Scilab Textbook Companion for Fundamentals of Turbomachinery by W. W. Peng[1]

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Book Description

Title: Fundamentals of Turbomachinery

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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

Introduction

Scilab code Exa 1.1 I

```
clear all; clc;
//This numerical is Ex 1_1E,page 9.
Pso=20.5
Psc=20.5*550//converting hp to fps system
Qo=385
Qc=385/449//converting gpm to ft^3/s
E=0.83
dp=E*Psc/(Qc*144)
printf('The pressure rise is %g psi',dp)
disp("After rounding off,pressure rise is 75.8 psi")
dpr=75.8
dHw=75.8*144/62.4//62.4 is accelaration due to gravity in fps system
printf(' The head of water is %g ft of water',dHw)
disp("After rounding off the value of head of water the answer is 175 ft of water.")
dhwr=175//rounded off value of head of water
sg=0.72//specific gravity of oil
dHo=dhwr/sg
printf(' The head of oil is %g ft of oil',dHo)
disp("After rounding off the value of head of oil
```

```
   the answer is 243 ft of oil.")
```

Scilab code Exa 1.2 I

```
clear all; clc;
//This numerical is Ex 1_1S,page 10.
E=0.83//efficiency
Ps=15300
Q=87.4
Qs=87.4/3600//flow rate in meter cube per sec
rho=998
g=9.81
sg=0.72
dp=E*Ps/Qs
printf('\n The change in pressure (dp)is %g',dp)
dpr=523000//rounded value of dp
disp("The rounded off value of dp is 523kPa.")
dHw=dpr/(rho*g)
printf(' dHw is equal to %g m of water',dHw)
disp("The rounded off value of dHw is 53.4 m of
   water.")
dHwr=53.4//rounded off value of dHw
disp("Thus we can determine head of oil.")
dHoil=dHwr/sg
printf(' dHoil is given by %g m of oil',dHoil)
disp("The rounded off value of dHoil is 74.2 m of
   oil.")
```

Scilab code Exa 1.3 I

```
clear all; clc;
//This numerical is Ex 1_2E,page 10.
Q=12000
```

```
A=3.5
rho_a=0.0762
E=0.85
r=2.5//resistance of duct system
V=Q/(60*A)
printf('The air flow velocity at discharge is %0.2f ft/s',V)
KE=(rho_a*(V^2))/(32.2*2)
printf('\n The product is %0.2f lb/ft^2',KE)
//PE=KE
Hv=KE/62.4
printf('\n The dynamic head is %0.3f ft',Hv)
disp("The value of dynamic head in inches of water is 0.74.")
Hvi=0.74//Head in inches
Ht=r+Hvi
printf('\n The total head is %0.2f inches of water',Ht)
p_tot=Ht*62.4
Ps=Q*p_tot/(60*12*E)
printf('\n The shaft power is %0.1f ft-lb/s',Ps)
disp("The shaft power is 7.2 hp.")
```

Scilab code Exa 1.4 I

```
clear all; clc;
//This numerical is Ex 1_2S,page 11.
Q=340
A=0.325
V=Q/(60*A)
printf('The air flow velocity at discharge is %0.1f m/s',V)
rho_a=1.22
Vr=17.4
Hd=(rho_a*(Vr^2))/2
```

```
printf('\n The dynamic pressure head is %0.1f Pa',Hd)
Hdr=184.7//rounded off value of Hd
rho_w=998//density of water=rhow
g=9.81
H=0.0635
dp=rho_w*g*H//static pressure head
printf('\n The static pressure head is %0.1f Pa',dp)
dpr=621.7
p_tot=Hdr+dpr
printf('\n The total pressure head is %0.1f Pa',p_tot)
p_tot=806.4
E=0.85//efficiency
Ps=Q*p_tot/(60*E)
printf('\n The shaft power is %g W',Ps)
disp("The shaft power is 5.376 kW.")
```

Scilab code Exa 1.5 I

```
clear all; clc;
//This numerical is Ex 1_3E,page 11.
H=295//net head in ft
Q=148//water flow rate
n=1800//rpm
E=0.87//efficiency
a=62.4//product of density and accelaration due to gravity
omega=(n*2*%pi)/60
dp=a*H
printf('The pressure is %g lb/ft^2',dp)
Ps=E*Q*dp
printf('\n Output power is equal to %0.3f lb-ft/s',Ps)
disp("The output output power can also be written as
```

```
2.37*10^6 lb-ft/s")
disp("Output power in terms of horsepower is given by 4309hp.")
Psr=2370000//rounded off value of Ps
Torque=Psr/omega
printf(' The output torque is %g lb-ft.',Torque)
disp("The output torque can also be written as 12.57*10^3 lb-ft")
```

Scilab code Exa 1.6 I

```
clear all; clc;
//This numerical is Ex 1_3S,page 12.
H=90
Q=4.2//water flow rate(in m^3/s)
n=1800
E=0.87//efficiency
rho=998
g=9.81
omega=(n*2*%pi)/60
dp=rho*g*H
printf('The pressure is %g N/m^2',dp)
Ps=E*Q*dp
printf('\n Output power is equal to %0.3f N-m/s',Ps)
disp("After rounding off the value of output power is 3220 kW.")
Psr=3220000//rounded off value of Ps
Torque=Psr/omega
printf(' The output torque is %g N-m.',Torque)
disp("After rounding off the output torque comes out to be 17.1*10^3 N-m.")
```

Chapter 2

Dimensional Analysis

Scilab code Exa 2.1 DA

```
clear all; clc;
//This numerical is Ex 2_1,page 18.

//These are examples given in the book,they are used to teach conversions from one unit to another

rho=0.075//lbm/ft^3

V=120

RHO_c=rho/32.2//rho conerted to slug/ft^3

disp("The initial value of rho was given in lb/ft^3. In order to convert it to slug/ft^3,we have used the conversion factor 1/32.2.")

printf("\nThe initial value of rho was 0.075lb/ft^3 after coverting it is %0.5f slug/ft^3",RHO_c)

p_d=RHO_c*V^2/2

```

```
printf("\nHence the value of dynamic pressure is %0.2f (slug/ft^3)(ft/s)",p_d)

p_dc=p_d/(12^2)//converting slug*s/ft^2 to lbf/in^2

printf("\nThe final value of dynamic pressure is %0.3f lbf/in^2",p_dc)

printf("\nHence we can say that the dynamic power is equal to  %0.3f psi.",p_dc)
```

Scilab code Exa 2.2 DA

```
clear all; clc;
//This numerical is Ex 2_2,page 18.

// This numerical is used an example to teach conversion factors
T0=600
T1=550
Cp=0.24
halfVsquare=Cp*32.2*778*(T0-T1)
printf("\n The value of half of V^2 is %g (Btu/slug*R)(lbf-ft/Btu)(R)",halfVsquare)
printf("\n The value of half of V^2 ca also be written as %g lbf-ft/slug",halfVsquare)
printf("\n The value of half of V^2 is also equal to  %g (ft/s)^2",halfVsquare)
V=sqrt(halfVsquare*2)
printf("\n\n The value of V is equal to %0.1f ft/s",V)
```

Scilab code Exa 2.3 DA

```
clear all; clc;
//This numerical is Ex 2_3,page 19.

// This numerical is used an example to teach conversion factors

rho=0.85*62.4
p=50//in psi
g=32.2
disp("Since pressure is the product of density, gravitaional accelaration and head, we can convert pressure in psi to head in ft using suitable conversion factors.")
H=p*144/( (rho/32.2)*32.2)
printf("The value of head H is given by %0.1f lb/ft^2/((slug/ft^3)*(ft/s^2))",H)
printf("\nThus the value of H is equal to %0.1f ft",H)
```

Scilab code Exa 2.4 DA

```
clear all; clc;
//This numerical is Ex 2_4,page 19.

//converting dynamic pressure of air from 2_1 to wg

pd=16.77//lbf/ft^2
rho_w=62.4/32.2
g=32.2
disp("From pressure=density*gravitational accelaration *head, we can find out the value of head")
h=pd/(rho_w*g)
printf(" Hence the value of head H is %0.3f (lbf/ft^2)/(lbf/ft^3)",h)
```

```
printf("\n The value of head H can also be given by
    %0.3f ft",h)
```

Scilab code Exa 2.5 DA

```
clear all; clc;
//This numerical is Ex 2_1E,page 29.
Q1=80
N1=1000
N2=1500
delta_p1=150
P_s1=8

disp("From phi_2=phi_1 we have Q2/(D^3*N2)=Q1/(D^3*
    N1)")
Q2=Q1*N2/N1
printf(" The value of Q2 is equal to %g gpm \n",Q2)

disp("From psi_1=psi_2 we have delta p 2/(rho*D^2*N2
    ^2)=delta p 1/(rho*D^2*N1^2)")
delta_p2=delta_p1*((N2/N1)^2)
printf(" The value of delta_p2 is equal to %g psig \
    n",delta_p2)

disp("From pi_2=pi_1 we have P_s2=P_s1*((N2/N1)^3)")
P_s2=P_s1*(N2/N1)^3
printf(" The value of P_s2 is equal to %g hp \n",
    P_s2)

disp("The efficiencies are same at the corresponding
     points,so E1=E2")
E1=Q1*delta_p1*0.00223*144/(550*P_s1)
printf(" The value of E1=E2 is equal to %g \n",E1)
disp("Thus the efficiency is equal to 87.57%")
```

Scilab code Exa 2.6 DA

```
clear all; clc;
//This numerical is Ex 2_1S,page 29.
Q1=18.2
N1=1000
N2=1500
delta_p1=10.3
P_s1=6

Q2=Q1*N2/N1
printf("\n The value of Q2 is equal to %g m^3/h",Q2)

delta_p2=delta_p1*((N2/N1)^2)
printf("\n The value of delta_p2 is equal to %0.1f bars",delta_p2)

P_s2=P_s1*(N2/N1)^3
printf("\n The value of P_s2 is equal to %g kW",P_s2)

E1=((Q1/3600)*delta_p1*10^2)/(P_s1)
printf("\n The value of E1=E2 is equal to %g ",E1)
disp("Thus the efficiency is equal to 86.8%")
```

Scilab code Exa 2.7 DA

```
clear all; clc;
//This numerical is Ex 2_2E,page 30.
P_ho=30//hydraulic output power
Q=5//flow rate at best efficiency point
g=32.2
```

```
rho=1.938
Hp=320
N=600

delta_pm=P_ho*550/Q
printf("Value of discharge head P_m %g lb/ft^2",delta_pm)

Hm=delta_pm/(rho*g)
printf("\n Value of H_m=%0.2f ft",Hm)
disp("From the similarity law, H_p/H_m=((Np/Nm)^2)*((Dp/Dm)^2)")

//let x=Hp/Hm
x=Hp/Hm
printf(" H_p/H_m =%0.2f",x)
disp("Thus (N_p/N_m)*(D_p/D_m) is equal to 2.46")
disp("Also the flow rate Q_p/Q_m=(N_p/N_m)*(D_p/D_m)^3")
z=350/5//value of Qp/Qm
printf(" Hence the value of Q_p/Q_m is equal to %g",z)
disp("Thus D_p/D_m=5.33 ,N_p/N_m=0.461")
//Let y=Np/Nm=0.461
y=0.461
N_m=N/y
printf(" Thus N_m = %g rpm",N_m)
```

Scilab code Exa 2.8 DA

```
clear all; clc;
//This numerical is Ex 2_2S,page 30.
//The value given in the book for N_m is 1315,but on calculating the true value is found out to be 1304.35
```

```

P_ho=22.4//hydraulic output power
Q=0.14//flow rate at best efficiency point
g=9.8
rho=998
H_p=97.5
N=600

delta_pm=P_ho/Q
printf("Value of discharge head P_m %g  kPa",delta_pm)

H_m=delta_pm*10^3/(rho*g)
printf("\n Value of H_m=%g m",H_m)
disp("From the similarity law, H_p/H_m=((N_p/N_m)^2)*((D_p/D_m)^2)")

//let x=Hp/Hm
H_mr=16.3//rounded off value
x=H_p/H_mr
printf(" H_p/H_m =%0.2f",x)
disp("Thus (N_p/N_m)*(D_p/D_m) is equal to 2.45")
disp("Also the flow rate Q_p/Q_m=(N_p/N_m)*(D_p/D_m)^3")
z=9.9/0.14//value of Qp/Qm
printf(" Thus the value of Q_p/Q_m is %0.1f",z)
disp("Thus D_p/D_m=5.4 ,N_p/N_m=0.46")
//Let y=Np/Nm=0.461
y=0.46
N_m=N/y//where N=600 and y=0.46
printf(" Hence N_m = %g rpm",N_m)//value given in the book is 1315,but on calculating the true value is found out to be 1304.35
```

Scilab code Exa 2.9 DA

```
clear all; clc;
//This numerical is Ex 2_3E,page 31.

N=1500
E=0.74
Q=250*0.00223//0.00223 is conversion factor
printf("Q is equal to %g",Q)
H=18
g=32.2
Q_o=250//before converting Q

disp("From the dimensional specific speed (N_s) and fig2.1 , we select a Francis type pump and efficiency is estimated to be equal to 74%")

N_s=N*(Q_o^0.5)/(H^0.75)
printf("\n N_s is equal to %0.0f rpm(gpm^0.5)/(ft^0.75)",N_s)
disp("To find the approximate size,Figure 2.2 has to be used")

omega=N*%pi/30
printf("\n omega is equal to %0.0f",omega)

omega_s=omega*(Q^0.5)/((g*H)^0.75)
printf("\n omega_s is equal to %0.4f",omega_s)

disp("From figure 2.2, it is obtained that delta_s=3.1")
D=(3.1*(Q^0.5))/((g*H)^0.25)
printf("\n Hence D is equal to %0.3f ft",D)
disp("Hence D is equal to 5.7 in ")
```

Scilab code Exa 2.10 DA

```
clear all; clc;
//This numerical is Ex 2_4E,page 31.

disp("From phi equal to Qm/(Dm^3*Nm)=Qp/(Dp^3*Np) and psi=g*Hm/(Dm^2*Nm^2)=g*Hp/(Dp^2*Np^2), we have Qm=Qp*((Dm/Dp)^3)*(Nm/Np) and Hm=Hp*((Dm/Dp)^2)*(Nm/Np)^2)")

Q_p=25
//let x=Dm/Dp=1/5
x=1/5
N_m=3600
N_p=1800
H_p=160
E=0.92
//let y=rho*g=62.4
y=62.4

Q_m=Q_p*((x)^3)*(N_m/N_p)
printf("\n The value of Q_m is equal to %g ft^3/s",Q_m)

H_m=H_p*((x^2)*(N_m/N_p)^2)
printf("\n The value of H_m is equal to %g ft",H_m)

P_s=E*y*Q_m*H_m/550//1/550 is conversion factor
printf("\n The value of P_s is equal to %0.02f hp",P_s)
```

Scilab code Exa 2.11 DA

```
clear all; clc;
//This numerical is Ex 2_4S,page 31.
disp("From phi equal to Qm/(Dm^3*Nm)=Qp/(Dp^3*Np) and psi=g*Hm/(Dm^2*Nm^2)=g*Hp/(Dp^2*Np^2), we
```

```
   have Qm=Qp*((Dm/Dp)^3)*(Nm/Np) and Hm=Hp*((Dm/Dp)
   ^2)*(Nm/Np)^2)")

Q_p=42
//let x=Dm/Dp=1/5
x=1/5
N_m=3600
N_p=1800
H_p=50
E=0.92
rho=998
g=9.81
//let y=Q/60=0.011166
y=0.011166

Q_m=Q_p*((x)^3)*(N_m/N_p)
printf("\n The value of Q_m is equal to %g cmm",Q_m)

H_m=H_p*((x^2)*(N_m/N_p)^2)
printf("\n The value of H_m is equal to %g m",H_m)

Q_mr=0.67//rounded off
P_s=E*rho*g*(y)*H_m
printf("\n The value of P_s is equal to %0.1f W",P_s
   )
```

Chapter 3

Energy Transfer in Turbomachines

Scilab code Exa 3.1 ETT

```
clear all; clc;
//This numerical is Ex 3_1E,page 43.
N=800
Q=1750//in gallon per minute
r_1=3
b_1=4
r_2=9
b_2=3

omega=N*%pi/30
printf('\n The angular velocity is %g rad/s',omega)
omega_r=83.7
disp("After rounding off the value of angular
   velocity is 83.7 rad/s")


U_1=omega_r*r_1/12
printf(' U_1=%g',U_1)
disp("After rounding off the value of U_1 is 20.9 ft
```

```
/s”)
U_1r=20.9//rounded value of U1


U_2=omega_r*r_2/12
printf(’ U_2=%g’,U_2)
disp(”After rounding off the value of U_2 is 62.7 ft/s”)


A_1=2*%pi*r_1*b_1/144
printf(’ A_1=%g ft^2’,A_1)
disp(”After rounding off the value of A_1 is 0.523 ft^2”)

A_2=2*%pi*r_2*b_2/144
printf(’ A_2=%g ft^2’,A_2)
disp(”After rounding off the value of A_2 is 1.18 ft^2”)
A_1r=0.523//rounded off
A_2r=1.18//rounded off


V_r1=(Q*0.00223)/(A_1r)
printf(’ The value of V_r1 is %g’,V_r1)
disp(”The value of V_r1 after rounding off is 7.47 ft/s”)

V_r2=(Q*0.00223)/(A_2r)
printf(’ The value of V_r2 is %g’,V_r2)
disp(”The value of V_r2 after rounding off is 3.27 ft/s”)//actual value is 3.30,however the value given in the book is 3.27 ft/s
```

Scilab code Exa 3.2 ETT

```
clear all; clc;
//This numerical is Ex 3_1S,page 43.
N=800
Q=397//in meter cube per hour
r_1=7.6
b_1=10.2
r_2=22.9
b_2=7.6
omega=N*%pi/30
printf('The angular velocity is %g rad/s',omega)
omegar=83.7
disp("After rounding off the value of angular velocity is 83.7 rad/s")
U_1=omega*r_1/100
printf(' U_1=%g',U_1)
disp("After rounding off the value of U_1 is 6.36 m/s")
U_1r=6.36//rounded value of U1
U_2=omega*r_2/100
printf(' U_2=%g',U_2)
disp("After rounding off the value of U_2 is 19.2 m/s")
A_1=2*%pi*r_1*b_1
printf(' A_1=%g cm^2',A_1)
disp("After rounding off the value of A_1 is 487 cm^2")
A_2=2*%pi*r_2*b_2
printf(' A_2=%g cm^2',A_2)
disp("After rounding off the value of A_2 is 1093.5 cm^2")
A_1r=487//rounded off
A_2r=1093.5//rounded off
V_r1=(Q/3600)/(A_1r/10000)
printf(' The value of V_r1 is %g',V_r1)
disp("The value of V_r1 after rounding off is 2.26 m/s")
V_r2=(Q/3600)/(A_2r/10000)
printf(' The value of V_r2 is %g',V_r2)
```

```
disp("The value of V_r2 after rounding off is 1.01 m/s")
```

Scilab code Exa 3.3 ETT

```
clear all; clc;
//This numerical is Ex 3_2E,page 44.

V_r1=7.47
U_1=20.9
V_r2=3.27
U_2=62.7

//let x=tanbeta1
x=V_r1/U_1
printf("\n The value of  _f1 is equal to %0.3f degrees",x)
beta_f1=(atan(x))*180/%pi
printf("\n Thus the value of  _f1 is %0.2f degrees",beta_f1)

V_1=V_r1
W_1=(U_1^2+V_r1^2)^0.5
printf("\n Thus the value of W_1 is %0.2f ft/s",W_1)

beta_f2=beta_f1-10
printf("\n Hence the value of beta_f2 is equal to %0.2f degrees",beta_f2)

//rounding of value of betaf2 to be equal to 9.6
beta_f2=9.6
W_u2=V_r2/tan(beta_f2*%pi/180)
printf("\n Hence the value of W_u2 is %0.1f ft/s",W_u2)

```

```
V_u2=U_2-W_u2
printf("\n Hence the value of V_u2 is equal to %0.1f ft/s",V_u2)


//rounding off Wu2
W_u2=19.3
W_2=(W_u2^2+V_r2^2)^0.5
printf("\n The value of W_u2 is equal to %0.3f ft/s",W_2)

//rounding off Vu2
V_u2=43.4
V_2=(V_u2^2+V_r2^2)^0.5
printf("\n Thus he value of V_2 is equal to %0.2f ft/s",V_2)
```

Scilab code Exa 3.4 ETT

```
clear all; clc;
//This numerical is Ex 3_2S,page 44.

V_r1=2.26
U_1=6.36
V_r2=1.01
U_2=19.2

//let x=tan(beta_1)
x=V_r1/U_1
printf("\n The value of  _f1 is equal to %0.3f degrees",x)
beta_f1=(atan(x))*180/%pi
printf("\n Thus the value of  _f1 is %0.1f degrees",beta_f1)

```

```
V_1=V_r1
W_1=(U_1^2+V_r1^2)^0.5
printf(”\n Thus the value of W_1 is %0.2f m/s”,W_1)

beta_f2=beta_f1-10
printf(”\n Hence the value of  _f2 is equal to %0.1f degrees”,beta_f2)

//rounding of value of betaf2 to be equal to 9.6
beta_f2=9.6
W_u2=V_r2/tan(beta_f2*%pi/180)
printf(”\n Hence the value of W_u2 is %0.2f m/s”,W_u2)

V_u2=U_2-W_u2
printf(”\n Hence the value of V_u2 is equal to %0.2f m/s”,V_u2)


//rounding off W_u2
W_u2=5.97
W_2=(W_u2^2+V_r2^2)^0.5
printf(”\n The value of W_2 is equal to %0.3f m/s”,W_2)

//rounding off V_u2
V_u2=13.23
V_2=(V_u2^2+V_r2^2)^0.5
printf(”\n Thus he value of V_2 is equal to %0.2f m/s”,V_2)
```

Scilab code Exa 3.5 ETT

```
clear all; clc;
//This numerical is Ex 3_3E,page 46.
```

```
//the value given in the book for Um is 200.5,but on calculating the value comes out to be 200.3

r_t=24
r_h=10
N=1250
Q=53000

r_m=(0.5*(r_t^2+r_h^2))^0.5
printf("\n The mean radius rm is equal to %0.1f in",r_m)
disp("Converting to feet we have r_m equal to 1.53 ft")


//rm in feet equals 1.53
r_m=1.53
U_m=((N*%pi)/30)*r_m
printf(" Um = %0.1f ft/s",U_m)//the value given in the book for Um is 200.5,but on calculating the value comes out to be 200.3

A=(%pi*(r_t^2-r_h^2))/144
printf("\n The value of A is %0.1f ft^2",A)

//rounding off A to be 10.4
A=10.4
V_a2=Q/(A*60)
V_a1=V_a2
printf("\n V_a1=V_a2 %0.1f ft/s",V_a2)

beta_f1=(atan(U_m/V_a1))*180/%pi
beta_b1=beta_f1
printf("\n beta_b1=beta_f1 %0.1f degrees",beta_b1)


rho_w=62.4
rho_a=0.0762
```

```
g=32.2
H_w=2/12
disp("We know that g*Ha=(rho_w/rho_a)*g*H_w=U_mV_u2=Um*(U_m-V_a2*tan(beta_f2))")
disp("Hence we can find out the value of tan( _f2). Thus we can determine value of  _f2.")
//Let n=U_m*(U_m-V_a2*tan(beta_f2)) and m=(rho_w/rho_a)*g*H_w
m=(rho_w/rho_a)*g*H_w
//therefore tan_betaf2=(U_m-m/U_m)/V_a2
tanbeta_f2=(U_m-m/U_m)/V_a2
beta_f2=(atan(tanbeta_f2))*180/%pi
printf("\n Thus the value of  _f2 is equal to %0.1f degrees",beta_f2)
```

