# Scilab Textbook Companion for Turbomachines by A. V. Arasu[1]

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# Book Description

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

**Exa** Example (Solved example)

**Eqn** Equation (Particular equation of the above book)

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

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

# Contents

# List of Scilab Codes

# Chapter 1

# BASIC CONCEPTS OF TURBO MACHINES

**Scilab code Exa 1.1** COMPRESSION WORK

```
clc
clear
//input data
P01=1//initial pressure of a fluid in bar
P02=10//final pressure of a fluid in bar
T01=283//initial total temperature in K
ntt=0.75//total-to-total efficiency
d=1000//density of water in kg/m^3
r=1.4//ratio of specific heats for air
Cp=1.005//specific at heat at constant pressure in
    kJ/kg.K

//calculations
h0s1=(1/d)*(P02-P01)*10^2//enthalpy in kJ/kg
h01=(h0s1/ntt)//enthalpy in kJ/kg
T02s=T01*(P02/P01)^((r-1)/r)//temperature in K
h0s2=(Cp*(T02s-T01))//enthalpy in kJ/kg
h02=(h0s2/ntt)//enthalpy in kJ/kg

```

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

**Scilab code Exa 1.2** EFFICIENCY

```
clc
clear
//input data
P01=7//Total initial pressure of gases at entry in
   bar
T01=1100//Total initial temperature in K
P02=1.5//Total final pressure of gases at exit in
   bar
T02=830//Total final temperature in K
C2=250//Exit velocity in m/s
r=1.3//Ratio of specific heats of gases
M=28.7//Molecular weight of gases
R1=8.314//Gas constant of air in kJ/kg.K

//calculations
T02s=T01*(P02/P01)^((r-1)/r)//Final temperature in K
ntt=((T01-T02)/(T01-T02s))//Total-to-total
   efficiency
R=(R1/M)//Gas constant of given gas in kJ/kg.K
Cp=((r*R)/(r-1))//Specific heat of given gas at
   constant pressure in kJ/kg.K
T2s=(T02s-((C2^2)/(2*Cp*1000)))//Temperature in
   isentropic process at exit in K
nts=((T01-T02)/(T01-T2s))//Total-to-static
   efficiency

//output
```

```
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

```
clc
clear
//input data
h0=6//Change in total enthalpy in kJ/kg
T01=303//Total inlet temperature of fluid in K
P01=1//Total inlet pressure of fliud in bar
Cp=1.005//specific at heat at constant pressure in kJ/kg.K
ntt=0.75//Adiabatic total-to-total efficiency
r=1.4//ratio of specific heats for air

//calculations
T02=T01+(h0/Cp)//Exit total termperature of fliud in K
P1=(1+((ntt*h0)/(Cp*T01)))^(r/(r-1))//Total pressure ratio of fluid
h0s=ntt*h0//Change in enthalpy of process in kJ/kg
P0=((h0s*1000)/100)//Change in pressure in bar
P02=P0+P01//Total outlet pressure of fliud in bar
P2=(P02/P01)//Total pressure ratio of fliud

//output
printf('(a)The exit total temperature of fliud is %3.2f K\n(b)The total pressure ratio if:\n(1)The fliud is air is %3.3f\n(2)The fliud is liquid water is %3.0i',T02,P1,P2)
```

**Scilab code Exa 1.4** TOTAL PRESSURE

```
clc
clear
//input data
W=100//Output power developed in kW
Q=0.1//Flow through device in m^3/s
d=800//Density of oil in kg/m^3
ntt=0.75//Total-to-total efficiency
C1=3//inlet flow velocity of oil in m/s
C2=10//outlet flow velocity of oil in m/s

//calculations
m=d*Q//Mass flow rate of oil in kg/s
h0=-(W/m)//Change in total enthalpy in kJ/kg
h0s=(h0/ntt)//Isentropic change in total enthalpy in kJ/kg
P0=((d*h0s)*(1/100))//Change in total pressure of oil in bar
P=P0-((d/(2000*100))*(C2^2-C1^2))//Change in static pressure in bar

//output
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

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

```
ns1=0.86//Stage efficiency of first and second stages
ns2=0.84//Stage efficiency of third and fourth stages
r=1.4//ratio of specific heats for air

//calculations
u=1-(P)^((r-1)/r)//constant
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
W12=u*(1+(1-(u*ns1)))*ns1//Actual work output from first two stages in (kW*Cp*T01)
W34=T03*u*(1+(1-(u*ns2)))*ns2//Actual work output from last two stages in (kW*Cp*T01)
W=(W12+W34)//Total actual work output from turbine in (kW*Cp*T01)
Ws=1-(1-u)^N//Total isentropic work due to single stage compressor in (kW*Cp*T01)
n=(W/Ws)//Overall turbine efficiency

//output
printf('the overall efficiency of the turbine is %3.3f',n)
```

---

**Scilab code Exa 1.6** COMPRESSOR EFFICIENCY

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

```
T2=320//Final temperature of air in K
P=1400*9.81*10^-5//Pressure developed by compressor
    in bar
r=1.4//ratio of specific heats for air

//calculations
P2=P1+P//Final pressure of air in bar
T2s=T1*(P2/P1)^((r-1)/r)//Isentropic temperature at
    exit in K
nc=((T2s-T1)/(T2-T1))//compressor efficiency
np=((r-1)/r)*((log10(P2/P1))/(log10(T2/T1)))//
    Infinitesimal stage efficiency

//output
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

```
clc
clear
//input data
P1=1.01//Input pressure to compressor in bar
T1=305//Input temperature to compressor in K
P2=3//Output pressure from compressor in bar
r=1.4//ratio of specific heats for air
nc=0.75//compressor efficiency

//calculations
T2s=T1*(P2/P1)^((r-1)/r)//Isentropic output
    temperature from compressor in K
T2=T1+((T2s-T1)/nc)//Actual output temperature from
    compressor in K
np=((r-1)/r)*((log10(P2/P1))/(log10(T2/T1)))//
```

```
Infinitesimal efficiency of compressor

//output
printf('The infinitesimal efficiency of the compressor is %3.3f',np)
```

**Scilab code Exa 1.8** POLYTROPIC EFFICIENCY

```
clc
clear
//input data
P=2.2//Pressure ratio across a gas turbine
n=0.88//Efficiency of a gas turbine
T1=1500//Inlet temperature of the gas in K
r=1.4//ratio of specific heats for air

//calculations
T2s=T1*(1/P)^((r-1)/r)//Isentropic output temperature from gas turbine in K
T2=T1-(n*(T1-T2s))//actual output temperature from gas turbine in K
np=(r/(r-1))*((log10(T1/T2))/(log10(P)))//Polytropic efficiency of the turbine

//output
printf('The polytropic efficiency of the turbine is %3.3f',np)
```

**Scilab code Exa 1.9** STATES AND EFFICIENCIES

```
clc
clear
// input data
```

```
P=1.3//Pressure ratio of stages
N=8//Number of stages
m =45//The flow rate through compressor in kg/s
nc=0.8//Overall efficiency of the compressor
P1=1//Initial pressure of the air at entry in bar
T1=308//Initial temperature of the air at entry in K
r=1.4//ratio of specific heats for air

//calculations
PN=(P)^8//Overall pressure ratio of all 8 stages
TN=PN^((r-1)/r)//Overall temperature ratio of all 8
    stages
TN1s=TN*T1//Ideal exit temperature in K
TN1=((TN1s-T1)/nc)+T1//Actual exit temperature in K
PN1=PN*P1//Actual exit pressure in bar
np=((r-1)/r)*((log10(PN1/P1))/(log10(TN1/T1)))//
    Polytropic efficiency of the cycle
ns=((((P)^((r-1)/r))-1)/(((P)^((r-1)/(r*np)))-1))//
    The stage efficiency of the cycle

//output
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

```
clc
clear
//input data
P=11//Overall pressure ratio in three stages of a
    gas turbine
nt=0.88//Overall efficiency in three stages of a gas
```

```
turbine
T1=1500//Temperature at inlet of a gas turbine in K
r=1.4//ratio of specific heats for air

//calculations
T0=nt*T1*(1-(1/P)^((r-1)/r))//Overall change in temperature in all stages in K
TN1=T1-T0//Temperature at final stage of a gas turbine in K
np=((r/(r-1))*log10(T1/TN1))/(log10(P))//Overall polytropic efficiency of the gas turbine
Ts=T0/3//Individual stage change in temperature in K
T2=T1-Ts//Exit temperature at the end of first stage in K
P1=(T1/T2)^(r/(np*(r-1)))//Pressure ratio at first stage of gas turbine
ns1=((1-(1/P1)^((np*(r-1))/r))/(1-(1/P1)^((r-1)/r)))//Stage efficiency of first stage
T3=T2-Ts//Exit temperature at the end of second stage in K
P2=(T2/T3)^(r/(np*(r-1)))//Pressure ratio at second stage of gas turbine
ns2=((1-(1/P2)^((np*(r-1))/r))/(1-(1/P2)^((r-1)/r)))//Stage efficiency of second stage
T4=T3-Ts//Exit temperature at the end of third stage in K
P3=(T3/T4)^(r/(np*(r-1)))//Pressure ratio at the third stage of gas turbine
ns3=((1-(1/P3)^((np*(r-1))/r))/(1-(1/P3)^((r-1)/r)))//Stage efficiency of third stage

//output
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

```
clc
clear
//input data
N=4//Number of stages in compressor
m=45//mass flow rate of air delivered by compressor
   in kg/s
P1=1.2//Pressure ratio at first stage
ns=0.65//Stage efficiency of first stage
r=1.4//ratio of specific heats for air
Cp=1.005//specific at heat at constant pressure in
   kJ/kg.K
T1=293//Temperature of air at inlet in K

//calculations
P=(P1)^N//Overall pressure in all 4 stages
np=((r-1)/r)*((log10(P1))/(log10((((P1^((r-1)/r))-1)
   /ns)+1)))//Polytropic efficiency of the cycle
nc=(((P1^(N*((r-1)/r)))-1)/((P1^(N*((r-1)/(r*np))))
   -1))//Overall efficiency of the cycle
TN1=T1*((P1^(N))^((r-1)/(r*np)))//Final temperature
   at the exit of the compressor at final stage in K
W=m*Cp*(TN1-T1)//Power required to drive the
   compressor in kW

//output

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

```
clc
clear
//input data
P0=0.2*9.81*(10^3)*(10^-5)//Total increase in pressure in bar
P01=1.04//Total inlet pressure of air in bar
T01=291//Total inlet temperature of air in K
ntt=0.72//Total-to-total efficiency of the process
r=1.4//ratio of specific heats for air
Cp=1.005//specific at heat at constant pressure in kJ/kg.K

//calculations
P2=P0+P01//The total exit pressure in bar
T02=((((P2/P01)^((r-1)/r)-1)*T01)/ntt)+T01//Total temperature at the outlet in K
h0=Cp*(T02-T01)//Actual change in total enthalpy in kJ/kg
h0s=h0*ntt//Isentropic change in total enthalpy in kJ/kg

//output
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

```
clc
clear
//input data
P=5//Pressure ratio in the process
ntt=0.8//Total-to-total efficiency of the process
m=5//Air flow rate through turbine in kg/s
W=500//Total power output from the turbine in kW
r=1.4//ratio of specific heats for air
Cp=1.005*10^3//specific at heat at constant pressure
    in J/kg.K
C2=100//Flow velocity of air in m/s

//calculations
T=(W*10^3)/(m*Cp)//Total change in temperature in
   the process in K
T02s=(1/P)^((r-1)/r)//Isentropic temperature at the
   outlet from turvine in (K*T01)
T01=(T/ntt)*(1/(1-0.631))//Inlet total temperature
   in K
T02=T01-T//Actual exit total temperature in K
T2=T02-((C2^2)/(2*Cp))//Actual exit static
   temperature in K
T02s1=T02s*T01//Isentropic temperature at the outlet
    from turbine in K
T2s=T02s1-((C2^2)/(2*Cp))//Actual isentropic
   temperature in K
nts=(T/(T01-T2s))//Total-to-static efficiency

//output
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

```
clc
clear
//input data
N=3//Number of stages in turbine
P=2//Pressure ratio of each stage
ns=0.75//Stage efficiency of each stage
T1=873//Initial temperature of air in K
m=25//Flow rate of air in kg/s
r=1.4//ratio of specific heats for air
Cp=1.005//specific at heat at constant pressure in J
    /kg.K

//calculations
np=(r/(r-1))*((log(1-(ns*(1-(1/P)^((r-1)/r)))))/(log
    (1/P)))//Polytropic efficiency of the process
nt=((1-(1/P)^(N*np*((r-1)/r)))/(1-(1/P)^(N*((r-1)/r)
    )))//Overall efficiency of the turbine
W=m*Cp*T1*(1-(1/P)^(N*np*((r-1)/r)))//Power
    developed by the turbine in kW
RF=nt/ns//Reheat factor of the process

//output
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)

//comments
// 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

```
clc
clear
//input data
c =2.25//Chord length of an aerofoil in m
l=13.5//Span of the aerofoil in m
C=125//Velocity of the aerofoil in m/s
Cl=0.465//Lift coefficient
Cd=0.022//Drag coefficient
d=1.25//Density of the air in kg/m^3

//calculations
A=c*l//Area of cross section of the aerofoil in m^2
W=Cl*d*((C^2)/2)*A*10^-3//Weight carried by the
    wings of aerofoil in kN
D=Cd*d*((C^2)/2)*A//Drag force on the wings of
    aerofoil in N
P=D*C*10^-3//Power required to the drive the
    aerofoil in kW

//output
printf('(a)Weight carrried 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 %3.3f kW',W,D,P)


//comments
// error in the first review is not printing the value of drag force which is corrected
```

**Scilab code Exa 2.2** DIAMETER OF PARACHUTE

```
clc
clear
//input data
W=980//The weight of the object being dropped by parachute in N
C=5//The maximum terminal velocity of dropping in m/s
d=1.22//The density of the air in kg/m^3
Cd=1.3//The drag coefficient of the parachute

//calculations
A=W/(Cd*d*((C^2)/2))//The area of cross section in m^2
D=((A*4)/(3.14))^(1/2)//Diameter of the parachute in m

//output
printf('The required diameter of the parachute is %3.2f m',D)
```

**Scilab code Exa 2.3** COEFFICIENT OF LIFT

```
clc
clear
//input data
A=10*1.2//Area of the airplane wing in m^2
C=((240*10^3)/3600)//Velocity of the wing in m/s
F=20//Total aerodynamic force acting on the wing in kN
LD=10//Lift-drag ratio
d=1.2//Density of the air in kg/m^3

//calculations
L=(F)/(1.01)^(1/2)//The weight that the plane can carry in kN
Cl=(L*10^3)/(d*A*((C^2)/2))//Coefficient of the lift

//output
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

```
clc
clear
//input data
m=25//Mass flow rate of the air in kg/s
d=1.1//Density of the air in kg/m^3
Ca=157//Axial flow velocity of the air in m/s
N=150//Rotational speed of the air in rev/s
U=200//Mean blade speed in m/s
lc=3//Rotor blade aspect ratio
sc=0.8//Pitch chord ratio

//calculations
rm=(U)/(2*3.145*N)//Mean radius of the blades in m
```

```
A=(m)/(d*Ca)//The annulus area of flow in m^2
l=(A)/(2*3.1*rm)//The blade height in m
C=l/lc//The chord of the blades in m
S=sc*C//The blade pitch in m
n=(2*3.141*rm)/(S)//Number of blades

//output

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

```
clc
clear
//input data
sc=0.8//Pitch-chord ratio of compressor blade
b1=45//Relative air angle at inlet in degree
b2=15//Relative air angle at oulet in degree
a1=b1//Cascade air angle at inlet in degree
a2=b2//Cascade air angle at outlet in degree

//calculations
en=a1-a2//Nominal deflection angle of the blade in degree
m=((0.23*(1)^2))+(0.1*a2/50)//An emperical constant for a circular arc camber where (2*a/c)=1
t=(a1-a2)/(1-0.233)//Blade camber angle in degree
d=(m*(sc)^(1/2))*t//The deviation angle of the blade in terms of (degree*t)
ps=a1-(t/2)//The blade stagger for a given circular arc cascade in degree
```

```

//output
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

```
clc
clear
//input data
t=25//The camber angle of aero foil blades in degree
ps=30//The blade stagger angle in degree
sc=1//The pitch-chord ratio of the blades
in=5//The nominal value of incidence in degree

//calculations
a1=ps+(t/2)//The cascade blade angle at inlet in degree
a2=a1-t//The cascade blade angle at outlet in degree
a1n=in+a1//The nominal entry air angle in degree
a2n=atand((tand(a1n))-(1.55/(1.0+(1.5*sc))))//The nominal exit air angle in degree

//output
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

```
clc
clear
//input data
C1=75//Velocity of air entry in m/s
a1=48//Air angle at entry in degree
a2=25//Air angle at exit in degree
cs=0.91//The chord-pitch ratio
P0m=(11*9.81*10^3)/10^3//The stagnation pressure
    loss in N/m^2
d=1.25//The density of the sair in kg/m^3

//calculations
Cp=(P0m/(0.5*d*C1^2))//The pressure loss coefficient
am=atand((tand(a1)+tand(a2))/2)//The mean air angle
    in degree
Cd=2*(1/cs)*(P0m/(d*C1^2))*((cosd(am))^3/(cosd(a1))
    ^2)//The drag coefficient
Cl=(2*(1/cs)*cosd(am)*(tand(a1)-tand(a2)))-(Cd*tand(
    am))//THe lift coefficient

//output
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

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

```
P0m=(17.5*9.81*10^3)/10^3//The average loss in stagnation pressure across cascade in N/m^2

//calculations
Cp=(P0m/(0.5*d*C1^2))//The pressure loss coefficient in the cascade
am=atand((tand(a2)-tand(a1))/2)//The mean air angle in degree
Cd=2*(sc)*(P0m/(d*C1^2))*((cosd(am))^3/(cosd(a2))^2)//The drag coefficient
Cl=(2*(sc)*cosd(am)*(tand(a1)+tand(a2)))+(Cd*tand(am))//THe lift coefficient

//output
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

```
clc
clear
//input data
W=30000//The weight of the jet plane in N
A=20//The area of the wing in m^2
C=250*5/18//The speed of the jet plane in m/s
P=750//The power delivered by the engine in kW
d=1.21//Density of the air in kg/m^3

//calculations
L=W//The lift force on the plane is equal to the weight of the plane in N
Pd=0.65*P//The power required to overcome the drag resistance in kW
D=(Pd/C)*10^3//The drag force on the wing in N
```

