2f degree\n      (b)Blade to gas speed
    ratio is %3.3f\n      (c)Degree of reaction is %3.3
    f\n(3)Tip section\n      (a)\n          Absolute air
    angle is %3.2f degree\n          Relative air
    angle is %3.2f degree\n      (b)Blade to gas speed
    ratio is %3.3f\n      (c)Degree of reaction is %3.3
    f\n',b1h,b2h,sopt,Rh,b1m,b2m,s,Rm,b1t,b2t,st,Rf)

```


Chapter 6

RADIAL FLOW GAS AND STEAM TURBINES

Scilab code Exa 6.1 FLOW AND LOADING COEFFICIENTS

```
1  clc
2  clear
3  //input data
4  P00=3//The pressure at which air is received in bar
5  T00=373//The temperature at which air is received in
   K
6  rt=0.5//The rotor tip diameter of turbine in m
7  rh=0.3//The rotor exit diameter of the turbine in m
8  b=0.03//The rotor blade width at entry in m
9  b11=60//The air angle at rotor entry in degree
10 a11=25//The air angle at nozzle exit in degree
11 Ps=2//The stage pressure ratio
12 nn=0.97//The nozzle efficiency
13 N=7200//The speed of the turbine rotation in rpm
14 R=287//The universal gas constant in J/kg.K
15 Cp=1005//The specific heat of air at constant
   pressure in J/kg.K
16 r=1.4//The ratio of specific heats of air
17
```

```

18 //calculations
19 U1=(3.14*rt*N)/60//Peripheral velocity of impeller
    at inlet in m/s
20 Cr=U1/(cotd(a11)-cotd(b11))//The radial velocity at
    inlet in m/s
21 ps1=Cr/U1//Flow coefficient
22 sl=1+(ps1*cotd(b11))//Loading coefficient
23 DR=((1-(ps1*cotd(b11)))/2)//Degree of reaction
24 nts=((sl*U1^2)/(Cp*T00*(1-((1/Ps)^((r-1)/r)))))//
    Stage efficiency of the turbine
25 C2=Cr//Absolute velocity at the exit in m/s
26 U2=(3.1415*rh*N)/60//Peripheral velocity of impeller
    at exit in m/s
27 b22=atand(C2/U2)//The air angle at rotor exit in
    degree
28 dT=DR*U1*Cr*cotd(a11)/Cp//Total actual change in
    temperature in a stage turbine in K
29 dT0=(U1*Cr*cotd(a11))/Cp//The total change in
    temperature in turbine in K
30 T02=T00-dT0//The exit absolute temperature in K
31 T2=T02-((C2^2)/(2*Cp))//The actual exit temperature
    in K
32 T1=dT+T2//The actual inlet temperature in K
33 Cx1=Cr*cotd(a11)//Inlet absolute velocity of air in
    tangential direction in m/s
34 C1=Cx1/cosd(a11)//Absolute velocity at the inlet in
    m/s
35 dT1=(C1^2/2)/(Cp*nn)//The absolute change in
    temperature at the first stage in K
36 dP1=(1-(dT1/T00))^(r/(r-1))//The absolute pressure
    ratio in first stage
37 P1=dP1*P00//The inlet pressure in bar
38 d1=(P1*10^5)/(R*T1)//The inlet density in kg/m^3
39 A1=3.1415*rt*b//The inlet area of the turbine in m^2
40 m=d1*A1*Cr//The mass flow rate of air at inlet in kg
    /s
41 P2=P00/Ps//The exit pressure in bar
42 d2=(P2*10^5)/(R*T2)//The exit density of air in kg/m

```

```

^3
43 bh=(m/(d2*3.1415*rh*Cr))//Rotor width at the exit in
    m
44 W=m*U1*Cx1*10^-3//The power developed by the turbine
    in kW
45
46 //output
47 printf('(a)\n    (1)The flow coefficient is %3.3f\n
    (2)The loading coefficient is %3.3f\n(b)\n
    (1)The degree of reaction is %3.4f \n    (2)The
    stage efficiency of the turbine is %3.4f \n(c)\n
    (1)The air angle at the rotor exit is %3.2f
    degree\n    (2)The width at the rotor exit is %3
    .4f m\n(d)\n    (1)The mass flow rate is %3.2f kg
    /s\n    (2)The power developed is %3.2f kW',ps1,
    s1,DR,nts,b22,bh,m,W)

```

Scilab code Exa 6.2 NOZZLE EXIT AIR ANGLE

```

1  clc
2  clear
3  //input data
4  P0=4//Overall stage pressure ratio
5  T00=557//Temperature at entry in K
6  P3=1//Diffuser exit pressure in bar
7  m=6.5//Mass flow rate of air in kg/s
8  ps1=0.3//Flow coefficient
9  N=18000//Speed of the turbine in rpm
10 Dt=0.42//Rotor tip diameter in m
11 D2m=0.21//Mean diameter at rotor exit in m
12 R=287//The universal gas constant in J/kg.K
13 Cp=1.005//The specific heat of air at constant
    pressure in kJ/kg.K
14 r=1.4//The ratio of specific heats of air
15

```

```

16 //calculations
17 U1=(3.1415*Dt*N)/60//Peripheral velocity of impeller
    at inlet in m/s
18 Cr1=ps1*U1//The radial velocity at inlet in m/s
19 a11=atand(Cr1/U1)//The nozzle exit air angle in
    degree
20 W=m*U1^2*10^-3//Power developed by turbine in kW
21 dT=(1/P0)^((r-1)/r)//The total isentropic
    temperature ratio in entire process
22 T3s=dT*T00//The final isentropic temperature at exit
    in K
23 dh2=W/m//The absolute enthalpy change in the first
    two stages in kJ/kg
24 ns=dh2/(Cp*(T00-T3s))//The stage efficiency of the
    turbine
25 T02=T00-(W/(m*Cp))//The absolute temperature at the
    entry of second stage in K
26 T03=T02//The absolute temperature at exit of second
    stage in K
27 dH=Cp*(T02-T3s)//The total enthalpy loss in kJ/kg
28 dHn=dH/2//The enthalpy loss in the nozzle in kJ/kg
29 C1=Cr1/sind(a11)//Absolute velocity at the inlet in
    m/s
30 dH0=((C1^2)/(2000*Cp))+(dHn)//The isentropic
    absolute enthalpy loss in nozzle in kJ/kg
31 dT0=dH0/Cp//The isentropic absolute temperature loss
    in nozzle in K
32 T1s=T00-dT0//The isentropic temperature at the entry
    in K
33 P1=P0*(T1s/T00)^(r/(r-1))//The pressure at the entry
    of turbine in bar
34 T1=T00-(((C1^2)/(2000*Cp))//The temperature at the
    entry of turbine in K
35 d1=(P1*10^5)/(R*T1)//The density of the air at inlet
    in kg/m^3
36 b1=m/(d1*Cr1*3.141*Dt)//The width of the rotor at
    inlet in m
37 C2=Cr1//The absolute velocity at the second stage

```

```

    entry in m/s
38 T2=T02-(((C2^2)/(2000*Cp))//The temperature at the
    second stage entry in K
39 P23=(T2/T03)^(r/(r-1))//The pressure ratio at the
    second stage
40 P2=P23*P3//The pressure at the second stage in bar
41 d2=(P2*10^5)/(R*T2)//The density of the air at
    second stage in kg/m^3
42 C2=Cr1//The absolute velocity at the second stage in
    m/s
43 A2=m/(d2*C2)//The area of cross section at the
    second stage in m^2
44 h2=(A2/(3.14*D2m))//The rotor blade height at the
    exit in m
45 M1=C1/(r*R*T1)^(1/2)//The mach number at the nozzle
46 U2=(3.14*D2m*N)/60//The Peripheral velocity of
    impeller at exit in m/s
47 M2r=(((C2^2)+(U2^2))^(1/2))/(r*R*T2)^(1/2)//The mach
    number at the rotor exit
48 Ln=(dHn*10^3)/((C1^2)/2)//The nozzle loss
    coefficient
49 Lr=(dHn*10^3)/((((C2^2)+(U2^2))^(1/2))^2)/2//The
    rotor loss coefficient
50
51 //output
52 printf('(a)The nozzle exit air angle is %3.2f degree
    \n(b)The power developed is %3.1f kW\n(c)The
    stage efficiency is %3.4f \n(d)The rotor width at
    the entry is %3.5f m\n(e)The rotor blade height
    at the exit is %3.4f m\n(f)\n    (1)The mach
    number at the nozzle exit is %3.4f\n    (2)The
    mach number at the rotor exit is %3.2f\n(g)\n
    (1)The nozzle loss coefficient is %3.4f\n    (2)
    The rotor loss coefficient is %3.3f',a11,W,ns,b1,
    h2,M1,M2r,Ln,Lr)

```

Scilab code Exa 6.3 IMPELLER TIP SPEED

```
1  clc
2  clear
3  //input data
4  ntt=0.9//Total-to-total efficiency
5  P00=300//The pressure at entry to the nozzle in kPa
6  T00=1150//The temperature at entry to the nozzle in
   K
7  T1=1013//The static temperature at the outlet of the
   nozzle in K
8  P03=100//The pressure at the outlet of the diffuser
   in kPa
9  R=284.5//The universal gas constant in J/kg.K
10 Cp=1.147//The specific heat of air at constant
   pressure in kJ/kg.K
11 r=1.33//The ratio of specific heats of given gas
12
13 //calculations
14 U1=(ntt*Cp*1000*T00*(1-((P03/P00)^((r-1)/r))))^(1/2)
   //The impeller tip speed in m/s
15 T01=T00//The absolute temperature at the entry in K
16 C1=(2000*Cp*(T01-T1))^(1/2)//The absolute velocity
   at the inlet of turbine in m/s
17 a11=acosd(U1/C1)//The flow angle at the nozzle outlet
   in degree
18 M1=C1/(r*R*T1)^(1/2)//The mach number at the nozzle
   outlet
19
20 //output
21 printf('(a)The impeller tip speed is %3.1f m/s\n(b)
   The flow angle at the nozzle outlet is %3.2f
   degrees\n(c)The mach number at the nozzle outlet
   is %3.2f ',U1,a11,M1)
```

Scilab code Exa 6.4 VOLUME FLOW RATE

```
1  clc
2  clear
3  //input data
4  D1=0.09//Rotor inlet tip diameter in m
5  D2t=0.062//Rotor outlet tip diameter in m
6  D2h=0.025//Rotor outlet hub diameter in m
7  N=30000//Blade speed in rpm
8  d2=1.8//Density of exhaust gases at impeller exit in
   kg/m^3
9  C2s=0.447//Ratio of absolute velocity and isentropic
   velocity at exit
10 U1Cs=0.707//Ratio of impeller tip velocity and
   isentropic velocity
11
12 //calculations
13 U1=(3.1415*D1*N)/60//The impeller tip speed in m/s
14 Cs=U1/U1Cs//Isentropic velocity in m/s
15 C2=C2s*Cs//Absolute velocity at the exit in m/s
16 A2=(3.141/4)*((D2t^2)-(D2h^2))//Area at the exit in
   m^2
17 Q2=A2*C2//Volume flow rate at the impeller exit in m
   ^3/s
18 M=d2*Q2//Mass flow rate in kg/s
19 W=M*U1^2//Power developed in W
20
21 //output
22 printf('(a)Volume flow rate at the impeller exit is
   %3.3f m^3/s\n(b)Power developed is %i W',Q2,W)
```

Scilab code Exa 6.5 ROTOR DIAMETER