Scilab code Exa 3.6 ETT

```
clear all; clc;
//This numerical is Ex 3_3S,page 46.

r_t=0.6
r_h=0.25
N=1250
Q=1500

r_m=(0.5*(r_t^2+r_h^2))^0.5
printf("\n The mean radius rm is equal to %0.2f in.",r_m)

U_m=((N*%pi)/30)*r_m
printf(" On converting,U_m = %0.1f m/s",U_m)

A=(%pi*(r_t^2-r_h^2))
printf("\n The value of A is %0.4f m^2",A)

```

```

V_a2=Q/(A*60)
V_a1=V_a2
printf("\n V_a1=V_a2 %0.1f m/s",V_a2)

beta_f1=(atan(U_m/V_a1))*180/%pi
beta_b1=beta_f1
printf("\n beta_b1=beta_f1 %0.1f degrees",beta_b1)


rho_w=998
rho_a=1.22
g=9.8
H_w=5/100
U_m=60.2//rounding off Um
disp("We know that g*H_a=(rho_w/rho_a)*g*H_w=U_mV_u2=U_m*(U_m-V_a2*tan(beta_f2))")
disp("Hence we can find out the value of tanbet_f2")
//Let n=U_m*(U_m-V_a2*tan(beta_f2)) and m=(rho_w/rho_a)*g*H_w
m=(rho_w/rho_a)*g*H_w
//therefore tanbeta_f2=(U_m-m/U_m)/V_a2
tanbeta_f2=(U_m-m/U_m)/V_a2
beta_f2=(atan(tanbeta_f2))*180/%pi
printf("\n Thus the value of beta_f2 is equal to %0.1f degrees",beta_f2)
```

Scilab code Exa 3.7 ETT

```
clear all; clc;
//This numerical is Ex 3_4E,page 49.

//the value of deltaE2 slightly differs from the value given in the book. However the calculated value is correct for te given substitutions
```

```

N=120
r_1=1.8
b_1=0.3

omega=(N*%pi)/30
printf("\n Omega is equal to %0.3f rad/s",omega)

U_1=r_1*omega
printf("\n U_1 is equal to %0.1f ft/s",U_1)

r_m2=(0.5*(1^2+0.4^2))^0.5
//rounding off the value of rm2
r_m2=0.761

U_2=r_m2*omega
printf("\n U_2 is equal to %0.2f ft/s",U_2)

A_1=2*%pi*r_1*b_1
printf("\n A_1 is equal to %0.2f ft^2",A_1)

r_t2=1.0
r_h2=0.4
b_2=0.5
A_2=%pi*(r_t2+r_h2)*b_2
printf("\n A_2 is equal to %0.2f ft^2",A_2)

disp("Assume swirl free flow at discharge that is V_u2=0 and  _f1= _b1 ,  _f2= _b2 .")

V_m2=U_2*tan(15*(%pi/180))
printf("\n So V_m2=U_2tan15 is equal to %0.2f ft/s",V_m2)
disp("Thus now we can determine Q")

V_m2=2.56//rounding off
Q=V_m2*A_2
disp("Q=V_m2*A_2=V_r1*A_1")
```

```
printf(”\n Thus Q is equal to %0.2f ftˆ3/s”,Q)

disp(”Since the value of Q,A_1 is known,we can determine the value of V_r1”)
V_r1=Q/A_1
printf(” The value of V_r1 is equal to %0.2f ft/s”,V_r1)

beta_f1=27
W_u1=V_r1/tan((beta_f1*%pi)/180)
printf(”\n W_u1 is equal to %0.2f ft/s”,W_u1)

V_u1=U_1-W_u1
printf(”\n The value of V_u1 is %0.2f ft/s”,V_u1)

U_1=22.6//rounding off
V_u1=19.3//rounding off
delta_Et=U_1*V_u1
printf(”\n delta_Et is equal to %0.1f ftˆ2/sˆ2”,delta_Et)//the value given in the book is 437.1, but the actual value is as calculated for the given values of U1 and Vu1

m=(62.4/32.2)*5.63
P_s=m*delta_Et
printf(”\n Thus P_s is equal to %0.1f ft*lbf/s”,P_s)//since value of deltaEt differs from the one given in the book,so does the value of Ps
disp(”Converting P_s to hp we get 8.65hp”)
```

Scilab code Exa 3.8 ETT

```
clear all; clc;
//This numerical is Ex 3_4S,page 50.
//the value of deltaE2 slightly differs from the
```

```
   value given in the book. However the calculated
   value is correct for te given substitutions

N=120
r_1=54.8
b_1=9.1

omega=(N*%pi)/30
printf("\n Omega is equal to %0.3f rad/s",omega)

U_1=r_1*omega/100
printf("\n U_1 is equal to %0.1f m/s",U_1)

r_m2=(0.5*(30.5^2+ 12.2^2))^0.5

U_2=r_m2*omega/100
printf("\n U_2 is equal to %0.2f m/s",U_2)

A_1=2*%pi*r_1*b_1/10000
printf("\n A1 is equal to %0.3f m^2",A_1)

r_t2=30.5
r_h2=12.2
b_2=15.2
A_2=%pi*(r_t2+r_h2)*b_2/10000
printf("\n A_2 is equal to %0.3f m^2",A_2)

disp("Assume swirl free flow at discharge that is
   V_u2=0 and  _f1= _b1 ,  _f2= _b2 .")

V_m2=U_2*tan(15*(%pi/180))
printf("\n So V_m2=U_2tan15 is equal to %0.3f m/s",
   V_m2)
disp("Thus now we can determine Q")

Q=V_m2*A_2
disp("Q=V_m2*A_2=V_r1*A_1")
printf("\n Thus Q is equal to %0.3f m^3/s",Q)
```

```

disp("Since the value of Q,A_1 is known,we can determine the value of V_r1")
Q=0.159
V_r1=Q/A_1
printf(" The value of V_r1 is equal to %0.4f m/s",V_r1)//actual values are taken,hence a 0.0005 difference in answer is observed

beta_f1=27// f1
V_r1=0.508//rounding off Vr1
W_u1=V_r1/tan((beta_f1*%pi)/180)
printf("\n W_u1 is equal to %0.4f m/s",W_u1)

W_u1=0.997//rounding off
U_1=6.9//rounding off
V_u1=U_1-W_u1
printf("\n The value of V_u1 is %0.2f m/s",V_u1)//0.02 difference obtained because of substituting the values as they ahve been found out


V_u1=5.92//as substituted in the book
delta_Et=U_1*V_u1
printf("\n deltaEt is equal to %0.2f m^2/s^2",delta_Et)//

m=998*0.782*0.204
P_s=m*delta_Et
printf("\n Thus P_s is equal to %0.0f W",P_s)
disp("Converting P_s to kW we get 6.503kW")
```

Scilab code Exa 3.9 ETT

```
clear all; clc;
```

```
//This numerical is Ex 3_5E,page 52.

//this numerical is based on numerical 3.4E
//values found in the book for numerical 3.4E will be used to solve this numerical(3.5E)

delta_Et=437.1
U_1=22.6
U_2=9.56
V_m2=2.56
V_2=2.56

V_r1=1.66
W_u1=3.26
W_1=(V_r1^2+W_u1^2)^0.5
printf("\n W_1 is equal to %0.2f ft/s",W_1)

W_2=(U_2^2+V_m2^2)^0.5
printf("\n W_2 is equal to %0.2f ft/s",W_2)

V_u1=19.3
V_1=(V_r1^2+V_u1^2)^0.5
printf("\n V_1 is equal to %0.2f ft/s",V_1)

Rt=0.5*[(U_1^2-U_2^2)+(W_2^2-W_1^2)]/(delta_Et)
printf("\n Thus the value Rt is equal to %0.3f",Rt)
```

Scilab code Exa 3.10 ETT

```
clear all; clc;
//This numerical is Ex 3_5S,page 53.

//this numerical is based on numerical 3_4S
//values found in the book for numerical 3_4S will be used to solve this numerical(3.5S)
```

```

delta_Et=40.85
U_1=6.9
U_2=2.92
V_m2=0.782
V_2=0.782//since V2=Vm2

V_r1=0.508
W_u1=0.997
W_1=(V_r1^2+W_u1^2)^0.5
printf("\n W1 is equal to %0.2f ft/s",W_1)

W_2=(U_2^2+V_m2^2)^0.5
printf("\n W_2 is equal to %0.2f ft/s",W_2)

Rt=0.5*[(U_1^2-U_2^2)+(W_2^2-W_1^2)]/(delta_Et)
printf("\n Thus the value Rt is equal to %0.3f",Rt)
```

Scilab code Exa 3.11 ETT

```
clear all; clc;
//This numerical is Ex 3_6E,page 53.
disp("The velocity diagram is similar to that in figure 3.19")

r_t=1.2
r_h=0.7
N=4800
V_1=600

r_m=[0.5*(r_t^2+r_h^2)]^0.5
printf("\n r_m is equal to %0.3f ft",r_m)

A=%pi*(r_t^2-r_h^2)
printf("\n A is equal to %0.2f ft^2",A)
```

```

r_m=0.982//rounding off rm
U=(N*%pi*r_m)/30
printf("\n U is equal to %0.1f ft/s",U)

V_a1=V_1*cos(60*%pi/180)//angle is given as 60 degrees
printf("\n V_a1 is equal to %0.2f ft/s",V_a1)

V_u1=V_1*sin(60*%pi/180)//angle is given as 60 degrees
printf("\n V_u1 is equal to %0.1f ft/s",V_u1)

//let tan(betaf1)=(Vu1-U)/Va1=x
x=(V_u1-U)/V_a1
printf("\n tan( f1 ) is equal to %0.4f",x)
beta_f1=(atan(x))*180/%pi
printf("\n Hence  f1= %0.2f degrees",beta_f1)

disp(" f1= b1. Also  b2= f2=alpha_1=60 degrees")
disp("From the velocity diagram we have V_u2=W_u1=V_u1-U")
W_u1=V_u1-U
printf("\n Thus Wu1 = %g ft/s",W_u1)

//let l=Ps/m=U*(Vu1+Vu2)
V_u2=W_u1//already stated above
l=U*(V_u1+V_u2)
printf("\n P_s/m=U*(V_u1+V_u2) is equal to %g (ft/s)^2",l)
disp("Thus we can round it off to 29*10^5 (ft/s)^2")

disp("Where m=rho*V_a1*A")
rho=0.085/32.2
m=rho*V_a1*A
printf("\n m= %0.2f slug/s",m)

disp("Thus we can determine P_s")
```

```
l=2.69*10^5//rounded off value
m=2.36//rounded off value
P_s=(l*m)/550
printf(" P_s =%0.0f hp",P_s)
```

Scilab code Exa 3.12 ETT

```
clear all; clc;
//This numerical is Ex 3_6S,page 54.

disp("The velocity diagram is similar to that in figure 3.19")

r_t=0.36
r_h=0.21
N=4800
V_1=183

r_m=[0.5*(r_t^2+r_h^2)]^0.5
printf("\n rm is equal to %0.3f m",r_m)

A=%pi*(r_t^2-r_h^2)
printf("\n A is equal to %0.2f m^2",A)

r_m=0.295//rounding off rm
U=(N*%pi*r_m)/30
printf("\n U is equal to %0.1f m/s",U)

V_a1=V_1*cos(60*%pi/180)//angle is given as 60 degrees
printf("\n V_a1 is equal to %0.2f m/s",V_a1)

V_u1=V_1*sin(60*%pi/180)//angle is given as 60 degrees
printf("\n V_u1 is equal to %0.1f m/s",V_u1)
```

```

//let tan(betaf1)=(Vu1−U)/Va1=x
x=(V_u1-U)/V_a1
printf(”\n tan(  1) is equal to %g m/s^2”,x)

beta_f1=(atan(x))*180/%pi
printf(”\n We have  _b1=  _f1= %0.2f degrees”, beta_f1)//value in book is 6.35 degrees Difference is obtained because actual value of x is substituted. Value substituted in the book is not 0.111 or 0.11147.

disp(”  _f1= _b1. Also  _b2= _f2=alpha_1=60 degrees”)
disp(”From the velocity diagram we have V_u2=W_u1=V_u1−U”)
W_u1=V_u1-U
printf(”\n Thus W_u1 = %0.2f m/s”,W_u1)

//let l=Ps/m=U*(Vu1+Vu2)
V_u2=W_u1//already stated above
l=U*(V_u1+V_u2)
printf(”\n P_s/m=U*(V_u1+V_u2) is equal to %g (m/s)^2”,l)
disp(”Thus we can round it off to 2.5*10^4 (m/s)^2”)

disp(”Where m=rho*V_a1*A”)
rho=1.36
V_a1=91.5//rounded off
A=0.269//rounded off
m=rho*V_a1*A
printf(”\n m= %0.1f kg/s”,m)

disp(”Thus we can determine P_s”)
l=2.5*10^4//rounded off value
m=33.5//rounded off value
P_s=(l*m)
printf(” P_s =%0.0f W”,P_s)
```

```
disp("Thus on rounding off P_s is equal to 837kW")
```

Scilab code Exa 3.13 ETT

```
clear all; clc;
//This numerical is Ex 3_7E,page 54.

//Velocity diagrams are not drawn. This is with Scilab team's permission.
//The numerical part of the question has been solved.

r_t=5.2
r_h=3.5
N=4500

A=%pi*(r_t^2-r_h^2)
printf(" A is equal to %0.2f in^2",A)
disp("On converting to feet we get A= 0.322 ft^2")

r_m=[0.5*(r_t^2+r_h^2)]^0.5
printf("\n rm is equal to %0.2f in",r_m)
disp(" On converting to feet we get rm =0.369ft")

r_m=0.369//in feet
U_m=(N*%pi*r_m)/30
printf("\n U_m is equal to %0.0f ft/s",U_m)

disp("From inlet velocity triangle we have V_1/sin( _1+pi/2)+U_m/sin(aplha_1- _1)")
disp("Hence V_1=174*(sin(120)/sin(25))")

V_1=174*(sin(120*%pi/180)/sin(25*%pi/180))
printf(" V_1 = %0.2f ft/s",V_1)

```

```
alpha_1=(55*%pi)/180//radians
V_1=356.5//rounded off
V_a=V_1*cos(alpha_1)
printf(”\n Thus V_a= %0.1f ft/s”,V_a)

rho=0.095
V_a=204.5//rounded off
A=0.322//rounded off
m=rho*V_a*A
printf(”\n m= %0.3f lb/s”,m)

disp(”From delta_E=U_m*V_u1 we have P_s=m*delta_E”)
m=6.25/32.2//in lbf
U_m=174//rounded off
V_u1=356.5*sin((55*%pi)/180)
delta_E=U_m*V_u1
P_s=m*delta_E
printf(” P_s is equal to %0.1f ft-lbf/s”,P_s)
disp(”On converting we get P_s = 17.9hp”)
```

Chapter 4

Centrifugal Pumps

Scilab code Exa 4.1 CP

```
clear all; clc;

N=1750
r_2=0.15
U_2=N*%pi*r_2/30
printf(”With U_2= %0.1f m/s”,U_2)

b_2=0.012

A_2=2*%pi*r_2*b_2
printf(” and A_2= %0.4f m^2”,A_2)

disp(”Equations 4.3 and 4.4 can be rewritten.”)
disp(”H_a= _s*(U_2/g)*(U_2−Q/(A_2*tan _b2))−kQ
    ^2...(4.3)”)
disp(” _Ha/ _Q=(− _s*(U_2/(g*A_2*tan _b2)))−2*
   k_Q...(4.4)”)
disp(”Thus the equations become”)

disp(”(27.5/9.8)*(27.5−(4.5/(1000*0.0113*tan(60))))*
     s −k*(4.5/1000)^2=60”)
```

```
disp("(27.5/(9.8*0.0113*tan(60)))*  s +(2*(4.5/1000))
    *k=2.5*1000")

disp("from equation 4.3   _s =(60+(2.025*10^-5)*k)
    /76.25")
disp("from equation 4.4   _s =(25-(9*10^-5)*k)/1.434"
    )
disp("Solving for   s  and k we get   _s =0.852 and k
    =2.642*10^5")

H_a=60
Q=4.5/1000
k=2.642*10^5
ETA_h=H_a/(H_a+k*(Q^2))
printf(" Thus ETA_h= %0.4f",ETA_h)

P_s=3.2*10^3
rho=1000
g=9.8
ETA_oa=(rho*Q*g*H_a)/P_s
printf("\n ETA_oa= %0.3f",ETA_oa)//answer given in
    the book is0.825,however the correct answer is0
    .827.

disp("Eta_m=0.946")
```

Scilab code Exa 4.2 CP

```
clear all; clc;

disp("The relevant formulae are given as : ")
disp("Eta_1 =((62.4*0.00223*Q_1*H_1/(550*P_s1)))*100
    ")
disp("Q_2=Q_1*N_2/N_1")
disp("H_2=H_1*(N_2/N_1)^2")
```

```
disp("P_s2=P_s1*((N_2/N_1)^3)")
disp("H and P_s at Q=0 are obtained with extrapolition")

Q_1= [0 285 435 540 785 920 1275];
H_1= [205 200 195 190 186 172 130];
P_s1=[28 31 36 42 44 49 58];

Eta_1 = zeros(1,length(Q_1));
Q_2=zeros(1,length(Q_1));
H_2=zeros(1,length(Q_1));
P_s2=zeros(1,length(Q_1));
Eta_2=zeros(1,length(Q_1));

for i = 1: length(Q_1)


    Eta_1(i) =((62.4*0.00223*Q_1(i)*H_1(i)/(550*P_s1(i))))*100;//multiplied by 100 to get answer in percentage
    Q_2(i) = Q_1(i)*1850/1350;//Since Q2=Q1*N2/N1 and N2=1850 and N1=1350
    H_2(i) = H_1(i)*((1850/1350)^2);//Since H2=H1*((N2/N1)^2)
    P_s2(i)=P_s1(i)*((1850/1350)^3)
    Eta_2(i)=Eta_1(i)
end

table = [Q_1'H_1'P_s1'Eta_1'Q_2'H_2'P_s2'Eta_2'];
disp("  Q_1(gpm)   H_1(ft)    P_s1(hp)   Eta_1(%)   Q_2(gpm)          H_2(ft)         P_s2(hp)         Eta_2(%)")
disp(table)

figure()
plot(Q_1,H_1,'o',Q_1,P_s1,'d',Q_1,Eta_1,'s')
legend("H_1(ft)","P_s1(hp)","Eta_1(%)",-1)
xlabel("Q_1(gpm)")
```

```
ylabel("H_1(ft), P_s1(hp) , Eta_1(%)")
set(gca(),"grid",[1 1])

figure(1)
plot(Q_2,H_2,'o',Q_2,P_s2,'d',Q_2,Eta_2,'s')
legend("H_2(ft)","Ps_2(hp)","Eta_2(%)",-1)
xlabel("Q_2(gpm)")
ylabel("H_2(ft), Ps_2(hp) , Eta_2(%)")
set(gca(),"grid",[1 1])
```

Scilab code Exa 4.3 CP

```
clear all; clc;

disp("The expression Ps=rho*Q*gH/Eta is used to
   calculate the shaft power for al finite flow rate
    conditions.For the shutoff condition,since Eta
   is zero,Ps has to be extrapolated. Also 0.1H is
   plotted instead of H in the same chart since its
   order of magnitude is higher than others.")

disp("The efficiency and NPSHR are read from the
   constant contours with interpolation and Ps is
   calculated with the above equation.")

Q = [40 80 120 160 200 220];
OneTenthH = [27 26.5 25.5 24 21.5 20];
eff = [30 42.5 52 56.7 57 54.5];
NPSHR = [5 5.5 6.1 7.3 11.5 16];

Ps = zeros(1,length(Q));

for i = 1: length(Q)


```

```
        Ps(i)=(62.4*0.00223*Q(i)*OneTenthH(i)*10)/((
           eff(i)/100)*550);//550 is conversion factor

end

disp("  Q(gpm)  1/10H(ft)  eff(%)  NPSHR(ft)  Ps(hp)")

table=[Q' OneTenthH' eff' NPSHR'  Ps' ];
disp(table)

plot(Q,OneTenthH,'o',Q,NPSHR,'d',Q,Ps,'s',Q,eff,'*')
legend("OneTenthH(ft)","NPSHR(ft))","Ps(hp)","eff(%)
   ",-1)
xlabel("Q(gpm)")
ylabel("OneTenthH(ft), NPSHR(ft) , Ps(hp) eff(%)")
set(gca(),"grid",[1 1])
```

Scilab code Exa 4.4 CP

```
clear all; clc;

disp("From figure 4.7a, H=235ft, Q=170 gpm at b.e.p.
    of 57.5%. ")
disp("The corresponding NPSHR is 8.7ft. From the
   steam table we have pv=3.73 psia at T=150 degrees
    Farenheit")
disp("Also NPSPA=pt-pf+rho*g*Z-pv is greater than or
    equal to NPSPR ")
disp("Thus we can determine the value of Z")

NPSHR=8.7
p_t=20
p_f=1.5*((170/50)^2)
p_v=3.73
//Let x=rho*g=62.4
```

```
x=62.4

Z=NPSHR-[p_t-p_f-p_v]*(144/(x))//144 is conversion factor

printf(” Thus the value of Zis equal to %0.1f ft”,Z)
```

Scilab code Exa 4.5 CP

```
clear all; clc;

disp(”The b.e.p. of all  four trims are read as follows”)
Dia=[9.25 8 7 6];
Q=[220 170 155 130];
H=[330 235 170 120];
Ps=[29 17 12.5 8];
eff=[62.5 57.5 53.5 49.5];
table=[Dia'   Q'   H'     Ps'     eff']
disp(”Dia(in)  Q(gpm)  H(ft)  Ps(hp)  eff(%)”)
disp(table)

disp(”From the similarity laws Q is proportional to D, H proportional to D^2 and Ps proportional to D^3”)

disp(”The performance should be”)

Di=[9.25 8 7 6];
Q=[220 190 166 143 ];
H=[330 246 189 139];
P_s=[29 18.7 12.5 7.9];
eff=[62.5 62.5 62.5 62.5];

disp(”Dia(in)  Q(gpm)  H(ft)  P_s(hp)  eff(%)”)
```

```
table=[Dia'   Q'   H'         P_s'         eff']
disp(table)
```

Scilab code Exa 4.6 CP

```
clear all; clc;

disp("From figure 4.7a,we have NPSHR=8.7ft=2.65m at Q=170gpm for the b.e.p. condition of the 8in impeller.")

disp("From figure 4.18 we have deltaNPSH=0.6ft=0.18m and pv=69kPa at T=90 degrees celsius for water.")
disp("The total NPSPA is equal to  pt-rho*g*Z-pf-pv and the total NPSPR is equal to rho*g*(NPSHR-deltaNPSH)")
disp("To avoid cavitation , at the pump inlet ,it is required to have NPSPA>NPSPR")
disp("Hence it is required (pt-rho*g*Z-pf-pv)>rho*g*(NPSHR-deltaNPSH)")
p_f=10
p_v=69
rho=998
g=9.8
Z=2
NPSHR=2.65
deltaNPSH=0.18
p_t=p_f+p_v+rho*g*(Z+NPSHR-deltaNPSH)/1000//1000 is conversion factor
printf("\n Thus pt is equal to  %0.1f kPA",p_t)
```