```
Cd=D/(0.5*d*A*C^2)//The coefficient of drag for the wing
Cl=L/(0.5*d*A*C^2)//The coefficient of lift for the wing

//output
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

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

```
Dh=0.15//The eye internal diamater in m
r=1.4//Ratio of specific heats of air
d=1.189//The density of the air in kg/m^3

//calculations
T01=T1+((C1^2)/(2*Cp))//The stagnation temperature at inlet in K
P01=P1*(T01/T1)^(r/(r-1))//The stagnation pressure at inlet in bar
T02s=(T01)*(P02/P01)^((r-1)/r)//The temperature after isentropic compression from P01 to P02 in K
T=(T02s-T01)/nc//The actual rise in total temperature in K
W=Cp*(10^-3)*(T)//The work done per unit mass in kJ/kg
U2=((W*(10^3))/(WS))^(1/2)//The impeller tip speed in m/s
Dt=(U2*60)/(3.1415*N)//The impeller tip diameter in m
P=m*W//Power required to drive the compressor in kW
d1=((P1*10^5)/(R*T1))//The density of the air entry in kg/m^3
De=(((4*m)/(d*C1*3.14))+(Dh^2))^(1/2)//The eye external diameter in m

//output
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

```
clc
clear
//input data
Q1=20//Discharge of air to the centrifugal compressor in m^3/s
V1=Q1//Volume of rate is equal to the discharge in m^3/s
P1=1//Initial pressure of the air to the centrifugal compressor in bar
T1=288//Initial temperature of the air to the centrifugal compressor in K
P=1.5//The pressure ratio of compression in centrifugal compressor
C1=60//The velocity of flow of air at inlet in m/s
Cr2=C1//The radial velocity of flow of air at outlet in m/s
Dh=0.6//The inlet impeller diameter in m
Dt=1.2//The outlet impeller diameter in m
N=5000//The speed of rotation of centrifugal compressor in rpm
n=1.5//polytropic index constant in the given law PV^n
Cp=1005//The specific heat of air at constant pressure in J/kg.K

//calculations
U1=(3.14*Dh*N)/60//Peripheral velocity of impeller at inlet in m/s
b11=atand(C1/U1)//The blade angle at impeller inlet in degree
U2=(3.14*Dt*N)/60//Peripheral velocity of impeller top at outlet in m/s
T2=T1*(P)^((n-1)/n)//Final temperature of the air to the centrifugal compressor in K
Cx2=((Cp*(T2-T1))/U2)//The whirl component of absolute velocity in m/s
Wx2=U2-Cx2//The exit relative velocity in m/s
a2=atand(Cr2/Cx2)//The blade angle at inlet to
```

```
casing in degree
b22=atand(Cr2/Wx2)//The blade angle at impeller outlet in degree
b1=Q1/(2*3.14*(Dh/2)*C1)//The breadth of impeller blade at inlet in m
V2=(P1*V1*T2)/(T1*P*P1)//Volume flow rate of air at exit in m^3/s
Q2=V2//Volume flow rate is equal to discharge in m^3/s
b2=Q2/(2*3.14*(Dt/2)*Cr2)//The breadth of impeller blade at outlet in m

//output
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)


//comments
//error in the first review is not printing the value of V2 which is corrected
```

**Scilab code Exa 3.3** OVERALL DIAMETER

```
clc
clear
//input data
m=14//The mass flow rate of air delivered to
```

```
centrifugal compressor in kg/s
P01=1//The inlet stagnation pressure in bar
T01=288//The inlet stagnation temperature in K
P=4//The stagnation pressure ratio
N=200//The speed of centrifygal compressor in rps
ss=0.9//The slip factor
ps=1.04//The power input factor
ntt=0.8//The overall isentropic efficiency
r=1.4//The ratio of specific heats of air
Cp=1005//The specific heat of air at constant pressure in J/kg.K

//calculations
pp=ss*ps*ntt//The pressure coefficient
U2=((Cp*T01*((P^((r-1)/r))-1))/pp)^(1/2)//Peripheral velocity of impeller top at outlet in m/s
D2=U2/(3.14*N)//The overall diameter of the impeller in m

//output
printf('The overall diameter of the impeller is %3.2f m',D2)
```

**Scilab code Exa 3.4** INLET RELATIVE MACH NUMBER

```
clc
clear
//input data
D1=0.457//Impeller diameter at inlet in m
D2=0.762//Impeller diameter at exit in m
Cr2=53.4//Radial component of velocity at impeller exit in m/s
ss=0.9//Slip factor
N=11000//Impeller speed in rpm
P2=2.23//Static pressure at impeller exit in bar
```

```
T01=288//The inlet stagnation temperature in K
P01=1.013//The inlet stagnation pressure in bar
C1=91.5//Velocity of air leaving the guide vanes in m/s
a11=70//The angle at which air leaves the guide vanes in degrees
r=1.4//The ratio of specific heats of air
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant pressure in J/kg.K

//calculations
Cx1=C1*cosd(a11)//Inlet absolute velocity of air in tangential direction in m/s
Ca1=Cx1*tand(a11)//Radial component of absolute velocity at inlet in m/s
U1=(3.14*D1*N)/(60)//Peripheral velocity of impeller at inlet in m/s
Wx1=U1-Cx1//Relative whirl component of velocity at inlet in m/s
W1=((Wx1^2)+(Ca1^2))^(1/2)//Relative velocity at inlet in m/s
T1=T01-((C1^2)/(2*Cp))//The inlet air temperature in K
a1=(r*R*T1)^(1/2)//The velocity of air in m/s
M1r=W1/a1//Initial relative mach number
U2=(3.14*D2*N)/60//Peripheral velocity of impeller top at exit in m/s
W=(ss*U2^2)-(U1*Cx1)//Work done by the compressor in kJ/kg
T02=(W/Cp)+T01//The outlet stagnation temperature in K
Cx21=ss*U2//Absolute whirl component of velocity with slip consideration in m/s
C2=((Cx21^2)+(Cr2^2))^(1/2)//The absolute velocity of air at exit in m/s
T2=T02-((C2^2)/(2*Cp))//The exit temperature of air in K
```

```
P02=P2*(T02/T2)^(r/(r-1))//The exit stagnation
   pressure of compressor in bar
nc=(T01/(T02-T01))*(((P02/P01)^((r-1)/r))-1)//Total
   head isentropic efficiency

//output
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

```
clc
clear
//input data
N=16500//The running speed ofradial blade of a
   centrifugal compressor in rpm
P=4//The total pressure ratio
P01=1//The atmospheric pressure in bar
T01=298//THe atmospheric temperature in K
Dh=0.16//The hub diameter at impeller eye in m
Ca=120//The axial velocity at inlet in m/s
C1=Ca//The absolute velocity at inlet in m/s
sp=0.7//The pressure coefficient
C3=120//The absolute velocity at diffuser exit in m/
   s
m=8.3//The mass flow rate in kg/s
nc=0.78//The adiabatic total-to-total efficiency
r=1.4//The ratio of specific heats of air
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant
   pressure in J/kg.K

//calculations
T1=T01-((C1^2)/(2*Cp))//The inlet temperature in K
```

```
P1=P01*(T1/T01)^(r/(r-1))//The inlet pressure in bar
d1=(P1*10^5)/(R*T1)//The inlet density of air in kg/m^3
Dt=(((4*m)/(3.14*d1*Ca))+(0.16^2))^(1/2)//The eye tip diameter in m
T=((T01)*((P^((r-1)/r))-1))/nc//The overall change in temperature in K
ssps=sp/nc//The product of slip factor and power factor
U2=(T*Cp/ssps)^(1/2)//Peripheral velocity of impeller top at exit in m/s
D2=(U2*60)/(3.14*N)//The impeller tip diameter in m
Uh=(3.14*Dh*N)/60//Peripheral velocity of eye hub in m/s
bh=atand(C1/Uh)//Blade angle at eye hub in degree
Ut=(3.14*Dt*N)/60//Peripheral velocity of eye tip in m/s
bt=atand(C1/Ut)//Blade angle at eye tip in degree
T03=T01+T//Temperature at the exit in K
T3=T03-((C3^2)/(2*Cp))//Exit static temperature in K
P3=(P*P01)*(T3/T03)^(r/(r-1))//Exit static pressure in bar
W=m*Cp*(T03-T01)*10^-6//Power required to drive the compressor in mW
//output
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

```
clc
clear
//input data
Dt=0.25//Tip diameter of the eye in m
Dh=0.1//Hub diameter of the eye in m
N=120//Speed of the compressor in rps
m=5//Mass of the air handled in kg/s
P01=102//Inlet stagnation pressure in kPa
T01=335//Inlet total temperature in K
r=1.4//The ratio of specific heats of air
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant pressure in J/kg.K

//calculations
d1=(P01*10^3)/(R*T01)//Density at the inlet of inducer in kg/m^3
Dm=(Dh+Dt)/2//Mean impeller diameter in m
b=(Dt-Dh)/2//Impeller blade height in m
C1=m/(d1*3.14*Dm*b)//Axial velocity component at the inlet in m/s
T11=T01-((C1^2)/(2*Cp))//Inlet temperature in K
P11=P01*(T11/T01)^(r/(r-1))//Inlet pressure in kPa
d11=(P11*10^3)/(R*T11)//Inlet density with mean impeller diameter an blade height in kg/m^3
C11=m/(d11*3.14*Dm*b)//Axial velocity component at inlet using mean blade values in m/s
T12=T01-((C1^2)/(2*Cp))//Initial temperature using modified axial velocity in K
P12=P01*(T12/T01)^(r/(r-1))//Initial pressure at inlet usin modified axial velocity in kPa
d12=(P12*10^3)/(R*T12)//Inlet density with modified axial velocity in kg/m^3
C12=m/(d12*3.14*Dm*b)//Axial velocity component at inlet using modified axial velocity in m/s
U1=3.14*Dm*N//Peripheral velocity of impeller at
```

```
    inlet in m/s
b1=atand(C12/U1)//The blade angle at impeller inlet
    in degree
W11=C12/sind(b1)//Relative velocity at inlet in m/s
Mr11=W11/(r*R*T12)^(1/2)//Initial relative mach
    number
Ca=C12//Axial velocity at IGV in m/s
W12=Ca//Relative velocity at inlet usin IGV in m/s
a1=atand(Ca/U1)//Air angle at IGV exit in degree
C13=Ca/sind(a1)//The velocity of flow of air at
    inlet in m/s
T13=T01-((C13^2)/(2*Cp))//Initial temperature using
    IGV in K
Mr12=W12/(r*R*T13)^(1/2)//Initial relative mach
    number using IGV

//output5
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

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

```
T01=288//The ambient air temperature in K
P01=1//The ambient air pressure in bar
r=1.4//The ratio of specific heats of air
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant
    pressure in J/kg.K

//calculations
Cx2=ss*U2//outlet absolute velocity of air in
    tangential direction in m/s
C2=((Cx2^2)+(Cr2^2))^(1/2)//Axial velocity component
     at the outlet in m/s
T=(ss*(U2^2))/Cp//Total change in temperature in K
T02=T+T01//The final ambient air temperature in K
T2=T02-((C2^2)/(2*Cp))//The actual final air
    temperature in K
M2=(C2)/(r*R*T2)^(1/2)//Exit absolute mach number
P=((1+(ss*T/T01))^(r/(r-1)))//The overall pressure
    ratio
P02=P*P01//The final ambient pressure in bar
P2=P02*(T2/T02)^(r/(r-1))//The absolute final
    pressure in bar
d2=(P2*10^5)/(R*T2)//The final density of air at
    exit in kg/m^3
m=d2*A*Cr2//The mass flow rate in kg/s

//output
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

```
clc
clear
//input data
```

```
Dh=0.175//Hub diameter of the eye in m
Dt=0.3125//Tip diameter of the eye in m
m=20//Mass of the air handled in kg/s
N=16000//Speed of the compressor in rpm
T01=288//The ambient air temperature in K
P01=100//The ambient air pressure in kPa
Ca=152//The axial component of inlet velocity of eye
    in m/s
r=1.4//The ratio of specific heats of air
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant
   pressure in J/kg.K


//calculations
A=(3.14/4)*((Dt^2)-(Dh^2))//Annulus area of flow at
   the impeller eye in m^2
Ut=(3.1415*Dt*N)/60//Impeller eye tip speed in m/s
Uh=(3.1415*Dh*N)/60//Impeller eye hub speed in m/s
a1=90-20//Blade angle at inlet in degree
C1=Ca/sind(a1)//The air entry velocity into the
   impeller eye in m/s
T1=T01-((C1^2)/(2*Cp))//The actual inlet air
   temperature in K
P1=P01*(T1/T01)^(r/(r-1))//The actual inlet air
   pressure in kPa
d1=P1/(R*T1)//The initial density of air at entry in
    kg/m^3
b1h=atand(Ca/(Uh-(Ca/tand(a1))))//Impeller angle at
   the hub in degree
b1t=atand(Ca/(Ut-(Ca/tand(a1))))//Impeller angle at
   the tip of eye in degree
Cx1=Ca/tand(a1)//Inlet absolute velocity of air in
   tangential direction in m/s
Wx1=Ut-Cx1//Relative whirl component of velocity at
   inlet in m/s
W1=((Wx1^2)+(Ca^2))^(1/2)//Relative velocity at
   inlet in m/s
```

```
Mr1=W1/(r*R*T1)^(1/2)//Maximum mach number at the
    eye

//output
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

```
clc
clear
//input data
P1=100//The air in take pressure in kPa
T1=309//The air in take temperature in K
H=0.750//Pressure head developed in mm W.G
P=33//Input power to blower in kW
nb=0.79//Blower efficiency
nm=0.83//Mechanical efficiency
r=1.4//The ratio of specific heats of air
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
d=(P1*10^3)/(R*T1)//Density of air flow at inlet in
    kg/m^3
dP=dw*g*H//Total change in pressure in N/m^2
IW=dP/d//Ideal work done in J/kg
Wm=IW/nb//Actual work done per unit mass flow rate
```

```
    in J/kg
W=P*nm//Actual power input in kW
m=(W*10^3)/Wm//Mass flow rate in kg/s
Q=m/d//Volume flow rate in m^3/s
P2=P1+(dP/10^3)//The exit pressure of air in kPa
T2=T1+(Wm/(Cp))//The exit temperature of air in K

//output
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

```
clc
clear
//input data
H=0.075//Pressure developed by a fan in m W.G
D2=0.89//The impeller diameter in m
N=720//The running speed of the fan in rpm
b22=39//The blade air angle at the tip in degree
b2=0.1//The width of the impeller in m
Cr=9.15//The constant radial velocity in m/s
d=1.2//Density of air in kg/m^3
r=1.4//The ratio of specific heats of air
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
IW=(dw*g*H)/d//Ideal work done in J/kg
```

```
U2=(3.1415*D2*N)/60//The impeller tip speed in m/s
Wx2=Cr/tand(b22)//Relative whirl component of
    velocity at outlet in m/s
Cx2=U2-(Wx2)//Outlet absolute velocity of air in
    tangential direction in m/s
Wm=U2*Cx2//Actual work done per unit mass flow rate
    in J/kg
nf=IW/Wm//Fan efficiency
Q=3.1415*D2*b2*Cr//The discharge of the air by fan
    in m^3/s
m=d*Q//Mass flow rate of the air by the fan in kg/s
W=m*Wm*10^-3//Power required to drive the fan in kW
R=1-(Cx2/(2*U2))//Stage reaction of the fan
sp=2*Cx2/U2//The pressure coefficient

//output
printf('(a)The fan efficiency is %3.3f\n(b)The
    Discharge of air by the fan is %3.3f m^3/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

```
clc
clear
//input data

b22=30//The blade air angle at the tip in degrees
D2=0.466//The impeller diameter in m
Q=3.82//The discharge of the air by fan in m^3/s
m=4.29//Mass flow rate of the air by the fan in kg/s
H=0.063//Pressure developed by a fan in m W.G
```

```
pi2=0.25//Flow coefficient at impeller exit
W=3//Power supplied to the impeller in kW
r=1.4//The ratio of specific heats of air
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant pressure in J/kg.K
g=9.81//Acceleration due to gravity in m/s^2
dw=10^3//Density of water in kg/m^3

//calculations
IW=Q*dw*g*H*(10^-3)//Ideal work done in kW
nf=IW/W//Fan efficiency
U2=(((W*10^3)/m)/(1-(pi2/tand(b22))))^(1/2)//The impeller tip speed in m/s
Cr2=pi2*U2//The radial velocity at exit in m/s
Cx2=U2-(Cr2/tand(b22))//Outlet absolute velocity of air in tangential direction in m/s
sp=2*Cx2/U2//Presuure coefficient of the fan
R=1-(Cx2/(2*U2))//Degree of reaction of the fan
N=(U2*60)/(3.141592*D2)//Rotational speed of the fan in rpm
b2=Q/(3.14*D2*Cr2)//Impeller width at the exit in m

//output
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

```
clc
clear
//input data
```

```
N=3000//The running speed of the blower in rpm
D2=0.75//The impeller diameter in m
Cr2=57//The radial velocity at exit in m/s
Cx1=0//Inlet absolute velocity of air in tangential direction in m/s
DR=0.58//Degree of reaction of the blower
nc=0.75//Total-to-total efficiency
r=1.4//The ratio of specific heats of air
R=287//The universal gas constant in J/kg.K
Cp=1.005//The specific heat of air at constant pressure in J/kg.K
T01=298//The inlet stagnation temperature in K
P01=1*101.325//The inlet stagnation pressure in kPa

//calculations
U2=(3.1415*D2*N)/60//The impeller tip speed in m/s
Cx2=2*(1-DR)*U2//Outlet absolute velocity of air in tangential direction in m/s
Wx2=U2-Cx2//Relative whirl component of velocity at outlet in m/s
b22=atand(Cr2/Wx2)//The blade air angle at the tip in degree
Wm=U2*Cx2*10^-3//Actual work done per unit mass flow rate when Cx1=0 in kW/(kg/s)
T=Wm/Cp//Total change in temperature in blower in K
P=(1+(nc*(T/T01)))^(r/(r-1))//Total pressure ratio in the blower
P02=P*P01//The outlet stagnation pressure from blower in kPa