```

1  clc
2  clear
3  //input data
4  P00=3.5//Total-to-static pressure ratio
5  P2=1//Exit pressure in bar
6  T00=923//Inlet total temperature in K
7  U1Cs=0.66//Blade to isentropic speed ratio
8  D=0.45//Rotor diameter ratio
9  N=16000//Speed from nozzle in rpm
10 a11=20//Nozzle exit angle in degree
11 nn=0.95//Nozzle efficiency
12 b1=0.05//Rotor width at inlet in m
13 R=287//The universal gas constant in J/kg.K
14 Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
15 r=1.4//The ratio of specific heats of air
16
17
18 //Calculations
19 T2s=T00*(1/P00)^((r-1)/r)//Isentropic temperature at
    the exit in K
20 Cs=(2*Cp*(T00-T2s))^(1/2)//The isentropic velocity
    in m/s
21 U1=U1Cs*Cs//The impeller tip speed in m/s
22 D1=(U1*60)/(3.14*N)//Rotor inlet diameter in m
23 D2=D*D1//Rotor outlet diameter in m
24 Cr2=U1*tand(a11)//The relative velocity at the exit
    in m/s
25 U2=(3.1415*D2*N)/60//Peripheral velocity of impeller
    at exit in m/s
26 b22=atand(Cr2/U2)//The air angle at rotor exit in
    degree
27 T02=T00-((U1^2)/(Cp))//The absolute temperature at
    the exit in K
28 T2=T02-((Cr2^2)/(2*Cp))//The temperature at the exit
    of turbine in K
29 T1=T2+((U1^2)/(2*Cp))//The temperature at the entry
    of turbine in K

```

```

30 T1s=T00-((T00-T1)/nn)//Isentropic temperature at the
    entry in K
31 P1=P00*(T1s/T00)^(r/(r-1))//The pressure at the
    entry stage in bar
32 d1=(P1*10^5)/(R*T1)//The density of the air at the
    inlet in kg/m^3
33 A1=3.1415*D1*b1//The area at the inlet in m^2
34 Cr1=Cr2//The relative velocity at the entry in m/s
35 m=d1*A1*Cr1//The mass flow rate for a 90degree IFR
    turbine Degree of Reaction is 0.5 in kg/s
36 W=(m*U1^2)*10^-6//Power developed in MW
37 d2=(P2*10^5)/(R*T2)//The density of the air at the
    exit in kg/m^3
38 b2=m/(d2*3.141*D2*Cr2)//Rotor width at the exit in m
39 D2h=D2-b2//Hub diameter at the exit in m
40 D2t=D2+b2//Tip diameter at the exit in m
41 nts=(W*10^6)/(m*Cp*(T00-T2s))//Total-to-static
    efficiency
42 C1=U1/cosd(a11)//Absolute velocity at the entry in m
    /s
43 Ln=(Cp*(T1-T1s))/((C1^2)/2)//Nozzle enthalpy loss
    coefficient
44 W2=((U2^2)+(Cr2^2))^(1/2)//Resultant relative
    velocity at the exit in m/s
45 T2s=T1*(P2/P1)^((r-1)/r)//Isentropic temperature at
    the exit in K
46 Lr=(Cp*(T2-T2s))/((W2^2)/2)//Rotor enthalpy loss
    coefficient
47
48 //output
49 printf('(a)\n    (1)Rotor inlet diameter is %3.2f m\
n    (2)Rotor outlet diameter is %3.3f m\n(b)The
air angle at rotor exit is %3.2f degree\n(c)The
mass flow rate for a 90degree IFR turbine Degree
of Reaction is 0.5 is %3.2f kg/s\n(d)Power
developed is %3.3f MW\n(e)\n    (1)Hub diameter
at the exit is %3.4f m\n    (2)Tip diameter at
the exit is %3.4f m\n(f)Total-to-static

```

```

efficiency is %3.4f\n(g)Nozzle enthalpy loss
coefficient is %3.4f\n(h)Rotor enthalpy loss
coefficient is %3.4f',D1,D2,b22,m,W,D2h,D2t,nts,
Ln,Lr)

```

Scilab code Exa 6.6 TOTAL TO STATIC EFFICIENCY

```

1  clc
2  clear
3  //input data
4  P00=700//Total-to-static pressure ratio
5  T00=1145//Inlet total temperature in K
6  P1=527//The pressure at the entry stage in bar
7  T1=1029//The temperature at the entry of turbine in
   K
8  P2=385//The pressure at the second stage in bar
9  T2=915//The temperature at the second stage entry in
   K
10 T02=925//The absolute temperature at the exit in K
11 D2mD1=0.49//The ratio of rotor exit mean diameter to
   rotor inlet diameter
12 N=24000//Blade speed in rpm
13 R1=8.314//The gas constant of given gas in kJ/kg.K
14 r=1.67//The ratio of specific heats of the gas
15 m=39.94//Molecular weight of a gas
16
17 //calculations
18 R=R1/m//The universal gas constant in kJ/kg.K
19 Cp=(r*R)/(r-1)//The specific heat of air at constant
   pressure in kJ/kg.K
20 T2ss=T00*(P2/P00)^((r-1)/r)//Isentropic stage
   temperature at the exit in K
21 nts=(T00-T02)/(T00-T2ss)//Total-to-static efficiency
   of the turbine
22 U1=(Cp*1000*(T00-T02))^(1/2)//The impeller tip speed

```

```

    in m/s
23 D1=(U1*60)/(3.1415*N)//Rotor inlet diameter in m
24 D2m=D1*D2mD1//Rotor exit mean diameter in m
25 C1=(2*Cp*(T00-T1))^(1/2)//Absolute velocity at the
    entry in m/s
26 T1s=T00*(P1/P00)^((r-1)/r)//Isentropic temperature
    at the entry in K
27 Ln=(Cp*(T1-T1s))/((C1^2)/2)//Nozzle enthalpy loss
    coefficient
28 C2=(2*Cp*1000*(T02-T2))^(1/2)//The temperature at
    the exit of turbine in K
29 U2=(3.14*D2m*N)/(60)//Peripheral velocity of
    impeller at exit in m/s
30 W2=((C2^2)+(U2^2))^(1/2)//Resultant relative
    velocity at the exit in m/s
31 T2s=T1*(P2/P1)^((r-1)/r)//stage temperature at the
    exit in K
32 Lr=(Cp*1000*(T2-T2s))/((W2^2)/2)//Rotor enthalpy
    loss coefficient
33 ntt=1/((1/nts)-((C2^2)/(2*U1^2)))//Total-to-total
    efficiency
34
35 //output
36 printf('(a)Total-to-static efficiency of the turbine
    is %3.3f\n(b)\n    (1)Rotor inlet diameter is %3
    .3f m\n    (2)Rotor exit mean diameter is %3.3f m
    \n(c)\n    (1)Nozzle enthalpy loss coefficient is
    %3.4f\n    (2)Rotor enthalpy loss coefficient is
    %3.4f\n(d)Total-to-total efficiency is %3.4f',
    nts,D1,D2m,Ln,Lr,ntt)

```

Chapter 7

DIMENSIONAL AND MODEL ANALYSIS

Scilab code Exa 7.5 SPEED OF PROTOTYPE

```
1  clc
2  clear
3  //input data
4  Nm=1000//Speed of the model in rpm
5  Hm=8//Head of the model in m
6  Pm=30//Power of the model in kW
7  Hp=25//Head of the prototype in m
8  DmDp=1/5//The scale of the model to original
9
10 //calculations
11 Np=((Hp/Hm)^(1/2))*(DmDp)*(Nm)//Speed of the
    prototype in rpm
12 Pp=(Pm)*((1/DmDp)^(5))*(Np/Nm)^(3)//Power developed
    by the prototype in kW
13 QpQm=((1/DmDp)^(3))*(Np/Nm)//Ratio of the flow rates
    of two pump(model and prototype)
14
15 //output
16 printf('(1)Speed of prototype pump is %3.1f rpm\n(2)
```

Power developed by the prototype pump is %3i kW\n
 (3) Ratio of the flow rates of two pumps is %3.4f'
 ,Np,Pp,QpQm)

Scilab code Exa 7.6 HEAD SPEED AND SCALE RATIO

```

1  clc
2  clear
3  //input data
4  Hp=85//Head of the prototype in m
5  Qp=(20000/3600)//Flow rate of the prototype in m^3/s
6  Np=1490//Speed of the prototype in rpm
7  Dp=1.2//Diameter of the prototype in m
8  dp=714//Density of the prototype fluid in kg/m^3
9  Pp=4//Power of the prototype in MW
10 Pm=500*10^-3//Power of the model in MW
11 Qm=0.5//Flow rate of the prototype in m^3/s
12 dm=1000//Density of the model fluid (water) in kg/m
    ^3
13
14 //calculations
15 NpNm=(Qp/Qm)//Ratio of the speeds of the prototype
    and the model in terms of (Dm/Dp)^(3)
16 DmDp=1/(((NpNm)^(3))*(dp/dm)*(Pm/Pp))^(1/4)//The
    ratio of the diameters of model and the prototype
    or the scale ratio
17 NmNp=1/(NpNm*((DmDp)^(3)))//The speed ratio or the
    ratio of speeds of the model and the prototype
18 HmHp=((1/NmNp)^(2))*((1/DmDp)^(2))//The head ratio
    or the ratio of heads of the model and the
    prototype
19
20 //output
21 printf('(1)The head ratio of the model is %3.1f\n(2)
    The speed ratio of the model is %3.1f\n(3)The
  
```

```
    scale ratio of the model is %3.1f', HmHp, NmNp, DmDp
)
```

Scilab code Exa 7.7 SPEED AND DISCHARGE OF THE MODEL

```
1  clc
2  clear
3  //input data
4  Np=400//The speed of the prototype in rpm
5  Qp=1.7//The discharge of the prototype in m^3/s
6  Hp=36.5//The head of the prototype in m
7  Pp=720//The power input of the prototype in kW
8  Hm=9//The head of the model in m
9  DmDp=1/6//The scale of model to prototype
10
11 //calculations
12 Nm=((Hm/Hp)^(1/2))*(1/DmDp)*Np//Speed of the model
    in rpm
13 Qm=((DmDp)^(3))*(Nm/Np)*(Qp)//Discharge of the model
    in m^3/s
14 Pm=((DmDp)^(5))*((Nm/Np)^(3))*Pp//Power required by
    the model in kW
15
16 //output
17 printf('(a)Speed of the model is %3.2f rpm\n(b)
    Discharge of the model is %3.4f m^3/s\n(c)Power
    required by the model is %3.2f kW', Nm, Qm, Pm)
```

Scilab code Exa 7.8 IMPELLER DIAMETER OF PUMP2

```
1  clc
2  clear
3  //input data
```



```

4 N1=1000//The running speed of the pump-1 in rpm
5 D1=0.3//The impeller diameter of pump-1 in m
6 Q1=0.02//The discharge of pump-1 in m^3/s
7 H1=15//The head developed by the pump-1 in m
8 N2=1000//The running speed of the pump-2 in rpm
9 Q2=0.01//The discharge of pump-2 in m^3/s
10
11 //calculations
12 D2=(((Q2/Q1)*(N1/N2))^(1/3))*(D1)//Impeller diameter
    of the pump-2 in m
13 H2=(((D2/D1)*(N2/N1))^(2))*(H1)//Head developed by
    the pump-2 in m
14
15 //output
16 printf('(a)Impeller diameter of the pump-2 is %3.3f
    m\n(b)Head developed by the pump-2 is %3.2f m',D2
    ,H2)

```

Scilab code Exa 7.9 SPECIFIC SPEEDS

```

1 clc
2 clear
3 //input data
4 DmDp=1/10//The model ratio to prototype
5 Pm=1.84//Power developed by the model in kW
6 Hm=5//Head developed by the model in m
7 Nm=480//Speed of the model in rpm
8 Hp=40//Head developed by the prototype in m
9
10 //calculations
11 Np=(((Hp/Hm)^(1/2))*(DmDp)*(Nm))//Speed of the
    prototype in rpm
12 Pp=(((1/DmDp)^(5))*((Np/Nm)^(3))*Pm)//Power developed
    by the prototype in kW
13 Nsp=(((Np*((Pp)^(1/2)))/((Hp)^(5/4)))//Specific speed

```