Scilab code Exa 4.7 CP

```
clear all; clc;

disp("(a) Start wit calculation of specific speed")

N=2400
Q=1200
H=450
N_s=(N*Q^0.5)/(H^0.75)
printf("Ns= %0.0f rpm*gpm^0.5/ft^0.75",N_s)

disp("From figure 4.20 we obtain overall efficiency is equal to 0.76")
Q=1200
delta_p=0.00223*62.4*450
ETA_oa=0.76
P_s=(Q*delta_p)/(ETA_oa)
printf("Since Ps=(Q*delta_p)/(ETA_oa),P_s= %0.0f ft-lbf/s",P_s)

disp("To determine the inlet configuration:")
N=2400
omega=N*%pi/30
printf("Omega = %0.0frad/s",omega)
tau=P_s/omega
printf("\n = %0.0f lbf-ft",tau)

disp("Hence the shaft diameter Dsh can be determined ")
sigma_s=10000
D_sh=(16*tau/(144*%pi*sigma_s))^(1/3)
printf("D_sh= %0.4f ft =1.34 inches",D_sh)

disp("A pure radial inet confuguratin isbselected that is Dt1=Dh1=D1(see figure 4.19).The impeller eyee area and leading edge diameters can be calculated from the following equations.")

disp("U_1=0.5*omega*D_1")
```

```
disp(”Q=A_1*V_1=A_e*V_e”)
disp(”V_1=1.1*V_e”)
disp(”  _f1=taninverse(V1/U1)”)

disp(”Where A_1=  _1*pi*D_1*b_1”)
disp(”Where A_e=pi*D_e^2/4”)
disp(”With   _1=Q/(A_e*U_e)=Q/(pi*omega*re^3)=27”)
disp(”Thus we obtain re=2.8 in and selecting r1=3.2 inches the final results are obtained as Ve=Q/(pi*D_e^2/4)=15.6ft”)
disp(”V_1=17.2ft/s , A_1=22.4in^2, b2=1.24in with  _1 =0.9 assumed. Also U_1=66.9ft/s,  _f1 =14.4 degrees,  _b1 =17 degrees and W_1=69.1 ft/s”)

disp(”(c) The impeller discharge is determined ”)
omega=251
Q=2.676
//elt x=g*H=14490
x=14490
omega_s=omega*(Q^0.5)/((x)^0.75)
printf(”\nomegas is %0.3f”,omega_s)

delta_s=9
D_2=delta_s*(Q^0.5)/((x)^0.25)
printf(”\nD2= %0.4f ft = 16.1in”,D_2)

D_2=1.342//rounded off
omega=251
U_2=D_2*omega/2
printf(”\n U_2= %0.2f”,U_2)//in the book the answer has been rounded off to 168.5

disp(”Selecting  _b2 =27.5 degrees”)
Zb=6.5*((1+0.4)/(1-0.4))*sin((((17+27.5)/2)*%pi/180)
printf(”\nZb= %0.2f is approximately equal to 6”,Zb)
MUs=1-%pi*sin((27.5/6)*%pi/180)
printf(”\nThus  s= %0.3f”,MUs)//The answer given in the book is 0.76,but the more accurate answer is
```

```
    0.749

ETA_h=1-0.8/((1200)^0.25)
printf("\n ETA_h= %0.3f",ETA_h)

disp("(3) Substituting these values into the Euler equation ,we obtain values of Vu2 and Vr2")
ETA_h=0.864
U_2=168.5
V_u2=x/(ETA_h*U_2)
printf("\n Vu2= %0.2f ft/s",V_u2)//value given in the book is equal to 99.6,however the more accurate value is equal to 99.53

disp("Vu2=  *(U2-Vr2/tan b2)")
disp("Hence we can find out the value of Vr2=19.4 ft/s")
V_r2=19.4
V_u2=99.6//rounded off value taken in the book
U_2=168.5
W_2=[V_r2^2+(U_2-V_u2)^2]^0.5
printf("W2= %0.2f ft/s",W_2)

disp("Hence W2/W1 >1 , which is not appropriate. A different D2 has to be selected,say D2=15in.")
disp("So we have U_2=159.6 ft/s,V_u2=106.9 ft/s , V_rt=8.5ft/s, and W_2=50.7 ft/s")
disp("Hence W_2/W_1=0.74, which is acceptable")

disp("The outlet dimensions are calculated as A2=Q/Vr2")
Q=1200
V_r2=8.5
A_2=(Q*0.00223)/V_r2//0.00223 is conversion factor to convert gallons per minute to cubic feet per second
printf("\nThus A_2= %0.3f ft^2",A_2)
disp("On converting, we get A2=45.3 in^2")
```

```
disp("A_2=  _2 *pi*D_2*b_2 , where  _2 =1-(Zb*t)/(pi*D_2*sin( _b2))")
Zb=6
t=0.25
D_2=15
beta_b2=27.5*%pi/180//converting to radians
epsilon_2=1-(Zb*t)/(%pi*D_2*sin(beta_b2))
printf("Thus  2 = %0.2f",epsilon_2)
A_2=45.3//in inches
b_2=A_2/(epsilon_2*%pi*D_2)
printf("\nThus we can determine b_2 which is equal to %0.0f in",b_2)

epsilon_1=1-(6*0.25)/(%pi*6.4*sin(17*%pi/180))
printf("\n _1= %0.2f",epsilon_1)
disp("b_1 has to be adjusted")
b_1=1.3*0.9/0.74
printf("\nThus b_1 is equal to %0.2f in",b_1)

disp("The blade profile is constructed by assuming a linear blade angle distribution")
disp(" b= b1+( b2- b1)*(r-r1)/(r2-r1))=17+2.44(r-3.2)")
disp("where  b is in degrees and r is in inches.")
disp("Also deltatheta can be expressed as (180/pi)*deltar/(r*tan b)")
disp("If we select deltar=0.43 in,then  b, deltatheta,theta,dL and L can be calculated and tabulated as follows")

r=[3.2 3.63 4.06 4.49 4.92 5.35 5.78 6.21 6.64 7.07 7.5];
beta_1=[17 18.05 19.1 20.15 21.2 22.25 23.3 24.35 25.4 26.45 27.5];
dthita=[25.188 20.831 17.528 14.957 12.913 11.259 9.8993 8.768 7.8157 7.006 6.3116 ];
thita=[0 25.188 46.018 63.546 78.502 91.415 102.67 112.57 121.34 129.16 136.16];
```

```
dL=[1.4709 1.388 1.3143 1.2484 1.1892 1.1358 1.0873 1.0431 1.0026 0.9655 0.9314];
L=[0 1.471 2.859 4.173 5.422 6.611 7.747 8.834 9.877  10.88 11.85];
r_2=[3.2 3.63 4.06 4.49 4.92 5.35 5.78 6.21 6.64 7.07 7.5];
beta_2=[17 17.6 18.2 18.8 19.4 20 20.6 21.2 21.8 22.4 23];
dthita_2=[25.19 21.4 18.46 16.12 14.22 12.65 11.34 10.23 9.279 8.456 7.74];
thita_2=[0 25.2 46.6 65 81.2 95.4 108 119 130 139 147];
dL_2=[1.471 1.422 1.377 1.334 1.295 1.257 1.222 1.189 1.158 1.129 1.101];
L_2=[0 1.471 2.893 4.27 5.604 6.899 8.157 9.379 10.57 11.73 12.85];

table=[r' beta_1' dthita' thita' dL' L' r_2' beta_2'  dthita_2' thita_2' thita_2' dL_2' L_2']
disp("The table is in the given order:beta,dthita,thita,dL,L.r,beta,dthita,thita,thita,dL,L")
disp(table)

disp("The table shows that with  b2=27.5 degrees the blade lemgth L=11.85 in.")
sigma_s=6*11.85/(%pi*15)
printf(" Hence the solidity is sigma_s= %0.2f which is too low.",sigma_s)

sigma_s=9*12.85/(%pi*15)
printf("\n Hence the new  b2=23 degrees and Zb=9 are selected so that we hae final value of sigma_s=%0.2f.",sigma_s)

disp("The final values of the impeller outlet dimensions are revised:")
disp("A2=0.194 ft^2=27.9 in^2, b2=0.67 in , with mu_s=0.86, epsilon_2=0.88 , Vr2=13.8 ft/s , W2
```

```
=51.8 ft/s”)
```

Scilab code Exa 4.8 CP

```
clear all; clc;

disp(”From example 4.7 we have Q=1200gpm,H=450ft,N=2400rpm”)
disp(”Furthermore Ns=851 rpm*(gpm^0.5)/(ft^0.75),D2=15in,b2=0.67in,U2=156.9 ft/s.”)
disp(”Also, b2=23 degrees, s=0.86,V2=13.8ft/s and Vu2=106.9ft/s”)
disp(”Hence we have the angular momentum L=r2*Vu2 ”)
L=15*106.9/(2*12)
printf(” Thus L= %0.2f dt/s^2”,L)

disp(”Fom figure 4.24 we have K3=0.46 and Ns=851.”)
disp(”Hence the volute exit velocity Vt=K3*(2*g*H)^0.5”)
V_3=0.46*sqrt(2*32.2*450)
printf(”\n Thus Vt= %0.2f ft/s”,V_3)

disp(”Also A_t=Q/V_t ”)
A_t=1200*0.00223/78.3
printf(” At= %0.3f ft^2 which is equal to 4.92 in^2”,A_t)
disp(”Also from Figure 4.24 we have (D3-D2)/D2=0.08”)

r_3=7.5*(1+0.08)
printf(”\n r3= %0.2f”,r_3)
disp(”If the trapezoid with an included angle of 30 degrees is selected for bassic geometry of the volute cross section,the dimensions from each section can be calculated from Athita*Vthita=(Q*
```

```
thita)/(2*pi)")

disp("r_c*V_thita=CL")
disp("A_thita=0.5*h*(a+b)")
disp("(a-b)/(2*h)=tan(15)")
disp("x_c=h*(2a+b)/(3*(a+b))")
disp("rc=r3+x_c")

disp("where b=1.82 b2=1.206 in. is selected")
disp("The equations are to be solved with iterations and performed with a spreadsheet.")
disp("The initial velocity is selected as V_thita=V_t")
disp("Then A_thita is calculated from 1,a and h from (3) and (4), and x_c and r_c from (5) and (6)")
disp("Then the improved V_thita is obtained from (2) and the process is repeated until the discrepancies of the repeated values are small enough.")
disp("In the final design the trapezoid is modified by roundidng off the corners and the area may be increassed by 5 to 10 percent to accomodate the blockage due to the boundary layer and sme secondary flows.")//final answers have not been provided in the book
```

Scilab code Exa 4.9 CP

```
clear all; clc;
//Values of tenPs0 and eff slightly vary from those given in the book. On calculating it was found out that the values given here are more accurate than those given in the textbook

disp("Use the motor calibration curves to convert
```

```
input electrical power to shaft  power for the corresponding rotating speed. The result is provided below.")

Q1=[40 80 120 140 160 180 200 220];
dp1=[77 76 70 66 64 62 55 48];
Ps1=[5.2 5.6 6 6.5 7.2 7.6 7.75 7.8];
N1=[1775 1772 1765 1760 1755 1753 1750 1747];
table=[Q1' dp1' Ps1' N1'];
disp("   Q1  dp1(psi)  Ps1(hp)  N1(rpm)")
disp(table)

disp("Convert each operating condition of flow rate, pressure rise and shaft power from the test rotating speed to the rated speed of 1750rpm.")
Q0 = zeros(1,length(Q1));
dp0 = zeros(1,length(Q1));
tenPs0= zeros(1,length(Q1));
eff=zeros(1,length(Q1));
for i = 1: length(Q1)


   Q0(i)=Q1(i)*(1750/N1(i));
   dp0(i)=dp1(i)*(1750/N1(i))*(1750/N1(i));
   tenPs0(i)=10*Ps1(i)*(1750/N1(i))*(1750/N1(i))*(1750/N1(i));//values slightly differ from those given in the book,however on calculation the values given here are more accurate than those given in the book
   eff(i)=100*(Q0(i)*dp1(i)*144)/(449*550*tenPs0(i)/10);//since eff depends on tenPs0,hence they differ too
end

table2=[Q0' dp0' tenPs0' eff'];
disp("    Q0(gpm)      dp0(psi)      tenps(hp)    eff(%)")
disp(table2)
```

```

plot(Q0,dp0,’o’,Q0,tenPs0,’d’,Q0,eff,’s’)
legend(”dp(psi) ”,”10Ps(hp)”,”Eff (%)”,-1)
xlabel(”Q(gpm))”)
ylabel(”dp(psi, 10Ps(hp),Eff(%))”)
set(gca(),”grid”,[1 1])
```

Scilab code Exa 4.10 CP

```
clear all; clc;
//Value of s differs. The one given in the book is incorrect. On calculation the value is equal to the one provided here.

disp(”The dynamic pressure at the inlet is calculated from pd1=rho*V1^2/2”)

Q=220*0.00223//0.00223 is conversion factor
D=5
A=%pi*(D^2)/4
V_1=(Q*144)/(A)
printf(” V1=Q/A= %0.2f ft/s”,V_1)

rho=62.4
V_1=3.60
p_d1=(rho*(V_1^2))/(2*144*32.2)
printf(” \npd1= %0.3f psi”,p_d1)

disp(”The vapor pressure of water at 80 degrees Farenheit is obtained from steam tables as pv=0.507psia.”)
disp(”The required NPSH is designated at the condition such that discharge pressure drops for 3% from the non cavitation condition.”)

```

```
dpdash=0.97*70
printf(" Hence from the above test data,the correspondin dpdash= %0.2f psi",dpdash)

p_1dash=7.2+(7.5-7.2)*(67.9-67.5)/0.5
printf("\n p1dash can also be obtained %0.2f psia",p_1dash)

disp("Also NPSPR=p1dash+pd1-pv")
p_1dash=7.44//rounded off
p_d1=0.087//rounded off
p_v=0.507
NPSPR=p_1dash+p_d1-p_v
printf("\n Hence NPSPR = %0.2f psia",NPSPR)

NPSPR=7.02//rounded off
NPSPHR=2.307*NPSPR
printf("\n NPSPHR= %0.2f ft",NPSPHR)

N=3500
Q=220
NPSHR=16.2
S=(N*(Q^0.5))/((NPSHR)^0.75)
printf("\n S= %0.0f rpm*(gpm^0.5)/(ft^0.75))",S)//S=6419 but on calculation it is found out that S=6429. Hence the value given here is correct.
```

Scilab code Exa 4.11 CP

```
clear all; clc;

disp("With H=k*(Q^2)+3,the constant k can be obtained.")

H=10*144/62.4
```

```
printf("We have H= %0.2f ft and Q=25gpm",H)

Q_1=25
k=(H-3)/(Q_1^2)
printf("\nThus k= %0.4f ft/(gpm^2)",k)

disp("Thus the H/Q relationship can be tabulated and plotted as follows")

Q=[0 5 10 15 20 25 30];
Hdash = zeros(1,length(Q));

for i = 1: length(Q)


   Hdash(i)=(0.0321*((Q(i))^2)+3);
end

table = [Q' Hdash'];
disp("  Q(gpm)  H(ft)")
disp(table)

plot(Q,Hdash)

xlabel("Q (gpm)")
ylabel("H(ft)")

disp("(b) Rewrite H=0.0321*(Q^2)+3 into Q=5.581*((H-3)^0.5)")
disp("From Qc=2Q and Hc=H,we have Qc=11.16*(Hc-3)^0.5 or Qc^2=124.6*(Hc-3)")
disp("Or Hc=0.00802*Qc^2+3")
disp("It is the expression of the combined system")
```

Scilab code Exa 4.12 CP

```
clear all; clc;

disp("The single pump performance is given as
   follows")
Q=[0 70 130 172 186 190 195 200];
H=[1600 1500 1275 920 785 540 435 285];
table=[Q' H'];
disp("  Q(gpm)  H(ft)")
disp(table)

disp("a) Two connected in series")
Q_1=[0 70 130 172 186 190 195 200];
H_1=[3200 3000 2550 1840 1570 1080 870 570];
table1=[Q_1' H_1']
disp("  Q_1(gpm)  H_1(ft)")
disp(table1)

disp("b) Two connected in parallel")
Q_2=[0 140 260 344 372 380 390 400];
H_2=[1600 1500 1275 920 785 540 435 285];
table2=[Q_2' H_2']
disp("  Q2(gpm)  H2(ft)")
disp(table2)

plot(Q,H,'o',Q_1,H_1,'d',Q_2,H_2,'s')
legend("H(ft))","H1(ft)","H2(ft)",-1)
xlabel("Q (gpm)")
ylabel("H(ft)")
set(gca(),"grid",[1 1])
```

Scilab code Exa 4.13 CP

```
clear all; clc;

disp("The specific speeds for all three options can
```

```
be calculated”)

N_sa=3600*(500^0.5)/(350^0.75)
printf(”Nsa= %0.0f rpm*(gpm^0.5)/(ft^0.75)”,N_sa)

N_sb=4320*(500^0.5)/(350^0.75)
printf(”\nNsb= %0.0f ”,N_sb)

N_sc=3600*((500^0.5)/(175^0.75))
printf(”\nNsc= %0.0f”,N_sc)

disp(”From figures 4.20 and 4.36, we oobtain Effa=0.75, Dsa=1.7,Effb=0.78,Dsb=1.4,Effc=0.80,Dsc=1.31”)

D_sa=1.7
Q=500
H=350
D_a=D_sa*(Q^0.5)/(H^0.25)
printf(”\nDa=Dsa*(Q^0.5)/(H^0.25)= %0.1f in”,D_a)

D_sb=1.4
D_b=D_sb*(Q^0.5)/(H^0.25)
printf(”\nDb= %0.1f in”,D_b)

D_sc=1.1
D_c=D_sc*(Q^0.5)/(H^0.25)
printf(”\nDc= %0.1f in”,D_c)//for Dsc=1.1 the value determined is correct. The value of Dc given in the book is incorrect.

Q=500*0.00223//conversion from gpm to cubic ft/s
//let x=rho*g
x=62.4
P_h=Q*x*H
printf(”\nThe output hydraulic power is equal to %0.0f ft-lbf/s = 44.3hp=33kW”,P_h)

```

```
P_a=33/(0.75*0.9)
printf(”\nThe power required for option a= %0.1f kW”,P_a)

P_b=33/(0.78*0.95*0.9)
printf(”\nThe power required for option b= %0.1f kW”,P_b)

P_c=33/(0.80*0.9)
printf(”\nThe power required for option c= %0.1f kW”,P_c)
```

Chapter 5

Axial Flow Pumps and Fans

Scilab code Exa 5.1 AF

```
clear all; clc;

disp("From figure 5.3a, we have Cl=0.36, Cd=0.017
   and alpha=1.8 degrees at maximum L/D")

N=3500
C_l=0.36
alpha=1.8
C_d=0.017
r_t=13.25
r_h=3.25
Zb=7
Q=11560//cfm
gamma_1=70
alpha=1.8

A=%pi*(r_t^2-r_h^2)
printf("\n A is equal to %0.1f in^2",A)
disp("On converting it in terms of feet we have A=
   3.6 ft^2")

```

```
r_m=[0.5*(r_t^2+r_h^2)]^0.5
printf(”\n rm is equal to %0.2f in”,r_m)
disp(”On converting it in terms of feet we have rm =0.804 ft ”)

r_m=0.804//in feet
U_m=(N*%pi*r_m)/30
printf(”\n Um is equal to %0.1f ft/s”,U_m)

r_m=9.65//in inches
s=(2*%pi*r_m)/Zb
printf(”\n s= %0.2f in”,s)

disp(”Va=V1=Q/A”)

A=3.6//in square feet
V_1=Q/(A*60)//divided by 60 to get answer in terms of ft/s
printf(”\n V1=Va= %0.2f ft/s”,V_1)

U_m=294.7//rounded off
V_1=53.5//rounded off
beta_1=(atan(U_m/V_1))*180/%pi
printf(”\n  1= %0.1f degrees”,beta_1)

beta_m=gamma_1+alpha
printf(”\n  m= %0.1f degrees”,beta_m)

disp(”From tan m=(tan 1+tan 2)/2 ,  2 =30.1 degrees; Then Wmcos m=Va”)
V_a=53.5//in ft/s
W_m=V_a/(cos(beta_m*%pi/180))
printf(”\n So Wm= %0.1f ft/s”,W_m)

W_m=171.3//rounded off
rho=0.0762/32.2
cm=3.5
s=8.66//rounded off
```

```
disp("hence we have deltapr=((rho*Wm^2)/2)*(cm/s)*(Cl*sin(betam*%pi/180)-Cd*cos(betam*%pi/180))")
delta_pr=((rho*W_m^2)/2)*(cm/s)*(C_l*sin(beta_m*%pi/180)-C_d*cos(beta_m*%pi/180))
printf("\n deltapr= %0.4f lb/ft^2 ",delta_pr)
disp("On rounding off we get deltapr= 4.73 lbf/ft^2")
disp("Thus deltapr=0.0328psia=0.91 in.wg")

disp("Across the stator, from the velocity diagram, we have Wu2=Va*tan 2 and V2=(Va^2+(Um-Wu2)^2)^0.5")

beta_2=30.1*%pi/180
V_a=53.5//rounded off
W_u2=V_a*tan(beta_2)
printf(" Thus Wu2 is equal to %0.0f ft/s",W_u2)

U_m=294.7//rounded off
V_2=(V_a^2+(U_m-W_u2)^2)^0.5
printf("\n V2= %0.0f ft/s",V_2)

disp("So assuming V_3=V_a")

V_a=53.5//rounded off
V_2=269//rounded off
eta_s=0.85//efficiency
rho=0.0762/32.2
delta_ps=(((eta_s*rho)/2)*(V_2^2-V_a^2))/144//144 is conversion factor
disp("delta_ps=(((etas*rho)/2)*(V2^2-Va^2))")
printf("\n deltaps is equal to %0.3f psia",delta_ps)
disp("On converting the unit deltaps = 1.12 ft which is equal to 13.44 inches of water")
```