//output
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

```
clc
clear
//input data
D1=0.18//The impeller inner diameter in m
D2=0.2//The impeller outer diameter in m
C1=21//The absolute velocity at the entry in m/s
C2=25//The absolute velocity at the exit in m/s
W1=20//The relative velocity at the entry in m/s
W2=17//The relative velocity at the exit in m/s
N=1450//The running speed of the fan in rpm
m=0.5//The mass flow rate of the air in fan in kg/s
nm=0.78//The motor efficiency of the fan
d=1.25//The density of the air in kg/m^3
r=1.4//The ratio of specific heats of air
R=287//The universal gas constant in J/kg.K
Cp=1.005//The specific heat of air at constant
    pressure in J/kg.K

//calculations
U1=(3.14*D1*N)/60//Peripheral velocity of impeller
    at inlet in m/s
U2=(3.14*D2*N)/60//The impeller tip speed in m/s
dH=(((U2^2)-(U1^2))/2)+(((W1^2)-(W2^2))/2)//The
    actual total rise in enthalpy in kJ/kg
dH0=dH+(((C2^2)-(C1^2))/2)//The stage total
    isentropic rise in enthalpy in kJ/kg
dP0=d*dH0//The stage total pressure rise in N/m^2
dP=d*dH//The actual total rise in pressure in N/m^2
R=dP/dP0//The degree of reaction of the fan
W=m*(dH0)//The work done by the fan per second in W
P=W/nm//The power input to the fan in W

```

```
//output
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

```
clc
clear
//input data
dH=0.14//Rise in static pressure of the air by fan
   in m of water
N=650//The running speed of the fan in rpm
P=85*0.735//Power consumed by the fan in kW
H1=0.75//The static pressure of the air at the fan
   in m of Hg
T1=298//The static pressure at the fan of air in K
m=260//Mass flow rate of air in kg/min
dHg=13590//Density of mercury in kg/m^3
dw=1000//Density of water in kg/m^3
g=9.81//Acceleration due to gravity in m/s^2
R=287//The universal gas constant in J/kg.K

//calculations
P1=dHg*g*H1*10^-3//The inlet static pressure in kPa
dP=dw*g*dH*10^-3//The total change in static
   pressures at inlet and outlet in kPa
P2=P1+dP//The exit static pressure in kPa
d1=(P1*10^3)/(R*T1)//The inlet density of the air in
    kg/m^3
Q=m/d1//The volume flow rate of air in fan in m^3/
   min

//output
```

```
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

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

```

```
//calculations
b2=b1-db//The angle made by the relative velocity
    vector at entry in degree
a1=b2//Air flow angle at exit in degree as DR=0.5
U=(3.1415*D*N)/60//The blade mean speed in m/s
T2=((U*dCx)/(Cp*1000))+T1//The exit air temperature
    in K
P2=P1*(T2/T1)^(r/(r-1))//The exit air pressure in
    bar
dP=P2-P1//The pressure rise in bar
Ca=(2*U*DR)/(tand(b2)+tand(b1))//The axial velocity
    in m/s
A1=3.1415*D*b//The inlet flow area in m^2
d1=(P1*10^5)/(R*T1)//The inlet air density in kg/m^3
m=d1*A1*Ca//The amount of air handled in kg/s
W=m*Cp*(T2-T1)//The power developed in kW

//output
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

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

```
Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
r=1.4//The ratio of specific heats of air

//calculations
T02s=T01*(P02/P01)^((r-1)/r)//Total isentropic head
    temperature in delivery pipe in K
nc=(T02s-T01)/(T02-T01)//Total head isentropic
    efficiency
np=((log10(P02/P01))/((r/(r-1))*(log10(T02/T01))))//
    Polytropic efficiency
T2=T02*(P2/P02)^((r-1)/r)//Static temperature in
    delivery pipe in K
C2=(2*Cp*(T02-T2))^(1/2)//The air velocity in
    delivery pipe in m/s

//output
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

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

```
    pressure in J/kg.K
r=1.4//The ratio of specific heats of air

//calculations
T0n1s=T01*(Po)^((r-1)/r)//The isentropic temperature of air leaving compressor stage in K
T0n1=((T0n1s-T01)/nc)+T01//The temperature of air leaving compressor stage in K
dta2ta1=(Cp*(T0n1-T01))/(N*U*Ca)//The difference between tan angles of air exit and inlet
sta1tb1=U/Ca//The sum of tan of angles of air inlet and the angle made by the relative velocity
b1=atand((dta2ta1+sta1tb1)/2)//The angle made by the relative velocity vector at exit in degree as the DR=1 then a2=b1
a1=atand(tand(b1)-dta2ta1)//Air flow angle at exit in degree
W=Cp*(T0n1-T01)*10^-3//Power required per kg of air/s in kW

//output
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

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

```
np=0.9//Polytropic efficiency of compressor
dT0=20//Temperature rise in first stage in K
R=287//The universal gas constant in J/kg.K
Cp=1.005//The specific heat of air at constant pressure in kJ/kg.K
r=1.4//The ratio of specific heats of air


//calculations
T02=T01+dT0//Stagnation temperature of air at outlet in K
T0n1=((W*10^3)/(m*Cp))+T01//The temperature of air leaving compressor stage in K
P0n1=P01*(T0n1/T01)^((np*r)/(r-1))//Pressure at compressor outlet in bar
P1=(T02/T01)^((np*r)/(r-1))//The pressure ratio at the first stage
N=((log10(P0n1/P01)/log10(P1)))//Number of stages
T0n1T01=(P0n1/P01)^((r-1)/(np*r))//The temperature ratio at the first stage
T0n1sT01=(P0n1/P01)^((r-1)/r)//The isentropic temperature ratio at the first stage
nc=((T0n1sT01-1)/(T0n1T01-1))//The overall isentropic efficiency

//output
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

```
clc
clear
//input data
```

```
DR=0.5//Degree of reaction
b1=44//Blade inlet angle in degree
b2=13//Blade outlet angle in degree
Po=5//The pressure ratio produced by the compressor
nc=0.87//The overall isentropic efficiency
T01=290//Inlet temperature in K
U=180//Mean blade speed in m/s
l=0.85//Work input factor
R=0.287//The universal gas constant in kJ/kg.K
Cp=1005//The specific heat of air at constant pressure in J/kg.K
r=1.4//The ratio of specific heats of air

//calculations
a2=b1//Air flow angle at entry in degree as DR=0.5
a1=b2//Air flow angle at exit in degree as DR=0.5
T0n1s=T01*(Po)^((r-1)/r)//The isentropic temperature of air leaving compressor stage in K
T0n1=((T0n1s-T01)/nc)+T01//The temperature of air leaving compressor stage in K
Ca=U/(tand(b2)+tand(b1))//The axial velocity in m/s
N=((Cp*(T0n1-T01))/(l*U*Ca*(tand(a2)-tand(a1))))//The number of stages
ds=(Cp*(10^-3)*log(T0n1/T01))-(R*log(Po))//Change in entropy in kJ/kg.K

//output
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

```
clc
clear
//input data
```

```
D=0.6//Mean diameter of compressor in m
N=15000//Running speed of the compressor in rpm
dT=30//Actual overall temperature raise in K
PR=1.3//Pressure ratio of all stages
m=57//Mass flow rate of air in kg/s
nm=0.86//Mechanical efficiency
T1=308//Initial temperature in K
T2=328//Temperature at rotor exit in K
r=1.4//The ratio of specific heats of air
Cp=1.005//The specific heat of air at constant
    pressure in kJ/kg.K

//calculations
W=m*Cp*dT//Work done in kW
P=W/nm//Power required in kW
ns=((T1*((PR^((r-1)/r))-1))/(dT))//Stage efficiency
R=(T2-T1)/(dT)//Reaction ratio

//output
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

```
clc
clear
//input data
Pr=2//The pressure ratio of first stage
P1=1.01//The inlet pressure in bar
T1=303//The inlet temperature in K
nc=0.83//Overall efficency of the compressor
pi=0.47//The flow coefficient
dCxCa=0.5//Ratio of change of whirl velocity to
    axial velocity
```

```
D=0.5//Mean diameter in m
r=1.4//The ratio of specific heats of air
Cp=1005//The specific heat of air at constant
    pressure in J/kg.K

//calculations
dT=T1*((Pr^((r-1)/r))-1)/nc//The Actual overall
    temperature raise in K
dCx=dCxCa*pi//The change of whirl velocity in m/s
U=(dT*Cp/dCx)^(1/2)//The mean blade speed in m/s
N=(U*60)/(3.1415*D)//Speed at which compressor runs
    in rpm
Cx2=(U+(dCx*U))/2//The whirl velocity at exit in m/s
Cx1=U-Cx2//The whirl velocity at entry in m/s
Ca=pi*U//The axial velocity in m/s
C1=((Ca^2)+(Cx1^2))^(1/2)//The inlet absolute
    velocity of air in m/s

//output
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

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

```
Mr1=0.92//Mach number relative to tip
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant pressure in kJ/kg.K
r=1.4//The ratio of specific heats of air
g=9.81//Acceleration due to gravity in m/s^2

//calculations
T1=T01-((C1^2)/(2*Cp))//The inlet temperature in K
W1=Mr1*(r*R*T1)^(1/2)//The relative velocity at entry in m/s
b11=acosd((C1)/(W1))//The inlet rotor angle at tip in degree
Ut=W1*sind(b11)//Tip speed in m/s
rt=(Ut*60)/(2*3.1415*N)//The tip radius in m
b12=atand((tand(b11))-((Cp*dT0)/(l*Ut*C1)))//The outlet rotor angle at tip in degree
P1=P01*(T1/T01)^(r/(r-1))//The inlet pressure in bar
d1=(P1*10^5)/(R*T1)//The density of air at the entry in kg/m^3
Dt=2*rt//The tip diameter in m
Dh=DhDt*(Dt)//The hub diameter in m
A1=(3.141/4)*((Dt^2)-(Dh^2))//The area of cross section at the entry in m^2
rm=((Dt/2)+(Dh/2))/2//The mean radius in m
h=((Dt/2)-(Dh/2))//The height of the blade in m
A=2*3.1415*rm*h//The area of the cross section in m^2
m=d1*A*C1//The mass flow rate in kg/s
P03P01=(1+((ns*dT0)/T01))^(r/(r-1))//The stagnation pressure ratio
P=m*Cp*dT0*10^-3//The power required in kW
Uh=(3.1415*Dh*N)/60//The hub speed in m/s
b21=atand(Uh/C1)//The rotor air angle at entry in degree
b22=atand(tand(b21)-((Cp*dT0)/(l*Uh*C1)))//The rotor air angle at exit in degree

```

```
//output
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

```
clc
clear
//input data
Ur=150//The blade root velocity in m/s
Um=200//The mean velocity in m/s
Ut=250//The tip velocity in m/s
dT0=20//The total change in temperature in K
Ca=150//The axial velocity in m/s
l=0.93//The work done factor
Rm=0.5//Reaction at mean radius
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant
   pressure in J/kg.K
r=1.4//The ratio of specific heats of air

//calculations
dtb1tb2=((Cp*dT0)/(l*Um*Ca))//The difference between
    the tangent angles of blade angles at mean
atb1tb2=((2*Rm*Um)/(Ca))//The sum of the tangent
   angles of blade angles at mean
b1m=atand((atb1tb2+dtb1tb2)/2)//The inlet blade
```

```
angle in degree at mean
a2m=b1m//The exit air angle in degree as the Reaction at mean radius is 0.5
b2m=atand(tand(b1m)-dtb1tb2)//The exit blade angle in degree at mean
a1m=b2m//The inlet air angle in degree as the reaction at mean radius is 0.5
rmrh=Um/Ur//The ratio of radii of mean and root velocities at hub
a1h=atand(tand(a1m)*(rmrh))//The inlet air angle in degree at hub
b1h=atand((Ur/Ca)-(tand(a1h)))//The inlet blade angle in degree at hub
a2h=atand(tand(a2m)*(rmrh))//The outlet air angle in degree at hub
b2h=atand((Ur/Ca)-(tand(a2h)))//The outlet blade angle in degree at hub
Rh=((Ca*(tand(b1h)+tand(b2h)))/(2*Ur))//The degree of reaction at the hub
rmrt=Um/Ut//The ratio of radii of mean and tip velocities at tip
a1t=atand(tand(a1m)*(rmrt))//The inlet air angle in degree at tip
b1t=atand((Ut/Ca)-(tand(a1t)))//The inlet blade angle in degree at tip
a2t=atand(tand(a2m)*(rmrt))//The outlet air angle in degree at tip
b2t=atand((Ut/Ca)-(tand(a2t)))//The outlet blade angle in degree at tip
Rt=((Ca*(tand(b1t)+tand(b2t)))/(2*Ut))//The degree of reaction at tip

//output
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 %3.2f
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 %3.3f\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 %3.3f\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

```
clc
clear
//input data
Uh=150//The blade root velocity in m/s
Um=200//The mean velocity in m/s
Ut=250//The tip velocity in m/s
dT0=20//The total change in temperature in K
Ca1m=150//The axial velocity in m/s
l=0.93//The work done factor
Rm=0.5//Reaction at mean radius
N=9000//Rotational speed in rpm
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant
   pressure in J/kg.K
r=1.4//The ratio of specific heats of air

//calculations
dtb1tb2=((Cp*dT0)/(l*Um*Ca1m))//The difference
   between the tangent angles of blade angles at
   mean
```

```
atb1tb2=((2*Rm*Um)/(Ca1m))//The sum of the tangent angles of blade angles at mean
b1m=atand((atb1tb2+dtb1tb2)/2)//The inlet blade angle in degree at mean
a2m=b1m//The exit air angle in degree as the Reaction at mean radius is 0.5
b2m=atand(tand(b1m)-dtb1tb2)//The exit blade angle in degree at mean
a1m=b2m//The inlet air angle in degree as the reaction at mean radius is 0.5
Dh=(Uh*60)/(3.141*N)//Hub diameter in m
Dm=(Um*60)/(3.141*N)//Mean diameter in m
Cx1m=Ca1m*tand(a1m)//The whirl velocity at inlet at mean in m/s
Cx2m=Ca1m*tand(a2m)//The whirl velocity at exit at mean in m/s
Cx1h=(Cx1m*(Dh/2)/(Dm/2))//The whirl velocity at inlet at hub in m/s
Cx2h=(Cx2m*(Dh/2)/(Dm/2))//The whirl velocity at exit at hub in m/s
K1=(Ca1m^2)+(2*(Cx1m^2))//Sectional velocity in m/s
Ca1h=((K1)-(2*(Cx1h^2)))^(1/2)//The axial velocity at hub inlet in (m/s)^2
w=(2*3.141*N)/60//Angular velocity of blade in rad/s
K2=(Ca1m^2)+(2*(Cx2m^2))-(2*((Cx2h/(Dh/2))-(Cx1m/(Dm/2))))*(w*(Dm/2)^(2))//Sectional velocity in (m/s)^2
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
a1h=atand(Cx1h/Ca1h)//Air angle at inlet in hub in degree
b1h=atand((Uh-Cx1h)/Ca1h)//Blade angle at inlet in hub in degree
a2h=atand(Cx2h/Ca2h)//Air angle at exit in hub in degree
b2h=atand((Uh-Cx2h)/Ca2h)//Blade angle at exit in hub in degree
```

```
W1=Ca1h/cosd(b1h)//Relative velocity at entry in hub
     in m/s
W2=Ca2h/cosd(b2h)//Relative velocity at exit in hub
    in m/s
Rh=((W1^2)-(W2^2))/(2*Uh*(Cx2h-Cx1h))//The degree of
     reaction at hub
Dt=(Ut*60)/(3.141*N)//Tip diameter in m
Cx1t=(Cx1m*(Dt/2)/(Dm/2))//The whirl velocity at
    inlet at tip in m/s
Cx2t=(Cx2m*(Dt/2)/(Dm/2))//The whirl velocity at
    exit at tip in m/s
Ca1t=(K1-(2*Cx1t^2))^(1/2)//Axial velocity at tip
    inlet in m/s
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
a1t=atand(Cx1t/Ca1t)//Air angle at inlet in tip in
    degree
b1t=atand((Ut-Cx1t)/Ca1t)//Blade angle at inlet in
    tip in degree
a2t=atand(Cx2t/Ca2t)//Air angle at exit in tip in
    degree
b2t=atand((Ut-Cx2t)/Ca2t)//Blade angle at exit in
    tip in degree
W1=Ca1t/cosd(b1t)//Relative velocity at entry in tip
     in m/s
W2=Ca2t/cosd(b2t)//Relative velocity at exit in tip
    in m/s
Rt=((W1^2)-(W2^2))/(2*Ut*(Cx2t-Cx1t))//The degree of
     reaction at tip

//output
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

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

```

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

```
ntt=dh0ss/dh0r//The overall total-to-total
   efiiciency
DR=dPr/(dPr+dPs)//The degree of reaction for the
   stage

//output
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 %3.2f
   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

```
clc
clear
//input data
Q=2.5//The amount of air which fan takes in m^3/s
P1=1.02//The inlet pressure of air in bar
T1=315//The inlet temperature of air in K
dH=0.75//The pressure head delivered by axial flow
   fan in m W.G
T2=325//The delivery temperature of air in K
R=287//The universal gas constant in J/kg.K
Cp=1.005//The specific heat of air at constant
   pressure in kJ/kg.K
r=1.4//The ratio of specific heats of air
g=9.81//Acceleration due to gravity in m/s^2

//calculations
d=(P1*10^5)/(R*T1)//The density of air in kg/m^3
```

```
m=d*Q//The mass flow rate of air in kg/s
W=m*Cp*(T2-T1)//Power required to drive the fan in kW
dP=((10^3)*g*dH)/(10^5)//The overall pressure difference in bar
P2=P1+(dP)//The exit pressure in bar
nf=((T1*(((P2/P1)^((r-1)/r))-1))/(T2-T1))//Static fan efficiency

//output
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

```
clc
clear
//input data
b2=10//Rotor blade air angle at exit in degree
Dt=0.6//The tip diameter in m
Dh=0.3//The hub diameter in m
N=960//The speed of the fan in rpm
P=1//Power required by the fan in kW
pi=0.245//The flow coefficient
P1=1.02//The inlet pressure in bar
T1=316//The inlet temperature in K
R=287//The universal gas constant in J/kg.K
Cp=1.005//The specific heat of air at constant pressure in kJ/kg.K
r=1.4//The ratio of specific heats of air
g=9.81//Acceleration due to gravity in m/s^2

//calculations
A=(3.141/4)*((Dt^2)-(Dh^2))//Area of the fan at
```

```
    inlet in m^2
Dm=(Dt+Dh)/2//The mean rotor diameter in m
U=(3.141*Dm*N)/60//The mean blade speed in m/s
Ca=pi*U//The axial velocity in m/s
Q=A*Ca//The flow rate of air in m^3/s
d=(P1*10^5)/(R*T1)//Density of air in kg/m^3
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
Wm=U*(U-(Ca*tand(b2)))//Work done per unit mass in J
    /kg
m=d*Q//Mass flow rate in kg/s
W=m*Wm//Work done in W
no=W/(P*10^3)//Overall efficiency

//output
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

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