```

    of the prototype
14 Nsm=((Nm*((Pm)^(1/2)))/((Hm)^(5/4)))//Specific speed
    of the prototype
15
16 //output
17 printf('(a)Power developed by the prototype is %3i
    kW\n(b)Speed of the prototype is %3.2f rpm\n(c)
    Specific speed of the prototype is %3.1f\n(d)
    Specific speed of the model is %3.1f\n Thus the
    specific speed of the model is equal to the
    prototype and thus it is verified ',Pp,Np,Nsp,Nsm)

```

Scilab code Exa 7.10 SPEED DISCHARGE AND POWER

```

1  clc
2  clear
3  //input data
4  DmDp=1/10//The model ratio to prototype
5  Hm=5//The head developed by the model in m
6  Hp=8.5//The head developed by the prototype in m
7  Pp=8000*10^3//The power developed by the prototype
    in W
8  Np=120//The speed of running of the prototype in rpm
9  d=1000//density of the water in kg/m^3
10 g=9.81//Acceleration due to gravity in m/s^2
11 n0=0.85//Overall efficiency of the prototype
12
13 //calculations
14 Nm=((Hm/Hp)^(1/2))*(1/DmDp)*(Np)//Speed of the model
    in rpm
15 Qp=Pp/(d*g*n0*Hp)//Discharge from the prototype in m
    ^3/s
16 Qm=((DmDp)^(3))*(Nm/Np)*(Qp)//Discharge from the
    model in m^3/s
17 Pm=((DmDp)^(5))*((Nm/Np)^(3))*(Pp)*10^-3//Power of

```

```

    the model in kW
18
19 //output
20 printf('(a)Speed of the model is %3.1f rpm\n(b)
    Discharge from the model is %3.3f m^3/s\n(c)Power
    of the model is %3.1f kW',Nm,Qm,Pm)

```

Scilab code Exa 7.11 SPEED AND POWER DEVELOPED

```

1  clc
2  clear
3  //input data
4  P1=6600//Initial power developed by the turbine in
    kW
5  N1=100//Initial speed of the turbine in rpm
6  H1=30//Initial head of the turbine in m
7  H2=18//Final head of the turbine in m
8
9  //calculations
10 N2=N1*((H2/H1)^(1/2))//The final speed of the
    turbine in rpm
11 P2=P1*((H2/H1)^(3/2))//The final power developed by
    the turbine in kW
12
13 //output
14 printf('(1)The final speed of the turbine is %3.2f
    rpm\n(2)The final power developed by the turbine
    is %3i kW',N2,P2)

```

Scilab code Exa 7.12 PERFORMANCE OF TURBINE

```

1  clc
2  clear

```

```

3 //input data
4 H1=25//The initial head on the turbine in m
5 N1=200//The initial speed of the turbine in rpm
6 Q1=9//The initial discharge of the turbine in m^3/s
7 n0=0.9//Overall efficiency of the turbine
8 H2=20//The final head on the turbine in m
9 d=1000//density of the water in kg/m^3
10 g=9.81//Acceleration due to gravity in m/s^2
11
12 //calculations
13 N2=N1*((H2/H1)^(1/2))//The final speed of the
    turbine in rpm
14 Q2=Q1*((H2/H1)^(1/2))//The final discharge of the
    turbine in m^3/s
15 P1=n0*d*g*Q1*H1*10^-3//Power produced by the turbine
    initially in kW
16 P2=P1*((H2/H1)^(3/2))//Power produced by the turbine
    finally in kW
17
18 //output
19 printf('(a)The final speed of the turbine is %3.2f
    rpm\n(b)The final discharge of the turbine is %3
    .2f m^3/s\n(c)Power produced by the turbine
    initially is %3.3f kW\n(d)Power produced by the
    turbine finally is %3.2f kW',N2,Q2,P1,P2)

```

Scilab code Exa 7.13 SPECIFIC SPEED

```

1 clc
2 clear
3 //input data
4 P1=5000*10^3//The initial power produced in W
5 H1=250//The initial head produced in m
6 N1=210//The initial speed of turbine in rpm
7 n0=0.85//Overall efficiency of the turbine

```

```

8 H2=160//The final head produced in m
9 d=1000//density of the water in kg/m^3
10 g=9.81//Acceleration due to gravity in m/s^2
11
12
13 //calculations
14 Nu=N1/((H1)^(1/2))//The unit speed of the turbine
15 Pu=P1/((H1)^(3/2))*10^-3//The unit power of the
    turbine
16 Q1=P1/(d*g*n0*H1)//The initial discharge of the
    turbine in m^3/s
17 Qu=Q1/((H1)^(1/2))//The unit discharge of the
    turbine
18 Q2=Qu*((H2)^(1/2))//The final discharge of the
    turbine in m^3/s
19 N2=Nu*((H2)^(1/2))//The final speed of the turbine
    in rpm
20 P2=Pu*((H2)^(3/2))//The final power of the turbine
    in kW
21 Ns=(N2*((P2)^(1/2)))/((H2)^(5/4))//The specific
    speed of the turbine
22
23 //output
24 printf('(a)The unit speed of the turbine is %3.2f\n(
    b)The unit power of the turbine is %3.3f\n(c)The
    unit discharge of the turbine is %3.3f\n(d)The
    final discharge of the turbine is %3.2f m^3/s\n(e
    )The final speed of the turbine is %3.2f rpm\n(f)
    The final power of the turbine is %3.1f kW\n(g)
    The specific speed of the turbine is %3.2f ',Nu,Pu
    ,Qu,Q2,N2,P2,Ns)

```

Chapter 8

HYDRAULIC PUMPS

Scilab code Exa 8.1 TORQUE DELIVERED

```
1  clc
2  clear
3  //input data
4  D=1.3//Diameter of the pump in m
5  Q=3.5/60//Discharge of water by pump in m^3/s
6  U2=10//Tip speed of pump in m/s
7  Cr2=1.6//Flow velocity of water in pump in m/s
8  b2=30//Outlet blade angle tangent to impeller
   periphery in degree
9  Cx1=0//Whirl velocity at inlet in m/s
10 U=10//Tip speed of pump in m/s
11 d=1000//Density of water in kg/m^3
12 g=9.81//Acceleration due to gravity in m/s^2
13
14 //calculations
15 Wx2=Cr2/tand(b2)//Exit relative velocity in m/s
16 E=(U2/g)*(U2-(Wx2))//Euler head in m or W/(N/S)
17 m=d*Q//Mass flow rate of water in kg/s
18 W=E*m*g//Power delivered in W
19 r=D/2//Radius of the pump in m
20 T=W/(U/r)//Torque delivered in Nm
```

```

21
22 //output
23 printf('Torque delivered by the impeller is %3.1f Nm
    ',T)

```

Scilab code Exa 8.2 THEORETICAL HEAD

```

1  clc
2  clear
3  //input data
4  b2=30//Impeller blade angle to the tangent at
    impeller outlet in degree
5  d=0.02//Blade depth in m
6  D=0.25//Blade diameter in m
7  N=1450//Pump rotation speed in rpm
8  Q=0.028//Flow rate of the pump in m^3/s
9  sf=0.77//Slip factor
10 g=9.81//Acceleration due to gravity in m/s^2
11
12 //calculations
13 A=3.1415*d*D//Flow area in m^2
14 Cr2=Q/A//Flow velocity in m/s
15 Wx2=Cr2/tand(b2)//Exit relative velocity in m/s
16 U2=(3.14*D*N)/60//Tip speed of pump in m/s
17 Cx2=U2-Wx2//Absolute whirl component at exit in m/s
18 E=(U2*Cx2)/g//Euler head with no whirl at inlet in m
19 Cx21=sf*Cx2//Actual value of component of absolute
    value in tangential direction in m/s
20 Es=sf*E//Theoretical head with slip in m
21 Z=(3.145*sind(b2))/((1-sf)*(1-((Cr2/U2)*cotd(b2))))
    //Number of blades required based on stodola slip
    factor
22
23 //output
24 printf('(a) Theoretical head with slip is %3.2f m\n(b

```

)Number of blades required is %3.f',Es,Z)

Scilab code Exa 8.3 DISCHARGE

```
1  clc
2  clear
3  //input data
4  D2=0.4//Outer diameter of impeller in m
5  b2=0.05//Outlet width of impeller in m
6  N=800//Running speed of pump in rpm
7  Hm=16//Working head of pump in m
8  b22=40//Vane angle at outlet in degree
9  nm=0.75//Manometric efficiency
10 g=9.81//Acceleration due to gravity in m/s^2
11
12 //calculations
13 U2=(3.1415*D2*N)/60//Impeller tip speed in m/s
14 Cx2=(g*Hm)/(U2*nm)//Absolute whirl component at exit
    in m/s
15 Wx2=U2-Cx2//Exit relative velocity in m/s
16 Cr2=Wx2*tand(b22)//Flow velocity of water in pump in
    m/s
17 A=3.14*D2*b2//Area of flow in m^2
18 Q=A*Cr2//Discharge of the pump in m^3/s
19
20 //output
21 printf('The discharge of the pump is %3.4f m^3/s',Q)
```

Scilab code Exa 8.4 VANE INLET ANGLE

```
1  clc
2  clear
3  //input data
```



```

4 D2D1=2//The ratio of outer and inner diameter
5 N=1200//The running speed of pump in rpm
6 Hm=75//Total head producing work in m
7 Cr1=3//Flow velocity through impeller at inlet in m/
  s
8 Cr2=Cr1//Flow velocity through impeller at outlet in
  m/s
9 b22=30//Vanesset back angle at outlet in degree
10 D2=0.6//Outlet diameter of impeller in m
11 d=1000//Density of water in kg/m^3
12 b2=0.05//Width of impeller at outlet in m
13 g=9.81//Acceleartion due to gravity in m/s^2
14
15 //calculations
16 D1=D2/D2D1//Inlet diameter of impeller in m
17 U1=(3.1415*D1*N)/60//Impeller tip speed at inlet in
  m/s
18 b11=atand(Cr1/U1)//Vane angle at inlet in degree
19 U2=(3.1415*D2*N)/60//Impeller tip speed at exit in m
  /s
20 A=3.1415*D2*b2//Area of flow in m^2
21 Q=A*Cr2//Discharge of the pump in m^3/s
22 m=d*Q//Mass flow rate of water in kg/s
23 Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
24 Cx2=U2-Wx2//Absolute whirl component at exit in m/s
25 W=m*U2*Cx2*10^-3//Work done per second in kW
26 nm=Hm/((U2*Cx2)/g)//Manometric efficiency
27
28 //output
29 printf('(a)Vane angle at inlet is %3.3f degree\n(b)
  Work done per second is %3.2f kW\n(c)Manometric
  efficiency is %3.4f',b11,W,nm)

```

Scilab code Exa 8.5 ANGLES AND EFFICIENCIES