Scilab code Exa 5.2 AF

```
clear all; clc;

disp(”a)”)
disp(”Convert: 1) Q=5 mˆ3/s=10595 cfm”)
disp(”2) rhoa=0.0761lbm/ftˆ3”)

disp(”3) SP=deltap/(rhow∗g)”)
delta_ps=500
rho_w=1000
g=9.8
SP=delta_p/(rho_w*g)
printf(”Hence SP = %0.3f m”,SP)
disp(”Thus SP= 2.01 in.wg.”)

disp(”b)”)
disp(”Calculating the specific speed:Ns”)
N_s=1500*((10575)^0.5)/(2.01)^0.75
printf(”The value of Ns is equal to %0.2f rpm∗(cfmˆ0.5)/(in of waterˆ0.75)”,N_s)

N=1500
omega=N*%pi/30
printf(”\nOmega = %0.0f rad/s”,omega)

omega_s=157*(5^0.5)/((500/1.22)^0.75)
printf(”\nSo omegas = %0.2f ”,omega_s)

disp(”From figure 5.10b,we select v=Dh/Dt=0.5 and the blade number Zb=6∗v/(1−v)”)
v=0.5
Zb=6*v/(1-v)
printf(”Hence Zb= %0.2f”,Zb)

disp(”From figure 2.2,the specific diameter obtained as deltas is approximately equal to 1.5”)
D_t=1.5*(5^0.5)/((500/1.22)^0.25)
```

```
printf("\nHence Dt = %0.3f m",D_t)

v=0.5
D_t=0.74//rounded off
D_h=v*D_t
printf("\nDh= %0.2f m",D_h)

A=%pi*(D_t^2)*(1-v^2)/4
printf("\nAlso A = %0.4f m^2",A)

D_m=((D_t^2+D_h^2)/2)^0.5
printf("\nDm = %0.4f m",D_m)

A=0.322//rounded off
Q=5
V_a=Q/A
printf("\nVa= %0.1f m/s",V_a)

U_m=omega*D_m/2
printf("\nUm = %0.2f",U_m)

V_a=15.5//rounded off
PHI_m=V_a/U_m
printf("\nPHIm = %0.3f",PHI_m)

disp("Now from figure 5.10c we can obtain Phim*(s/c)=0.65")
//let s/c=x
PHI_m=0.337//rounded off
x=0.65/PHI_m
printf("\nThus (s/c)= %0.2f",x)

disp("Here s= pi*Dm/Zb")
s= %pi*D_m/Zb
printf("\n Thus s= %0.3f m",s)

disp("Assuming V1=V3=Va=15.5 m/s the total head can be calculated from g*Ht=deltaps/rho+Va^2/2")
```

```
//let y=g*Ht=deltaps/rho+(Va^2)/2
rho_a=1.22
y=delta_ps/rho_a+(V_a^2)/2
printf("\ng*Ht = %0.0f (m/s)^2",y)
disp("or TP=2.59 in.wg")

disp("c)")
ETA_h=0.77
V_u2=(y)/(ETA_h*U_m)//Since y=(g*Ht)
printf("\nVu2 is equal to %0.0f m/s",V_u2)

beta_1=(atan(U_m/V_a))*180/%pi
printf("\n 1= %0.2f degrees",beta_1)

beta_2=(atan(((U_m-V_u2)/V_a)))*180/%pi
printf("\n  2= %0.2f degrees",beta_2)

//let m=tan m =0.5*(tan 1+tan 2)
beta_1=71.3//rounded off
beta_2=63.4//rounded off
m=0.5*(tan(beta_1*%pi/180)+tan(beta_2*%pi/180))
printf("\ntan m =0.5*(tan 1+tan 2) =%0.3f",m)
beta_m=(atan(m))*180/%pi
printf("\n  m = %0.0f",beta_m)

disp("We know that Cl=2*(s/c)*(tan 1 -tan 2)*cos m
   ")
x=1.93//rounded off
beta_1=71.3
beta_2=63.4
beta_m=68
//Let a=tan 1
//Let b=tan 2
//Letc=cos m
a=tan(beta_1*%pi/180)
b=tan(beta_2*%pi/180)
c=cos(beta_m*%pi/180)
a=2.95//rounded off
```

```
b=2.0//rounded off
c=0.374//rounded off
Cl=2*x*(a-b)*c//Since x=(s/c)
 printf("\nCl= %0.2f ",Cl)

 disp("This is the cascade coefficient required.To use the isolated airfoil data,we obtain K=1.2 from figure 5.9 with gamma=60 degrees. Hence we can determine Cli")

 C_li=1.37/1.2
 printf("\nCli= %0.2f",C_li)

disp("d)")
disp("If NACA 4312 airfoil selection is selected,at Alpha=12 degrees,Cli=1.14 and Cl/Cd=L/D=12")
disp("Substituting the above mentioned data in Rr=Wmu/Um=phi*tan( m )")
phi=0.337
d=tan(beta_m*%pi/180)
R_r=phi*d
printf("\n Thus Rr= %0.3f",R_r)
disp("deltar is approximately=deltas is approximately=0.08")
Eta_h=0.337*(((0.834-(0.337*0.08))/(0.337+(0.08*0.834)))+((1-0.834-(0.337*0.08))/(0.337+(0.08*(1-0.834)))))
printf("\nETAh= %0.2f",Eta_h)
disp("Etah=0.80 is approximately equal to 0.77")
disp("Also gamma=betam-alpha=68-12=56 degrees")
disp("c=s/1.93")
c=s/1.93
printf("\nThus c = %0.2f m",c)

disp("e)")
disp("Double check the data obtained with those given in Figure 5.1.It is shown that Etas=0.74,Ds=0.35=c.")
```

```
SP=2.01
CFM=10595
Dt=0.35*(CFM^0.5)/(SP^0.25)
printf(”\nHence the value of Dt= %0.1f in”,D_t)
disp(”On converting,Dt=0.77m”)
disp(”It is close to what we have. However, some alternative design maybe performed with the selection of a little higher hub-tip ratio v and other availabe airfoil sections”)
```

Scilab code Exa 5.3 AF

```
clear all; clc;

disp(”From equation 5.11 with Vu=constant,we have (Vu^2/r)dr+(Va)dVa=0 ”)
disp(”Or Vu^2lnr+Va^2/2=C”)
disp(”Or Vu^2*ln(r/rh)=(Vah^2-Va^2)/2”)
disp(”Or Va^2=Vah^2-2*Vu^2*ln(r/rh)”)

V_ah=70
//let m=Vah^2
m=V_ah^2
printf(”\n Vah^2 = %0.0f”,m)

V_u=500
//let n=Vu^2
n=V_u^2
printf(”\n Vu^2= %0.0f”,n)

//let x=Vu^2*2
x=n*2//Since n=Vu^2
printf(”\n 2*Vu^2= %0.0f”,x)

disp(”Thus Va=(4900-5000*ln(0.5r))^0.5 m/s”)
```

```
disp("and at the tip,Vat=27.1m/s")
```

Scilab code Exa 5.4 AF

```
clear all; clc;

disp("Assume uniform axial flow at the inlet")
disp("(a) At the hub")
disp("V_a=15.5m/s")

omega=157
D_h=0.37
U_h=0.5*omega*D_h
printf(" Uh= %0.2f m/s",U_h)

disp("Vu2=(Vmu2*Dm)/Dh")
V_mu2=15
D_m=0.585
V_u2=(V_mu2*D_m)/D_h
printf(" Hence Vu2= %0.1f m/s",V_u2)

V_a=15.5
disp("tan( 1 )=(Uh/Va). Hence we can determine value of  1 ")
//let x=Uh/Va
x=U_h/V_a
beta_1=(atan(x))*180/%pi
printf("  1= %0.1f degrees",beta_1)

disp("tan( 2 )=(Uh–Vu2)/Va")
//Let y=(Uh–Vu2)/Va
y=(U_h-V_u2)/V_a
beta_2=(atan(y))*180/%pi
printf("  2= %0.2f degrees \n",beta_2)

```

```
disp("(b) At the tip")

U_t=0.5*(157*0.74)
printf("\n Ut= %0.2f m/s",U_t)

V_u2=(15*0.585)/0.74
printf("\n Vu2= %0.2f m/s",V_u2)

//let p=atan(58.09/15.5)
p=(atan(58.09/15.5))*180/%pi
printf("\n  1 = %0.0f degrees",p)

//let q=atan((58.09-11.86)/15.5)
q=atan((58.09-11.86)/15.5)*180/%pi
printf("\n  2 = %0.3f degrees",q)
disp("On rounding off  2 =71.4")
```

Scilab code Exa 5.5 AF

```
clear all; clc;

disp("Since the pressure changes are small compared with the barometric pressure,constant densities are assumed that is rho3 =rho2=rhoa where rhoa=pa/(RTa)")
p_a=14.6
T_a=535
R=53.3
rho_a=(p_a*144)/(R*T_a)//144 is the conversion factor
printf("rhoa= %0.4f lbm/ft^3",rho_a)

A2=5*6.5
printf("\nA2 equals %g in^2",A2)
disp("On converting A2=0.225ft^2")
```

```

A3=%pi*6.065^2/4
printf("\nA3 equals %0.1f in^2",A3)
disp("On converting A3=0.2007ft^2")

disp("From (rho3*V3^2)/2=rhow*g*pv3,V3 can be calculated")
rho_w=62.4
g=32.2
rho_3=0.0737
j=sqrt(2*rho_w*g/(rho_3*12))
printf("V3=%0.1f * pv3^0.5 ft/s",j)

disp("The inlet flow rate can be calculated as Q=Q3=V3*A3=0.2007*60*V3=12.04*V3")
disp("Also the dynamic pressure can be calculated as pv2=pv3*((A3/A2)^2)*(rho3/rho2)=(0.2/0.225)^2*pv3=0.79pv3")

disp("The total pressure pt2=ps2+pv2")
disp("To correct these data to a fixed speed of 3500 rpm,the fan laws can be used as Qdash=Q*3500/N, pt2dash=pt2*((3500/N)^2) and Hdash=H*((3500/N)^3).")
disp("The total efficiency can be calculated as ETAt=(rhow*g*pt2dash*Qdash)/(Hdash)")
disp("On simplifying ETAt=Qdash*pt2dash/(6346*Hdash)")

p_v3=[2.4 2.1 1.9 1.5 1.2 0.8 0.4];
p_s2=[2.5 4.2 6.0 6.8 7.6 8.5 9.5];
N=[3450 3520 3500 3420 3430 3500 3520];
H=[1.1 1.25 1.49 1.55 1.67 1.72 1.81];

V_3=zeros(1,length(p_v3));
Q=zeros(1,length(p_v3));
p_v2=zeros(1,length(p_v3));
p_t2=zeros(1,length(p_v3));
```

```
Qdash=zeros(1,length(p_v3));
tenpt2dash=zeros(1,length(p_v3));
tenHdash=zeros(1,length(p_v3));
eta_t=zeros(1,length(p_v3));

for i = 1: length(p_v3)


    V_3(i) = 67.4*sqrt(p_v3(i));
    Q(i) = 12.04*V_3(i);
    p_v2(i) =0.79*p_v3(i);
    p_t2(i)= p_s2(i)+p_v2(i);
    Qdash(i)= Q(i)*(3500/(N(i)));
    tenpt2dash(i)= 10*p_t2(i)*((3500/N(i))^2);
    tenHdash(i)= 10*H(i)*((3500/(N(i)))^3);
    eta_t(i)= ((Qdash(i)*(tenpt2dash(i))/10)/(6346*(tenHdash(i))/10))*100;
end

disp(”The table is in the order given in the book, that is pv3, ps2, N, H, V3, Q, pv2, pt2, Qdash, tenpt2dash, tenHdash and etat.”)
table=[p_v3' p_s2' N' H' V_3' Q' p_v2' p_t2' Qdash' tenpt2dash' tenHdash' eta_t' ];
disp(table)

plot(Q,tenpt2dash,'o',Q,tenHdash,'d',Q,eta_t,'s')
legend(”tenpt2dash (inches of water)”,”tenHdash (hp)”,”eta_t (%)”,-1)
xlabel(”Q(cfm)”)
ylabel(”tenpt2dash (inches of water), tenHdash (hp), eta_t (%)”)
set(gca(),”grid”,[1 1])
```

Scilab code Exa 5.6 AF

```
clear all; clc;

disp(”Since dBt=10*[((log10^dBb)/10)+(10^dBf/10)] we can determine dBf”)

//let x=10^(dBt/10)
x=10^7

//let y=10^(dBb/10)
y=10^6.5

//let z=x-y
z=x-y

disp(”dBf=10*(log(10^(dBt/10)+10^(dBb/10)))”)
dBf=10*[log10(z)]
printf(” Thus dBf= %0.2f”,dBf)
```

Scilab code Exa 5.7 AF

```
clear all; clc;

disp(”The average flow velocity V is determined as V=Q/A”)
Q=7000
A=%pi*(1.5^2)/4
V=Q/A
printf(” Thus V = %0.2f fpm”,V)
disp(”Thus V is approximately equal to 4000fpm”)

disp(”So we have 100% effective discharge duct length Le=[2.5+(4000-2500)/1000]*D”)
D=1.5
Le=[2.5+(4000-2500)/1000]*D
printf(”\n Since D=1.5 ft, Le is equal to %0.2f ft”,
```

```
    Le)

//let x=L1/Le
L1=0.75
x=L1/Le
printf("\n Since L1=0.75,L1/Le=%0.3f",x)

disp("So the line V in figure 5.18 can be used to
    obtain SEF1=0.255in.wg")
disp("For the two elbows we have L2/D and C2")
//let y=L2/D
L2=3
y=L2/D
printf("\n The value of L2/D is equal to %0.2f",y)
disp("From figure 5.19a,C2=4.2")

disp("Hence we can obtain SEF2=4.2*(rho*V^2/2)")
rho=0.075
V=4000
SEF2=4.2*((rho/32.2)*(V/60)^2/2)*(12/62.4)//
    constants used are conversion factors
printf("\n SEF2 is equal to %0.2f in.wg",SEF2)
```

Scilab code Exa 5.8 AF

```
clear all; clc;

disp("We have the duct resistance deltap
    =0.25*((7000/5000)^2)")
delta_p=0.25*((7000/5000)^2)
printf(" deltap %0.2f in.wg at 7000cfm",delta_p)

disp("The density in the building can be calculated
    from rho=p/R*T")
p=12.5
```

```
R=53.3
T=85+460
rho=p*144/(R*T)//144 is convesrion factor
printf("\n rho= %0.5f lbm/ft^3",rho)

disp("So the equivalent SPe of the required fan at STP can be found out")
SPe=0.49*0.075/0.0619
printf("\n SPe = %0.4f in.wg.",SPe)

disp("Form figure 5.24a,at SP=0.5,Q1=6894,N1=347, BHP1=0.76 and Q2=7660, N2=360, BHP2=0.88. Hence for Q=7000cfm we can determine Ndash")
Ndash=347+(360-347)*((7000-6894)/(7660-6894))
printf("\n Ndash is equal to %0.2f rpm",Ndash)

BHPdash=0.76+(0.88-0.76)*0.138
printf("\n BHPdash= %0.4f",BHPdash)

disp("At Sp=5/8=0.625 in.wg.,Q1=6894,N1=375,BHP1=0.92 and Q2=7660,N2=387,BHP2=1.05,so for Q=7000 cfm we can determine Ndbldash and BHPdbldassh")

Ndbldash=375+((387-375)*0.138)
printf("\n Ndbldash %0.2f rpm",Ndbldash)

BHPdbldash=0.92+(1.05-0.92)*0.138
printf("\n BHPdbldash %0.4f hp",BHPdbldash)

disp("Again interpolating for SPe=0.593,we have values of N and BHP as mentioned below ")
N=348.8+(376.6-348.8)*((0.593-0.5)/(0.625-0.5))
printf("\n N= %0.0frpm",N)
BHP=0.776+(0.938-0.776)*0.744
printf("\n BHP= %0.4f hp",BHP)

disp("Correcting for the reduced air density,the actual BHP is determined")
```

```
BHP=0.896*0.0619/0.075
printf("\n Actual BHP is equal to %0.4f",BHP)
```

Scilab code Exa 5.9 AF

```
clear all; clc;

disp("1.Convert the system specification to Qdash
   =10000cfm with the correeesponding total pressure
   loss")
delta_p_ldash=0.5*((10000/5000)^2)
printf("\n delta(pl)dash= %0.0f in.wg.",
   delta_p_ldash)

disp("2. Draw a system line(which is a straight line
    with slope of 2 on a log-log chart)passing this
   point and intercept at 700rpm")

disp("Read the operating condition as Q=11000cfm,
   deltap=2.51 in.wg. and Ps=5.6hp")
```

Chapter 6

Centrifugal Fans Blowers and Compressors

Scilab code Exa 6.1 C

```
clear all; clc;

disp("Pick the data rows for the flow rates of 10241 and 13965 cfm and list them in the first four columns of the table below.")
disp("Convert the flow rate Q,static pressure SP and brake horsepower BHP values for various rpm into 300rpm based on the fan laws.")
disp("That is Q1=Q*(300/N), SP1=SP((300/N)^2),BHP1=BHP*((300/N)^3)")
disp("Calculate the static efficiency using ETAs=(Q*SP)/(6346*BHP)")
disp("The results are plotted into the chart")





Q=[10241 10241 10241 10241 10241 10241 10241 13965
```

```
   13965 13965 13965 13965 13965 13965 13965 ];
SP= [0.25 0.375 0.5 0.625 0.75 1 1.25 0.25 0.375 0.5 0.625 0.75 1 1.25 1.5];
N= [300 321 341 363 385 427 466 380 396 413 428 444 473 506 537];
BHP= [0.82 1.03 1.23 1.45 1.68 2.19 2.75 1.58 1.86 2.16 2.43 2.72 3.3 3.89 4.51];

Q1= zeros(1,length(Q));
SP1 = zeros(1,length(Q));
BHP1 = zeros(1,length(Q));
ETA=zeros(1,length(Q));

for i = 1: length(Q)

   Q1(i)=Q(i)*(300/N(i))
   SP1(i)=SP(i)*((300/N(i))^2)
   BHP1(i)=BHP(i)*((300/N(i))^3)
   ETA(i)=(Q(i)*SP(i))/(6346*BHP(i))

end

//disp("      phi        psi          eff(%)     pai            N(rpm)          Ps(mw)           Q(m^3/s)")

table = [Q' SP' N' BHP' Q1' SP1' BHP1' ETA'];
disp("      Q          SP            N           BHP           Q1                SP1              BHP1             ETA")
disp("    (cfm)     (in.wg)      rpm                           (cfm)        (in.wg)")
disp(table)

plot(Q1,SP1,'o',Q1,BHP1,'d',Q1,ETA,'s')
legend("SP1(in.wg)","BHP1(hp)","ETA",-1)
xlabel("Q(cfm)")
ylabel("SP1(in.wg), BHP1(hp) , ETA")
set(gca(),"grid",[1 1])
```

Scilab code Exa 6.2 C

```
clear all; clc;

disp("Assume as given Na=2400 rpm")
disp("T1a=68 degrees Farenheit=528R,p1=14.7 psia,p2a=8.5psig=23.2 psia")
disp("Qa=1800cfm,Eta=0.70 Nb=3600rpm and T1b=50 to 95 degrees Farenheit")

Q_a=1800
N_b=3600
N_a=2400
Q_b=Q_a*(N_b/N_a)
printf("\n Qb= %0.0f cfm",Q_b)

disp("((p2/p1)_b)^((k-1)/k)-1=(T1a/T1b)*[((p2/p1)_a)-1]*((Nb/Na)^2)")
disp("On simplifying ((p2/p1)_b)=0.313*(T1a/T1b)")
disp("We obtain p2b=14.7*[1+0.313*(T1a/T1b)]^3.5=36.6 to 39.3 psia")
disp("Also Psb=rho_1b*Q_b*H_i/Eta={(p_1b/(R*T_1b))*Qb*Cp*T_1b*[(p2/p1)^((k-1)/k)-1]}/Eta")
disp("Psb=[(3.5*14.7*144*2700/(550*60))*0.313*(T1a/T1b)]/0.7")
disp("Psb=271*(T1a/T1b)=257.8 to 280.6hp")

disp("From rho_0*Q_dash=rho_1*Q,we have the flow rate measured at the standard condition,Q_dashb=(rho_1b/rho_0)*Qb=(T0/T1b)*Qb=2795 to 2568 cfm")
```

Scilab code Exa 6.3 C

```
clear all; clc;
//Answer of H_ib given in the book is 5830,however it is incorrect. The correct answer is found out to be 5837.4883

disp(”rho_a=p/(R∗T)”)
rho_a=(13.7*0.491*144)/(53.33*(-10+460))
printf(” rho_a= %0.5f lbm/ft^3”,rho_a)

disp(”Qb=Q∗(Nb/Na)”)
Q=(180/0.0403)*(12000/25000)
printf(” q= %0.0f cfm”,Q)

disp(”Hb=Ha∗((Nb/Na)^2)”)
disp(”we obtain”)
disp(”((p2/p1)^((k−1)/k)_b)=[((p2/p1)^((k−1)/k)_a)−1]∗((Nb/Na)^2)∗(T1a/T1b)+1”)
//let x=((p2/p1)^((k−1)/k)_b)
p2=34.5
p1=13.7
//let y=((k−1)/k)
y=0.2857
Nb=12000
Na=25000
T_1a=450
T_1b=535
x=[(p2/p1)^(y)-1]*((Nb/Na)^2)*(T_1a/T_1b)+1
printf(” ((p2/p1)^((k−1)/k)_b)=%0.4f\n”,x)

disp(”So p2b=((1.0585)^3.5)∗(p1b)”)
p_1b=30
p_2b=((1.0585)^3.5)*(p_1b)
printf(” p2b= %0.1f in.Hg”,p_2b)

disp(”H_ib=[(k∗R∗T_1b)/(k−1)]∗[(((p2/p1)^((k−1)/k)_b)−1]”)
k=1.4
R=53.33
```

```
T_1b=535
p2=36.6
p1=30
y=0.2857
H_ib=[(k*R*T_1b)/(k-1)]*[((p2/p1)^y)-1]
printf(" H_ib=%0.4f ft-lbf/lbm",H_ib)//Answer of H_ib given in the book is 5830,however it is incorrect. The correct answer is found out to be 5837.4883 on calculating

disp("rho_b*Qb=mb")
mb=(30*0.491*144)/(53.33*535)*2144
printf(" mb= %0.1f lbm/min",mb)

disp("Thus Psb=mb*Hib/Eta")
P_sb=159.4*5830/(60*550*0.70)
printf(" Psb= %0.1f hp",P_sb)
```

Scilab code Exa 6.4 C

```
clear all; clc;

Q_c=1000
N_a=3550
N_c=4000
Q_a=Q_c*(N_a/N_c)
printf("\n Qa=Qc*(Na/Nc)=%0.1f cfm",Q_a)

disp("H=Cp*T1*[(p2/p1)^((k-1)/k)-1]")
disp("Ha/Hc=((Na/Nc)^2)")
disp("Where ka=1.40,Cpa=0.24 Btu/lbm*degrees Farenheit,,T1a=530R,((ka-1)/ka)=0.2857 and kc=1.30")
disp("Cpc=0.20Btu/(lbm*degrees Farenheit),T1c=550R,((kc-1)/kc)=0.2307, we have:")
```

```
disp("(Cpa*T1a)*[[(p2/p1)^((k-1)/k)-1]]_a/{(Cpc*T1c)*[[(p2/p1)^((k-1)/k)-1]]_c}=((3550/4000)^2)")
//let x=(Cpa*T1a)*[[(p2/p1)^((k-1)/k)-1]]_a/{(Cpc*T1c)*[[(p2/p1)^((k-1)/k)-1]]_c}
x=((3550/4000)^2)
printf(" Thus the value is equal to %0.3f",x)

disp("Or")
disp("(0.24*530*[(p2/p1)^(0.2857-1]_a)/(0.20*550*[(19.7/17.7)^(0.2307)-1])=0.787")
disp("Hence ((p2/p1)^0.2857)_a=1+(0.787*0.025)/1.156=1.017")
disp("p2a=15.6 psia")
```

Scilab code Exa 6.5 C

```
clear all; clc;
//the answer of p02b given in the book is 94.1, however the right answer is 92.05 which is rounded off to 92.1 here

p_02b=90+0.5*0.00237*((500)^2)/144
printf("\n p02b= %0.1f psia",p_02b)

//let x=T02/T01
x=(480+460)/(60+460)
printf("\n T02/T01= %0.4f which is also =(94.1/14.7)^((0.2857)/(Eta_p)) ",x)//answer given in the book is 94.1,which is substituted
disp("From (0.2857/Eta_p)*ln(94.1/14.7)=ln(1.807) we can obtain the polytropic efficiency")
Eta_p=(log(94.1/14.7)/log(1.807))*0.2857
printf("Eta_p= %0.4f",Eta_p)

disp("0.85=[(4.5)^(0.2857)-1]/[(4.5)^(0.2857/Eta_p)
```

```
-1")
disp("Thus 0.5638/((4.5^(0.2857/Eta_p))-1)")
disp("We have polytropic efficiency for compressor A,Eta_pa=0.878.")
disp("Hence,compressor bB is moe efficient")
```

Scilab code Exa 6.6 C

```
clear all; clc;

disp("The specifications are N=1800 rpm=188.5 rad/s,Q=14000cfm=233.3 cfs,and sp=5 in.wg")
N=1800
Q=233.3
sp=5
Ns=N*(Q^0.5)/(sp^0.75)
disp("Ns=%0.0f rpm*(cfm^0.5)/(in water^0.75)")

disp("From Figure 5.1,selecting the air foil blade,we have Etas=0.80 and Ds=d2*(sp^0.25)/Q^0.5=0.33")

Q=14000
sp=5
Eta_s=0.8
P_s=Q*sp/(Eta_s*6356)
printf(" Ps=%0.2f hp",P_s)//incorrectly rounded off in the book

d2=0.33*(14000^0.5)/(5^0.25)
printf("\n d2=%0.0f in",d2)

tau=(13.7*550)/(1800*%pi/30)
printf("\n   =%0.0f lbf-ft",tau)