```
pressure in kJ/kg.K
r=1.4//The ratio of specific heats of air
g=9.81//Acceleration due to gravity in m/s^2

//calculations
A=(3.141/4)*((Dt^2)-(Dh^2))//Area of the fan at inlet in m^2
Dm=(Dt+Dh)/2//The mean rotor diameter in m
U=(3.141*Dm*N)/60//The mean blade speed in m/s
Ca=pi*U//The axial velocity in m/s
Q=A*Ca//The flow rate of air in m^3/s
d=(P1*10^5)/(R*T1)//Density of air in kg/m^3
b1=atand(U/Ca)//Rotor blade angle at entry in degree
dPst=((d*(U^2)*(1-((pi*tand(b2))^2)))/2)//Static pressure rise across the stage in N/m^2
dPr=dPst//Static pressure rise across the rotor in N/m^2
Wm=U*(U-(Ca*tand(b2)))//Work done per unit mass in J/kg
dP0st=d*Wm//Stagnation pressure of the stage in N/m^2
DR1=dPr/dP0st//Degree of reaction
DR2=(Ca/(2*U))*(tand(b1)+tand(b2))//Degree of reaction

//output
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

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

```
P1=100*10^3//The atmospheric pressure in Pa
T1=310//The atmospheric temperature in K
nb=0.8//The efficiency of the blower
nm=0.85//The mechanical efficiency
P=30//The power input in kW
R=287//The universal gas constant in J/kg.K
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
no=nb*nm//Overall efficiency of the blower
d=(P1)/(R*T1)//The density of the air in kg/m^3
dP=((no*P*10^3)/m)*d//The pressure developed in N/m
    ^2
dH=((dP)/(g*dw))*(10^3)//The pressure developed in
    mm W.G

//output
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

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

```
nf=0.79//Static fan efficiency
R=287//The universal gas constant in J/kg.K
Cp=1.005//The specific heat of air at constant
   pressure in kJ/kg.K
r=1.4//The ratio of specific heats of air
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
no=nm*nf//Overall efficiency
Dt=Dh/DhDt//The tip diameter in m
Dm=(Dt+Dh)/2//Mean rotor diameter in m
U=(3.141*Dm*N)/60//The mean blade speed in m/s
dPd=((U^2)/2)*psi//The ratio of change in pressure
   to density in J/kg
Wi=dPd*m//The ideal work in W
P=Wi/nm//The power required by the fan in W
d=P1/(R*T1)//The density of the air in kg/m^3
A=(3.141/4)*((Dt^2)-(Dh^2))//Area of cross section
   of the fan in m^2
Ca=m/(d*A)//The axial velocity of air in m/s
pi=Ca/U//The flow coefficient
tb1tb2=psi/(2*pi)//The difference between tangent
   angles of rotor inlet and exit angles
b2=atand((1-(dPd/U^2))/pi)//The exit rotor angle in
   degree
b1=atand((tand(b2))+(tb1tb2))//The inlet rotor angle
    in degree
dP=d*dPd//The pressure developed in N/m^2
dH=(dP/(dw*g))*10^3//Pressure developed in mm of W.G

//output
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

```
clc
clear
//input data
C1=500//Steam velocity in m/s
U=200//Blade speed in m/s
b2=(90-25)//Exit angle of moving blade measured in
   axial direction in degree
a1=(90-20)//Nozzle angle in axial direction in
   degree
m=5//Steam flow rate in kg/s

printf('The scale of the velocity vector diagram is
   1:50\n\nThe following values are obtained from
   the velocity vector diagram')

b1=33//Moving blade inlet angle in degree
a2=56//Direction of steam at the exit in degree
C2=160//Exit velocity of the steam in m/s
Wx1=270//Inlet whirl velocity in m/s
```

```
Wx2=285//Exit whirl velocity in m/s
Ca1=175//Inlet axial velocity in m/s
Ca2=135//Exit axial velocity in m/s

//calculations
Wm=U*(Wx1+Wx2)*10^-3//Work done per kg of steam in
   kW/kg
AT=m*(Ca1-Ca2)//Axial thrust in N
W=m*Wm//Power developed in kW
Ndia=((U*(Wx1+Wx2))/((C1^2)/2))//Diagram or blade
    efficiency

//output
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 %3.3f',b1,C2,a2,Wm,AT,W,Ndia)
```

**Scilab code Exa 5.2** AXIAL THRUST ON BLADING

```
clc
clear
//input data
U=300//Blade speed in m/s
a=20//Nozzle angle in degree
dhs=473//Isentropic heat drop in kJ/kg
Nn=0.85//Nozzle efficiency
W2W1=0.7//Blade velocity coefficient
nM=0.9//Mechanical efficiency

//initial calculations
dh=Nn*dhs//Useful heat drop converted into kinetic
```

```
energy in kJ/kg
C1=(2*1000*dh)^(1/2)//Velocity of steam at exit from nozzle in m/s

printf('The scale of the velocity vector diagram is 1:100\n\nThe following values are obtained from the velocity vector diagram')

Ca1=310//Inlet axial velocity in m/s
Ca2=210//Exit axial velocity in m/s
Wx1=550//Inlet whirl velocity in m/s
Wx2=380//Exit whirl velocity in m/s
W1=620//inlet Blade velocity in m/s

//calculations
W2=W2W1*W1//Exit bladde velocity in m/s
AT=Ca1-Ca2//Axial thrust in N/kg
Wm=U*(Wx1+Wx2)*10^-3//Work developed per kg of steam/sec in kW/(kg/s)
P=Wm*nM//Power developed per kg of steam/sec in kW/(kg/s)
m=3600/P//Steam rate per kW.hr in kg
Ndia=((U*(Wx1+Wx2))/((C1^2)/2))//Diagram or blade efficiency
MNdia=(sind(90-a))^(2)//Maximum blade efficiency under optimum conditions
Ns1=Wm/dhs//Stage efficiency
Ns2=Ndia*Nn//Stage efficiency in other method
E=(((W1^2)-(W2^2))/2)*10^-3//Energy loss in blade friction in kJ/kg

//output
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

```
clc
clear
//input data
P1=5//Input pressure of steam in bar
P2=3//Exhaust pressure of steam in bar
C0=75//Carry over velocity of steam in m/s
a1=20//Nozzle angle in degree
UC1=0.4//The direction of blade rotation and blade
    speed ratio
b2=20//Blade exit angle in degree
m=2.5//Steam flow rate in kg/s
W=206//Power Output of the stage in kW
Nn=0.9//Efficiency of the nozzle

printf('Assuming isentropic expansion the enthalpy
    drop can be found from steam table\n\nThe
    following values are obtained from steam tables')

h1=2747.5//Enthalpy at initial pressure in kJ/kg
s1=6.819//Entropy at initial pressure in kJ/kg.K
s2=s1//Entropy at final pressure in kJ/kg.K
sfp2=1.647//Entropy of fliud at final pressure in kJ
    /kg.K
sfgp2=5.367//Entropy of fliud-gas mixture at final
    pressure in kJ/kg.K
hfg=2170.1//Enthalpy of fliud-gas mixture in kJ/kg
hf=551.5//Enthalpy of fliud in kJ/kg

printf('\n\nThe scale of the velocity vector diagram
```

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

W1=280//Relative velocity at inlet in m/s
W2=240//Relative velocity at exit in m/s

//calculations
x2=(s2-sfp2)/sfgp2//The percentage of wet steam
h2s=hf+(x2*hfg)//The isentropic enthalpy at the
   second stage in kJ/kg
dhs=h1-h2s//Isentropic heat drop in kJ/kg
C1=((2000*Nn*dhs)+(C0^2))^(1/2)//Velocity of steam
   at exit from nozzle in m/s
U=UC1*C1//Blade speed in m/s
Wx1Wx2=(W*10^3)/(m*U)//The sum of whirl components
   of velocity in m/s
Ndia=(U*Wx1Wx2)/((C1^2)/2)//Diagram efficiency
RV=W2/W1//Relative velocity ratio
E=dhs+((C0^2)/2000)//Energy supplied per kg in kJ/kg
Ns1=(U*Wx1Wx2)/(E*10^3)//Stage efficiency
Ns2=Ndia*Nn//Stage efficiency in other method

//output
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

```
clc
clear
//input data
```

```
C1=600//Velocity of steam at exit from nozzle in m/s
U=120//Blade speed in m/s
a1=16//Nozzle angle in degree
b2=18//Discharge angle for first moving ring in degree
a11=21//Discharge angle for the fixed ring in degree
b22=35//Discharge angle for the second moving ring in degree
Wr=0.9//Blade velocity coefficient
m=1//Mass flow rate in kg/s

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

W1=485//Relative velocity at inlet for first stage in m/s
W2=Wr*W1//Relative velocity for first stage at exit in m/s
Wx1=460//Inlet whirl  velocity for first stage in m/s
Wx2=410//Exit whirl velocity for first stage  in m/s
Ca1=170//Inlet axial velocity for first stage  in m/s
Ca2=135//Exit axial velocity for first stage in m/s
C2=325//Exit velocity of the steam for first stage in m/s
b1=20//Blade inlet angle for first row of moving blade in degree
C11=Wr*C2//Steam velocity at inlet to second row of moving blades in m/s
W12=190//Relative velocity at inlet for second stage in m/s
W22=Wr*W12//Relative velocity at exit for second stage in m/s
Wx11=155//Inlet whirl velocity  for second stage in m/s
Wx22=140//Exit whirl velocity for second stage  in m
```

```
    /s
Ca11=110//Inlet axial velocity for second stage  in
    m/s
Ca22=100//Exit axial velocity for second stage in m/
    s
b11=35//Blade inlet angle for second row of moving
    blade in degree
dWx1=Wx1+Wx2//Driving force for first stage in m/s
dWx11=Wx11+Wx22//Driving force for second stage in m
    /s
dW=(dWx1+dWx11)*1//Total driving force for unit mass
     flow rate in N
AT1=Ca1-Ca2//Axial thrust for first stage in m/s
AT2=Ca11-Ca22//Axial thrust for second stage in m/s
AT=(AT1+AT2)*1//Total axial thrust for unit mass
    flow rate in N
DP=m*U*(dWx1+dWx11)*10^-3//Diagram power in kW
DE=(U*(dWx1+dWx11))/((C1^2)/2)//Diagram efficiency
MDE=(sind(90-a1))^2//Maximum  diagram efficiency

//output
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 %3.3f\n(e)Maximum
     diagram efficiency is %3.3f',b1,b11,dWx1,dWx11,
    dW,AT,DP,DE,MDE)
```

**Scilab code Exa 5.5** ROTOR SPEED

```
clc
clear
//input data
C1=100//Velocity of steam at exit from nozzle in m/s
h=0.04//Mean blade height in m
b2=20//Exit angle of moving blade in degree
CaU=3/4//Ratio of flow velocity and blade speed at
    mean radius
m=10000/3600//steam flow rate in kg/s

//calculations
a1=b2//Nozzle angle in degree
Ca=C1*cosd(90-a1)//Flow velocity in m/s
U=Ca/CaU//Mean blade velocity in m/s
v=0.60553//Specific volume of steam from steam table
     at 3 bar with dry saturated steam in m^3/kg
A=(m*v)/Ca//Annulus area in m^2
D=A/(3.1415*h)//Mean blade diameter in m
N=(U*60)/(3.14*D)//Rotor speed in rpm

printf('\n\nThe scale of the velocity vector diagram
     is 1:10\n\nThe following values are obtained
    from the velocity vector diagram')

W1=59//Relative velocity at inlet for first stage in
     m/s
Wx1Wx2=142//Sum of whirl components of velocity in m
    /s
DP=m*U*Wx1Wx2*10^-3//Diagram power in kW
Wm=U*(Wx1Wx2)//Work done per kg of steam in kJ/kg
W2=C1//Relative velocity at exit for first stage in
    m/s
E=((C1^2)/2)+(((W2^2)-(W1^2))/2)//Energy input per
    kg in kJ/kg when W2=C1
Ndia=Wm/E//Diagram efficiency
RV=(W2-W1)/W1//Percentage increase in relative
    velocity
dH=((W2^2)-(W1^2))/2*10^-3//Enthalpy drop in the
```

```
    moving blades in kJ/kg
H=2*dH//Total enthalpy drop in two stages in kJ/kg

//output
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

```
clc
clear
//input data
R=0.5//Degree of reaction
P1=14//Initial pressure in bar
T1=588//Initial temperature in K
P2=0.14//Final pressure in bar
Ns=0.75//Stage efficiency
RF=1.04//Reheat factor
N=20//No. of stages
W=11770//Total power output in kW
a1=20//Exit blade angle in degree
hD=1/12//Ratio of blade height to blade mean
    diameter

//calculations
hs1=3080//Isentropic enthalpy at initial condition
    from mollier chart in kJ/kg
hs2=2270//Isentropic enthalpy at final condition
    from mollier chart in kJ/kg
dhs=hs1-hs2//Isentropic enthalpy change in kJ/kg
```

```
Nt=Ns*RF//Overall efficiency
dh=Nt*dhs//Actual enthalpy drop in kJ/kg
hs=dh/N//Enthalpy drop per stage in kJ/kg
m=W/dh//Mass flow rate in kg/s
C11=1.43*1//Velocity of steam at exit from nozzle in
    m/s in terms of U for 0.5 degree of reaction
Wm=1*((2*C11*sind(90-a1))-1)//Work done per mass of
    steam in terms of U^2 in kJ/kg
U=((hs*10^3)/Wm)^(1/2)//Mean blade velocity in m/s
    as work done equals enthalpy drop per stage
C1=1.43*U//Velocity of steam at exit from nozzle in
    m/s
Ca=C1*cosd(90-a1)//Flow velocity in m/s
v=1.618//Specific volume of steam from steam table
    at 1.05 bar with dry saturated steam in m^3/kg
D=((m*v)/(hD*3.14*Ca))^(1/2)//Blade mean diameter in
    m
N=(U*60)/(3.14*D)//Rotor speed in rpm

//output
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

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

```
height in degree
b2m=75//Outlet angle of the rotor blade at mid height in degree
N=6000//Speed of turbine in rpm

//calculations
rm=(rh+rt)/2//Mean radius in m
Um=(2*3.14*rm*N)/60//Mean blade speed at mean radius in m/s
Ca=Um/((tand(a1m))-(tand(b1m)))//Flow velocity in m/s
Cx1m=Ca*tand(a1m)//Velocity of whirl at inlet at mid height in m/s
Cx2m=Ca*tand(b2m)-Um//Velocity of whirl at inlet at mid height in m/s
Cx1h=(Cx1m*rm)/rh//Velocity of whirl at inlet at hub height in m/s
a1h=atand(Cx1h/Ca)//Inlet angle of the nozzle blade at hub height in degree
Uh=(2*3.1415*rh*N)/60//Mean blade speed at hub in m/s
b1h=atand(tand(a1h)-(Uh/Ca))//Inlet angle of the rotor blade at hub in degree
Cx2h=Cx2m*rm/rh//Velocity of whirl at outlet at hub in m/s
b2h=atand((Uh+Cx2h)/Ca)//Outlet angle of the rotor blade at hub in degree
Cx1t=Cx1m*rm/rt//Velocity of whirl at inlet at tip in m/s
a1t=atand(Cx1t/Ca)//Inlet angle of the nozzle blade at tip height in degree
Ut=(2*3.14*rt*N)/60//Mean blade speed at tip in m/s
b1t=atand(tand(a1t)-(Ut/Ca))//Inlet angle of the rotor blade at tip in degree
Cx2t=Cx2m*rm/rt//Velocity of whirl at outlet at tip in m/s
b2t=atand((Ut+Cx2t)/Ca)//Outlet angle of the rotor blade at hub in degree
```

```
Rh=(Ca/(2*Uh))*(tand(b2h)-tand(b1h))//Degree of reaction at hub
Rt=(Ca/(2*Ut))*(tand(b2t)-tand(b1t))//Degree of reaction at tip

//output
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

```
clc
clear
//input data
Ca=180//Air velocity at the exit of nozzle in m/s
a1=(90-27)//Nozzle inclination perpendicular to direction of rotation in degree
R=0.5//Degree of reaction
U=180//Blade speed in m/s

//calculations
Cx1=Ca*tand(a1)//Inlet whirl velocity in m/s
b11=atand((Cx1-U)/Ca)//Inlet angle of the rotor blade at inlet velocity triangle in degree
pi=Ca/U//Ratio of air velocity and blade velocity
```

```
b21=atand((2*R/pi)+tand(b11))//Outlet angle of the rotor blade at inlet velocity triangle in degree
C2=Ca//Exit velocity of the steam in m/s
b22=atand(U/C2)//Outlet angle of the rotor blade at outlet velocity triangle in degree
b12=b11//Inlet angle of the rotor blade at outlet velocity triangle in degree as np change in rotor inlet conditions
R=(pi*(tand(b22)-tand(b12)))/2//Degree of reaction

//output
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

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

```
W=m*Cp*(T0-T2)//Power developed by turbine in kW
Wm=Cp*(T0-T2)//Stage work done per unit mass flow rate in kJ/kg
Wx1Wx2=Wm*10^3/U//Sum of whirl components of velocity at inlet and outlet in m/s
Wx1=(Ca*tand(a1))-U//Inlet whirl velocity in m/s
Wx2=Wx1Wx2-Wx1//Outlet whirl velocity in m/s
R=(Wx2-Wx1)/(2*U)//Degree of reaction
Wx2Wx1=Wm*10^3*R//Energy input due to whirl component velocity in (m/s)^2
C1=Ca/cosd(a1)//Velocity of steam at exit from nozzle in m/s
nb=(Wm*10^3)/(((C1^2)/2)+Wx2Wx1)//Blade efficiency

//output
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

```
clc
clear
//input data
R=0.5//Degree of reaction
P0=2.2//Inlet pressure in bar
T0=443//Inlet temperature in K
N=2400//Rotor running speed in rpm
Dm=0.5//Rotor mean diameter in m
a1=36//Rotor inlet angle in degree
a2=19//Stator exit angle in degree
ns=0.88//Stage efficiency
m=1//Mass flow rate of steam in kg/s

//calculations
```

```
b2=a1//Outlet angle of the rotor blade in degree
b1=a2//Inlet angle of the rotor blade in degree
U=(3.1415*Dm*N)/60//Mean blade speed in m/s
Ca=(2*U*R)/(tand(b2)-tand(b1))//Axial velocity in m/
    s
W=m*U*Ca*(tand(a1)+tand(a2))*10^-3//Power output in
    kW
dh=W/ns//Stage enthalpy drop in kJ/kg

//output
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