```

1  clc
2  clear
3  //input data
4  Q=75//Discharge from the pump in l/s
5  D1=0.1//Inlet diameter of the pump in m
6  D2=0.29//Outlet diameter of the pump in m
7  Hm=30//Total head producing work in m
8  N=1750//Speed of the pump in rpm
9  b1=0.025//Width of impeller at inlet per side in m
10 b2=0.023//Width of impeller at outlet in total in m
11 a11=90//The angle made by the entering fluid to
    impeller in degree
12 b22=27//Vanesset back angle at outlet in degree
13 Qloss=2.25//Leakage loss in l/s
14 ml=1.04//Mechanical loss in kW
15 cf=0.87//Contraction factor due to vane thickness
16 n0=0.55//Overall efficiency
17 d=1000//Density of water in kg/m^3
18 g=9.81//Acceleration due to gravity in m/s^2
19
20 //calculations
21 U1=(3.1415*D1*N)/60//Blade inlet speed in m/s
22 A1=3.1415*D1*b1*cf*10^3//Area of flow at inlet in m
    ^2
23 Qt=Q+Qloss//Total quantity of water handled by pump
    in l/s
24 Qts=Qt/2//Total quantity of water handled by pump
    per side in l/s
25 Cr1=(Qts*10^-3)/(A1*10^-3)//Flow velocity through
    impeller at inlet in m/s
26 b11=atan(Cr1/U1)//Inlet vane angle in degree
27 A2=3.1415*D2*(b2/2)*cf*10^3//Area of flow at outlet
    in m^2 here b2 is calculated per side
28 Cr2=Qts/A2//Velocity of flow at outlet in m/s
29 U2=(3.1415*D2*N)/60//Peripheral speed at outlet in m
    /s
30 Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
31 Cx2=U2-Wx2//Absolute whirl component at exit in m/s

```

```

32 a22=atand(Cr2/Cx2)//The absolute water angle at
    outlet in degree
33 C2=Cr2/sind(a22)//Absolute velocity of water at exit
    in m/s
34 nh=Hm/((U2*Cx2)/g)//Manometric efficiency
35 nv=Q/Qt//Volumetric efficiency
36 SP=(d*g*(Q*10^-3/2)*Hm)/n0*10^-3//Shaft power in kW
37 nm=(SP-m1)/SP//Mechanical efficiency
38
39 //output
40 printf('(a)Inlet vane angle is %3.2f degree\n(b)The
    absolute water angle is %3.2f degree\n(c)Absolute
    velocity of water at exit is %3.2f m/s\n(d)
    Manometric efficiency is %3.3f\n(e)Volumetric
    efficiency is %3.4f\n(f)Mechanical efficiency is
    %3.3f ',b11 ,a22 ,C2 ,nh ,nv ,nm)

```

Scilab code Exa 8.6 MANOMETRIC HEAD AND OVERALL EFFICIENCY

```

1  clc
2  clear
3  //input data
4  Hi=0.25//Vaccum gauge reading in m of Hg vaccum
5  P0=1.5//Pressure gauge reading in bar
6  Z01=0.5//Effective height between gauges in m
7  P=22//Power of electric motor in kW
8  Di=0.15//Inlet diameter in m
9  Do=0.15//Outlet diameter in m
10 Q=0.1//Discharge of pump in m^3/s
11 dHg=13600//Density of mercury in kg/m^3
12 dw=1000//Density of water in kg/m^3
13 g=9.81//Acceleration due to gravity in m/s^2
14
15 //calculations
16 Pi=dHg*g*Hi//Inlet pressure in N/m^2 vaccum

```

```

17 Po=P0*10^5//Outlet pressure in N/m^2
18 V0=Q/((3.1415*Do^2)/4)//Velocity of water in
    delivery pipe in m/s
19 Vi=V0//velocity of water in suction pipe in m/s
20 Hm=((Po+Pi)/(dw*g))+((V0^2-Vi^2)/(2*g))+(Z01)//
    Manometric head in m
21 n0=(dw*g*Q*Hm)/(P*10^3)//Overall efficiency
22
23 //output
24 printf('(a)Manometric head is %3.2f m\n(b)Overall
    efficiency is %3.3f',Hm,n0)

```

Scilab code Exa 8.7 IMPELLER DIAMETER

```

1 clc
2 clear
3 //input data
4 Hm=20//Head against which work is produced in pump
    in m
5 b22=45//Vanes set back angle at outlet in degree
6 N=600//Rotating speed of pump in rpm
7 Cr1=2//Flow velocity through impeller at inlet in m/
    s
8 Cr2=Cr1//Flow velocity through impeller at outlet in
    m/s
9 g=9.81//acceleration due to gravity in m/s^2
10
11 //calculations
12 Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
13 U2=(4+(16+(4*3*792.8))^(1/2))/(2*3)// Blade outlet
    speed in m/s
14 //The above equation is obtained by solving
15 //Cx2=U2-Wx2 //Absolute whirl component at
    exit in m/s
16 //C2=(Cx2^2+Cr2^2)^(1/2) //Absolute velocity

```

```

of water at exit in m/s
17 //Hm=(U2*Cx2/g) - ((C2^2)/(4*g)) //Total head
producing work in m
18 //3*(U2^2) - (4*U2) - 792.8=0
19 D2=(60*U2)/(3.1415*N) //Impeller diameter in m
20
21 //output
22 printf('The impeller diameter is %3.4f m',D2)

```

Scilab code Exa 8.8 POWER REQUIRED

```

1 clc
2 clear
3 //input data
4 n0=0.7 //Overall efficiency
5 Q=0.025 //Discharge of water by the pump in m^3/s
6 H=20 //Height of supplied by the pump in m
7 D=0.1 //Diameter of the pump in m
8 L=100 //Length of the pipe in m
9 f=0.012 //Friction coefficient
10 g=9.81 //Acceleration due to gravity in m/s^2
11 d=1000 //Density of water in kg/m^3
12
13 //calculations
14 V0=Q/((3.1415/4)*D^2) //Velocity of water in the pipe
in m/s
15 hf0=(4*f*L*V0^2)/(2*g*D) //Loss of head due to
friction in pipe in m
16 Hm=H+hf0+(V0^2/(2*g)) //Manometric head in m
17 P=(d*g*Q*Hm)/(n0)*10^-3 //Power required to drive the
pump in kW
18
19 //output
20 printf('Power required to drive the pump is %3.2f kW
',P)

```

Scilab code Exa 8.9 RISE IN PRESSURE IN THE IMPELLER

```
1  clc
2  clear
3  //input data
4  Q=0.015//Discharge of water in pump in m^3/s
5  D1=0.2//Internal diameter of the impeller in m
6  D2=0.4//External diameter of the impeller in m
7  b1=0.016//Width of impeller at inlet in m
8  b2=0.008//Width of impeller at outlet in m
9  N=1200//Running speed of the pump in rpm
10 b22=30//Impeller vane angle at outlet in degree
11 g=9.81//Acceleration due to gravity in m/s^2
12 d=1000//Density of water in kg/m^3
13
14 //calculations
15 printf('From velocity triangles the following values
        have been deduced')
16 a11=90//The absolute water angle at inlet in degree
17 Cx1=0//Absolute whirl component at inlet in m/s
18 A1=3.1415*D1*b1//Area of flow at inlet in m^2
19 Cr1=Q/A1//Flow velocity through impeller at inlet in
    m/s
20 C1=Cr1//Absolute velocity at inlet in m/s
21 A2=3.1415*D2*b2//Area of flow at outlet in m^2
22 Cr2=Q/A2//Flow velocity through impeller at outlet
    in m/s
23 U2=(3.1415*D2*N)/60//Blade outlet speed in m/s
24 Cx2=U2-(Cr2/tand(b22))//Absolute whirl component at
    outlet in m/s
25 C2=(Cx2^2+Cr2^2)^(1/2)//Velocity at impeller exit in
    m/s
26 Ih1=((Cx2*U2)/g)-((C2^2)/(2*g))+((C1^2)/(2*g))//
    Pressure rise in impeller in m
```

```

27
28 //output
29 printf('\n\nThe rise in pressure in the impeller is
    %3.3 f m',Ih1)

```

Scilab code Exa 8.10 EXIT BLADE ANGLE

```

1  clc
2  clear
3  //input data
4  Ih1=3//Head loss in impeller in m
5  Cr2=4.64//Flow velocity through impeller at outlet
    in m/s
6  U2=30//Blade outlet speed in m/s
7  dPi=35.3//Difference in pressure gauge readings at
    impeller inlet and outlet in m of water
8  Pg=4.7//Pressure gain in the casing in m of water
9  n=0.385//Part of absolute kinetic energy converted
    into pressure gain
10 g=9.81//Acceleration due to gravity in m/s^2
11 d=1000//Density of water in kg/m^3
12 ss=0.85//Slip coefficient
13
14 //calculations
15 Kei=Pg/n//Kinetic energy at impeller exit in m/s
16 C2=((Kei)*2*g)^(1/2)//Velocity at impeller exit in m
    /s
17 Cx22=(C2^2-Cr2^2)^(1/2)//Absolute whirl component at
    outlet with fluid slip in m/s
18 Cx2=Cx22/ss//Ideal absolute whirl velocity in m/s
19 b22=atand(Cr2/(U2-Cx2))//Blade angle at exit in
    degree
20 Wm=ss*U2*Cx2//Euler work input in J/kg
21 nm=dPi/(U2*Cx22/g)//Manometric efficiency
22 dP=(U2*Cx22/g)-(Ih1)-(C2^2/(2*g))//Pressure rise in

```

```

    impeller in m
23
24 //output
25 printf('(a)\n    Exit blade angle is %3.2f degree\n
    Euler work input is %3.2f J/kg\n(b) Manometric
    efficiency is %3.4f\n(c) Pressure rise in the
    impeller is %3.3f m', b22, Wm, nm, dP)

```

Scilab code Exa 8.11 VOLUME FLOW RATE THROUGH IMPELLER

```

1  clc
2  clear
3  //input data
4  r1=0.051//Eye radius of the impeller in m
5  D2=0.406//Outer diameter of the impeller in m
6  b11=(90-75)//Inlet blade angle measured from
    tangential flow direction in degree
7  b22=(90-83)//Outlet blade angle measured from
    tangential flow direction in degree
8  b=0.064//Blade depth in m
9  Cx1=0//Inlet whirl velocity in m/s
10 nh=0.89//Hydraulic efficiency
11 g=9.81//Acceleration due to gravity in m/s^2
12 d=1000//Density of water in kg/m^3
13 N=900//Rotating speed of impeller in rpm
14
15 //calculations
16 w=(2*3.1415*N)/60//Angular velocity at inlet in rad/
    s
17 U1=(w*r1)//Inlet tangential impeller velocity in m/s
18 C1=U1*tand(b11)//Velocity at impeller inlet in m/s
19 A=2*3.1415*r1*b//Area of flow through the pump in m
    ^2
20 Cr1=C1//Flow velocity through impeller at inlet in m
    /s

```



```

21 Q=A*Cr1//Volume flow through the pump in m^3/s
22 r2=D2/2//Outer radius of the impeller in m
23 Cr2=(r1*Cr1)/r2//Flow velocity through impeller at
    outlet in m/s
24 U2=w*r2//Outlet tangential impeller velocity in m/s
25 Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
26 E=(U2/g)*(U2-Wx2)//Theoretical head developed in m
27 Hm=nh*E//Total stagnation head developed by the pump
    in m
28 dP021=Hm*d*g*10^-3//Total pressure head coefficient
    in kPa
29 Cx2=U2-(Cr2/tand(b22))//Absolute whirl velocity in m
    /s
30 C2=(Cr2^2+Cx2^2)^(1/2)//Velocity at impeller exit in
    m/s
31 dP21=(Hm-(((C2^2)-(C1^2))/(2*g)))*d*g*10^-3//The
    static pressure head in kPa
32 P=d*g*Q*Hm*10^-3//Power given to the fluid in kW
33 Ps=P/nh//Input power to impeller in kW
34
35 //output
36 printf('(a)Volume flow rate through the impeller is
    %3.4f m^3/s\n(b)\n    stagnation pressure rise
    across the impeller is %3.1f kPa\n    Static
    pressure rise across the impeller is %3.1f kPa\n(
    c)Power given to fluid is %3.2f kW\n(d)Input
    power to impeller is %3.2f kW',Q,dP021,dP21,P,Ps)

```

Scilab code Exa 8.12 IMPELLER DIAMETER

```

1 clc
2 clear
3 //input data
4 Q=0.04//Discharge of the pump design in m^3/s
5 Ns=0.075//Specific speed in rev

```