```

```
tau=40
s_s=10000
ds=[(16*tau)/(%pi*s_s)]^(1/3)
printf("\n The shaft diameter is found out to be %0.2f in",ds)
disp("Where s_s is the assumed maximum allowable shear stress of the shaft material.")
disp("Hence d_d is set as 0.75in and d_h=1.0in or rh=0.5in. Using the maximum W1 criteria,we ave  f1=35.2 degrees and r1=9.88 inches which is rounded off to 10 inches.")

disp("Also we have b1=5 inches and  b1= f1+i=37 degrees")
omega=188.5
r2=13/12
U2=omega*r2
printf(" To determine outlet dimensions we have U2=%0.1f ft/s",U2)

disp("For a straight blade we have dashb2=52 degrees, so try  b2=45 degrees")
disp("Zb=26 and mu_s=0.794")
disp("Since the static pressure is specified but the total pressure is needed in the Euler equation, the discharge flow is needed.")
disp("Setting b2=b1=5 incheswe can determine the values of A2 and A3")

r2=13
b2=5
A2=2*%pi*r2*b2/144
printf(" A2=%0.3f ft^2",A2)

A2=2.83
A3=1.5*A2
printf("\n The fan discharge area A3 is set as A3=1.5*A2=%0.2f ft^2",A3)
```

```
disp("Hence we have V3=Q/A3=54.8 ft/s")

sp=62.4*5/12
rho=0.00237
V3=54.8
tp=sp+(0.5)*rho*(V3^2)
printf(" tp=%0.2f lbf/ft^2",tp)

disp("Also Eta_t=Eta_s*(tp/sp)=Eta_imp*Eta_v*Eta_m and assuming Eta_v*Eta_m=0.95")
Eta_imp=((0.8*29.5)/26)/(0.95)
printf(" So we hae Eta_imp= %0.4f",Eta_imp)

disp("So from the Euler equation, we have (29.5/0.00237)=154.8*(204.2-(82.4/tan b2))")
disp(" _b2 =33.6 degrees")
disp("Since Zb and mu_s are related to  b2 ,we have to repeat the calculations")
disp("The new alues Zb=20 and mu_s=0.781 and  _b2 =33.9 degrees are obtained")
disp("Hence the final values are 20 and  _b2 =33.9 degrees")

disp("From equation(6.12) we have( d /dr)=(1/(2*tan f1)*[2*(r/r1)*(1/r1)]")
disp("Hence tan dash_b2=[dr/(r*d )_r2]=tan f1*((r1/r2)^2)")
tan_beta_dashb2=tan((35.2*%pi/180)*[(10/13)^2])
printf(" Thus the value of tan dash_b2= %0.3f",tan_beta_dashb2)//Answer f=given in the book is 0.417,however the more correct answer is 0.380
betab2dash=((atan(tan_beta_dashb2))*180/%pi)
printf("\n _dash_b2= %0.1f degrees",betab2dash)// Since value of tan 'b2 is different,  'b2 is different
disp("This value is smaller than  b2 which is expected from 6.13c")
```

Scilab code Exa 6.7 C

```
clear all; clc;

disp("Inlet Configuration selection: Mr1,t=0.75 and
    f1=25 degrees")
M_r1t=0.75
beta_f1=25*%pi/180
M_1t=M_r1t*sin(beta_f1)
printf(" M_1t=%0.3f",M_1t)

disp("T1=To1/(1=((k−1))*(M_1t^2)/2")
T1=530/(1+0.2*(0.317^2))
printf("\n Thus the value of T1= %0.1fR",T1)

a1=(1.4*53.33*32.2*519.6)^0.5
printf("\n a1= %0.2f ft/s",a1)//answer provided here
    is more accurate

V_1t=0.317*1117.6
printf("\n V1=%0.1f ft/s",V_1t)

W_1t=0.75*1117.6
printf("\n W_1t= %0.1f ft/s",W_1t)

U_1t=[(838.2^2)-(354.3^2)]^0.5
printf("\n U_1t= %0.1f ft/s",U_1t)

omega=1623
U_1t=759.6
r_1t=U_1t/omega
printf("\n So we have r_1t= %0.3f ft=5.6in",r_1t)

//let x=k/k−1
```

```
x=3.5
po1=14.7
T_1=519.6
T_o1=530
p1=po1*[(T_1/T_o1)^x]
printf(”\n So we have p1= %0.1f psia”,p1)

p1=13.7
R=53.33
T1=519.6
rho1=(p1*144)/(R*T_1)
printf(”\n rho1= %0.4f lbm/ft^3”,rho1)

m=17
rho1=0.0713
V1=354.3
A1=m/(rho1*V1)
printf(”\n A1= %0.3f ft^2=96.9 in ^2,assuming uniform inlet flow.\n\n”,A1)

disp(”From pi*[(r_1t^2)-(r_1h^2)]=A1”)
disp(”We have r_1h={[(r_1t^2)-A1]/pi}^0.5=0.72 in”)
disp(”U_1h=97.0 ft/s”)

disp(” _f1 ,h=taninverse(V_1h/U_1h)”)
V_1h=354.3
U_1h=97
beta_f1h=(atan(V_1h/U_1h))*180/%pi
printf(”  f1= %0.1f degrees”,beta_f1h)

disp(”(B) Outlet Configuration From”)

Cp=0.24
To1=530
//let y=(k-1)/k=0.2857
y=0.2857
//let m=po2/po1
m=2.5
```

```
H_ad=Cp*To1*778*[(m)^(y)-1]
printf(" H_ad=H_ad=Cp*To1*778[(po2/po1)^((k-1)/k)-1] %0.0f ft-lbf/lbm ",H_ad)

m=17
rho1=0.0713
Q1=m/rho1
printf("\n Q1=%0.1f ft^3/s",Q1)

N=15500
H_ad=29614
Q1=238.4
Ns=N*(Q1^0.5)/((H_ad)^0.75)
printf("\n We obtain specific speed %0.0f rpm*{(ft^3/s)^0.5}(ft-lbf/lbm)^0.75 ",Ns)

disp("Fom figure 6.7 we have estimated Eta_c=0.87 and Ds=D2*(H_ad)/(Q1^0.5)=1.50")
D2=1.5*(238.4^0.5)/(29614^0.25)
printf("\n D2=%0.4f ft=21.2 inches or r2=10.6 in. and U2=r2*omega=1433.7 ft/s",D2)

disp("Referring to figure 6.16c,we have T_sso3=T_o1*(po3/po1)^((k-1)/k)")
//((k-1)/k)=x
x=0.2857
T_o1=530
//let l=po3/po1
l=2.5
T_sso3=T_o1*(l^x)
printf(" T_sso3= %0.1f R ",T_sso3)
disp("From Eta_c=(T_sso3-(T_o1))/(To3-To1) we have To2=To3")
//let l=To2/To3
l=(1/0.87)*(688.6-530)+530
printf(" To2/To3 %0.1fR",l)
disp("Also from Etam=U2*Vu2/[Cp*(T_o2-T_o1)]")

```

```
Vu2=0.95*0.24*778*32.2*(712.3-530)/(1433.7)
printf(" With the estimated Eta_m=0.95,Vu2=%0.1f ft/s",Vu2)

disp("Flow coefficient   =Vm2/U2=0.30 ")
Vm2=0.3*1433.7
printf(" Vm2=%0.1f ft/s",Vm2)

disp("W2=[Vm2^2+(U2-Vu2)^2]^0.5=827.9 ft/s")
disp("V2=[Vu2^2+Vm2^2]^0.5=844.1 ft/s")

W1t=838.2
W2=827.9
Df=W1t/W2
printf(" Hence we have diffusion factor Df=%0.3f. The value is less than 1.9 which is okay.",Df)

disp("The impeller efiiciency can be estiamted form the losses fraction X=(1-Eta_imp)/(1-Eta_c) is approximately =0.6 ")
Eta_imp=1-0.6*(1-0.87)
printf("\n Eta_imp %0.3f",Eta_imp)

disp("Hence from Eta_imp=(T_so2-T_o1)/(T_o2-T_o1),we  have T_so2=T_o1+Eta_imp*(To2-T_o1)=698R and po2=po1*(T_so2/T_o1)^(k/(k-1))")
po1=14.7
T_so2=698.1
T_o1=530
//Let x=(k/(k-1))
x=3.5
po2=po1*(T_so2/T_o1)^x
printf(" po2=%0.2f psia ",po2)

disp("Then from the energy equation we have T2=T_o2-V2^2/(2*Cp)=653.0R")
disp("Hence p2=p02*(T2/To2)^(k/(k-1))=28.4psia and rho2=p2/(R*T2)=0.117lbm/ft^3")
```

```

disp("Selecting Zb=16 and using the Stanitz fromula for the slip coefficient we have Vdash_u2=Vu2+0.63*pi*U2/Zb")
Vu2=726.3
U2=1433.7
Zb=16
 Vdash_u2=Vu2+0.63*%pi*U2/Zb
printf(" Vdash_u2= %0.1f ft/s",Vdash_u2)

disp("tan _b2=Vm2/(U2-Vdash_u2)")
Vm2=430.1
U2=1433.7
Vdash_u2=903.6
tan_beta_b2=Vm2/(U2-Vdash_u2)
printf(" tan _b2=%0.2f ",tan_beta_b2)

betab2=(atan(tan_beta_b2))*180/%pi
printf("\n  _b2= %0.0f degrees",betab2)

disp("With blade thickness t=0.15,contraction factor is determined")
Zb=16
t=0.15
betab2=39*%pi/180
D2=21.3
epsilon2=1-[(Zb*t)/(sin(betab2))]/(%pi*D2)
printf(" Thus epsilon2= %0.2f",epsilon2)

disp("Hence from the mass equation we can determine b2")
b2=17/(0.117*430.1*%pi*1.765*0.94)
printf(" b2=%0.4f=0.7 8inch",b2)
```

Scilab code Exa 6.8 C

```
clear all; clc;

disp("Using figure 6.7 the specific speed Ns=N(V1^0.5)/(H_ad^0.75) should be calculated based on the inlet volumetric  flow rate V1 and the adiabetic head per stage H_ad")
p1=14.7
R=53.3
T1=530
rho1=p1*144/(R*T1)//144 is conversion factor.the actual formula is rho1=p1/(R*T1)
printf(" From rho1=p1/(R*T1) =%0.3f lbm/ft^3, we have V1",rho1)

V1=100/0.075
printf("\n Thus V1= %0.0f ft^3/s.",V1)

disp("Also from equation (A.3), we have total adiabetic head  H_ad=Cp*T1*[(pe/pi)^((k-1)/k)-1]")
Cp=0.24
T1=530
pe=50
pi=14.7
//Let y= (k-1)/k
y=0.2857
H_ad=Cp*T1*778*[{(pe/pi)^(y)}-1]//778 is conversion factor
printf(" Thus  H_ad= %0.0f lbf-ft/lbm \n",H_ad)

disp("The specific speeds for different number of stages are calculated as follows ")

Ns=4800*(1333^0.5)/(41436^0.75)
printf(" For n=1 , Ns=4800*(1333^0.5)/(41436^0.75)= %0.0f ",Ns)

Ns=4800*(1333^0.5)/(13812^0.75)
```

```
printf("\n For n=3 , Ns=4800*(1333^0.5)/(13812^0.75)=%0.2f ",Ns)

Ns=4800*(1333^0.5)/(10359^0.75)
printf("\n For n=4 , Ns=4800*(1333^0.5)/(10359^0.75)=%0.0f ",Ns)

Ns=4800*(1333^0.5)/(6906^0.75)
printf("\n For n=6 , Ns=4800*(1333^0.5)/(6906^0.75)=%0.0f ",Ns)

Ns=4800*(1333^0.5)/(5179^0.75)
printf("\n For n=8 , Ns=4800*(1333^0.5)/(5179^0.75)=%0.0f ",Ns)

disp("Reading the curves in figure 6.7,the best efficient point is around Ns=280 with Eta=0.90")
disp("ds=D*(H_ad^0.25)/(V1^0.5)=0.7")
disp("Hence 8 stage mixed flow impellers are selected.")

D=0.7*(1333^0.5)/((41436/8)^0.25)
printf(" The impeller diameter is calculated to be = %0.1f ft",D)

m=100
H_ad=41436
Eta=0.9
Ps=m*H_ad/(Eta*550)//converting units
printf("\n The total required shaft power Ps=m*H_ad/(Eta)=%0.0f hp",Ps)
```

Scilab code Exa 6.9 C

```
clear all; clc;
```

```

disp("The inlet specific volume is calculated from the ideal gas equation")
R=53.3
T1=580
p1=65
nu1=(R*T1)/(144*p1)
printf(" nu1=%0.3f ft^3/lbm=",nu1)

disp("Q1=m*v1=4594 cfm")

R=53.3
T1=580
//let y=(n/(n-1))
y=2.625
p2=250
p1=65
H_oa=R*T1*(y)*[(p2/p1)^(1/y)-1]
printf(" The overall adiabetic head is calculated as H_o/a= %0.0f ft-lbf/lbm",H_oa)

y=(0.75*1.4)/(1.4-1)
printf("\n Where n/(n-1)=(Eta_p*k)/(k-1)=%0.3f",y)

disp("From figure 6.7 , a centrifugal compressor with speed N=10000rpm is appropriate for the present application")

disp("To use figure 6.7,the specific speed can be calculated from Ns=N*(V1^0.5)/(H_ad^0.75)")
V1=4954/60
printf(" Where V1= %0.1f cfs",V1)
disp("H_ad=(H_o/a)/Eta_s is the head for each stage .")
disp("Selecting the number of stages to be 2,4, and 6,the head for each stage and specific speed  can be calculated ,then the total-to=total adiabetic efficiencies can be read ")
```

```
disp(”The required shaft horse power can be
   calculated with the volumetric and mechanical
   efficiencies assumed to be 0.98 and 0.95
   respectively”)
disp(”That is Ps=(m*(H_o/a)/(33000*Eta_ad*Eta_v*
   Eta_m)”)

H_oa=54417
V1=82.6
Eta_v=0.98
Eta_m=0.95
N=10000

StageNo=[2 4 6];
Eta_ad=[0.72 0.83 0.87];


H_ad= zeros(1,length(StageNo));
Ns = zeros(1,length(StageNo));
Ps = zeros(1,length(StageNo));

for i = 1: length(StageNo)


    H_ad(i) =H_oa/(StageNo(i));
    Ns(i) =N*(V1^0.5)/(H_ad(i)^0.75);
    Ps(i) = (m*H_oa)/(33000*Eta_ad(i)*Eta_v*Eta_m);
end

disp(”StageNo    H_ad              Ns         Eta_ad
   Ps”)
disp(”          (ft-lbf/lbm)                              (
   hp)”)
table = [StageNo' H_ad' Ns' Eta_ad' Ps'];
disp(table)
```

Scilab code Exa 6.10 C

```
clear all; clc;

disp("From table 6.1 at 1.25 SP,the rotating speeds
   for Q1=11172cfm and Q2=12103cfm are N1=474rpm and
    N2=483 rpm respectively")
Ns=474+[(483-474)*(12000-11172)]/[12103-11172]
printf(" Hence the rotating speed for the selected
   fan is determined by inetrpolation %0.0f rpm\n\n"
   ,Ns)

disp("Select a few data points around 482 rpm from
   table 6.1 as:")
Q=[14896 12103 11172  11172 10241 7448];
N=[490 448 436 474 466 360];
SP=[1.0 1.0 1.0 1.25 1.25 0.75];
BHP=[3.66 2.67 2.40 2.97 2.75 1.2];

disp(" Q(cfm)   N(rpm)   SP(in.wg)   BHP(hp)")
table=[Q' N' SP' BHP']
disp(table)

disp("Convert them into conditiond of 482 rpm
   according to the similarity laws,resulting in")
Q1=[14653 13021 12350 11360 10593 9972];
SP1=[0.967 1.16 1.22 1.29 1.34 1.34];
BHP1=[3.5 3.20 3.24 3.12 3.04 2.88];
table1=[Q1' SP1' BHP1']
disp(" Q(cfm)   SP(in.wg)   BHP(hp)")
disp(table1)

disp("The system curve can be calculated from the
   following table")
```

```

Q2=[10000 11000 12000 13000 14000];
H2=[0.87 1.05 1.25 1.47 1.70];

sqrQ2 = zeros(1,length(Q2));

for i = 1: length(Q2)


    sqrQ2(i) = [Q2(i)]^2;

end


table2=[Q2' H2']
disp("  Q(cfm)  H(in.wg)")
disp(table2)

disp("The system curve can be calculated from H versus Q^2. It is plotted as shown.")
//The system curve has not been provided in the book for this numerical. However they have mentioned that the parameters for the curve are H and Q^2, and as such has been plotted here.
plot(sqrQ2,H2)
xlabel("Q^2 ")
ylabel("H")
set(gca(),"grid",[1 1])
xtitle("System curve: H versus Q squared")
```

Chapter 7

Axial Flow Compressors

Scilab code Exa 7.1 AFC

```
clear all; clc;

disp("From (poe/poi)=[(Toi+ns*deltaTo)]^(k*eff*p/(k-1))")
disp("From the above mentioned equation we can find out the value of deltaTo")
delta_To=((8^(1/(3.5*0.87)))-1)*530/7
printf("deltaTo= %0.1f degrees Farenheit",delta_To)

Q=450
r_m1=9
b=3
V_a1=(Q*144)/(2*%pi*r_m1*b)
printf("\n Thus Va1 = %0.0f fps",V_a1)

N=12000
U=(N*%pi*9)/(30*12)
printf("\n N= %0.1f fps",U)

disp("deltaho=U*Va*(tan 1-tan 2) and R=( /2)*(tan 1+tan 2")
```

```
//let y= tan 1-tan 2
y=[(0.24*778*74.2*32.2)/(942.5*382)]
printf("\n Thus tan 1-tan 2= %0.2f",y)

//let x=tan 1+tan 2
x=(0.5*2*942.5/382)
printf("\n Thus tan 1+tan 2= %0.3f",x)

disp("Hence we get tan 1 =1.853")
tanbeta1=1.853
beta_1=(atan(tanbeta1))*180/%pi
printf("\n The value of  1= %0.1f degrees",beta_1)
disp("Also tan 2 =0.613")
tanbeta2=0.613
beta_2=(atan(tanbeta2))*180/%pi
printf("\n The value of  2=  1= %0.1f degrees",beta_2)

disp("Ps=m*Cp*ns*deltaTo/etam")
P_s=(0.075*450*0.24*778*7*74.2)/(550*0.95)
printf("\n The total power required is Ps= %0.0f hp",P_s)

disp("The adiabetic efficiency is given as ((poe/poi)^(((k-1)/k))-1/((Toe/Toi)-1)")
ETA_ad=0.811/0.979
printf("\n Thus adiabetic efficiency is %0.4f",ETA_ad)//answer given in the book is 0.827,but this is more accurate

disp("ETAc=ETAm*ETAad")
ETA_m=0.95
ETA_ad=0.827
ETA_c=ETA_m*ETA_ad
printf(" Hence ETAc= %0.3f ",ETA_c)
disp("Thus ETAc=78.6%")
```

Scilab code Exa 7.2 AFC

```
clear all; clc;

r_h=15
r_t=24
r_m=((r_h^2+r_t^2)/2)^0.5
printf("rm= %0.0f in",r_m)

N=6000
r_m=20
U_m=N*%pi*r_m/(12*30)
printf("\n U_m= %0.2f ft/s",U_m)

disp("We have psia=lamda*psi=lambda*phi*(tan m1-
    tan m2)")
//let x=tan m1-tan m2
x=(0.24*778*32.2*35)/(0.92*1047.2*450)
printf("\n Hence we can find out tan m1-tan m2= %0
    .3f",x)

disp("From equation 7.2B for Rm=0.5 we have  m1=
     m2")
disp("We get values of tan m1+tan m1=2.325 and
    tan m2+tan m2=2.325")

disp("Hence we have tan m1-tan m1=0.485")

tanalpham1=0.92
alpham_1=((atan(tanalpham1)))*180/%pi
printf("\n Thus  m1= %0.1f degrees",alpham_1)

tanalpham2=1.405
alpham_2=((atan(tanalpham2)))*180/%pi
```

```
printf("\n Thus  m2= %0.2f degrees",alpham_2)

disp("To determine the flow angles at the hub and tip,we use the free vortex condition of Vur=const, or rhtan h=rttan t=rmtan m.Hence the flow angles can be determined.")

tanalphah1=0.92*20/15
printf("\n tan h1= %0.3f",tanalphah1)
alpha_h1=((atan(tanalphah1))*180/%pi
printf("\nThus  h1= %0.1f degrees",alpha_h1)

tanalphat1=0.92*20/24
printf("\n\n tan t1= %0.3f",tanalphat1)
alpha_t1=((atan(tanalphat1))*180/%pi
printf("\n Thus  t1= %0.1f degrees",alpha_t1)

tanalphah2=1.405*20/15
printf("\n\n tan h2= %0.3f",tanalphah2)
alpha_h2=((atan(tanalphah2))*180/%pi
printf("\n Thus  h1= %0.1f degrees",alpha_h2)

tanalphat2=1.405*20/24
printf("\n\n tan t2= %0.3f",tanalphat2)
alpha_t2=((atan(tanalphat2))*180/%pi
printf("\n Thus  h1= %0.1f degrees",alpha_t2)

disp("The degree of reaction at the hub and tip can be determined.")
Rh=1-((1-0.5)/((15/20)^2))
Rt=1-((1-0.5)/((24/20)^2))
printf("\n Rh= %0.2f",Rh)
printf("\n Rt= %0.2f",Rt)
```

Scilab code Exa 7.3 AFC

```
clear all; clc;

disp("From the previous numerical wee have  m1= m2=54.5 degrees,  tan m1=1.405")
disp(" m2= m1=42.6 degrees. Thus tan m2=0.92")

disp("tan m1-tan m2=1.55(1+1.5*(s/c)),thus we can determine s/c")
//let x= s/c
x=[1.55/(1.405-0.92)-1]/1.5
printf("Thus (s/c)= %0.2f",x)

disp("Also b/c=3,we have c=(rt-rh)/3")
rt=24
rh=15
c=(rt-rh)/3
printf("\n c= %0.0f in",c)

s=1.47*c
printf("\n Hence we determine s to be equal to %0.1f in",s)

rm=20
Zb=2*%pi*rm/s
printf("\n Zb= %0.0f",Zb)

disp("The blade angles can be estimated from  b1= m1-i and  b2= m2- ")
disp("Where i=3 degrees and  =m*  *((s/c)^0.5)")

//let n=a/c
n=0.5
disp("m=0.23*((2*(a/c))^2)+0.1*( m2/50)")
disp("  = m1- m2")
thita=11.9
m=0.23+(0.1*42.6/50)//for circular blade
printf("\n m= %0.3f",m)
m=0.315
```

```
x=1.47
delta=m*thita*(x^0.5)
printf("\n   = %0.1f degrees",delta)

beta_b1=54.5-3
printf("\n  b1= %0.1f degrees",beta_b1)

beta_b2=42.6-4.5
printf("\n  b2= %0.1f degrees",beta_b2)
```