```
clc
clear
//input data
P0=800//Inlet pressure of hot gas in kPa
T1=973//Inlet temperature of hot gas in K
P2=100//Final pressure of hot gas in kPa
a1=73//Nozzle angle in degree
m=35//Mass flow rate in kg/s
ns=0.9//Nozzle efficiency
Cp=1.005//Specific heat of gas at constant pressure
    in kJ/kg.K
r=1.4//Ratio of specific heats of air

//calculations
b1=atand(tand(a1)/2)//Inlet angle of the rotor blade
     in degree
b2=b1//Outlet angle of the rotor blade in degree
pi=2/tand(a1)//Flow coefficient
psil=pi*(tand(b1)+tand(b2))//Blade loading
    coefficient
```

```
dh=ns*Cp*T1*(1-(P2/P0)^((r-1)/r))//Change in
    enthalpy in kJ/kg
W=m*dh*10^-3//Power developed in MW

//output
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

```
clc
clear
//input data
P0=100//Initial pressure of steam in bar
T0=773//Initial temperature of steam in K
D=1//Turbine diameter in m
N=3000//Speed of turbine in rpm
m=100//Mass flow rate of steam in kg/s
a1=70//Exit angle of the first stage nozzle in
    degree
ns1=0.78//Stage efficiency of first stage
ns2=ns1//Stage efficiency of second stage

//calculations
U=(3.1415*D*N)/60//Mean blade speed in m/s
C1=(2*U)/sind(a1)//Velocity of steam at exit from
    nozzle in m/s
b11=atand(tand(a1)/2)//Inlet angle of the rotor
    blade in degree
b21=b11//Outlet angle of the rotor blade in degree
b12=b21//Inlet angle of the rotor blade in second
```

```
stage in degree
b22=b12//Outlet angle of the rotor blade in second stage in degree
W=4*m*U^2*10^-6//Total work done in both the stages in MW
dh02=2*U^2*10^-3//Change in enthalpy in first stage of turbine in kJ/kg
dh02s=(dh02/ns1)//Change in enthalpy isentropically of turine first stage in kJ/kg
printf('The values of enthalpy and specific volume are taken from the mollier chart at inlet and exit conditions respectively')
h0=3370//Enthalpy at beginning of first stage in kJ/kg
h2=h0-dh02//Enthalpy at the end of first stage in kJ/kg
h2s=h0-dh02s//Isentropic enthalpy at the end of first stage in kJ/kg
v2=0.041//Specific volume at the end of first stage in m^3/kg
dh24=2*U^2*10^-3//Change in enthalpy in second stage of turbine in kJ/kg
dh24s=dh24/ns2//Change in enthalpy isentropically of turine second stage in kJ/kg
h4=h2-dh24//Enthalpy at beginning of second stage in kJ/kg
h4s=h2-dh24s//Isentropic enthalpy at the end of second stage in kJ/kg
v4=0.05//Specific volume at the end of second stage in m^3/kg

Ca=C1*cosd(a1)//Axial velocity in m/s
h1r=(m*v2)/(3.1415*D*Ca)//Blade height at first stage rotor exit in m
h2r=(m*v4)/(3.1415*D*Ca)//Blade height at second stage rotor exit in m

//output
```

```
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 degres\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

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

```
//calculations
U=(3.1415*D*N)/60//Mean blade speed in m/s
C1=(4*U)/sind(a1)//Velocity of steam at exit from nozzle in m/s
Ca=C1*cosd(a1)//Axial velocity in m/s
Wx1=3*U//Inlet whirl velocity in m/s
b11=atand(Wx1/Ca)//Inlet angle of the rotor blade in degree
b21=b11//Outlet angle of the rotor blade in degree
C2=Ca//Velocity of steam at exit from stage in m/s
b22=atand(U/Ca)//Outlet angle of the rotor blade  in degree
b12=b22//Inlet angle of the rotor blade in  in degree
W=m*8*U^2*10^-6//Total work done or power developed in MW
printf('The values of enthalpy and specific volume are taken from the mollier chart at inlet and exit conditions respectively')
h0=3370//Enthalpy at beginning of  stage in kJ/kg
dh04=(W*10^3)/m//Change in enthalpy  of turbine in kJ/kg
dh04s=dh04/ns//Change in enthalpy isentropically of turine  in kJ/kg
h4=h0-dh04//Enthalpy at beginning of stage in kJ/kg
h4s=h0-dh04s//Isentropic enthalpy at the end of stage in kJ/kg
v4=0.105//Specific volume at the end of stage in m^3/kg
h=(m*v4)/(3.1415*D*Ca)//Rotor blade height in m

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 degres\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 m^3/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

```
clc
clear
//input data
a1=(90-30)//Nozzle angle in axial direction in
   degree
Ca=180//Axial velocity in m/s
U=280//Rotor blade speed in m/s
R=0.25//Degree of reaction

//calculations
Cx1=Ca*tand(a1)//Velocity of whirl at inlet in m/s
b1=atand((Cx1-U)/Ca)//Blade angle at inlet in degree
b2=a1//Blade angle at exit in degree as degree of
   reaction is 0.5

//output
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

```
clc
clear
//input data
R=0.5//Degree of reaction
ns=0.85//Stage efficiency
P0=800//Inlet pressure of hot gas in kPa
T0=900//Inlet temperature of hot gas in K
U=160//Blade speed in m/s
m=75//Mass flow rate of hot gas in kg/s
a1=70//Absolute air angle at first stage nozzle exit
    in degree

//calculations
C1=U/sind(a1)//Velocity of steam at exit from nozzle
    in m/s
Ca=C1*cosd(a1)//Axial velocity of hot gas in m/s
C2=Ca//Velocity of steam at exit from stage in m/s
b1=0//Blade angle at inlet in degree as Wx1=0
a2=b1//Stator exit angle in degree as degree of
   reaction is 0.5
b2=a1//Blade angle at outlet in degree as degree of
   reaction is 0.5
Cx2=0//Velocity of whirl at outlet in m/s
Cx1=U//Velocity of whirl at inlet in m/s
W=m*U*(Cx1+Cx2)*10^-6//Power developed in MW
Wm=W*10^3/m//Work done per unit mass flow rate in kJ
   /kg
dhs=Wm/ns//Isentropic enthalpy drop in kJ/kg

//output
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

```
clc
clear
//input data
b1m=46//Rotor blade angle at entry at mean section in degree
b2m=75//Rotor blade angle at exit at mean section in degree
a1m=75//Nozzle angle at exit at mean section in degree
DhDt=0.6//Hub to tip ratio
N=7500//Mean rotor speed in rpm
Dh=0.45//Hub diameter in m

//calculations
R=0.5//Degree of reaction as a1m=b2m
a2m=b1m//Stator angle at exit at mean section in degree
Dm=(Dh+(Dh/DhDt))/2//Mean diameter of turbine at mean section in m
Um=(3.1415*DhDt*N)/60//Mean blade speed in m/s
Ca=Um/(tand(a1m)-tand(b1m))//Axial velocity in m/s
pi=Ca/Um//Flow coefficient
psil=pi*(tand(b1m)+tand(b2m))//Blade loading coefficient
a1h=atand(tand(a1m)*((Dm/2)/(Dh/2)))//Nozzle angle at inlet at root section in degree
Uh=(3.14*Dh*N)/60//Blade speed at root section in m/s
b1h=atand(tand(a1h)-(Uh/Ca))//Rotor blade angle at entry at root section in degree
a2h=atand(tand(a2m)*((Dm/2)/(Dh/2)))//Stator angle at exit at root section in degree
```

```
b2h=atand((Uh/Ca)+tand(a2h))//Rotor blade angle at exit at root section in degree
pih=Ca/Uh//Flow coefficient at root section
Rh=(pih/2)*(tand(b2h)-tand(b1h))//Degree of reaction at root section
psilh=pih*(tand(b1h)+tand(b2h))//Blade loading coefficient at root section

//output
printf('Mean section\n    (a)Degree of reaction is %3.1f\n    (b)Blade loading coefficient is %3.2f\nRoot section    (a)Degree of reaction is %3.2f\n    (b)Blade loading coefficient is %3.2f',R,psil,Rh,psilh)
```

**Scilab code Exa 5.17** GAS VELOCITIES

```
clc
clear
//input data
T00=973//Total head inlet temperature in K
P00=4.5//Total head inlet pressure in bar
P2=1.6//Static head outlet pressure in bar
m=20//Gas flow rate in kg/s
a1=(90-28)//Nozzle outlet angle measured perpendicular to blade velocity in degree
Dmh=10//Mean blade diameter to blade height ratio
NLC=0.1//Nozzle loss coefficient
Cp=1155.6//Specific heat of gas at a constant pressure in kJ/kg
R=289//Gas constant in J/kg
r=1.333//Ratio of specific heats of gas

//calculations
T2ss=T00*(P2/P00)^((r-1)/r)//Isentropic temperature
```

```
at outlet in mid section in K here T00=T01
T1s=T2ss//Isentropic temperature at inlet at mid section in K
C1m=(2*Cp*(T00-T1s)/1.1)^(1/2)//Velocity of steam at exit from nozzle at mid section in m/s
T1=T00-((C1m^2)/(2*Cp))//Gas temperature at mid section in K
d=(P2*10^5)/(R*T1)//Density of gas in kg/m^3
Rg=(Cp*(r-1)/r)//Gas constant of the gas in kJ/kg
Ca=C1m*cosd(a1)//Axial velocity in m/s
h=((m/(d*Ca))*(1/(Dmh*3.1415)))^(1/2)//Hub height in m
Dm=Dmh*h//Mean blade diameter in m
Dh=Dm-h//Hub diameter in m
a1h=atand(((Dm/2)/(Dh/2))*tand(a1))//Discharge angle at hub in degree
C1h=Ca/cosd(a1h)//Gas velocity at hub section in m/s
T1h=T00-((C1h^2)/(2*Cp))//Gas temperature at hub in K here T01=T00
Dt=Dm+h//Tip diameter in m
a1t=atand(((Dm/2)/(Dt/2))*tand(a1))//Gas discharge angle at tip in degree
C1t=Ca/cosd(a1t)//Gas velocity at tip in m/s
T1t=T00-((C1t^2)/(2*Cp))//Gas temperature in K here T00=T01

//output
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

```
clc
clear
//input data
a1=75//Nozzle air angle in degree
Rh=0//Degree of reaction
N=6000//Running speed of hub in rpm
Dh=0.45//Hub diameter in m
Df=0.75//Tip diameter in m


//calculations
Uh=(3.1415*Dh*N)/60//Hub speed in m/s
C1h=Uh/((sind(a1))/2)//Velocity of steam at exit
    from nozzle in hub in m/s
Cah=C1h*cosd(a1)//Axial velocity at hub in m/s
Cx1h=C1h*sind(a1)//Whirl component of velocity at
    inlet in hub in m/s
b1h=atand((Cx1h-Uh)/Cah)//Rotor blade angle at entry
     at hub section in degree
b2h=b1h//Rotor blade angle at exit at mean section
    in degree as zero reaction section
sopt=sind(a1)/2//Blade to gas speed ratio at hub
rm=((Dh/2)+(Df/2))/2//Mean radius in m
rmrh=(rm/(Dh/2))^((sind(a1))^2)//Ratio of inlet
    velocity at hub and mean for constant nozzle air
    angle at hub section
C1m=C1h/rmrh//Velocity of steam at exit from nozzle
    at mean section in m/s
Cx1m=Cx1h/rmrh//Velocity of whirl at inlet at mean
    section in m/s
Ca1m=Cah/rmrh//Axial velocity at mean section in m/s
Um=(3.1415*2*rm*N)/60//Mean blade speed in m/s
```

```
b1m=atand((Cx1m-Um)/Ca1m)//Rotor blade angle at entry at mean section in degree
b2m=atand(Um/Ca1m)//Rotor blade angle at exit at mean section in degree for axial exit Cx2=0
s=Um/C1m//Blade to gas ratio at mean
Rm=(Ca1m/(2*Um))*(tand(b2m)-tand(b1m))//Degree of reaction of mean section
rmrt=((rm)/(Df/2))^((sind(a1))^2)//Ratio of inlet velocity at tip and mean for constant nozzle air angle at tip section
C1t=C1m*rmrt//Velocity of steam at exit from nozzle at tip section in m/s
Cx1t=Cx1m*rmrt//Velocity of whirl at inlet at tip section in m/s
Ca1t=Ca1m*rmrt//Axial velocity at tip section in m/s
Ut=(3.1415*Df*N)/60//Mean tip speed in m/s
b1t=atand((Cx1t-Ut)/Ca1t)//Rotor blade angle at entry at tip section in degree
b2t=atand(Ut/Ca1t)//Rotor blade angle at exit at tip section in degree for axial exit Cx2=0
st=Ut/C1t//Blade to gas ratio at tip
Rf=(Ca1t/(2*Ut))*(tand(b2t)-tand(b1t))//Degree of reaction of tip section

//output
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 %3.3f\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 %3.3f\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

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

```

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

```
^3
bh=(m/(d2*3.1415*rh*Cr))//Rotor width at the exit in m
W=m*U1*Cx1*10^-3//The power developed by the turbine in kW

//output
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,sl,DR,nts,b22,bh,m,W)
```

**Scilab code Exa 6.2** NOZZLE EXIT AIR ANGLE

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

```

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

```
entry in m/s
T2=T02-((C2^2)/(2000*Cp))//The temperature at the second stage entry in K
P23=(T2/T03)^(r/(r-1))//The pressure ratio at the second stage
P2=P23*P3//The pressure at the second stage in bar
d2=(P2*10^5)/(R*T2)//The density of the air at second stage in kg/m^3
C2=Cr1//The absolute velocity at the second stage in m/s
A2=m/(d2*C2)//The area of cross section at the second stage in m^2
h2=(A2/(3.14*D2m))//The rotor blade height at the exit in m
M1=C1/(r*R*T1)^(1/2)//The mach number at the nozzle
U2=(3.14*D2m*N)/60//The Peripheral velocity of impeller at exit in m/s
M2r=(((C2^2)+(U2^2))^(1/2))/(r*R*T2)^(1/2)//The mach number at the rotor exit
Ln=(dHn*10^3)/((C1^2)/2)//The nozzle loss coefficient
Lr=(dHn*10^3)/(((((C2^2)+(U2^2))^(1/2))^2)/2)//The rotor loss coefficient

//output
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

```
clc
clear
//input data
ntt=0.9//Total-to-total efficiency
P00=300//The pressure at entry to the nozzle in kPa
T00=1150//The temperature at entry to the nozzle in K
T1=1013//The static temperature at the outlet of the nozzle in K
P03=100//The pressure at the outlet of the diffuser in kPa
R=284.5//The universal gas constant in J/kg.K
Cp=1.147//The specific heat of air at constant pressure in kJ/kg.K
r=1.33//The ratio of specific heats of given gas

//calculations
U1=(ntt*Cp*1000*T00*(1-((P03/P00)^((r-1)/r))))^(1/2) //The impeller tip speed in m/s
T01=T00//The absolute temperature at the entry in K
C1=(2000*Cp*(T01-T1))^(1/2)//The absolute velocity at the inletof turbine in m/s
a11=acosd(U1/C1)//The flow angle at the nozzle oulet in degree
M1=C1/(r*R*T1)^(1/2)//The mach number at the nozzle outlet

//output
printf('(a)The impeller tip speed is %3.1f m/s\n(b)The flow angle at the nozzle oulet 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

```
clc
clear
//input data
D1=0.09//Rotor inlet tip diameter in m
D2t=0.062//Rotor outlet tip diameter in m
D2h=0.025//Rotor outlet hub diameter in m
N=30000//Blade speed in rpm
d2=1.8//Density of exhaust gases at impeller exit in
    kg/m^3
C2s=0.447//Ratio of absolute velocity and isentropic
    velocity at exit
U1Cs=0.707//Ratio of impeller tip velocity and
    isentropic velocity

//calculations
U1=(3.1415*D1*N)/60//The impeller tip speed in m/s
Cs=U1/U1Cs//Isentropic velocity in m/s
C2=C2s*Cs//Absolute velocity at the exit in m/s
A2=(3.141/4)*((D2t^2)-(D2h^2))//Area at the exit in
    m^2
Q2=A2*C2//Volume flow rate at the impeller exit in m
    ^3/s
M=d2*Q2//Mass flow rate in kg/s
W=M*U1^2//Power developed in W

//output
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

```
clc
clear
//input data
P00=3.5//Total-to-static pressure ratio
P2=1//Exit pressure in bar
T00=923//Inlet total temperature in K
U1Cs=0.66//Blade to isentropic speed ratio
D=0.45//Rotor diameter ratio
N=16000//Speed from nozzle in rpm
a11=20//Nozzle exit angle in degree
nn=0.95//Nozzle efficiency
b1=0.05//Rotor width at inlet in m
R=287//The universal gas constant in J/kg.K
Cp=1005//The specific heat of air at constant
    pressure in J/kg.K
r=1.4//The ratio of specific heats of air


//Calculations
T2s=T00*(1/P00)^((r-1)/r)//Isentropic temperature at
     the exit in K
Cs=(2*Cp*(T00-T2s))^(1/2)//The isentropic velocity
    in m/s
U1=U1Cs*Cs//The impeller tip speed in m/s
D1=(U1*60)/(3.14*N)//Rotor inlet diameter in m
D2=D*D1//Rotor outlet diameter in m
Cr2=U1*tand(a11)//The relative velocity at the exit
    in m/s
U2=(3.1415*D2*N)/60//Peripheral velocity of impeller
     at exit in m/s
b22=atand(Cr2/U2)//The air angle at rotor exit in
    degree
T02=T00-((U1^2)/(Cp))//The absolute temperature at
    the exit in K
T2=T02-((Cr2^2)/(2*Cp))//The temperature at the exit
     of turbine in K
T1=T2+((U1^2)/(2*Cp))//The temperature at the entry
    of turbine in K
```

```
T1s=T00-((T00-T1)/nn)//Isentropic temperature at the entry in K
P1=P00*(T1s/T00)^(r/(r-1))//The pressure at the entry stage in bar
d1=(P1*10^5)/(R*T1)//The density of the air  at the inlet in kg/m^3
A1=3.1415*D1*b1//The area at the inlet in m^2
Cr1=Cr2//The relative velocity at the entry in m/s
m=d1*A1*Cr1//The mass flow rate for a 90degree IFR turbine Degree of Reaction is 0.5 in kg/s
W=(m*U1^2)*10^-6//Power developed in MW
d2=(P2*10^5)/(R*T2)//The density of the air at the exit in kg/m^3
b2=m/(d2*3.141*D2*Cr2)//Rotor width at the exit in m
D2h=D2-b2//Hub diameter at the exit in m
D2t=D2+b2//Tip diameter at the exit in m
nts=(W*10^6)/(m*Cp*(T00-T2s))//Total-to-static efficiency
C1=U1/cosd(a11)//Absolute velocity at the entry in m/s
Ln=(Cp*(T1-T1s))/((C1^2)/2)//Nozzle enthalpy loss coefficient
W2=((U2^2)+(Cr2^2))^(1/2)//Resultant relative velocity at the exit in m/s
T2s=T1*(P2/P1)^((r-1)/r)//Isentropic temperature at the exit in K
Lr=(Cp*(T2-T2s))/((W2^2)/2)//Rotor enthalpy loss coefficient