```

6  b22=(180-120)//Outlet angle with the normal in
    degree
7  H=35//Distance to which pumping of water is done in
    m
8  Dp=0.15//Diameter of suction and delivery pipes in m
9  L=40//Combined length of suction and delivery pipes
    in m
10 WD=1/10//Width to diameter ratio at outlet of
    impeller
11 f=0.005//Friction factor
12 g=9.81//Acceleration due to gravity in m/s^2
13 nh=0.76//Hydraulic efficiency neglecting the slip
14 n=0.06//Percentage occupied by blades on
    circumference area
15
16 //calculations
17 A=(3.1415/4)*(Dp^2)//Area of flow in pipe in m^2
18 V=Q/A//Velocity in the pipes in m/s
19 OL=3*V^2/(2*g)//Other losses in the pipes in m
20 TL=(4*f*L*V^2/(2*g*Dp))+(OL)//Total losses in a pipe
    in m
21 TH=TL+H//Total required head in m
22 N=(Ns*((g*H)^(3/4)))/((Q)^(1/2))//The speed of the
    pump in rev/s
23 Ao=3.1415*WD*(1-n)//Flow area perpendicular to
    impeller outlet periphery in terms of D^2 in m^2
    In this the area is calculated using
    only the circumferential area without blades
24 Cr2=Q/Ao//Flow velocity through impeller at outlet
    in m/s
25 U2=3.1415*N//Outlet tangential impeller velocity in
    m/s in terms of D
26 Cx2=(g*H)/(U2*nh)//Absolute whirl velocity in m/s
27
28 //The following steps are for calculating the cubic
    root equation in D
29 //This is obtained by solving      tand(b22)=(Cr2/(Cx2
    -U2))    all values are substituted in terms of D

```

```

30 //The final equation which is obtained is      D
      ^3-0.0495D+0.0008=0
31 //The above equation is solved using the following
      formulae
32
33 a=0//Coefficient of D^2 in the above equation
34 b=-0.0511//Coefficient of D in the above equation
35 c=0.00083//Constant term in above equation
36 q=c+((2*(a^3))/27)-(a*b/3)//Constant in solving the
      cubic equation
37 p=((3*b)-(a^2))/3//Constant in solving the cubic
      equation
38 d=(p/2)^2+(q/3)^3//Constant in solving the cubic
      equation
39 u=((-q/2)+(d^(1/2)))^(1/3)//Constant in solving the
      cubic equation
40 v=((-q/2)-(d^(1/2)))^(1/3)//Constant in solving the
      cubic equation
41 D=(u+v)/2//Impeller diameter in m
42
43 //output
44 printf('The pump impeller diameter is %3.3f m',D)

```

Scilab code Exa 8.13 SPECIFIC SPEED

```

1  clc
2  clear
3  //input data
4  N=2875//Speed of the pump in rpm
5  Q=57.2/3600//Discharge of the pump in m^3/s
6  Hm=42.1//Total head developed by the pump in m
7  d=1000//Density of the water in kg/m^3
8  g=9.81//Acceleration due to gravity in m/s^2
9  n=0.76//Efficiency of the pump
10

```

```

11 //calculations
12 Ns=(N*Q^(1/2))/(Hm^(3/4))//Specific speed of the
    pump
13 P=((d*g*Q*Hm)/n)*10^-3//Power input in kW
14
15 //calculations
16 printf('(a) Specific speed of the pump is %3.f\n(b)
    Power input is %3.3f kW',Ns,P)

```

Scilab code Exa 8.14 MANOMETRIC EFFICIENCY

```

1  clc
2  clear
3  //input data
4  D1=0.6//Inlet impeller diameter in m
5  D2=1.2//Outlet impeller diameter in m
6  Cr2=2.5//Radial flow velocity in m/s
7  N=200//Running speed of the pump in rpm
8  Q=1.88//Discharge of the pump in m^3/s
9  Hm=6//Head which the pump has to overcome in m
10 b22=26//Vane angle at exit at tangent to impeller in
    degree
11 d=1000//Density of the water in kg/m^3
12 g=9.81//Acceleration due to gravity in m/s^2
13
14 //calculations
15 U2=(3.1415*D2*N)/60//Outlet tangential impeller
    velocity in m/s
16 Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
17 Cx2=U2-Wx2//Absolute whirl velocity in m/s
18 nm=(Hm/(U2*Cx2/g))//Manometric efficiency
19 N1s=((2*g*Hm*60^2)/((3.1415^2)*((1.2^2)-(0.6^2))))
    ^(1/2)//Least starting speed of the pump in rpm
20
21 //output

```

```

22 printf('(1)Manometric efficiency is %3.3f\n(2)Least
    speed to start the pump is %3.2f rpm',nm,N1s)

```

Scilab code Exa 8.15 HYDRAULIC OR MANOMETRIC EFFICIENCY

```

1  clc
2  clear
3  //input data
4  D2=1.25//External diameter of the impeller in m
5  D1=0.5//Internal diameter of the impeller in m
6  Q=2//Discharge of the pump in m^3/s
7  Hm=16//Head over which pump has to operate in m
8  N=300//Running speed of the pump in rpm
9  b22=30//Angle at which vanes are curved back in
    degree
10 Cr1=2.5//Flow velocity through impeller at inlet in
    m/s
11 Cr2=Cr1//Flow velocity through impeller at outlet in
    m/s
12 d=1000//Density of the water in kg/m^3
13 g=9.81//Acceleration due to gravity in m/s^2
14
15 //calculations
16 U2=(3.1415*D2*N)/60//Outlet tangential impeller
    velocity in m/s
17 Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
18 Cx2=U2-Wx2//Absolute whirl velocity in m/s
19 nm=(Hm*g)/(U2*Cx2)//Manometric or hydraulic
    efficiency
20 m=d*Q//Mass flow rate of water in kg/s
21 W=m*U2*Cx2*10^-3//Fluid power developed by the
    impeller in kW
22 Ps=W//Power required by the pump in kW neglecting
    mechanical loses
23 N1s=((2*g*Hm)/(((3.1415/60)^2)*(D2^2-D1^2)))^(1/2)//

```

```

    Minimum starting speed of the pump in rpm
24
25 //output
26 printf('(a)Manometric or hydraulic efficiency is %3
    .3f \n(b)Power required by the pump is %3.2f kW\n
    (c)Minimum starting speed of the pump is %3.1f
    rpm ',nm ,Ps ,Nls)

```

Scilab code Exa 8.16 HEAT GENERATED BY PUMP

```

1  clc
2  clear
3  //input data
4  n=3//Number of stages
5  D2=0.4//Outlet impeller diameter in m
6  b2=0.02//Outlet impeller width in m
7  b22=45//Backward vanes angle at outlet in degree
8  dA=0.1//Reduction in circumferential area
9  nm=0.9//Manometric efficiency of the pump
10 Q=0.05//Discharge of the pump in m^3/s
11 N=1000//Running speed of the pump in rpm
12 n0=0.8//Overall efficiency of the pump
13 g=9.81//Acceleration due to gravity in m/s^2
14 d=1000//Density of water in kg/m^3
15
16 //calculations
17 A2=(1-dA)*3.1415*D2*b2//Area of flow at outlet in m
    ^2
18 Cr2=Q/A2//Flow velocity through impeller at outlet
    in m/s
19 U2=(3.1415*D2*N)/60//Outlet impeller tangential
    velocity in m/s
20 Wx2=Cr2//Exit relative velocity in m/s as tand(b22)
    =1
21 Cx2=U2-Wx2//Absolute whirl velocity in m/s

```

```

22 Hm=(nm*U2*Cx2)/g//Head over which pump has to
    operate in m
23 H=n*Hm//Total head generated by the pump in m
24 P=d*g*Q*Hm*n//Power output from the pump in W
25 Ps=P/n0*10^-3//Shaft power input in kW
26
27 //output
28 printf('(1)The head generated by the pump is %3.2f m
    \n(2)Shaft power input is %3.3f kW',H,Ps)

```

Scilab code Exa 8.17 NUMBER OF PUMPS

```

1  clc
2  clear
3  //input data
4  H=156//Total head operated by the pumps in m
5  N=1000//Running speed of the pump in rpm
6  Ns=20//Specific speed of each pump
7  Q=0.150//Discharge of the pump in m^3/s
8
9  //calculations
10 Hm=((N*(Q)^(1/2))/(Ns))^(4/3)//Head developed by
    each pump in m
11 n=H/Hm//Number of pumps
12
13 //output
14 printf('The number of pumps are %3.f',n)

```

Scilab code Exa 8.18 IMPELLER DIAMETER AND NUMBER OF STAGES

```

1  clc
2  clear
3  //input data

```

```

4 Q1=120//Discharge of each of the multi stage pump in
   parallel in first case in m3/s
5 Q2=450//Discharge of the multi stage pump in second
   case in m3/s
6 H1=16//Head of each stage in first case in m
7 D1=0.15//Diameter of impeller in first case in m
8 H=140//Total head developed by all pumps in second
   case in m
9 N1=1500//Running speed of the pump in rpm in first
   case
10 N2=1200//Running speed of the pump in rpm in second
   case
11 //calculations
12 H2=H1*((Q2/Q1)*((N2/N1)2))(4/6)//Head of each
   stage in second case in m
13 n=H/H2//Number of stages in second case
14 D2=D1*((N1/N2)(2)*(H2/H1))(1/2)//Diameter of
   impeller in second case in m
15
16 //output
17 printf('(a)number of stages required is %3.f\n(b)
   Diameter of impeller in the second case is %3.2 f
   m',n,D2)

```

Scilab code Exa 8.19 CAVITATION PARAMETER

```

1 clc
2 clear
3 //input data
4 H=36//Initial total head of the pump in m
5 Q1=0.05//Initial discharge of the pump in m3/s
6 H2=3.5//Sum of static pressure and velocity head at
   inlet in m
7 P01=0.75//Atmospheric pressure initially in m of Hg
8 Pvap1=1.8*103//Vapour pressure of water initially

```



```

    in Pa
9 Pvap2=830//Vapour pressure of water finally in Pa
10 P02=0.62//Atmospheric pressure finally in m of Hg
11 g=9.81//Acceleration due to gravity in m/s^2
12 dW=1000//Density of water in kg/m^3
13 dHg=13.6//Density of mercury in kg/m^3
14
15 //calculations
16 NPSH=H2-((Pvap1)/(dW*g))//Net positive suction head
    in m
17 s=NPSH/H//Cavitation parameter when pump develops
    same total head and discharge
18 dH1=(P01*dHg)-(s*H)-(Pvap1/(dW*g))//The height
    reduced in initial condition above supply in m
19 dH2=(P02*dHg)-(s*H)-(Pvap2/(dW*g))//The height
    reduced in final condition above supply in m
20 Z=dH1-dH2//The total height which the pump must be
    lowered at new location in m
21
22 //output
23 printf('(a)The cavitation parameter is %3.4f\n(b)\n
    The height reduced in initial condition above
    supply is %3.1f m\n    The height reduced in
    final condition above supply is %3.2f m\n    The
    total height which the pump must be lowered at
    new location is %3.2f m',s,dH1,dH2,Z)

```

Scilab code Exa 8.20 VANE ANGLE AT ENTRY

```

1 clc
2 clear
3 //input data
4 Dt=1//Impeller outlet diameter in m
5 Dh=0.5//Diameter of the boss in m
6 Ns=38//Specific speed of the pump

```