Scilab code Exa 7.4 AFC

```
clear all; clc;

disp("We have psia=lamda*psi=lambda*phi*(tan m1-tan m2) and R=0.5*  (tan 1+tan 2) we can obtain the values of tan 1 and tan 2")
//let x=tan m1-tan m2
x=0.35/(0.92*0.5)
printf("\n tan m1-tan m2= %0.3f",x)

//let y=tan 1+tan 2
y=2*0.5/0.5
printf("\nThus tan 1+tan 2= %0.3f",y)

disp("Hence tan 1 =1.38")
tanbeta1=1.38
beta_1=((atan(tanbeta1)))*180/%pi
printf("\nThus the value of  1 is equal to %0.1f degrees",beta_1)

disp("tan 2 =0.619")
tanbeta2=0.619
beta_2=((atan(tanbeta2)))*180/%pi
printf("\nThus the value of  1 is equal to %0.1f
```

```
degrees",beta_2)

disp("For each stage we have psi=Cp*deltaTos/((Um)^2)")
delta_T_os=0.35*(920^2)/6012
printf("\nHence deltaTos= %0.1f R",delta_T_os)

Cp=0.24*778*32.2
printf("\nWhere Cp = %0.0f ft-lbf/slug",Cp)

disp("For overall compressor form equation 47.4 we have (Poe/poi)=[(1+deltaToe/Toi)]^(k*eff*p/(k-1))")
delta_T_oe=530*[(4.5^(0.2857/0.9))-1]
printf("\nThus deltaToe= %0.0f R",delta_T_oe)

disp("The number of stages can be calculated as  ns=deltaToe/deltaTos")
delta_T_oe=324
delta_T_os=49.3
ns=delta_T_oe/delta_T_os
printf("\nThus ns= %0.2f",ns)
disp("ns is approximately equal to 7")

disp("Hence the actual values are: ")
delta_T_oe=7*49.3
printf("deltaToe= %0.1f R",delta_T_oe)

//let f=poe/po1
f=(1+(345.1/530))^(0.9*3.5)
printf("\n poe/po1= %0.2f",f)

disp("The adiabetic efficiency is given as ((poe/poi)^(((k-1)/k))-1/((Toe/Toi)-1)")
//let  k-1/k=d
d=0.2857
f=4.85

```

```
ETA_ad=((f^(d))-1)/((345.1/530))
printf("\nETAad= %0.4f",ETA_ad)
//let r=ETAd*100
r=ETA_ad*100
printf("\n Thus ETAad= %0.2f percent",r)
```

Scilab code Exa 7.5 AFC

```
clear all; clc;

disp("Assume constant axial flow velocity Va=500 ft/s , no prewhirl and hence V1=Va for the first stage and frre vortex conditions for all stages.")

disp("1. First Stage")

T1=530-((500^2)/(2*6012))
printf("T1= %0.1f R",T1)

p1=14.7*((509.2/530)^3.5)
printf("\n p1= %0.2f psia",p1)

rho_1=(12.78*144)/(53.33*509.2)
printf("\n rho_1= %0.5f lm/ft^3",rho_1)

disp("With a selected nu=rh/rt=0.45, A=m/(rho_1*Va)")
m=65
rho_1=0.0677
Va=500
A=m/(rho_1*Va)
printf("\n A= %0.2f ft^2 = 276.5in^2",A)

disp("A=pi*(r_t^2)*(1-nu^2)")
```

```
A=276.5
nu=0.45
r_t=sqrt(A/(%pi*(1-(nu^2))))
printf("\n r_t= %0.1f in",r_t)

disp("rm=7.6in")

disp("Ut=rt*omega")
N=15000
omega=N*%pi/30
rt=10.5/12//in feet
Ut=rt*omega
printf("\n Ut %0.1f ft/s",Ut)

rh=4.7/12//in feet
Uh=rh*omega
printf("\n Uh= %0.1f ft/s",Uh)

rm=7.6/12//in feet
Um=rm*omega
printf("\n Um= %0.1f ft/s",Um)//answer given in the book is 996.6,however 994.8 is more accurate

disp("Without inlet whirl flow,we have Wt=(Ut^2+Va^2)^0.5")
Ut=1374.4
Va=500
Wt=sqrt(Ut^2+Va^2)
printf("\n Thus Wt = %0.0ft/s",Wt)

Uh=615.2
Va=500
Wh=sqrt(Uh^2+Va^2)
printf("\n Thus Wh = %0.1ft/s",Wh)

Um=996.6//This is the answer substituted in the book,although as mentioned earlier 994.8 is more accurate.
```

```
Va=500
Wm=sqrt(Um^2+Va^2)
printf("\n Thus Wm = %0.1ft/s",Wm)

tanbeta1m=Um/Va
printf("\n tan 1m= %0.2f",tanbeta1m)

beta1m=((atan(tanbeta1m)))*180/%pi
printf("\n  1m= %0.1f degrees",beta1m)

disp("With a1=(k*R*T1)^0.5=1309ft/s,the relative Mach numbers can be determined.")
Wt=1463
a1=1309
M_rt=Wt/a1
printf("\n M_rt= %0.2f",M_rt)

Wh=792.8
M_rh=Wh/a1
printf("\nM_rh= %0.3f",M_rh)

Wm=1115.0
M_rm=Wm/a1
printf("\n M_rm= %0.2f",M_rm)

disp("Hence the relative flow at the leading edge is transonic,and a supersonic blade might be needed.")
disp("From the previous sum,to achieve a pressure ratio of 4.5,we have deltaTos=324/7=46.3R.")
disp("So deltaTos=45R is selected at the first stage.")
disp("From Cp*deltaTos=lambda*Um*Va*(tan 1m-tan 2m),with lambda=0.95,we obtain tan 2m=1.42. Thus 2m=54.8 degrees")

tanbeta1=1.99
tanbeta2=1.42
```

```
Va=500
Um=996.6
R=(Va/(2*Um))*(tanbeta1+tanbeta2)
printf(”\n R=(Va/(2*Um))*(tanbeta1+tanbeta2)= %0.3f”,R)

disp(”We have nu=(1-R)^0.5”)
nu=sqrt(1-R)
printf(”\n nu= %0.2f”,nu)

disp(”This is less than the selected value and is acceptable.”)
beta1=63.3
beta2=54.8
deHaller=cos(beta1*%pi/180)/cos(beta2*%pi/180)
printf(”\n Also checking the deHaller number W2/W1=cos 1/cos 2=%0.2f >0.70,it is also acceptable”,deHaller)

disp(”Before proceeding to the next stages,the following parameters have to be specified. The summation of deltaTos should add upto 324degrees. So the following arramgement is chosen”)
Stage_number=[1 2 3 4 5 6 7 ];
deltaTos_R=[45 46 47 47 47 47 45];
lambda=[0.95 0.93 0.90 0.89 0.88 0.86 0.85];
R=[0.855 0.8 0.7 0.63 0.60 0.55 0.5];
table=[Stage_number’ deltaTos_R’ lambda’ R’]
disp(”The table from left to right has values of Stagenumber deltaTos lamdbda and R”)
disp(table)

disp(”2.Second Stage”)

To1=530+45
printf(”To1= %0.0f R”,To1)

po1=14.7*((1+(0.9*45/530))^3.5)
```

```
printf("\n po1= %0.0f psia",po1)

disp("With the specified values of deltaTos,lamda
    and R,equations 7.1 and 7.2A can be solved for
    tan 1 and tan 2.")
disp("Hence  1 =62.1 degrees and  2 =52.4 degrees,
    where W2/W1=0.76>0.70")
beta1=62.1*%pi/180//converting to radians
V1=[(Va^2)+(Um-(Va*tan(beta1)))^2]^0.5
printf("Also we have V1=[(Va^2)+(Um-(Va*tan(beta1)))
    ^2]^0.5= %0.2f ft/s",V1)//answer in the book is
    502.6,however the value found out here is more
    accurate

Cp=6012
V1=502.6
T1=To1-((V1^2)/(2*Cp))
printf("\nT1= %0.0f R",T1)

po1=19
T1=554
To1=575
p1=po1*((T1/To1)^3.5)
printf("\np1= %0.1f psia",p1)

disp("rho1= p1/(R*T1)= 0.0813 lb_m/ft^3")



disp("A=m/(rho1*Va)=230")
disp("A is also = 2*pi*r_m*b")
disp("Where b=rt-rh and rm is the same as that for
    the first stage. Hence we have rt=10 in,rh=5.2 in
     and nu=0.52,which is greater than nu_min(0.447)
    ")

disp("3.Third to Seventh stage")
disp("The calculation procedure for these stages
```

```
will be similar to the second stage. The calculations have not been repeated in the book, and hence the same is done here.")
disp("The results are as follows")

Stagenumber=[1 2 3 4 5 6 7];
To1=[530 575 621 668 715 762 809];
po1=[14.7 19 24.3 30.5 37.9 46.3 55.9];
rt=[10.5 10 9.6 9.3 9.1 8.9 8.8];
rh=[4.7 5.2 5.6 5.9 6.1 6.3 6.5];
rm=[7.6 7.6 7.6 7.6 7.6 7.6 7.6 ];
beta1=[63.3 62.1 59.7 57.5 56.5 54.7 52.4];
beta2=[54.9 52.3 47.2 43.2 41.4 38 34.8]
table2=[Stagenumber' To1' po1' rt' rh' rm' beta1' beta2']
disp("Stageno. To1      po1      rt      rh      rm      beta1      beta2")
disp(table2)

disp("The final discharge stagnation pressure can also be checked with the flow across the last stage such that poe=po3=po1(1+ETAs*(deltaTos/To1))^(k/(k-1))")
po1=55.9*(1+(0.9*45/809))^3.5
printf("po1= %0.1f psia",po1)
//let n=poe/poi
n=66.3/14.7
printf("\n This checks with poe/poi = %0.2f",n)
```

Scilab code Exa 7.6 AFC

```
clear all; clc;

disp("We have psi=lambda*[1−  *(tan 1+tan 2)] and R=0.5+[(  /2)*(tan 2−tan 1)]")
```

```
disp("We have tan 1+tan 2=(1-psi/lamda)=1.01")
disp("tan 1-tan 2=(1-2R)/  =-0.545,or psi=lambda*(1-1.01*  ) and R=0.5+0.272*   Hence  dash=0.495,assuming lamda to be constant we can determine the values of psi_dash and R_dash")

lambda=0.9
//Let (tanalpha1+tanbeta2)=x
x=1.01
phi_dash=0.495
psi_dash=lambda*[1-(phi_dash*(x))]
printf("\n psi_dash= %0.2f",psi_dash)

//Let= 0.5*(tanbeta2-tanalpha1=y
y=0.272
R_dash=0.5+[(phi_dash*0.272)]
printf("\n R_dash= %0.3f",R_dash)
```

Chapter 8

Gas Turbines

Scilab code Exa 8.1 GT

```
clear all; clc;

disp("From ETAad=(1-((p0e/p0i)^(ETAs*(k-1)/k)))
   /(1-((p0e/p0i)^(k-1)/k)))")
ETA_ad=(1-((14.7/200)^(0.85/3.5)))/(1-(14.7/200)
   ^(0.2857))
printf("\n ETAad= %0.3f",ETA_ad)

disp("T_soe/T_0i=((p0e/p0i)^((k-1)/k))")
//let T_soe/T_0i=w
w=(14.7/200)^0.2857
printf("\n T_soe/T_0i= %0.4f",w)

T_soe=0.4743*(1800+460)
printf("\n T_soe= %0.0f R",T_soe)

disp("ETAad=(T_0i-T_0e)/(T_0i-T_soe)=0.893")
T_0i=T_soe/w//since T_soe/T_0i=w
T_0e=T_0i-(ETA_ad*(T_0i-T_soe))
printf(" Thus T_0e= %0.0f R=739 degrees Farenheit",
   T_0e)
```

```

disp("Also for impulse turbine, we have  2= 3. Hence from delta_H0=Um*(V_u2-V_u3)=Um*[Um+Va*tan 2 -(Um-Va*tan( 3))]=2*Um*Va*tan ")
delta_h0=2*750*400*tan(50*%pi/180)
printf("\n delta_h0= %g is approximately equal to 7.15*10^5 ((ft/s)^2)",delta_h0)
//Let 0.24*778*32.2*delta_T0=u
u=7.15*10^5
delta_T0=u/(0.24*778*32.2)
printf("\n\n Or 0.24*778*32.2*delta_T0=7.15*10^5,we have temperature rise per stage = %0.0f degrees Farenheit",delta_T0)

n_s=(1800-739)/119
printf("\n Hence the number of stages n_s= %0.2f is approximately equal to 9",n_s)
```

Scilab code Exa 8.2 GT

```
clear all; clc;

disp("Referring to figure 8.3,we have T_s2=T_01*((p2/p01)^((k-1)/k))")
T_01=2860
p2=180
p01=250
k=1.4//k=(Cp/Cv)
T_s2=T_01*((p2/p01)^((k-1)/k))
printf(" T_s2= %0.0f R",T_s2)

disp(" From  _s=(h2-hs2)/((V_2^2)/2),we have Cp*(T2-Ts2=  _s*(V_2^2)/2.Combining with Cp*(T_02-T_2)=((V_2^2)/2),where T02=T01, we have Cp*(T_02-Ts2)=(1+ s)*((V_2^2)/2)")
```

```
disp("V2=[2*Cp*(T_02-T_s2)/(1+  s)]^0.5")
T_02=T_01
Cp=0.24*778*32.2
epsilon_s=0.07
T_s2=2604
V2=[2*Cp*(T_02-T_s2)/(1+epsilon_s)]^0.5
printf(" V2= %0.0f ft/s",V2)

V2=1696
alpha2=65*%pi/180//converting to radians
V_u2=V2*sin(alpha2)
printf("\n Hence we have V_u2=V2*sin(  2) = %0.0f ft/s",V_u2)

Va=V2*cos(alpha2)
printf("\n Va=V2*cos(alpha2)= %0.1f ft/s",Va)

disp("T2=T_02-(V_2^2)/(2*Cp)")
T_02=2860
V2=1696
Cp=0.24*778*32.2
T2=T_02-(V2^2)/(2*Cp)
printf(" Hence we have T2= %0.0f R ",T2)

disp("Since V1=Va,we have T1=T_01-((V1^2)/(2*Cp))")
V1=716.8
T_01=2860//2860R
T1=T_01-((V1^2)/(2*Cp))
printf("T1= %0.0f R",T1)

disp("From delta_E=Cp*delta_T0s=U*(V_u2+V_u3)=U*V_u2, we have U=Ps/(m*V_u2)")
Ps=375*550*32.2//converting unit of Ps
m=3
V_u2=1537
U=Ps/(m*V_u2)
printf("U=%0.0f ft/s",U)

```

```
disp("  =Va/U")
Va=716.8
U=1440
phi=Va/U
printf("  =%0.3f",phi)

tanbeta3=U/Va
printf("\n tan 3= %0.2f",tanbeta3)

beta3=((atan(tanbeta3))*180/%pi)
printf("\n  3= %0.1f degrees",beta3)

alpha3=0
phi=0.498
alpha2=65*%pi/180
R=1+((phi/2)*(tan(alpha3)-tan(alpha2)))
printf("\n R= %0.3f",R)

disp("Also from the velocity diagram in figure 8.4, we have tan 2=tan 2 -(1/ )=0.136,so  2 =7.8 degrees")
disp("Similarly we have W3=Va/cos 3 =1606 ft/s and W2=Va/cos 2 =723.5 ft/s")
disp("Across the rotor we have h2+(W2^2)/2=h3+(W3^2)/2. Hence T3=T2+(W2^2)-(W3^2)/(2*Cp)=2450R")
disp("We have Ts3=T3- r*(W3^2)/(2*Cp)=2424R")
disp("Also p3=p2*(Ts3/T2)^(k/(k-1))=136.9 psia")
ETAs=(1+(0.12*(1606^2)+0.07*(1696^2)*(2450/2621))/(2*0.24*778*32.2*(2817-2450)))^-1
printf(" From equation 8.2 we have ETAs= %0.4f",ETAs)

//Let j=0.498/2
j=0.498/2
//Let k=0.12*[(sec(63.5*%pi/180))^2]
k=0.12*[(sec(63.5*%pi/180))^2]
//Let l=0.07*(2450/2621)*[(sec(65*%pi/180))^2]
l=0.07*(2450/2621)*[(sec(65*%pi/180))^2]
```

```
//let m=tan(63.5∗%pi/180)+tan(7.8∗%pi/180)
m=tan(63.5*%pi/180)+tan(7.8*%pi/180)

ETAs=[1+((j*(k+1))/m)]^-1
printf("\n From equation 8.3 we have ETAs= %0.4f",ETAs)

disp("Also ETAs can be calculated from ETAs=(T_01−T_03)/(T_01−T_ss03)")
disp("We have T_03=T3+V3^2/(2∗Cp)")
disp("p03=p3∗(T_03/T3)^(k/(k−1))")
disp("T_ss03=T_01∗(p_03/(p_01)∗((k−1)/k))")
ETAs=(2860-2493)/(2860-2450)
printf(" Hence we have ETAs= %0.3f",ETAs)
```

Scilab code Exa 8.3 GT

```
clear all; clc;

disp("Use the velocity diagram shown in figure 8.2 or 8.4")
disp("We have Vatan 2=Vatan 2 −Um")
disp("Or tan 2=tan 2 −Um/Va")

tanbeta2=tan(75*%pi/180)-1200/500
printf(" Thus tan 2= %0.2f",tanbeta2)
beta2=((atan(tanbeta2))*180/%pi)
printf("\n Thus  2= %0.2f",beta2)

disp("Also Vatan 3=Vatan 3+Um")
disp("tan 3=tan 3+Um/Va")
tanbeta3=tan(10*%pi/180)+1200/500
printf(" tan 3= %0.2f",tanbeta3)
beta3=((atan(tanbeta3))*180/%pi)
printf("\n  3= %0.2f",beta3)
```

```

disp("From Cp*deltaT0s=deltaE=Um(Vu2+Vu3)=UmVa(
   tan 2+tan 3)")
deltaE=1200*500*(tan(75*%pi/180)+tan(10*%pi/180))
printf(" Thus Cp*deltaT0s=deltaE= %g=2.34*10^6 ((ft/
   s)^2)",deltaE)

deltaT0s=(2.34*(10^6))/(0.24*778*32.2)
disp("deltaT0s=(2.34*(10^6))/(0.24*778*32.2)")
printf(" Thus deltaT0s= %0.2f R which is rounded off
    to 890R",deltaT0s)

disp("Hence neglecting leakage and mechanical losses
    , we have shaft power output Ps=mCpdeltaT0s")
Ps=50*2.34*(10^6)/(32.2*550)
printf("\n Hence we have Ps= %0.2f hp wich is
   rounded off to 6607hp",Ps)

disp("The degree of reaction at the mean radius can
   be determined from equation 8.5A")
R=(500/(2*1200))*(tan(68.8*%pi/180)-tan(53.1*%pi
   /180))
printf("\n Thus R = %0.3f",R)

disp("To determine the radii the flow area A2 can be
    determined from m=rho2*A2*Va. The density rho2
   can be determined from p2 and T2 which can be
   caalculated as follows.")
disp("From Cp*T02=CpT2+V2^2/2 and V2= VA/cos 2")
V2=500/(cos(75*%pi/180))
printf("\n V2= %0.0f ft/s",V2)

T2=2000-(1932^2)/(2*0.24*778*32.2)
printf("\n Thus we have T2= %0.0f degrees Farenheit
   = 2150R",T2)

disp("From the definition of loss coefficient  e we
    have Ts2=T2- sV2^2/(2*Cp)")
```

```
Ts2=1690-(0.08*(1932^2))/(2*.24*778*32.2)
printf("\n Ts2= %0.2f degrees Farenheit which is
   equal to 2125.2R",Ts2)

//Let x= P2/p01
x=(2125.2/2460)^(1.4/0.4)
printf("\n and P2/p01= %0.2f",x)


P2=200*0.60
printf("\n P2= %0.0f psia",P2)

disp("Hence the density can be calculated as rho2=p2
   /(R*T2)")

rho2=120*144/(53.3*2150)
printf("\n Thus ro2=%0.3f lbm/ft^3",rho2)

A2=50/(0.151*500)
printf("\n A2=m/(rho2*Va)=%0.3f ft^2",A2)

//let y=rt^2-rh^2
y=0.662/%pi
printf("\n rt^2-rh^2=A2/pi=%0.3f",y)

rm=30*1200/(8000*%pi)
printf(" and rm= %0.2f ft",rm)

disp("rt^2+rh^2=2*rm^2=4.09ft^2")
disp("and 1.466ft,rh=1.393ft")
rt=1.466
rh=1.393
b=rt-rh
printf(" b= %0.3f ft=0.88in",b)
```

Scilab code Exa 8.4 GT

```
clear all; clc;

disp("For N/(T01^1/2)=40,the following data of p02/p01,  /p01 and Eta can be obtained from figure 8.9a")
//let x=p02/p01
x=[0.70 0.75 0.8];
//let y=  /p01
y=[8.7 5.3 2.2];
Eta=[0.81 0.64 0.41];
//let z=Ps/(p01*((T01)^1/2))
z=[0.066 0.040 0.017];
//let i=m*((T01)^1/2)/p01
i=[2.48 2.34 2.0];
table=[x' y'Eta' z' i'];
disp(" The columns of the table are in the order p02/p01   /p01 Eta Ps/(p01*((T01)^1/2)) and m*((T01)^1/2)/p01")
disp(table)

disp("The power and mass flow rate have to be obtained with the following manipulations. ")
disp("Frpm Ps=  *omega, wee obtain:")
disp("Ps/(p01*((T01)^0.5))=  *N*pi/(30*550*p01*((T01)^0.5))")
disp("Also from Ps/m=Eta*Cp*T01[1-(p02/p01)^((k-1)/k)] we obtain")
disp("m*(T01^0.5)/p01={[Ps/(p01*T01^0.5)]/(Eta*Cp)}*[1-(p02/p01)^((k-1)/k)]^-1")
disp("Where (k-1)/k=0.40/1.4")

//Let j=(k-1)/k=0.40/1.4
j=0.40/1.4
printf("Thus=(k-1)/k %0.4f",j)

disp("And Cp= 0.24*Btu/(1bm*R)")
```

```
Cp=0.24*778/(550)
printf("Thus Cp= %0.4f hp-s/(lbm*R)",Cp)
```

Scilab code Exa 8.5 GT

```
clear all; clc;

disp("From Um=rm*omega")
disp("We have rm=30*Um/(N*pi)")
rm=30*850/(8000*%pi)
printf(" Thus rm= %0.2f ft=12.1 in",rm)

disp("rm=(rt^2+rh^2/2)^0.5 or rt^2+rh^2=293.8")
disp("Combined with b=rt-rh=4 in,we have rt^2-4rt
    -138.9=0,thus rt=13.95 in")

disp("and rh=9.95 in")

disp("To find the number of stages required the
    exhaust air temperature can be estimated as T0e=
    T0i*(p0e/p0i)^((k-1)/k)")
T0e=1400*(14.7/60)^0.2857
printf(" Thus T0e= %0.1f R",T0e)

disp("The maximum energy available per unit mass of
    air is delta_Hs=Cp*(T0i-T0e)")
delta_Hs=0.24*(1400-936.7)
printf(" delta_Hs= %0.1f Btu/lbm",delta_Hs)

disp("The maximum energy transfer per stage with an
    impulse turbine is deltaEi=2*Um^2")
delta_Ei=2*(850^2)/(32.2*778)
printf(" delta_Ei= %0.2f Btu/lbm",delta_Ei)

disp("Hence the required number of stages is ETAsi=
```

```
   delta_Hs/delta_Ei”)
ETAsi=111.2/57.68
printf(” ETAsi= %0.2f which is approximately equal
   to 2”,ETAsi)

disp(”With the reaction turbine stages,it will be
   delta_Er=Um^2”)
delta_Er=850^2/(32.2*778)
printf(” delta_Er= %0.2f Btu/lbm”,delta_Er)
disp(”And ETAse=3.85 is approximatly equal to 4”)
```