//output
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

```
clc
clear
//input data
P00=700//Total-to-static pressure ratio
T00=1145//Inlet total temperature in K
P1=527//The pressure at the entry stage in bar
T1=1029//The temperature at the entry of turbine in K
P2=385//The pressure at the second stage in bar
T2=915//The temperature at the second stage entry in K
T02=925//The absolute temperature at the exit in K
D2mD1=0.49//The ratio of rotor exit mean diameter to rotor inlet diameter
N=24000//Blade speed in rpm
R1=8.314//The gas constant of given gas in kJ/kg.K
r=1.67//The ratio of specific heats of the gas
m=39.94//Molecular weight of a gas

//calculations
R=R1/m//The universal gas constant in kJ/kg.K
Cp=(r*R)/(r-1)//The specific heat of air at constant pressure in kJ/kg.K
T2ss=T00*(P2/P00)^((r-1)/r)//Isentropic stage temperature at the exit in K
nts=(T00-T02)/(T00-T2ss)//Total-to-static efficiency of the turbine
U1=(Cp*1000*(T00-T02))^(1/2)//The impeller tip speed
```

```
 in m/s
D1=(U1*60)/(3.1415*N)//Rotor inlet diameter in m
D2m=D1*D2mD1//Rotor exit mean diameter in m
C1=(2*Cp*(T00-T1))^(1/2)//Absolute velocity at the entry in m/s
T1s=T00*(P1/P00)^((r-1)/r)//Isentropic temperature at the entry in K
Ln=(Cp*(T1-T1s))/((C1^2)/2)//Nozzle enthalpy loss coefficient
C2=(2*Cp*1000*(T02-T2))^(1/2)//The temperature at the exit of turbine in K
U2=(3.14*D2m*N)/(60)//Peripheral velocity of impeller at exit in m/s
W2=((C2^2)+(U2^2))^(1/2)//Resultant relative velocity at the exit in m/s
T2s=T1*(P2/P1)^((r-1)/r)//stage temperature at the exit in K
Lr=(Cp*1000*(T2-T2s))/((W2^2)/2)//Rotor enthalpy loss coefficient
ntt=1/((1/nts)-((C2^2)/(2*U1^2)))//Total-to-total efficiency

//output
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

```
clc
clear
//input data
Nm=1000//Speed of the model in rpm
Hm=8//Head of the model in m
Pm=30//Power of the model in kW
Hp=25//Head of the prototype in m
DmDp=1/5//The scale of the model to original

//calculations
Np=((Hp/Hm)^(1/2))*(DmDp)*(Nm)//Speed of the
    prototype in rpm
Pp=(Pm)*((1/DmDp)^(5))*(Np/Nm)^(3)//Power developed
    by the prototype in kW
QpQm=((1/DmDp)^(3))*(Np/Nm)//Ratio of the flow rates
     of two pump(model and prototype)

//output
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

```
clc
clear
//input data
Hp=85//Head of the prototype in m
Qp=(20000/3600)//Flow rate of the prototype in m^3/s
Np=1490//Speed of the prototype in rpm
Dp=1.2//Diameter of the prototype in m
dp=714//Density of the prototype fluid in kg/m^3
Pp=4//Power of the prototype in MW
Pm=500*10^-3//Power of the model in MW
Qm=0.5//Flow rate of the prototype in m^3/s
dm=1000//Density of the model fluid (water) in kg/m^3

//calculations
NpNm=(Qp/Qm)//Ratio of the speeds of the prototype and the model in terms of (Dm/Dp)^(3)
DmDp=1/(((NpNm)^(3))*(dp/dm)*(Pm/Pp))^(1/4)//The ratio of the diameters of model and the prototype or the scale ratio
NmNp=1/(NpNm*((DmDp)^(3)))//The speed ratio or the ratio of speeds of the model and the prototype
HmHp=((1/NmNp)^(2))*((1/DmDp)^(2))//The head ratio or the ratio of heads of the model and the prototype

//output
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

```
clc
clear
//input data
Np=400//The speed of the prototype in rpm
Qp=1.7//The discharge of the prototype in m^3/s
Hp=36.5//The head of the prototype in m
Pp=720//The power input of the prototype in kW
Hm=9//The head of the model in m
DmDp=1/6//The scale of model to prototype

//calculations
Nm=((Hm/Hp)^(1/2))*(1/DmDp)*Np//Speed of the model
    in rpm
Qm=((DmDp)^(3))*(Nm/Np)*(Qp)//Discharge of the model
     in m^3/s
Pm=((DmDp)^(5))*((Nm/Np)^(3))*Pp//Power required by
    the model in kW

//output
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

```
clc
clear
//input data
```

```
N1=1000//The running speed of the pump−1 in rpm
D1=0.3//The impeller diameter of pump−1 in m
Q1=0.02//The discharge of pump−1 in m^3/s
H1=15//The head developed by the pump−1 in m
N2=1000//The running speed of the pump−2 in rpm
Q2=0.01//The discharge of pump−2 in m^3/s

//calculations
D2=(((Q2/Q1)*(N1/N2))^(1/3))*(D1)//Impeller diameter of the pump−2 in m
H2=(((D2/D1)*(N2/N1))^(2))*(H1)//Head developed by the pump−2 in m

//output
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

```
clc
clear
//input data
DmDp=1/10//The model ratio to prototype
Pm=1.84//Power developed by the model in kW
Hm=5//Head developed by the model in m
Nm=480//Speed of the model in rpm
Hp=40//Head developed by the prototype in m

//calculations
Np=((Hp/Hm)^(1/2))*(DmDp)*(Nm)//Speed of the prototype in rpm
Pp=((1/DmDp)^(5))*((Np/Nm)^(3))*Pm//Power developed by the prototype in kW
Nsp=((Np*((Pp)^(1/2)))/((Hp)^(5/4)))//Specific speed
```

```
of the prototype
Nsm=((Nm*((Pm)^(1/2)))/((Hm)^(5/4)))//Specific speed of the prototype

//output
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

```
clc
clear
//input data
DmDp=1/10//The model ratio to prototype
Hm=5//The head developed by the model in m
Hp=8.5//The head developed by the prototype in m
Pp=8000*10^3//The power developed by the prototype in W
Np=120//The speed of running of the prototype in rpm
d=1000//density of the water in kg/m^3
g=9.81//Acceleration due to gravity in m/s^2
n0=0.85//Overall efficiency of the prototype

//calculations
Nm=((Hm/Hp)^(1/2))*(1/DmDp)*(Np)//Speed of the mpdel in rpm
Qp=Pp/(d*g*n0*Hp)//Discharge from the prototype in m^3/s
Qm=((DmDp)^(3))*(Nm/Np)*(Qp)//Discharge from the model in m^3/s
Pm=((DmDp)^(5))*((Nm/Np)^(3))*(Pp)*10^-3//Power of
```

```
   the model in kW

//output
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

```
clc
clear
//input data
P1=6600//Initial power developed by the turbine in
   kW
N1=100//Initial speed of the turbine in rpm
H1=30//Initial head of the turbine in m
H2=18//Final head of the turbine in m

//calculations
N2=N1*((H2/H1)^(1/2))//The final speed of the
   turbine in rpm
P2=P1*((H2/H1)^(3/2))//The final power developed by
   the turbine in kW

//output
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

```
clc
clear
```

```
//input data
H1=25//The initial head on the turbine in m
N1=200//The initial speed of the turbine in rpm
Q1=9//The initial discharge of the turbine in m^3/s
n0=0.9//Overall efficiency of the turbine
H2=20//The final head on the turbine in m
d=1000//density of the water in kg/m^3
g=9.81//Acceleration due to gravity in m/s^2

//calculations
N2=N1*((H2/H1)^(1/2))//The final speed of the turbine in rpm
Q2=Q1*((H2/H1)^(1/2))//The final discharge of the turbine in m^3/s
P1=n0*d*g*Q1*H1*10^-3//Power produced by the turbine initially in kW
P2=P1*((H2/H1)^(3/2))//Power produced by the turbine finally in kW

//output
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

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

```
H2=160//The final head produced in m
d=1000//density of the water in kg/m^3
g=9.81//Acceleration due to gravity in m/s^2


//calculations
Nu=N1/((H1)^(1/2))//The unit speed of the turbine
Pu=P1/((H1)^(3/2))*10^-3//The unit power of the
    turbine
Q1=P1/(d*g*n0*H1)//The initial discharge of the
    turbine in m^3/s
Qu=Q1/((H1)^(1/2))//The unit discharge of the
    turbine
Q2=Qu*((H2)^(1/2))//The final discharge of the
    turbine in  m^3/s
N2=Nu*((H2)^(1/2))//The final speed of the turbine
    in rpm
P2=Pu*((H2)^(3/2))//The final power of the turbine
    in kW
Ns=(N2*((P2)^(1/2)))/((H2)^(5/4))//The specific
    speed of the turbine

//output
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

```
clc
clear
//input data
D=1.3//Diameter of the pump in m
Q=3.5/60//Discharge of water by pump in m^3/s
U2=10//Tip speed of pump in m/s
Cr2=1.6//Flow velocity of water in pump in m/s
b2=30//Outlet blade angle tangent to impeller
    periphery in degree
Cx1=0//Whirl velocity at inlet in m/s
U=10//Tip speed of pump in m/s
d=1000//Density of water in kg/m^3
g=9.81//Acceleration due to gravity in m/s^2

//calculations
Wx2=Cr2/tand(b2)//Exit relative velocity in m/s
E=(U2/g)*(U2-(Wx2))//Euler head in m or W/(N/S)
m=d*Q//Mass flow rate of water in kg/s
W=E*m*g//Power delivered in W
r=D/2//Radius of the pump in m
T=W/(U/r)//Torque delivered in Nm
```

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

**Scilab code Exa 8.2** THEORETICAL HEAD

```
clc
clear
//input data
b2=30//Impeller blade angle to the tangent at
  impeller outlet in degree
d=0.02//Blade depth in m
D=0.25//Blade diameter in m
N=1450//Pump rotation speed in rpm
Q=0.028//FLow rate of the pump in m^3/s
sf=0.77//Slip factor
g=9.81//Acceleration due to gravity in m/s^2

//calculations
A=3.1415*d*D//Flow area in m^2
Cr2=Q/A//Flow velocity in m/s
Wx2=Cr2/tand(b2)//Exit relative velocity in m/s
U2=(3.14*D*N)/60//Tip speed of pump in m/s
Cx2=U2-Wx2//Absolute whirl component at exit in m/s
E=(U2*Cx2)/g//Euler head with no whirl at inlet in m
Cx21=sf*Cx2//Actual value of component of absolute
  value in tangential direction in m/s
Es=sf*E//Theoretical head with slip in m
Z=(3.145*sind(b2))/((1-sf)*(1-((Cr2/U2)*cotd(b2))))
  //Number of blades required based on stodola slip
   factor

//output
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

```
clc
clear
//input data
D2=0.4//Outer diameter of impeller in m
b2=0.05//Outlet width of impeller in m
N=800//Running speed of pump in rpm
Hm=16//Working head of pump in m
b22=40//Vane angle at outlet in degree
nm=0.75//Manometric efficiency
g=9.81//Acceleration due to gravity in m/s^2

//calculations
U2=(3.1415*D2*N)/60//Impeller tip speed in m/s
Cx2=(g*Hm)/(U2*nm)//Absolute whirl component at exit in m/s
Wx2=U2-Cx2//Exit relative velocity in m/s
Cr2=Wx2*tand(b22)//Flow velocity of water in pump in m/s
A=3.14*D2*b2//Area of flow in m^2
Q=A*Cr2//Discharge of the pump in m^3/s

//output
printf('The discharge of the pump is %3.4f m^3/s',Q)
```

**Scilab code Exa 8.4** VANE INLET ANGLE

```
clc
clear
//input data
```

```
D2D1=2//The ratio of outer and inner diameter
N=1200//The running speed of pump in rpm
Hm=75//Total head producing work in m
Cr1=3//Flow velocity through impeller at inlet in m/s
Cr2=Cr1//Flow velocity through impeller at outlet in m/s
b22=30//Vanes set back angle at outlet in degree
D2=0.6//Outlet diameter of impeller in m
d=1000//Density of water in kg/m^3
b2=0.05//Width of impeller at outlet in m
g=9.81//Acceleartion due to gravity in m/s^2

//calculations
D1=D2/D2D1//Inlet diameter of impeller in m
U1=(3.1415*D1*N)/60//Impeller tip speed at inlet in m/s
b11=atand(Cr1/U1)//Vane angle at inlet in degree
U2=(3.1415*D2*N)/60//Impeller tip speed at exit in m/s
A=3.1415*D2*b2//Area of flow in m^2
Q=A*Cr2//Discharge of the pump in m^/s
m=d*Q//Mass flow rate of water in kg/s
Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
Cx2=U2-Wx2//Absolute whirl component at exit in m/s
W=m*U2*Cx2*10^-3//Work done per second in kW
nm=Hm/((U2*Cx2)/g)//Manometric efficiency

//output
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

```
clc
clear
//input data
Q=75//Discharge from the pump in l/s
D1=0.1//Inlet diameter of the pump in m
D2=0.29//Outlet diameter of the pump in m
Hm=30//Total head producing work in m
N=1750//Speed of the pump in rpm
b1=0.025//Width of impeller at inlet per side in m
b2=0.023//Width of impeller at outlet in total in m
a11=90//The angle made by the entering fluid to impeller in degree
b22=27//Vanes set back angle at outlet in degree
Qloss=2.25//Leakage loss in l/s
ml=1.04//Mechanical loss in kW
cf=0.87//Contraction factor due to vane thickness
n0=0.55//Overall efficiency
d=1000//Density of water in kg/m^3
g=9.81//Acceleration due to gravity in m/s^2

//calculations
U1=(3.1415*D1*N)/60//Blade inlet speed in m/s
A1=3.1415*D1*b1*cf*10^3//Area of flow at inlet in m^2
Qt=Q+Qloss//Total quantity of water handled by pump in l/s
Qts=Qt/2//Total quantity of water handled by pump per side in l/s
Cr1=(Qts*10^-3)/(A1*10^-3)//Flow velocity through impeller at inlet in m/s
b11=atand(Cr1/U1)//Inlet vane angle in degree
A2=3.1415*D2*(b2/2)*cf*10^3//Area of flow at outlet in m^2 here b2 is calculated per side
Cr2=Qts/A2//Velocity of flow at outlet in m/s
U2=(3.1415*D2*N)/60//Peripheral speed at outlet in m/s
Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
Cx2=U2-Wx2//Absolute whirl component at exit in m/s
```

```
a22=atand(Cr2/Cx2)//The absolute water angle at outlet in degree
C2=Cr2/sind(a22)//Absolute velocity of water at exit in m/s
nh=Hm/((U2*Cx2)/g)//Manometric efficiency
nv=Q/Qt//Volumetric efficiency
SP=(d*g*(Q*10^-3/2)*Hm)/n0*10^-3//Shaft power in kW
nm=(SP-ml)/SP//Mechanical efficiency

//output
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

```
clc
clear
//input data
Hi=0.25//Vaccum gauge reading in m of Hg vaccum
P0=1.5//Pressure gauge reading in bar
Z01=0.5//Effective height between gauges in m
P=22//Power of electric motor in kW
Di=0.15//Inlet diameter in m
Do=0.15//Outlet diameter in m
Q=0.1//Discharge of pump in m^3/s
dHg=13600//Density of mercury in kg/m^3
dw=1000//Density of water in kg/m^3
g=9.81//Acceleration due to gravity in m/s^2

//calculations
Pi=dHg*g*Hi//Inlet pressure in N/m^2 vaccum
```

```
Po=P0*10^5//Outlet pressure in N/m^2
V0=Q/((3.1415*Do^2)/4)//Velocity of water in delivery pipe in m/s
Vi=V0//vleocity of water in suction pipe in m/s
Hm=((Po+Pi)/(dw*g))+((V0^2-Vi^2)/(2*g))+(Z01)//Manometric head in m
n0=(dw*g*Q*Hm)/(P*10^3)//Overall efficiency

//output
printf('(a)Manometric head is %3.2f m\n(b)Overall efficiency is %3.3f',Hm,n0)
```

**Scilab code Exa 8.7** IMPELLER DIAMETER

```
clc
clear
//input data
Hm=20//Head against which work is produced in pump in m
b22=45//Vanes set back angle at outlet in degree
N=600//Rotating speed of pump in rpm
Cr1=2//Flow velocity through impeller at inlet in m/s
Cr2=Cr1//Flow velocity through impeller at outlet in m/s
g=9.81//acceleration due to gravity in m/s^2

//calculations
Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
U2=(4+(16+(4*3*792.8))^(1/2))/(2*3)//   Blade outlet speed in m/s
    //The above equation is obtained by solving
    //Cx2=U2-Wx2      //Absolute whirl component at exit in m/s
    //C2=(Cx2^2+Cr2^2)^(1/2)     //Absolute velocity
```

```
of water at exit in m/s
    //Hm=(U2*Cx2/g)-((C2^2)/(4*g))    //Total head producing work in m
    //3*(U2^2)-(4*U2)-792.8=0
D2=(60*U2)/(3.1415*N)//Impeller diameter in m

//output
printf('The impeller diameter is %3.4f m',D2)
```

**Scilab code Exa 8.8** POWER REQUIRED

```
clc
clear
//input data
n0=0.7//Overall efficiency
Q=0.025//Discharge of water by the pump in m^3/s
H=20//Height of supplied by the pump in m
D=0.1//Diameter of the pump in m
L=100//Length of the pipe in m
f=0.012//Friction coefficient
g=9.81//Acceleration due to gravity in m/s^2
d=1000//Density of water in kg/m^3

//calculations
V0=Q/((3.1415/4)*D^2)//Velocity of water in the pipe in m/s
hf0=(4*f*L*V0^2)/(2*g*D)//Loss of head due to friction in pipe in m
Hm=H+hf0+(V0^2/(2*g))//Manometric head in m
P=(d*g*Q*Hm)/(n0)*10^-3//Power required to drive the pump in kW