```

7 Ca=2//Velocity of the flow in m/s
8 H=6//Head which the pump has to drive in m
9
10 //calculations
11 A=(3.1415/4)*(Dt^2-Dh^2)//Area of flow in m^2
12 Q=A*Ca//Discharge of the pump in m^3/s
13 N=(Ns*H^(3/4))/(Q^(1/2))//Pump speed in rpm
14 U1=(3.1415*Dh*N)/60//Blade inlet speed in m/s
15 b1=atand(Ca/U1)//Vane angle at the entry of the pump
    when the flow is axial at inlet in degree
16
17 //output
18 printf('(a)Pump speed is %3.3f rpm\n(b)Vane angle at
    the entry of the pump when the flow is axial at
    inlet is %3.2f degree',N,b1)

```

Scilab code Exa 8.21 PUMP SPEED

```

1 clc
2 clear
3 //input data
4 Q=0.180//Discharge of the pump in m^3/s
5 H=2//Head developed by the pump in m
6 Ns=250//Specific speed of the pump
7 SR=2.4//Speed ratio of the pump
8 FR=0.5//Flow ratio of the pump
9 g=9.81//Acceleration due to gravity in m/s^2
10
11 //calculations
12 N=(Ns*(H^(3/4)))/(Q^(1/2))//Pump speed in rpm
13 U=SR*(2*g*H)^(1/2)//Peripheral velocity in m/s
14 D=(60*U)/(3.1415*N)//Runner diameter of the pump in
    m
15 Ca=FR*(2*g*H)^(1/2)//Velocity of flow in m/s
16 Dh=((D^2)-(Q*4/(Ca*3.14)))^(1/2)//Boss diameter of

```

```

    the pump in m
17
18 //output
19 printf('(a)Pump speed is %3.i rpm\n(b)Runner
    diameter of the pump is %3.2 f m\n(c)Boss diameter
    of the pump is %3.2 f m\n',N,D,Dh)

```

Scilab code Exa 8.22 JET PUMP EFFICIENCY

```

1  clc
2  clear
3  //input data
4  Hs=2.5//Height of the pipe above suction reservoir
    in m
5  H1=18//Height of the pipe below supply reservoir in
    m
6  H=2.7//Total height through which the pump lifts
    water in m
7  Q1=2.75//Discharge of water used from supply
    reservoir in l/s
8  Qt=7.51//Discharge of water totally delivered in l/s
9
10 //calculations
11 Hd=H-Hs//Height of the pipe from discharge reservoir
    in m
12 Qs=Qt-Q1//Discharge of water in delivery reservoir
    in l/s
13 nj=(Qs/Q1)*((Hs+Hd)/(H1-Hd))//Jet pump efficiency
14
15 //output
16 printf('The efficiency of the jet pump is %3.3 f',nj)

```

Chapter 9

HYDRAULIC TURBINES

Scilab code Exa 9.1 DIMENSIONLESS POWER SPECIFIC SPEED

```
1  clc
2  clear
3  //input data
4  H=91.5//Head of the pelton wheel at inlet in m
5  Q=0.04//Discharge of the pelton wheel in m3/s
6  N=720//Rotating speed of the wheel in rpm
7  Cv=0.98//Velocity coefficient of the nozzle
8  n0=0.8//Efficiency of the wheel
9  UC1=0.46//Ratio of bucket speed to jet speed
10 g=9.81//Acceleration due to gravity in m/s2
11 dw=1000//Density of water in kg/m3
12
13 //calculations
14 P=dw*g*H*Q*n0*10-3//Power developed in kw
15 C1=Cv*(2*g*H)(1/2)//Jet speed in m/s
16 U=UC1*C1//Wheel speed in m/s
17 w=(2*3.1415*N)/60//Angular velocity of the wheel in
    rad/s
18 D=(2*U)/w//Diameter of the wheel in m
19 A=Q/C1//Jet area in m2
20 d=((4*A)/3.1415)(1/2)//Jet diameter in m
```

```

21 Dd=D/d//Wheel to jet diameter ratio at centre line
    of the buckets
22 Nsp=((1/(g*H))^(5/4))*(((P*10^3)/dw)^(1/2))*(N/60)
    *2*3.1415//Dimensionless power specific speed in
    rad
23
24 //output
25 printf('(a)Wheel-to-jet diameter ratio at the centre
    line of the buckets is %3.1f \n(b)\n    The jet
    speed of the wheel is %3.2f m/s\n    Wheel speed
    is %3.1f m/s\n(c)Dimensionless power specific
    speed is %3.3f rad ',Dd,C1,U,Nsp)

```

Scilab code Exa 9.2 DISCHARGE OF TURBINE

```

1  clc
2  clear
3  //input data
4  H=500//Head over which pelton wheel works in m
5  P=13000//Power which pelton wheel produces in kW
6  N=430//Speed of operation of pelton wheel in rpm
7  n0=0.85//Efficiency of the wheel
8  g=9.81//Acceleration due to gravity in m/s^2
9  dw=1000//Density of water in kg/m^3
10 Cv=0.98//Velocity coefficient
11 UC=0.46//Speed ratio
12
13 //calculations
14 Q=(P*10^3)/(dw*g*H*n0)//Discharge of the turbine in
    m^3/s
15 C=Cv*(2*g*H)^(1/2)//Jet speed in m/s
16 U=UC*C//Wheel speed in m/s
17 D=(U*60)/(3.1415*N)//Wheel diameter in m
18 d=((Q/C)*(4/3.1415))^(1/2)//Diameter of the nozzle
    in m

```

```

19
20 //output
21 printf('(a) Discharge of the turbine is %3.2f m^3/s\n
      (b) Diameter of the wheel is %3.2f m\n(c) Diameter
      of the nozzle is %3.3f m',Q,D,d)

```

Scilab code Exa 9.3 POWER AVAILABLE AT THE NOZZLE

```

1  clc
2  clear
3  //input data
4  D=0.8 //Mean diameter of the bucket in m
5  N=1000 //Running speed of the wheel in rpm
6  H=400 //Net head on the pelton wheel in m
7  Q=0.150 //Discharge through the nozzle in m^3/s
8  g=9.81 //Acceleration due to gravity in m/s^2
9  UC1=0.46 //Ratio of bucket speed to jet speed
10 dw=1000 //Density of water in kg/m^3
11 a=15 //Side clearance angle in degree
12
13 //calculations
14 m=dw*Q //Mass flow rate through the nozzle in kg/s
15 U=(3.1415*D*N)/60 //Wheel speed in m/s
16 C1=U/UC1 //Jet speed in m/s
17 P=(1/2)*m*C1^2*(10^-3) //Power available at the
      nozzle in kW
18 W1=C1-U //Relative inlet fluid velocity in m/s
19 W2=W1 //Relative exit fluid velocity in m/s assuming
      no loss of relative velocity
20 Wx2=W2*cosd(a) //Exit whirl velocity component in m/s
21 Cx2=Wx2-U //Absolute exit whirl velocity in m/s
22 Cx1=C1 //Absolute inlet whirl velocity in m/s
23 Wm=U*(Cx1+Cx2) //Work done per unit mass flow rate in
      W/(kg/s)
24 nH=(Wm/g)/((C1^2/2)/g) //Hydraulic efficiency

```

```

25
26 //output
27 printf('(a)Power available at the nozzle is %3.3f kW
    \n(b)Hydraulic efficiency is %3.3f',P,nH)

```

Scilab code Exa 9.4 OVERALL EFFICIENCY

```

1  clc
2  clear
3  //input data
4  n=2//Number of jets
5  SP=20000*0.736//Shaft power of the wheel in kW
6  D=0.15//Diameter of each jet in m
7  H=500//Net head on the turbine in m
8  Cv=1.0//Velocity coefficient
9  g=9.81//Acceleration due to gravity in m/s^2
10 d=1000//Density of water in kg/m^3
11
12 //calculations
13 C1=Cv*(2*g*H)^(1/2)//Velocity of each jet in m/s
14 A=(3.1415/4)*D^2//Area of each jet in m^2
15 Qj=A*C1//Discharge of each jet in m^3/s
16 Q=2*Qj//Total discharge in m^3/s
17 P=d*g*Q*H*10^-3//Power at turbine inlet in kW
18 no=SP/P//Overall efficiency
19
20 //output
21 printf('The overall efficiency of the turbine is %3
    .3f',no)

```

Scilab code Exa 9.5 THEORETICAL HYDRAULIC EFFICIENCY

```

1  clc

```

```

2 clear
3 //input data
4 a=170//Jet deflection angle in degree
5 K=1-0.12//Percentage of effective relative velocity
   after considering friction
6 UC1=0.47//Ratio of bucket speed to jet speed
7 GH=600//Gross head on the wheel in m
8 P=1250//Actual power developed by the wheel in kW
9 Hl=48//Head loss in nozzle due to pipe friction in m
10 D=0.9//Bucket circle diameter of the wheel in m
11 ATnH=0.9//The ratio between actual and calculated
   hydraulic efficiency
12 g=9.81//Acceleration due to gravity in m/s^2
13 dw=1000//Density of water in kg/m^3
14 Cv=0.98//Velocity coefficient
15
16 //calculations
17 H=GH-Hl//Net head after loses at entry to nozzle in
   m
18 C1=Cv*(2*g*H)^(1/2)//Jet speed in m/s
19 U=UC1*C1//Wheel bucket speed in m/s
20 N=(U*60)/(3.1415*D)//Wheel rotational speed in rpm
21 Wm=U*((C1-U)*(1-(K*cosd(a))))//Work done per unit
   mass flow rate in W/(kg/s)
22 Tnh=Wm/(C1^2/2)//Theoretical hydraulic efficiency
23 Anh=ATnH*Tnh//Actual hydraulic efficiency
24 m2=(P*10^3)/(Anh*(1/2)*C1^2)//Mass flow rate for
   both the nozzles in kg/s
25 m=m2/2//Mass flow rate of each nozzle in kg/s
26 d=((4*m)/(dw*C1*3.1415))^(1/2)//Nozzle diameter in m
27
28 //output
29 printf('(a)theoretical hydraulic efficiency is %3.2f
   \n(b)Wheel rotational speed is %3.f rpm\n(c)
   diameter of the nozzle is %3.4f m',Tnh,N,d)

```

Scilab code Exa 9.6 DIAMETER OF THE WHEEL

```
1  clc
2  clear
3  //input data
4  H=60//Head on the pelton wheel in m
5  N=200//Speed of the pelton wheel in rpm
6  P=100//Power developed by the pelton wheel in kW
7  Cv=0.98//Velocity coefficient
8  UC1=0.45//Speed ratio
9  n0=0.85//Overall efficiency of the wheel
10 g=9.81//Acceleration due to gravity in m/s^2
11 dw=1000//Density of water in kg/m^3
12
13 //calculations
14 C1=Cv*(2*g*H)^(1/2)//Velocity of the jet in m/s
15 U=UC1*(2*g*H)^(1/2)//Velocity of the buckets in m/s
16 D=(60*U)/(3.1415*N)//Diameter of the wheel in m
17 Q=(P*10^3)/(dw*g*H*n0)//Discharge of the wheel in m
    ^3/s
18 d=((4*Q)/(3.1415*C1))^(1/2)//Diameter of the jet in
    m
19 Z=15+(D/(2*d))+1//Number of buckets rounding off to
    nearest decimal as the final answer has a decimal
    value less than 0.5
20 w=5*d//Width of the buckets in m
21 de=1.2*d//Depth of the buckets in m
22
23 //output
24 printf('(a)Diameter of the wheel is %3.2f m\n(b)
    Diameter of the jet is %3.3f m\n(c)Number of
    buckets is %3.f\n(d)Size of the buckets is \n
    width of the bucket is %3.3f m\n    Depth of the
    bucket is %3.3f m',D,d,Z,w,de)
```

Scilab code Exa 9.7 DIAMETER OF WHEEL AND POWER DEVELOPED