Scilab code Exa 8.6 GT

```
clear all; clc;

disp(”From figure 8.14c we have Pl=620hp at N=18400
   rpm. Pick a point on the curve of N/(T01^0.5)
   =18400/(530^0.5)=800”)
disp(”In figure 8.14a,say p02/p01=5”)
disp(”So we have”)

disp(”m(T01^0.5)/p01    ETAc    p02(psia)    m(lbm/s)
     p03(psia)    p03/p04”)
disp(”    5.7              0.85      73.5         3.64
          71.5          4.86”)

disp(”where p02=5*14.7”)
 p02=5*14.7
 printf(” Thus p02= %0.2f”,p02)

disp(”m=5.7*14.7/(530^0.5)”)
 m=5.7*14.7/(530^0.5)
 printf(” m= %0.2f”,m)

disp(”73.5-2”)
```

```
 p03=73.5-2
 printf(" m= %0.2f psia",p03)

//Let i=p03/p04
i=71.5/14.7
printf("\n p03/p04= %0.2f",i)

disp("Then from figure 8.14b,with p03/p04 and m3=m2 we have")
disp("m(T01^0.5)/p01        T03(R)    N/(T03^0.5)    ETAt")
disp("2.56                   2528          366          0.87")

disp("where T03=(2.56*71.5/3.64)^2")
T03=(2.56*71.5/3.64)^2
printf(" T03= %0.2f",T03)

disp("N/T03=18400/(2528^0.5)")
//let k=N/T03
k=18400/(sqrt(2528))
printf(" Thus T03= %0.2f",k)

disp("So from equations (8.1),(7.4) and(8.11) we have:")
disp("delta_T034=ETAt*T03*[1-(p04/p03)^((k-1)/k)]")
delta_T034=0.87*2528*[1-(4.86)^(-0.248)]
printf(" delta_T034 = %0.0f R",delta_T034)

disp("delta_T012=(T01/ETAc)*[(p02/p01)^((k-1)/k)-1]")
delta_T012=(530/0.85)*[(5^0.2857)-1]
printf(" delta_T012= %0.0fR",delta_T012)

P0=3.64*(0.28*713-0.24*(364/0.95))
printf(" \n and P0=3.64*(0.28*713-0.24*(364/0.95))= %0.0f Btu/s=554hp, which is less than Pl",P0)

```

```
disp("So we pick another point on the same curve , say p02/p01=5.2, and repeat the calculations ")

disp("m(T01^0.5)/p01  ETAc  p02(psia)  m(lbm/s)  p03(psia)  p03/p04  m(T01^0.5)/p01  T03(R)  N/(T03^0.5)  ETAt")
disp("5.6                0.88    76.4         3.57          74.4         5.06       2.55               2824     346            0.85")

delta_T034=0.85*2824*[1-(5.06^(-0.248))]
printf("\n The new delta_T034= %0.2fR",delta_T034)//the book has rounded off the value to 794R,the value calculated in this code is more accurate

delta_T012=(530/0.88)*[(5.2^0.2857)-1]
printf("\n delta_T012= %0.0fR",delta_T012)

P0=3.57*(0.28*794-0.24*362/0.95)
printf("\n Net output power P0= %0.0f Btu/s=660hp, which is much greater than Pl \n\n",P0)

disp("Pick another point say p02/p01=5.15")

disp("m(T01^0.5)/p01  ETAc  p02(psia)  m(lbm/s)  p03(psia)  p03/p04  m(T01^0.5)/p01  T03(R)  N/(T03^0.5)  ETAt")
disp("5.65               0.87    75.7         3.61          73.7         5.01       2.55               2710     353            0.86")

delta_T034=0.86*2710*[1-(5.01^(-0.248))]
printf("\n\n From new values delta_T034= %0.0f R",delta_T034)

delta_T012=(530/0.87)*[(5.15^(0.2857))-1]
printf("\n and delta_T012= %0.0f R",delta_T012)

```

```
P0=3.61*(0.28*768-0.24*(364/0.95))
printf("also P0= %0.1f Btu/s =628hp",P0)

disp("P0 is close to Pl")
disp("So the running point is around p02/p01=5.15, m (T01^0.5)/p01=5.65")
disp("and N/(T01^0.5)=800 on the compressor characteristics")
disp("It is not too close to the surge line and hence is safe.")
```

Scilab code Exa 8.7 GT

```
clear all; clc;

disp("Velocity diagrams at the rotor inlet and outlet are given.")

disp("Velocities at the rotor inlet can be calculated .")

r2=5/12
N=15000
U2=r2*N*%pi/30
printf(" U2=r2*N*pi/30 = %0.1f ft/s",U2)

alpha2=85*%pi/180//converting to radians
V2=U2/sin(alpha2)
printf("\n V2= %0.0f ft/s",V2)

Vr2=U2/(tan(alpha2))
printf("\n Vr2=W2= %0.1f ft/s",Vr2)

disp("Hence from Cp(T02-T2)=V2^2/2, where T02=T01, we have")
```

```
T02=2000
V2=657
Cp=0.24*778*32.2
T2=T02-(V2^2)/(2*Cp)
printf("\n T2=T02-(V2^2)/(2*Cp) =%0.1fR",T2)

disp("From  n =(T2-T2_dash)/((V2^2)/(2*Cp)), we have ")
T2=1964.1
epsilon_n=0.08
V2=657
T2_dash=T2-epsilon_n*V2^2/(2*Cp)
printf(" T2_dash=T2-epsilon_n*V2^2/(2*Cp)= %0.1fR",T2_dash)

p01=50
T2_dash=1961.2
T01=2000
//let i=(k/(k-1))
i=3.5
p2=p01*(T2_dash/T01)^i
printf("\n p2= %0.1f psia",p2)

p2=46.7
R=53.3
T2=1964.1
rho2=p2*144/(R*T2)//conversion factor=144
printf("\n rho2= %0.3f lb,/ft^3",rho2)

rho2=0.064
Vr2=57.3
A2=(2*%pi*5*2/144)
m=rho2*Vr2*A2
printf("\n So the mass flow rate m=rho2*Vr2*A2= %0.2f lbm/s",m)

disp("Assuming whirl-free flow at the rotor outlet under the design condition, we have")
```

```
U2=654.5
delta_E=(U2)^2
printf("\n delta_E=U2*Vu2=U2^2 %g ((ft/s)^2)=428370/(32.2*550)=24.2hp/(lbm/s)",delta_E)

m=1.60
delta_E=24.2//after converting to new units
Ps=m*delta_E
printf("\n Ps= %0.1f hp",Ps)

rm3=2.06/12
Um3=rm3*N*%pi/30
printf("\n Um3= %0.2f ft/s",Um3)

beta3=30*%pi/180//converting to radians
V3=Um3/(tan(beta3))
printf("\n V3 = %0.0f ft/s",V3)

W3=Um3/sin(beta3)
printf("\n W3 = %0.2f ft/s",W3)//the value has been rounded off to 539.2 in the book,however the value found here is more accurate

disp("The turbine efficiency can be determined from equations 8.12 and 8.13. Without detailed calculations wthe result is given as ETAt=0.691")

disp("The exhaust pressure/temperature can be determined from te following calculations with the help of figure 8.21")
delta_E=428370/(32.2*778)
printf(" From Cp(T01-T03)=delta_E= %0.1fBtu/lbm",delta_E)

disp("(T01-T03)/(T01-T3dash)=Etat=0.691")

T03=2000-(17.1/0.24)
printf(" T03= %0.0f R",T03)
```

```

T01=2000
T03=1929
ETAt=0.691
T3_dash=T01-(T01-T03)/ETAt
printf("\n T3_dash=T01-(T01-T03)/ETAt %0.0fR =",T3_dash)

//let i=k/(k-1)
i=3.5
p01=50
T3_dash=1897
T01=2000
p3=p01*(T3_dash/T01)^i
printf("\n p3=p01*(T3_dash/T01)^i= %0.1f psia",p3)

T2=1964.4
p3=41.6
p2=46.7
// Let l=(k-1)/k
l=0.2857
T3_dbldash=T2*(p3/p2)^(l)
printf("\n T3_dbldash=T2*(p3/p2)^(1/i)=%0.2fR",T3_dbldash)//answer given in the book is 1900.3 R,however the value tabulated here is more accurate

T3_dbldash=1900.3
epsilon_r=0.45
W3=539.2
Cp=0.24*32.2*778
T3=T3_dbldash+epsilon_r*(W3^2)/(2*Cp)
printf("\n T3= %0.1f R",T3)
```

Chapter 9

Steam Turbines

Scilab code Exa 9.1 ST

```
clear all; clc;

rm=8/12
N=7500
U=rm*N*%pi/30
printf("The peripheral velocity is calculated as U=%0.1f ft/s\n\n",U)

disp("From equation 9.1 we have U/V1=sin 1/4")
//let x= U/V1
alpha1=70*%pi/180
x=(sin(alpha1))/4
printf("\n Thus U/V1= %0.4f",x)

V1=U/x
printf("\n Thus V1= %0.1f ft/s",V1)

disp("From velocity diagram at station1 we have V1sin 1-W1sin 1=U and V1cos 1=W1cos 1 or W1sin 1")
//let y= W1sin 1
```

```
V1=2228.8
U=523.6
y=V1*sin(alpha1)-U
printf("\n Hence W1sin 1= %0.1f ft/s",y)

//Let z=W1cos 1
z=V1*cos(alpha1)
printf("\n Thus W1cos 1= %0.1f ft/s",z)

disp("Hence tan 1 =2.06")
tanbeta1=2.06
beta1=(atan(tanbeta1))*180/%pi
printf("\n Thus beta1= %0.1f degrees and W1=1746 ft/s",beta1)

disp("At station 2 we have W2sin 2-V2sin 2=U and V2cos 2=W2cos 2 , with W2=W1=1746ft/s and  1= 2 =64.1 degrees")
//Let l=V2sin 2
l=1746*sin(64.1*%pi/180)-523.6
printf(" Thus V2sin 2=%0.0f ft/s",l)

//m=V2cos 2
m=1746*cos(64.1*%pi/180)
printf("\n V2cos 2 %0.2f ft/s",m)

disp("Hence tan 2 =1.373")
tanalpha2=1.373
alpha2=((atan(tanalpha2)*180/%pi))
printf(" Hence  2= %0.2f degrees",alpha2)

disp("Hence V2=1295.2 ft/s")

disp("At station 3 we have V3sin 3-W3sin 3=U=523.6 ft/s")
disp("Also W3cos 3=V3cos 3")
//let n=V3cos 3
V3=1295.2
```

```
alpha3=53.9*%pi/180
n=V3*cos(alpha3)
printf(" Thus W3cos 3= %0.1f ft/s",n)

disp("Hence tan 3 =0.685")
tanbeta3=0.685
beta3=((atan(tanbeta3))*180/%pi)
printf(" Hence  3= %0.1f degrees",beta3)

disp("Thus W3=925.1 ft/s")

disp("Also W4=W3=925.1ft/s")
disp("  4= 3 =34.4 degrees")
disp("And V4=VaV1cos 4")
beta4=34.4*%pi/180
//let y=Va*V1
y=925.0848
V4=y*cos(beta4)
printf(" Thus V4= %0.1f ft/s",V4)
disp("  4 =0 degrees")

disp("From these velocities,the energy transfers of the rotors can be calculated")

U=523.6
V1=2228.8
alpha1=70*%pi/180
V2=1295.2
alpha2=53.9*%pi/180
delta_E1=U*(V1*sin(alpha1)+V2*sin(alpha2))
printf(" Thus delta_E1= %0.1f ((ft/s)^2)",delta_E1)

delta_E1=1.643*(10^6)/(32.2*778)//converting units from (ft/s)^2 to Btu/lb
printf("\n On converting to Btu/lb we have delta_E1=%0.1f Btu/lb",delta_E1)

V3=1295.2
```

```
alpha3=alpha2
delta_E2=U*(V3*sin(alpha3))
printf("\n delta_E2=%0.1f ((ft/s)^2)",delta_E2)
delta_E2=0.546*(10^6)/(32.2*778)
printf("\n On converting to Btu/lb we have delta_E2=%0.1f Btu/lb",delta_E2)

delta_Ec=65.6+21.8
printf("\n Hence the total energy transfer is delta_Ec= %0.1f Btu/lb",delta_Ec)
disp("To compare with that calculated with equation9.3,we have delta_Ec=8*U^2")
delta_Ec=8*(U^2)
printf(" delta_Ec= %0.2f ((ft/s)^2)",delta_Ec)
delta_Ec=2.19*10^6/(32.2*778)//converting units
printf("\n On converting we have delta_Ec= %0.2f Btu/lb",delta_Ec)//answer given in the book is 87.5, however 87.42 is more accurate

disp("The difference is due to round off error.")
disp("The static enthalpies and pressure at stations 1,2,3 and 4 are same for the ideal case and can be calculated from h1=h01-((V1)^2)/2 ")
disp("Where h01=h0i=1405Btu/lb from the Mollier diagram for p0i=3000 psia,T01=950 degrees Farenheit")
//let l=(V1^2)/2
V1=2228.8
 l=(V1^2)/(2*32.2*778)
printf(" Thus (V1^2)/2 = %0.0f Btu/lb",l)

disp("Hence we have h1=1306 Btu/lb and p1=1400psia")
```

Scilab code Exa 9.2 ST

```
clear all; clc;

disp("To use Figure 9.8,with Qf= U ^2/delta_Hs=2*g_c*lambda^2*R_H")
disp("The value of R_H can be estimated with equation 8.4.")
disp("Using k=1.3 for steam and suusming ETA_p=0.90 we have ETAad=[1-(p_e/p_i)^(ETAp*(k-1)/k)]/[1-(p_e/p_i)^(k-1)/k]=0.931")

ETA_ad=0.931
ETA_p=0.90
R_H=ETA_ad/ETA_p
printf(" R_H=ETA_ad/ETA_p= %0.3f",R_H)

disp("For impulse stages,the optimal efficiencies occur at lambda=U/V2=sin 2 /2=0.47 with alpha2=70 degrees")
QF=2*25052*(0.47^2)*1.035
printf(" So Qf can be calculated as %0.0f",QF)

disp("From figure 9.8, the efficiency can be estimated as ETA=83%")

disp("From the Mollier diagram in figure A1 we have hi=1525 Btu/lbm,hse=1150 Btu/lbm,with s_i=s_es=1.8Btu/lb-R")
delta_Hs=1525-1150
printf(" Hence delta_Hs=%0.0f Btu/lbm",delta_Hs)

summation_sqr(U)=11455*375
printf("\n So we have  U^2=%0.0f ((ft/s)^2)",summation_sqr(U))

disp("With 10 identical stages,we have U^2=429562")
sqr(U)=429562
U=sqrt(sqr(U))
printf(" Thus U= %0.0f ft/s",U)
```

```
omega=3600*%pi/30
D=2*U/omega
printf("\n The turbine diameter D= %0.3f ft",D)//The
    answer has been incorrectly rounded off to 3.47
   in the book. A more accurate answer is provided
   here.
```

Scilab code Exa 9.3 ST

```
clear all; clc;

disp("The tangential velocity at the rotor mean
   radius is Um")
rm=1.5
N=3600
Um=rm*N*%pi/30
printf("Um=rm*N*pi/30= %0.1f",Um)

disp("From the velocity diagram in figure 8.11 for
   the impulse stages we have delta_h0")
disp("delta_h0=delta_Et=UmVu2-UmVu3/g_c=UmVu2/g_c
   =2((Um)^2)/gc")
Um=565.5
gc=32.2
delta_h0=2*((Um)^2)/gc
printf("\n delta_h0= %0.0f lbf-ft/lbm=25.5 Btu/lbm",
   delta_h0)

disp("From the Mollier diagram in appendix A, we
   have hoi=1565 Btu/lbm")
disp("For the stages with constant mean radi,we have
    hoi-hoe=n_s*delta_hoe or hoe=h0i-n_s*delta_hoe")
h_oe=1565-(12*25.5)
printf(" hoe= %0.0f Btu/lbm.",h_oe)
```

```

disp("Also from ETA_ad=(hoi-hoe)/(hoi-hsoe), we have hsoe=hoi-(hoi-hoe)/ETA_ad")
h_soe=1565-306/0.85
printf(" hsoe= %0.0f Btu/lbm",h_soe)

disp("From s_soe=Soi=1.69 Btu/(lbm-R),we have poe=50 psia and Toe=450 degrees Farenheit")
disp("Also from given efficiencies we have Ps=ETAv*ETAm*m*n_s*delta_ho")
Ps=0.92*0.90*7*12*19863/550
printf(" Ps=%0.0f hp",Ps)
```

Scilab code Exa 9.4 ST

```
clear all; clc;

disp("Based on the law of Willian we have m_t=0.5+CP_s")
C=(7-0.5)/2512
printf(" Where C= %0.4f lbm/(hp-s)\n",C)

disp("So we have SR=mt/Ps=0.5/Ps+(2.6*10^-3)")
disp("And HR=Q_h*SR")


disp("OR at full load,")
SR_1=(0.5/2512)+(2.6*10^-3)
printf("\n SR_1= %0.4f lbm/(hp-s)=10.1 lbm/(hp-h)",SR_1)

HR_1=1750*10.1
printf("\n HR_1=%0.0f Btu/(hp-h)",HR_1)


```

```
disp("at 50% load,")
SR_2=(0.5/1256)+(2.6*10^-3)
printf("\n SR_2= %0.4f lbm/(hp-s)=10.8 lbm/(hp-h)",SR_2)

HR_2=1750*10.8
printf("\n HR_2=%0.0f Btu/(hp-h)",HR_2)
```

Scilab code Exa 9.5 ST

```
clear all; clc;

disp("To calculate the thermal efficiency,the units have to be consisitent. With hp=0.707 Btu/s=2545 Btu/h, we have ETAth=Ps+Qe/Qin")
ETA_th=(2512*0.707+1259*7)/(7*1750)
printf(" Thus ETA_h= %0.3f",ETA_th)

ETA_th=2512*0.707/(7*1750)
printf("\n For the simple shaft power system,we have  ETA_th= %0.3f",ETA_th)

ETA_th=2545/17675
printf("\n From the heat rate,ETA_th=2545/HR %0.3f",ETA_th)
```

Scilab code Exa 9.6 Steam Turbines

```
clear all; clc;

disp("The enthalpies at various points have t be determined first. For the steam turbine cycle,fro
```

```
the Mollier diagram or steam tables,we have h1=hf1=83.6")

h2=83.6+(0.0185*(1000-1.5)*144)/(778*0.80)
printf(" h2=h1+nu*deltap/ETA_p =%0.1f Btu/lbm",h2)

disp("h3=1447 Btu/lbm")

disp("s_s4=s3=1.61 Btu/(lbm-R)")

disp("hs4=925 Btu/lbm")

disp("Hence from ETAst=(h3-h4)/(h3-hs4) we have h4=h3-(h3-hs4)*ETAst")
h3=1447
hs4=925
ETA_st=0.85
h4=h3-(h3-hs4)*ETA_st
printf(" h4= %0.0f Btu/lbm",h4)

h4=1003
h2=87.9
h1=83.6
ETA_ths=[(h3-h4)-(h2-h1)]/(h3-h2)
printf("\n The thermal efficiency of the steam turbine cycle is then obtained as ETA_th,s=(Wst-Wp)/(Qin,s)=%0.4f ",ETA_ths)//it has been rounded off to 32.3 in the book

disp("For the gas turbine cycle, an ideal gas with constant Cp is assumed for the working gas. With Cp=0.24 Btu/(lbm-R) and k=1.4 we have T6")
T5=540
//Let n=p6/p5 and m= (k-1)/k
n=15
m=0.2857
ETAc=0.82
T6=T5+[T5*({(n)^(m)}-1)]/ETAc
```

```
printf(”\n T6= %0.0fR=849 degrees Farenheit”,T6)

T7=2560
//let b=(1/15)^0.2857
b=0.461
ETA_gt=0.85
T8=T7-T7*[1-b]*ETA_gt
printf(”\n T8=%0.0f R= 928 degrees Farenheit”,T8)

disp(”Which should be greater than T3”)
T7=2560
T8=1388
T6=1309
T5=540
ETA_thg=[(T7-T8)-(T6-T5)]/(T7-T6)
printf(”\n The thermal efficiency of the gas turbine is obtained as %0.3f=32.2 percent”,ETA_thg)

disp(”From the energy balance equation across  the HRSG,we have m_g*Cp*(T8–T9)”)
disp(”ms/mg=[Cp*(T8–T9)]/(h3–h2)”)
//let x=ms/mg
Cp=0.24
T8=928
T9=450
h3=1447
h2=87.9
x=[Cp*(T8-T9)]/(h3-h2)
printf(”\n Thus ms/mg=%0.3f”,x)

disp(”Hence the thermal efficiency of the combined cycle is obtained as ETA_th,c=[(Wgt–Wc)+(ms/mg)*(Wst–Wp)]/[Cp*(T7–T6)]”)
ETA_thc=[0.24*(1172-769)+0.084*(439.7)]/(0.24*1251)
printf(”\n ETA_th,c= %0.3f=44.5 percent”,ETA_thc)
```

Chapter 10

Hydraulic Turbines

Scilab code Exa 10.1 HT

```
clear all; clc;
//the values of omegas and energycoeeficient differ from the ones given in the book
//the reasons for the same are mentioned in the code below
H=85
Q=16
E=0.9//efficiency
g=9.8
rho=998

P_o=E*rho*Q*g*H/1000
printf("The estimated power (Po) is equal to %0.0f kW",P_o)


disp("From figure 10.11,a Francis Turbine is selected. Then with the synchronous speed of 16 poles N is determined")
N=120*60/16
printf("N is equal to %grpm",N)
```

```


N_s=(N*Q^0.5)/H^0.75
printf("\nWe have value of Ns equal to %0.1f rpm(m^3/s)^0.5",N_s)


Ksigma=2.11
n=450/60
g=9.8
sigma=(Ksigma*n*Q^0.5)/((g*H)^0.75)
printf("\n Value of sigma is equal to %0.2f",sigma)


omega=(%pi*N)/30
V=16
omega_s=(omega*V^0.5)/((g*H)^0.75)//Answer given in the book is 1.33,this is because H has been wrongly substitued as 75. The correct substitution(H=85),gives the answer equal to 1.2157.
thita=1.9
K=1.054
printf("\n Value of omegas is equal to %g",omega_s)


disp("From figure 10.10 we have thita=1.9 for nq=Ns=64.3")
disp("Since K*D*(g*H)^0.25/Q^0.5=thita , we can determine D.")

D=(thita*(Q^0.5))/(((g*H)^0.25)*K)
printf("\n Value of D is equal to %0.2f m ",D)


disp("From figure 10.9 we have efficiency=0.95,which is close to the original estimation")
D=1.34//value of D is approximately equal to 1.34
```

```
k_phi=(%pi^2)/4
k_psi=(%pi^2)/2
flowcoeff=Q/(k_phi*n*(D^3))
printf(”The flow coefficient is equal to %0.3f”, flowcoeff)


energycoeff=(g*H)/(k_psi*(n^2)*(D^2))
printf(”\nThe energy coefficient is equal to %0.4f”, energycoeff)//Answer given in the book is 1.47, this is because H has been wrongly substitued as 75. The correct substitution(H=85),gives the answer equal to 1.6713.
```