//output
printf('Power required to drive the pump is %3.2f kW',P)
```

**Scilab code Exa 8.9** RISE IN PRESSURE IN THE IMPELLER

```
clc
clear
//input data
Q=0.015//Discharge of water in pump in m^3/s
D1=0.2//Internal diameter of the impeller in m
D2=0.4//External diameter of the impeller in m
b1=0.016//Width of impeller at inlet in m
b2=0.008//Width of impeller at outlet in m
N=1200//Running speed of the pump in rpm
b22=30//Impeller vane angle at outlet in degree
g=9.81//Acceleration due to gravity in m/s^2
d=1000//Density of water in kg/m^3

//calculations
printf('From velocity triangles the following values
    have been deduced')
a11=90//The absolute water angle at inlet in degree
Cx1=0//Absolute whirl component at inlet in m/s
A1=3.1415*D1*b1//Area of flow at inlet in m^2
Cr1=Q/A1//Flow velocity through impeller at inlet in
    m/s
C1=Cr1//Absolute velocity at inlet in m/s
A2=3.1415*D2*b2//Area of flow at outlet in m^2
Cr2=Q/A2//Flow velocity through impeller at outlet
    in m/s
U2=(3.1415*D2*N)/60//Blade outlet speed in m/s
Cx2=U2-(Cr2/tand(b22))//Absolute whirl component at
    outlet in m/s
C2=(Cx2^2+Cr2^2)^(1/2)//Velocity at impeller exit in
    m/s
Ihl=((Cx2*U2)/g)-((C2^2)/(2*g))+((C1^2)/(2*g))//
    Pressure rise in impeller in m
```

```

//output
printf('\n\nThe rise in pressure in the impeller is
    %3.3f m',Ihl)
```

---

**Scilab code Exa 8.10** EXIT BLADE ANGLE

```
clc
clear
//input data
Ihl=3//Head loss in impeller in m
Cr2=4.64//Flow velocity through impeller at outlet
    in m/s
U2=30//Blade outlet speed in m/s
dPi=35.3//Difference in pressure gauge readings at
    impeller inlet and outlet in m of water
Pg=4.7//Pressure gain in the casing in m of water
n=0.385//Part of absolute kinetic energy converted
    into pressure gain
g=9.81//Acceleration due to gravity in m/s^2
d=1000//Density of water in kg/m^3
ss=0.85//Slip coefficient

//calculations
Kei=Pg/n//Kinetic energy at impeller exit in m/s
C2=((Kei)*2*g)^(1/2)//Velocity at impeller exit in m
    /s
Cx22=(C2^2-Cr2^2)^(1/2)//Absolute whirl component at
     outlet with fliud slip in m/s
Cx2=Cx22/ss//Ideal absolute whirl velocity in m/s
b22=atand(Cr2/(U2-Cx2))//Blade angle at exit in
    degree
Wm=ss*U2*Cx2//Euler work input in J/kg
nm=dPi/(U2*Cx22/g)//Manometric efficiency
dP=(U2*Cx22/g)-(Ihl)-(C2^2/(2*g))//Pressure rise in
```

```
impeller in m

//output
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

```
clc
clear
//input data
r1=0.051//Eye radius of the impeller in m
D2=0.406//Outer diameter of the impeller in m
b11=(90-75)//Inlet blade angle measured from tangential flow direction in degree
b22=(90-83)//Outlet blade angle measured from tangential flow direction in degree
b=0.064//Blade depth in m
Cx1=0//Inlet whirl velocity in m/s
nh=0.89//Hydraulic efficiency
g=9.81//Acceleration due to gravity in m/s^2
d=1000//Density of water in kg/m^3
N=900//Rotating speed of impeller in rpm

//calculations
w=(2*3.1415*N)/60//Angular velocity at inlet in rad/s
U1=(w*r1)//Inlet tangential impeller velocity in m/s
C1=U1*tand(b11)//Velocity at impeller inlet in m/s
A=2*3.1415*r1*b//Area of flow through the pump in m^2
Cr1=C1//Flow velocity through impeller at inlet in m/s
```

```
Q=A*Cr1//Volume flow through the pump in m^3/s
r2=D2/2//Outer radius of the impeller in m
Cr2=(r1*Cr1)/r2//Flow velocity through impeller at outlet in m/s
U2=w*r2//Outlet tangential impeller velocity in m/s
Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
E=(U2/g)*(U2-Wx2)//Theoretical head developed in m
Hm=nh*E//Total stagnation head developed by the pump in m
dP021=Hm*d*g*10^-3//Total pressure head coefficient in kPa
Cx2=U2-(Cr2/tand(b22))//Absolute whirl velocity in m/s
C2=(Cr2^2+Cx2^2)^(1/2)//Velocity at impeller exit in m/s
dP21=(Hm-(((C2^2)-(C1^2))/(2*g)))*d*g*10^-3//The static pressure head in kPa
P=d*g*Q*Hm*10^-3//Power given to the fluid in kW
Ps=P/nh//Input power to impeller in kW

//output
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

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

```
b22=(180-120)//Outlet angle with the normal in degree
H=35//Distance to which pumping of water is done in m
Dp=0.15//Diameter of suction and delivery pipes in m
L=40//Combined length of suction and delivery pipes in m
WD=1/10//Width to diameter ratio at outlet of impeller
f=0.005//Friction factor
g=9.81//Acceleration due to gravity in m/s^2
nh=0.76//Hydraulic effficiency neglecting the slip
n=0.06//Percentage occupied by blades on circumference area

//calculations
A=(3.1415/4)*(Dp^2)//Area of flow in pipe in m^2
V=Q/A//Velocity in the pipes in m/s
OL=3*V^2/(2*g)//Other loses in the pipes in m
TL=(4*f*L*V^2/(2*g*Dp))+(OL)//Total loses in a pipe in m
TH=TL+H//Total required head in m
N=(Ns*((g*H)^(3/4)))/((Q)^(1/2))//The speed of the pump in rev/s
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
Cr2=Q/Ao//Flow velocity through impeller at outlet in m/s
U2=3.1415*N//Outlet tangential impeller velocity in m/s in terms of D
Cx2=(g*H)/(U2*nh)//Absolute whirl velocity in m/s

//The following steps are for calculating the cubic root equation in D
//This is obtained by solving    tand(b22)=(Cr2/(Cx2-U2))    all values are substituted in terms of D
```

```
//The final equation which is obtained is D^3-0.0495D+0.0008=0
//The above equation is solved using the following formulae

a=0//Coefficient of D^2 in the above equation
b=-0.0511//Coefficient of D in the above equation
c=0.00083//Constant term in above equation
q=c+((2*(a^3))/27)-(a*b/3)//Constant in solving the cubic equation
p=((3*b)-(a^2))/3//Constant in solving the cubic equation
d=(p/2)^2+(q/3)^3//Constant in solving the cubic equation
u=((-q/2)+(d^(1/2)))^(1/3)//Constant in solving the cubic equation
v=((-q/2)-(d^(1/2)))^(1/3)//Constant in solving the cubic equation
D=(u+v)/2//Impeller diameter in m

//output
printf('The pump impeller diameter is %3.3f m',D)
```

**Scilab code Exa 8.13** SPECIFIC SPEED

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

```

```
//calculations
Ns=(N*Q^(1/2))/(Hm^(3/4))//Specific speed of the
    pump
P=((d*g*Q*Hm)/n)*10^-3//Power input in kW

//calculations
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

```
clc
clear
//input data
D1=0.6//Inlet impeller diameter in m
D2=1.2//Outlet impeller diameter in m
Cr2=2.5//Radial flow velocity in m/s
N=200//Running speed of the pump in rpm
Q=1.88//Discharge of the pump in m^3/s
Hm=6//Head which the pump has to overcome in m
b22=26//Vane angle at exit at tangent to impeller in
     degree
d=1000//Density of the water in kg/m^3
g=9.81//Acceleration due to gravity in m/s^2

//calculations
U2=(3.1415*D2*N)/60//Outlet tangential impeller
    velocity in m/s
Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
Cx2=U2-Wx2//Absolute whirl velocity in m/s
nm=(Hm/(U2*Cx2/g))//Manometric efficiency
Nls=((2*g*Hm*60^2)/((3.1415^2)*((1.2^2)-(0.6^2))))
    ^(1/2)//Least starting speed of the pump in rpm

//output
```

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

**Scilab code Exa 8.15** HYDRAULIC OR MANOMETRIC EFFICIENCY

```
clc
clear
//input data
D2=1.25//External diameter of the impeller in m
D1=0.5//Internal diameter of the impeller in m
Q=2//Discharge of the pump in m^3/s
Hm=16//Head over which pump has to operate in m
N=300//Running speed of the pump in rpm
b22=30//Angle at which vanes are curved back in
   degree
Cr1=2.5//Flow velocity through impeller at inlet in
   m/s
Cr2=Cr1//Flow velocity through impeller at outlet in
   m/s
d=1000//Density of the water in kg/m^3
g=9.81//Acceleration due to gravity in m/s^2

//calculations
U2=(3.1415*D2*N)/60//Outlet tangential impeller
   velocity in m/s
Wx2=Cr2/tand(b22)//Exit relative velocity in m/s
Cx2=U2-Wx2//Absolute whirl velocity in m/s
nm=(Hm*g)/(U2*Cx2)//Manometric or hydraulic
   efficiency
m=d*Q//Mass flow rate of water in kg/s
W=m*U2*Cx2*10^-3//Fluid power developed by the
   impeller in kW
Ps=W//Power required by the pump in kW neglecting
   mechanical loses
Nls=((2*g*Hm)/(((3.1415/60)^2)*(D2^2-D1^2)))^(1/2)//
```

```
Minimum starting speed of the pump in rpm

//output
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,N1s)
```

---

**Scilab code Exa 8.16** HEAT GENERATED BY PUMP

```
clc
clear
//input data
n=3//Number of stages
D2=0.4//Outlet impeller diameter in m
b2=0.02//Outlet impeller width in m
b22=45//Backward vanes angle at outlet in degree
dA=0.1//Reduction in circumferential area
nm=0.9//Manometric efficiency of the pump
Q=0.05//Discharge of the pump in m^3/s
N=1000//Running speed of the pump in rpm
n0=0.8//Overall efficiency of the pump
g=9.81//Acceleration due to gravity in m/s^2
d=1000//Density of water in kg/m^3

//calculations
A2=(1-dA)*3.1415*D2*b2//Area of flow at outlet in m^2
Cr2=Q/A2//Flow velocity through impeller at outlet in m/s
U2=(3.1415*D2*N)/60//Outlet impeller tangential velocity in m/s
Wx2=Cr2//Exit relative velocity in m/s as tand(b22)=1
Cx2=U2-Wx2//Absolute whirl velocity in m/s
```

```
Hm=(nm*U2*Cx2)/g//Head over which pump has to
    operate in m
H=n*Hm//Total head generated by the pump in m
P=d*g*Q*Hm*n//Power output from the pump in W
Ps=P/n0*10^-3//Shaft power input in kW

//output
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

```
clc
clear
//input data
H=156//Total head operated by the pumps in m
N=1000//Running speed of the pump in rpm
Ns=20//Specific speed of each pump
Q=0.150//Discharge of the pump in m^3/s

//calculations
Hm=((N*(Q)^(1/2))/(Ns))^(4/3)//Head developed by
    each pump in m
n=H/Hm//Number of pumps

//output
printf('The number of pumps are %3.f',n)
```

**Scilab code Exa 8.18** IMPELLER DIAMETER AND NUMBER OF STAGES

```
clc
clear
//input data
```

```
Q1=120//Discharge of each of the multi stage pump in parallel in first case in m^3/s
Q2=450//Discharge of the multi stage pump in second case in m^3/s
H1=16//Head of each stage in first case in m
D1=0.15//Diameter of impeller in first case in m
H=140//Total head developed by all pumps in second case in m
N1=1500//Running speed of the pump in rpm in first case
N2=1200//Running speed of the pump in rpm in second case
//calculations
H2=H1*((Q2/Q1)*((N2/N1)^2))^(4/6)//Head of each stage in second case in m
n=H/H2//Number of stages in second case
D2=D1*(((N1/N2)^(2))*(H2/H1))^(1/2)//Diameter of impeller in second case in m

//output
printf('(a)number of stages required is %3.f\n(b) Diameter of impeller in the second case is %3.2f m',n,D2)
```

**Scilab code Exa 8.19** CAVITATION PARAMETER

```
clc
clear
//input data
H=36//Initial total head of the pump in m
Q1=0.05//Initial discharge of the pump in m^3/s
H2=3.5//Sum of static pressure and velocity head at inlet in m
P01=0.75//Atmospheric pressure initially in m of Hg
Pvap1=1.8*10^3//Vapour pressure of water initially
```

```
in Pa
Pvap2=830//Vapour pressure of water finanlly in Pa
P02=0.62//Atmospheric pressure finally in m of Hg
g=9.81//Acceleration due to gravity in m/s^2
dW=1000//Density of water in kg/m^3
dHg=13.6//Density of mercury in kg/m^3

//calculations
NPSH=H2-((Pvap1)/(dW*g))//Net positive suction head in m
s=NPSH/H//Cavitation parameter when pump dvelops same total head and discharge
dH1=(P01*dHg)-(s*H)-(Pvap1/(dW*g))//The height reduced in initial condition above supply in m
dH2=(P02*dHg)-(s*H)-(Pvap2/(dW*g))//The height reduced in final condition above supply in m
Z=dH1-dH2//The total height which the pump must be lowered at new location in m

//output
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

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

```
Ca=2//Velocity of the flow in m/s
H=6//Head which the pump has to drive in m

//calculations
A=(3.1415/4)*(Dt^2-Dh^2)//Area of flow in m^2
Q=A*Ca//Discharge of the pump in m^3/s
N=(Ns*H^(3/4))/(Q^(1/2))//Pump speed in rpm
U1=(3.1415*Dh*N)/60//Blade inlet speed in m/s
b1=atand(Ca/U1)//Vane angle at the entry of the pump
    when the flow is axial at inlet in degree

//output
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

```
clc
clear
//input data
Q=0.180//Discharge of the pump in m^3/s
H=2//Head developed by the pump in m
Ns=250//Specific speed of the pump
SR=2.4//Speed ratio of the pump
FR=0.5//Flow ratio of the pump
g=9.81//Acceleration due to gravity in m/s^2

//calculations
N=(Ns*(H^(3/4)))/(Q^(1/2))//Pump speed in rpm
U=SR*(2*g*H)^(1/2)//Peripheral velocity in m/s
D=(60*U)/(3.1415*N)//Runner diameter of the pump in
   m
Ca=FR*(2*g*H)^(1/2)//Velocity of flow in m/s
Dh=((D^2)-(Q*4/(Ca*3.14)))^(1/2)//Boss diameter of
```

```
    the pump in m

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

**Scilab code Exa 8.22** JET PUMP EFFICIENCY

```
clc
clear
//input data
Hs=2.5//Height of the pipe above suction reservoir
    in m
H1=18//Height of the pipe below supply reservoir in
    m
H=2.7//Total height through which the pump lifts
    water in m
Q1=2.75//Discharge of water used from supply
    reservoir in l/s
Qt=7.51//Discharge of water totally delivered in l/s

//calculations
Hd=H-Hs//Height of the pipe from discharge reservoir
     in m
Qs=Qt-Q1//Discharge of water in delivery reservoir
    in l/s
nj=(Qs/Q1)*((Hs+Hd)/(H1-Hd))//Jet pump efficiency

//output
printf('The efficiency of the jet pump is %3.3f',nj)
```

# Chapter 9

# HYDRAULIC TURBINES

**Scilab code Exa 9.1** DIMENSIONLESS POWER SPECIFIC SPEED

```
clc
clear
//input data
H=91.5//Head of the pelton wheel at inlet in m
Q=0.04//Discharge of the pelton wheel in m^3/s
N=720//Rotating speed of the wheel in rpm
Cv=0.98//Velocity coefficient of the nozzle
n0=0.8//Efficiency of the wheel
UC1=0.46//Ratio of bucket speed to jet speed
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
P=dw*g*H*Q*n0*10^-3//Power developed in kw
C1=Cv*(2*g*H)^(1/2)//Jet speed in m/s
U=UC1*C1//Wheel speed in m/s
w=(2*3.1415*N)/60//Angular velocity of the wheel in
    rad/s
D=(2*U)/w//Diameter of the wheel in m
A=Q/C1//Jet area in m^2
d=((4*A)/3.1415)^(1/2)//Jet diameter in m
```

```
Dd=D/d//Wheel to jet diameter ratio at centre line of the buckets
Nsp=((1/(g*H))^(5/4))*(((P*10^3)/dw)^(1/2))*(N/60)*2*3.1415//Dimensionless power specific speed in rad

//output
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

```
clc
clear
//input data
H=500//Head over which pelton wheel works in m
P=13000//Power which pelton wheel produces in kW
N=430//Speed of operation of pelton wheel in rpm
n0=0.85//Efficiency of the wheel
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3
Cv=0.98//Veloity coefficient
UC=0.46//Speed ratio

//calculations
Q=(P*10^3)/(dw*g*H*n0)//Discharge of the turbine in m^3/s
C=Cv*(2*g*H)^(1/2)//Jet speed in m/s
U=UC*C//Wheel speed in m/s
D=(U*60)/(3.1415*N)//Wheel diameter in m
d=((Q/C)*(4/3.1415))^(1/2)//Diameter of the nozzle in m
```

```
//output
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

```
clc
clear
//input data
D=0.8//Mean diameter of the bucket in m
N=1000//Running speed of the wheel in rpm
H=400//Net head on the pelton wheel in m
Q=0.150//Discharge through the nozzle in m^3/s
g=9.81//Acceleration due to gravity in m/s^2
UC1=0.46//Ratio of bucket speed to jet speed
dw=1000//Density of water in kg/m^3
a=15//Side clearance angle in degree

//calculations
m=dw*Q//Mass flow rate through the nozzle in kg/s
U=(3.1415*D*N)/60//Wheel speed in m/s
C1=U/UC1//Jet speed in m/s
P=(1/2)*m*C1^2*(10^-3)//Power available at the
   nozzle in kW
W1=C1-U//Relative inlet fluid velocity in m/s
W2=W1//Relative exit fluid velocity in m/s assuming
   no loss of relative velocity
Wx2=W2*cosd(a)//Exit whirl velocity component in m/s
Cx2=Wx2-U//Absolute exit whirl velocity in m/s
Cx1=C1//Absolute inlet whirl velocity in m/s
Wm=U*(Cx1+Cx2)//Work done per unit mass flow rate in
   W/(kg/s)
nH=(Wm/g)/((C1^2/2)/g)//Hydrualic effciency
```