```
1  clc
2  clear
3  //input data
4  N=300 //Running speed of the wheel in rpm
5  H=150 //OPerating head of the wheel in m
6  dD=1/12 //Ratio of nozzle diameter to wheel diameter
7  Cv=0.98 //Velocity coefficient
8  UC1=0.46 //Speed ratio
9  g=9.81 //Acceleration due to gravity in m/s^2
10 dw=1000 //Density of water in kg/m^3
11 n0=0.84 //Overall efficiency
12
13 //calculations
14 C1=Cv*(2*g*H)^(1/2) //Velocity of jet in m/s
15 U=UC1*(2*g*H)^(1/2) //Velocity of the wheel in m/s
16 D=(60*U)/(3.14*N) //Diameter of the wheel in m
17 d=D*dD //Diameter of the jet in m
18 Q=(3.1415/4)*(d^2)*C1 //Quantity of water required in
    m^3/s
19 Pa=dw*g*Q*H //Power available at the nozzle in kW
20 P=n0*Pa*10^-3 //Power developed in kW
21 disp(U)
22 //output
23 printf('(a)Diameter of the wheel is %3.2f m\n(b)
    Diameter of the jet is %3.3f m\n(c)Quantity of
    water required is %3.3f m^3/s\n(d)Power developed
    is %3.1f kW',D,d,Q,P)
```

Scilab code Exa 9.8 HYDRAULIC EFFICIENCY

```

1  clc
2  clear
3  //input data
4  N=1260//Rotational speed of the francis turbine in
      rpm
5  H=124//The net head in m
6  Q=0.5//Volume flow rate of the turbine in m3/s
7  r1=0.6//Radius of the runner in m
8  b1=0.03//Height of the runner vanes at inlet in m
9  b11=72//Angle of inlet guide vanes in radial
      direction in degree
10 g=9.81//Acceleration due to gravity in m/s2
11 dw=1000//Density of water in kg/m3
12 Cx2=0//Absolute exit whirl velocity in m/s as flow
      is radial at outlet
13
14 //calculations
15 m=dw*Q//Mass flow rate in kg/s
16 T1=-m*r1//Torque by the turbine in Nm in terms of
      Cx1
17 A=2*3.1415*r1*b1//Area at inlet in m2
18 Cr1=Q/A//Inlet flow velocity in m/s
19 Cx1=Cr1*tand(b11)//Absolute inlet whirl velocity in
      m/s
20 T=-T1*Cx1//Torque by water on the runner in Nm
21 w=(2*3.1415*N)/60//Angular velocity of the turbine
      in rad/s
22 W=T*w*10-3//Power exerted in kW
23 nH=W*103/(dw*g*Q*H)//Hydraulic efficiency
24
25 //output
26 printf('(a)Torque by water on the runner is %3.f Nm\
      n(b)Power exerted is %3i kW\n(c)Hydraulic
      efficiency is %3.3 f',T,W,nH)

```

Scilab code Exa 9.9 INLET GUIDE VANE ANGLE

```
1  clc
2  clear
3  //input data
4  n0=0.74//Overall efficiency
5  H=5.5//Net head across the turbine in m
6  P=125//Required Power output in kW
7  N=230//Speed of the runner in rpm
8  nH=(1-0.18)//Hydraulic efficiency
9  g=9.81//Acceleration due to gravity in m/s^2
10 dw=1000//Density of water in kg/m^3
11 U1=0.97*(2*g*H)^(1/2)//Runner tangential velocity in
    m/s
12 Cr1=0.4*(2*g*H)^(1/2)//Flow velocity in m/s
13
14 //calculations
15 Cx1=(nH*g*H)/U1//Absolute inlet whirl velocity in m/
    s    as flow is radial at outlet Cx2=0 in m/s
16 a11=atand(Cr1/Cx1)//Inlet guide vane angle in degree
17 b11=180+atand(Cr1/(Cx1-U1))//Angle of inlet guide
    vanes in radial direction in degree
18 D1=(U1*60)/(3.1415*N)//Runner inlet diameter in m
19 Q=(P*10^3)/(n0*dw*g*H)//Flow rate in m^3/s
20 b1=Q/(3.1415*D1*Cr1)//Height of runner in m
21
22 //output
23 printf('(a)Inlet guide vane angle is %3.1f degree\n(
    b)Angle of inlet guide vanes in radial direction
    is %3.1f degree\n(c)Runner inlet diameter is %3.3
    f m\n(d)Height of runner is %3.3f m',a11,b11,D1,
    b1)
```

Scilab code Exa 9.10 ABSOLUTE VELOCITY OF WATER AT ENTRY

```

1  clc
2  clear
3  //input data
4  D=1.4//Diameter of the turbine in m
5  N=430//Speed of the turbine in rpm
6  Cr1=9.5//Flow velocity without shock at runner in m/
   s
7  C2=7//Absolute velocity at the exit without whirl in
   /s
8  dSPH=62//Difference between the sum of static and
   potential heads at entrance to runner and at exit
   from runner in m
9  W=12250//Power given to runner in kW
10 Q=12//Flow rate of water from the turbine in m^3/s
11 H=115//Net head from the turbine in m
12 g=9.81//Acceleration due to gravity in m/s^2
13 dw=1000//Density of water in kg/m^3
14
15 //calculations
16 U1=(3.1415*D*N)/60//Runner tip speed in m/s
17 Cx1=(W*10^3)/(dw*Q*U1)//Absolute inlet velocity in m
   /s as flow is radial at outlet Cx2=0 in m/s
   as Cx2=0 as zero whirl at outlet
18 a1=atand(Cr1/Cx1)//Guide vane angle in degree
19 C1=(Cr1^2+Cx1^2)^(1/2)//Inlet velocity in m/s
20 b1=atand(Cr1/(Cx1-U1))//Runner blade entry angle in
   degree
21 dHr=dSPH+(((C1^2)-(C2^2))/(2*g))-(U1*Cx1/g)//Loss of
   head in the runner in m
22
23 //output
24 printf('(a)\n      (1)Guide vane angle at inlet is %3
   .1f degree\n      (2)Inlet absolute velocity of
   water at entry to runner is %3.1f m/s\n(b)Runner
   blade entry angle is %3.1f degree\n(c)Total Loss
   of head in the runner is %3.2f m',a1,C1,b1,dHr)

```

Scilab code Exa 9.11 RUNNER BLADE ANGLES

```
1  clc
2  clear
3  //input data
4  D1=0.9//External diameter of the turbine in m
5  D2=0.45//Internal diameter of the turbine in m
6  N=200//Speed of turbine running in rpm
7  b1=0.2//Width of turbine at inlet in m
8  Cr1=1.8//Velocity of flow through runner at inlet in
   m/s
9  Cr2=Cr1//Velocity of flow through runner at outlet
   in m/s
10 a11=10//Guide blade angle to the tangent of the
    wheel in degree
11 a22=90//Discharge angle at outlet of turbine in
    degree
12 g=9.81//Acceleration due to gravity in m/s^2
13 dw=1000//Density of water in kg/m^3
14
15 //calculations
16 C1=Cr1/sind(a11)//Absolute velocity of water at
    inlet of runner in m/s
17 Cx1=Cr1/tand(a11)//Velocity of whirl at inlet in m/s
18 U1=(3.1415*D1*N)/60//Runner tip speed at inlet in m/
    s
19 Wx1=Cx1-U1//Inlet whirl velocity component in m/s
20 W1=(Wx1^2+Cr1^2)^(1/2)//Relative velocity at inlet
    in m/s
21 b11=atand(Cr1/Wx1)//Runner blade entry angle in
    degree
22 U2=(3.1415*D2*N)/60//Runner tip speed at exit in m/s
23 b22=atand(Cr2/U2)//Runner blade exit angle in degree
24 b2=D1*b1/D2//Width of runner at outlet in m
```

```

25 Q=3.1415*D1*b1*Cr1//Discharge of water in turbine in
    m^3/s
26 m=dw*Q//Mass of water flowing through runner per
    second in kg/s
27 V2=Cr2//Velocity of water at exit in m/s
28 H=(U1*Cx1/g)+(V2^2/(2*g))//Head at the turbine inlet
    in m
29 W=m*U1*Cx1*10^-3//Power developed in kW
30 nH=(U1*Cx1/(g*H))//Hydraulic efficiency
31
32 //output
33 printf('(a)Absolute velocity of water at inlet of
    runner is %3.3f m/s\n(b)Velocity of whirl at
    inlet is %3.3f m/s\n(c)Relative velocity at inlet
    is %3.3f m/s\n(d)\n    Runner blade entry angle
    is %3.2f degree\n    Runner blade exit angle is
    %3.2f degree\n(e)Width of runner at outlet is %3
    .1f m\n(f)Mass of water flowing through runner
    per second is %3.f kg/s\n(g)Head at the turbine
    inlet is %3.3f m\n(h)Power developed is %3.3f kW\
    n(i)Hydraulic efficiency is %3.4f',C1,Cx1,W1,b11,
    b22,b2,m,H,W,nH)

```

Scilab code Exa 9.12 DESIGN OF INWARD FLOW FRANCIS TURBINE

```

1 clc
2 clear
3 //input data
4 P=330//Power output from the turbine is kW
5 H=70//Head of operating turbine in m
6 N=750//Speed of the turbine in rpm
7 nH=0.94//Hydraulic efficiency
8 n0=0.85//Overall efficiency
9 FR=0.15//Flow ratio
10 BR=0.1//Breadth ratio

```

```

11 D1D2=2//Ratio inner and outer diameter of runner
12 g=9.81//Acceleration due to gravity in m/s^2
13 dw=1000//Density of water in kg/m^3
14
15 //calculations
16 Cr1=FR*(2*g*H)^(1/2)//Flow velocity at inlet in m/s
17 Q=(P*10^3)/(dw*g*H*n0)//Discharge at outlet in m^3/s
18 D1=(Q/(nH*3.1415*BR*Cr1))^(1/2)//Runner inlet
    diameter in m
19 b1=BR*D1//Height of the runner vanes at inlet in m
20 U1=(3.1415*D1*N)/60//Runner tip speed at inlet in m/
    s
21 Cx1=(nH*g*H)/(U1)//Velocity of whirl at inlet in m/s
22 a11=atand(Cr1/Cx1)//Guide blade angle in degree
23 b11=atand(Cr1/(Cx1-U1))//Runner vane angle at inlet
    in degree
24 D2=D1/D1D2//Runner outlet diameter in m
25 U2=(3.1415*D2*N)/60//Runner tip speed at outlet in m
    /s
26 Cr2=Cr1//Flow velocity at outlet in m/s
27 b22=atand(Cr2/U2)//Runner vane angle at outlet in
    degree
28 b2=D1*b1/D2//Width at outlet in m
29
30 //output
31 printf('(a)Flow velocity at inlet is %3.2f m/s\n(b)
    Discharge at outlet is %3.3f m^3/s\n(c)Runner
    inlet diameter is %3.3f m\n(d)Height of the
    runner vanes at inlet is %3.4f m\n(e)Guide blade
    angle is %3.2f degree\n(f)    Runner vane angle
    at inlet is %3.2f degree\n    Runner vane
    angle at outlet is %3.2f degree\n(g)Runner outlet
    diameter is %3.4f m\n(h)Width at outlet is %3.4f
    m\n(i)Runner tip speed at inlet is %3.2f m/s\n(j
    )Velocity of whirl at inlet is %3.f m/s',Cr1,Q,D1
    ,b1,a11,b11,b22,D2,b2,U1,Cx1)

```

Scilab code Exa 9.13 SPEED OF THE WHEEL