Scilab code Exa 10.2 HT

```
clear all; clc;

disp(”From psi=(g*H)/(omega^2*D^2)  and N=30*omega/pi we get N=172.7/(psi^0.5)”)
disp(”Also from phi=Q/(omega*D^3) and pi=Ps/(rho*omega^3*D^5) we get Q=0.353*phi*N and Ps=0.0087*N^3*pi”)
disp(”Pick the points along 80% gate opening curve, read the values for phi,psi, and efficiency from figure 10.14”)

phi=[0.158 0.151 0.14 0.127 0.108 0.092 0.076 0.066];
psi= [0.093 0.083 0.071 0.06 0.048 0.04 0.03 0.025];
E= [55 56.5 58 62.5 69 71.5 67.5 60];//efficiency
pai= [0.0078 0.0067 0.0058 0.0045 0.0034 0.0025 0.0015 0.001];

N = zeros(1,length(phi));
```

```
Ps = zeros(1,length(phi));
Q = zeros(1,length(phi));

for i = 1: length(phi)


    N(i) = 172.7/sqrt(psi(i));
    Ps(i) = 0.0087*N(i)^3*pai(i)*10^-3;
    Q(i) = 0.353*phi(i)*N(i);
end

disp("    phi     psi       eff(%)    pai        N(rpm)        Ps(mw)         Q(m^3/s)")

table = [phi' psi' E' pai' N' Ps' Q'];
disp(table)

plot(N,Ps,'o',N,Q,'d',N,E,'s')
legend("Ps (mw)","Q (m^3/s)","Eff (%)",-1)
xlabel("N (rpm)")
ylabel("Ps (mW), Q (m^3/s) , eff (%)")
set(gca(),"grid",[1 1])
```

Scilab code Exa 10.3 HT

```
clear all; clc;
D=3
dn=0.08
H=350
En=0.82
CVb=0.95
Em=0.90
Ev=0.96
g=9.8

```

```
V2=(2*En*g*H)^0.5
printf(” The jet flow velocity is equal to %0.0f m/s”,V2)

Um=0.5*V2
printf(”\n Optimum wheel tangential velocity is Um is equal to %0.1f m/s”,Um)

N=(60*Um)/(%pi*D)
printf(”\n The rotating speed N is equal to %0.1f rpm”,N)

disp(”Under the maximum utilization factor condition,we have beta3=90 degrees”)
disp(” Since delta Emax=(1+CVb)*U(V2–U),we get the equation delta Emax=1.95*(U^2)”)
delta_E_max=(1+CVb)*Um*(V2-Um)
printf(” The value of deltaEmax is equal to %g N–m/kg”,delta_E_max)

An=(%pi/4)*(dn^2)
Q=V2*An
printf(”\n The flow rate is %0.3f m^3/s”,Q)

m=998*Q
Ps=Em*Ev*m*delta_E_max/1000
printf(”\n The total shaft power output is %0.1f kW”,Ps)

Ns=(N*(Q^0.5))/(H^0.75)
printf(”\n The specific speed can be calculated as %0.2f rpm((m^3/s)^0.5)/(m^0.75)”,Ns)

omega=%pi*N/30
omega_s=omega*(Q^0.5)/((g*H)^0.75)
printf(”\n In non dimensional form , omegas is equal to %0.3f”,omega_s)
```

Scilab code Exa 10.4 HT

```
clear all; clc;
H=80
Q=63
Es=0.97
N=400
V3=25
Dh3=2
rh3=1/12
g=32.2

Ksigma=2.11
n=N/60
sigma=(Ksigma*n*(Q^0.5))/((g*H)^0.75)
printf(" The value of sigma is equal to %0.2f ",sigma)

disp("We have thita=2.4. Thita is also equal to Kt*D2*((g*H)^0.25)/(Q^0.5)")
thita=2.4
Kt=1.054
D2=(thita*(Q^0.5))/(Kt*((g*H)^0.25))
printf(" Thus the value of D2 is %0.1f ft",D2)

D2r=2.5//rounded off D2
U2=(D2r*N*%pi)/60
printf("\n U2 is equal to %0.2f ft/s",U2)

V2=(2*g*H*Es)^0.5
printf("\n The inlet flow velocity V2 is equal to %0.2f ft/s",V2)

disp("From the inlet velocity diagram for alpha2=20
```

```
degrees we have Vr2=V2*sinalpha2")
alpha2=20
Vr2=V2*(sin(alpha2*%pi/180))
printf(" Vr2 is equal to %0.2f ft/s",Vr2)

tanbeta2=Vr2/(V2*(cos(alpha2*%pi/180))-U2)
printf("\n The value of tanbeta2 is %0.2f",tanbeta2)
beta2=(atan(tanbeta2))*180/%pi
printf("\n Thus value of beta2 is %0.1f degrees",beta2)

disp("Selecting the incidence i=2.2 degrees we have betab2=62 degrees")

disp("A2=Q/Vr2=(%pi*D2*b2) From this equation we can determine the value of b2.")
A2=Q/Vr2
printf(" A2 is equal to %0.2f ft^2",A2)
b2=A2/(%pi*D2)
printf("\n b2 is equal to %0.2f ft",b2)
disp("Thus b2= 4 inches")

disp("At the outlet with rh3=1 inch, setting gamma=15 degrees and V3=25")
gamma1=15
 A3=Q/V3
printf(" The value of A3 is equal to %g ft^2",A3)
 rt3=((A3*(cos(gamma1*%pi/180)))/%pi+(rh3^2))^0.5
 printf("\n The value of rt3 is %0.2f ft",rt3)
 disp("On converting the value of rt3 from feet to inches we get rt3=10.6inches")

 rt3c=10.6//converted value of rt3
 rh3c=1//converted value in inches
 rm3=((((rt3c^2+ rh3c^2)/2)^0.5)/12)
 printf(" The mean radius rm3 is equal to %0.3f ft",rm3)
 Um3=26.3
```

```
tanbetam3=V3/Um3
printf("\n The value of tanbetam3 %0.2f",tanbetam3)
betam3=atan(tanbetam3)*180/%pi
printf("\n The value of betam3 whih is equal to
   betabm3 if no deviation is assumed is equal to
   %0.2f degrees",betam3)
disp("On rounding off we get the value og betam3
   =43.6 degrees")
```

Scilab code Exa 10.5 HT

```
clear all; clc;
disp("To use figure 10.21 we need the dimensional
   power specific speed. So the shaft power has to
   be estimated from figure 10.9 where the non
   dimensional omegas is needed.")

Ve=5
Hl=0.7

H=80
Q=63
Es=0.97
N=400
V3=25
Dh3=2
rh3=1/12
g=32.2

omega=N*%pi/30
omega_s=omega*(Q^0.5)/((g*H)^0.75)
printf(" The value of omegas is %0.2f",omega_s)

disp("We have efficiency=0.95")
E=0.95
```

```
rho=1.9378
Ps=E*rho*g*Q*H/550//conversion factor =1/550
printf(" The value of Ps %0.2f hp",Ps)

Nsp=N*(Ps^0.5)/(80^1.25)
printf("\nThe value of Nsp is equal to %0.2f rpm(hp^0.5)/ft^1.25",Nsp)

disp("From figure 10.21, we obtain sigma approximately equal to 0.1 or NSPHavail/H is greater than or equal to 0.1")
disp("NSPHavail =Ha-Z+Hl+Ve^2/(2*g)) and NSPH avail is greater than or equal to 8 ft.")
disp("At T=70 degrees farenheit we have the value of Ha equal to")
Ha=14.7*144/62.4
printf(" %0.2f ft.",Ha)
Hv=0.363*144/62.4
printf("\n The value of Hv is equal to %0.2f ft",Hv)
K=(Ve^2)/(2*g)
NPSHavail=8
printf("\n The value of (Ve^2)/(2*g) is equal to %0.2f ft",K)
//In the book the value of Zmax is directly stated
//I have used the given formualae and substiuted the values in it
//let NPSHavail=8
//then from the given formula we can find out the value of Zmax

NPSH_avail=8
H_vr=0.84//rounded off value
Kr=0.39//rounded off value
H_ar=33.9//rounded off value
Z =H_ar-NPSH_avail+Hl+Kr-H_vr//Kr= rounded off value of (Ve^2)/(2*g)
printf("\n The value of Zmax is equal to %0.1f ft",Z)
```

Chapter 11

Wind Turbines

Scilab code Exa 11.1 WT

```
clear all; clc;

Pe=1.5
Eg=0.96//generator efficiency
Em=0.94//transmission efficiency
P=Pe/(Eg*Em)
printf('\n The power is equal to %0.3f MW',P)
disp("After converting to W the magnitude of power is equal to 1.662*10^6 W")

Cp=0.47//from figure 11.10
V=13
rho=1.222
disp(" Since P=Cp(0.5*rho*A*V^3),thus on substituting the values we get P=630.9A")
A=P*10^6/(Cp*0.5*rho*V^3)// Since P=Cp*(0.5*rho*A*V^3)
printf(' On substituing the value of P in P=630.9A we get A equal to %g',A)

disp("After rounding off,the area is equal to 2634.7
```

```
m^2")
Ar=2634.7//rounded off A
//A=R^2*pi
R=sqrt(A/%pi)
printf(' The Radius is equal to %g m',R)

disp("After rounding off the,area is equal to 28.9m")
Rr=28.9//rounded off
D=2*Rr
printf(' The Diameter is equal to %g m',D)

omega=(V/R)*5.3// In the book diameter has been incorrectly substituted in place of radius(R). That is the reason why this particular answer doesn't match with the one given in the book.
printf('\n Omega is equal to %0.2f rad/s',omega)
N=(omega*30)/%pi//since N is proportional to omega and the answer for omega doesnt match with the answer given in the book(because of the aforementioned reason), the answer of N doesn't match either.
printf('\n RPM is equal to %g rpm',N)
```

Scilab code Exa 11.2 WT

```
clear all; clc;

V= 40*(5280/3600)
printf('V is equal to %0.2f ft/s',V)
N=80
omega=(N*%pi)/30
printf('\n\nomega is equal to %0.2f rad/s',omega)
rt=15
rh=1
```

```
Vt=(rt*omega)/V//tip velocity ratio
printf('\n\nThe tip velocity ratio is equal to %0.2f ',Vt)

Zb=12/Vt
printf('\n \n Optimum number of blades is equal to %0.2f ',Zb)
disp("On approximating,the optimum number of blades is equal to 5")

rm=[(rt^2+rh^2)/2]^0.5
printf('\nThe mean radius is equal to %0.2f ft',rm)

Um=rm*omega
printf('\n\nThe blade peripheral velocity at the mean radius is equal to %0.1f ft/s',Um)

disp("Assuming V1=V")
beta_1=(atan(Um/V))*180/%pi
printf('\nThe relative flow angle at the inlet is equal to %0.1f degrees',beta_1)

beta_2=65
tanbetam=0.5*(tan(beta_1*%pi/180)+tan(beta_2*%pi/180))
printf('\n\nThe value of tan of beta m is equal to %0.3f ',tanbetam)
beta_m=(atan(tanbetam))*180/%pi
printf('\n \n Mean relative flow angle (betam) is equal to %0.2f degrees',beta_m)

Wm=V/cos(beta_m*%pi/180)
printf('\n\nThe relative flow velocity (Wm) is equal to %0.1f ft/s',Wm)

rho=0.0763
gc=32.2
c=1.2
```

```
Cl=0.28
Cd=0.015
F_um=(rho*Wm^2*c*(Cl*cos(beta_m*%pi/180)-Cd*sin(beta_m*%pi/180))/(2*32.2))
printf('\n\nThe tangential force (Fum), is equal to %0.2f lb/ft',F_um)

delta_r=14//rt-rh=deltar
Z_br=5//approximated value of Zb
P_s=rm*F_um*delta_r*omega*Z_br/550
printf('\n\nPs is approximately equal to %0.1f hp',P_s)

A=%pi*rt^2
A_r=707//rounding of A=706.9 to 707
P_smax=((8/27)*(rho/gc)*707*58.67^3)/550
printf('\n\nFrom the actuator theory,the maximum possible shaft power will be equal to %0.1f hp.',P_smax)
```

Scilab code Exa 11.3 WT

```
clear all; clc;

V= 40//in mph
V=58.9//in mph
//more accurately
V= 40*(5280/3600)
a=0.27
V1=V*(1-a)
printf('V1 is equal to %0.1f ft/s',V1)

N=60
D=50
U=(N*%pi/30)*(D/2)
```

```
printf('\nU is equal to %0.1f ft/s',U)

//from velocity triangle
A=90+45
printf('\nA is equal to %g degrees',A)

//from cosine law
W=(U^2+V1^2-2*U*V1*cos(A*%pi/180))^0.5
printf('\nW is equal to %0.1f ft/s',W)

//from sine law
sinB=V1*(sin(A*%pi/180))/W
printf('\nsinB is equal to %0.4f ft/s',sinB)

B=asin(sinB)*180/%pi
printf('\nB is equal to %0.1f degrees',B)

setting_angle=85
alpha=B-(90-setting_angle)
printf('\nalpha is equal to %0.1f degrees',alpha)

//from figure
Cl=0.58
Cd=0.027
rho=0.0763
gc=32.2
c=1.2
Wr=189.8//rounded off W
Fu=rho*Wr^2*c*(Cl*sin(B*%pi/180)-Cd*cos(B*%pi/180))/(2*gc)
printf('\nFu is equal to %0.3f lb/ft',Fu)

disp("After rounding off the tangential force (Fu) is equal to 3.38 lb/ft")
```

Chapter 12

Review on Thermodynamics and Compressible Flow

Scilab code Exa 12.1 A

```
clear all; clc;

disp("Assuming steady state flow,an adiabetic
   process and neligible difference between the
   inlet/outlet flow velocities.")
T1=25+273
p2=600
p1=120
k=1.4
T_s2=T1*((p2/p1)^((k-1)/k))
printf(" T_s2= %0.0f K",T_s2)

disp("With constant Cp assumed, we have Eta_c=(Ts2-
   T1)/(T2-T1)")
T_s2=472
T1=298
T2=503
Eta_c=(T_s2-T1)/(T2-T1)
printf(" Eta_c=%0.4f=84.8 percent",Eta_c)
```

```

//let w_c/m=x
Cp=1.004
T1=298
T2=503
T1=298
x=Cp*T1*((T2/T1)-1)
printf("\n w_c/m=Cp*T1*((T2/T1)-1) %0.1f kJ/kg",x)
```

Scilab code Exa 12.2 A

```
clear all; clc;

disp("The gas density at the inlet can be calculated as rho1=p1/(R*T1)")
p1=14.7
R=35.11
T1=30+460
rho_1=p1*144/(R*T1)
printf(" rho1= %0.3f lbm/ft^3",rho_1)

m=0.123*150/60
printf("\n Hence we have mass flow rate m= %0.3f lbm/s",m)
disp("Neglecting the mechanical and leakage  and assuming ideal gas with constant Cp,we cam obtain T2")

T1=490
p2=40
p1=14.7
k=1.29
Eta_c=0.87
T2=T1*(1+[(p2/p1)^((k-1)/k)-1]/[Eta_c])
printf(" T2=%0.0fR",T2)
```

```

//let −w_c/m=x
Cp=0.2007
T2=632
T1=490
x=Cp*(T2-T1)
printf("\n −w_c/m=%0.1f Btu/lbm",x)

omega_c=0.307*28.5*778/550
printf("\n −omega_c=%0.1f hp",omega_c)

disp("For an isothermal process, we have −wc/m=p1*v1
    *ln(p2/p1)")
p1=14.7
v1=144/0.123
p2=40
x=p1*v1*log(p2/p1)
printf(" Thus −wc/m= %0.2f lbf−ft/lbm",x)

wc=0.307*17227/550
printf("\n Hence −wc= %0.1f hp",wc)
```

Scilab code Exa 12.3 A

```
clear all; clc;

disp("From the stam Mollier diagram,we have h1=1528
    Btu/lbm,s1=1.82 Btu/(lbm_R at 250 psia and 1000
    degrees Farenheit)")
disp("Hence at p2=10 psia,we have hs2=1165 btu/lbm,
    where ss2=s1")
disp("From Eta_t=(h1−h2)/(h1−hs2) we have")

h2=1528-0.85*(1528-1165)
printf("\n h2= %0.2f Btu/lbm",h2)
```

```

m=1.2
h1=1528
h2=1219.5
w_t=m*(h1-h2)
printf("\n wt= %0.2f Btu/s",w_t)//Wrongly rounded
    off in the book. A more accurate answer is 370.2.

w_t=370.3*778/550//converting units
printf("\n On converting units, we have wt= %0.1f hp
    ",w_t)//Since the basic value of w_t differs from
     that given in the book,so does the converted
    value.
```

Scilab code Exa 12.4 A

```
clear all; clc;

disp("From Ts2/T1=T3/Ts4=(p2/p1)^((k-1)/k),we have
    Ts2=901 R")
disp("Ts4=1264.6R")
disp("From Eta_c=(Ts2-T1)/(T2-T1) we have T2=980.2")
disp("Hence w_c=Cp*(T2-T1)=149.4hp/(lbm/s)")
disp("From Eta_t=(T3-T4)/(T3-Ts4),we have T4=1374.5R
     we hence wt=249.7hp/(lbm/s)")
disp("w=w_t-w_c")
w_t=249.7
w_c=149.4
w=w_t-w_c
printf(" w=%0.1f hp/(lbm/s)",w)
disp("q_in=Cp*(T3-T2)=383.5hp/(lbm/s)")
w=100.2
q_in=383.5
Eta_th=w/q_in
printf(" Eta_th=w/qin %0.2f =26 percent",Eta_th)
```

Scilab code Exa 12.5 A

```
clear all; clc;

disp("From Eta_hx=(T_dash-T_2)/(T_4-T_dash4),T_4dash=T_2")

disp("we have T_2dash=T_2+Eta_hx*(T_4-T_2)")
T_2=980.2
Eta_hx=0.7
T_4=1374.5
T_2=980.2
T_2dash=T_2+Eta_hx*(T_4-T_2)
printf(" T_2dash=%0.1f R",T_2dash)

Cp=0.339
T_3=2110
T_2dash=1256.2
q_in=Cp*(T_3-T_2dash)
printf("\n q_in %0.1f hp/(lbm/s)",q_in)

Eta_th=99.8/289.4
printf("\n Eta_th=%0.4f=34.6 percent",Eta_th)//in the book the value of Eta_th is rounded off to 34.6 and hence the same is done here.
```

Scilab code Exa 12.6 A

```
clear all; clc;

disp("referring to figure A-14a,Va=650mph=953ft/s")
```

```
Ta=510
Va=953
Cp=0.24*778*32.2
T01=Ta+Va^2/(2*Cp)
printf(" T01=%0.1f R",T01)

disp("from Eta_i=(Ts01-Ta)/(T01-Ta),we have Ts01=Ta+Eta_i(T01-Ta)=577.9R")
pa=10.5
Ts01=577.9
Ta=510
//let x=k/(k-1)
x=3.5
p01=pa*(Ts01/Ta)^(x)
printf(" p01=%0.1f psia",p01)

p03=5*16.3
printf("\n p03=p02=%0.1f psia",p03)

T01=585.5
Ts02=T01*(5^0.2857)
printf("\n Ts02=%0.1f R",Ts02)

disp("From Eta_c= (Ts02-T01)/(T02-T01),we have T)2=T01 +(Ts02-T01)/Eta_c=1012.7R")
disp("For the turbojet w_c=w_t is assumed,we have T04=T03-(T02-T01)")
T03=1810
T02=1012.7
T01=585.5
T04=T03-(T02-T01)
printf(" T04= %0.1f R",T04)

disp("From Eta_t=(T03-T04)/(T03-Ts04)=1318.9R and p04=p03*(T_s04/T_03)^3.5=26.9 psia")

disp("To check whether the flow is choked at the nozzle exit,we calculate te choking condition
```

```
   from Tc=2*T_04/(k+1)")
T_04=1382.8
k=1.4
Tc=2*T_04/(k+1)
printf(" Tc= %0.1f R",Tc)

T04=1382.8
Tc=1152.3
Eta_n=0.92
T_sc=T04-(T04-Tc)/Eta_n
printf("\n T_sc= %0.1f R",T_sc)

p04=26.9
Tsc=1132.3
T04=1382.8
pc=p04*(Tsc/T04)^3.5
printf("\n pc= %0.2f psia",pc)

disp("Since pc>pa the flow is choked at the nozzle
   exit plane,and hence we have T5=Tc=1152.3R,ps=pc
   =13.36 psia")

k=1.4
R=53.33
T5=1152.3
Vj=(k*R*T5*32.2)^0.5//conversion factor=32.2
printf(" Vj= %0.1f ft/s",Vj)

p5=13.36
rho5=p5*144/(R*T5)//144 = conversion factor
printf("\n rho5 %0.4f lbn/ft^3",rho5)

disp("m=rho*V*A")

A5=60/(0.0313*1664.4)
printf(" A5= %0.2f ft^2",A5)

disp("F=m*(Vj-Va)+A5*(p5-pa)")
```

```
F=60*(1664.4-953)/32.2+1.15*(13.36-10.5)*144
printf(" F= %0.1f lbf",F)
```

Scilab code Exa 12.7 A

```
clear all; clc;

disp("Referring to figure A-12 and assuming pure saturated liquid at the condenser outlet,we have h9=hf=93 Btu/lbm from the steam table")
disp("With p8=p9=2 psia and p6=100 psia,we have h6=h9+delta_p*144/(Eta_p*rho)")
h9=93
delta_p=100-2
Eta_p=0.8
rho=62.4*778
h6=h9+delta_p*144/(Eta_p*rho)
printf(" h6=%0.1f Btu/lbm",h6)

disp("Assuming T6 to be approximately equal to T9=585 R with the definition of boiler efficiency Eta_b=(h7-h6)*m_w/[Cp*(T4-T5)*m_g]")
h7=0.75*0.24*(1374.5-585)/0.10+93.4
printf(" h7= %0.2f Btu/lbm",h7)

disp("Assuming p6 to be approximately equal to p7=100 psia,we obtain s8s=s7=1.908 Btu/lbmR and h8s=1120 btu/lbm from the steam table")
disp("From the definition of turbine efficiency, Eta_t=(h7-h8)/(h7-h8s) we can determine the value of h8")
h8=1514.5-0.84*(1514.5-1120)
printf(" h8=%0.0f Btu/lbm",h8)
disp("Or w_t=h7-h8=331.4 Btu/lbm,w_p=0.4 Btu/lbm")

```

```
disp("Hence the additional power output from the steam power plant per unit mass flow rate of gas through the gas turbine is delta_w=(w_t-w_p)*m_w*/m_g")
delta_w=331*0.1
printf(" delta_w= %0.1f Btu/lbm=hp/(lbm/s)",delta_w)

Eta_th=(99.8+46.8)/(382.6)
printf("\n The new thermal efficiency = %0.3f =38.3 percent",Eta_th)
```

Scilab code Exa 12.8 A

```
clear all; clc;

disp("We have h4=104 Btu/lbm,h2=h1=53 Btu/lbm,p4=p1=20psia,s4=s-s3=0.226Btu/lbm-R and Hs3=122 Btu/lbm")
h4=104
hs3=122
Eta_c=0.75
h_3dash=h4+(hs3-h4)/Eta_c
printf("h_3dash=%0.0f Btu/lbm",h_3dash)

w_i=h_3dash-h4
printf("\n The compressor work required per unit mass is w_i =%0.0f Btu/lbm",w_i)

h1=53
qi=h4-h1
printf("\n The heat absorbed by the evaporator per unit mass =qi= %0.0f Btu/lbm",qi)

beta1=qi/w_i
printf("\n The coefficient of performance beta= %0.1
```

```
   f",beta1)

m=10
Pc=m*w_i
printf("\n The total compressor power required Pc=%0
   .0f=240 Btu/s=340 hp",Pc)

qi=51
Qr=m*qi
printf("\n The refrigeration capacity is Qr= %0.0f
   Btu/s=153 tons",Qr)
```