```

//output
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

```
clc
clear
//input data
n=2//Number of jets
SP=20000*0.736//Shaft power of the wheel in kW
D=0.15//Diameter of each jet in m
H=500//Net head on the turbine in m
Cv=1.0//Velocity coefficient
g=9.81//Acceleration due to gravity in m/s^2
d=1000//Density of water in kg/m^3

//calculations
C1=Cv*(2*g*H)^(1/2)//Velocity of each jet in m/s
A=(3.1415/4)*D^2//Area of each jet in m^2
Qj=A*C1//Discharge of each jet in m^3/s
Q=2*Qj//Total discharge in m^3/s
P=d*g*Q*H*10^-3//Power at turbine inlet in kW
no=SP/P//Overall efficiency

//output
printf('The overall efficiency of the turbine is %3
    .3f',no)
```

**Scilab code Exa 9.5** THEORETICAL HYDRAULIC EFFICIENCY

```
clc
```

```
clear
//input data
a=170//Jet deflection angle in degree
K=1-0.12//Percentage of effective relative velocity after considering friction
UC1=0.47//Ratio of bucket speed to jet speed
GH=600//Gross head on the wheel in m
P=1250//Actual power developed by the wheel in kW
Hl=48//Head loss in nozzle due to pipe friction in m
D=0.9//Bucket circle diameter of the wheel in m
ATnH=0.9//The ratio between actual and calculated hydraulic efficiency
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3
Cv=0.98//Velocity coefficient

//calculations
H=GH-Hl//Net head after loses at entry to nozzle in m
C1=Cv*(2*g*H)^(1/2)//Jet speed in m/s
U=UC1*C1//Wheel bucket speed in m/s
N=(U*60)/(3.1415*D)//Wheel rotational speed in rpm
Wm=U*((C1-U)*(1-(K*cosd(a))))//Work done per unit mass flow rate in W/(kg/s)
Tnh=Wm/(C1^2/2)//Theoretical hydraulic efficiency
Anh=ATnH*Tnh//Actual hydrualic effficiency
m2=(P*10^3)/(Anh*(1/2)*C1^2)//Mass flow rate for both the nozzles in kg/s
m=m2/2//Mass flow rate of each nozzle in kg/s
d=((4*m)/(dw*C1*3.1415))^(1/2)//Nozzle diameter in m

//output
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

```
clc
clear
//input data
H=60//Head on the pelton wheel in m
N=200//Speed of the pelton wheel in rpm
P=100//Power developed by the pelton wheel in kW
Cv=0.98//Velocity coefficient
UC1=0.45//Speed ratio
n0=0.85//Overall efficiency of the wheel
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
C1=Cv*(2*g*H)^(1/2)//Velocity of the jet in m/s
U=UC1*(2*g*H)^(1/2)//Velocity of the buckets in m/s
D=(60*U)/(3.1415*N)//Diameter of the wheel in m
Q=(P*10^3)/(dw*g*H*n0)//Discharge of the wheel in m^3/s
d=((4*Q)/(3.1415*C1))^(1/2)//Diameter of the jet in m
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
w=5*d//Width of the buckets in m
de=1.2*d//Depth of the buckets in m

//output
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

```
clc
clear
//input data
N=300//Running speed of the wheel in rpm
H=150//OPerating head of the wheel in m
dD=1/12//Ratio of nozzle diameter to wheel diameter
Cv=0.98//Velocity coefficient
UC1=0.46//Speed ratio
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3
n0=0.84//Overall efficiency

//calculations
C1=Cv*(2*g*H)^(1/2)//Velocity of jet in m/s
U=UC1*(2*g*H)^(1/2)//Velocity of the wheel in m/s
D=(60*U)/(3.14*N)//Diameter of the wheel in m
d=D*dD//Diameter of the jet in m
Q=(3.1415/4)*(d^2)*C1//Quantity of water required in
    m^3/s
Pa=dw*g*Q*H//Power available at the nozzle in kW
P=n0*Pa*10^-3//Power developed in kW
disp(U)
//output
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

```
clc
clear
//input data
N=1260//Rotational speed of the francis turbine in rpm
H=124//The net head in m
Q=0.5//Volume flow rate of the turbine in m^3/s
r1=0.6//Radius of the runner in m
b1=0.03//Height of the runner vanes at inlet in m
b11=72//Angle of inlet guide vanes in radial direction in degree
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3
Cx2=0//Absolute exit whirl velocity in m/s as flow is radial at outlet

//calculations
m=dw*Q//Mass flow rate in kg/s
T1=-m*r1//Torque by the turbine in Nm in terms of Cx1
A=2*3.1415*r1*b1//Area at inlet in m^2
Cr1=Q/A//Inlet flow velocity in m/s
Cx1=Cr1*tand(b11)//Absolute inlet whirl velocity in m/s
T=-T1*Cx1//Torque by water on the runner in Nm
w=(2*3.1415*N)/60//Angular velocity of the turbine in rad/s
W=T*w*10^-3//Power exerted in kW
nH=W*10^3/(dw*g*Q*H)//Hydraulic efficiency

//output
printf('(a)Torque by water on the runner is %3.f Nm\n(b)Power exerted is %3i kW\n(c)Hydraulic efficiency is %3.3f',T,W,nH)
```

**Scilab code Exa 9.9** INLET GUIDE VANE ANGLE

```
clc
clear
//input data
n0=0.74//Overall efficiency
H=5.5//Net head across the turbine in m
P=125//Required Power output in kW
N=230//Speed of the runner in rpm
nH=(1-0.18)//Hydraulic efficiency
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3
U1=0.97*(2*g*H)^(1/2)//Runner tangential velocity in m/s
Cr1=0.4*(2*g*H)^(1/2)//Flow velocity in m/s

//calculations
Cx1=(nH*g*H)/U1//Absolute inlet whirl velocity in m/s    as flow is radial at outlet Cx2=0  in m/s
a11=atand(Cr1/Cx1)//Inlet guide vane angle in degree
b11=180+atand(Cr1/(Cx1-U1))//Angle of inlet guide vanes in radial direction in degree
D1=(U1*60)/(3.1415*N)//Runner inlet diameter in m
Q=(P*10^3)/(n0*dw*g*H)//Flow rate in m^3/s
b1=Q/(3.1415*D1*Cr1)//Height of runner in m

//output
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 %3.3f 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

```
clc
clear
//input data
D=1.4//Diameter of the turbine in m
N=430//Speed of the turbine in rpm
Cr1=9.5//Flow velocity without shock at runner in m/s
C2=7//Absolute velocity at the exit without whirl in /s
dSPH=62//Difference between the sum of static and potential heads at entrance to runner and at exit from runner in m
W=12250//Power given to runner in kW
Q=12//Flow rate of water from the turbine in m^3/s
H=115//Net head from the turbine in m
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
U1=(3.1415*D*N)/60//Runner tip speed in m/s
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
a1=atand(Cr1/Cx1)//Guide vane angle in degree
C1=(Cr1^2+Cx1^2)^(1/2)//Inlet velocity in  m/s
b1=atand(Cr1/(Cx1-U1))//Runner blade entry angle in degree
dHr=dSPH+(((C1^2)-(C2^2))/(2*g))-(U1*Cx1/g)//Loss of head in the runner in m

//output
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

```
clc
clear
//input data
D1=0.9//External diameter of the turbine in m
D2=0.45//Internal diameter of the turbine in m
N=200//Speed of turbine running in rpm
b1=0.2//Width of turbine at inlet in m
Cr1=1.8//Velocity of flow through runner at inlet in
    m/s
Cr2=Cr1//Velocity of flow through runner at outlet
   in m/s
a11=10//Guide blade angle to the tangent of the
   wheel in degree
a22=90//Discharge angle at outlet of turbine in
   degree
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
C1=Cr1/sind(a11)//Absolute velocity of water at
   inlet of runner in m/s
Cx1=Cr1/tand(a11)//Velocity of whirl at inlet in m/s
U1=(3.1415*D1*N)/60//Runner tip speed at inlet in m/
   s
Wx1=Cx1-U1//Inlet whirl velocity component in m/s
W1=(Wx1^2+Cr1^2)^(1/2)//Relative velocity at inlet
   in m/s
b11=atand(Cr1/Wx1)//Runner blade entry angle in
   degree
U2=(3.1415*D2*N)/60//Runner tip speed at exit in m/s
b22=atand(Cr2/U2)//Runner blade exit angle in degree
b2=D1*b1/D2//Width of runner at outlet in m
```

```
Q=3.1415*D1*b1*Cr1//Discharge of water in turbine in
    m^3/s
m=dw*Q//Mass of water flowing through runner per
    second in kg/s
V2=Cr2//Velocity of water at exit in m/s
H=(U1*Cx1/g)+(V2^2/(2*g))//Head at the turbine inlet
    in m
W=m*U1*Cx1*10^-3//Power developed in kW
nH=(U1*Cx1/(g*H))//Hydraulic efficiency

//output
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

```
clc
clear
//input data
P=330//Power output from the turbine is kW
H=70//Head of operating turbine in m
N=750//Speed of the turbine in rpm
nH=0.94//Hydraulic efficiency
n0=0.85//Overall efficiency
FR=0.15//Flow ratio
```

```
BR=0.1//Breadth ratio
D1D2=2//Ratio inner and outer diameter of runner
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
Cr1=FR*(2*g*H)^(1/2)//Flow velocity at inlet in m/s
Q=(P*10^3)/(dw*g*H*n0)//Discharge at outlet in m^3/s
D1=(Q/(nH*3.1415*BR*Cr1))^(1/2)//Runner inlet diameter in m
b1=BR*D1//Height of the runner vanes at inlet in m
U1=(3.1415*D1*N)/60//Runner tip speed at inlet in m/s
Cx1=(nH*g*H)/(U1)//Velocity of whirl at inlet in m/s
a11=atand(Cr1/Cx1)//Guide blade angle in degree
b11=atand(Cr1/(Cx1-U1))//Runner vane angle at inlet in degree
D2=D1/D1D2//Runner outlet diameter in m
U2=(3.1415*D2*N)/60//Runner tip speed at outlet in m/s
Cr2=Cr1//Flow velocity at outlet in m/s
b22=atand(Cr2/U2)//Runner vane angle at outlet in degree
b2=D1*b1/D2//Width at outlet in m

//output
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

```
clc
clear
//input data
H=30//Working head of the turbine in m
D1=1.2//Inlet wheel diameter in m
D2=0.6//Outlet wheel diameter in m
b11=90//Vane angle at entrance in degree
a11=15//Guide blade angle in degree
Cx2=0//Velocity of whirl at inlet in m/s
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
U11=1/tand(a11)//Runner tip speed at inlet in m/s in terms of Cr1
Cr1=(H/((U11^2/g)+(1/(2*g))))^(1/2)//Flow velocity at inlet in m/s
Cr2=Cr1//Flow velocity at outlet in m/s
U1=Cr1*U11//Runner tip speed at inlet in m/s
N=(60*U1)/(3.1415*D1)//Speed of the wheel in rpm
U2=(3.1415*D2*N)/60//Runner tip speed at inlet in m/s
b22=atand(Cr2/U2)//Vane angle at exit in degree

//output
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

```
clc
clear
//input data
D1=0.6//Internal runner diameter in m
D2=1.2//External runner diameter in m
a11=15//Guide blade angle in degree
Cr1=4//Flow velocity at inlet in m/s
Cr2=Cr1//Flow velocity at outlet in m/s
N=200//Speed of the turbine in rpm
H=10//Head of the turbine in m
a22=90//Discharge angle at outlet in degree
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
U1=(3.1415*D1*N)/60//Runner tip speed at inlet in m/
    s
U2=(3.1415*D2*N)/60//Runner tip speed at outlet in m
    /s
Cx1=Cr1/tand(a11)//Velocity of whirl at inlet in m/s
Wx1=Cx1-U1//Inlet whirl velocity component in m/s
b11=atand(Cr1/Wx1)//Vane angle at entrance in degree
b22=atand(Cr2/U2)//Vane angle at exit in degree
Wm=U1*Cx1//Work one per unit mass flow rate in W/(kg
    /s)      as Cx2=0 in m/s
nH=(U1*Cx1/(g*H))//Hydraulic efficiency

//output
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

```
clc
clear
//input data
H=23//Net head across the turbine in m
N=150//Speed of the turbine in rpm
P=23//Power developed by the turbine in MW
D=4.75//Blade tip diameter in m
d=2//Blade hub diameter in m
nH=0.93//Hydraulic efficiency
n0=0.85//Overall efficiency
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
dm=(D+d)/2//Mean diameter of the turbine in m
Pa=(P*10^6)/n0//Power available in MW
Q=(Pa/(dw*g*H))//Flow rate in the turbine in m^3/s
Um=(3.1415*dm*N)/60//Rotor speed at mean diameter in
    m/s
Pr=Pa*nH*10^-6//Power given to runner in MW
Cx1=Pr*10^6/(dw*Q*Um)//Velocity of whirl at inlet in
    m/s    as Cx2=0 in m/s
Ca=Q/((3.1415/4)*(D^2-d^2))//Axial velocity in m/s
b11=180-(atand(Ca/(Um-Cx1)))//Inlet blade angle in
   degree
Wx2=Um//Outlet whirl velocity component in m/s
b22=atand(Ca/Wx2)//Outlet blade angle in degree

//output
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

```
clc
clear
//input data
P=9100//Power developed by the turbine in kW
H=5.6//Net head available at the turbine in m
SR=2.09//Speed ratio
FR=0.68//Flow ratio
n0=0.86//Overall effiiciency of the turbine
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3
DbD=1/3//Ratio of diameter of the boss to diameter of the runner

//calculations
U1=SR*(2*g*H)^(1/2)//Runner tip speed at inlet in m/s
Cr1=FR*(2*g*H)^(1/2)//Flow velocity at inlet in m/s
Q=(P*10^3)/(n0*dw*g*H)//Discharge through the turbine in m^3/s
D=(Q*4/(3.1415*Cr1*((1^2)-(DbD^2))))^(1/2)//Diameter of the runner in m
N=(U1*60)/(3.1415*D)//Speed of the the turbine in rpm
Ns=(N*(P)^(1/2))/(H)^(5/4)//Specific speed
disp(Q)
//output
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

```
clc
clear
//input data
```

```
H=20//Head developed over the turbine in m
P=11800//Power developed by turbine in kW
D=3.5//Outer diameter of the runner in m
Db=1.75//Hub diameter in m
a11=35//Guide blade angle in degree
nH=0.88//Hydraulic efficiency
n0=0.84//Overall efficiency
Cx2=0//Velocity of whirl at outlet in m/s
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
Q=(P*10^3)/(n0*g*H*dw)//Discharge of turbine in m^3/s
Cr1=Q/((3.1415/4)*(D^2-Db^2))//Flow velocity at inlet in m/s
Cx1=Cr1/tand(a11)//Velocity of whirl at inlet in m/s
U1=(nH*H*g)/(Cx1)//Runner tip speed at inlet in m/s
Wx1=U1-Cx1//Inlet whirl velocity component in m/s
b11=180-(atand(Cr1/-Wx1))//Runner inlet angle in degree
Cr2=Cr1//Flow velocity at outlet in m/s      for a kaplan turbine
U2=U1//Runner tip speed at outlet in m/s      for a kaplan turbine
b22=atand(Cr2/U2)//Runner outlet angle in degree
N=(U1*60)/(3.1415*D)//The speed of the turbine in rpm

//output
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

```
clc
clear
//input data
N=50//Speed of the turbine in rpm
d=6//Runner diameter of the turbine in m
Ae=20//Effective area of flow in m^2
b11=150//The angle of the runner blades at inlet in degree
b22=20//The angle of the runner blade at outlet in degree
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
U1=(3.141*d*N)/60//Runner tip speed at inlet in m/s
U2=U1//Runner tip speed at outlet in m/s
Cr2=U2*tand(b22)//Flow velocity at outlet in m/s
Cr1=Cr2//Flow velocity at inlet in m/s
Q=Ae*Cr1//Discharge by the  turbine in m^3/s
Cx1=U1-(Cr1/(tand(180-b11)))//Velocity of whirl at inlet in m/s
P=dw*g*Q*(U1*Cx1/g)*10^-3//Theoretical Power developed in kW
C2=Cr2//Absolute outlet velocity in m/s
H=(U1*Cx1/g)+(C2^2/(2*g))//Net head across the turbine in m
nH=(U1*Cx1/g)/(H)//Hydraulic efficiency

//output
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

```
clc
clear
//input data
D=8//Outer diameter of the turbine in m
Db=3//Inner diameter of the turbine in m
P=30000//Power developed by the turbine in kW
nH=0.95//Hydraulic efficiency
N=80//Speed of the turbine in rpm
H=12//Head operated by the turbine in m
Q=300//Discharge through the runner in m^3/s
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
U1=(3.1415*D*N)/60//Runner tip speed at inlet in m/s
U2=U1//Runner tip speed at outlet in m/s     as flow is axial
Cr1=Q/((3.1415/4)*(D^2-Db^2))//Flow velocity at inlet in m/s
Cr2=Cr1//Flow velocity at outlet in m/s      as flow is axial
b22=atand(Cr2/U2)//The angle of the runner blade at outlet in degree
Cx1=(nH*g*H)/U1//Velocity of whirl at inlet in m/s
b11=180-(atand(Cr1/(U1-Cx1)))//The angle of the runner blade at inlet in degree
nM=(P*10^3)/(dw*g*Q*(Cx1*U1/g))//Mechanical efficiency
n0=nM*nH//Overall efficiency

//output
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

```
clc
clear
//input data
P=11500//Rated power of the turbine in kW
H=4.3//Average head of the turbine in m
n0=0.91//Overall efficiency of the turbine
DbD=0.3//Ratio of Diameters of runner boss and
   runner
SR=2//Speed ratio
FR=0.65//Flow ratio
g=9.81//Acceleration due to gravity in m/s^2
dw=1000//Density of water in kg/m^3

//calculations
U=SR*(2*g*H)^(1/2)//Runner tip speed in m/s
Cr=FR*(2*g*H)^(1/2)//Flow velocity in m/s
Q=(P*10^3)/(n0*dw*g*H)//Discharge of the turbine in
   m^3/s
D=((4*Q)/(Cr*3.1415*(1^2-DbD^2)))^(1/2)//Runner
   diameter in
N=(60*U)/(3.1415*D)//Speed of the turbine in rpm

//output
printf('(a)Runner diameter of the turbine is %3.2f m
   \n(b)Operating speed of the turbine is %3.1f rpm'
   ,D,N)
```