```
1  clc
2  clear
3  //input data
4  H=30//Working head of the turbine in m
5  D1=1.2//Inlet wheel diameter in m
6  D2=0.6//Outlet wheel diameter in m
7  b11=90//Vane angle at entrance in degree
8  a11=15//Guide blade angle in degree
9  Cx2=0//Velocity of whirl at inlet in m/s
10 g=9.81//Acceleration due to gravity in m/s^2
11 dw=1000//Density of water in kg/m^3
12
13 //calculations
14 U11=1/tand(a11)//Runner tip speed at inlet in m/s in
    terms of Cr1
15 Cr1=(H/(((U11^2/g)+(1/(2*g))))^(1/2)//Flow velocity
    at inlet in m/s
16 Cr2=Cr1//Flow velocity at outlet in m/s
17 U1=Cr1*U11//Runner tip speed at inlet in m/s
18 N=(60*U1)/(3.1415*D1)//Speed of the wheel in rpm
19 U2=(3.1415*D2*N)/60//Runner tip speed at inlet in m/
    s
20 b22=atand(Cr2/U2)//Vane angle at exit in degree
21
22 //output
23 printf('(a)Speed of the wheel is %3.2f rpm\n(b)Vane
    angle at exit is %3.2f degree',N,b22)
```

Scilab code Exa 9.14 HYDRAULIC EFFICIENCY

```

1  clc
2  clear
3  //input data
4  D1=0.6//Internal runner diameter in m
5  D2=1.2//External runner diameter in m
6  a11=15//Guide blade angle in degree
7  Cr1=4//Flow velocity at inlet in m/s
8  Cr2=Cr1//Flow velocity at outlet in m/s
9  N=200//Speed of the turbine in rpm
10 H=10//Head of the turbine in m
11 a22=90//Discharge angle at outlet in degree
12 g=9.81//Acceleration due to gravity in m/s^2
13 dw=1000//Density of water in kg/m^3
14
15 //calculations
16 U1=(3.1415*D1*N)/60//Runner tip speed at inlet in m/
   s
17 U2=(3.1415*D2*N)/60//Runner tip speed at outlet in m
   /s
18 Cx1=Cr1/tand(a11)//Velocity of whirl at inlet in m/s
19 Wx1=Cx1-U1//Inlet whirl velocity component in m/s
20 b11=atand(Cr1/Wx1)//Vane angle at entrance in degree
21 b22=atand(Cr2/U2)//Vane angle at exit in degree
22 Wm=U1*Cx1//Work one per unit mass flow rate in W/(kg
   /s)      as Cx2=0 in m/s
23 nH=(U1*Cx1/(g*H))//Hydraulic efficiency
24
25 //output
26 printf('(a)\n      Inlet vane angle is %3.2f degree\n
      Outlet vane angle is %3.2f degree\n(b)Work
      done by the water on the runner per kg of water
      is %3.2f W/(kg/s)\n(c)Hydraulic efficiency is %3
      .4f ',b11,b22,Wm,nH)

```

Scilab code Exa 9.15 INLET AND OUTLET BLADE ANGLES

```

1  clc
2  clear
3  //input data
4  H=23//Net head across the turbine in m
5  N=150//Speed of the turbine in rpm
6  P=23//Power developed by the turbine in MW
7  D=4.75//Blade tip diameter in m
8  d=2//Blade hub diameter in m
9  nH=0.93//Hydraulic efficiency
10 n0=0.85//Overall efficiency
11 g=9.81//Acceleration due to gravity in m/s^2
12 dw=1000//Density of water in kg/m^3
13
14 //calculations
15 dm=(D+d)/2//Mean diameter of the turbine in m
16 Pa=(P*10^6)/n0//Power available in MW
17 Q=(Pa/(dw*g*H))//Flow rate in the turbine in m^3/s
18 Um=(3.1415*dm*N)/60//Rotor speed at mean diameter in
    m/s
19 Pr=Pa*nH*10^-6//Power given to runner in MW
20 Cx1=Pr*10^6/(dw*Q*Um)//Velocity of whirl at inlet in
    m/s    as Cx2=0 in m/s
21 Ca=Q/((3.1415/4)*(D^2-d^2))//Axial velocity in m/s
22 b11=180-(atand(Ca/(Um-Cx1)))//Inlet blade angle in
    degree
23 Wx2=Um//Outlet whirl velocity component in m/s
24 b22=atand(Ca/Wx2)//Outlet blade angle in degree
25
26 //output
27 printf('(a)The inlet blade angle at mean radius is
    %3.1f degree\n(b)The outlet blade angle at mean
    radius is %3.1f degree',b11,b22)

```

Scilab code Exa 9.16 DIAMETER OF RUNNER AND SPECIFIC SPEED OF TURBINE

```

1  clc
2  clear
3  //input data
4  P=9100//Power developed by the turbine in kW
5  H=5.6//Net head available at the turbine in m
6  SR=2.09//Speed ratio
7  FR=0.68//Flow ratio
8  n0=0.86//Overall efficiency of the turbine
9  g=9.81//Acceleration due to gravity in m/s^2
10 dw=1000//Density of water in kg/m^3
11 DbD=1/3//Ratio of diameter of the boss to diameter
    of the runner
12
13 //calculations
14 U1=SR*(2*g*H)^(1/2)//Runner tip speed at inlet in m/
    s
15 Cr1=FR*(2*g*H)^(1/2)//Flow velocity at inlet in m/s
16 Q=(P*10^3)/(n0*dw*g*H)//Discharge through the
    turbine in m^3/s
17 D=(Q*4/(3.1415*Cr1*((1^2)-(DbD^2))))^(1/2)//Diameter
    of the runner in m
18 N=(U1*60)/(3.1415*D)//Speed of the the turbine in
    rpm
19 Ns=(N*(P)^(1/2))/(H)^(5/4)//Specific speed
20 disp(Q)
21 //output
22 printf('(a)Diameter of the runner of the turbine is
    %3.2f m\n(b)Speed of the turbine is %3.1f rpm\n(c
    )The specific speed is %3.2f',D,N,Ns)

```

Scilab code Exa 9.17 RUNNER INLET AND OUTLET VANE ANGLES

```

1  clc
2  clear
3  //input data

```

```

4 H=20//Head developed over the turbine in m
5 P=11800//Power developed by turbine in kW
6 D=3.5//Outer diameter of the runner in m
7 Db=1.75//Hub diameter in m
8 a11=35//Guide blade angle in degree
9 nH=0.88//Hydraulic efficiency
10 n0=0.84//Overall efficiency
11 Cx2=0//Velocity of whirl at outlet in m/s
12 g=9.81//Acceleration due to gravity in m/s^2
13 dw=1000//Density of water in kg/m^3
14
15 //calculations
16 Q=(P*10^3)/(n0*g*H*dw)//Discharge of turbine in m^3/
    s
17 Cr1=Q/((3.1415/4)*(D^2-Db^2))//Flow velocity at
    inlet in m/s
18 Cx1=Cr1/tand(a11)//Velocity of whirl at inlet in m/s
19 U1=(nH*H*g)/(Cx1)//Runner tip speed at inlet in m/s
20 Wx1=U1-Cx1//Inlet whirl velocity component in m/s
21 b11=180-(atand(Cr1/-Wx1))//Runner inlet angle in
    degree
22 Cr2=Cr1//Flow velocity at outlet in m/s      for a
    kaplan turbine
23 U2=U1//Runner tip speed at outlet in m/s      for a
    kaplan turbine
24 b22=atand(Cr2/U2)//Runner outlet angle in degree
25 N=(U1*60)/(3.1415*D)//The speed of the turbine in
    rpm
26
27 //output
28 printf('(1)\n    (a)The runner inlet angle is %3.2f
    degree\n    (b)The runner outlet angle is %3.1f
    degree\n(2)The speed of the turbine is %3.2f rpm'
    ,b11,b22,N)

```

Scilab code Exa 9.18 DISCHARGE POWER AND HYDRAULIC EFFICIENCY

```

1  clc
2  clear
3  //input data
4  N=50//Speed of the turbine in rpm
5  d=6//Runner diameter of the turbine in m
6  Ae=20//Effective area of flow in m^2
7  b11=150//The angle of the runner blades at inlet in
   degree
8  b22=20//The angle of the runner blade at outlet in
   degree
9  g=9.81//Acceleration due to gravity in m/s^2
10 dw=1000//Density of water in kg/m^3
11
12 //calculations
13 U1=(3.141*d*N)/60//Runner tip speed at inlet in m/s
14 U2=U1//Runner tip speed at outlet in m/s
15 Cr2=U2*tand(b22)//Flow velocity at outlet in m/s
16 Cr1=Cr2//Flow velocity at inlet in m/s
17 Q=Ae*Cr1//Discharge by the turbine in m^3/s
18 Cx1=U1-(Cr1/(tand(180-b11)))//Velocity of whirl at
   inlet in m/s
19 P=dw*g*Q*(U1*Cx1/g)*10^-3//Theoretical Power
   developed in kW
20 C2=Cr2//Absolute outlet velocity in m/s
21 H=(U1*Cx1/g)+(C2^2/(2*g))//Net head across the
   turbine in m
22 nH=(U1*Cx1/g)/(H)//Hydraulic efficiency
23
24 //output
25 printf('(a) Discharge of the turbine is %3.1f m^3/s\n
   (b) Theoretical Power developed is %3.2f kW\n(c)
   Hydraulic efficiency is %3.4f ',Q,P,nH)

```

Scilab code Exa 9.19 BLADE ANGLES AND EFFICIENCIES

```

1  clc
2  clear
3  //input data
4  D=8//Outer diameter of the turbine in m
5  Db=3//Inner diameter of the turbine in m
6  P=30000//Power developed by the turbine in kW
7  nH=0.95//Hydraulic efficiency
8  N=80//Speed of the turbine in rpm
9  H=12//Head operated by the turbine in m
10 Q=300//Discharge through the runner in m3/s
11 g=9.81//Acceleration due to gravity in m/s2
12 dw=1000//Density of water in kg/m3
13
14 //calculations
15 U1=(3.1415*D*N)/60//Runner tip speed at inlet in m/s
16 U2=U1//Runner tip speed at outlet in m/s      as flow
    is axial
17 Cr1=Q/((3.1415/4)*(D2-Db2))//Flow velocity at
    inlet in m/s
18 Cr2=Cr1//Flow velocity at outlet in m/s      as flow
    is axial
19 b22=atand(Cr2/U2)//The angle of the runner blade at
    outlet in degree
20 Cx1=(nH*g*H)/U1//Velocity of whirl at inlet in m/s
21 b11=180-(atand(Cr1/(U1-Cx1)))//The angle of the
    runner blade at inlet in degree
22 nM=(P*103)/(dw*g*Q*(Cx1*U1/g))//Mechanical
    efficiency
23 n0=nM*nH//Overall efficiency
24
25 //output
26 printf('(a)Blade angle at\n      inlet is %3.2f degree
    \n      outlet is %3.2f degree\n(b)Mechanical
    efficiency is %3.3f\n(c)Overall efficiency is %3
    .3f ',b11,b22,nM,n0)

```

Scilab code Exa 9.20 RUNNER DIAMETER AND SPEED

```
1  clc
2  clear
3  //input data
4  P=11500//Rated power of the turbine in kW
5  H=4.3//Average head of the turbine in m
6  n0=0.91//Overall efficiency of the turbine
7  DbD=0.3//Ratio of Diameters of runner boss and
   runner
8  SR=2//Speed ratio
9  FR=0.65//Flow ratio
10 g=9.81//Acceleration due to gravity in m/s^2
11 dw=1000//Density of water in kg/m^3
12
13 //calculations
14 U=SR*(2*g*H)^(1/2)//Runner tip speed in m/s
15 Cr=FR*(2*g*H)^(1/2)//Flow velocity in m/s
16 Q=(P*10^3)/(n0*dw*g*H)//Discharge of the turbine in
   m^3/s
17 D=((4*Q)/(Cr*3.1415*(1^2-DbD^2)))^(1/2)//Runner
   diameter in
18 N=(60*U)/(3.1415*D)//Speed of the turbine in rpm
19
20 //output
21 printf('(a)Runner diameter of the turbine is %3.2f m
   \n(b)Operating speed of the turbine is %3.1f rpm'
   ,D,N)
```
